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FINAL

INTERIM FEASIBILITY STUDY FOR SURFICIAL GROUNDWATER FOR A PORTION OF OPERABLE UNIT NO. 10 SITE 35 - CAMP GEIGER AREA FUEL FARM

MARINE CORPS BASE
CAMP LEJEUNE, NORTH CAROLINA

CONTRACT TASK ORDER 0232

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LIST OF ACRONYMS AND ABBREVIATIONS

ARARs	Applicable or Relevant and Appropriate Requirements
AST	aboveground storage tank
ATEC	ATEC Associates, Inc.
AWQC	Federal Ambient Water Quality Criteria
Baker	Baker Environmental, Inc.
bgs	below ground surface
BRA	baseline risk assessment
BTEX	benzene, toluene, ethylbenzene, xylenes
CAA	Clean Air Act
CAMA	Coastal Area Management Act
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CLEAN	Comprehensive Long-Term Environmental Action Navy
CLP	Contract Laboratory Program
COC	contaminant of concern
COPC	contaminant of potential concern
CSA	Comprehensive Site Assessment
CWA	Clean Water Act
1,2-DCE	1,2-dichloroethene
DEM	Division of Environmental Management
DoN	Department of the Navy
DOT	Department of Tranportation
EPA	Envorinmental Protection Agency
ERA	ecological risk assessment
ESE	Environmental Science and Engineering, Inc.
FAWQC	Federal Ambient Water Quality Criteria
FFA	Federal Facilities Agreement
FFS	Focused Feasibility Study
FSAP	Field Sampling and Analysis Plan
gpm	gallons per minute

HI	hazard index
HQW	high quality water
i	hydraulic gradient
IAS	in situ air sparging
IAS	Initial Assessment Study
ICR	incremental cancer risk
IDW	investigative derived wastes
IR	ingestion rate
IRA	interim remedial action
IRP	Installation Restoration Program
K	hydraulic conductivity
kg	kilograms
LANTDIV	Naval Facilities Engineering Command, Atlantic Division
LAW	Law Engineering
MCB	Marine Corps Base
MCL	maximum contaminant level
mg/kg	milligram per kilogram
mg/L	milligram per liter
ml	milliliter
mL/g	milliliters per gram
msl	mean sea level
MTBE	methyl-tertiary-butyl-ether
MW	monitoring well
μg/g	micrograms per gram
μg/L	micrograms per liter
NAAQS	National Ambient Air Quality Standards
NC DOT	North Carolina Department of Transportation
NC DEHNR	North Carolina Department of Environment, Health and Natural Resources
NCAC	North Carolina Administrative Code
NCMFC	North Carolina Marine Fisheries Commission
NCP	National Oil and Hazardous Substances Contingency Plan
NCWP	Near Coastal Waters Program
NCWQC	North Carolina Water Quality criteria
NCWQS	North Carolina Water Quality Standards

NCWRC	North Carolina Wildlife Resources Commission
NEESA	Naval Energy and Environmental Support Activity
NEP	National Estuary Program
NPL	National Priorities List
NPS	National Park Service
NPW	net present worth
NUS	NUS Corporation
O&G	oil and grease
O&M	operation and maintenance
OU	Operable Unit
PAH	polynuclear aromatic hydrocarbon
PCBs	polychlorinated biphenyls
PCE	tetrachloroethene
POTW	publicy-owned treatment works
ppb	parts per billion
ppm	parts per million
PVC	polyvinyl chloride
QA/QC	quality assurance/quality control
QI	quotient index
RA	risk assessment
RAA	remedial action alternative
RBC	risk based concentrations
RCRA	Resource Conservation and Recovery Act
RfD	reference dose
RGO	remediation goal option
RI/FS	remedial investigation/feasibility study
RL	remediation level
ROD	record of decision
SAP	Sample and Analysis Plan
SARA	Superfund Amendments and Reauthorization Act
SDWA	Safe Drinking Water Act
SMCL	Secondary Drinking Water Regulations
SOPs	standard operating procedures
SVE	soil vapor extraction
SVOCs	semivolatile organic compounds

TAL	target analyte list
TBC	to be considered
TCE	trichloroethene
TCL	target compound list
TICs	tentatively identified compounds
TPH	total petroleum hydrocarbons
trans-1,2-DCE	trans-1,2-dichloroethene
USC	United States Code
USCS	Unified Soil Classification System
USDI	United States Department of the Interior
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
USMC	United States Marine Corps
UST	underground storage tank
VOCs	volatile organic compounds
WAR	Water and Air Research, Inc.
WQSV	water quality screening values
WS	Wilderness Society

EXECUTIVE SUMMARY

This report presents the Draft Interim Feasibility Study (FS) for groundwater in the vicinity of the Fuel Farm at Operable Unit (OU) No. 10, Site 35 - Camp Geiger Area Fuel Farm, located at Marine Corps Base (MCB), Camp Lejeune, North Carolina. The Interim FS is based on data collected during the Remedial Investigation (RI) conducted at Site 35 (Baker, 1994), as well as data collected under previous investigations.

Purpose of the Interim FS

The purpose of this Interim FS is to identify and evaluate various remedial actions for contaminated groundwater in the vicinity of the Fuel Farm at Site 35. The results of the RI indicate that the extent of groundwater contamination has not been adequately defined to date, although contaminated groundwater is present in the area of the proposed highway downgradient from the Fuel Farm. It is a known source of ongoing contamination to Brinson Creek. The Interim FS is intended to develop potential remedial actions that will provide for the protection of human health and the environment from contaminated groundwater in this area prior to the completion of a comprehensive FS that considers remedial actions for the entire area of contaminated groundwater as well as other media including surface water and sediments. The comprehensive FS will not be initiated until additional data is obtained from Site 35 to more clearly define the extent and possible sources of contaminated groundwater.

Site Description and Location

Camp Geiger is located at the extreme northwest corner of MCB Camp Lejeune and contains a mixture of troop housing, personnel support and training facilities. The main entrance is located along U.S. Route 17, approximately 3.5 miles southwest of the City of Jacksonville, North Carolina. Site 35, the Camp Geiger Area Fuel Farm, refers primarily to five, 15,000-gallon aboveground storage tanks (ASTs), a pump house, a fuel loading/unloading pad, an oil water separator, and a distribution island situated just north of the intersection of Fourth and "G" Streets.

Site History

Construction of Camp Geiger was completed in 1945, four years after construction of MCB, Camp Lejeune was initiated. Originally, the Fuel Farm ASTs were used for the storage of No. 6 fuel oil, but were later converted for storage of other petroleum products including unleaded gasoline, diesel fuel, and kerosene. The date of their conversion is not known.

Routinely, the ASTs at Site 35 supply fuel to an adjacent dispensing pump. A leak in an underground line at the station was reportedly responsible for the loss of roughly 30 gallons per day of gasoline over an unspecified period (Law, 1992). The leaking line was subsequently sealed and replaced.

The ASTs at Site 35 are currently used to dispense gasoline, diesel, and kerosene to government vehicles, and to supply underground storage tanks (USTs) in use at Camp Geiger and the nearby New River Marine Corps Air Station. The ASTs are supplied by commercial carrier trucks which deliver product to fill ports located on the fuel loading/unloading pad located south of the ASTs. Six, short-run (120 feet maximum), underground fuel lines are currently utilized to distribute the product from the unloading pad to the ASTs. Product is dispensed from the ASTs via trucks and underground piping.

Reports of a release from an underground distribution line near one of the ASTs date back to 1957-58 (ESE, 1990). Apparently, the leak occurred as the result of damage to a dispensing pump. At that time the Camp Lejeune Fire Department estimated that thousands of gallons of fuel were released although no records of the incident are available. The fuel reportedly migrated to the east and northeast toward Brinson Creek. Interceptor trenches were excavated and the captured fuel was ignited and burned.

In April 1990, an undetermined amount of fuel was discovered by Camp Geiger personnel along two unnamed drainage channels north of the Fuel Farm. Apparently, the source of the fuel, believed to diesel or jet fuel, was an unauthorized discharge from a tanker truck that was never identified. The Activity reportedly initiated an emergency clean-up which included the removal of approximately 20 cubic yards of soil.

The Fuel Farm is scheduled to be decommissioned in 1995. Plans are currently being prepared to empty, clean, dismantle, and remove the ASTs along with all concrete foundations, slabs on grade, berms, and associated underground piping. The Fuel Farm will be removed to make way for a six-lane divided highway proposed by the North Carolina Department of Transportation (NCDOT). Construction of the highway is also scheduled to commence in 1995.

In addition to the Fuel Farm dismantling, soil remediation activities will take place along the highway right-of-way as per an Interim Record of Decision executed on September 15, 1994. The soil remediation work is scheduled to commence following the demolition of the Fuel Farm.

Previous Investigations and Findings

Previous investigations conducted at Site 35 include the Initial Assessment Study of Marine Corps Base, Camp Lejeune, North Carolina (WAR, 1983), Final Site Summary Report, MCB Camp Lejeune (ESE, 1990) Draft Field Investigation/Focused Feasibility Study, Camp Geiger Fuel Spill Site (NUS, 1990), Underground Fuel Investigation and Comprehensive Site Assessment (Law, 1992) and the Addendum Report of Underground Fuel Investigation and Comprehensive Site Assessment (Law, 1993), the Interim Remedial Action Remedial Investigation/Feasibility Study (Baker, 1994), and the Remedial Investigation Report (Baker, 1994).

The Initial Assessment Study identified Site 35 as one of 23 sites warranting further investigation. Environmental media were not sampled as part of this study.

ESE performed the Confirmation Study at the Fuel Farm between 1984 and 1987. Soil, groundwater, surface water, and sediment samples were obtained and analyzed for lead and oil and grease. Groundwater was also analyzed for volatile organics. Oil and grease results indicated that soils northeast of the Fuel Farm were potentially impacted by site activities.

Additional wells were installed by NUS Corporation during the Focused Feasibility Study, which was conducted in 1990. Soil cuttings obtained from two of the four well boreholes contained hydrocarbon related contamination.

Law conducted the Comprehensive Site Assessment in 1991. A total of 18 soil borings were drilled, sampled and converted to nested wells that monitor the water table aquifer at two depths. An additional three soil borings were drilled to provide stratigraphic data. Five more soil borings were drilled to provide data regarding vadose zone contamination. Nine hand-auger samples were also obtained. A follow-up study was conducted subsequent to the Comprehensive Site Assessment. Three additional borings were drilled, sampled and converted to wells.

Law identified areas of impacted soil and groundwater directly beneath and apart from the Fuel Farm. The nature of the contamination included both chlorinated organic compounds (e.g., TCE, trans-1,2-DCE, and vinyl chloride) and petroleum hydrocarbons (e.g., TPH, MTBE, BTEX). The majority of the soil contamination encountered appeared to be associated with a fluctuating groundwater table. Two plumes of shallow groundwater contaminated with petroleum constituents and two plumes contaminated with chlorinated organics were identified. All four plumes were located north of Fourth Street and east of E Street except for a portion of a TCE plume extending southwest of Fourth Street.

The Interim Remedial Action RI conducted by Baker in 1993 and 1994 consisted of drilling seven additional soil borings including five in those areas where groundwater contamination plumes were suspected. In general, the Interim Remedial Action RI data confirm the findings of the CSA (Law, 1992) that indicated contaminated soil conditions at Site 35 are primarily associated with a fluctuating shallow groundwater plume.

The Interim Remedial Action RI/FS culminated with an executed Interim Record of Decision (ROD), signed on September 15, 1994, for the remediation of contaminated soil along and adjacent to the proposed highway right-of-way at Site 35. Three areas of contaminated soil have been identified. The first area is located in the vicinity of the Fuel Farm ASTs, and the two other areas are located north of the Fuel Farm. The larger of these two areas is located along "F" Street in the vicinity of monitoring well MW-25. Baker has estimated that approximately 3,600 cubic yards (4,900 tons) of contaminated soil is present in these areas. Contaminated soil located in these areas is scheduled for removal and disposal at an off-site recycling facility beginning July 1995.

A fourth area of soil contamination, located immediately north of Building G480, was also identified in the Interim ROD. Additional data pertaining to this fourth area became available subsequent to the execution of the Interim ROD. This data indicated that contaminated soil was encountered in this area during the removal of a UST there in January 1994. The contaminated soil was excavated and reportedly disposed off site; however, no documentation is available regarding how or where the soil was disposed. An additional soil investigation will be conducted in this area to confirm that the contaminated soil was not returned to the excavation and that follow-up soil remediation in this area is not necessary.

A comprehensive RI was conducted by Baker in 1994 to evaluate the nature and extent of the threat to public health and the environment caused by the release of hazardous substances, pollutants, or contaminants, and to support a Feasibility Study evaluation of potential remedial alternatives. The RI field program was initiated on April 11, 1994. Data gathering activities were derived from: a soil gas survey and groundwater screening investigation, a soil investigation, a groundwater investigation, a surface water and sediment investigation, and an ecological investigation. The results of this investigation are discussed in the following sections: "Nature and Extent of Contamination" and "Summary of Site Risks."

Two USTs located near the Fuel Farm have been the subject of previous investigations conducted under an Activity-wide UST program. The two USTs include a No. 6 fuel oil UST situated adjacent to the former Mess Hall Heating Plant, and a No. 2 fuel oil UST situated adjacent to the Explosive Ordnance and Disposal Armory, Office, and Supply Building. The former UST was abandoned in place years ago (date unknown) and has been the subject of previous environmental investigations performed by ATEC Associates, Inc. and Law. The latter UST was removed in January 1994, and is the UST associated with the fourth area of soil contamination identified in the Interim ROD signed September 15, 1994, which is mentioned above.

Nature and Extent of Contamination

The nature and extent of contamination was determined based on the analytical results of the various media considered under the RI (Baker, 1994), including soil, groundwater, sediment, surface water, and fish tissue.

Surface and Subsurface Soil

Relatively few detections of VOCs and SVOCs were observed in surface and subsurface soil samples obtained under the RI. Pesticides were detected in surface soil samples only, but, are not deemed to be site related. No PCBs were detected in surface or subsurface soil samples. Detected inorganics were generally similar to background surface and subsurface soil concentrations at Camp Lejeune.

Groundwater

The nature and extent of groundwater contamination was considered based on the interval of groundwater monitored and included the upper portion of the surficial aquifer, the lower portion of the surficial aquifer, and the upper portion of the Castle Hayne aquifer.

No significant contamination was detected in the upper portion of the Castle Hayne aquifer. This indicates that, to date, the suspected semi-confining layer that separates the surficial aquifer from the Castle Hayne aquifer has served effectively as an aquitard.

Extensive groundwater contamination was observed in the surficial aquifer along both the upper and lower monitored intervals. Fuel-related organic contaminants, when encountered, appear more prevalent in the upper portion of the surficial aquifer. Conversely, solvent-related organic contaminants, when encountered, appear more prevalent in the lower portion of the surficial aquifer. This is likely due to the fact that the latter have specific gravities that are greater than one, while fuel-related contaminants have specific gravities less than one.

The extent of fuel-related contamination appears to be adequately defined based on the data obtained to date. It is limited to the area north of Fourth Street in the vicinity of obvious suspected sources such as the Fuel Farm, and nearby former UST sites.

The extent of solvent-related contamination has not been completely defined to date nor have all of its sources been identified. A plume appears to extend from north of Fourth Street south to Fifth Street beyond which the RI did not extend in the southerly direction. The source of this plume has not been determined. A second smaller plume is present in the vicinity of the Former Vehicle

Maintenance Garage (Building TC474). This plume appears to be adequately defined with Building TC474 and the immediate vicinity as the likely source of contamination.

Elevated levels of inorganic contaminants (total and dissolved) were detected in groundwater samples obtained from within the surficial aquifer. It is questionable whether this contamination is due to past site activities because the results are similar to those obtained by Baker at other Camp Lejeune sites. The elevated total metals are believed to be caused by suspended particulates in the samples.

Surface Water and Sediment

Significant levels of organic and inorganic contaminants were detected in sediment samples obtained from locations adjacent to and downstream of Site 35. The results of VOC analyses were "masked" by the presence of high levels of Tentatively Identified Compounds (TICs), and consequently, few VOC detections were reported. Nevertheless, the Baker field team commented during sampling that the sediment samples appeared to contain elevated levels of fuel-related contaminants which could also explain the presence of TICs. Lead at elevated levels was also detected in these sediment samples, and like the organic contaminants, could be related to Site 35.

Surface water contamination was limited to a single detection of lead and zinc downstream of Site 35 at levels in excess of the WQSVs and the NCWQS. No organic contaminants were detected in surface water samples.

Fish

A variety of organic and inorganic contaminants were detected in fillet and whole body samples analyzed under the RI. The most significant contaminants detected were the pesticides dieldrin and 4,4-DDD, and a single inorganic mercury. These contaminants were primarily responsible for the calculated risk to human health in excess of EPA guidelines.

Summary of Site Risks

As part of the RI Baker calculated that the human health risk associated with Site 35 is in excess of the acceptable range. The total risk was driven by future potential exposure to groundwater (specifically driven by the contaminants: cis-1,2-dichloroethene, trichloroethene, benzene, antimony, arsenic, barium, beryllium, chromium, cadmium, manganese, and vanadium) and current potential exposure to fish (due to mercury).

The ecological risk assessment indicated that the aquatic community within Brinson Creek was representative of an estuarine community and does not appear to be adversely impacted by surface water and sediment quality. Additionally, there are no significant adverse impacts to terrestrial receptors from site-related contaminants.

Remediation Levels

This section presents the remediation levels (RLs) chosen for OU No. 10. RLs are chosen by the risk manager for the COCs and are included in the Interim FS and the Interim ROD. These numbers derived from the RGOs are no longer goals and should be considered required levels for the remedial actions to achieve.

The RLs associated with OU No. 10 are presented on Table ES-1. This list was based on a comparison of contaminant-specific ARARs (or ARAR-based RGOs) and the site-specific risk-based RGOs. If a COC had an ARAR, the most limiting (or conservative) ARAR was selected as the RL for that contaminant. If a COC did not have an ARAR, the most conservative risk-based RGO was selected for the RL.

In order to determine the final COCs for OU No. 10, the contaminant concentrations detected at each site were compared to the RLs presented on Table ES-1. The contaminants which exceed at least one of the RLs have been retained as final COCs. The contaminants that did not exceed any of the RLs are no longer considered as COCs with respect to this Interim FS. The final COCs and their associated RLs are presented on Table ES-2.

Several inorganic COCs, including arsenic, beryllium, antimony, barium, cadmium, manganese, nickel, and vanadium, were detected in concentrations that exceeded remediation levels. However, these inorganics will not be addressed in this Interim FS because it is unlikely that their presence is a result of past site activities. (The inorganic concentrations are similar to those detected at other Camp Lejeune sites.) Recently, Baker has employed new sampling techniques for inorganics in groundwater utilizing low-flow pumps. The low-flow pumps minimize particle disturbance and have resulted in reduced levels of total inorganics in groundwater analytical results. As recommended in the RI, inorganics at OU No. 10 will be re-sampled using this low-flow sampling technique. Based on previous experience on other sites at this Activity, it is probable that detected concentrations for some inorganic COCs will then fall below remediation levels. Thus, inorganic COCs exceeding remediation levels will not be addressed at this time and Table ES-3 presents a final list of COCs to be addressed in this Interim FS.

Summary of Alternatives

Various technologies and process options were screened and evaluated under the Interim Remedial Action FS. Ultimately, five Remedial Action alternatives (RAAs) were developed and are listed as follows:

- RAA 1 - No Action
- RAA 2 - No Action with Institutional Controls
- RAA 3 - Groundwater Collection and On-Site Treatment
- RAA 4 - In Situ Air Sparging and Off-Gas Carbon Adsorption
- RAA 5 - In Well Aeration and Off-Gas Carbon Adsorption

A brief description of each alternative as well as the estimated cost and timeframe to implement the alternative are as follows:

- RAA 1: No Action

Total Net Present Worth (30 years):	$0
Months to Implement:	0

Under the No action RAA, no remedial actions will be performed to reduce the toxicity, mobility, or volume of the contaminated surficial groundwater at Site 35. This method assumes that passive remediation will occur via natural attenuation processes and that the contaminant levels will be reduced over an indefinite period of time. However, the achievable reductions versus time are difficult, if not impossible to predict.

The No Action RAA is required by the NCP to provide a baseline for comparison with other alternatives. Since contaminants will remain at the site under this alternative, USEPA is required by the NCP [40 CFR 300.515(e) (ii)] to review the effects of this alternative no less often than every five years.

- RAA 2: No Action with Institutional Controls

  Total Net Present Worth (30 years): $299,800
  Months to Implement: 2

Under RAA No. 2, no remedial actions will be performed to reduce the toxicity, mobility, or volume of the contaminated surficial groundwater at Site 35. This RAA provides for the revision of the Base Master Plan to include restrictions on the use of the surficial aquifer in the vicinity of the Fuel Farm. This will reduce the risk to human health and the environment posed by this media by eliminating one exposure pathway; however, the impacted surficial groundwater will remain a potential source of contamination to Brinson Creek.

In addition to the aquifer-use restrictions, long-term groundwater monitoring is to be included under this RAA to provide data regarding the impact of natural attenuation and the progress of contaminant migration. Long-term groundwater monitoring includes the semi-annual collection and analysis (TCL VOCs) of groundwater samples from 11 monitoring wells, the development of a semi-annual monitoring report, and the replacement of one monitoring well every five years.

Since contaminants will remain at the site under this alternative, the USEPA is required by the NCP [40 CFR 300.515(e) (iii)] to review the effects of this alternative no less often than every five years.

- RAA 3: Groundwater Collection and On-Site Treatment

  Total Net Present Worth (30 years): $3,000,500
  Months to Implement: 3

RAA 3 is a source collection and treatment alternative, the source being the contaminated surficial groundwater in the vicinity of the Fuel Farm at Site 35. Under this alternative a vertical interceptor trench, approximately two feet wide, by 30 feet deep, by 1,080 feet long, will be installed at the downgradient edge of the contaminated plume in the area between the proposed highway and Brinson Creek. The interceptor trench will be constructed from the ground surface to the semi-confining layer at the base of the surficial aquifer. The purpose of the interceptor trench is to collect contaminated surficial groundwater for transfer to an on-site treatment facility prior to it being discharged to Brinson Creek.

The type of interceptor trench proposed under RAA 4 is termed a "biopolymer slurry drainage trench." This type of trench can be installed without dewatering or structural bracing. Through the use of a natural, biodegradable slurry, the walls of a trench excavation can be supported and the trench can be installed without personnel entering an excavation.

compared to other trenching methods, this technique is safer and cost-effective in areas with a high groundwater and unstable soil because there are no costs for dewatering and water disposal or shoring.

A biopolymer slurry drainage trench is constructed in much the same manner as a typical slurry cut-off wall. However, unlike a bentonite-clay slurry, a biodegradable biopolymer slurry supports the walls of the trench while excavated materials are removed and drainage structures are installed. The biopolymer slurry then naturally biodegrades after the trench is backfilled. In the end, a permeable wall is left intact. In this case an impermeable geomembrane will be installed along the downgradient side of the trench so that groundwater will enter the trench from only the upgradient direction.

The interceptor trench will be designed to collect groundwater at a rate roughly equal to the groundwater flow (5 to 10 gpm) across the upgradient face of the trench (31,900 square feet). Flow across the downgradient face of the trench will be restricted by an impermeable geomembrane barrier. Drawdown of the groundwater surface will be minimized so as to mitigate the potential of excessive ground settlement beneath the highway. The collected groundwater will be conveyed to an on-site treatment plant located just east of the proposed highway right-of-way, creek-side, where it appears that adequate space and firm foundation material is available.

Baker, LANTDIV, and MCB, Camp Lejeune will negotiate with NC DOT regarding the specifics for site access to the creek-side of the new highway. The EPA and NC DEHNR will be kept abreast of developments on this subject. In this FS, Baker proposes an access road running along the east side of the highway from the south.

The collected groundwater will be treated sufficiently to allow for its discharge to Brinson Creek at a point downstream of Site 35. It is anticipated that the groundwater treatment system will include filtration for the removal of suspended solids, a settling tank for the removal of metals, sludge collection and disposal, volatilization (air stripping) for the removal of VOCs, and secondary treatment of VOC emissions from the air stripper and of the treated groundwater (i.e., via carbon adsorption). The treatment plant effluent will be sampled once a month to insure that water discharged to Brinson Creek meets all applicable water quality standards.

RAA 3 assumes that the Base Master Plan will be modified to include restrictions on the use of the surficial aquifer in the vicinity of the Fuel Farm. This will reduce the risk to human health and the environment posed by this media by eliminating one exposure pathway.

In addition to aquifer-use restrictions, long-term groundwater monitoring is to be included under this RAA to provide date regarding the impact of natural attenuation and the progress of contaminant migration. Long-term groundwater monitoring includes the semi-annual collection and analysis (TCL VOCs) of groundwater samples from 11 monitoring wells, the development of a semi-annual monitoring report, and the replacement of one monitoring well every five years.

Since contaminants will remain at the site under this alternative, the USEPA is required by the NCP {40 CFR 300.515(e) (iii)] to review the effects of this alternative no less often than every five years.

- RAA 4: In Situ Air Sparging and Off-Gas Carbon Adsorption

  Total Net Present Worth (30 years): $2,459,600
  Months to Implement: 3

In situ air sparging (IAS) is a technique in which air is injected into water saturated zones for the purpose of removing organic contaminants primarily via volatilization and secondarily via aerobic biodegradation. IAS systems introduce contaminant-free air into an impacted aquifer near the base of the zone of contamination, forcing VOC contaminants to transfer from the groundwater into sparged air bubbles. The air bubbles are then transported into soil pore spaces in the unsaturated zone where they are typically collected via soil vapor extraction (SVE) and conveyed to an on-site, off-gas treatment system.

An IAS system typically is comprised of the following components: 1) air injection wells; 2) an air compressor; 3) air extraction wells; 4) a vacuum pump; 5) associated piping and valving for air conveyance; and 6) an off-gas treatment system (e.g., activated carbon, combustion, or oxidation). Under RAA 4 a line of air sparging wells will be installed between the proposed highway and Brinson Creek in order to treat and contain the contaminated plume near its downgradient extreme. Based on empirical data from similar sites, the radius of influence of an air sparging well ranges from five to almost 200 feet, but is typically on the order of 25 feet (EPA, 1992). For the purpose of the FS, Baker estimates that 43 sparging wells, 30 feet deep, and 43 SVE wells, 4 feet deep, would be required. The proposed off-gas treatment system (activated carbon) will be located just east of the proposed highway right-of-way, creek-side, where it appears that there is adequate space and firm foundation material available. The air emissions from the off-gas treatment system will be sampled monthly to insure that all applicable air emissions standards are being met.

Air sparging systems are most effective in sandy soils, but, can be adversely impacted by high levels of inorganic compounds in the groundwater which oxidize and precipitate when contacted by the sparged air. These organics can form a heavy scale on well screens and clog the well space of the sand pack surrounding the well screen resulting in a reduction in permeability. A field pilot test is recommended to determine the loss of efficiency over time as a result of inorganics precipitation and oxidation, the radius of influence of the wells under various heads of injection air pressure, and the rate of off-gas organic contaminant removal via carbon adsorption and carbon breakthrough.

Baker, LANTDIV, and MCB, Camp Lejeune will negotiate with NC DOT regarding the specifics for site access to the creek side of the new highway. The EPA and NC DEHNR will be kept abreast of developments on this subject. In this FS, Baker proposes an access road running along the east side of the highway from the south.

RAA 4 assumes that the Base Master Plan will be modified to include restrictions on the use of the surficial aquifer in the vicinity of the Fuel Farm. This will reduce the risk to human health and the environment posed by this media by eliminating one exposure pathway.

In addition to aquifer-use restrictions, long-term groundwater monitoring is to be included under this RAA to provide data regarding the impact of natural attenuation and the progress of contaminant migration. Long-term groundwater monitoring includes the semi-annual collection and analysis (TCL VOCs) of groundwater samples from 11 monitoring wells, the development of a semi-annual monitoring report, and the replacement of one monitoring well every five years.

Since contaminants will remain at the site under this alternative, the USEPA is required by the NCP [40 CFR 300.515 (e) (iii)] to review the effects of this alternative no less often than every five years.

- RAA 5: In Well Aeration and Off-Gas Carbon Adsorption

Total Net Present Worth (30 years):	$2,519,700
Months to Implement:	3

In well aeration is a new technology that utilizes circulating air flow within a groundwater well that, in effect, turns the well into an air stripper. In well aeration differs from air sparging in that volatilization occurs outside the well via air sparging and within the well via in well aeration. Similar to air sparging, this technique removes organic contaminants from groundwater primarily via volatilization and secondarily via aerobic biodegradation. Under RAA 5 a line of in well aeration wells will be installed between the proposed highway and Brinson Creek in order to treat and contain the contaminated plume near its downgradient extreme. The radius of influence, or capture zone, of an in well aeration well is reportedly much greater than that of a typical air sparging well system. Using modeling equations and graphical solutions, the developers of this technology have calculated a radius of influence of over 100 feet at Site 35.

For the purpose of the FS, Baker estimates that six in well aeration wells would be required. Volatilized organics collected by this technology, unlike air sparging, will be treated at each in well aeration well by independent air treatment/carbon adsorption systems which will rest adjacent to the wells. The air emissions from the off-gas treatment system will be sampled monthly to insure that all applicable air emissions standards are being met. Each well and aboveground off-gas treatment system will be housed in a small prefabricated building.

In well aeration systems, like IAS systems, are most effective in sandy soils, but, can be adversely impacted by high levels of inorganic compounds in the groundwater which oxidize and precipitate when contacted by air. These inorganics can form a heavy scale on well screens and clog the well space of the sand pack surrounding the well screen resulting in a reduction in permeability. A field pilot test is recommended to determine the loss of efficiency over time as a result of inorganics precipitation and oxidation, the radius of influence of the wells under various heads of injection air pressure, and the rate of off-gas organic contaminant removal via carbon adsorption and carbon breakthrough.

Baker, LANTDIV, and MCB, Camp Lejeune will negotiate with NC DOT regarding the specifics for site access to the creek side of the new highway. The EPA and NC DEHNR will be kept abreast of developments on this subject. In this FS, Baker proposes an access road running along the east side of the highway from the south.

RAA 5 assumes that the Base Master Plan will be modified to include restrictions on the use of the surficial aquifer in the vicinity of the Fuel Farm. This will reduce the risk to human health and the environment posed by this media by eliminating one exposure pathway.

In addition to aquifer-use restrictions, long-term groundwater monitoring is to be included under this RAA to provide data regarding the impact of natural attenuation and the progress of contaminant migration. Long-term groundwater monitoring includes the semi-annual collection and analysis (TCL VOCs) of groundwater samples from 11 monitoring wells, the development of a semi-annual monitoring report, and the replacement of one monitoring well every five years.

Since contaminants will remain at the site under this alternative, the USEPA is required by the NCP [40 CFR 300.515 (e) (iii)] to review the effects of this alternative no less often than every five years.

Comparative Analysis of Alternatives

This Interim FS has identified and evaluated a range of RAAs potentially applicable to the groundwater concerns at Site 35 (OU No. 10). Table ES-4 presents a summary of this evaluation. A comparative analysis in which the alternatives are evaluated in relation to one another with respect to the nine evaluation is presented below. The purpose of this analysis is to identify the relative advantages and disadvantages of each RAA.

Overall Protection of Human Health and the Environment

RAA 1 (No Action) and RAA 2 (No Action With Institutional Controls) are similar in that neither alternative involves active treatment. RAA 2 provides for some overall protection to human health through the incorporation of aquifer-use restrictions which are not included under RAA 1.

RAA 3 (Groundwater Collection and On-Site Treatment), RAA 4 (In Situ Air Sparging And Off-Gas Carbon Adsorption), and RAA 4 (In Well Aeration And Off-Gas Carbon Adsorption) have a common element in that each is intended to reduce groundwater contamination at the downgradient extreme of the contaminated plume and to serve as a barrier to future contaminated groundwater discharge to Brinson Creek. RAA 3 would likely be the most effective barrier in that it is designed to span the entire length and depth of the contaminated portion of the surficial aquifer and will be equipped with an impermeable geomembrane along its downgradient face. RAA 3 is the only treatment alternative that will impact both organic and inorganic contaminants which could be important if it is determined in the future that inorganic contaminants in groundwater are still a concern.

Compliance With ARARs

RAA 1 (No action) and RAA 2 (No Action With Institutional Controls) are no action alternatives that will not comply with ARARs. RAA 3 (Groundwater Collection and On-Site Treatment), RAA 4 (In Situ Air Sparging And Off-Gas Carbon Adsorption), and RAA 5 (In Well Aeration And Off-Gas Carbon Adsorption) are primarily source control measures that will reduce contaminant levels over a limited area defined as the particular zone of influence of each system.

Wetlands disturbance will be an issue with RAA 3, 4, and 5, but, most significantly with RAA 3 which includes the excavation of an approximately two-foot wide, by 30-foot deep, by 1,080-foot interceptor trench. The disturbance associated with RAA 4 and 5 is limited primarily to drilling and well installations, although of the two, RAA 4 will have the greater impact due to the large number of wells to be installed.

Treated air and groundwater discharge are provisions of RAA 3, whereas, only air emissions are a part of RAA 4 and 5. These discharges will need to comply with applicable ARARs.

Long-Term Effectiveness and Permanence

In the case of all five RAAs, contamination will remain at the site and require a USEPA review on five year basis. RAA 1 (No Action) and RAA 2 (No Action With Institutional Controls) provide for no active means of contaminant reduction although, under RAA 2, aquifer-use restrictions will provide a permanent means for protection against direct human exposure to the contaminated surficial groundwater.

The effectiveness of RAA 3 (Groundwater Collection and On-Site Treatment), RAA 4 (In Situ Air Sparging And Off-Gas Carbon Adsorption), and RAA 5 (In Well Aeration and Off-Gas Carbon Adsorption) can be assumed to be roughly equivalent without the benefit of the results of field pilot-scale testing. RAA 3 may be the most difficult of the three to install, however, once installed it will likely be the most reliable and easiest to control. RAA 4 and 5 may encounter clogging problems if dissolved metals precipitate out of solution when placed in contact with forced air. At a minimum the metals problem will prompt increased maintenance which could lead to complete well replacement. RAA 4 has the additional problem of releasing toxic vapors to the atmosphere during operation because it is difficult to apply sufficient vacuum to the vadose zone where the groundwater surface is within a few feet of the ground surface.

Reduction of Toxicity, Mobility, or Volume Through Treatment

No reduction of contaminants will occur under RAA 1 (No Action) and RAA 2 (No Action With Institutional Controls) as the result of active treatment because active treatment is not provided for under these RAAs.

RAA 3 (Groundwater Collection and On-Site Treatment) provides for on-site treatment of the collected contaminated groundwater (organics and inorganics) using standard wastewater treatment technology. Conversely, RAA 4 (In Situ Air Sparging And Off-Gas Carbon Adsorption) and RAA 5 (In Well Aeration And Off-Gas Carbon Adsorption) provide for treatment of the organic phase of contaminated groundwater in-situ. Both RAA 4 and 5 utilize primarily volatilization technology and biodegradation technology secondarily. The principle difference between the two is that under RAA 4 both volatilization and biodegradation occur outside the well and within the soil column. Under RAA 5, volatilization occurs within the well while biodegradation occurs outside the well within the soil column. Under RAA 4 it may be difficult to efficiently collect all of the volatilized organic contaminants via conventional soil vapor extraction because of the proximity of the groundwater surface to the ground surface at this site. Without an efficient means of collecting the volatilized organics under RAA 4, toxic vapors may be released to the atmosphere. Under RAA 5 this is not a concern because the volatilization is conducted within the well and conveyed to an adjacent activated carbon unit via piping which means the system is essentially a closed loop.

RAA 3 will produce the highest volume of residual waste during operation because it is the only alternative involving groundwater treatment. However, the volume of air treatment under RAA 3 will be less than that under RAAs 4 and 5 because the latter are specifically designed as air volatilization systems. Under RAAs 4 and 5 a small volume of contaminated water will be generated because extracted air contains water which condenses and collects in a knock-out tank at the treatment facility.

Short-Term Effectiveness

Worker protection against exposure will not be a significant issue for any of the RAAs. Each system provided for under RAA 3 (Groundwater Collection and On-Site Treatment), RAA 4 (In Situ Air Sparging and Off-Gas Carbon Adsorption), and RAA 5 (In Well Aeration and Off-Gas Carbon Adsorption) will require approximately 30 to 60 days to install with the total time in the field for construction being a little longer. It has also been assumed that system start-up and testing operations will require an additional 90 days.

Under RAA 1 (No Action) and RAA 2 (No Action With Institutional Controls) there will be no increase in the risks to the community resulting from implementation of the RAA. RAAs 3 and 5 will likely present minimal risk of community exposure during implementation and operation because they are, in essence, closed loop systems. RAA 4 has the potential for releases of toxic vapors to the atmosphere because of close proximity of the groundwater surface to the ground surface will make efficient soil vapor extraction difficult.

Some disturbance of the wetlands is expected under RAAs 3, 4, and 5. The greatest disturbance will be associated with RAA 3.

Implementability

Aside from RAAs 1 and 2, which are no action or essentially no action alternatives, RAA 3 (Groundwater Collection And On-Site Treatment) will present greater technical challenges during construction than RAA 4 (In Situ Air Sparging and Off-Gas Carbon Adsorption), and RAA 5 (In Well Aeration and Off-Gas Carbon Adsorption). This is because RAA 3 involves the construction of a two foot wide by 30 foot deep by 1,080 feet long interceptor trench while RAAs 4 and 5 involve primarily well installation.

The interceptor trench under RAA 3 represents specialized technology that is available from a limited number of vendors, whereas, the air sparging technology of RAA 4 is relatively commonplace, and in well aeration (RAA 5) is a proprietary technology offered by a single vendor.

The proposed groundwater monitoring plan coupled with routine system maintenance and monitoring should be sufficient to provide sufficient notice of a system failure under either RAA 3, 4 or 5. The purpose of the monitoring is to provide for system adjustments with sufficient time so that a significant contaminant release to the environment will not occur.

Because each system under RAA 3, 4, and 5 will require construction within a wetlands area and because air and water discharges are incorporated into the designs, the intent of federal and state wetlands and air and water discharge permits must be met.

Cost

The estimated total present worth costs of the alternatives, excluding RAA 1: No Action, range from $299,800 for RAA 2: No Action with Institutional Controls to $3,000,500 for RAA 3: Groundwater Collection and On-Site Treatment. These costs are based on the assumption of 30 years of active use, with an annual interest rate of five percent. The ranking of the alternatives in terms of costs is as follows:

TABLE ES-1

REMEDIATION LEVELS FOR COCs
OPERABLE UNIT NO. 10 (SITE 35)
INTERIM FEASIBILITY STUDY CTO-232
MCB CAMP LEJEUNE, NORTH CAROLINA

Can we keep all inorganics together?

Contaminant of Concern	RL(1)	Basis of Goal	Corresponding Risk
Benzene	1	NCWQS(2)	
Trichloroethene	2.8	NCWQS	
Arsenic	50	NCWQS	
Beryllium	4	MCL(3)	
cis-1,2-Dichloroethene	70	NCWQS	
trans-1,2-Dichloroethene	70	NCWQS	
Ethyl Benzene	29	NCWQS	
Methyl Tertiary Butyl Ether	200	NCWQS	
Toluene	1,000	NCWQS	
Xylenes	530	NCWQS	
Naphthalene	626	Risk-Ingestion	HI(4)=1
Antimony	6	MCL(5)	
Barium	2,000	NCWQS	
Cadmium	5	NCWQS	
Cobalt	939	Risk-Ingestion	HI=1
Copper	1,000	NCWQS	
Manganese	50	NCWQS	
Mercury	1.1	NCWQS	
Nickel	100	NCWQS	
Selenium	50	NCWQS	
Vanadium	110	Risk-Ingestion	HI=1
Zinc	2,100	NCWQS	

Notes: Concentrations expressed in microgram per liter (ug/L)

(1) RL = Remediation Level

(2) NCWQS = North Carolina Water Quality Standards for Groundwater

(3) MCL = Maximum Contaminant Level

(4) HI = Hazard Index

RAA	1:	No Action	$0
RAA	2:	No Action with Institutional Controls	$299,800
RAA	4:	In Situ Air Sparging and Off-Gas Carbon Adsorption	$2,459,600
RAA	5:	In Well Aeration and Off-Gas Carbon Adsorption	$2,519,700
RAA	3:	Groundwater Collection and On-Site Treatment	$3,000,500

USEPA/State Acceptance

The USEPA and NC DEHNR have indicated their concurrence with the RAAs developed under this FS, in general, and with RAA 5 as the proposed alternative, in particular. The ROD also identified RAA 3 as the proposed alternative should RAA 5 be determined to be technically infeasible based on the results of a field pilot test.

Community Acceptance

Based on the lack of community participation at a public meeting held on May 10, 1995, no adverse community reaction to the proposed remedial action is anticipated.

TABLE ES-2

COCs THAT EXCEED REMEDIATION LEVELS
OPERABLE UNIT NO. 10 (SITE 35)
INTERIM FEASIBILITY STUDY CTO-232
MCB CAMP LEJEUNE, NORTH CAROLINA

Keep inorganics together

Contaminant of Concern	RL[1,2]
Benzene	1
Trichloroethene	2.8
Arsenic	50
Beryllium	4
cis-1,2-Dichloroethene	70
trans-1,2-Dichloroethene	70
Ethyl Benzene	29
Methyl Tertiary Butyl Ether	200
Xylenes	530
Antimony	6
Barium	2,000
Cadmium	5
Manganese	50
Nickel	100
Vanadium	110

(1) RL = Remediation Level
(2) Groundwater RLs expressed as ug/L (ppb)

What? Can we include max or range of detects in this table so we have an idea of how much cleanup is req'd?

TABLE ES-3

ORGANIC COCs THAT EXCEED REMEDIATION LEVELS
OPERABLE UNIT NO. 10 (SITE 35)
INTERIM FEASIBILITY STUDY CTO-232
MCB CAMP LEJEUNE, NORTH CAROLINA

Contaminant of Concern	RL(1,2)
Benzene	1
Trichloroethene	2.8
cis-1,2-Dichloroethene	70
trans-1,2-Dichloroethene	70
Ethyl Benzene	29
Methyl Tertiary Butyl Ether	200
Xylenes	530

(1) RL = Remediation Level

(2) Groundwater RLs expressed as ug/L (ppb)

TABLE ES-4

SUMMARY OF DETAILED ANALYSIS
OPERABLE UNIT NO. 10 (SITE 35)
INTERIM FEASIBILITY STUDY, CTO-0232
MCB CAMP LEJEUNE, NORTH CAROLINA

Evaluation Criteria	RAA 1 No Action	RAA 2 No Action with Institutional Controls	RAA 3 Groundwater Collection and On-Site Treatment	RAA 4 In Situ Air Sparging and Off-Gas Carbon Adsorption	RAA 5 In Well Aeration and Off-Gas Carbon Adsorption
OVERALL PROTECTIVENESS					
• Human Health	Potential risks associated with groundwater exposure will remain. Some reduction in contaminant levels may result from natural attenuation.	Aquifer-use restrictions mitigate risks from direct groundwater exposure.	Active collection and treatment will reduce contaminant levels in groundwater within capture zone of interceptor trench (estimated at 100 feet upgradient maximum). Aquifer-use restrictions will also mitigate risks from direct groundwater exposure.	Active in situ volatilization and biodegradation will reduce contaminant levels in groundwater within radius of influence of wells (estimated at 25 feet). Aquifer-use restrictions will also mitigate risks from direct groundwater exposure.	Active in-well volatilization and in situ biodegradation will reduce contaminant levels in groundwater within radius of influence of wells (estimated 100 feet). Aquifer-use restrictions will also mitigate risks from direct groundwater exposure.
• Environment	Contaminated groundwater will continue to be a source of future contamination to Brinson Creek.	Contaminated groundwater will continue to be a source of future contamination to Brinson Creek.	Interceptor trench serves as a barrier to contaminated groundwater discharge to Brinson Creek.	Air sparging wells serve as a barrier to contaminated groundwater discharge to Brinson Creek.	Aeration wells serve as a barrier to contaminated groundwater discharge to Brinson Creek.
COMPLIANCE WITH ARARs					
• Chemical-Specific	No active effort made to reduce groundwater contaminant levels to below federal or state ARARs.	No active effort made to reduce groundwater contaminant levels to below federal or state ARARs.	Reductions in groundwater contaminant levels to below federal or state ARARs can be expected within capture zone of interceptor trench. Reductions upgradient will be less substantial if at all.	Reductions in groundwater contaminant levels to below federal or state ARARs can be expected within radius of influence of wells. Reductions upgradient will be less substantial if at all.	Reductions in groundwater contaminant levels to below federal or state ARARs can be expected within radius of influence of wells. Reductions upgradient will be less substantial if at all.
• Location-Specific	Not Applicable.	Not Applicable.	Wetlands and alligators (endangered species) are concerns because of proposed location of interceptor trench. It is assumed that necessary approvals can be obtained.	Wetlands and alligators (endangered species) are concerns because of proposed location of interceptor trench. It is assumed that necessary approvals can be obtained.	Wetlands and alligators (endangered species) are concerns because of proposed location of interceptor trench. It is assumed that necessary approvals can be obtained.
• Action-Specific	Not Applicable.	Not Applicable.	Can be designed to meet these ARARs.	Can be designed to meet these ARARs.	Can be designed to meet these ARARs.

TABLE ES-4 (Continued)

SUMMARY OF DETAILED ANALYSIS
OPERABLE UNIT NO. 10 (SITE 35)
INTERIM FEASIBILITY STUDY, CTO-0232
MCB CAMP LEJEUNE, NORTH CAROLINA

Evaluation Criteria	RAA 1 No Action	RAA 2 No Action with Institutional Controls	RAA 3 Groundwater Collection and On-Site Treatment	RAA 4 In Situ Air Sparging and Off-Gas Carbon Adsorption	RAA 5 In Well Aeration and Off-Gas Carbon Adsorption
LONG-TERM EFFECTIVENESS AND PERFORMANCE					
• Magnitude of Residual Risk	Any long-term effect on contamination will be the result of natural attenuation processes only.	Any long-term effect on contamination will be the result of natural attenuation processes only. Aquifer-use restrictions will provide a permanent means for protection against direct exposure to the contaminated surficial groundwater.	Provides an effective means of intercepting contaminated groundwater and blocking its discharge to Brinson Creek for as long as it remains in operation. Aquifer-use restrictions will provide a permanent means for protection against direct exposure to the contaminated surficial groundwater.	Provides an effective means of intercepting and treating contaminated groundwater prior to its discharge to Brinson Creek for as long as it remains in operation. Toxic vapors escaping to the air due to poor vapor extraction may increase risk to community. Aquifer-use restrictions will provide a permanent means for protection against direct exposure to the contaminated surficial groundwater.	Provides an effective means of intercepting and treating contaminated groundwater prior to its discharge to Brinson Creek for as long as it remains in operation. Aquifer-use restrictions will provide a permanent means for protection against direct exposure to the contaminated surficial groundwater.
• Adequacy and Reliability of Controls	Not Applicable.	Aquifer-use restrictions are reliable if enforced. Enforcement is likely as Camp Geiger is a controlled military installation	Interceptor trench involves basic technology and should be adequate and reliable for an indefinite period.	Air sparging has a long track record of commercial use and should be able to be controlled adequately and reliably for an indefinite period. High levels of metals in groundwater could short circuit the system prompting frequent maintenance. Well replacement over several years may result.	In well aeration is a relatively new technology without a substantial commercial track record. High levels of metals could short circuit the system prompting frequent maintenance. Well replacement over several years may result.
• Estimated Period of Operation	30 Years	30 Years	30 years unless additional active treatment actions are implemented upgradient.	30 years unless additional active treatment actions are implemented upgradient.	30 years unless additional active treatment actions are implemented upgradient.
• Need for 5-Year Review	Review required because no active treatment is included	Review required because no active treatment is included.	Review required because area impacted by treatment will be limited.	Review required because area impacted by treatment will be limited.	Review required because area impacted by treatment will be limited.

TABLE ES-4 (Continued)

SUMMARY OF DETAILED ANALYSIS
OPERABLE UNIT NO. 10 (SITE 35)
INTERIM FEASIBILITY STUDY, CTO-0232
MCB CAMP LEJEUNE, NORTH CAROLINA

Evaluation Criteria	RAA 1 No Action	RAA 2 No Action with Institutional Controls	RAA 3 Groundwater Collection and On-Site Treatment	RAA 4 In Situ Air Sparging and Off-Gas Carbon Adsorption	RAA 5 In Well Aeration and Off-Gas Carbon Adsorption
REDUCTION OF TOXICITY, MOBILITY, OR VOLUME THROUGH TREATMENT					
• Treatment Process Used	No active treatment process applied.	No active treatment process applied.	On-site groundwater treatment includes filtration, metals precipitation, air stripping, air and water carbon adsorption.	In situ volatilization and biodegradation. Off-gas carbon adsorption.	In situ volatilization and biodegradation. Off-gas carbon adsorption.
• Reduction of Toxicity, Mobility or Volume	No reduction except by natural attenuation.	No reduction except by natural attenuation.	Reduction of organic and inorganic contaminants expected within capture zone of trench.	Reduction of organic contaminants expected within radius of influence of wells.	Reduction of organic contaminants expected within radius of influence of wells.
• Residuals Remaining After Treatment	No active treatment process applied.	No active treatment process applied.	Residuals include metals sludge and spent carbon which would have to be disposed of properly.	Residuals requiring disposal include spent carbon and a small volume of condensed contaminated vapor (water).	Residuals requiring disposal include spent carbon and a small volume of condensed contaminated vapor (water).
• Statutory Preference for Treatment	Not satisfied.	Not satisfied.	Satisfied except that area impacted by treatment is limited and does not include entire plume of contaminated surficial groundwater.	Satisfied except that area impacted by treatment is limited and does not include entire plume of contaminated surficial groundwater.	Satisfied except that area impacted by treatment is limited and does not include entire plume of contaminated surficial groundwater.
SHORT-TERM EFFECTIVENESS					
• Community Protection	Risks to community not increased by remedy implementation.	Risks to community not increased by remedy implementation.	Minimal, if any, risks during collection and treatment.	Possible migration of toxic vapors through ground surface because vapor extraction is difficult to control when groundwater surface is within several feet of ground surface.	Minimal, if any, risks during operation and treatment.
• Worker Protection	None.	Protection required during well installation and sampling.	Trench installation procedure limits worker exposure by design.	Minimal potential for worker exposure.	Minimal potential for worker exposure.
• Environmental Impacts	Continued impacts from unchanged existing conditions.	Continued impacts from unchanged existing conditions.	Wetlands disturbance during installation could be significant. Trench will serve as a barrier for contaminated groundwater discharge to Brinson Creek.	Minimal wetlands disturbance. System will serve as a barrier for contaminated groundwater discharge to Brinson Creek.	Minimal wetlands disturbance. System will serve as a barrier for contaminated groundwater discharge to Brinson Creek.
• Installation Period	Not Applicable.	Less than 30 days required to install additional groundwater monitoring wells.	60 to 90 days estimated to install trench and treatment system.	60 to 90 days estimated to install aeration wells and treatment system.	60 to 90 days estimated to install aeration wells and treatment system.

TABLE ES-4 (Continued)

SUMMARY OF DETAILED ANALYSIS
OPERABLE UNIT NO. 10 (SITE 35)
INTERIM FEASIBILITY STUDY, CTO-0232
MCB CAMP LEJEUNE, NORTH CAROLINA

Evaluation Criteria	RAA 1 No Action	RAA 2 No Action with Institutional Controls	RAA 3 Groundwater Collection and On-Site Treatment	RAA 4 In Situ Air Sparging and Off-Gas Carbon Adsorption	RAA 5 In Well Aeration and Off-Gas Carbon Adsorption
IMPLEMENTABILITY					
• Ability to Construct and Operate	No construction or operation activities.	Involves standard well installation and sampling only.	Soft ground in wetlands areas may hamper construction and result in delays. Once installed, operating is straight-forward using commercially proven technology. Approximately 2,000 to 3,000 cubic yards of potentially contaminated soil excavated from the trench will require disposal. Lack of access may be a significant cost factor.	Construction of activities involve primarily well installation which has been previously executed successfully in this area. Disposal of drill cuttings required. Thin vadose zone may hamper effective vapor extraction which could result in the release of toxic vapors to atmosphere. High metals in groundwater could clog well screens which would require frequent maintenance or well replacement.	Construction of activities involve primarily well installation which has been previously executed successfully in this area. Disposal of drill cuttings required. High metals in groundwater could clog well screens which would require frequent maintenance or well replacement.
• Ability to Monitor Effectiveness	No monitoring.	Proposed monitoring will provide an indication of effects of natural attenuation and progress of contaminants migration.	Proposed monitoring will give notice of failure so that system can be adjusted before a significant contaminant release occurs.	Proposed monitoring will give notice of failure so that system can be adjusted before a significant contaminant release occurs.	Proposed monitoring will give notice of failure so that system can be adjusted before a significant contaminant release occurs.
• Availability of Services and Equipment	None required.	Well installation and sampling services available from multiple vendors.	Biopolymer trench technology available from a limited number of vendors.	Air sparging technology is available from multiple vendors.	In well aeration is a patented priority technology currently available from only one vendor.
• Requirements for Agency Coordination	None required.	Must submit semi-annual reports to document sampling reports.	None required, provided the intent of wetlands and air and water discharge permits is met.	None required, provided the intent of wetlands and air and water discharge permits is met.	None required, provided the intent of wetlands and air and water discharge permits is met.
COSTS					
• Net Present Worth (30 years)	$0	$299,800	$3,000,500	$2,459,600	$2,519,700

1.0 INTRODUCTION

This report presents the Draft Interim Feasibility Study (FS) for groundwater in the vicinity of the Fuel Farm at Operable Unit (OU) No. 10, Site 35 - Camp Geiger Area Fuel Farm, located at Marine Corps Base (MCB), Camp Lejeune, North Carolina. It has been prepared by Baker Environmental, Inc. (Baker) under contract with the Naval Facilities Engineering Command, Atlantic Division (LANTDIV).

This Interim FS has been conducted in accordance with the guidelines and procedures delineated in the National Oil and Hazardous Substance Pollution Contingency Plan (NCP) for remedial actions (40 CFR 300.430). These NCP regulations were promulgated under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA), commonly referred to as Superfund, and amended by the Superfund Amendments and Reauthorization Act (SARA) signed into law on October 17, 1986. The United States Environmental Protection Agency's (USEPA's) document Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA (USEPA, 1988b) has been used as guidance for preparing this document.

This Interim FS is based on data collected during the Remedial Investigation (RI) conducted at Site 35 (Baker, 1994), as well as data collected under previous investigations. The FS focuses on contaminated groundwater in the vicinity of the Fuel Farm.

1.1 Purpose of the Interim FS

The purpose of this Interim FS is to identify and evaluate various remedial actions for contaminated groundwater in the vicinity of the Fuel Farm at Site 35. Contaminated groundwater is present in the area of the proposed highway and is a source of ongoing contamination to Brinson Creek. The results of the RI indicate that the extent of groundwater contamination has not been adequately defined to date. The Interim FS is intended to develop potential remedial actions that will provide for the protection of human health and the environment from contaminated groundwater in this area prior to the completion of a comprehensive FS that considers remedial actions for the entire area of contaminated groundwater as well as other media including surface water and sediments. The comprehensive FS will be not initiated until additional data is obtained from Site 35 to define the extent and possible sources of contaminated groundwater.

The FS process under CERCLA serves to ensure that appropriate remedial alternatives are developed and evaluated, such that relevant information concerning the remedial action options can be presented, and an appropriate remedy selected. The FS involves two major phases:

- Development and screening of remedial action alternatives, and
- Detailed analysis of remedial action alternatives.

The first phase includes the following major activities: (1) developing remedial action objectives, (2) developing general response actions, (3) identifying volumes or areas of affected media, (4) identifying and screening potential technologies and process options, (5) evaluating process options, (6) assembling alternatives, (7) defining alternatives, and (8) screening and evaluating alternatives. Section 121(b)(1) of CERCLA requires that an assessment of permanent solutions and alternative treatment technologies or resource recovery technologies that, in whole or in part, will result in a permanent and significant decrease in the toxicity, mobility, or volume of the hazardous substance, pollutant, or contaminant be conducted. In addition, according to CERCLA, treatment alternatives should be developed ranging from an alternative that, to the degree possible, would eliminate the need for long-term management to alternatives involving treatment that would reduce toxicity, mobility, or volume as their principal element. A containment option involving little or no treatment and a no action alternative should also be developed.

The second phase of the FS consists of: (1) evaluating the potential alternatives in detail with respect to nine evaluation criteria to address statutory requirements and preferences of CERCLA, and (2) performing a comparative analysis of the evaluated alternatives.

1.2 Report Organization

This Interim FS Report is organized in five sections. The Introduction (Section 1.0) presents a brief discussion of the FS process, and site background information including a summary of the nature and extent of contamination at the site. Section 2.0 contains the remedial action objectives, remediation goal options, and remediation levels. Section 3.0 contains the identification and preliminary screening of the remedial action technologies. In addition, Section 3.0 discusses the general response actions. Section 4.0 contains the development and preliminary screening of remedial action alternatives. Section 5.0 presents the results of the detailed analysis of the remedial alternatives (both individual analysis and comparative analysis). The detailed analysis is based on a set of nine criteria including short- and long-term effectiveness, implementability, cost, state and local acceptance, compliance with applicable regulations, and overall protection of human health and the environment. The references for Sections 1.0 through 5.0 are listed at the end of each section.

1.3 Background Information

This section presents background information pertaining to Site 35 including the site description and location, site history, previous investigations and findings, physical characteristics of the study are, nature and extent of contamination, and conclusions and recommendations from the RI.

1.3.1 Site Description and Location

MCB, Camp Lejeune (also referred to as the "Activity") is located in Onslow County, North Carolina (Figure 1-1). The Activity currently covers approximately 234 square miles and is bisected by the New River, which flows in a southeasterly direction and forms a large estuary before entering the Atlantic Ocean. The borders of the Activity are defined by the U.S. Route 17 and State Route 24 to the west and northwest, respectively. The eastern border is defined by the Atlantic Ocean shoreline and the City of Jacksonville, North Carolina, borders the Activity to the north.

Camp Geiger is located at the extreme northwest corner of MCB Camp Lejeune and contains a mixture of troop housing, personnel support and training facilities. The main entrance is located along U.S. Route 17, approximately 3.5 miles southeast of the City of Jacksonville, North Carolina. Site 35, the Camp Geiger Area Fuel Farm, refers primarily to five, 15,000-gallon aboveground storage tanks (ASTs), a pump house, a fuel loading/unloading pad, an oil water separator, and a distribution island situated just north of the intersection of Fourth and "G" Streets. Results of previous investigations have expanded the study area beyond the confines of the Fuel Farm. To date, the study area is bounded on the west by D Street, on the north by Second Street, on the east by Brinson Creek, and on the south by Fifth Street and Building No. TC572 (Figure 1-2). However, the focus of this Interim FS is on contaminated groundwater north of Fourth Street and east of "E" Street.

1.3.2 Site History

Construction of Camp Geiger was completed in 1945, four years after construction of MCB, Camp Lejeune was initiated. Originally, the Fuel Farm ASTs were used for the storage of No. 6 fuel oil, but were later converted for storage of other petroleum products including unleaded gasoline, diesel fuel, and kerosene. The date of their conversion is not known.

Routinely, the ASTs at Site 35 supply fuel to an adjacent dispensing pump. A leak in an underground line at the station was reportedly responsible for the loss of roughly 30 gallons per day of gasoline over an unspecified period (Law, 1992). The leaking line was subsequently sealed and replaced.

The ASTs at Site 35 are currently used to dispense gasoline, diesel, and kerosene to government vehicles, and to supply underground storage tanks (USTs) in use at Camp Geiger and the nearby New River Marine Corps Air Station. The ASTs are supplied by commercial carrier trucks which deliver product to fill ports located on the fuel loading/unloading pad located south of the ASTs. Six, short-run (120 feet maximum), underground fuel lines are currently utilized to distribute the product from the unloading pad to the ASTs. Product is dispensed from the ASTs via trucks and underground piping.

Reports of a release from an underground distribution line near one of the ASTs date back to 1957-58 (ESE, 1990). Apparently, the leak occurred as the result of damage to a dispensing pump. At that time the Camp Lejeune Fire Department estimated that thousands of gallons of fuel were released although records of the incident have since been destroyed. The fuel reportedly migrated to the east and northeast toward Brinson Creek. Interceptor trenches were excavated and the captured fuel was ignited and burned.

Another abandoned underground distribution line extended from the ASTs to the former Mess Hall Heating Plant, located adjacent to "D" Street, between Third and Fourth Streets. The underground line dispensed No. 6 fuel oil to a UST which fueled the Mess Hall boiler. The Mess Hall, located across "D" Street to the west, is believed to have been demolished along with its Heating Plant in the 1960s.

In April 1990, an undetermined amount of fuel was discovered by Camp Geiger personnel along two unnamed drainage channels north of the Fuel Farm. Apparently, the source of the fuel, believed to diesel or jet fuel, was an unauthorized discharge from a tanker truck that was never identified. The Activity reportedly initiated an emergency clean-up which included the removal of approximately 20 cubic yards of soil.

The Fuel Farm is scheduled to be decommissioned in April 1995. Plans are currently being prepared to empty, clean, dismantle, and remove the ASTs along with all concrete foundations, slabs on grade, berms, and associated underground piping. The Fuel Farm is being removed to make way for a six-lane divided highway proposed by the North Carolina Department of Transportation (NCDOT) (Figure 1-3). Construction of the highway is scheduled to commence in July 1995.

In addition to the Fuel Farm dismantling, soil remediation activities will take place along the highway right-of-way as per an Interim Record of Decision executed on September 15, 1994. The soil remediation work is scheduled to commence in May 1995.

1.3.3 Previous Investigations and Findings

The purpose of this section is to summarize existing information pertaining to previous environmental studies involving Site 35. Information presented herein can be found in the Initial Assessment Study of Marine Corps Base, Camp Lejeune, North Carolina (WAR, 1983), Final Site Summary Report, MCB Camp Lejeune (ESE, 1990) Draft Field Investigation/Focused Feasibility Study, Camp Geiger Fuel Spill Site (NUS, 1990), Underground Fuel Investigation and Comprehensive Site Assessment (Law, 1992) and the Addendum Report of Underground Fuel Investigation and Comprehensive Site Assessment (Law, 1993), the Interim Remedial Action Remedial Investigation/Feasibility Study (Baker, 1994), and the Remedial Investigation Report (Baker, 1994). Excerpts from each of the above reports are presented in the appendices of the Remedial Investigation Report (Baker, 1994). Sample locations associated with each of these studies are depicted on Figure 1-4.

1.3.3.1 Initial Assessment Study

MCB, Camp Lejeune was placed on the National Priority List (NPL) in 1983 after the Initial Assessment Study identified 76 potentially contaminated sites at the Activity (Water and Air Resources, 1983). Site 35 was identified as one of 23 sites warranting further investigation. Sampling and analysis of environmental media was not conducted during the Initial Assessment Study.

1.3.3.2 Confirmation Study

ESE performed Confirmation Studies of the 23 sites requiring further investigation and investigated Site 35 between 1984 and 1987 (ESE, 1990). In 1984, ESE advanced three hand-auger borings and collected groundwater and soil samples from each location. Soils were analyzed for lead and oil and grease. Lead was detected in soil samples obtained from hand auger borings at concentrations ranging from 6 to 8 mg/kg. Oil and grease was also detected at concentrations ranging from 40 to 2,200 mg/kg.

Shallow groundwater samples were obtained from the open boreholes and analyzed for lead, oil and grease, and volatile organic compounds (VOCs) including benzene, trans-1,2-dichloroethene (T-1,2-DCE), trichloroethene (TCE), and methylene chloride. Lead was detected in each sample ranging from 3,659 µg/L to 1,063 µg/L. Oil and grease was detected in only one sample at 46,000 µg/L. The only detected VOC was methylene chloride in one sample at 4 µg/L.

In 1986, ESE collected two sediment and two surface water samples from Brinson Creek and installed three permanent monitoring wells: two east of and one west of the Fuel Farm. Surface water and sediment samples were analyzed for lead, oil and grease and ethylene dibromide. Groundwater samples were obtained in December 1986 and again in March 1987 and were analyzed for lead, oil and grease, and VOCs.

No target analytes were detected in either surface water sample. Both sediment samples were reported to contain lead and oil and grease although no data indicating actual levels of detection were provided in ESE's report. Levels were reported to be higher in the upstream sample, prompting ESE to suggest that the discharge of contaminated groundwater to the creek is occurring at the far northern section of the fuel farm ASTs or that the source of oil and grease and lead may be upstream.

Lead was detected in only one of six samples (33 µg/L) obtained from the three permanent monitoring wells. Oil and grease was detected in all six samples ranging from 200 µg/L to 12,000 µg/L. Detected VOCs included benzene (1.3 µg/L to 30 µg/L), trans-1,2-DCE (3.2 µg/L to 29 µg/L), and TCE (detected at 11 µg/L on both sample dates).

1.3.3.3 Focused Feasibility Study

A Focused Feasibility Study (FFS) was conducted in 1990 in the area north of the Fuel Farm by NUS Corporation (NUS). The investigation included the installation of four groundwater monitoring wells. Results of laboratory analyses revealed that groundwater in one well and soil cuttings from two borings were contaminated with petroleum hydrocarbons. No nonaqueous product was observed.

A geophysical investigation was conducted by NUS as part of the FFS in an attempt to identify USTs at the site of the former gas station. The results indicated the presence of a geophysical anomaly to the north of the former gas station.

1.3.3.4 Comprehensive Site Assessment

Law Engineering, Inc. (Law) conducted a Comprehensive Site Assessment (CSA) during the fall of 1991 (Law, 1992). The CSA involved the drilling of 18 soil borings to depths ranging from 15 to 44.5 feet. These soil borings were ultimately converted to nested wells that monitor the water table aquifer along two zones. The shallow zone, or water table zone, generally extends from 2.5 to 17.5 feet, below ground surface (bgs). The deeper zone monitored by the nested wells generally ranges from 17.5 to 35 feet bgs. Five additional soil borings were drilled and nine soil borings were hand-augered to provide data regarding soil contamination in the vadose zone. Additional groundwater data was provided via 21 drive-point groundwater or "Hydropunch" samples. A "Tracer" study was also performed to investigate the integrity of the ASTs and underground distribution piping.

Soil and groundwater samples obtained under the CSA were analyzed for both organic and inorganic compounds. Groundwater analyses included purgeable hydrocarbons (EPA 601), purgeable aromatics and methyl-tertiary butyl ether (MTBE) (EPA 602), polynuclear aromatic hydrocarbons (EPA 610), and unfiltered lead (EPA 239.2). Soil analyses were limited to total petroleum hydrocarbons (TPH) (SW846 3rd Edition, 5030/3550: gasoline/diesel fractions) and lead (SW846 3rd Edition, 6010). Ten soil samples were analyzed for ignitability by SW846 3rd Edition, 1010.

The results of the CSA identified areas of impacted soil and groundwater. The nature of the contamination included both halogenated (i.e., chlorinated) organic compounds (e.g., TCE, trans-1,2-DCE, and vinyl chloride) and nonhalogenated, petroleum-based constituents (e.g., TPH, MTBE, benzene, toluene, ethylbenzene, and xylene). The contamination encountered was typically identified in both shallow (2.5 to 17.5 feet bgs) and deep (17.5 to 35 feet bgs) wells.

Law also identified several plumes of shallow groundwater contamination including two plumes comprised primarily of petroleum-based constituents (e.g., BTEX) and two plumes comprised of halogenated organic compounds (e.g., TCE). The plumes are all located north of Fourth Street and east of E Street except for a portion of a TCE plume. This plume extends southwest beyond the corner of Fourth and E Streets.

In general, contaminant concentrations in soil were greatest in those samples taken at or below the water table. Law concluded that soil contamination at Site 35 was likely due to the presence of a dissolved phase groundwater plume and seasonal fluctuations of the water table.

A follow-up to the CSA was conducted by Law in 1992. Reported as an Addendum to the CSA (Law, 1993), it was designed to provide further characterization of the southern extent of the petroleum contamination resulting from historical releases. Three monitoring wells were installed including MW-26, -27, and PW-28. Soil samples were obtained from each of these locations and analyzed for TPH (gasoline and diesel fractions). As part of the follow-up, a pump test was performed to estimate the hydraulic characteristics of the surficial aquifer. This test was designed to determine performance characteristics of a designated pumping well and to estimate hydraulic parameters of the aquifer. An approximate hydraulic conductivity of 100 feet/day was determined for the surficial aquifer.

1.3.3.5 Interim Remedial Action RI/FS

Baker conducted an Interim Remedial Action RI/FS beginning in December of 1993. An additional seven soil borings were located within and around groundwater contaminant plume areas identified during the CSA. In addition to the soil borings, thirteen shallow soil samples were taken adjacent to Brinson Creek to determine the extent of contamination emanating from Site 35. Two of these shallow soil samples were situated upstream along Brinson Creek to provide background information on TPH and oil and grease.

In addition to soil sampling, a second round of groundwater level measurements was obtained for comparison to those presented in the CSA.

The most prevalent contaminants detected in soil samples taken during the Interim Remedial Action RI were benzene, toluene, ethylbenzene, xylenes, naphthalene, and 2-methylnaphthalene. These constituents are commonly associated with fuel contamination. TPH (gasoline and diesel) and oil and grease were also observed, in addition to sporadic occurrences of lead, chromium, vanadium, and arsenic.

Analytical results, in general, confirm the previous findings that contamination in the majority of the identified soil is associated with a dissolved petroleum hydrocarbon contaminant plume in shallow groundwater. Oil and grease results observed in shallow soil samples obtained from the Brinson Creek area are likely influenced by the presence of naturally occurring organics in soils or an upgradient contamination source. This is supported by elevated background concentrations of oil and grease in surface soil samples obtained along the banks of Brinson Creek approximately 1/2-mile upstream of the site. In two areas, the results of soil sampling indicated the presence of elevated petroleum hydrocarbon contamination at locations sufficiently above the top of groundwater such that the source may not have been attributable to fluctuating groundwater. Both areas were located north of the Fuel Farm in areas where past unauthorized discharges of fuel products were reported to have occurred.

The Interim Remedial Action RI/FS culminated with an executed Interim Record of Decision (ROD), signed on September 15, 1994, for the remediation of contaminated soil along and adjacent to the proposed highway right-of-way at Site 35. Three areas of contaminated soil have been identified (see Figure 1-2). The first area is located in the vicinity of the Fuel Farm ASTs, and the two other areas are located north of the Fuel Farm. The larger of these two areas is located along "F" Street in the vicinity of monitoring well MW-25. Baker has estimated that approximately 3,600 cubic yards (4,900 tons) of contaminated soil is present in these areas. Contaminated soil located in these areas is scheduled for removal and disposal at an off-site recycling facility beginning July 1995.

A fourth area of soil contamination, located immediately north of Building G480, was also identified in the Interim ROD. Additional data pertaining to this fourth area became available subsequent to the execution of the Interim ROD. This data indicated that contaminated soil was encountered in this area during the removal of a UST there in January 1994. The contaminated soil was excavated and reportedly disposed off site; however, no documentation is available regarding how or where the soil was disposed. An additional soil investigation will be conducted in this area to confirm that the contaminated soil was not returned to the excavation and that follow-up soil remediation in this area is not necessary.

1.3.3.6 Remedial Investigation/Feasibility Study

A comprehensive RI was conducted by Baker in 1994 to evaluate the nature and extent of the threat to public health and the environment caused by the release of hazardous substances, pollutants, or contaminants, and to support a Feasibility Study evaluation of potential remedial alternatives.

The RI field program was initiated on April 11, 1994. Data gathering activities were derived from: a soil gas survey and groundwater screening investigation, a soil investigation, a groundwater investigation, a surface water and sediment investigation, and an ecological investigation.

Soil Gas Survey and Groundwater Screening Investigation

Baker monitored the collection of 67 soil gas samples and 72 groundwater screening samples from sample locations established across the Site 35 study area. This investigation focused on obtaining additional information to assess the source(s) of halogenated compounds in shallow groundwater. The majority of the sample locations were located south of the Fuel Farm and south of Fourth Street, and were based on the results of previous investigations, which revealed elevated levels of halogenated compounds in groundwater. The purpose of this activity was to assist in the placement of soil borings/monitoring wells.

Soil Investigation

The soil investigation involved the drilling of 26 soil borings at locations primarily determined by the results of the soil gas survey and groundwater screening investigation. Borings were advanced to three depths and included 10 shallow borings (14 to 17 feet bgs), 11 intermediate borings (41 to 47 feet bgs), and five deep borings drilled to a depth equivalent to 5 to 10 feet below the semi-confining layer separating the surficial aquifer from the Castle Hayne aquifer (Figure 1-4).

Soil samples obtained from the borings were analyzed for TCL volatiles, semivolatiles, pesticides/PCBs, and TAL metals, as well as a variety of engineering parameters that will be useful in the FS and remedial design process.

Groundwater Investigation

The groundwater investigation included the installation of shallow, intermediate, and deep groundwater monitoring wells. The shallow monitoring wells were installed to intercept the upper portion of the surficial aquifer. The intermediate wells were constructed to monitor the lower portion of the surficial aquifer with screens set just above what appeared to be a semi-confining layer separating the surficial aquifer from the underlying Castle Hayne aquifer. A total of 21 shallow and intermediate wells were installed under the RI. In addition, five deep groundwater wells were installed to monitor the upper portion of the Castle Hayne aquifer immediately below the suspected semi-confining layer (Figure 1-4).

Groundwater samples were obtained from each of the 26 newly installed wells and 29 existing wells. The samples were analyzed for TCL volatiles, semivolatiles, pesticides/PCBs, and TAL metals, as well as a variety of engineering parameters.

Surface Water/Sediment Investigation

Surface water and sediment samples were obtained along Brinson Creek which flows roughly north to south immediately east of the Fuel Farm. Samples were obtained from ten stations including three upstream and seven adjacent/downstream locations. Surface water and sediment samples were also collected from an off-base reference station. The reference stations included the White Oak River watershed.

The surface water and sediment samples were analyzed for TCL volatiles, semivolatiles, pesticides/PCBs, TAL metals, and particle size distribution.

Ecological Investigation

The ecological investigation included biological sampling (i.e., fish, shellfish, and benthic macroinvertebrates) along Brinson Creek and along three streams in the nearby White Oak River watershed including Webb Creek, Hadnot Creek, and Holland Mill Creek. The work performed in the White Oak River watershed was part of an overall ecological background investigation conducted as part of the RI.

1.3.3.7 <u>Other Investigations</u>

Two USTs located near the Fuel Farm have been the subject of previous investigations conducted under an Activity-wide UST program. The two USTs include a No. 6 fuel oil UST situated adjacent to the former Mess Hall Heating Plant, and a No. 2 fuel oil UST situated adjacent to the Explosive Ordnance and Disposal Armory, Office, and Supply Building. The former UST was abandoned in place years ago (date unknown) and has been the subject of previous environmental investigations performed by ATEC Associates, Inc. and Law. The latter UST was removed in January 1994 and is reported to be scheduled for an upcoming comprehensive environmental investigation.

1.3.4 Physical Characteristics of the Study Area

This section presents a brief discussion of the physical characteristics of Site 35, Camp Geiger Area Fuel Farm, including: surface features, meteorology, hydrology, geology (regional and site), soils, hydrogeology (regional and site), land usage, regional ecology, and a water supply well inventory of the area. Additional information is included in the RI report (Baker, 1994).

1.3.4.1 Surface Features

The generally flat topography of MCB Camp Lejeune is typical of the seaward portions of the North Carolina Coastal Plain. Elevations on the Activity vary from sea level to 72 feet above mean sea level (msl); however, the elevation of most of Camp Lejeune is between 20 and 40 feet msl.

Drainage at Camp Lejeune is generally toward the New River, except in areas near the coast which drain through the Intracoastal Waterway. In developed areas, natural drainage has been altered by asphalt cover, storm sewers, and drainage ditches. Approximately 70 percent of Camp Lejeune is in broad, flat interstream areas. Drainage is poor in these areas and the soils are often wet (WAR, 1983).

The U.S. Army Corps of Engineers has mapped the limits of 100-year floodplain at Camp Lejeune at 7.0 feet above msl in the upper reaches of the New River (WAR, 1983); this increases downstream to 11 feet above msl near the coastal area (WAR, 1983). Site 35 does not lie within the 100-year floodplain of the New River.

The surface of the study area is primarily covered with vegetation, however, a significant portion is covered by roads, buildings, and parking areas. Northeastern and eastern portions of the site are bordered by Brinson Creek, wetlands, and woodlands.

The topography of Site 35 is relatively flat. An average elevation between 11 and 18 feet mean sea level (msl) was recorded during a recent survey of the site. Changes in elevation are gradual giving the site a flat appearance. The elevation drops dramatically adjacent to Brinson Creek defining the creek's channel. Surface runoff across the study area is primarily toward Brinson Creek via man-made drainage ditches, storm drains and catch basins and natural drainage patterns. Impervious surfaces such as roadways, paved parking lots, and buildings modify surface runoff and infiltration across the study area.

1.3.4.2 Climatology

MCB Camp Lejeune is located within the Coastal Plain physiographic province of North Carolina. Coastal Plain elevations range from 200 feet above msl at the western boundary to generally 30 feet or less in areas of tidal influence to the east. The tidal portion of the Coastal Plain, where MCB Camp Lejeune is situated, is generally flat and swampy.

Although coastal North Carolina lacks distinct wet and dry seasons, there is some seasonal variation in average precipitation. July tends to receive the most precipitation and rainfall amounts during summer are generally the greatest. Daily showers during the summer are not uncommon, nor are periods of one or two weeks without rain. Convective showers and thunderstorms contribute to the variability of precipitation during the summer months. October tends to receive the least amount of precipitation, on average. Throughout the winter and spring months precipitation occurs primarily in the form of migratory low pressure storms. MCB Camp Lejeune's average yearly rainfall is approximately 52 inches.

Coastal Plain temperatures are moderated by the proximity of the Atlantic Ocean. The ocean effectively reduces the average daily fluctuation of temperature. Lying 50 miles offshore at its nearest point, the Gulf Stream tends to have little direct effect on coastal temperatures. The southern reaches of the cold Labrador Current offsets any warming effect the Gulf Stream might otherwise provide.

MCB Camp Lejeune experiences hot and humid summers; however, ocean breezes frequently produce a cooling effect. The winter months tend to be mild, with occasional brief cold spells. Average daily temperatures range from 38° F to 58° F in January and 72° F to 86° F in July. The average relative humidity, between 75 and 85 percent, does not vary greatly from season to season.

Observations of sky conditions indicate yearly averages of approximately 112 days clear, 105 partly cloudy, and 148 cloudy. Measurable amounts of rainfall occur 120 days per year, on the average. Prevailing winds are generally from the south-southwest 10 months of the year, and from the north-northwest during September and October. The average wind speed for MCAS New River is 6.9473 miles per hour.

1.3.4.3 Surface Water Hydrology

The majority of MCB Camp Lejeune is situated near sea level (i.e., estuarine conditions which are tidally influenced). The New River is the dominant surface water feature and receives drainage from Brinson Creek. It flows in a southerly direction and empties into the Atlantic Ocean through the New River Inlet.

A single surface water (Brinson Creek) body forms the eastern boundary of the study area. Several surface drainage pathways lead to Brinson Creek with flows southeast to the New River. Brinson Creek is designated by the North Carolina Fisheries Rules as Class I inland fishing waters, whereas the New River is designated by Class C coastal fishing waters.

The New River is also designated as Class SC, High Quality Water (HQW) (NC DEHNR, 1993, and NCMFC, 1992). In addition, the section of the New River where Site 35 is located is classified as a primary fish nursery area, but it is not a water supply.

1.3.4.4 Geology

This section describes the regional geology of MCB Camp Lejeune and the site geology of OU No. 10.

Regional Geology

MCB Camp Lejeune is located in the Atlantic Coastal Plain physiographic province. The sediments of the Atlantic Coastal Plain consist of interbedded sands, clays, calcareous clays, shell beds, sandstone, and limestone. These sediments are layered in interfingering beds and lenses that gently dip and thicken to the southeast (ESE, 1990). Regionally, they comprise 10 aquifers and nine confining units which overlie igneous and metamorphic basement rocks of pre-Cretaceous age.

These sediments were deposited in marine or near-marine environments and range in age from early Cretaceous to Quaternary time.

United States Geological Survey (USGS) studies at MCB Camp Lejeune indicate that the area is underlain by sand and limestone aquifers separated by semi-confining units (i.e., in some portions of the base) of silt and clay. These aquifers include the water table (surficial), Castle Hayne, Beaufort, Peedee, Black Creek, and upper and lower Cape Fear. The combined thickness of these sediments is approximately 1,500 feet. Less permeable clay and silt beds function as confining units or semi-confining units which separate the aquifers and impede the flow of groundwater between aquifers.

Site Geology

Numerous borings were advanced within the study area during the field investigations conducted by Baker. The following provides a brief description of the stratigraphy underlying the study area. Additional information is included in the RI Report (Baker, 1994).

Soil conditions are generally uniform throughout the study area. In general, the shallow soils consist of unconsolidated deposits of silty sand, clayey silt, silt, and sand. These soils represent the Quaternary age "undifferentiated" Formation which characterizes the shallow water table aquifer and is underlain by the Castle Hayne Formation. Sands are primarily fine to medium grained and contain varied amounts of silt (0-50%), shell fragments (0-35%), and clay (0-10%). Results of the standard penetration tests indicate that the sands have a relative density of loose to dense. Based on field observations, the sands classify as silty sand (SM) and/or poorly graded sand (SP) according to the USCS.

Silts are plastic to nonplastic, contain varied amounts of sand (0-50%) and clay (0-10%), and classify as ML or MH. Standard penetration tests indicate that the silts have a relative density of loose to dense for the nonplastic, and soft to very stiff for the plastic.

Geologic cross-sections were constructed to illustrate subsurface soil beneath the study area. As shown on Figure 1-5, several areas were traversed to provide a cross-sectional view of the study area. Three cross-sections were constructed: A-A' crosses west to east across the upper portion of the study area; B-B' crosses north to south; and C-C' crosses west to east across the lower portion of the study area.

Cross-section A-A' (see Figure 1-6) represents subsurface soils to an elevation of -51.3 feet msl from the western boundary of the study area to the eastern boundary. The soil underlying this portion of the area consists of fine to medium sands, clayey silts, and silty sands.

In general, on the western portion of the study area, a fine sand with trace to some silt is underlain by another fine sand that is partially cemented with calcium carbonate and contains 10-20% shell fragments to a depth of approximately -25 msl. Underlying the partially cemented sand is a very dense, greenish gray, fine sand containing some silt, trace to some shell fragments. This soil unit is the semi-confining unit separating the Quaternary sediments from the Castle Hayne Formation. The semi-confining unit appears to be approximately 8 to 12 feet thick, generally thickening toward the east. Beneath this unit resides the Castle Hayne Formation. The upper portion of the Castle Hayne was described as a partially cemented, gray, fine sand with some shell fragment and limestone fragments encountered periodically.

On the eastern portion of the study area this entire sequence of soil types appears to be overlain by silty clay or a clayey silt. The unit is not uniform and varies from approximately 4 to 20 feet thick.

Cross-section B-B' (see Figure 1-7) represents the subsurface soil conditions to an elevation of -42.1 feet. The soils consisted of clayey silts, sands, silty sands, pats, and clays. Overall the soils did not differ substantially from those encountered in the A-A' cross-section. In general, a fine to medium sand with trace to some silt was interbedded with silts, silty sands, clayey silts and clays to an elevation of -6 to -12 msl. The only dramatic difference was the 8 feet of peat observed in soil boring 35MW-34B. This boring was located in the southeastern portion of the study area.

Beneath the fine to medium sand resides the partially cemented, gray, fine sand with trace to some shell fragments. The semi-confining unit underlies this unit followed by the Castle Hayne Formation.

Cross-section C-C' (see Figure 1-8) represents the soils beneath the southern portion of the site to an elevation of -51.3. In general, the soils consisted of the same types observed in the other cross-sections previously discussed. The only difference in this cross-section when compared with the others is the increase in interbedded soils on the eastern portion of the area.

Overall, the soils encountered during investigations within the study area are fairly consistent throughout. Note that within the study area, a laterally continuous semi-confining unit was present and within 2 feet msl.

1.3.4.5 Surface Soils

According to the SCS Soil Survey the site is underlain by a single distinct soil unit, the Baymeade-Urban (BaB) Land Complex. Baymeade-Urban soils exhibit 0 to 6 percent slopes and only about 30 percent of their surface area has been altered through urbanization. Infiltration is rapid and surface water runoff slow in the remaining undisturbed areas. The seasonal high water table ranges from 4 to 5 feet bgs for Baymeade-Urban soils.

1.3.4.6 Hydrogeology

The following sections discuss the regional and site-specific hydrogeologic conditions. The information presented on the regional hydrogeology is from literature (Harned, et al., 1989); site-specific hydrogeologic information presented is from data collected during the field investigation.

Regional Hydrogeology

The surficial water table aquifer lies in a series of undifferentiated sediments, primarily sand and clay, which commonly extend to depths of 50 to 100 feet. This aquifer is not used for water supply at MCB Camp Lejeune because of its low yielding production rates. A confining unit is present underlying the surficial aquifer within the eastern portion of MCB Camp Lejeune (Harned, et al., 1989).

The principal water supply aquifer for the Activity lies in a series of sand and limestone beds between 50 and 300 feet bgs. This series of sediments generally is known as the Castle Hayne formation. The Castle Hayne Formation is about 150 to 350 feet thick in the area and contains the most productive aquifer in North Carolina. Estimated transmissivity (T) and hydraulic conductivity (K) values for the Castle Hayne aquifer range from 4,300 to 24,500 ft^2/day (32,200 to 183,300 gallons/foot/day) and 14 to 82 feet/day, respectively (Harned et al., 1989).

Onslow County and MCB Camp Lejeune lie in an area where the Castle Hayne aquifer contains freshwater, although the proximity of saltwater in deeper layers just below the aquifer and in the New River estuary is of concern in managing water withdrawals from the aquifer. Overpumping of the deeper parts of the aquifer could cause intrusion of saltwater. The aquifer contains water having less than 250 milligrams per liter (mg/l) chloride throughout the area of the Base (Harned et al., 1989).

The aquifers that lie below the Castle Hayne consist of thick sequences of sand and clay. Although some of these aquifers are used for water supply elsewhere in the Coastal Plain, they contain saltwater in the MCB Camp Lejeune area and are not used (Harned et al., 1989).

Rainfall in the MCB Camp Lejeune area enters the ground in recharge areas, infiltrates the soil, and moves downward until it reaches the water table, which is the top of the saturated zone. In the saturated zone, groundwater flows in the direction of lower hydraulic head, moving through the system to discharge areas like the New River and its tributaries or the ocean (Harned et al., 1989).

Water levels in wells tapping the surficial aquifer vary seasonally. The surficial aquifer receives more recharge in the winter than in the summer when much of the water evaporates or is transpired by plants before it can reach the water table. Therefore, the water table generally is highest in the winter months and lowest in summer or early fall (Harned et al., 1989).

In semi-confined aquifers, water is under excess head and the level to which it rises in a tightly cased well is called the potentiometric surface. The hydraulic head in the semi-confined Castle Hayne aquifer, shows a different pattern of variation over time. Some seasonal variation also is common in the potentiometric surface of the Castle Hayne aquifer, but the changes tend to be slower and over a smaller range than for water table wells (Harned et al., 1989).

Site Hydrogeology

This section describes the site hydrogeologic conditions for the surficial (water table aquifer) and the deep (Castle Hayne aquifer) water-bearing zones at Site 35. Hydrogeologic characteristics in the vicinity of the site were evaluated by reviewing existing information (e.g., USGS publications) and installing a network of shallow, intermediate, and deep monitoring wells.

Groundwater was encountered at varying depths during the drilling program. This variation is primarily attributed to topographical changes. In general, the groundwater was encountered between 5.5 and 8.5 feet bgs. The water table nears the surface in the area of Brinson Creek, where the topography drops.

Based on groundwater level measurements, shallow groundwater elevations exhibited some fluctuation over the three month period. This water table aquifer exhibited a 0.73 to 3.25 foot increase in elevation. This increase may be due to increased precipitation experienced during the latter portion of the summer and early fall of 1994. Typically at MCB, Camp Lejeune, a higher water table is noted in the spring and a lower water table is noted in the late fall. However, the spring of 1994 was reported by Activity personnel as being unseasonably dry and may have resulted in a decrease in the elevation of the groundwater.

Shallow groundwater flows toward the northeast, with an average gradient of 1.7×10^{-2} ft/ft.

Hydraulic conductivity test were performed at the site between September 9 and 10, 1994. The average hydraulic conductivity for the upper portion of the water table aquifer is 0.628 ft/day (2.22×10^{-4} cm/sec), and the average for the lower portion of the water table aquifer is 5.16 ft/day (1.8×10^{-3} cm/sec).

A study of data from other aquifer tests (pump tests) performed at MCB Camp Lejeune was conducted by Baker to further evaluate aquifer characteristics and production capacities. Based on this data, average pumping rates range from 0.5 to 3 gallons per minute (gpm); transmissivity ranges from 7.17 to 7,099.20 ft^2/day; storativity ranges from 1.51×10^{-3} to 7.48×10^{-2} ; and hydraulic conductivity ranged from 0.48 to 1.42 ft/day.

Fluctuation of the groundwater elevations within the deep wells was observed over the three months. However the fluctuation was not as dramatic as in the shallow and intermediate wells. Fluctuations ranged from 0.88 to 1.77 feet. It is not uncommon for a semi-confined aquifer to not respond to precipitation or seasonal fluctuations with the same magnitude as an unconfined aquifer. The presence of the semiconfining unit will impede the vertical migration of precipitation causing a delayed and minimal effect on the head of the aquifer.

The upper portion of the Castle Hayne Aquifer also flows northeast across the site with a gradient of 1.4×10^{-2}. The calculated hydraulic conductivity for this unit was calculated at 6.03 ft/day (2.03×10^{-3} cm/sec). These values are consistent with the sands encountered in the upper portion of the Castle Hayne Formation beneath the site (Fetter, 1980).

1.3.4.7 Land Use and Demography

Present military population of MCB, Camp Lejeune is approximately 40,928 active duty personnel. The military dependent community is in excess of 32,081. About 36,086 of these personnel and dependents reside in base housing units. The remaining personnel and dependents live off base and have had dramatic effects on the surrounding area. An additional 4,412 civilian employees perform facilities management and support functions. The population of Onslow County has grown from 17,739 in 1940, prior to the formation of the base, to its present population of 121,350.

Site 35, the Camp Geiger Area Fuel Farm, is presently used to dispense gasoline, diesel, and kerosene to government vehicles and to supply USTs in use at Camp Geiger and the New River Marine Corps Air Station. The Fuel Farm is planned for demolition for a proposed highway. Barracks are located within 1,000 feet of the site and many warehouses and storage facilities are located adjacent to and within the boundaries of the study area. A COMMARFORLANT Nuclear Biological Chemical Defense School Training Range is located adjacent to the southeast boundary of the site.

Sensitive environmental areas would include Brinson Creek and associated unnamed tributaries.

1.3.4.8 Regional Ecology

MCB Camp Lejeune is located in the Coastal Plain Province. The ecology of the region is influenced by climate, which is characterized by hot, humid summers and cool winters. Some subfreezing cold spells occur during the winters, and there are occasional accumulations of snow that rarely persist. The average precipitation is 55.96 inches and the mean temperature is 60.9°F. The area exhibits a long growing season, typically more than 230 days. Soils in the region range from very poorly drained muck to well-drained sandy loam.

A number of natural communities are present in the Coastal Plain Province. Subcommunities and variations of these major community types are also present, and alterations of natural communities have occurred in response to disturbance and intervention (i.e., forest cleared to become pasture). The natural communities found in the area are summarized as follows:

- Mixed Hardwood Forest - Found generally on slopes of ravines. Beech is an indicator species with white oak, tulip, sweetgum, and holly.
- Southeastern Evergreen Forest - Dominated by pines, especially longleaf pine.
- Loblolly Pine/Hardwoods Community - Second growth forest that includes loblolly pine with a mix of hardwoods -- oak, hickory, sweetgum, sour gum, red maple, and holly.
- Southern Floodplain Forest - Occurs on the floodplains of rivers. Hardwoods dominate with a variety of species present. Composition of species varies with the amount of moisture present.
- Maritime Forest - Develops on the lee side of stable sand dunes protected from the ocean. Live oak is an indicator species with pine, cedar, yaupon, holly, and laurel oak. Deciduous hardwoods may be present where forest is mature.
- Pocosins - Lowland forest community that develops on highly organic soils that are seasonally flooded. Characterized by plants adapted to drought and acidic soils low in nutrients. Pond pine is dominant tree with dense layer of evergreen shrubs. Strongly influenced by fire.
- Cypress\Tupelo Swamp Forest - Occurs in the lowest and wettest areas of floodplains. Dominated by bald cypress and tupelo.
- Freshwater Marsh - Occurs upstream from tidal marshes and downstream from non-tidal freshwater wetlands. Cattails, sedges, and rushes are present. On the coast of North Carolina swamps are more common than marshes.
- Salt Marsh - Regularly flooded, tidally influenced areas dominated by salt-tolerant grasses. Saltwater cordgrass is a characteristic species. Tidal mud flats may be present during low tide.

- Salt Shrub Thicket - High areas of salt marshes and beach areas behind dunes. Subjected to salt spray and periodic saltwater flooding. Dominated by salt resistant shrubs.

- Dunes/Beaches - Zones from the ocean shore to the maritime forest. Subjected to sand, salt, wind, and water.

- Ponds and Lakes - Low depressional areas where water table reaches the surface or where ground is impermeable. In ponds, rooted plants can grow across the bottom. Fish populations managed in these ponds include redear, bluegill, largemouth bass, and channel catfish (USMC, 1987).

- Open Water - Marine and estuarine waters as well as all underlying bottoms below the intertidal zone.

Camp Lejeune covers approximately 108,800 acres, 84 percent of which is forested (USMC, 1987). Approximately 45.1 percent of this is pine forest, 22 percent is mixed pine/hardwood forest, and 16.8 percent is hardwood forest. Nine percent of the base, a total of 3,587 acres, is wetland and includes pure pond pine stands, mixed pond pine/hardwood, marshes, pocosins, and wooded swamps.

The base also contains 80 miles of tidal streams, 21 miles of marine shoreline, and 12 freshwater ponds. The soil types range from sandy loams to fine sand and muck, with the dominant series being sandy loam (USMC, 1987). The base drains primarily to the New River or its tributaries. These tributaries include Northeast Creek, Southwest Creek, Wallace Creek, French Creek, Bear Head Creek, Brinson Creek, and Duck Creek.

Because of the natural resources on the base, forested areas are actively managed for timber. Game species are also managed for hunting and ponds are maintained for fishing. Game species managed include wild turkey, white-tailed deer, black bear, grey and fox squirrels, bobwhite quail, eastern cottontail and marsh rabbits, raccoons, and wood ducks.

Brinson Creek and the portion of the New River that includes Brinson Creek are classified by the NC DEHNR as SC NSW. The SC classifies the water body as tidal saltwater, which allows for aquatic life propagation and survival, fishing, wildlife, and secondary recreation. The NSW is for nutrient sensitive waters, which require limitations on nutrient inputs (NC DEHNR, 1993). Brinson Creek is designated by the North Carolina Fisheries Rules as Class I - inland fishing waters, whereas the New River is designated by Class C - coastal fishing waters (NCMFC, 1992).

Hadnot Creek, Holland Mill Creek (including Cartwheel Branch) and the section of the White Oak River that encompasses Hadnot Creek, Holland Mill Creek, and Webb Creek are classified as SA from their source to the White Oak River. The SA classifies the water body as a tidal saltwater with shellfishing for market purposes and the following uses: primary recreation, aquatic life propagation and survival, fishing, wildlife, and secondary recreation. Webb Creek is classified as C from its source to the White Oak River. The C classifies the water body as a fresh water with the following uses: aquatic life propagation and survival, fishing, wildlife, and secondary recreation. The section of the White Oak River that encompasses these three creeks is designated by the North Carolina Fisheries Rule as Class C - coastal fishing waters (NCMFC, 1992).

1.3.4.9 Site-Specific Ecology

During March 1994, Baker conducted a qualitative habitat evaluation of the terrestrial environment at Site 35. The study included the lower downstream reach of Brinson Creek because of its proximity to Site 36, a former landfill subject to future study. Vegetative communities and wildlife habitats present on-site at Site 35 are described below. Results of the study at Site 36 are located in the RI (Baker, 1994).

Three different habitat types are found at Site 35, including loblolly pine/hardwood forest, scrub/shrub wetland, and cleared open field. Small pockets of wetland are also found within the open field.

The area between Camp Geiger and the railroad and between Camp Geiger and Brinson Creek is classified as loblolly pine/hardwood forest according to Baker's habitat evaluation. The dominant conifers included loblolly pine (Pinus taeda) and red cedar (Juniperus virginiana). Some bald cypress (Taxodium distichum), is also present. Dominant deciduous trees include yellow poplar (Liriodendron tulipifera), sweetgum (Liquidambar styraciflua), and red maple (Acer rubrum). Potential bioreceptors found in this area include white-tailed deer (Odocoileus virginianus); gray fox (Urocyon cinereoargenteus); and, small mammals such as squirrels, rabbits (Syvilagus), moles, and voles. Song birds, as well as some upland game birds, probably occur in this area.

A narrow area of palustrine deciduous wetland is located within the floodplain of Brinson Creek and its tributary. The dominant vegetation in this wetland includes red maple, sweet gum, coastal plain willow (Salix caroliniana), and southern bayberry (Myrica cerifera). In some locations, the stream edge is dominated by narrow-leaved cattail (Typha augustifolia). Receptors expected to occur in this area include white-tail deer and small fur-bearing mammals such as raccoon (Procyon lotor), opossum (Didelphis marsupialis), mink (Mustela vison), and otter (Lutra canadensis). American wood cock (Philohela minor), wood ducks (Aix sponsa), and ruddy ducks (Oxyura jamaicensis) may feed in this area.

A narrow strip of open field is located across Brinson Creek from Camp Geiger. This area is a cleared right-of-way and is dominated by grasses and herbaceous plants. Small pockets of persistent emergent wetland are also present and are characterized by hydrophilic vegetation. White-tail deer, song birds, and various small mammals probably occur in this area.

1.3.4.10 Sensitive Environments

The sensitive environments at Site 35 include wetlands, threatened and endangered species, and other potentially sensitive environments.

Wetlands

According to the NWI maps, wetlands are present along Brinson Creek, along the unnamed tributary to Brinson Creek, and where Brinson Creek flows into the New River. A palustrine, forested, deciduous (PF06) wetland is located along Brinson Creek from Camp Geiger to the railroad. Wetlands along the tributary are classified as palustrine, forested, broad-leaved, deciduous (PF01) and wetlands at the confluence of Brinson Creek and the New River are classified as palustrine, forested, evergreen (PFO7). Wetlands of various classification are also identified along the New River.

Site-specific wetland delineations were not conducted at Sites 35 and 36 although potential wetland areas were noted during the habitat evaluation. These wetlands are illustrated on the biohabitat map contained in the RI report.

Threatened and Endangered Species

Surveys have been conducted to identify threatened and endangered species at Camp Lejeune and several programs are underway to manage and protect them. Of these protected species present at the base, the red-cockaded woodpecker (Picoides borealis), American alligator (Alligator Missippiensis), and sea turtles, are all covered by specific protection programs.

Four bird species, black skimmer (Rynchops niger), piping plover (Charadrius melodus), Bachmans sparrow (Aimophila aestialis), and peregrine falcon (Falco peregriaus) have also been identified during surveys at Camp Lejeune. The black skimmer and piping plover are sea and shore birds, respectively. Skimmers nest on low sandy islands and sand bars along the coast and piping plovers prefer beaches with broad open sandy flats above the high tide line. Skimmers feed above open water and piping plovers feed along the edge of incoming waves. Like the black skimmer and piping plover, Bachmans sparrows are very specific in their habitat requirements. They live in open stretches of pines with grasses and scattered shrubs for ground cover. Bachmans sparrows were observed at numerous locations throughout southern Camp Lejeune.

In addition to the protected species that breed or forage at Camp Lejeune, several protected whales migrate through the coastal waters off the base during spring and fall. These include the Atlantic right whale (Eubalaena glacialis), finback whale (Balaenoptera physalus), sei whale (Balaehoptera berealis), and sperm whale (Physeter Catodon). Before artillery or bombing practice is conducted in the area, aerial surveys are made to assure that whales are not present in the impact areas.

A natural heritage resources was conducted at Camp Lejeune (LeBlond, 1991) to identify threatened or endangered plants and areas of significant natural interest. From this list, the Rough-leaf loosestrife was the only federally threatened or endangered plant species found on the Marine Corps Base. In addition, several state endangered or threatened and federal and state candidate species were found on the MCB.

With the exception of the American Alligator, no endangered species have been recorded or are expected to occur at Site 35. An alligator was observed in Brinson Creek during site investigation activities.

Other Sensitive Environments

In addition to wetlands and protected species, other sensitive environments, including those listed in 40 CFR Part 300, were evaluated during Hazard Ranking System evaluations for MCB Camp Lejeune. These sensitive environments and their presence or absence at Sites 35 and 36 are discussed below.

- Marine Sanctuary - Sites 35 and 36 are not located within a Marine Sanctuary (NCMFC, 1992).
- National Park - Sites 35 and 36 are not located within a National Park (NPS, 1991).

- Designated Federal Wilderness Area - Sites 35 and 36 are not located within a Designated Federal Wilderness Area (WS, 1989).

- Areas Identified under the Coastal Zone Management Act - The North Carolina Coastal Area Management Act (CAMA) regulates various types of Areas of Environmental Concern including estuarine waters, coastal wetlands, public trust areas, and estuarine shoreline through the establishment of unified policies, criteria, standards, methods, and processes (CAMA, 1974).

- Sensitive Areas Identified under the National Estuary Program (NEP) or Near Coastal Waters Program (NCWP) - Sites 35 and 36 are not located within a Sensitive Area identified under the NEP or NCWP (USEPA, 1993).

- Critical Areas Identified under the Clean Lakes Program - Sites 35 and 36 are not located within a Critical Area identified under the Clean Lakes Program (NPS, 1991).

- National Monument - Sites 35 and 36 are not located near a National Monument (NPS, 1991).

- National Seashore Recreational Area - Sites 35 and 36 are not located within a National Seashore Recreational Area (NPS, 1991).

- National Lakeshore Recreational Area - Sites 35 and 36 are not located within a National Lakeshore Recreational Area (NPS, 1991).

- National Preserve - Sites 35 and 36 are not located within a National Preserve (NPS, 1991).

- National or State Wildlife Refuge - Sites 35 and 36 are not located within a National or State Wildlife Refuge (NCWRC, 1992).

- Unit of the Coastal Barrier Resource Program - Sites 35 and 36 are not located within a unit of the Coastal Barrier Resource Program (USDI, 1993).

- Administratively Proposed Federal Wilderness Area - Sites 35 and 36 are not located within an Administratively Proposed Federal Wilderness Area (WS, 1989, 1993).

- Spawning Areas Critical for the maintenance of fish/shellfish species within river, lake, or coastal tidal waters - Due to size restrictions, no critical spawning areas have been identified within the reach of Brinson Creek studied in this investigation (USMC, 1993). No specific spawning areas critical for the maintenance of fish/shellfish species in Brinson Creek have been designated as such by state agencies (NC DEHNR, 1993).

- Migratory pathways and feeding areas critical for maintenance of anadromous fish species within river reaches or areas in lakes or coastal tidal waters in which fish spend extended periods of time - Surface waters associated with Sites 35 and 36 are not migratory pathways or feeding areas critical for the maintenance of an anadromous fish species because there is not a significant population of anadromous fish in Brinson Creek (USMC, 1993).

- National river reach designated as Recreational - The New River and Brinson Creek are not designated as National Recreational Rivers (NPS, 1990, 1993).
- Federal designated Scenic or Wild River - The New River and Brinson Creek are not Federally designated Scenic or Wild Rivers (NPS, 1990, 1993).
- State land designated for wildlife or game management - Sites 35 and 36 are not located within a State game land (NCWRC, 1992).
- State designated Scenic or Wild River - The New River and Brinson Creek are not State designated Scenic or Wild Rivers (NCMFC, 1992).
- State designated Natural Area - Sites 35 and 36 are not located within a State designated Natural Area or Area of Significant Value (LeBlond, 1991).
- State designated areas for protection or maintenance of aquatic life - No areas within the boundaries of Sites 35 and 36 are designated as primary nursery areas or are unique or special waters of exceptional state or national recreational or ecological significance which require special protection to maintain existing uses (NC DEHNR, 1993).
- Areas of Significant Value - Sites 35 and 36 are not located within a State Area of Significant Value (LeBlond, 1991).
- State Registered Natural Resource Area - Sites 35 and 36 are not located within a State Registered Natural Resource Area (LeBlond, 1991).

1.3.4.11 Identification of Water Supply Wells

17 wells were identified within a one mile radius of the site. Information was not available for many of the wells. However, enough was available to formulate the following conclusions. Nine of the wells were installed in 1941 and 1942, two were estimated to have been installed in the 1950s, three were installed in the 1970s, one was installed in 1980, and two wells did not indicate the dates in which they were installed. The total depth of the wells range from 67 to 477 feet based on the available information. Screen depths range from 25 to 120 feet with some wells having multiple screens with varying lengths. The closest well is 1,320 feet to the north which is upgradient of Site 35. Given the distance of these wells in relationship to Site 35 and local geological/hydrogeological conditions, it is unlikely that contaminants, if present at Site 35, would migrate to these supply wells and impact the drinking water.

1.3.5 Nature and Extent of Contamination

This section describes the nature and extent of contamination at Site 35. The nature and extent was determined based on the analytical results of the various media considered under the RI (Baker, 1994), including soil, groundwater, sediment, surface water, and fish tissue.

Surface and Subsurface Soil

Relatively few detections of VOCs and SVOCs were observed in surface and subsurface soil samples obtained under the RI. The most significant contamination detected involved tetrachloroethane in subsurface soil at boring 35MW-30B located near the barracks southwest of the Fuel Farm. Pesticides were detected in surface soil samples only, but, are not deemed to be site related. No PCBs were detected in surface or subsurface soil samples. Detected inorganics were generally similar to background surface and subsurface soil concentrations at Camp Lejeune.

Groundwater

The nature and extent of groundwater contamination was considered based on the interval of groundwater monitored and included the upper portion of the surficial aquifer, the lower portion of the surficial aquifer, and the upper portion of the Castle Hayne aquifer.

No significant contamination was detected in the upper portion of the Castle Hayne aquifer. This indicates that, to date, the suspected semi-confining layer that separates the surficial aquifer from the Castle Hayne aquifer has served effectively as an aquitard.

Extensive groundwater contamination was observed in the surficial aquifer along both the upper and lower monitored intervals. Fuel-related organic contaminants, when encountered, appear more prevalent in the upper portion of the surficial aquifer. Conversely, solvent-related organic contaminants, when encountered, appear more prevalent in the lower portion of the surficial aquifer. This is likely due to the fact that the latter are heavier compounds. Figures 1-9 through 1-12 depict the approximate limits of the combined BTEX and halogenated compound plumes detected in the upper and lower portions of the surficial aquifer.

The extent of fuel-related contamination appears to be adequately defined based on the data obtained to date. It is limited to the area north of Fourth Street in the vicinity of obvious suspected sources such as the Fuel Farm, and nearby former UST sites.

The extent of solvent-related contamination has not been completely defined to date nor have all of its sources been identified. A plume appears to extend from north of Fourth Street south to Fifth Street beyond which the RI did not extend in the southerly direction. The source of this plume has not been determined. A second smaller plume is present in the vicinity of the Former Vehicle Maintenance Garage (Building TC474). This plume appears to be adequately defined with Building TC474 and the immediate vicinity as the likely source of contamination.

Elevated levels of inorganic contaminants (total and dissolved) were detected in groundwater samples obtained from within the surficial aquifer. It is questionable whether this contamination is due to past site activities because the results are similar to those obtained by Baker at other Camp Lejeune sites. The elevated total metals are believed to be caused by suspended particulates in the samples.

Surface Water and Sediment

Significant levels of organic and inorganic contaminants were detected in sediment samples obtained from locations adjacent to and downstream of Site 35. The results of VOC analyses were "masked" by the presence of high levels of Tentatively Identified Compounds (TICs), and consequently, few

VOC detections were reported. Nevertheless, the Baker field team commented during sampling that the sediment samples appeared to contain elevated levels of fuel-related contaminants which could also explain the presence of TICs. Lead at elevated levels was also detected in these sediment samples, and like the organic contaminants, could be related to Site 35.

Surface water contamination was limited to a single detection of lead and zinc downstream of Site 35 at levels in excess of the WQSVs and the NCWQS. No organic contaminants were detected in surface water samples.

Fish

A variety of organic and inorganic contaminants were detected in fillet and whole body samples analyzed under the RI. The most significant contaminants detected were the pesticides dieldrin and 4,4-DDD, and a single inorganic mercury. These contaminants were primarily responsible for the calculated risk to human health in excess of EPA guidelines.

1.3.6 Risk Assessment

This section summarizes the results of the risk assessment (RA) performed under the RI (Baker, 1994). The RA for Site 35 contains two parts: the baseline human health risk assessment and the ecological risk assessment. Both RA's are described in this section.

1.3.6.1 Baseline Human Health Risk Assessment

A baseline human health risk assessment (BRA) was performed utilizing the data obtained under the RI field investigation. Contaminants of potential concern (COPC) for the BRA were selected for each media as shown in Table 1-1. Section 2.0 of this Interim FS also discusses the COPCs.

The BRA highlighted the media of interest from the human health standpoint at OU No. 10 by identifying areas with elevated Incremental Cancer Risk (ICR) and Health Index (HI) values. Current and future potential receptors at the site include current military personnel, future residents (i.e., children and adults), and future construction workers. The total risk from each site for the these receptors was estimated by logically summing the multiple pathways likely to affect the receptor during a given activity. The risk to human health was derived based on the following receptors and contaminant exposure routes.

1. Current Military Personnel
    a. Incidental ingestion of COPC in surface soil + dermal contact with COPC in surface soil + inhalation of airborne COPC
2. Future Residents (Children and Adults)
    a. Incidental ingestion of COPC in surface soil + dermal contact with COPC in surface soil + inhalation airborne of COPC
    b. Ingestion of COPC in groundwater + dermal contact with COPC in groundwater + inhalation of volatile COPC

3. Future Construction Worker

    a. Incidental ingestion of COPC in on-site subsurface soil + dermal contact with COPC in subsurface soil + inhalation of airborne COPCs

4. Current Residents (Children and Adults)

    a. Ingestion of COPC in surface water and sediment + dermal contact with COPC in surface water and sediment

    b. Ingestion of fish tissue (adults only)

The total site ICR and HI values associated with current and future receptors at this site are presented in Table 1-2. The total site ICR estimated for future residential children (2.0E-03) and adults (4.3E-03) exceeded the USEPA's upper bound risk range (1E-04). The total site ICR estimated value for the current residential child (3.0E-07) is below the USEPA's upper bound risk range, while the current residential adult (1.4E-04) is slightly above the risk range (1E-04 to 1E-06). The total site ICR estimated for future construction workers (1E-07) was less than the USEPA's lower bound target risk range (1E -04 to 1E-06). The total site ICR estimated value for current military personnel (3.2E-06) is within the USEPA's upper bound risk range (1E-04 to 1E-06). Additionally, the total site HI for future residential children (65) and adults (28) exceed unity. The total site HI for current residential child (2.4E-02) is less than unity, while the total site HI for the current residential adult (3.5) is greater than unity. The total site HI estimated for the future construction worker (1.7E-02) did not exceed unity. Finally, the total site HI for the current military personnel (1.0E-01) did not exceed unity.

The total site risk was driven by future potential exposure to groundwater (specifically drien by the contaminants: cis-1,2-dichloroethene, trichloroethene, benzene, antimony, arsenic, barium, beryllium, chromium, cadmium, manganese, vanadium) and current potential exposure to fish (due to mercury).

1.3.6.2 Ecological Risk Assessment

An ecological risk assessment (ERA) was also conducted to assess the potential impacts to ecological receptors from contaminants detected at Site 35. Additional data obtained along Brinson Creek from Site 36, located downstream of Site 35, was also used in the ERA.

Similar to the BRA, COPC were selected for the media considered in the ERA. These media include sediment, surface water, surface soil, and biota.

Overall, metals and pesticides appear to be the most significant site related COPCs that have the potential to affect the integrity of the aquatic and terrestrial receptors at OU No. 10. Although the American alligator and red-cockade woodpecker have been observed at OU No. 10, potential adverse impacts to these threatened or endangered species are low due to the low levels of contaminants in their critical habitats.

Aquatic Ecosystem

Surface water quality showed exceedances of aquatic reference values for lead, mercury, and zinc. For sediments, concentrations of lead and the organics dieldrin, 4,4'-DDD, 4,4'-DDE, 4,4'-DDT, endrin, alpha-chlordane, and gamma-chlordane exceeded the aquatic reference values. In the surface water, mercury exceeded aquatic reference values in the upstream stations. Although these levels were indicative of a high potential for risk (QI > 100), mercury is not believed to be site related. Zinc exceeded unity slightly and was only found at a single station. Lead has a single exceedance of the aquatic reference value by slightly greater than 10 indicating a moderate potential for risk to aquatic receptors.

In the sediments, lead exceeded the lower sediment aquatic reference value throughout Brinson Creek. The only exceedances of the higher sediment aquatic reference value occurred downstream of Site 35 with the highest QI of 137 representing a high potential for risk to aquatic receptors. The lead detected in sediments is likely site related, the result of past reported surface spills/runoff and past and ongoing groundwater discharges to surface water. Pesticides exceeded the sediment aquatic reference values throughout Brinson Creek. The highest QI, 2,600 for dieldrin, represents a high potential for risk to aquatic receptors. There is no documented pesticide disposal or storage/preparation activities at Site 35. The pesticide levels detected in the sediments probably are a result of routine application (i.e., pest control) in the general vicinity of Site 35.

Although the pesticides in the sediments were found at levels indicating contamination throughout the watershed, the highest levels were observed in the lower reaches of Brinson Creek. This deposition trend may be related to the higher organics in the sediments in the lower reach, which would accumulate more of these types of contaminants.

The fish community sampled in Brinson Creek was representative of an estuarine ecosystem with both freshwater and marine species present. In addition, the presence of blue crabs, grass shrimp, and crayfish support the active use of Brinson Creek by aquatic species.

The absence of pathologies observed in the fish collected from Brinson Creek indicates that the surface water and sediment quality does not adversely impact the fish community.

The benthic macroinvertebrate community demonstrated the typical tidal/freshwater species trend of primarily chironmids and oligochaetes in the upper reaches and polychaetes and amphipods in the lower reaches. Species representative of both tolerant and intolerant taxa were present. Species richness and densities were representative of an estuarine ecosystem.

In summary, the aquatic community in Brinson Creek was representative of an estuarine community and does not appear to be adversely impacted by surface water and sediment quality.

Terrestrial Ecosystem

Surface soil quality indicated an infrequent potential for adversely impacting the terrestrial receptors that have indirect contact with the surface soils. This adverse impact is primarily due to arsenic and chromium concentrations in the surface soils. For the larger receptors (rabbit, raccoon, and quail) the terrestrial reference values exceeded unity only slightly. Therefore, there are no significant adverse impacts to terrestrial receptors from site-related contaminants.

1.3.7 Conclusions and Recommendations from the RI

This section contains the conclusions and recommendations made after the RI was completed.

Conclusions

- Site 35 is an active petroleum product Fuel Farm scheduled for decommissioning and dismantlement in early 1995. The Fuel Farm dates back to 1945 and has a poorly documented history of various spills and leaks associated with aboveground and underground storage tanks and associated piping.

- Site 35 is situated within Camp Geiger in the northwest corner of Camp Lejeune. It is located along Brinson Creek which is a boundary line between Camp Lejeune and adjacent private property.

- Several environmental studies have been conducted at Site 35 dating back to 1983. The data obtained to date indicate the presence of significant elevated levels of organic and inorganic contaminants in surficial groundwater, Brinson Creek sediments, and fish tissue. Contaminated soil (fuel-related) in the vicinity of a proposed highway through Site 35 has been addressed through an Interim Record of Decision executed on September 15, 1994. One potentially significant area of subsurface soil contamination was identified during the RI in the vicinity of the Barracks located southwest of the Fuel Farm based on detections of PCE subsurface soil samples obtained from borings 35MW-30B and -37B. In addition, the Baker field team commented that during the drilling of boring 35MW-29B, a strong odor was encountered although no VOCs or SVOCs were detected in subsurface soil samples obtained at this location.

- Organic contamination in groundwater is presently limited to the surficial aquifer which is monitored at two levels including the groundwater surface (upper portion) and atop an underlying suspected semi-confining layer (lower portion). The suspected semi-confining layer appears to be adequately serving as an effective aquitard separating the surficial aquifer from the underlying Castle Hayne aquifer as no significant levels of contamination were detected in the underlying Castle Hayne aquifer. Relative to organic contaminants, both fuel- and solvent-related contaminants were detected in groundwater samples obtained from the upper and lower portions of the surficial aquifer. In general, fuel-related contamination was detected most prevalently in samples obtained from wells monitoring the upper portion of the surficial aquifer. Conversely, solvent-related contaminants were more prevalent in groundwater samples obtained from wells monitoring the lower portion of the surficial aquifer.

  The source of the fuel-related groundwater contamination appears to be the Fuel Farm, underground piping, and nearby USTs. It appears to be adequately defined and somewhat limited to the area north of Fourth Street.

  Solvent-related contamination appears to be separated into two plumes. The smaller plume is located in the vicinity of Building TC474, a former Vehicle Maintenance Garage, which is its most likely source. The larger plume is located west of the Fuel Farm and extends from north of Fourth Street south to Fifth Street and possibly beyond. Based on data obtained to date the horizontal limits of the second solvent-related plume has not been defined and its source is not known.

- Elevated levels of inorganic contaminants (total and dissolved) were detected in groundwater samples obtained from within the surficial aquifer. It is questionable whether this contamination is due to past site activities because the results are similar to those obtained by Baker at other Camp Lejeune sites. It is believed that the elevated total metals are caused by suspended particulates in the samples. Recently, Baker has employed new sampling techniques for inorganics in groundwater utilizing low-flow pumps. The low-flow pumps minimize particle disturbance and have resulted in reduced levels of total inorganics in groundwater analytical results. This low-flow sampling technique was not utilized for the RI.

- Organic and inorganic contaminants were detected in sediment samples obtained at locations adjacent to and downstream of Site 35. The results of VOC analyses were "masked" by the presence of Tentatively Identified Compounds (TICs) at high levels. The TICs may be indicative of accumulated higher molecular weight hydrocarbons which are the remnants of past contamination.

  Inorganic contamination, primarily in the form of lead, was also detected at elevated concentrations and is likely related to Site 35.

- Baker calculated that the human health risk associated with Site 35 is in excess of the acceptable range. The total risk was driven by future potential exposure to groundwater and current potential exposure to fish.

- The ecological risk assessment indicated that the aquatic community within Brinson Creek was representative of an estuarine community and does not appear to be adversely impacted by surface water and sediment quality. Additionally, there are no significant adverse impacts to terrestrial receptors from site-related contaminants.

Recommendations

Based on the data obtained, it was recommended that:

- The remedial investigation at Site 35 be extended south of Fifth Street as needed to define the extent and locate the source(s) of solvent-related groundwater contamination in the surficial aquifer. Prepare and submit an addendum to the RI report that incorporates the data obtained.

- The monitoring wells screened within the surficial aquifer that were sampled under the RI be resampled for inorganic contaminants (total phase only) using low-flow pumping techniques. The data obtained should then be incorporated into an addendum to the RI Report prepared as a result of the additional investigation conducted south of Fifth Street in an effort to define the extent of solvent-related contamination in the surficial aquifer.

- Surface soils and sediments be resampled for mercury and zinc in order to replace that data which was rejected during validation. The data generated from the additional sampling of soils and sediments combined with the results of the low-flow groundwater sampling for metals should enable Baker to determine whether or not Site 35 is the source of elevated zinc and/or mercury concentrations in Brinson Creek surface water and fish. In addition, new information regarding metals concentrations in Site 35 media will be used to further evaluate the human health and environmental risks associated with the site. The soils and sediment data and any associated analyses will be incorporated into an addendum to the RI Report.

- Sediment samples along Brinson Creek be obtained at locations adjacent to and downstream of Site 35 and analyze for TPH (EPA Methods 5030 and 3550) so as to provide data regarding the extent of organic contamination that was "masked" by TICs in results obtained under the RI.

- An Interim Remedial Action Feasibility Study be prepared that focuses on groundwater in the vicinity of the Fuel Farm and north of Fourth Street. The purpose of this Interim FS will be to address groundwater contamination in this area which may be a continuing source of contamination to Brinson Creek.

- The northeastern edge of the halogenated organic plume has not been delineated. Therefore, soil and groundwater samples should be collected on the northern side of Brinson Creek in order to determine if the creek is acting as a barrier to groundwater contamination that may be migrating off-site.

- Special precautions be taken when soil excavation is performed during the construction of the new highway. Specifically, it is recommended that the written construction workplans reference the need for monitoring of volatile organic contaminant concentrations in the breathing zone of the workers, and that institutional and engineering controls be established to minimize human exposure to both VOCs and fugitive dust particulates. Although the calculated risk to human health for future construction workers on Site 35 is well below the EPA acceptable range, adverse exposure to a volatilized fraction of contaminants in the subsurface soil or inhalation of airborne contaminants in the form of dust particulates is possible.

SECTION 1.0 TABLES

TABLE 1-1

SUMMARY OF COPCs IDENTIFIED DURING THE REMEDIAL INVESTIGATION
OPERABLE UNIT NO. 10 (SITE 35)
INTERIM FEASIBILITY STUDY, CTO-0232
MCB CAMP LEJEUNE, NORTH CAROLINA

Contaminant	Surface Soil	Subsurface Soil	Groundwater		Surface Water		Sediment		Fish
1,1,2-Trchloroethane			●						
1,1-Dichloroethane			●						
1,1-Dichloroethene			●						
Benzene			●	X					
cis-1,2-Dichloroethene			●	X					
Ethylbenzene			●	X					
Heptachlor			●						X
Methyl Tertiary Butyl Ether			●	X					
Naphthalene				X					
Tetrachloroethane		X	●						
Toluene			●	X					
trans-1,2-Dichloroethene			●	X					
Trichloroethene			●	X					
Xylenes (Total)			●	X					
Aluminum									X
Antimony			●	X	●	X			
Arsenic			●	X	●		●	X	
Barium			●	X				X	X
Beryllium			●	X				X	
Cadmium			●	X					X
Cobalt				X				X	
Copper			●	X			●	X	X
Lead			●	X	●	X	●	X	X
Manganese			●	X	●	X		X	
Mercury			●	X	●	X	●		
Nickel			●	X			●	X	
Selenium			●	X					X
Thallium			●	X	●	X			
Vanadium				X		X		X	
Zinc			●	X		X	●	X	X
Iron					●				
2-Methylnaphthalene				X					
4,4'-DDE							●	X	X
4,4'-DDT							●	X	X
4,4'-DDD							●	X	X
alpha-Chlordane							●	X	X

TABLE 1-1 (Continued)

SUMMARY OF COPCs IDENTIFIED DURING THE REMEDIAL INVESTIGATION
OPERABLE UNIT NO. 10 (SITE 35)
INTERIM FEASIBILITY STUDY, CTO-0232
MCB CAMP LEJEUNE, NORTH CAROLINA

Contaminant	Surface Soil	Subsurface Soil	Groundwater		Surface Water		Sediment		Fish
beta-BHC									X
Carbon disulfide									X
Chromium							●		
Dieldrin	X						●	X	X
Endosulfan II								X	
Endrin Ketone									X
Endrin Aldehyde								X	
Endrin	X						●	X	X
gamma-BHC									X
gamma-Chlordane	X						●	X	
Heptachlor Epoxide								X	
Methoxychlor								X	

● Selected for comparison to existing criteria.

X Selected with respect to human risk.

TABLE 1-2

TOTAL SITE RISK CALCULATED DURING THE REMEDIAL INVESTIGATION
OPERABLE UNIT NO. 10 (SITE 35)
INTERIM FEASIBILITY, STUDY, CTO-0232
MCB CAMP LEJEUNE, NORTH CAROLINA

Receptors	Soil		Groundwater		Surface Water		Sediment		Fish		TOTALS	
	ICR	HI	ICR	HI	ICR	HI	ICR	HI	ICR	HI	ICR	HI
Future Child Resident	4.1E-05 (<1)	0.90 (<1)	2.0E-03	64 (98)	NA	NA	NA	NA	NA	NA	2.0E-03	65
Future Adult Resident	1.9E-05 (<1)	0.10 (<1)	4.3E-03	28 (99)	NA	NA	NA	NA	NA	NA	4.3E-03	28
Current Military Personnel	3.2E-06 (100)	0.10 (100)	NA	NA	NA	NA	NA	NA	NA	NA	3.2E-06	0.10
Future Construction Worker	1.0E-07 (100)	0.02 (100)	NA	NA	NA	NA	NA	NA	NA	NA	1.0E-07	0.02
Current Child Resident	NA	NA	NA	NA	ND	0.02 (74)	3.0E-07 (100)	<0.01 (26)	NA	NA	3.0E-07	0.02
Current Adult Resident	NA	NA	NA	NA	ND	0.01 (<1)	3.0E-07 (<1)	<0.01 (<1)	1.35E-04 (99)	3.56 (99)	1.4E-04	3.57

Notes: ICR = Incremental Lifetime Cancer Risk
HI = Hazard Index
Total = Soil + Groundwater
ND = Not Determined
NA = Not Applicable

SECTION 1.0 FIGURES

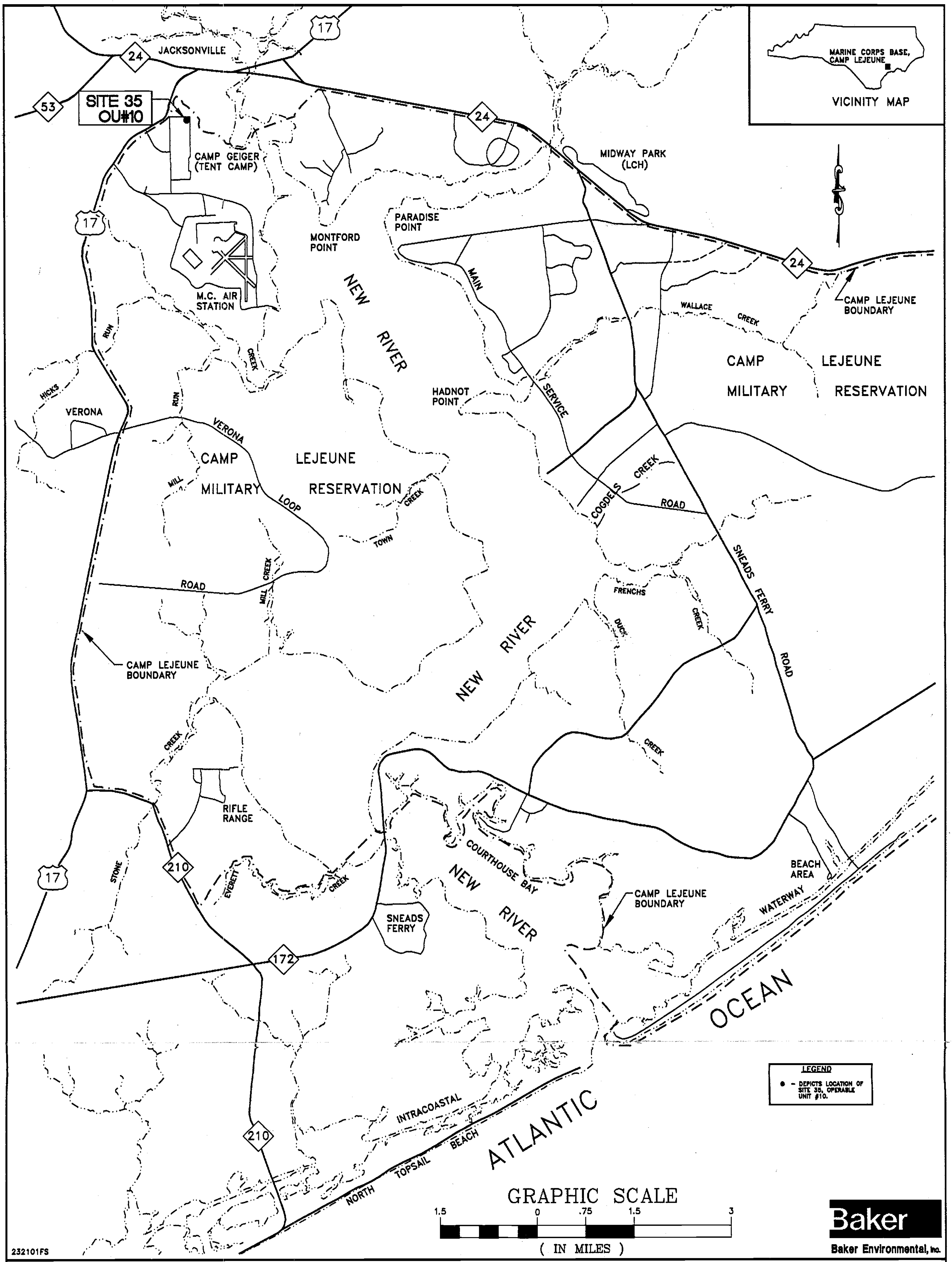


FIGURE 1-1
CAMP LEJEUNE AND SITE 35
LOCATION MAP
SITE 35, CAMP GEIGER AREA FUEL FARM INTERIM FS
CONTRACT TASK ORDER – 0232

MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

01538CC01Z

LEGEND

- FENCE LINE
- CONTOUR LINES DEPICTING SURFICIAL RELIEF
- APPROXIMATE LIMITS OF SOIL CONTAMINATION SUBJECT TO REMEDIATION UNDER INTERIM ROD CTO-0160 DATED AUGUST 31, 1994.

DATE	MAY 1995
SCALE	SEE BAR SCALE
DRAWN	WJH
REVIEWED	JSC
S.O.#	62470-232-0000-07000
CADD#	232102FS

NORTH

SITE 35, CAMP GEIGER AREA FUEL FARM INTERIM FS
MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

BAKER ENVIRONMENTAL, Inc.
Coraopolis, Pennsylvania

Baker
Baker Environmental, Inc.

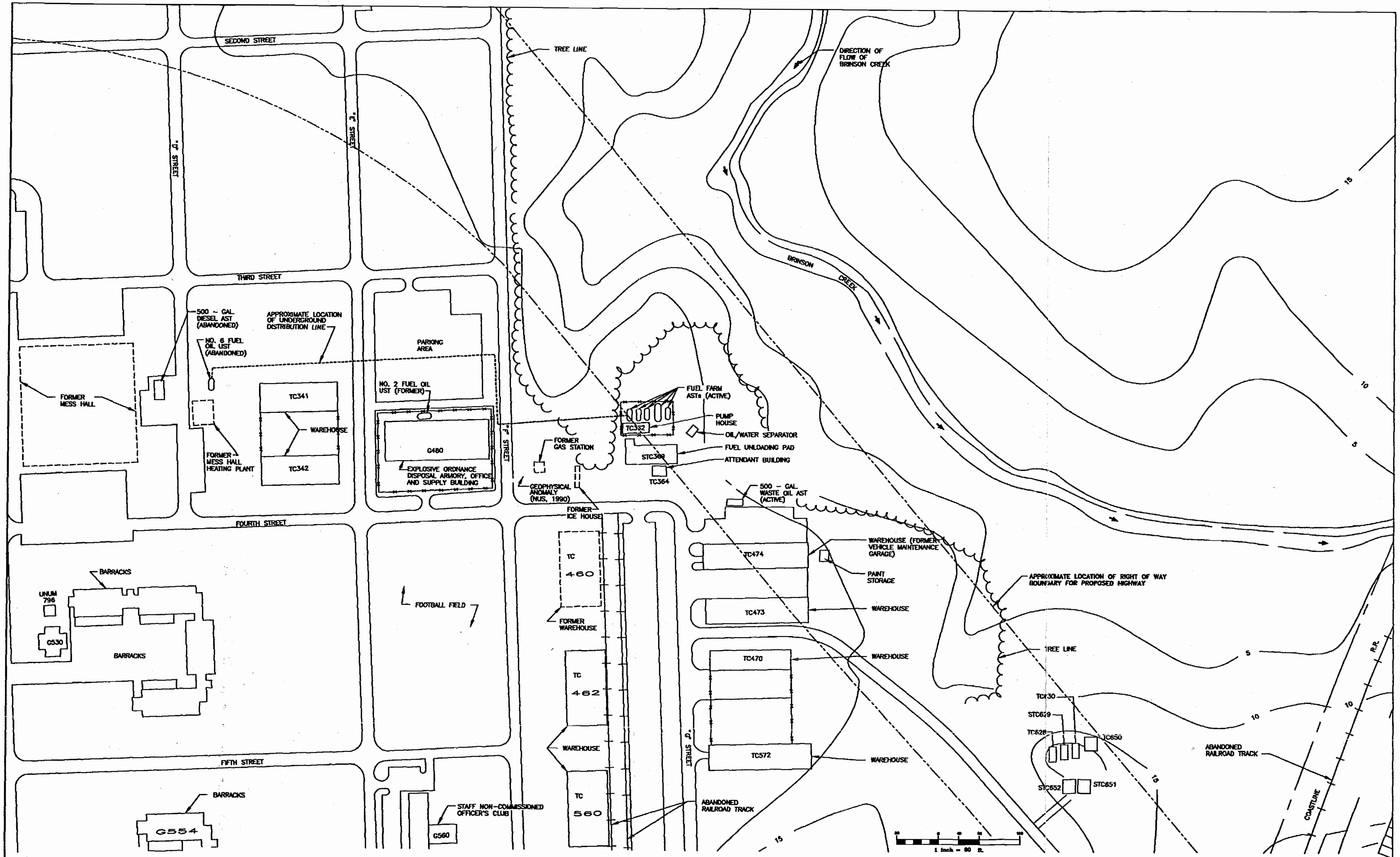
SITE PLAN
CONTRACT TASK ORDER - 0232

SCALE SEE BAR SCALE

DATE MAY 1995

FIGURE No.
1-2

01538CC02Y



LEGEND

-x-x- - FENCE LINE

—10— - CONTOUR LINES DEPICTING SURFICIAL RELIEF

-------- APPROXIMATE LOCATION OF THE UNDERGROUND DISTRIBUTION LINE

— — — — APPROXIMATE LOCATION OF RIGHT OF WAY BOUNDARY FOR PROPOSED HIGHWAY

DATE	DEC. 1994
SCALE	1" = 80'
DRAWN	WJH
REVIEWED	JSC
S.O.#	62470-232-0000-07000
CADD#	232103FS

NORTH

SITE 35, CAMP GEIGER AREA FUEL FARM INTERIM FS
MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

BAKER ENVIRONMENTAL, Inc.
Coraopolis, Pennsylvania

Baker
Baker Environmental, Inc.

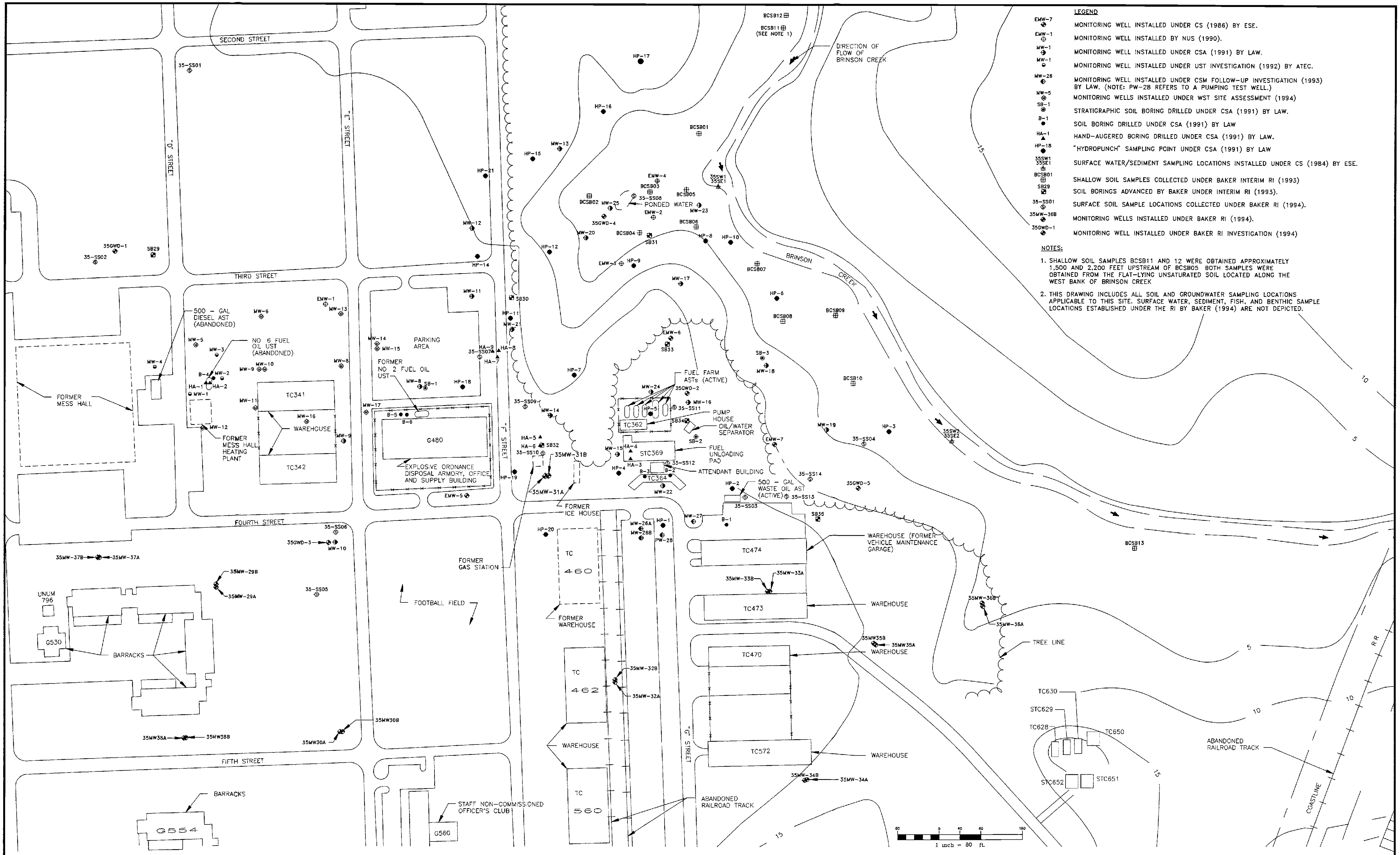
LOCATION OF PROPOSED
HIGHWAY RIGHT OF WAY
CONTRACT TASK ORDER - 0232

SCALE 1" = 80'

DATE DEC. 1994

FIGURE No.
1-3

01538CC032



LEGEND

EMW-7	MONITORING WELL INSTALLED UNDER CS (1986) BY ESE.
EMW-1	MONITORING WELL INSTALLED BY NUS (1990).
MW-1	MONITORING WELL INSTALLED UNDER CSA (1991) BY LAW.
MW-1	MONITORING WELL INSTALLED UNDER UST INVESTIGATION (1992) BY ATEC.
MW-26	MONITORING WELL INSTALLED UNDER CSM FOLLOW-UP INVESTIGATION (1993) BY LAW. (NOTE: PW-28 REFERS TO A PUMPING TEST WELL.)
MW-5	MONITORING WELLS INSTALLED UNDER WST SITE ASSESSMENT (1994)
SB-1	STRATIGRAPHIC SOIL BORING DRILLED UNDER CSA (1991) BY LAW.
B-1	SOIL BORING DRILLED UNDER CSA (1991) BY LAW
HA-1	HAND-AUGERED BORING DRILLED UNDER CSA (1991) BY LAW.
HP-18	"HYDROPUNCH" SAMPLING POINT UNDER CSA (1991) BY LAW
35SW1 35SE1	SURFACE WATER/SEDIMENT SAMPLING LOCATIONS INSTALLED UNDER CS (1984) BY ESE.
BCSB01	SHALLOW SOIL SAMPLES COLLECTED UNDER BAKER INTERIM RI (1993)
SB29	SOIL BORINGS ADVANCED BY BAKER UNDER INTERIM RI (1993).
35-SS01	SURFACE SOIL SAMPLE LOCATIONS COLLECTED UNDER BAKER RI (1994).
35MW-36B	MONITORING WELLS INSTALLED UNDER BAKER RI (1994).
35GWD-1	MONITORING WELL INSTALLED UNDER BAKER RI INVESTIGATION (1994)

NOTES:

1. SHALLOW SOIL SAMPLES BCSB11 AND 12 WERE OBTAINED APPROXIMATELY 1,500 AND 2,200 FEET UPSTREAM OF BCSB05 BOTH SAMPLES WERE OBTAINED FROM THE FLAT-LYING UNSATURATED SOIL LOCATED ALONG THE WEST BANK OF BRINSON CREEK
2. THIS DRAWING INCLUDES ALL SOIL AND GROUNDWATER SAMPLING LOCATIONS APPLICABLE TO THIS SITE. SURFACE WATER, SEDIMENT, FISH, AND BENTHIC SAMPLE LOCATIONS ESTABLISHED UNDER THE RI BY BAKER (1994) ARE NOT DEPICTED.

LEGEND

-x-x- - FENCE LINE
—15— - CONTOUR LINES DEPICTING SURFICIAL RELIEF

DATE	DEC. 1994
SCALE	1"= 80'
DRAWN	WJH
REVIEWED	JSC
S O #	62470-232-0000-07000
CADD#	232104FS

NORTH

SITE 35, CAMP GEIGER AREA FUEL FARM INTERIM FS
MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

BAKER ENVIRONMENTAL,Inc
Coraopolis, Pennsylvania

Baker
Baker Environmental, Inc.

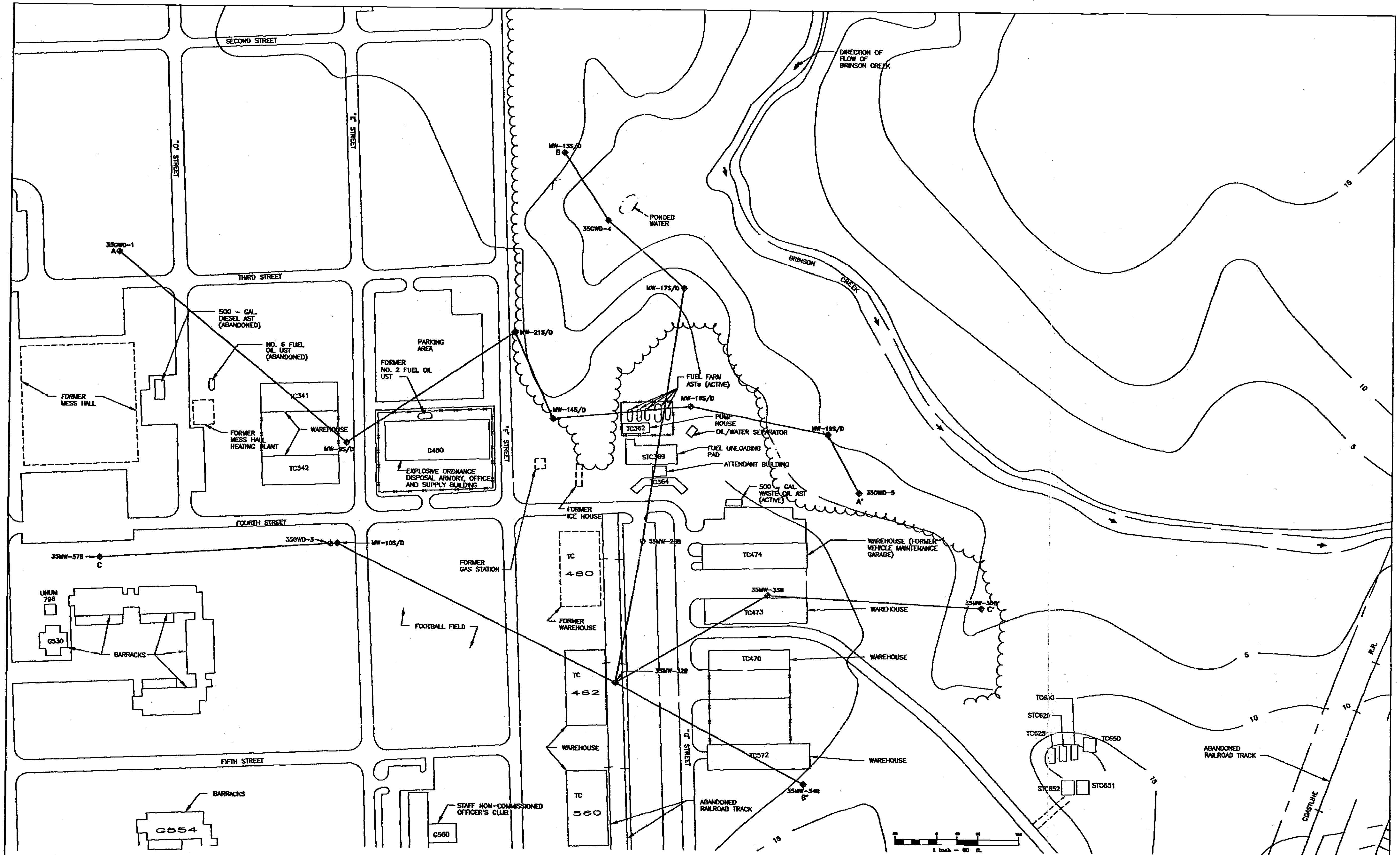
SAMPLING LOCATIONS
CONTRACT TASK ORDER - 0232

SCALE 1"= 80'

DATE DEC. 1994

FIGURE No
1-4

01538CC04X



LEGEND

-x-x- - FENCE LINE

—15— - CONTOUR LINES DEPICTING SURFICIAL RELIEF

35GWD-5 ⌖ - MONITORING WELL LOCATION AND DESCRIPTION

DATE	DEC. 1994
SCALE	1"= 80'
DRAWN	WJH
REVIEWED	JSC
S.O.#	62470-232-0000-07000
CADD#	232105FS

NORTH

SITE 35, CAMP GEIGER AREA FUEL FARM INTERIM FS
MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

BAKER ENVIRONMENTAL, Inc.
Coraopolis, Pennsylvania

Baker
Baker Environmental, Inc.

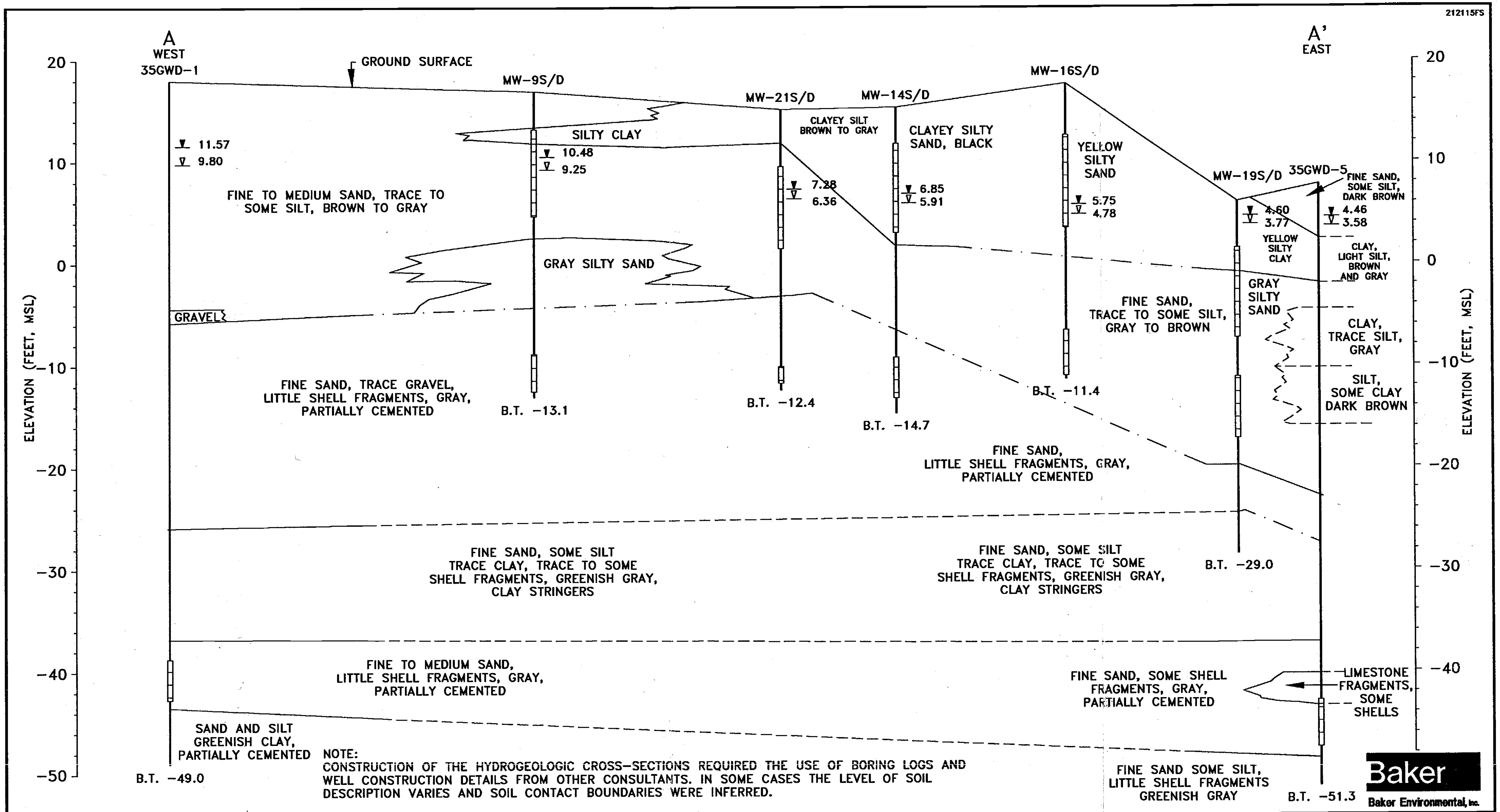
CROSS-SECTION LOCATIONS AT SITE 35
CONTRACT TASK ORDER - 0232

SCALE 1"= 80'

DATE DEC. 1994

FIGURE No.
1-5

01538CCB12



NOTE:
CONSTRUCTION OF THE HYDROGEOLOGIC CROSS-SECTIONS REQUIRED THE USE OF BORING LOGS AND WELL CONSTRUCTION DETAILS FROM OTHER CONSULTANTS. IN SOME CASES THE LEVEL OF SOIL DESCRIPTION VARIES AND SOIL CONTACT BOUNDARIES WERE INFERRED.

LEGEND

▼ 10.48	GROUNDWATER ELEVATION COLLECTED ON 9-9-94 (MSL)
▽ 9.25	GROUNDWATER ELEVATION COLLECTED ON 7-20-94 (MSL)
B.T. -49.0'	BORING TERMINATED, ELEVATION MSL
▯	WELL SCREEN INTERVAL
— · —	INFERRED SOIL CONTACT
——	ESTIMATED SOIL CONTACT
— — —	PROJECTED SOIL CONTACT

160 0 80 160 320

Horizontal Scale: 1 inch = 160 ft.

10 0 5 10 20

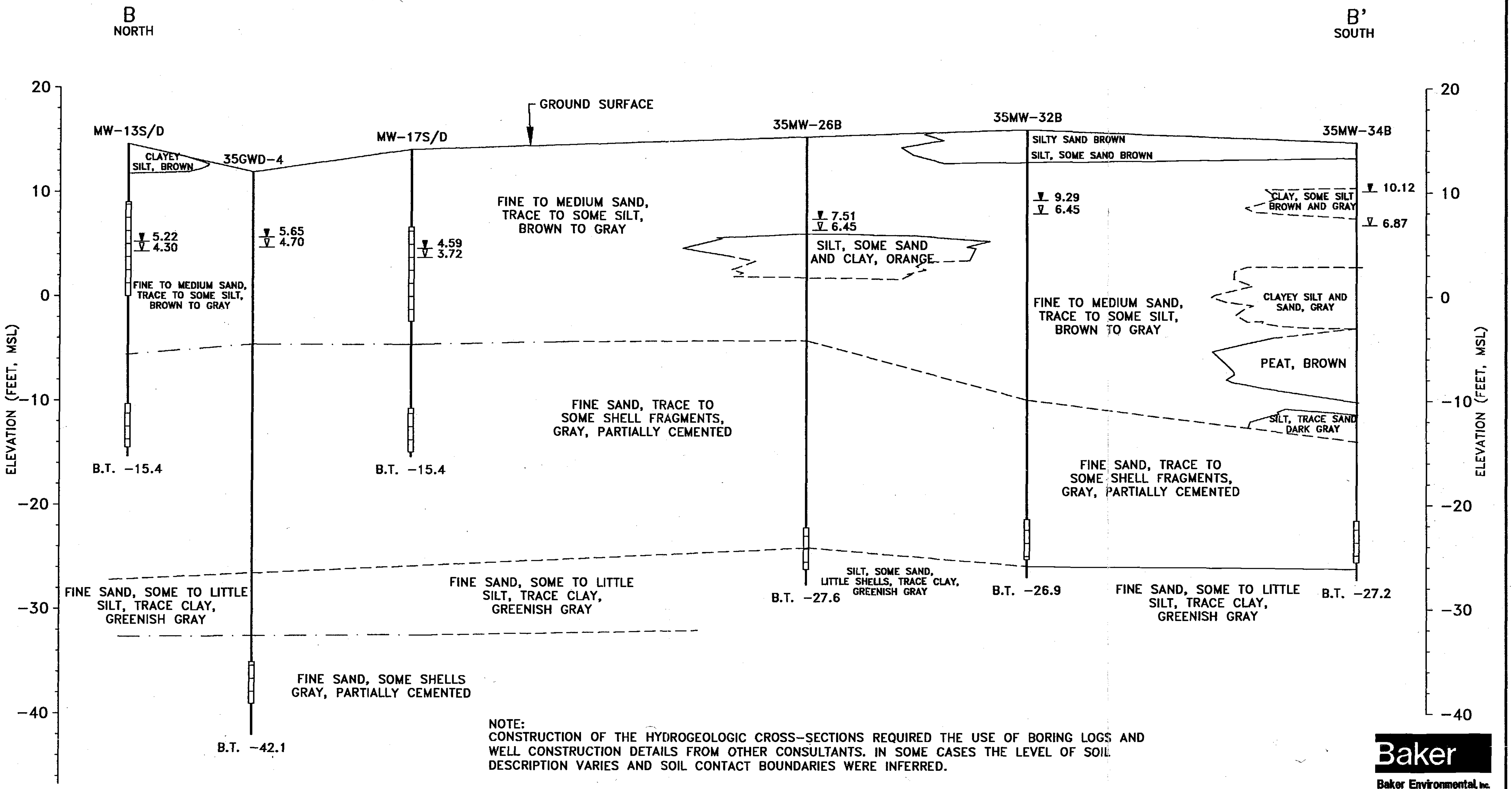
Vertical Scale: 1 inch = 10 ft.

THE SOIL BORING INFORMATION IS CONSIDERED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT THE RESPECTIVE BORING LOCATIONS. SUBSURFACE CONDITIONS INTERPOLATED BETWEEN BORINGS ARE ESTIMATED BASED ON ACCEPTED SOIL ENGINEERING PRINCIPLES AND GEOLOGIC JUDGEMENT.

FIGURE 1-6
HYDROGEOLOGIC CROSS-SECTION A-A'
SITE 35, CAMP GEIGER AREA FUEL FARM INTERIM FS
CONTRACT TASK ORDER 0232

MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

232116FS



NOTE:
CONSTRUCTION OF THE HYDROGEOLOGIC CROSS-SECTIONS REQUIRED THE USE OF BORING LOGS AND WELL CONSTRUCTION DETAILS FROM OTHER CONSULTANTS. IN SOME CASES THE LEVEL OF SOIL DESCRIPTION VARIES AND SOIL CONTACT BOUNDARIES WERE INFERRED.

Baker
Baker Environmental, Inc.

LEGEND

▼ 5.22	GROUNDWATER ELEVATION COLLECTED ON 9-9-94 (MSL)
▽ 4.30	GROUNDWATER ELEVATION COLLECTED ON 7-20-94 (MSL)
B.T. -42.1'	BORING TERMINATED, ELEVATION MSL
▯	WELL SCREEN INTERVAL
— · —	INFERRED SOIL CONTACT
———	ESTIMATED SOIL CONTACT
— — —	PROJECTED SOIL CONTACT

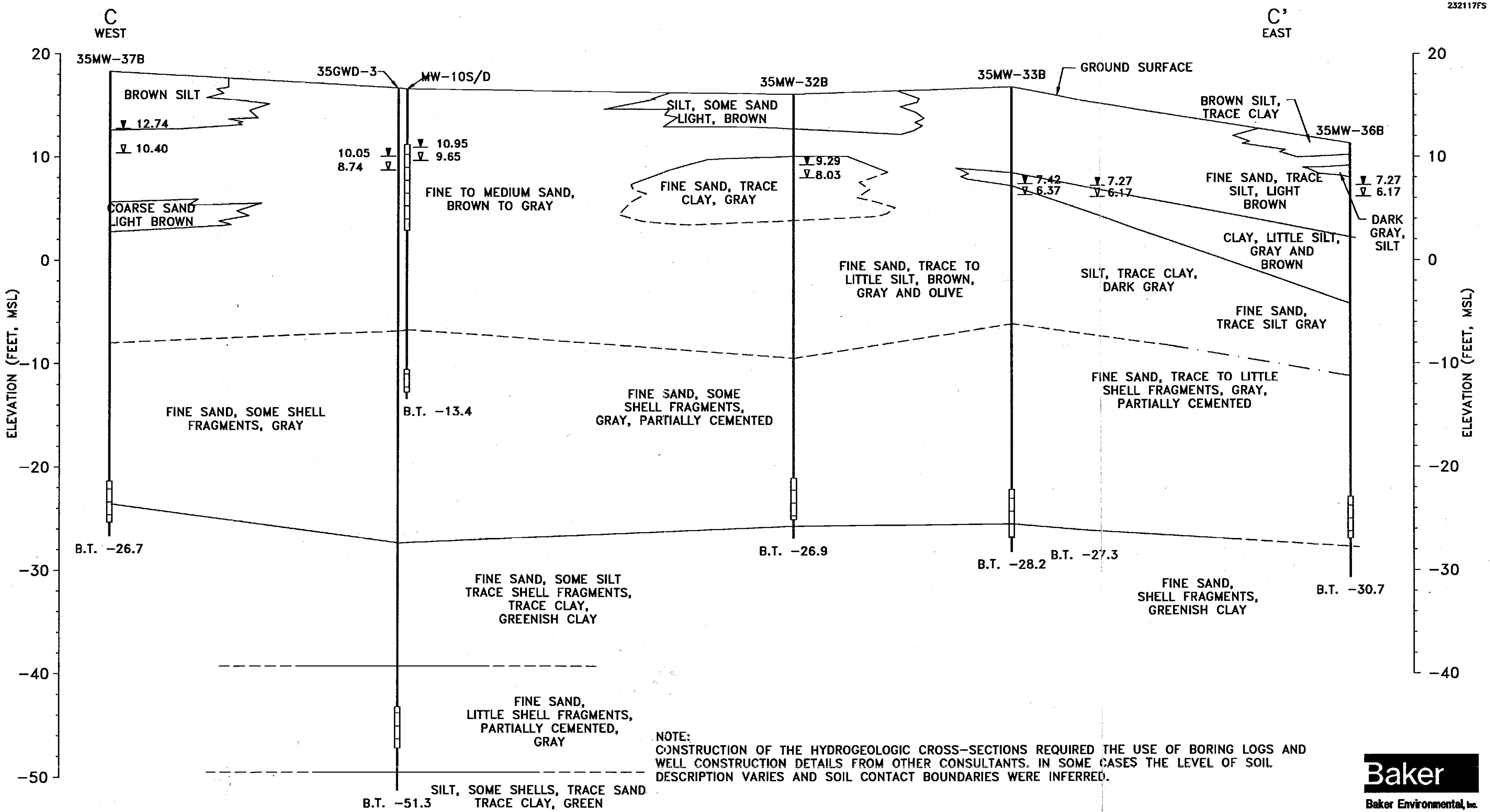
130 0 65 130 260
Horizontal Scale: 1 inch = 130 ft.

10 0 5 10 20
Vertical Scale: 1 inch = 10 ft.

THE SOIL BORING INFORMATION IS CONSIDERED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT THE RESPECTIVE BORING LOCATIONS. SUBSURFACE CONDITIONS INTERPOLATED BETWEEN BORINGS ARE ESTIMATED BASED ON ACCEPTED SOIL ENGINEERING PRINCIPLES AND GEOLOGIC JUDGEMENT.

1-7
HYDROGEOLOGIC CROSS-SECTION B-B'
SITE 35, CAMP GEIGER AREA FUEL FARM INTERIM FS
CONTRACT TASK ORDER - 0232

MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA



NOTE:
CONSTRUCTION OF THE HYDROGEOLOGIC CROSS-SECTIONS REQUIRED THE USE OF BORING LOGS AND WELL CONSTRUCTION DETAILS FROM OTHER CONSULTANTS. IN SOME CASES THE LEVEL OF SOIL DESCRIPTION VARIES AND SOIL CONTACT BOUNDARIES WERE INFERRED.

Baker
Baker Environmental, Inc.

LEGEND

▼ 12.74	GROUNDWATER ELEVATION COLLECTED ON 9-9-94 (MSL)
▽ 10.40	GROUNDWATER ELEVATION COLLECTED ON 7-20-94 (MSL)
B.T. -26.7'	BORING TERMINATED, ELEVATION MSL
▯	WELL SCREEN INTERVAL
— · —	INFERRED SOIL CONTACT
———	ESTIMATED SOIL CONTACT
— — —	PROJECTED SOIL CONTACT

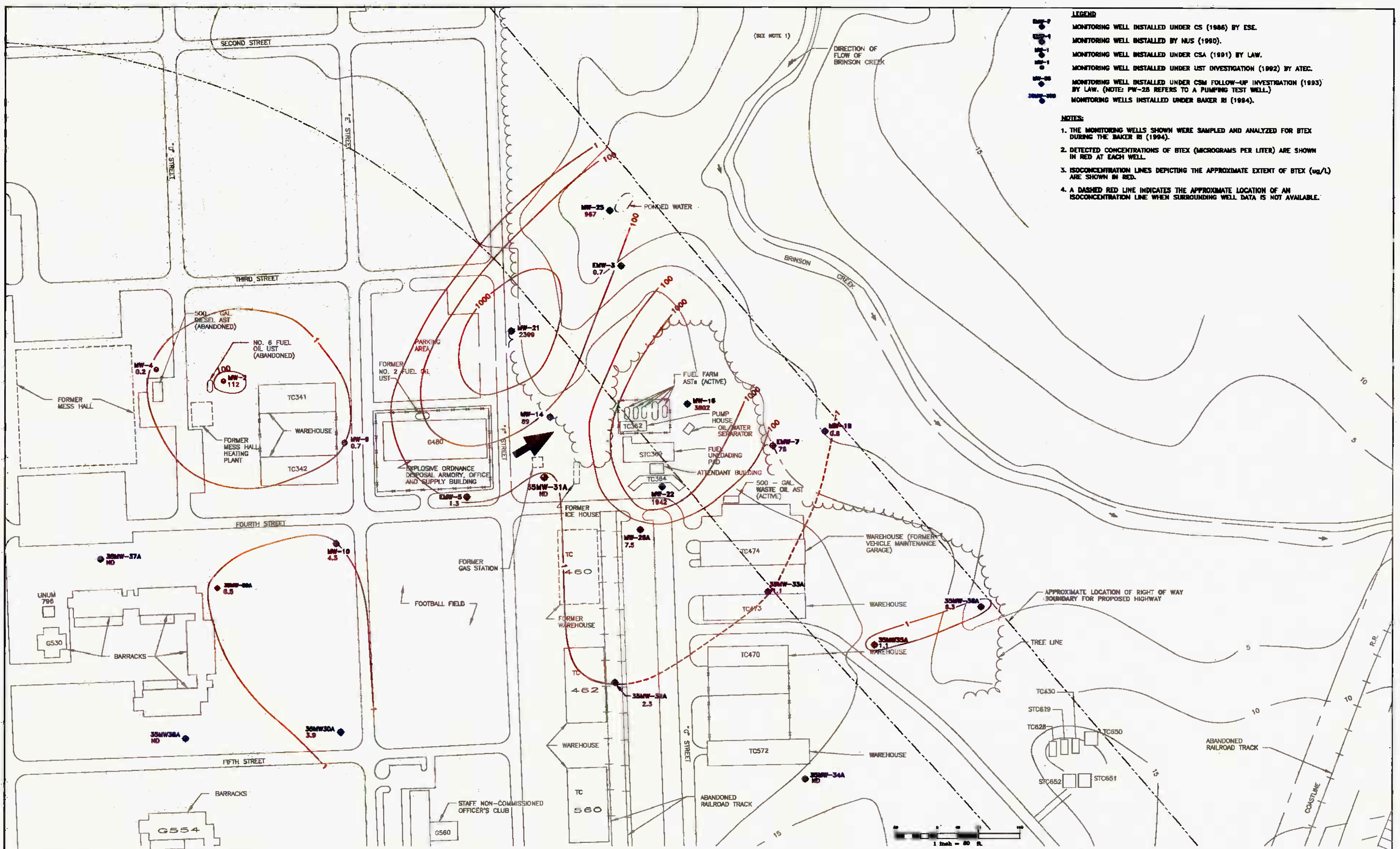
160 0 80 160 320
Horizontal Scale: 1 inch = 160 ft.

10 0 5 10 20
Vertical Scale: 1 inch = 10 ft.

THE SOIL BORING INFORMATION IS CONSIDERED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT THE RESPECTIVE BORING LOCATIONS. SUBSURFACE CONDITIONS INTERPOLATED BETWEEN BORINGS ARE ESTIMATED BASED ON ACCEPTED SOIL ENGINEERING PRINCIPLES AND GEOLOGIC JUDGEMENT.

FIGURE 1-8
HYDROGEOLOGIC CROSS-SECTION C-C'
SITE 35, CAMP GEIGER AREA FUEL FARM INTERIM FS
CONTRACT TASK ORDER - 0232

MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA



LEGEND

EMW-7 ●	MONITORING WELL INSTALLED UNDER CS (1986) BY ESE.
EMW-1 ●	MONITORING WELL INSTALLED BY NUS (1990).
MW-1 ●	MONITORING WELL INSTALLED UNDER CSA (1991) BY LAW.
MW-1 ●	MONITORING WELL INSTALLED UNDER UST INVESTIGATION (1992) BY ATEC.
MW-25 ●	MONITORING WELL INSTALLED UNDER CSM FOLLOW-UP INVESTIGATION (1993) BY LAW. (NOTE: PW-28 REFERS TO A PUMPING TEST WELL.)
35MW-30A ●	MONITORING WELLS INSTALLED UNDER BAKER RI (1994).

NOTES:

1. THE MONITORING WELLS SHOWN WERE SAMPLED AND ANALYZED FOR BTEX DURING THE BAKER RI (1994).
2. DETECTED CONCENTRATIONS OF BTEX (MICROGRAMS PER LITER) ARE SHOWN IN RED AT EACH WELL.
3. ISOCONCENTRATION LINES DEPICTING THE APPROXIMATE EXTENT OF BTEX (ug/L) ARE SHOWN IN RED.
4. A DASHED RED LINE INDICATES THE APPROXIMATE LOCATION OF AN ISOCONCENTRATION LINE WHEN SURROUNDING WELL DATA IS NOT AVAILABLE.

LEGEND

-x-x-	FENCE LINE
—15—	CONTOUR LINES DEPICTING SURFICIAL RELIEF
—50—	ISOCONCENTRATION LIMITS OF COMBINED BTEX
— - - —	APPROXIMATE LOCATION OF RIGHT OF WAY BOUNDARY FOR PROPOSED HIGHWAY
➡	APPROXIMATE GROUNDWATER FLOW DIRECTION

DATE	NOVEMBER 1994
SCALE	1" = 80'
DRAWN	REL
REVIEWED	JSC
S.O.#	62470-232-0000-07000
CADD#	232113FS

NORTH

SITE 35, CAMP GEIGER AREA FUEL FARM INTERIM FS
MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

BAKER ENVIRONMENTAL, Inc.
Coraopolis, Pennsylvania

Baker
Baker Environmental, Inc.

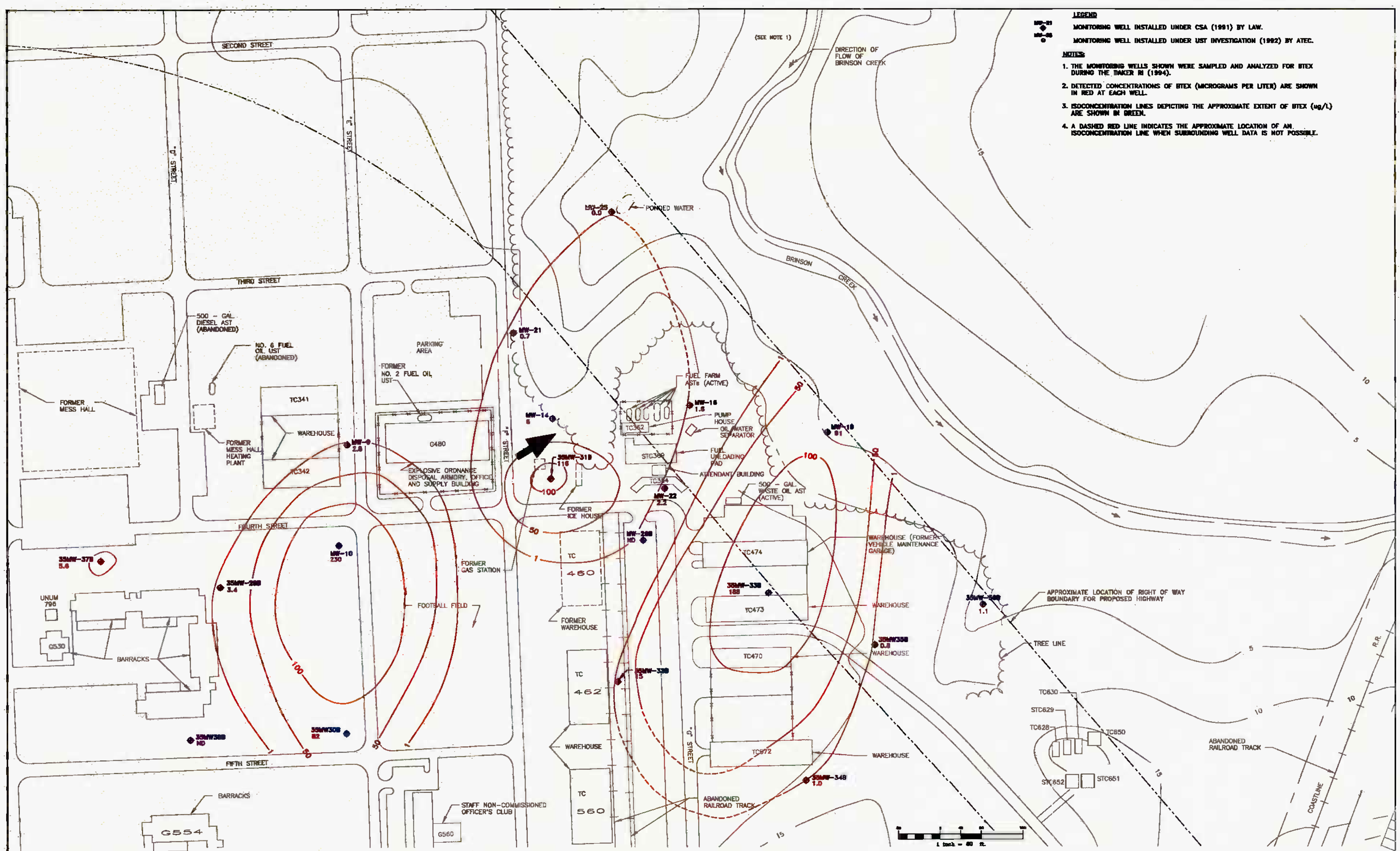
LIMITS OF COMBINED BTEX IN THE UPPER PORTION OF THE SURFICIAL AQUIFER
CONTRACT TASK ORDER – 0232

SCALE 1" = 80'

DATE NOVEMBER 1994

FIGURE No.
1–9

01538CC B2Y



LEGEND

MW-21 ◆ MONITORING WELL INSTALLED UNDER CSA (1991) BY LAW.

MW-08 ● MONITORING WELL INSTALLED UNDER UST INVESTIGATION (1992) BY ATEC.

NOTES:

1. THE MONITORING WELLS SHOWN WERE SAMPLED AND ANALYZED FOR BTEX DURING THE BAKER RI (1994).
2. DETECTED CONCENTRATIONS OF BTEX (MICROGRAMS PER LITER) ARE SHOWN IN RED AT EACH WELL.
3. ISOCONCENTRATION LINES DEPICTING THE APPROXIMATE EXTENT OF BTEX (ug/L) ARE SHOWN IN GREEN.
4. A DASHED RED LINE INDICATES THE APPROXIMATE LOCATION OF AN ISOCONCENTRATION LINE WHEN SURROUNDING WELL DATA IS NOT POSSIBLE.

LEGEND

-x-x- – FENCE LINE
—15— – CONTOUR LINES DEPICTING SURFICIAL RELIEF
—50— – ISOCONCENTRATION LIMITS OF COMBINED BTEX
– – – – APPROXIMATE LOCATION OF RIGHT OF WAY BOUNDARY FOR PROPOSED HIGHWAY
➡ – APPROXIMATE GROUNDWATER FLOW DIRECTION

DATE	DEC. 1994
SCALE	1"= 80'
DRAWN	WJH
REVIEWED	JSC
S.O.#	62470-232-0000-07000
CADD#	232112FS

NORTH

SITE 35, CAMP GEIGER AREA FUEL FARM INTERIM FS
MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

BAKER ENVIRONMENTAL,Inc.
Coraopolis, Pennsylvania

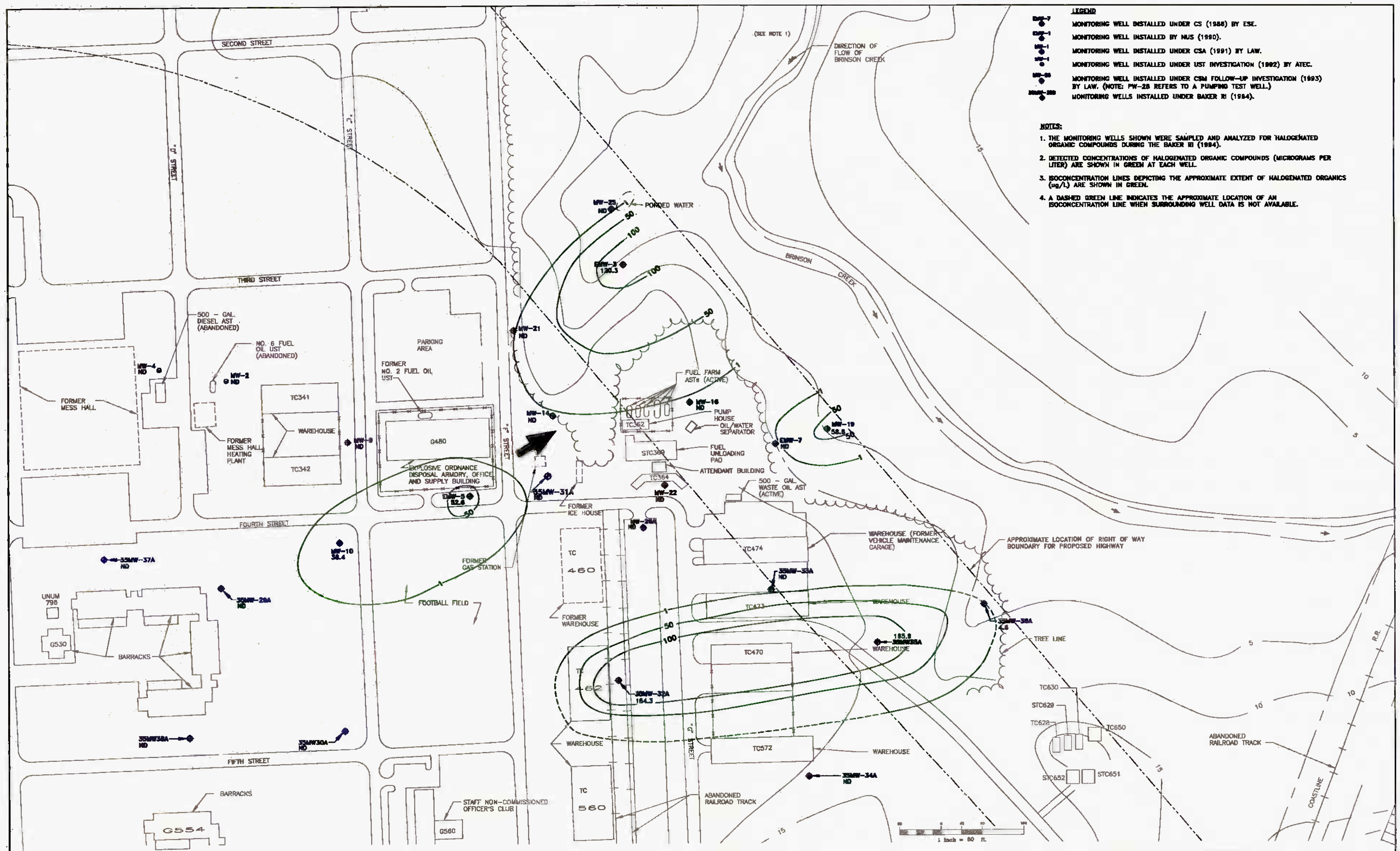
Baker
Baker Environmental, Inc.

LIMITS OF COMBINED BTEX IN THE
LOWER PORTION OF THE SURFICIAL AQUIFER
CONTRACT TASK ORDER – 0232

SCALE 1"= 80'

DATE DEC. 1994

FIGURE No.
1–10



LEGEND

- MONITORING WELL INSTALLED UNDER CS (1986) BY ESE.
- MONITORING WELL INSTALLED BY NUS (1990).
- MONITORING WELL INSTALLED UNDER CSA (1991) BY LAW.
- MONITORING WELL INSTALLED UNDER UST INVESTIGATION (1992) BY ATEC.
- MONITORING WELL INSTALLED UNDER CSM FOLLOW-UP INVESTIGATION (1993) BY LAW. (NOTE: PW-28 REFERS TO A PUMPING TEST WELL.)
- MONITORING WELLS INSTALLED UNDER BAKER RI (1994).

NOTES:

1. THE MONITORING WELLS SHOWN WERE SAMPLED AND ANALYZED FOR HALOGENATED ORGANIC COMPOUNDS DURING THE BAKER RI (1994).
2. DETECTED CONCENTRATIONS OF HALOGENATED ORGANIC COMPOUNDS (MICROGRAMS PER LITER) ARE SHOWN IN GREEN AT EACH WELL.
3. ISOCONCENTRATION LINES DEPICTING THE APPROXIMATE EXTENT OF HALOGENATED ORGANICS (ug/L) ARE SHOWN IN GREEN.
4. A DASHED GREEN LINE INDICATES THE APPROXIMATE LOCATION OF AN ISOCONCENTRATION LINE WHEN SURROUNDING WELL DATA IS NOT AVAILABLE.

LEGEND

- FENCE LINE
- CONTOUR LINES DEPICTING SURFICIAL RELIEF
- ISOCONCENTRATION LIMITS OF COMBINED HALOGENATED ORGANICS.
- APPROXIMATE LOCATION OF RIGHT OF WAY BOUNDARY FOR PROPOSED HIGHWAY
- APPROXIMATE GROUNDWATER FLOW DIRECTION

DATE	DEC. 1994
SCALE	1" = 80'
DRAWN	REL
REVIEWED	JSC
S.O.#	62470-232-0000-07000
CADD#	252110FS

NORTH

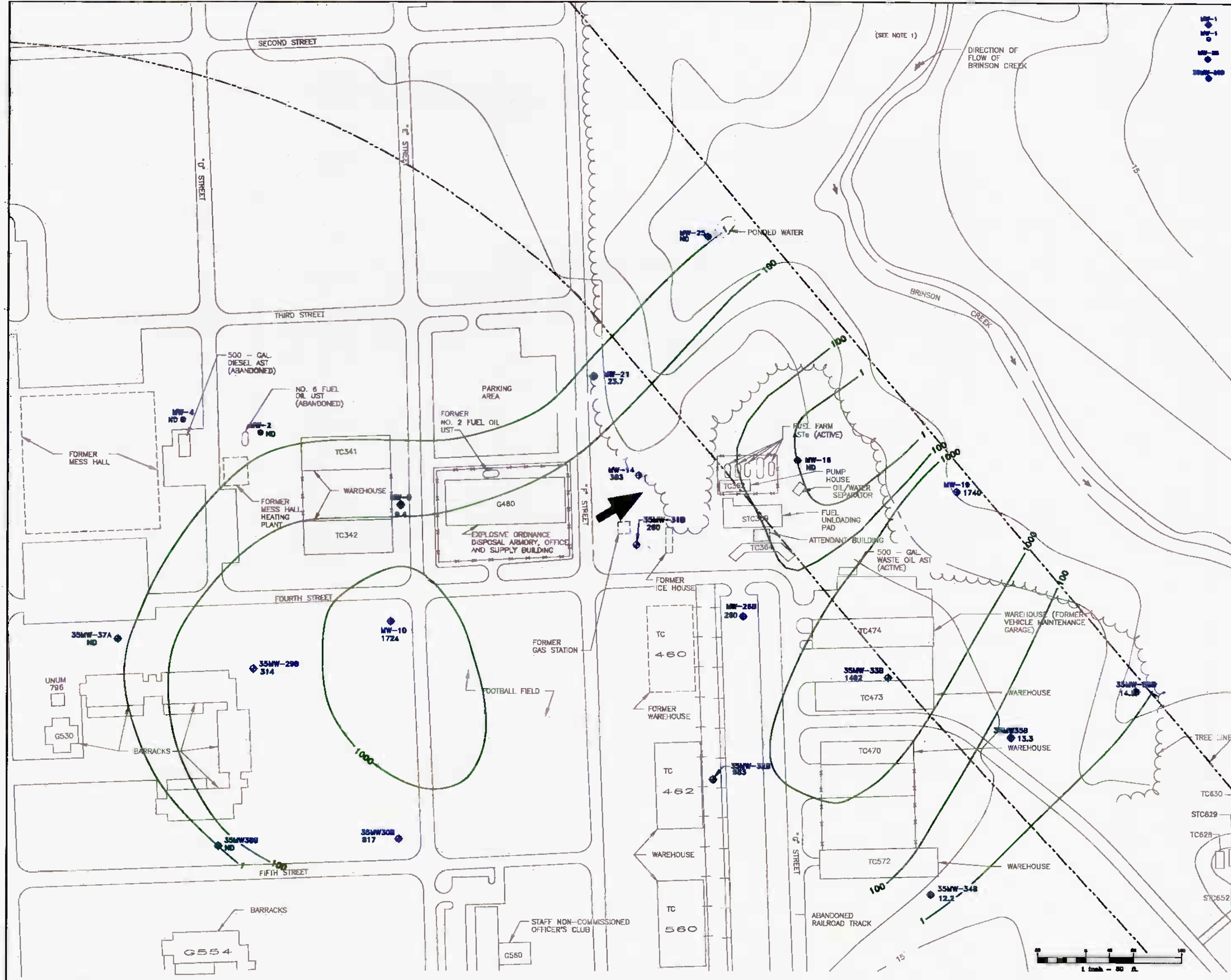
SITE 35, CAMP GEIGER AREA FUEL FARM INTERIM FS
MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

BAKER ENVIRONMENTAL, Inc.
Coraopolis, Pennsylvania

LIMITS OF COMBINED HALOGENATED ORGANIC COMPOUNDS IN THE UPPER PORTION OF THE SURFICIAL AQUIFER
CONTRACT TASK ORDER - 0232

SCALE 1" = 80'
DATE DEC. 1994

FIGURE No.
1-11



LEGEND

- MW-1 ◆ MONITORING WELL INSTALLED UNDER CSA (1991) BY LAW.
- MW-1 ○ MONITORING WELL INSTALLED UNDER UST INVESTIGATION (1992) BY ATEC.
- MW-25 ● MONITORING WELL INSTALLED UNDER CSM FOLLOW-UP INVESTIGATION (1993) BY LAW. (NOTE: PW-28 REFERS TO A PUMPING TEST WELL.)
- 35MW-30B ● MONITORING WELLS INSTALLED UNDER BAKER RI (1994).

NOTES:

1. THE MONITORING WELLS SHOWN WERE SAMPLED AND ANALYZED FOR HALOGENATED ORGANIC COMPOUNDS DURING THE BAKER RI (1994).
2. DETECTED CONCENTRATIONS OF HALOGENATED ORGANIC COMPOUNDS (MICROGRAMS PER LITER) ARE SHOWN IN GREEN AT EACH WELL.
3. ISOCONCENTRATION LINES DEPICTING THE APPROXIMATE EXTENT OF HALOGENATED ORGANICS (ug/L) ARE SHOWN IN GREEN.
4. A DASHED GREEN LINE INDICATES THE APPROXIMATE LOCATION OF AN ISOCONCENTRATION LINE WHEN SURROUNDING WELL DATA IS NOT AVAILABLE.

LEGEND

- -x-x- - FENCE LINE
- —15— - CONTOUR LINES DEPICTING SURFICIAL RELIEF
- —100— - ISOCONCENTRATION LIMITS OF COMBINED HALOGENATED ORGANICS.
- ------ - APPROXIMATE LOCATION OF RIGHT OF WAY BOUNDARY FOR PROPOSED HIGHWAY
- ➡ - APPROXIMATE GROUNDWATER FLOW DIRECTION

DATE	DEC. 1994
SCALE	1" = 80'
DRAWN	REL
REVIEWED	JSC
S.O.#	62470-232-0000-07000
CADD#	232111FS

NORTH

SITE 35, CAMP GEIGER AREA FUEL FARM INTERIM FS
MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

BAKER ENVIRONMENTAL, Inc.
Coraopolis, Pennsylvania

Baker
Baker Environmental, Inc.

LIMITS OF COMBINED HALOGENATED ORGANIC
COMPOUNDS IN THE LOWER PORTION
OF THE SURFICIAL AQUIFER
CONTRACT TASK ORDER - 0232

SCALE 1" = 80'

DATE DEC. 1994

FIGURE No.
1-12

2.0 REMEDIAL ACTION OBJECTIVES, REMEDIATION GOAL OPTIONS, AND REMEDIATION LEVELS

This section presents the remedial objectives and the development of remediation goal options (RGOs) and remediation levels (RLs). Section 2.1 presents the media of concern, Section 2.2 presents remedial action objectives, and Section 2.3 presents contaminants of concern for OU No. 10. RGOs, which are presented in Section 2.4, are chemical-specific concentration goals established for medium and land use combinations for the protection of human health and the environment. There are two general sources of chemical-specific RGOs: (1) concentrations based on applicable or relevant and appropriate requirements (ARARs) and, (2) risk-based concentrations for the protection of public health and the environment. The selection of RGOs includes: identifying the media(s) of concern, selection of contaminants of concern (COCs), evaluation of ARARs, and identification of site-specific information for the exposure pathway information (i.e., exposure frequency, duration, or intake rate data). Thus, the development of RGOs for OU No. 10 is detailed in Sections 2.1 through 2.4. In addition, Section 2.5 presents a comparison of risk-based remediation goal options to maximum contaminant concentrations in groundwater, while Section 2.6 discusses the uncertainty associated with risk-based RGOs. Finally, Section 2.7 presents the RLs chosen for OU No. 10 during this Interim FS.

2.1 Media of Concern

The results of the baseline human health RA presented in the RI Report (Baker, 1994) indicate that the total site risk (carcinogenic and non-carcinogenic) exceeds the generally accepted range established by the EPA and is driven by future potential exposure to surficial groundwater and current potential exposure to fish and noncarcinogenic risks. The other media (soil, sediment, surface water, and air) had ICRs less than 1.0E-04 and HIs less than 1.0. However, the evaluation of sediment media was based on the analytical results whereby volatile organic compound (VOC) levels were masked by the presence of Tentatively Identified Compounds at high levels. These results, along with observations by Baker field staff that the sediment samples appeared to contain fuel-related contaminants, prompted a recommendation in the RI Report that additional sediment samples be obtained and analyzed for TPH (via EPA Methods 5030 and 3550).

The focus of this Interim FS is surficial groundwater in the vicinity of the Fuel Farm with the emphasis placed on that contamination extending downgradient towards Brinson Creek. The contaminated surficial groundwater has been identified as a source of continued contamination to Brinson Creek. Remedial actions focused on contaminated surficial groundwater south and west of the Fuel Farm, and sediments in Brinson Creek, are subject to additional investigation and will be addressed in a comprehensive FS to be prepared following the completion of additional follow-up remedial investigation activities.

2.2 Remedial Action Objectives

Remedial action objectives are medium-specific or operable unit-specific goals established for protecting human health and the environment.

At Site 35, the specific media to be addressed by the Interim Remedial Action is contaminated surficial groundwater in the vicinity of the Fuel Farm extending downgradient towards Brinson Creek. The remedial action objectives for this surficial groundwater aquifer are:

- Mitigate the potential for direct exposure to the contaminated groundwater in the surficial aquifer.
- Minimize or prevent the horizontal and vertical migration of contaminated groundwater in the surficial aquifer.
- Restore the surficial aquifer to the remediation levels established for the groundwater COCs.

2.3 Contaminants of Concern

Contaminants of Potential Concern (COPCs) initially selected and evaluated in the RA (Table 1-1) were selected on the basis of frequency of detection, toxicity, and comparison to established criteria or standards. The final list of COPCs identified in the RA are termed Contaminants of Concern (COCs) for groundwater in this Interim FS (see Table 2-1). COCs from this list that were detected at levels not exceeding a regulatory or a risk-based remediation goal will be eliminated from further consideration later in Section 2.0. This final set of COCs will then become the basis for a set of remedial action objectives applicable to OU No. 10.

2.4 Remediation Goal Options

RGOs are based on federal and state criteria or risk-based concentrations. Federal and state criteria will be identified and evaluated in Section 2.4.1. Site-specific, risk-based RGOs for the COCs at OU No. 10 will be developed in Section 2.4.2. The results from both of these sections will be used to develop the initial set of RGOs for the operable unit.

2.4.1 Applicable or Relevant and Appropriate Federal and State Requirements

Under Section 121(d)(1) of CERCLA, remedial actions must attain a degree of cleanup which assures protection of human health and the environment. Additionally, CERCLA remedial actions that leave any hazardous substances, pollutants, or contaminants on site must meet, upon completion of the remedial action, a level or standard of control that at least attains standards, requirements, limitations, or criteria that are "applicable or relevant and appropriate" under the circumstances of the release. These requirements are known as "ARARs" or applicable or relevant and appropriate requirements. ARARs are derived from both federal and state laws. CERCLA's definition of "Applicable Requirements" is:

> ...cleanup standards, standards of control, or other substantive environmental protection requirements, criteria, or limitations promulgated under federal or state law that specifically address a hazardous substance, pollutant or contaminant, remedial action, location, or other circumstance at a CERCLA site. Drinking water criteria may be an applicable requirement for a site with contaminated groundwater that is used as a drinking water source.

CERCLA's definition of "Relevant and Appropriate Requirements" is:

> ...cleanup standards, standards of control and other substantive environmental protection requirements, criteria, or limitations promulgated under federal or state law that, while not "applicable" to a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance at a CERCLA site, address problems or situations sufficiently similar to those encountered at the CERCLA site that their use is well suited to the particular site.

EPA has also indicated that "other" federal and state criteria, advisories, and guidelines may have To Be Considered (TBC) during the development of remedial alternatives. TBCs are not promulgated, not enforceable, and do not have the same status as ARARs. Yet, they may be useful in establishing a cleanup level or in designing the remedial action, especially when no specific ARARs exist or they are not sufficiently protective. Examples of such other criteria include EPA Drinking Water Health Advisories, Carcinogenic Potency Factors, and Reference Doses.

There are three types of ARARs. The first type, chemical-specific ARARs, are requirements which set health or risk-based concentration limits or ranges for specific hazardous substances, pollutants, or contaminants. Federal Maximum Contaminant Levels (MCLs) established under the Safe Drinking Water Act (SDWA) are examples of chemical-specific ARARs.

The second type of ARAR, location-specific, sets restrictions on activities based upon the characteristics of the site and/or the nearby suburbs. Examples of this type of ARAR include federal and state siting laws for hazardous waste facilities and sites on the National Register of Historic Places.

The third classification of ARARs, action-specific, refers to the requirements that set controls or restrictions on particular activities related to the management of hazardous substances, pollutants, or contaminants. RCRA regulations for closure of hazardous waste storage units, RCRA incineration standards, and pretreatment standards under the Clean Water Act (CWA) for discharges to publicly-owned treatment works (POTWs) are examples of action specific ARARs.

Subsection 121(d) of CERCLA requires that federal and state substantive requirements that qualify as ARARs be complied with by remedies. Federal, state, or local permits do not need to be obtained for removal or remedial actions implemented on site but their substantive requirement must be obtained. "On site" is interpreted by the USEPA to include the areal extent of contamination and all suitable areas in reasonable proximity to the contamination necessary for implementation of the response action.

ARARs can be identified only on a site-specific basis. They depend on the detected contaminants at a site, site-specific characteristics, and particular remedial actions proposed for the site. Chemical-specific, location-specific, and action-specific ARARs identified for OU No. 10 are presented in the following section.

2.4.1.1 Chemical-Specific ARARs

The following chemical-specific ARARs were identified for Site 35: the North Carolina Water Quality Standards (NCWQSs) applicable to groundwaters, the federal MCLs, and Secondary MCLs. A brief description of each of these standards/guidelines is presented below.

North Carolina Water Quality Standards (Groundwater) - Under the North Carolina Administrative Code (NCAC), Title 15A, Subchapter 2L, Section .0200, (15A NCAC 2L.0200) the NC DEHNR has established water quality standards (NCWQSs) for three classifications of groundwater within the state: GA, GSA, and GC. Class GA waters are those groundwaters in the state naturally containing 250 milligram per liter (mg/L) or less of chloride. These waters are an existing or potential source of drinking water supply for humans. Class GSA waters are those groundwaters in the State naturally containing greater than 250 mg/L of chloride. These waters are an existing or potential source of water supply for potable mineral water and conversion to fresh water. Class GC water is defined as a source of water supply for purposes other than drinking. The NCAC T15A:02L.0300 has established sixteen river basins within the state as Class GC groundwaters (15A NCAC 2L.0201 and 2L.0300).

The water quality standards for groundwater are the maximum allowable concentrations resulting from any discharge of contaminants to the land or water of the state that may be tolerated without creating a threat to human health or that would otherwise render the groundwater unsuitable for its intended best usage. If the water quality standard of a substance is less than the limit of detectability, the substance shall not be permitted in detectable concentrations. If naturally occurring substances exceed the established standard, the standard will be the naturally occurring concentration as determined by the State. Substances which are not naturally occurring, and for which no standard is specified, are not permitted in detectable concentrations for Class GA or Class GSA groundwaters (15A NCAC 2L.0202).

The NCWQSs for substances in Class GA and Class GSA groundwaters are established as the lesser of:

- Systemic threshold concentration (based on reference dose and average consumption)
- Concentration which corresponds to an incremental lifetime cancer risk of 1.0E-6
- Taste threshold limit value
- Odor threshold limit value
- Federal MCL
- National Secondary Drinking Water Standard (or secondary MCL)

Note that the water quality standards for Class GA and Class GSA groundwaters are the same except for chloride and total dissolved solids concentrations (15A NCAC 2L.0202).

The Class GA groundwater NCWQSs for the groundwater COCs for OU No. 10 are listed on Table 2-2. As shown on the table, the majority of the state standards are the same or more stringent than the federal MCLs.

Federal Maximum Contaminant Levels - MCLs are enforceable standards for public water supplies promulgated under the SDWA and are designed for the protection of human health. MCLs are based on laboratory or epidemiological studies and apply to drinking water supplies consumed by a minimum of 25 persons. These standards are designed for prevention of human health effects associated with a lifetime exposure (70-year lifetime) of an average adult (70 kg) consuming two liters of water per day. MCLs also consider the technical feasibility of removing the contaminant from the public water supply.

Secondary MCLs are nonenforceable guidelines established under the SDWA. The secondary MCLs are set to control contaminants in drinking water that primarily affect the aesthetic qualities relating to public acceptance of drinking water.

Table 2-2 presents MCLs for groundwater COCs. For manganese and zinc, the secondary MCL has been listed.

2.4.1.2 Location-Specific ARARs

Potential location-specific ARARs identified for OU No. 10 are listed on Table 2-3. An evaluation determining the applicability of these location-specific ARARs with respect to OU No. 10 is also presented and summarized on Table 2-3. Based on this evaluation, specific sections of the following location-specific ARARs may be applicable to OU No. 10:

- Fish and Wildlife Coordination Act
- Federal Endangered Species Act
- North Carolina Endangered Species Act
- Executive Order 11990 on Protection of Wetlands
- Executive Order 11988 on Floodplain Management
- RCRA Location Requirements

Please note that the citations listed on Table 2-3 should not be interpreted to indicate that the entire citation is an ARAR. The citation listing is provided on the table as a general reference.

2.4.1.3 Action-Specific ARARs

Action-specific ARARs are typically evaluated following the development of alternatives since they are dependent on the type of action being considered. Therefore, at this step in the FS process, potential action-specific ARARs have only been identified and not evaluated for OU No. 10. A set of potential action-specific ARARs are listed on Table 2-4. These ARARs are based on RCRA, CWA, SDWA, and Department of Transportation (DOT) requirements. Note that the citations listed on Table 2-4 should not be interpreted to indicate that the entire citation is an ARAR. The citation listing is provided on the table as a general reference.

These ARARs will be evaluated after the remedial action alternatives have been identified for OU No. 10. Additional action-specific ARARs may also be identified and evaluated at that time.

2.4.2 Risk-Based Remediation Goal Options

In conjunction with the RGOs based on federal and state ARARs (Section 2.4.1), risk-based RGOs were developed for the groundwater COCs. The methodology used to derive the RGOs was in accordance with USEPA risk assessment guidance (USEPA, 1989a) (USEPA, 1991a). For noncarcinogenic effects, an action level was calculated that corresponds to an HI of 1.0, or unity, which is the level of exposure to a contaminant from all significant exposure pathways in a given medium below which it is unlikely for even sensitive populations to experience health effects. For carcinogenic effects, an action level was calculated that corresponds to 1.0E-04 (one in ten thousand) ICR over a lifetime as a result of exposure to the potential carcinogen from all significant exposure pathways for a given medium. A 1.0E-04 risk level was used as an end point for determining action levels for remediation. Based on the NCP (40 CFR 300.430), for known or suspected carcinogens, acceptable exposure levels are generally concentrations that represent an ICR between 1.0E-04 and 1.0E-06. The action levels for OU No. 10 are representative of acceptable incremental risks based on current and probable future use of the area.

Three steps were involved in estimating the risk-based RGOs for OU No. 10 COCs. These steps are generally conducted for a medium and land-use combination and involved identifying: (1) the most significant exposure pathways and routes, (2) the most significant exposure parameters, and (3) equations. The equations included calculations of total intake from a given medium and were based on identified exposure pathways and associated parameters.

2.4.2.1 Derivation of Risk Equations

The determination of chemical-specific RGOs was performed in accordance with USEPA guidance (USEPA, 1989a). Reference doses (RfDs) were used to evaluate noncarcinogenic contaminants, while cancer slope factors (CSFs) were used to evaluate carcinogenic contaminants.

Potential exposure pathways and receptors used to determine RGOs are site-specific and consider the current and/or future land use of a site. The following exposure scenarios were used in the determination of RGOs for OU No. 10:

- Ingestion of groundwater (future resident)

The potential risk estimated in the human health risk assessment indicated that the majority of the site-specific risk is likely to occur from exposure to groundwater. Groundwater does not appear to pose an appreciable risk with respect to both dermal contact and inhalation. For this Interim FS, the most conservative exposure pathway (i.e., groundwater ingestion) was used in the development of RGOs. The RGOs were calculated for future (adult and children) receptors in order to provide site-specific RGOs from which remedial alternatives could be generated.

Consistent with USEPA guidance, noncarcinogenic health effects were estimated using the concept of an average annual exposure. The action level incorporated the exposure time and/or frequency that represented the number of days per year and number of years that exposure occurs. This is used with a term known as the averaging time, which converts the daily exposure to an annual exposure. Carcinogenic health effects were calculated as an incremental lifetime cancer risk, and therefore represented the exposure duration (years) over the course of a potentially exposed individual's lifetime (70 years).

The estimation methods and models used in this section were consistent with current USEPA risk assessment guidance (USEPA, 1989a) (USEPA, 1991a). Exposure estimates associated with each exposure route are presented below. RGOs were developed, with site-specific inputs, for groundwater COCs presented in the human health risk assessment. However, in order to determine if a medium at a site requires remediation, estimated RGOs were compared to site-specific contaminant levels. This assessment was conducted to assure that media and contamination at each site would be addressed on a site-specific basis. The following sections present the equations and inputs used in the estimation of groundwater RGOs developed for OU No. 10.

Ingestion of Groundwater

Currently there are no receptors who are exposed to groundwater contamination in this area. Since groundwater is obtained from "noncontaminated" supply wells, pumped to water treatment plants, and distributed via a potable water system. However, it is assumed for the purposes of calculating remediation goals, that potable wells would pump groundwater from the site area for public consumption. Groundwater ingestion RGOs are characterized using the following equation:

$$Cw = \frac{TR \text{ or } THI \times BW \times AT_c \text{ or } AT_{nc} \times DY}{CSF \text{ or } 1/RfD \times EF \times ED \times IR \times (1{,}000\ \mu g/mg)}$$

Where:

Cw = contaminant concentration in groundwater (µg/L)
TR = total lifetime risk
THI = total hazard index
BW = body weight (kg)
ATc = averaging time carcinogens (yr)
ATnc = averaging time noncarcinogens (yr)
DY = days per year (day/year)
CSF = cancer slope factor $(mg/kg\text{-}day)^{-1}$
RfD = reference dose (mg/kg-day)
EF = exposure frequency (day/year)
ED = exposure duration (yr)
IR = ingestion rate (L/day)

Future On-Site Residents

Exposure to COCs via ingestion of groundwater was retained as a potential future exposure pathway for both children and adults.

An ingestion rate (IR) of 1.0 liter/day was used for the amount of water consumed by a 1 to 6 year old child weighing 15 kg. This ingestion rate provides a health conservative exposure estimate (for systemic, noncarcinogenic toxicants) designed to protect young children who could potentially be more affected than adolescents, or adults. This value assumes that children obtain all the tap water they drink from the same source for 350 days/year [which represents the exposure frequency (EF)]. An averaging time (AT) of 2,190 days (6 years x 365 days/year) is used for noncarcinogenic compound exposure.

The IR for adults was 2 liters/day (USEPA, 1989a). The exposure duration (ED) used for the estimation of adult CDIs was 30 years (USEPA, 1989a), which represents the national upper-bound (90th percentile) time at one residence. The averaging time for noncarcinogens was 10,950 days (30 years x 365 days/year). An AT of 25,550 days (70 years x 365 days/year) was used to evaluate exposure for both children and adults to potential carcinogenic compounds.

Table 2-5 presents a summary of the input parameters for the ingestion of groundwater scenarios.

2.4.2.2 Summary of Site-Specific Risk-Based Remediation Goal Options

COCs were chosen based on available toxicity data and frequency of detection and available ARARs. RGOs were generated for contaminants with available toxicity data. A summary of the risk-based RGOs calculated for the exposure scenarios is presented below. Separate RGOs for future adult residents and children have been calculated. In addition, both carcinogenic and noncarcinogenic RGOs have been calculated. Calculations are provided in Appendix A of this report.

Ingestion of Groundwater

The groundwater ingestion RGOs were estimated for the groundwater within the entire operable unit. Currently, there are no known receptors who are exposed to contaminated groundwater. Base personnel receive potable water via a base water distribution. However, a hypothetical future ingestion RGO was estimated for the COCs. In order to estimate conservative RGOs for subpopulations (i.e., adult resident and child resident), specific input variables were developed for each subpopulation. Tables 2-6 and 2-7 present the RGOs calculated for the carcinogenic and noncarcinogenic COCs in the groundwater, respectively.

2.5 Comparison of Risk-Based Remediation Goal Options to Maximum Contaminant Concentrations in Groundwater

Generally, RGOs are not required for any contaminants in a medium with a cumulative cancer risk of less than 1.0E-04, where an HI is less than or equal to 1.0, or where the RGOs are clearly defined by ARARs. In order to decrease uncertainties in the estimation of the reasonable maximum exposure (RME), which is the maximum exposure that is reasonably expected to occur at the site, the maximum concentration of a contaminant in a media can be compared to the estimated risk-based RGO if chemical-specific criteria are not available.

In Table 2-8, the carcinogenic and non-carcinogenic risk-based RGOs for groundwater ingestion with respect to future residential receptors (adult and children) are compared to the maximum groundwater contaminant concentrations detected at Site 35 during the RI. The NCWQSs and MCLs are also presented in this table.

2.6 Uncertainty Associated with Risk-Based RGOs

The uncertainties associated with calculating risk-based RGOs are summarized below. The RGO estimations presented in this section are quantitative in nature, and their results are highly dependent upon the accuracy of the input. The accuracy with which input values can be quantified is critical to the degree of confidence that the decision maker has in the action levels.

Most scientific computation involves a limited number of input variables, which are tied together by a scenario to provide a desired output. Some RGO inputs are based on literature values rather than measured values. In such cases the degree of certainty may be expressed as whether the estimate was based on literature values or measured values, not on how well defined the distribution of the input was. Some RGOs are based on parameters; the qualitative statement that the RGO was based on estimated inputs defines the certainty in a qualitative manner.

The toxicity factors, CSFs and RfDs, have uncertainties built into the assumptions used to calculate these values. Because the toxicity factors are determined from high doses administered to experimental animals and extrapolated to low doses to which humans may be exposed, uncertainties exist. Thus, toxicity factors could either overestimate or underestimate the potential effects on humans. However, because human data exists for very few chemicals, risks are based on these values. In addition, the exposure assumptions (e.g., 10 events per year, etc.) also have uncertainties associated with them.

Although RGOs are believed to be full protective for the RME individual(s), the existence of the same contaminants in multiple media or of multiple chemicals affecting the same populations(s), may lead to a situation where, even after attainment of all RGOs, protectiveness is not freely achieved (i.e., cumulative risk may fall outside the risk range).

2.7 Remediation Levels

This section presents the remediation levels (RLs) chosen for OU No. 10. RLs are chosen by the risk manager for the COCs and are included in the Interim FS and the Interim ROD. These numbers derived from the RGOs are no longer goals and should be considered required levels for the remedial actions to achieve.

The RLs associated with OU No. 10 are presented on Table 2-9. This list was based on a comparison of contaminant-specific ARARs (or ARAR-based RGOs) and the site-specific risk-based RGOs. If a COC had an ARAR, the most limiting (or conservative) ARAR was selected as the RL for that contaminant. If a COC did not have an ARAR, the most conservative risk-based RGO was selected for the RL. For all contaminants but arsenic, beryllium, and barium the most limiting ARAR was more conservative than the risk-based RGO. In the cases of arsenic, beryllium and barium, the federal MCLs wee selected in lieu of more conservative RGO values because the MCLs are generally based on the capacity of the best available technology to achieve reductions in groundwater contaminant concentrations.

In order to determine the final COC for OU No. 10, the contaminant concentrations detected at each site were compared to the RLs presented on Table 2-9. The contaminants which exceed at least one of the RLs have been retained as final COCs. The contaminants that did not exceed any of the RLs are no longer considered as COCs with respect to this Interim FS. The final COCs and their associated RLs are presented on Table 2-10.

Several inorganic COCs, including arsenic, beryllium, antimony, barium, cadmium, manganese, nickel, and vanadium, were detected in concentrations that exceeded remediation levels. However, these inorganics will not be addressed in this Interim FS because it is unlikely that their presence is a result of past site activities. (The inorganic concentrations are similar to those detected at other Camp Lejeune sites.) Recently, Baker has employed new sampling techniques for inorganics in groundwater utilizing low-flow pumps. The low-flow pumps minimize particle disturbance and have resulted in reduced levels of total inorganics in groundwater analytical results. As recommended in the RI, inorganics at OU No. 10 will be re-sampled using this low-flow sampling technique. Based on previous experience on other sites at this Activity, it is probable that detected concentrations for some inorganics will then fall below remediation levels. Thus, inorganic COCs exceeding remediation levels will not be addressed at this time and Table 2-11 presents a final list of COCs to be addressed in this Interim FS.

SECTION 2.0 TABLES

TABLE 2-1

PRELIMINARY GROUNDWATER CONTAMINANTS OF CONCERN
OPERABLE UNIT NO. 10 (SITE 35)
INTERIM FEASIBILITY STUDY, CTO-0232
MCB CAMP LEJEUNE, NORTH CAROLINA

COCs
Benzene
cis-1,2-Dichloroethene
Ethylbenzene
Methyl Tertiary Butyl Ether
Naphthalene
Toluene
trans-1,2-Dichloroethene
Trichloroethene
Xylenes (Total)
Antimony
Arsenic
Barium
Beryllium
Cadmium
Cobalt
Copper
Lead
Manganese
Mercury
Nickel
Selenium
Thallium
Vanadium
Zinc
2-Methylnaphthalene

TABLE 2-2

CHEMICAL-SPECIFIC ARARs EVALUATED FOR OPERABLE UNIT NO. 10 (SITE 35) INTERIM FEASIBILTIY STUDY CTO-232 MCB CAMP LEJEUNE, NORTH CAROLINA

Contaminant	NCWQS (1)	Federal MCL (2)
Benzene	1	5
Trichloroethene	2.8	5
Arsenic	50	50
Beryllium	NE	4
cis-1,2-Dichloroethene	70	70
trans-1,2-Dichloroethene	70	100
Ethyl Benzene	29	700
Methyl Tertiary Butyl Ether	200	NE
Toluene	1,000	1,000
Xylenes	530	10,000
Naphthalene	NE	NE
Antimony	NE	6
Barium	2,000	2,000
Cadmium	5	5
Cobalt	NE	NE
Copper	1,000	1,300(3)
Manganese	50	50(4)
Mercury	1.1	2
Nickel	100	100
Selenium	50	50
Vanadium	NE	NE
Zinc	2,100	5,000(4)

Notes: Concentrations expressed in microgram per liter (ug/L)

(1) NCWQS = North Carolina Water Quality Standards for Groundwater
(2) MCL = Safe Drinking Water Act Maximum Contaminant Level
(3) Action Level for Copper
(4) Secondary Maximum Contaminant Level (SMCL)
NE = No Criteria Established

TABLE 2-3

LOCATION-SPECIFIC ARARs EVALUATED FOR OPERABLE UNIT NO. 10 (SITE 35) INTERIM FEASIBILITY STUDY CTO-0232 MCB CAMP LEJEUNE, NORTH CAROLINA

Potential Location-Specific ARAR	General Citation	ARAR Evaluation
National Historic Preservation Act of 1966 - requires action to take into account effects on properties included in or eligible for the National Register of Historic Places and to minimize harm to National Historic Landmarks.	16 USC 470, 40 CFR 6.301(b), and 36 CFR 800	No known historic properties are within or near OU No. 10, therefore, this act will not be considered an ARAR
Archeological and Historic Preservation Act - establishes procedures to provide for preservation of historical and archeological data which might be destroyed through alteration of terrain.	16 USC 469, and 40 CFR 6.301(c)	No known historical or archeological data is known to be present at the sites, therefore, this act will not be considered an ARAR.
Historic Sites, Buildings and Antiquities Act - requires action to avoid undesirable impacts on landmarks on the National Registry of Natural Landmarks.	16 USC 461467, and 40 CFR 6.301(a)	No known historic sites, buildings or antiquities are within or near OU No. 10, therefore, this act will not be considered as an ARAR.
Fish and Wildlife Coordination Act - requires action to protect fish and wildlife from actions modifying streams or areas affecting streams.	16 USC 661-666	Brinson Creek is located near and within the operable unit boundaries. If remedial actions are implemented that modify this creek, this will be an applicable ARAR.
Federal Endangered Species Act - requires action to avoid jeopardizing the continued existence of listed endangered species or modification of their habitat.	16 USC 1531, 50 CFR 200, and 50 CFR 402	Many protected species have been sited near and on MCB Camp Lejeune such as the American alligator, the Bachmans sparrow, the Black skimmer, the Green turtle, the Loggerhead turtle, the piping plover, the Red-cockaded woodpecker, and the rough-leaf loosestrife (LeBlond, 1991),(Fussell, 1991),(Walters, 1991). In addition, the alligator has been sighted on Base (in Wallace Creek). Therefore, this will be considered an ARAR.

TABLE 2-3 (Continued)

LOCATION-SPECIFIC ARARs EVALUATED FOR OPERABLE UNIT NO. 10 (SITE 35) INTERIM FEASIBILITY STUDY CTO-0232 MCB CAMP LEJEUNE, NORTH CAROLINA

Potential Location-Specific ARAR	General Citation	ARAR Evaluation
North Carolina Endangered Species Act - per the North Carolina Wildlife Resources Commission. Similar to the Federal Endangered Species Act, but also includes State special concern species, State significantly rate species, and the State watch list.	GS 113-331 to 113-337	Since the American alligator has been sighted within MCB Camp Lejeune (in Wallace Creek), this will be considered an ARAR.
Rivers and Harbors Act of 1899 (Section 10 Permit) - requires permit for structures or work in or affecting navigable waters.	33 USC 403	No remedial actions will affect the navigable waters of the New River. Therefore, this act will not be considered an ARAR.
Executive Order 11990 on Protection of Wetlands - establishes special requirements for Federal agencies to avoid the adverse impacts associated with the destruction or loss of wetlands and to avoid support of new construction in wetlands if a practicable alternative exists.	Executive Order Number 11990, and 40 CFR 6	Based on a review of Wetland Inventory Maps, Brinson Creek has areas of wetlands. Therefore, this will be an applicable ARAR.
Executive Order 11988 on Floodplain Management - establishes special requirements for Federal agencies to evaluate the adverse impacts associated with direct and indirect development of a floodplain.	Executive Order Number 11988, and 40 CFR 6	Based on the Federal Emergency Management Agency's Flood Insurance Rate Map for Onslow County, OU No. 10 is primarily within a minimal flooding zone (outside the 500-year floodplain). However, the immediate areas around Brinson Creek are within the 100-year floodplain (FEMA, 1987). Therefore, this may be an ARAR for the operable unit.
Wilderness Act - requires that federally owned wilderness area are not impacted. Establishes nondegradation, maximum restoration, and protection of wilderness areas as primary management principles.	16 USC 1131, and 50 CFR 35.	No known federally-owned wilderness areas are located near the operable unit, therefore, this act will not be considered an ARAR.

TABLE 2-3 (Continued)

LOCATION-SPECIFIC ARARs EVALUATED FOR OPERABLE UNIT NO. 10 (SITE 35) INTERIM FEASIBILITY STUDY CTO-0232 MCB CAMP LEJEUNE, NORTH CAROLINA

Potential Location-Specific ARAR	General Citation	ARAR Evaluation
National Wildlife Refuge System - restricts activities within a National Wildlife Refuge.	16 USC 668, and 50 CFR 27	No known National Wildlife Refuge areas are located near the operable unit, therefore, this will not be considered an ARAR.
Scenic Rivers Act - requires action to avoid adverse effects on designated wild or scenic rivers.	16 USC 1271, and 40 CFR 6.302(e)	No known wild or scenic rivers are located near the operable unit, therefore, this act will not be considered an ARAR.
Coastal Zone Management Act - requires activities affecting land or water uses in a coastal zone to certify noninterference with coastal zone management.	16 USC 1451	No activities at the site will affect land or water uses in a coastal zone, therefore, this act will not be considered an ARAR.
Clean Water Act (Section 404) - prohibits discharge of dredged or fill material into wetland without a permit.	33 USC 404	No actions to discharge dredged or fill material into wetlands will be considered for the operable unit, therefore, this act will not be considered an ARAR.
RCRA Location Requirements - limitations on where on-site storage, treatment, or disposal of RCRA hazardous waste may occur.	40 CFR 264.18	These requirements may be applicable if the remedial actions for the operable unit include the on-site storage, treatment, or disposal of RCRA hazardous waste. Therefore, these requirements may be an applicable ARAR for the operable unit.

TABLE 2-4

ACTION-SPECIFIC ARARs
EVALUATED FOR OPERABLE UNIT NO. 10 (SITE 35)
INTERIM FEASIBILITY STUDY CTO-0232
MCB CAMP LEJEUNE, NORTH CAROLINA

Standard (1)	Action	General Citation
RCRA	Capping	40 CFR 264
	Closure	40 CFR 264, 244
	Container Storage	40 CFR 264, 268
	New Landfill	40 CFR 264
	New Surface Impoundment	40 CFR 264
	Dike Stabilization	40 CFR 264
	Excavation, Groundwater Diversion	40 CFR 264, 268
	Incineration	40 CFR 264, 761
	Land Treatment	40 CFR 264
	Land Disposal	40 CFR 264, 268
	Slurry Wall	40 CFR 264, 268
	Tank Storage	40 CFR 264, 268
	Treatment	40 CFR 264, 265, 268; 42 USC 6924; 51 FR 40641; 52 FR 25760
	Waste Pile	40 CFR 264, 268
CWA	Discharge to Water of United States	40 CFR 122, 125, 136
	Direct Discharge to Ocean	40 CFR 125
	Discharge to POTW	40 CFR 403, 270
	Dredge/Fill	40 CFR 264; 33 CFR 320-330; 33 USC 403
CAA (NAAQS)	Discharge to Air	40 CFR 50
SDWA	Underground Injection Control	40 CFR 144, 146, 147, 268
TSCA	PCB Regulations	40 CFR 761
DOT	DOT Rules for Transportation	49 CFR 107

(1) RCRA = Resource Conservation Recovery Act
CWA = Clean Water Act
CAA = Clean Air Act
(NAAQS) = National Ambient Air Quality Standards
SDWA = Safe Drinking Water Act
DOT = Department of Transportation

TABLE 2-5

INGESTION OF GROUNDWATER
RGO PARAMETERS
OPERABLE UNIT NO. 10 (SITE 35)
INTERIM FEASIBILITY STUDY CTO-0232
MCB CAMP LEJEUNE, NORTH CAROLINA

Ingestion of Groundwater Input Parameters			
Input Parameter	Description	Value	Rationale
C_w	Exposure Concentration	Calculated	USEPA, 1989a
TR	Total Lifetime Risk	1.0E-04	USEPA, 1991a
THI	Total Hazard Index	1.0	USEPA, 1991a
BW	Body Weight	Child 15 kg Adult 70 kg	USEPA, 1989a
ATc	Averaging Time Carcinogen	All 70 yr	USEPA, 1989a
ATnc	Averaging Time Noncarcinogen	Child 6 yr Adult 30 yr	USEPA, 1989a
DY	Days Per Year	365 days/yr	USEPA, 1989a
CSF	Carcinogenic Slope Factor	Chemical Specific	IRIS, HEAST, USEPA
RfD	Reference Dose	Chemical Specific	IRIS, HEAST, USEPA
EF	Exposure Frequency	Child 350 days/yr Adult 350 days/yr	USEPA, 1989a
ED	Exposure Duration	Child 6 yr Adult 30 yr	USEPA, 1991b
IR	Ingestion Rate	Child 1 L/day Adult 2 L/day	USEPA, 1989a

TABLE 2-6

INGESTION OF GROUNDWATER CARCINOGENIC RGOs
OPERABLE UNIT NO. 10 (SITE 35)
INTERIM FEASIBILITY STUDY CTO-232
MCB CAMP LEJEUNE, NORTH CAROLINA

Contaminant of Concern	Carcinogenic RGO	
	Adult Resident	Child Resident
Benzene	294	629
Trichloroethene	774	1,659
Arsenic	5	11
Beryllium	2	4

Notes: RGO = Remedial Goal Options
Remediation Goal Options concentrations expressed in ug/L (ppb)
Remediation Goal Options based on a risk of 1.0E-04

TABLE 2-7

INGESTION OF GROUNDWATER NONCARCINOGENIC RGOs
OPERABLE UNIT NO. 10 (SITE 35)
INTERIM FEASIBILITY STUDY CTO-232
MCB CAMP LEJEUNE, NORTH CAROLINA

Contaminant of Concern	Noncarcinogenic RGO	
	Adult Resident	Child Resident
Trichloroethene	219	94
cis-1,2-Dichloroethene	365	156
trans-1,2-Dichloroethene	730	313
Ethyl Benzene	3,650	1,564
Methyl Tertiary Butyl Ether	183	78
Toluene	7,300	3,129
Xylenes	73,000	31,286
Naphthalene	1,460	626
Antimony	15	6
Arsenic	11	5
Barium	2,555	1,095
Beryllium	183	78
Cadmium	18	8
Cobalt	2,190	939
Copper	1,354	580
Manganese	183	78
Mercury	11	5
Nickel	730	313
Selenium	183	78
Vanadium	256	110
Zinc	10,950	4,693

Notes: RGO = Remedial Goal Options
Remediation Goal Options concentrations expressed in ug/L (ppb)
Remediation Goal Options based on a HI of 1.0

TABLE 2-8

COMPARISON OF GROUNDWATER INGESTION RISK-BASED RGOs AND GROUNDWATER CRITERIA TO MAXIMUM GROUNDWATER CONTAMINANT LEVELS
OPERABLE UNIT NO. 10 (SITE 35)
INTERIM FEASIBILTIY STUDY CTO-232
MCB CAMP LEJEUNE, NORTH CAROLINA

Contaminant	NCWQS (1)	Federal MCL (2)	RGO (3)		Maximum Groundwater Concentration
			Adult	Child	
Benzene	1	5	294	629	1,660
Trichloroethene	2.8	5	774(4) 219(5)	1,659(4) 94(5)	900
Arsenic	50	50	5(4) 11(5)	11(4) 5(5)	165
Beryllium	NE	4	2(4) 183(5)	4(4) 78(5)	63.5
cis-1,2-Dichloroethene	70	70	365	156	973
trans-1,2-Dichloroethene	70	100	730	313	176
Ethyl Benzene	29	700	3,650	1,564	824
Methyl Tertiary Butyl Ether	200	NE	183	78	319
Toluene	1,000	1,000	7,300	3,129	984
Xylenes	530	10,000	73,000	31,286	1,700
Naphthalene	NE	NE	1,460	626	499
Antimony	NE	6	15	6	10.2
Barium	2,000	2,000	2,555	1,095	3,440
Cadmium	5	5	18	8	340
Cobalt	NE	NE	2,190	939	281
Copper	1,000	1,300(7)	1,354	580	140
Manganese	50	50(6)	183	78	1,420
Mercury	1.1	2	11	5	0.84
Nickel	100	100	730	313	524
Selenium	50	50	183	78	13.5
Vanadium	NE	NE	256	110	886
Zinc	2,100	5,000(6)	10,950	4,693	1,850

Notes: Concentrations expressed in microgram per liter (ug/L)

(1) NCWQS = North Carolina Water Quality Standards for Groundwater
(2) MCL = Safe Drinking Water Act Maximum Contaminant Level
(3) RGO = Risk-based Remediation Goal Options
(4) Carcinogenic RGO
(5) Noncarcinogenic RGO
(6) SMCL = Secondary Maximum Contaminant Level
(7) Action Level
NE = No Criteria Established

TABLE 2-9

REMEDIATION LEVELS FOR COCs
OPERABLE UNIT NO. 10 (SITE 35)
INTERIM FEASIBILITY STUDY CTO-232
MCB CAMP LEJEUNE, NORTH CAROLINA

Contaminant of Concern	RL(1)	Basis of Goal	Corresponding Risk
Benzene	1	NCWQS(2)	
Trichloroethene	2.8	NCWQS	
Arsenic	50	NCWQS	
Beryllium	4	MCL(3)	
cis-1,2-Dichloroethene	70	NCWQS	
trans-1,2-Dichloroethene	70	NCWQS	
Ethyl Benzene	29	NCWQS	
Methyl Tertiary Butyl Ether	200	NCWQS	
Toluene	1,000	NCWQS	
Xylenes	530	NCWQS	
Naphthalene	626	Risk-Ingestion	HI(4)=1
Antimony	6	MCL(5)	
Barium	2,000	NCWQS	
Cadmium	5	NCWQS	
Cobalt	939	Risk-Ingestion	HI=1
Copper	1,000	NCWQS	
Manganese	50	NCWQS	
Mercury	1.1	NCWQS	
Nickel	100	NCWQS	
Selenium	50	NCWQS	
Vanadium	110	Risk-Ingestion	HI=1
Zinc	2,100	NCWQS	

Notes: Concentrations expressed in microgram per liter (ug/L)

(1) RL = Remediation Level
(2) NCWQS = North Carolina Water Quality Standards for Groundwater
(3) MCL = Maximum Contaminant Level
(4) HI = Hazard Index

TABLE 2-10

COCs THAT EXCEED REMEDIATION LEVELS
OPERABLE UNIT NO. 10 (SITE 35)
INTERIM FEASIBILITY STUDY CTO-232
MCB CAMP LEJEUNE, NORTH CAROLINA

Contaminant of Concern	RL(1,2)
Benzene	1
Trichloroethene	2.8
Arsenic	50
Beryllium	4
cis-1,2-Dichloroethene	70
trans-1,2-Dichloroethene	70
Ethyl Benzene	29
Methyl Tertiary Butyl Ether	200
Xylenes	530
Antimony	6
Barium	2,000
Cadmium	5
Manganese	50
Nickel	100
Vanadium	110

(1) RL = Remediation Level
(2) Groundwater RLs expressed as ug/L (ppb)

TABLE 2-11

ORGANIC COCs THAT EXCEED REMEDIATION LEVELS
OPERABLE UNIT NO. 10 (SITE 35)
INTERIM FEASIBILITY STUDY CTO-232
MCB CAMP LEJEUNE, NORTH CAROLINA

Contaminant of Concern	RL(1,2)
Benzene	1
Trichloroethene	2.8
cis-1,2-Dichloroethene	70
trans-1,2-Dichloroethene	70
Ethyl Benzene	29
Methyl Tertiary Butyl Ether	200
Xylenes	530

(1) RL = Remediation Level
(2) Groundwater RLs expressed as ug/L (ppb)

3.0 IDENTIFICATION AND PRELIMINARY SCREENING OF REMEDIAL TECHNOLOGIES

This section covers the identification and preliminary screening of remedial action technologies that may be applicable for the remediation of the groundwater in the vicinity of the Fuel Farm at OU No. 10. Section 3.1 identifies a set of general response actions which correspond to the remedial action objectives. Section 3.2 identifies a set of remedial technologies and process options applicable to groundwater. Section 3.3 presents the preliminary screening of the remedial technologies and process options. Section 3.4 presents a summary of the preliminary screening, and Section 3.5 presents the process option evaluation.

3.1 General Response Actions

General response actions are broad-based, medium-specific categories of actions that can be identified to satisfy the remedial action objectives of an FS. Five general response actions have been identified that may satisfy the groundwater remedial action objectives at OU No. 10 including no action, institutional controls, containment actions, collection/discharge actions, and treatment actions.

A brief description of each of the above-mentioned general response actions follows.

3.1.1 No Action

The NCP requires the evaluation of the no action response as part of the FS process. A no action response provides the baseline assessment for comparison with other remedial alternatives that have a greater level of response. A no action alternative may be considered appropriate when there is no adverse or unacceptable risks to human health or the environment, or when the response action may cause a greater environmental or health danger than the no action alternative itself.

3.1.2 Institutional Controls

Institutional controls are actions that can be implemented at a site as part of a complete remedial alternative to minimize exposure to potential hazards. With respect to groundwater, institutional controls may include monitoring programs or ordinances which restrict aquifer use and placement of supply wells.

3.1.3 Source Containment Actions

Source containment actions include various technologies which contain and/or isolate the contaminants at a site. These measures are designed to isolate so as to prevent direct exposure to or migration of the contaminated media without disturbing or removing the waste/contaminants from the site. Source containment actions generally serve to cover, seal, chemically stabilize, or provide an effective barrier around specific areas of contamination.

3.1.4 Collection/Discharge Actions

Collection/discharge actions are typically associated with groundwater or surface water and are used to control the movement of contaminants through these media or to covey contaminated portions of these media to treatment units. For this Interim FS, groundwater collection/discharge actions at

OU No. 10 are addressed. Collection actions may include extraction wells or subsurface drains. Discharge actions are those means for discharging groundwater that has been treated. Discharge actions may be directed on site or off site.

3.1.5 Treatment Actions

3.1.5.1 Ex Situ Treatment

Ex situ treatment actions, as defined herein, involve physical and/or chemical means of reducing toxicity or destroying contaminants that are present in groundwater once it has been collected and conveyed above the ground surface. Ex situ treatment actions for groundwater are normally conducted on site, but off-site treatment actions are also considered.

3.1.5.2 In Situ Treatment

In situ treatment in groundwater refers to a process whereby groundwater contaminants are reduced or eliminated via technologies applied primarily below the ground surface. This type of treatment may involve groundwater extraction, treatment, and reinjection, as long as primary treatment occurs below the ground surface.

3.2 Identification of Remedial Action Technologies and Process Options

In this step, an extensive set of potentially applicable technology types and process options is identified for each of the general response actions identified for the media of concern at OU No. 10. The term "technology type" refers to general categories of technologies such as chemical treatment, thermal treatment, biological treatment, and in situ treatment. The term "technology process option" refers to specific processes within each technology type. For example, rotary kiln, fluidized bed, and multiple hearth incineration are process options of thermal treatment. Several technology types may be identified for each general response action, and numerous technology process options may exist within each technology type.

Remedial action technologies potentially applicable to OU No. 10 are listed in Table 3-1 with respect to their corresponding general response action. The applicable process options associated with each of the listed technologies are also listed in the table.

3.3 Preliminary Screening of Remedial Action Technologies and Process Options

In this step, the set of remedial action technologies and process options identified in the previous section is reduced (or screened) by evaluating the technologies with respect to technical implementability and site-specific factors. This screening step is site-specific and is accomplished by using readily available information from the RI, with respect to contaminant types, contaminant concentrations, and on-site characteristics, to screen out technologies and process options that cannot be effectively implemented at the site (USEPA, 1988). In general, all technologies/options which appear to be applicable to the site contaminants and to the site conditions are retained for further evaluation. The preliminary screening is presented in Table 3-2. Each of the process options remaining after the preliminary screening is evaluated in Section 3.4.

As shown in Table 3-2, several technologies and/or process options were eliminated from further evaluation since they were determined to be inappropriate for the site-specific characteristics and/or contaminant-specific characteristics of OU No. 10.

3.4 Process Options Evaluation

The objective of the process option evaluation is to select only one process option for each applicable remedial technology type to simplify the subsequent development and evaluation of alternatives without limiting flexibility during remedial design. More than one process option may be selected for a technology type if the processes are sufficiently different in their performance that one would not adequately represent the other. The representative process provides a basis for developing performance specifications during preliminary design. However, the specific process option used to implement the remedial action may not be selected until the remedial design phase.

The retained process options are evaluated based on effectiveness, implementability, and relative cost. The effectiveness evaluation focuses on: the potential effectiveness of process options in meeting the remedial action objectives, the potential impacts to human health and the environment during the construction and implementation phase, and how reliable the process is with respect to the contaminants of concern. The implementability evaluation focuses on the administrative feasibility of implementing a technology as well as the technical implementability. The cost evaluation plays a limited role in this screening. Only relative capital and operating and maintenance (O&M) costs are used instead of detailed estimates. Per the USEPA FS guidance, the cost analysis is made on the basis of engineering judgment.

A summary of the groundwater process option evaluation is presented in Table 3-3. It is important to note that the elimination of a process option does not mean that the process option/technology can never be reconsidered for the site. As previously stated, the purpose of this part of the Interim FS process is to simplify the development and evaluation of potential alternatives.

SECTION 3.0 TABLES

TABLE 3-1

POTENTIAL SET OF REMEDIAL ACTION TECHNOLOGIES AND PROCESS OPTIONS IDENTIFIED FOR OPERABLE UNIT NO. 10 (SITE 35) INTERIM FEASIBILITY STUDY, CTO-0232 MCB CAMP LEJEUNE, NORTH CAROLINA

Media	General Response Action	Remedial Action Technology	Process Option
Groundwater	No Action	No Action	Natural Attenuation
	Institutional Controls	Monitoring	Groundwater and Surface Water Monitoring
		Aquifer-Use Limitations	Restrictions in Base Master Plan
			Deed Restrictions
	Containment Actions	Capping	Clay/Soil Cap
			Asphalt/Concrete Cap
			Soil Cover
			Multilayered Cap
		Vertical Barriers	Grout Curtain
			Slurry Wall
			Sheet Piling
			Rock Grouting
		Horizontal Barriers	Grout Injection
			Block Displacement
	Collection/Discharge Actions	Extraction	Extraction Wells
			Extraction/Injection Wells
		Subsurface Drains	Interceptor Trenches
		On-Site Discharge	Reinjection
			Infiltration Galleries
			Surface Water
		Off-Site Discharge	POTW
			Base STP
			Surface Water
	Treatment Actions	Biological Treatment	Aerobic
			Anaerobic
		Physical/Chemical Treatment	Air Stripping
			Steam Stripping
			Carbon Adsorption
			Reverse Osmosis
			Ion Exchange
			Chemical Reduction
			Chemical Oxidation
			UV Oxidation
			Electrochemical Iron Generation

TABLE 3-1 (Continued)

POTENTIAL SET OF REMEDIAL ACTION TECHNOLOGIES AND PROCESS OPTIONS IDENTIFIED FOR OPERABLE UNIT NO. 10 (SITE 35)
INTERIM FEASIBILITY STUDY, CTO-0232
MCB CAMP LEJEUNE, NORTH CAROLINA

Media	General Response Action	Remedial Action Technology	Process Option
Groundwater (Cont.)	Treatment Actions (Cont.)	Physical/Chemical Treatment (Cont.)	Neutralization
			Precipitation
			Oil/Water Separator
			Filtration
			Flocculation
			Sedimentation
			Chemical Dechlorination
		Engineered Wetland Treatment	Constructed Wetlands
		Off-Site Treatment	POTW
			RCRA Facility
			Sewage Treatment Plant
		In-Situ Treatment	Biodegradation
			Air Sparging
			In Well Aeration
			Passive Treatment Wall

TABLE 3-2

PRELIMINARY SCREENING OF GROUNDWATER TECHNOLOGIES AND PROCESS OPTIONS
OPERABLE UNIT NO. 10 (SITE 35)
INTERIM FEASIBILITY STUDY, CTO-0232
MCB CAMP LEJEUNE, NORTH CAROLINA

General Response Action	Remedial Action Technology	Process Option	Description	Site-Specific Applicability	Screening Results
No Action	No Action	Natural Attenuation	Contaminated groundwater remains as is and natural subsurface process (for example, biodegradation, adsorption, and volatilization) reduce contaminant levels.	Potentially applicable to any site; the NCP requires a "no action" process option.	Retained
Institutional Controls	Monitoring	Groundwater or Surface Water Monitoring	Ongoing monitoring of groundwater or surface water.	Potentially applicable.	Retained
	Aquifer-Use Restrictions	Restrictions in Base Master Plan	Prohibit the use of the contaminated aquifer as a drinking water source.	Potentially applicable.	Retained
		Deed Restrictions	Limit the future use of land including placement of wells.	Not applicable to a military installation not on a closure list.	Eliminated
Containment Actions	Capping	Clay/Soil Cap Asphalt/Concrete Cap Soil Cover Multilayered Cap	Capping material placed over areas of contamination.	Not implementable due to the proposed highway that will span the Fuel Farm area and because the horizontal limits of the plume have not been defined to date.	Eliminated
	Vertical Barriers	Grout Curtain	Pressure injection of grout in a regular pattern of drilled holes to contain contamination.	Not applicable because the horizontal limits of the plume have not been defined to date.	Eliminated
		Slurry Wall	Trench around areas of contamination. The trench is filled with a soil bentonite slurry to limit migration of contaminants.	Not applicable due to the obstruction posed by the proposed highway.	Eliminated
		Sheet Piling	Interlocking sheet pilings installed via drop hammer around areas of contamination.	Not applicable due to the obstruction posed by the proposed highway.	Eliminated
		Rock Grouting	Specialty operation for sealing fractures, fissures, solution cavities, or other voids in rock to control flow of groundwater.	Not applicable because rock is not present within several hundred feet of the ground surface at the site.	Eliminated

TABLE 3-2 (Continued)

PRELIMINARY SCREENING OF GROUNDWATER TECHNOLOGIES AND PROCESS OPTIONS
OPERABLE UNIT NO. 10 (SITE 35)
INTERIM FEASIBILITY STUDY, CTO-0232
MCB CAMP LEJEUNE, NORTH CAROLINA

General Response Action	Remedial Action Technology	Process Option	Description	Site-Specific Applicability	Screening Results
Containment Actions (Continued)	Horizontal Barriers	Grout Injection	Pressure injection of grout to form a bottom seal across a site at a specific depth.	Generally used in conjunction with vertical barriers which have been primarily deemed not applicable at this site due to the presence of the proposed highway.	Eliminated
		Block Displacement	Continued pumping of grout into specially notched holes causing displacement of a block of contaminated groundwater.	Technique is experimental. Large area over which grout would be required limits this technique.	Eliminated
Collection Actions	Extraction	Extraction/Injection Wells	Extraction wells pull water from the aquifer. Injection wells inject uncontaminated groundwater to enhance collection of contaminated groundwater via the extraction wells. Or the injection wells can also inject material into an aquifer to remediate groundwater.	Not applicable because the extraction/injection process may induce intolerable ground settlement on the highway resulting from fluctuations in the groundwater table.	Eliminated
	Subsurface Drains	Interceptor Trenches	Perforated pipe installed in trenches backfilled with porous media to collect contaminated groundwater.	Potentially applicable because contamination is limited to a shallow zone and rate of extraction can be to limit effects on groundwater level.	Retained
Treatment Actions	Biological Treatment	Aerobic	Degradation of organics using microorganisms in an aerobic environment.	Potentially applicable to nonhalogenated organic COCs.	Retained
		Anaerobic	Degradation of organics using microorganisms in an anaerobic environment.	Potentially applicable to halogenated and nonhalogenated organic COCs. Development is in pilot-scale and is not commercially available.	Eliminated

TABLE 3-2 (Continued)

PRELIMINARY SCREENING OF GROUNDWATER TECHNOLOGIES AND PROCESS OPTIONS
OPERABLE UNIT NO. 10 (SITE 35)
INTERIM FEASIBILITY STUDY, CTO-0232
MCB CAMP LEJEUNE, NORTH CAROLINA

General Response Action	Remedial Action Technology	Process Option	Description	Site-Specific Applicability	Screening Results
Treatment Actions (Continued)	Physical/Chemical Treatment	Volatilization (Air/Stream Stripping)	Mixing large volumes of air/steam with water in a packed column to promote transfer of VOCs to air. Applicable to volatile organics.	Potentially applicable to halogenated and nonhalogenated organic COCs.	Retained
		Carbon Adsorption	Adsorption of contaminants onto activated carbon by passing water through carbon column. Applicable to wide range of organics.	Potentially applicable to most organic COCs.	Retained
		Reverse Osmosis	Using high pressure to force water through a membrane leaving contaminants behind. Applicable to dissolved solids (organic and inorganic).	Not applicable because dissolved solids are not anticipated to be a primary treatment concern at this site.	Eliminated
		Ion Exchange	Contaminated water is passed through a resin bed where ions are exchanged between resin and water. Applicable for inorganics, not organics.	Not applicable to the organic COCs. Inorganic compounds are not a primary treatment concern at this site.	Eliminated
		Chemical Reduction	Addition of a reducing agent to lower the oxidation state of a substance to reduce toxicity/solubility. Mainly applicable to inorganic wastes, phenols, pesticides, and sulfur-containing compounds	Not applicable to the organic COCs. Inorganic compounds are not a primary treatment concern at this site.	Eliminated
		Chemical Oxidation	Addition of an oxidizing agent to raise the oxidation state of a substance. Applicable to organics and some metals, primarily iron and manganese.	Not applicable to the organic COCs. Inorganic compounds are not a primary treatment concern at this site.	Eliminated
		Electrochemical Iron Generation	Electrical currents are used to put ferrous and hydroxyl ions into solution for subsequent removal via precipitation. Applicable to metals removal.	Not applicable to the organic COCs. Inorganic compounds are not a primary treatment concern at this site.	Eliminated

TABLE 3-2 (Continued)

PRELIMINARY SCREENING OF GROUNDWATER TECHNOLOGIES AND PROCESS OPTIONS
OPERABLE UNIT NO. 10 (SITE 35)
INTERIM FEASIBILITY STUDY, CTO-0232
MCB CAMP LEJEUNE, NORTH CAROLINA

General Response Action	Remedial Action Technology	Process Option	Description	Site-Specific Applicability	Screening Results
Treatment Actions (Continued)	Physical/Chemical Treatment (Continued)	Neutralization	Addition of an acid or base to a waste in order to adjust its pH. Applicable to acidic or basic waste streams.	Not applicable because pH adjustment is not a concern at this site.	Eliminated
		Precipitation	Materials in solution are transferred into a solid phase for removal. Applicable to particulates and metals.	Not applicable to the organic COCs. Inorganic compounds are not a primary treatment concern at this site.	Eliminated
		Oil/Water Separation	Materials in solution are transferred into a separate phase for removal. Applicable to petroleum hydrocarbons.	Not applicable because no free phase product was detected at the site.	Eliminated
		Filtration	Removal of suspended solids from solution by forcing the liquid through a porous medium. Applicable to suspended solids.	Not applicable because the removal of suspended solids and inorganic compounds is not a primary treatment concern at this site.	Eliminated
		UV Oxidation	Ultraviolet (UV) radiation, ozone, and/or hydrogen peroxide are used to destroy organic contaminants as water flows into a treatment tank; an ozone destruction unit treats off-gases from the treatment tank.	Potentially applicable to the organic COCs.	Retained
		Flocculation	Small, unsettleable particles suspended in a liquid medium are made to agglomerate into larger particles by the addition of flocculating agents. Applicable to particulates and inorganics.	Not applicable to the organic COCs. Particulates and inorganic compounds are not anticipated to be a primary treatment concern at this site.	Eliminated
		Sedimentation	Removal of suspended solids in an aqueous waste stream via gravity separation.	Not applicable to the organic COCs. Particulates and inorganic compounds are not anticipated to be a primary treatment concern at this site.	Eliminated

TABLE 3-2 (Continued)

PRELIMINARY SCREENING OF GROUNDWATER TECHNOLOGIES AND PROCESS OPTIONS
OPERABLE UNIT NO. 10 (SITE 35)
INTERIM FEASIBILITY STUDY, CTO-0232
MCB CAMP LEJEUNE, NORTH CAROLINA

General Response Action	Remedial Action Technology	Process Option	Description	Site-Specific Applicability	Screening Results
Treatment Actions (Continued)	Physical/Chemical Treatment (Continued)	Chemical Dechlorination (KPEG)	Process which uses specially synthesized chemical reagents to destroy hazardous chlorinated molecules or to toxify them to form other less harmful compounds. Applicable to PCBs, chlorinated hydrocarbons and dioxins.	Not applicable to the organic COCs.	Eliminated
	Thermal Treatment	Incineration/ Thermal Desorption	Combustion of waste at high temperatures. Different incinerator types can be applicable to pumpable organic wastes, combustible liquids, soils, slurries, or sludges.	Not applicable to non-combustible liquids such as the groundwater.	Eliminated
	Engineered Wetland Treatment	Constructed Wetlands	An engineered complex of plants, substrates, water, and microbial populations. Contaminants are removed via plant uptake, biodegradation (organics only), precipitation, and sorption processes.	Not applicable to the halogenated organic COCs.	Eliminated
	Off-site Treatment	POTW	Extracted groundwater discharged to Jacksonville POTW for treatment.	Not implementable since this POTW will not accept contaminated groundwater.	Eliminated
		RCRA Facility	Extracted groundwater discharged to licensed RCRA facility for treatment and/or disposal.	Not implementable due to large volume of groundwater.	Eliminated
		Sewage Treatment Plant	Extracted groundwater discharged to Base STP for treatment.	Not implementable since Base STP cannot effectively treat highly concentrated VOCs.	Eliminated

TABLE 3-2 (Continued)

PRELIMINARY SCREENING OF GROUNDWATER TECHNOLOGIES AND PROCESS OPTIONS
OPERABLE UNIT NO. 10 (SITE 35)
INTERIM FEASIBILITY STUDY, CTO-0232
MCB CAMP LEJEUNE, NORTH CAROLINA

General Response Action	Remedial Action Technology	Process Option	Description	Site-Specific Applicability	Screening Results
Treatment Actions (Continued)	In Situ Treatment	Bioventing	System of introducing nutrients and oxygen to waste for the stimulation or augmentation of microbial activity to degrade contamination. Applicable to nonhalogenated organic compounds.	Potentially applicable to the nonhalogenated COCs.	Retained
		Air Sparging	The injection of air under pressure in groundwater to remove VOCs via volatilization. Air bubbles migrate into the vadose zone where they can be extracted or treated by other methods. Introduction of air also may promote degradation of contaminants through biological transformation.	Potentially applicable using horizontal or angled drilling techniques.	Retained
		Dual-Phase Vacuum Extraction	Extraction of a two-phase air-water stream under high vacuum using wells screened above and below the water table.	Not applicable because the proposed highway serves as obstruction to the vertical wells required for the implementation of this type of system.	Eliminated
		In-Well Aeration (a.k.a. UVB, vacuum vaporizer well, in-situ air stripping)	Process of inducing air into a well by applying a vacuum. Results in an in-well airlift pump effect that serves to strip volatiles from groundwater inside the well.	Similar to air sparging. Potentially applicable.	Retained
		Passive Treatment Wall	A permeable reaction wall is installed across the flow path of a contaminant plume, allowing the plume to passively more through the wall.	Potentially applicable to the halogenated organic COCs.	Retained

TABLE 3-2 (Continued)

PRELIMINARY SCREENING OF GROUNDWATER TECHNOLOGIES AND PROCESS OPTIONS
OPERABLE UNIT NO. 10 (SITE 35)
INTERIM FEASIBILITY STUDY, CTO-0232
MCB CAMP LEJEUNE, NORTH CAROLINA

General Response Action	Remedial Action Technology	Process Option	Description	Site-Specific Applicability	Screening Results
Discharge Actions	On-Site Discharge	Reinjection • Injection Wells • InfiltrationGalleries	Treated water reinjection into the site aquifer via use of shallow infiltration galleries (trenches) or injection wells.	Not applicable. Could induce intolerable ground settlement above the highway from fluctuations in the groundwater table.	Eliminated
		Surface Water	Treated water discharged to Brinson Creek.	Potentially applicable.	Retained
	Off-Site Discharge	POTW	Treated water discharged to Jacksonville POTW.	Not implementable due to distance.	Eliminated
		Surface Water	Treated water discharged to New River.	Potentially applicable.	Retained
		Base STP	Treated water discharged to closest Base STP.	Not implementable due to distance.	Eliminated

TABLE 3-3

SUMMARY OF GROUNDWATER PROCESS OPTION EVALUATION
OPERABLE UNIT NO. 10 (SITE 35)
INTERIM FEASIBILITY STUDY, CTO-0232
MCB CAMP LEJEUNE, NORTH CAROLINA

General Response Action	Remedial Action Technology	Process Option	Evaluation			Evaluation Results
			Effectiveness	Implementability	Cost	
No Action	No Action	Natural Attenuation	• Evaluation not necessary since it is the only option under this general response action category.	• Evaluation not necessary since it is the only option under this general response action category.	• Evaluation not necessary since it is the only option under this general response action category.	Retained
Institutional Controls	Monitoring	Groundwater Monitoring	• Provides a means for evaluating impact of natural attenuation processes and monitoring contaminant migration.	• Readily implementable, but, will likely require additional monitoring well installation to replace those wells abandoned due to the highway.	• Low capital. • Low to moderate O&M.	Retained
	Aquifer-Use Restrictions	Restrictions in Base Master Plan	• Reduces future direct exposure to contaminated groundwater.	• Readily implementable by Camp Lejeune staff.	• Low capital. • No O&M.	Retained
Collection Actions	Subsurface Drains	Interceptor Trenches	• Commercial track record for collecting and containing a contaminated groundwater plume. • Applicable only for shallow groundwater plumes • Area of influence is limited	• Requires an experienced specialty contractor • May require handling and disposal of a substantial volume if contaminated soil is encountered during excavation • Potential exposures during installation • May require a special permit to install in a wetlands	• Low to moderate to high capital. • Low to moderate O&M	Retained

TABLE 3-3 (Continued)

SUMMARY OF GROUNDWATER PROCESS OPTION EVALUATION
OPERABLE UNIT NO. 10 (SITE 35)
INTERIM FEASIBILITY STUDY, CTO-0232
MCB CAMP LEJEUNE, NORTH CAROLINA

General Response Action	Remedial Action Technology	Process Option	Evaluation			Evaluation Results
			Effectiveness	Implementability	Cost	
Treatment Actions	Biological Treatment	Aerobic	• Not effective treatment for halogenated organics • High levels of halogenated organics may adversely impact treatment of nonhalogenated organics • Contaminants are converted to carbon dioxide and water	• Commercially available technology • Will require bench-scale testing	• Moderate capital. • Moderate O&M.	Eliminated
	Physical/ Chemical Treatment	Volatilization (Air/System Stripping)	• Can potentially remove all organic contaminants • Commercially proven and widely used technology • Contaminant transfer rather than destruction technology	• Commercially available technology • Secondary treatment of off gas may be required • May require air emissions treatment	• Low to moderate capital. • Low to moderate O&M.	Retained
		Carbon Adsorption	• Can potentially remove all organic contaminants • Commercially proven and widely used technology • Contaminant transfer rather than destruction technology	• Commercially available technology • Spent carbon must be properly regenerated or disposed • May require bench-scale testing	• Low to moderate capital. • Low to high O&M (dependent on loading rates and carbon life).	Eliminated
		UV Oxidation	• Can potentially remove all organic contaminants • Commercially proven technology • Contaminant destruction rather than transfer technology • Effectiveness is reduced by high iron and other organic levels in groundwater	• Commercially available technology • Secondary treatment of off gas may be required • May require bench-scale testing	• Moderate to high capital. • Moderate to high O&M.	Eliminated
	In Situ Treatment	Air Sparging	• Can potentially remove all organic contaminants • Commercially proven technology • Contaminant transfer rather than destruction technology	• Commercially available technology • Secondary treatment of off gas may be required • May require air emissions permit	• Moderate to high capital. • Low to moderate O&M.	Retained

TABLE 3-3 (Continued)

SUMMARY OF GROUNDWATER PROCESS OPTION EVALUATION
OPERABLE UNIT NO. 10 (SITE 35)
INTERIM FEASIBILITY STUDY, CTO-0232
MCB CAMP LEJEUNE, NORTH CAROLINA

General Response Action	Remedial Action Technology	Process Option	Evaluation			Evaluation Results
			Effectiveness	Implementability	Cost	
Treatment Actions (cont'd)	In Situ Treatment (cont'd)	In-Well Aeration	● Can potentially remove all organic contaminants. ● Limited commercial track record. ● Contaminant transfer rather than destruction technology.	● Patented technology licensed by a single vendor. ● Secondary treatment of off gas may be required. ● May require air emissions permit.	● Moderate to high capital. ● Low to moderate O&M.	Retained
		Passive Treatment Wall	● Not effective treatment for BTEX contaminants. ● Innovative technology with minimal long-term applications. ● Contaminant destruction technology.	● Technology currently provided by a single vendor. ● May require retrofit after prolonged remediation.	● Moderate to high capital. ● Low O&M.	Eliminated

5.0 DETAILED ANALYSIS OF ALTERNATIVES

This section of the FS contains the detailed analysis of the set of RAAs developed in Section 4.0. This analysis has been conducted to provide sufficient information to adequately compare the alternatives, select an appropriate remedy for the site, and demonstrate satisfaction of the CERCLA remedy selection requirements in the ROD (USEPA, 1988a).

The extent to which alternatives are assessed during this detailed analysis is influenced by the available data, the number and types of alternatives being analyzed, and the degree to which alternatives were previously analyzed during their development and screening (USEPA, 1988a).

The following nine evaluation criteria serve as the basis for conducting the detailed analysis:

1. Overall protection of human health and the environment
2. Compliance with ARARs
3. Long-term effectiveness and permanence
4. Reduction of toxicity, mobility, or volume
5. Short-term effectiveness
6. Implementability
7. Cost
8. USEPA/State acceptance
9. Community acceptance

The first two criteria (referred to as the Threshold Criteria) relate directly to statutory findings; the next five criteria (referred to as the Primary Balancing Criteria) are the primary criteria upon which the analysis is based; and the final two criteria (referred to as the Modifying Criteria) are typically evaluated following comment on the RI/FS report and the proposed plan.

5.1 Individual Analysis of Alternatives

The individual analysis of the RAAs is presented in the following subsections. This analysis includes an assessment and a summary profile of each of the RAAs against the evaluation criteria, and a comparative analysis among the alternatives to assess the relative performance of each with respect to each of the evaluation criterion.

The cost estimates that have been developed for each of the alternatives include both capital and operational expenditures. The cost evaluation presents the net present worth (NPW) values for each of the alternatives such that the options can be easily compared. The accuracy of each cost estimate depends upon the assumptions made and the availability of costing information. The present worth costs were calculated assuming a 30-year operational period (based on USEPA guidance) for all of the alternatives, a five percent discount factor, and a zero percent inflation rate. All costs presented in the following sections have been updated to 1995 dollar values.

For this FS, it has been assumed that groundwater monitoring will be conducted semiannually for 30 years. This assumption has been made for costing purposes only.

5.1.1 RAA 1: No Action

5.1.1.1 Description

Under the No action RAA, no remedial actions will be performed to reduce the toxicity, mobility, or volume of the contaminated surficial groundwater at Site 35. This method assumes that passive remediation will occur via natural attenuation processes and that the contaminant levels will be reduced over an indefinite period of time. However, the achievable reductions versus time are difficult, if not impossible to predict.

The No Action RAA is required by the NCP to provide a baseline for comparison with other alternatives. Since contaminants will remain at the site under this alternative, USEPA is required by the NCP [40 CFR 300.515(e) (ii)] to review the effects of this alternative no less often than every five years.

5.1.1.2 Assessment

Overall Protection of Human Health and the Environment

The No Action RAA does not provide for any protection to human health or to the environment with respect to exposure to contaminated surficial groundwater in the vicinity of the Fuel Farm at Site 35. Contaminants in the surficial groundwater will continue to be the source of future contamination via direct discharge to Brinson Creek. Reductions in contaminant levels may occur over time as a result of natural attenuation processes; however, the extent of the attenuation and time required to achieve any reductions is impossible to predict.

Compliance with ARARs

Under the No Action RAA, no active effort will be made to reduce the levels of various organic contaminants in the surficial groundwater to achieve the remediation goals. Therefore, this alternative will not achieve the remediation levels for the COCs identified in Section 2.7.

Long-Term Effectiveness and Permanence

Under the No Action RAA, any long-term or permanent effect on contamination in the surficial aquifer in the vicinity of the Fuel Farm is dependent on reductions achieved via natural attenuation processes. The extent and degree of natural attenuation and time required to achieve it is impossible to predict. Since contaminants will remain at the site under this alternative, USEPA is required by the NCP [40 CFR 300.515(e) (ii)] to review the effects of this alternative no less often than every five years.

Reduction of Toxicity, Mobility, or Volume

The No Action RAA does not provide for any form of active treatment with the exception of natural attenuation processes. Natural attenuation may reduce the toxicity, mobility, or volume of organic contaminants in the surficial groundwater at Site 35; however, the extent and degree of the natural attenuation and time required to achieve it is impossible to predict.

Short-Term Effectiveness

Under the No Action RAA, no construction or treatment activities will be implemented and, consequently, there will be no workers placed at risk to exposure to toxic chemicals. The risks to the public health and the environment will remain unchanged unless natural attenuation processes result in a substantial reduction in contaminant levels.

Implementability

The No Action RAA is easily implementable since no remediation or monitoring activities are required. In terms of administrative feasibility, this RAA should not require coordination with other agencies. The availability of services and materials is not applicable to this alternative.

Cost

There are no capital or operation and maintenance (O&M) costs associated with the No Action RAA.

USEPA/State Acceptance

The No Action RAA is a required component of an FS. It has historically not been deemed acceptable by the USEPA or NC DEHNR at contaminated sites with nearby receptors such as Brinson Creek.

Community Acceptance

There seems to be little public interest in this decision process. Although it can be assumed that the distinct odor which is occasionally prevalent around Brinson Creek due to contaminants would not be desirable to the local community. Under the No Action RAA this odor would persist and likely render this alternative unacceptable to the community.

5.1.2 RAA 2: No Action With Institutional Controls

5.1.2.1 Description

Under RAA No. 2, no remedial actions will be performed to reduce the toxicity, mobility, or volume of the contaminated surficial groundwater at Site 35. This RAA provides for the revision of the Base Master Plan to include restrictions on the use of the surficial aquifer in the vicinity of the Fuel Farm. This will reduce the risk to human health and the environment posed by this media by eliminating one exposure pathway; however, the impacted surficial groundwater will remain a potential source of contamination to Brinson Creek.

In addition to the aquifer-use restrictions, long-term groundwater monitoring is to be included under this RAA to provide data regarding the impact of natural attenuation and the progress of contaminant migration. Long-term groundwater monitoring includes the semi-annual collection and analysis (TCL VOCs) of groundwater samples from 11 monitoring wells, the development of a semi-annual monitoring report, and the replacement of one monitoring well every five years.

Since contaminants will remain at the site under this alternative, the USEPA is required by the NCP [40 CFR 300.515(e) (iii)] to review the effects of this alternative no less often than every five years.

5.1.2.2 Assessment

Overall Protection of Human Health and the Environment

The incorporation of aquifer-use restrictions into the Base Master Plan will provide for protection of human health and the environment to direct exposure to the contaminated surficial groundwater at Site 35. Since no active means of treatment or contaminant reduction is provided for under this RAA, contaminated surficial groundwater discharge to Brinson Creek can be expected to continue. Reductions in contaminant levels may occur over time as a result of natural attenuation processes; however, the extent and degree of the attenuation and time required to achieve it is impossible to predict.

RAA 2 includes long-term groundwater monitoring to provide data regarding the impact of natural attenuation and the progress of contaminant migration.

Compliance With ARARs

Under RAA 2 no effort will be made to reduce the levels of various organic contaminants in the surficial groundwater to achieve the remediation goals. Therefore, this alternative will not achieve the remediation levels for COCs identified in Section 2.7.

Long-Term Effectiveness and Permanence

Upon the implementation of aquifer-use restrictions, RAA 2 provides a permanent means for protecting human health from direct exposure to contaminants within the surficial aquifer at Site 35. However, the impacted surficial aquifer will remain a potential source of contaminant discharge to Brinson Creek. Reductions in contaminant levels may occur over time as a result of natural attenuation processes; however, the extent and degree of the attenuation and time required to achieve it is impossible to predict. Since contaminants will remain at the site under this alternative, USEPA is required by the NCP [40 CFR 300.515(e) (ii)] to review the effects of this alternative no less often than every five years.

Reduction of Toxicity, Mobility, or Volume

RAA 2 does not provide for any form of active treatment of the surficial groundwater at Site 35. Natural attenuation may reduce the toxicity, mobility, or volume of organic contaminants in the surficial groundwater at Site 35; however, the extent and degree of the attenuation and time required to achieve it is impossible to predict.

Short-Term Effectiveness

Under RAA 2, on-site activities will include the installation of four new groundwater monitoring wells and the semi-annual sampling of 11 wells. The potential for worker exposure is limited as these activities will be carried out by trained environmental professionals.

Upon implementation aquifer-use restrictions will reduce the risk of direct exposure to groundwater contamination by civilian and military personnel. However, the surficial aquifer will remain a potential future source contamination via direct discharge to Brinson Creek.

Implementability

RAA 2 will be relatively easy to implement since no remediation activities are involved. Some effort will be required to modify the Base Master Plan and prepare a long-term groundwater monitoring plan. The latter document will be subject to review and some agency interaction can be expected. It is anticipated that four new groundwater monitoring wells will need to be installed primarily as replacements for those wells abandoned when the proposed highway is constructed in 1955. In addition to these four new wells, seven existing wells will be sampled on a semi-annual basis. The results of sample analyses from these 11 wells will be presented in a report prepared semi-annually for agency review. This data will be used to monitor the effects of natural attenuation and the progress of contaminant migration.

Cost

The projected cost of RAA 2 is presented in Table 5-1.

USEPA/State Acceptance

This RAA, No Action with Institutional Controls, is a required component of an FS. It has historically not been deemed acceptable by the USEPA and NC DEHNR at contaminated sites with nearby receptors such as Brinson Creek.

Community Acceptance

There seems to be little public interest in this decision process. Although it can be assumed that the distinct odor which is occasionally prevalent around Brinson Creek due to contaminants would not be desirable to the local community. Under RAA 2 this odor would persist and likely render this alternative unacceptable to the community.

5.1.3 RAA 3: Groundwater Collection and On-Site Treatment

5.1.3.1 Description

RAA 3 is a source collection and treatment alternative, the source being the contaminated surficial groundwater in the vicinity of the Fuel Farm at Site 35. Under this alternative a vertical interceptor trench, approximately two-feet wide, by 30-feet deep, by 1,080 feet long, will be installed at the downgradient edge of the contaminated plume in the area between the proposed highway and Brinson Creek. The interceptor trench will be constructed from the ground surface to the semi-confining layer at the base of the surficial aquifer. The purpose of the interceptor trench is to collect contaminated surficial groundwater for transfer to an on-site treatment facility prior to it being discharged to Brinson Creek.

The type of interceptor trench proposed under RAA 3 is termed a "biopolymer slurry drainage trench." This type of trench can be installed without dewatering or structural bracing. Through the use of a natural, biodegradable slurry, the walls of a trench excavation can be supported and the trench can be installed without personnel entering an excavation. compared to other trenching methods, this technique is safer and cost-effective in areas with a high groundwater and unstable soil because there are not costs of dewatering and water disposal or shoring.

A biopolymer slurry drainage trench is constructed in much the same manner as a typical slurry cut-off wall. However, unlike a bentonite-clay slurry, a biodegradable biopolymer slurry supports the walls of the trench while excavated materials are removed and drainage structures are installed. The biopolymer slurry then naturally biodegrades after the trench is backfilled. In the end, a permeable wall is left intact. In this case an impermeable geotextile will be installed along the downgradient side of the trench so that groundwater will enter the trench from only the upgradient direction.

The interceptor trench will be designed to collect groundwater at a rate roughly equal to the groundwater flow (i.e., roughly 5 to 10 gpm. See calculations contained in Appendix C) across the upgradient face of the trench (31,900 square feet). Flow across the downgradient face of the trench will be restricted by an impermeable geomembrane barrier. Drawdown of the groundwater surface will be minimized so as to mitigate the potential of excessive ground settlement beneath the highway. The collected groundwater will be conveyed to an on-site treatment plant located just east of the proposed highway right-of-way, creek-side, where it appears that adequate space and firm foundation material is available.

Baker, LANTDIV, and MCB, Camp Lejeune will negotiate with NC DOT regarding the specifics for site access to the creek-side of the new highway. The EPA and NC DEHNR will be kept abreast of developments on this subject. In this FS, Baker proposes an access road running along the east side of the highway from the south.

The collected groundwater will be treated sufficiently to allow for its discharge to Brinson Creek at a point downstream of Site 35. It is anticipated that the groundwater treatment system will include filtration for the removal of suspended solids, a settling tank for the removal of metals, sludge collection and disposal, volatilization (air stripping) for the removal of VOCs, and secondary treatment of VOC emissions from the air stripper and of the treated groundwater (i.e., via carbon adsorption). The treatment plant effluent will be sampled once a month to insure that water discharged to Brinson Creek meets all applicable water quality standards.

RAA 3 assumes that the Base Master Plan will be modified to include restrictions on the use of the surficial aquifer in the vicinity of the Fuel Farm. This will reduce the risk to human health and the environment posed by this media by eliminating one exposure pathway.

In addition to aquifer-use restrictions, long-term groundwater monitoring is to be included under this RAA to provide date regarding the impact of natural attenuation and the progress of contaminant migration. Long-term groundwater monitoring includes the semi-annual collection and analysis (TCL VOCs) of groundwater samples from 11 monitoring wells, the development of a semi-annual monitoring report, and the replacement of one monitoring well every five years.

Since contaminants will remain at the site under this alternative, the USEPA is required by the NCP {40 CFR 300.515(e) (iii)] to review the effects of this alternative no less often than every five years.

5.1.3.2 Assessment

Overall Protection of Human Health and the Environment

RAA 3 provides for the overall protection of human health and the environment by intercepting contaminated surficial groundwater prior to its discharge to Brinson Creek and by restricting future use of the surficial aquifer. A reduction of contaminants in the surficial aquifer will result from the collection of groundwater via the interceptor trench and subsequent treatment. Contaminant reduction due to this system will be limited primarily to the zone of capture of the interceptor trench which, based on Baker's experience, will extend 100 feet or less upgradient of the trench.

Aquifer-use restrictions will serve to provide additional protection against direct exposure to contaminated surficial groundwater at the site.

Compliance With ARARs

Under RAA 3 substantial reductions of the levels of organic contaminants in the surficial groundwater can be expected within the capture zone of the interceptor trench. Upgradient of the capture zone some additional reductions can be expected from natural attenuation processes and because contaminants can be expected to continue to flow downgradient toward the interceptor trench. However, no direct means of treatment will be applied in this upgradient area under RAA 3 and it is unlikely that the remediation levels will be achieved upgradient of the capture zone of the interceptor trench.

This RAA proposes that the interceptor trench be installed in the wetlands area between the highway and Brinson Creek. Wetlands are specifically protected by ARARs as is the endangered alligator, one of which has been reported in this area. It is assumed that the intent of federal and state wetlands regulations will be met while conducting RAA 3 activities.

RAA 3 provides for treated groundwater discharge to Brinson Creek and for treated air discharge to the atmosphere. It is assumed that the intent of air and water discharge regulation will be met.

Long-Term Effectiveness and Permanence

RAA 3 will provide an effective and permanent means of intercepting and treating contaminated surficial groundwater and mitigating the risk of future discharges of contaminants to Brinson Creek for as long as the system operates. Additional reductions in contaminant levels may occur over time as a result of natural attenuation processes; however, the extent and degree of the attenuation and time required to achieve any reductions is impossible to predict. Aquifer-use restrictions will provide a permanent means of protection against direct exposure to the surficial aquifer.

The interceptor trench represents technology that requires special skills and experience to install and, consequently, is offered by a limited number of vendors. Once installed, the trench requires standard proven and reliable technology to operate and maintain. Routine maintenance and equipment replacement will be required, but, should be able to be completed without compromising the environmental protection component of the system.

Since contaminants will remain at the site under this alternative, USEPA is required by the NCP [40 CFR 300.515(e) (ii)] to review the effects of this alternative no less often than every five years.

Reduction of Toxicity, Mobility, or Volume

RAA 3 utilizes groundwater collection and on-site, aboveground treatment as the means for reducing contaminant levels in the surficial aquifer at Site 35. Within the capture zone of the interceptor trench a reduction of toxicity, mobility, and volume of organic contaminants in the surficial aquifer can be expected. Upgradient of this capture zone RAA 3 does not provide for any form of active treatment other than natural attenuation processes. Natural attenuation may reduce the toxicity, mobility, or volume of organic contaminants in the surficial groundwater at Site 35; however, the extent and degree of the attenuation and time required to achieve it is impossible to predict.

The on-site treatment process under RAA 3 will produce residual wastes that will require proper handling and disposal. These wastes include solids and metals sludge, and spent activated carbon. Excavated soil will be a residual waste of the trench installation process that will need proper disposal.

RAA 3 satisfies the statutory preference for treatment alternatives.

Short-Term Effectiveness

The installation procedure for the interceptor trench is designed to minimize worker exposure to contaminated groundwater and toxic vapors. During operation the collection and treatment of contaminated surficial groundwater is conducted essentially within a closed loop. The system allows minimal potential for community exposure to contaminants provided air emissions and treated groundwater ARARs are adhered to.

The installation of the trench will result in some disturbance of the wetlands area within which it is proposed to be placed. It has been reported that an alligator, identified as an endangered species, inhabits Brinson Creek. It is assumed that the Contractor will be able to satisfy the intentions of all regulations regarding protection of the wetlands and any endangered species.

RAA 3 will provide short-term protection against the discharge of groundwater contaminants to Brinson Creek. Aquifer-use restrictions will be in effect within a relatively short period; however, no short-term effect will be apparent because the surficial aquifer is not presently utilized at the Activity.

Implementability

RAA 3 will present technical and perhaps regulatory challenges to its implementation. These challenges will stem from the proposed location of the interceptor trench within a wetlands area situated between Brinson Creek and the proposed highway. In addition, biopolymer slurry trench installation is not widely performed and the number of contractors experienced with this method is limited.

Access to the area between the highway and Brinson Creek for construction equipment is limited and will possibly require the cooperation of NCDOT to incorporate access features into the proposed highway design. The proposed trench will be located in a soft soil area which may be difficult for heavy construction equipment to maneuver on. The construction of the trench will temporarily disturb the wetlands area although if proper steps are taken during installation, extraordinary restoration efforts may be avoided. It is assumed that the intent of wetlands regulations and all applicable air and water discharge regulations will be met.

The proposed groundwater monitoring program coupled with regular system operation and maintenance checks should be sufficient to provide notice of a system failure so that adjustments can be made before a significant contaminant release would occur.

Cost

The project cost of RAA 3 is presented in Table 5-2.

USEPA /State Acceptance

The USEPA and NC DEHNR have expressed their concurrence with the inclusion of this RAA. RAA 3 is a treatment technology and therefore acceptable to these agencies. Because RAA 3 is an above-ground technology, it is not as preferable as in situ alternatives, therefore, RAA 3 has been identified as the proposed alternative should RAA 5 be determined to be technically infeasible based on the results of a field test.

Community Acceptance

Based on the lack of community participation at a public meeting held on May 10, 1995, no adverse community reaction to the proposed remedial action is anticipated.

5.1.4 RAA 4: In Situ Air Sparging and Off-Gas Carbon Adsorption

5.1.4.1 Description

In situ air sparging (IAS) is a technique in which air is injected into water saturated zones for the purpose of removing organic contaminants primarily via volatilization and secondarily via aerobic biodegradation. IAS systems introduce contaminant-free air into an impacted aquifer near the base of the zone of contamination, forcing contaminants to transfer from the groundwater into sparged air bubbles. The air bubbles are then transported into soil pore spaces in the unsaturated zone where they are typically collected via soil vapor extraction (SVE) and conveyed to an on-site, off-gas treatment system.

An IAS system typically is comprised of the following components: 1) air injection wells; 2) an air compressor; 3) air extraction wells; 4) a vacuum pump; 5) associated piping and valving for air conveyance; and 6) an off-gas treatment system (e.g., activated carbon, combustion, or oxidation). Under RAA 4 a line of air sparging wells will be installed between the proposed highway and Brinson Creek in order to treat and contain the contaminated plume near its downgradient extreme. Based on empirical data from similar sites, the radius of influence of an air sparging well range from five to almost 200 feet, but is typically on the order of 25 feet (EPA, 1992). For the purpose of the FS, Baker estimates that 43 sparging wells, 30 feet deep, and 43 SVE wells, 4 feet deep, would be required. The proposed off-gas treatment system (activated carbon) will be located just east of the proposed highway where it appears that there is adequate space and firm foundation material available. The air emissions from the off-gas treatment system will be sampled monthly to insure that all applicable air emissions standards are being met.

Air sparging systems are most effective in sandy soils, but, can be adversely impacted by high levels of inorganic compounds in the groundwater which oxidized and precipitate when contacted by the sparged air. These organics can form a heavy scale on well screens and clog the well space of the sand pack surrounding the well screen resulting in a reduction in permeability. A field pilot test is recommended to determine the loss of efficiency over time as a result of inorganics precipitation and oxidation, the radius of influence of the wells under various heads of injection air pressure, and the rate of off-gas organic contaminant removal via carbon adsorption and carbon breakthrough.

Baker, LANTDIV, and MCB, Camp Lejeune will negotiate with NC DOT regarding the specifics for site access to the creek side of the new highway. The EPA and NC DEHNR will be kept abreast of developments on this subject. In this FS, Baker proposes an access road running along the east side of the highway from the south.

RAA 4 assumes that the Base Master Plan will be modified to include restrictions on the use of the surficial aquifer in the vicinity of the Fuel Farm. This will reduce the risk to human health and the environment posed by this media by eliminating one exposure pathway.

In addition to aquifer-use restrictions, long-term groundwater monitoring is to be included under this RAA to provide data regarding the impact of natural attenuation and the progress of contaminant migration. Long-term groundwater monitoring includes the semi-annual collection and analysis (TCL VOCs) of groundwater samples from 11 monitoring wells, the development of a semi-annual monitoring report, and the replacement of one monitoring well every five years.

Since contaminants will remain at the site under this alternative, the USEPA is required by the NCP [40 CFR 300.515 (e) (iii)] to review the effects of this alternative no less often than every five years.

5.1.4.2 Assessment

Overall Protection of Human Health and the Environment

This RAA will provide for the overall protect of human health and the environment by the application of in situ treatment technology to reduce the level of organic contaminants in the surficial aquifer and to provide, in essence, a barrier to minimize the potential for the discharge of organic contaminated groundwater to Brinson Creek. Contaminant reduction due to this system will be limited primarily to the radius of influence of the air sparging wells (estimated at approximately 25 feet).

Aquifer-use restrictions will serve to provide additional protection against direct exposure to contaminated surficial groundwater at the site.

Compliance With ARARs

Under RAA 4 substantial reductions of the levels of organic contaminants in the surficial groundwater can be expected within the radius of influence of the IAS system. Further upgradient some additional reductions can be expected from natural attenuation processes and because contaminants can be expected to continue to flow downgradient toward the air sparging wells.

However, no direct means of treatment will be applied in this upgradient area under RAA 4 and it is unlikely that the remediation levels will be achieved upgradient of the radius of influence of the IAS system.

This RAA proposes that the air sparging wells and much of the associated piping and appurtenances will be installed in the wetlands area between the highway and Brinson Creek. Wetlands are specifically protected by ARARs as is the endangered alligator, one of which has been reported in this area. It is assumed that the intent of federal and state wetlands regulation will be met while conducting RAA 4 activities.

It is also assumed that the intent of air emissions regulations be met during the implementation and operation of RAA 4.

Long-Term Effectiveness and Permanence

This RAA involves in situ treatment technology designed to permanently remove organic contaminants from the surficial aquifer. As an interim action, however, it will be confined to a limited area in the vicinity of the Fuel Farm at Site 35. Based on data obtained under the RI, contaminated surficial groundwater located upgradient of the proposed in situ air sparging system will continue to be a source of contamination to Brinson Creek, however, the organic contaminants should be effectively cut off from discharging to this surface water body by the IAS system.

Air sparging has a significant track record of commercial use and should be able to be controlled adequately and reliably for an indefinite period. High dissolved metals could be precipitated out of solution by the system and cause clogging. This would force frequent maintenance and equipment replacement.

Since contaminants will remain at the site under this alternative USEPA is required by the NCP [40 CFR 300.515 (e) (ii)] to review the effects of this alternative no less often than every five years.

Reduction of Toxicity, Mobility, or Volume

This RAA involves the application of in-situ air sparging technology which, by design, is intended to reduce the volume of volatile organic contaminants in the surficial aquifer where applied by a combination of volatilization and biodegradation. The technology, in essence, works like an in-situ air stripper by injecting air below the groundwater table and, in turn extracting air, presumably laden with volatile organics, from the vadose zone. The contaminants are collected and, in this case, transferred to activated carbon for ultimate disposal. Reductions of contaminants will be limited primarily to the zone defined by the radius of influence of the air sparging wells. Natural attenuation may reduce contaminant levels further over time.

System installation will result in drill cuttings (soil) for which proper disposal will be required. The on-site air treatment will produce residual wastes including spent activated carbon, and a small volume of contaminated water (i.e., condensed vapor collected in a knock-out tank).

RAA 4 satisfies the statutory preference for treatment alternatives.

Short-Term Effectiveness

The primary activity in constructing an IAS system is installing the air injection/extraction wells. This involves standard environmental drilling techniques which, when executed by experienced professionals, should involve minimal risk of exposure to workers. The potential exists for the release of toxic vapors to the atmosphere if the vapor extraction portion of the IAS system is not as efficient as the air sparging portion. This concern increases when IAS systems are installed in areas where the groundwater surface is within a few feet of the ground surface as is the case at Site 35. The release of toxic vapors to the atmosphere during operation of the IAS system could increase the risk of exposure to the surrounding community.

Relative to environmental impacts, the installation of the IAS system should result in minimal disturbance to the wetlands. Furthermore, the line of air sparging wells should serve as a barrier to organic contaminated groundwater discharge to Brinson Creek.

Implementability

IAS technology is widely used and commercially available. Nevertheless, a field pilot-scale study would be appropriate to ensure its effectiveness at Site 35 and to determine critical design parameters. In any in situ system where oxygen is injected, a concern is the effect on the system operation of metals precipitation and oxidation. At high enough levels the metals can clog the well screens, prompting frequent maintenance or even well replacement.

The implementation of this technology will require the installation of multiple air sparging wells in the area between the highway and Brinson Creek. Access to this area for construction equipment is limited and will require the cooperation of NCDOT to incorporate special access features into the proposed highway design.

The construction activities in the wetlands area may result in some disturbance and require restoration efforts. Meeting the intent of air emissions regulations will be necessary.

The proposed groundwater monitoring program coupled with regular system operation and maintenance checks including ambient air monitoring should be sufficient to provide notice of a system failure so that adjustments can be made before a significant contaminant release would occur.

Cost

The project cost of RAA 4 is presented in Table 5-3.

USEPA/State Acceptance

Based on comments received to date, USEPA and NC DEHNR appear to concur that RAA 4, In Situ Air Sparging and Off-Gas Carbon Adsorption, will present unacceptable risks due to uncontrolled vapor emissions. This in situ treatment technology is therefore not preferred.

Community Acceptance

There seems to be little public interest in this decision process. Although it can be assumed that the distinct odor which is occasionally prevalent around Brinson Creek due to contaminants would not be desirable to the local community. Under RAA 4 this odor may even be exaggerated and therefore likely render this alternative unacceptable to the community.

5.1.5 RAA 5: In Well Aeration and Off-Gas Carbon Adsorption

5.1.5.1 Description

In well aeration is a new technology that utilizes circulating air flow within a groundwater well that, in effect, turns the well into an air stripper. In well aeration differs from air sparging in that volatilization occurs outside the well via air sparging and within the well via in well aeration. Similar to air sparging, this technique removes organic contaminants from groundwater primarily via volatilization and secondarily via aerobic biodegradation. Under RAA 5 a line of in well aeration wells will be installed between the proposed highway and Brinson Creek in order to treat the contaminated plume near its downgradient extreme. The radius of influence, or capture zone, of an in well aeration well is reportedly much greater than that of a typical air sparging well system. Using modeling equations and graphical solutions, the developers of this technology have calculated a radius of influence of over 100 feet at Site 35.

For the purpose of the FS, Baker estimates that six in well aeration wells would be required to create a containment/remediation line spanning approximately 1,000 feet with wells spaced 180 feet apart. Volatilized organics collected by this technology, unlike air sparging, will be treated at each in well aeration well by independent carbon adsorption systems which will rest on skids adjacent to the wells. The air emissions from the off-gas treatment system will be sampled monthly to insure that all applicable air emissions standards are being met. Each well and aboveground off-gas treatment system will be housed in a small prefabricated building.

In well aeration systems, like IAS systems, are most effective in sandy soils, but, can be adversely impacted by high levels of inorganic compounds in the groundwater which oxidize and precipitate when contacted by air. These inorganics can form a heavy scale on well screens and clog the well space of the sand pack surrounding the well screen resulting in a reduction in permeability. A field pilot test is recommended to determine the loss of efficiency over time as a result of inorganics precipitation and oxidation, the radius of influence of the wells under various heads of injection air pressure, and the rate of off-gas organic contaminant removal via carbon adsorption and carbon breakthrough.

Baker, LANTDIV, and MCB, Camp Lejeune will negotiate with NC DOT regarding the specifics for site access to the creek side of the new highway. The EPA and NC DEHNR will be kept abreast of developments on this subject. In this FS, Baker proposes an access road running along the east side of the highway from the south.

RAA 5 assumes that the Base Master Plan will be modified to include restrictions on the use of the surficial aquifer in the vicinity of the Fuel Farm. This will reduce the risk to human health and the environment posed by this media by eliminating one exposure pathway.

In addition to aquifer-use restrictions, long-term groundwater monitoring is to be included under this RAA to provide data regarding the impact of natural attenuation and the progress of contaminant migration. Long-term groundwater monitoring includes the semi-annual collection and analysis (TCL VOCs) of groundwater samples from 11 monitoring wells, the development of a semi-annual monitoring report, and the replacement of one monitoring well every five years.

Since contaminants will remain at the site under this alternative, the USEPA is required by the NCP [40 CFR 300.515 (e) (iii)] to review the effects of this alternative no less often than every five years.

5.1.5.2 Assessment

Overall Protection of Human Health and the Environment

This RAA will provide for the overall protection of human health and the environment by the application of in situ treatment technology to reduce the level of organic contaminants in the surficial aquifer and to provide, in essence, a barrier to minimize the potential for the discharge of organic contaminated groundwater to Brinson Creek. Contaminant reduction due to this system will be limited primarily to the radius of influence of the in well aeration wells (estimated at slightly greater than 100 feet).

Aquifer-use restrictions will serve to provide additional protection against direct exposure to contaminated surficial groundwater at the site.

Compliance With ARARs

Under RAA 5 substantial reductions to the levels of organic contaminants in the surficial groundwater can be expected within the radius of influence of the in well aeration system. Further upgradient some additional reductions can be expected from natural attenuation processes and because contaminants can be expected to continue to flow downgradient toward the in well aeration system. However, no direct means of treatment will be applied in this upgradient area under RAA 5 and it is unlikely that the remediation levels will be achieved upgradient of the radius of influence of the in well aeration system.

This RAA proposes that the in well aeration wells and much of the associated piping and appurtenances will be installed in the wetlands area between the highway and Brinson Creek. Wetlands are specifically protected by ARARs as is the endangered alligator, one of which has been reported in this area. It is assumed that the intent of federal and state wetlands regulations will be met while conducting RAA 5 activities.

It is also assumed that the intent of all air emissions regulation be met during the implementation and operation of RAA 5.

Long-Term Effectiveness and Permanence

This RAA involves in situ treatment technology designed to permanently remove organic contaminants from the surficial aquifer. As an interim action, however, it will be confined to a limited area in the vicinity of the Fuel Farm at Site 35. Based on data obtained under the RI, contaminated surficial groundwater located upgradient of the proposed in well aeration system will continue to be a source of contamination to Brinson Creek, however, the organic contaminants should be effectively cut off from discharging to this surface water body by the in well aeration system.

In well aeration is a relatively new technology without a substantial commercial track record in the United States. Nevertheless, it is similar to air sparging and should be able to be fitted with adequate controls to ensure reliability. High dissolved metals could be precipitated out of solution by the system and cause clogging. This could force frequent maintenance and equipment replacement.

Since contaminants will remain at the site under this alternative, USEPA is required by the NCP [40 CFR 300.515 (e) (ii)] to review the effects of this alternative no less often than every five years.

Reduction of Toxicity, Mobility, or Volume

This RAA involves the application of in-situ volatilization and biodegradation technology which, by design, is intended to reduce the volume of organic contaminants in the surficial aquifer where applied. The technology, in essence, works like an in well air stripper by injecting air below the groundwater surface and, in turn extracting air, presumably laden with volatile organics, from the vadose zone. The contaminants are collected and, in this case, transferred to activated carbon for ultimate disposal. Reductions of contaminants will be limited primarily to the zone defined by the radius of influence of the air sparging wells. Natural attenuation may reduce contaminant levels further over time.

System installation will result in drill cuttings (soil) for which proper disposal will be required. The on-site air treatment will produce residual wastes including spent activated carbon and a small volume of contaminated water (i.e., condensed vapor collected in a knock-out tank).

RAA 5 satisfies the statutory preference for treatment alternatives.

Short-Term Effectiveness

The primary activity in constructing an in well aeration system is installing the wells. This involves standard environmental drilling techniques which, when executed by experience professionals, should involved minimal risk of exposure to workers. During operation, the collection and treatment of toxic vapors is conducted within essentially a closed loop. The system allows minimal potential for community exposure to contaminants provided air emission ARARs are adhered to.

Relative to environmental impacts, the installation of the in well aeration system should result in minimal disturbance to the wetlands. The wells should serve as a barrier to organic contaminated groundwater discharge to Brinson Creek.

Implementability

In well aeration is a relatively new technology. Baker has identified two companies which have developed remediation systems utilizing in well aeration. These companies are IEG Technologies Corporation and EG&G Environmental. The IEG systems have been commercially applied extensively in Germany, and are now beginning to find in-roads to the United States. EG&G in well aeration systems are currently operating at several sites overseas and here in the United States as well. Because this technology is still quite new to industry in the United States, a field pilot-scale study should be performed to determine its effectiveness and identify critical design parameters.

Such a study managed by Baker at Site 69 at Camp Lejeune is about to begin. The results of that pilot study should be sufficient and applicable at Site 35.

In any in situ system where oxygen is injected, a concern is the effect on the system operation of metals precipitation and oxidation. At high enough levels the metals can clog the well screens, prompting frequent maintenance or even well replacement.

The implementation of this technology will require the installation of multiple, custom-designed groundwater wells in the area between the highway and Brinson Creek. Access to this area for construction equipment is limited and might require the cooperation of NC DOT to incorporate special access features into the proposed highway design.

The construction activities in the wetlands area may result in some disturbance and require restoration efforts. Meeting the intentions of air emissions regulations will also be necessary.

The proposed groundwater monitoring program coupled with regular system operation and maintenance checks should be sufficient to provide notice of a system failure so that adjustments can be made before a significant contaminant release would occur.

Cost

The projected cost of RAA5 is presented in Table 5-4.

USEPA/State Acceptance

The USEPA and NE DEHNR have indicated their concurrence with the RAAs developed under this FS, in general, and with RAA 5 as the proposed alternative, in particular. The ROD also identified RAA 3 as the proposed alternative should RAA 5 be determined to be technically infeasible based on the results of a field pilot test.

Community Acceptance

Based on the lack of community participation at a public meeting held on May 10, 1995, no adverse community reaction to the proposed remedial action is anticipated.

5.2 Comparative Analysis

This interim FS has identified and evaluated a range of RAAs potentially applicable to the groundwater concerns at Site 35 (OU No. 10). Table 5-5 presents a summary of this evaluation. A comparative analysis in which the alternatives are evaluated in relation to one another with respect to the nine evaluation is presented below. The purpose of this analysis is to identify the relative advantages and disadvantages of each RAA.

5.2.1 Overall Protection of Human Health and the Environment

RAA 1 (No Action) and RAA 2 (No Action With Institutional Controls) are similar in that neither alternative involves active treatment. RAA 2 provides for some overall protection to human health through the incorporation of aquifer-use restrictions which are not included under RAA 1.

RAA 3 (Groundwater Collection and On-Site Treatment), RAA 4 (In Situ Air Sparging And Off-Gas Carbon Adsorption), and RAA 5 (In Well Aeration And Off-Gas Carbon Adsorption) have a common element in that each is intended to reduce groundwater contamination at the downgradient extreme of the contaminated plume and to serve as a barrier to future contaminated groundwater discharge to Brinson Creek. RAA 3 would likely be the most effective barrier in that it is designed to span the entire length and depth of the contaminated portion of the surficial aquifer and will be equipped with an impermeable geomembrane along its downgradient face. RAA 3 is the only treatment alternative that will impact both organic and inorganic contaminants which could be important if it is determined in the future that inorganic contaminants in groundwater are still a concern.

5.2.2 Compliance With ARARs

RAA 1 (No action) and RAA 2 (No Action With Institutional Controls) are no action alternatives that will not comply with ARARs. RAA 3 (Groundwater Collection and On-Site Treatment), RAA 4 (In Situ Air Sparging And Off-Gas Carbon Adsorption), and RAA 5 (In Well Aeration And Off-Gas Carbon Adsorption) are primarily source control measures that will reduce contaminant levels over a limited area defined as the particular zone of influence of each system.

Wetlands disturbance will be an issue with RAA 3, 4, and 5, but, most significantly with RAA 3 which includes the excavation of an approximately two-foot wide, by 30-foot deep, by 1,080-foot interceptor trench. The disturbance associated with RAA 4 and 5 is limited primarily to drilling and well installations, although of the two, RAA 4 will have the greater impact due to the large number of wells to be installed.

Treated air and groundwater discharge are provisions of RAA 3, whereas, only air emissions are a part of RAA 4 and 5. These discharges will need to meet the intentions of applicable regulations.

5.2.3 Long-Term Effectiveness and Permanence

In the case of all five RAAs, contamination will remain at the site and require a USEPA review on five year basis. RAA 1 (No Action) and RAA 2 (No Action With Institutional Controls) provide for no active means of contaminant reduction although, under RAA 2, aquifer-use restrictions will provide a permanent means for protection against direct human exposure to the contaminated surficial groundwater.

The effectiveness of RAA 3 (Groundwater Collection and On-Site Treatment), RAA 4 (In Situ Air Sparging And Off-Gas Carbon Adsorption), and RAA 5 (In Well Aeration and Off-Gas Carbon Adsorption) can be assumed to be roughly equivalent without the benefit of the results of field pilot-scale testing. RAA 3 may be the most difficult of the three to install, however, once installed it will likely be the most reliable and easiest to control. RAA 4 and 5 may encounter clogging problems if dissolved metals precipitate out of solution when placed in contact with forced air. At a minimum the metals problem will prompt increased maintenance which could lead to complete well replacement. RAA 4 has the additional problem of releasing toxic vapors to the atmosphere during operation because it is difficult to apply sufficient vacuum to the vadose zone where the groundwater surface is within a few feet of the ground surface.

5.2.4 Reduction of Toxicity, Mobility, or Volume Through Treatment

No reduction of contaminants will occur under RAA 1 (No Action) and RAA 2 (No Action With Institutional Controls) as the result of active treatment because active treatment is not provided for under these RAAs.

RAA 3 (Groundwater Collection and On-Site Treatment) provides for on-site treatment of the collected contaminated groundwater (organics and inorganics) using standard wastewater treatment technology. Conversely, RAA 4 (In Situ Air Sparging And Off-Gas Carbon Adsorption) and RAA 5 (In Well Aeration And Off-Gas Carbon Adsorption) provide for treatment of the organic phase of contaminated groundwater in-situ. Both RAA 4 and 5 utilize primarily volatilization technology and biodegradation technology secondarily. The principle difference between the two is that under RAA 4 both volatilization and biodegradation occur outside the well and within the soil column. Under RAA 5, volatilization occurs within the well while biodegradation occurs outside the well within the soil column. Under RAA 4 it may be difficult to efficiently collect all of the volatilized organic contaminants via conventional soil vapor extraction because of the proximity of the groundwater surface to the ground surface at this site. Without an efficient means of collecting the volatilized organics under RAA 4, toxic vapors may be released to the atmosphere. Under RAA 5 this is not a concern because the volatilization is conducted within the well and conveyed to an adjacent activated carbon unit via piping which means the system is essentially a closed loop.

RAA 3 will produce the highest volume of residual waste during operation because it is the only alternative involving groundwater treatment. However, the volume of air treatment under RAA 3 will be less than that under RAAs 4 and 5 because the latter are specifically designed as air volatilization systems. Under RAAs 4 and 5 a small volume of contaminated water will be generated because extracted air contains water which condenses and collects in a knock-out tank at the treatment facility.

5.2.5 Short-Term Effectiveness

Worker protection against exposure will not be a significant issue for any of the RAAs. Each system provided for under RAA 3 (Groundwater Collection and On-Site Treatment), RAA 4 (In Situ Air Sparging and Off-Gas Carbon Adsorption), and RAA 5 (In Well Aeration and Off-Gas Carbon Adsorption) will require approximately 30 to 60 days to install with the total time in the field for construction being a little longer. It has also been assumed that system start-up and testing operations will require an additional 90 days.

Under RAA 1 (No Action) and RAA 2 (No Action With Institutional Controls) there will be no increase in the risks to the community resulting from implementation of the RAA. RAAs 3 and 5 will likely present minimal risk of community exposure during implementation and operation because they are, in essence, closed loop systems. RAA 4 has the potential for releases of toxic vapors to the atmosphere because of close proximity of the groundwater surface to the ground surface will make efficient soil vapor extraction difficult.

Some disturbance of the wetlands is expected under RAAs 3, 4, and 5. The greatest disturbance will be associated with RAA 3.

5.2.6 Implementability

Aside from RAAs 1 and 2, which are no action or essentially no action alternatives, RAA 3 (Groundwater Collection And On-Site Treatment) will present greater technical challenges during construction than RAA 4 (In Situ Air Sparging and Off-Gas Carbon Adsorption), and RAA 5 (In Well Aeration and Off-Gas Carbon Adsorption). This is because RAA 3 involves the construction of a two-foot wide by 30-foot deep by 1,080 foot long interceptor trench while RAAs 4 and 5 involve primarily well installation.

The interceptor trench under RAA 3 represents specialized technology that is available from a limited number of vendors, whereas, the air sparging technology of RAA 4 is relatively commonplace, and in well aeration (RAA 5) is a relatively new technology offered by two vendors, IEG Technologies Corporation and EG&G Environmental.

The proposed groundwater monitoring plan coupled with routine system maintenance and monitoring should be sufficient to provide sufficient notice of a system failure under either RAA 3, 4 or 5. The purpose of the monitoring is to provide for system adjustments with sufficient time so that a significant contaminant release to the environment will not occur.

Because each system under RAA 3, 4, and 5 will require construction within a wetlands area and because air and water discharges are incorporated into the designs, federal and state agency interaction will be required.

5.2.7 Cost

The estimated total present worth costs of the alternatives, excluding RAA 1: No Action, range from $299,800 for RAA 2: No Action with Institutional Controls to $3,000,500 for RAA 3: Groundwater Collection and On-Site Treatment. These costs are based on the assumption of 30 years of active use. The ranking of the alternatives in terms of costs is as follows:

RAA	1:	No Action	$0
RAA	2:	No Action with Institutional Controls	$299,800
RAA	4:	In Situ Air Sparging and Off-Gas Carbon Adsorption	$2,459,600
RAA	5:	In Well Aeration and Off-Gas Carbon Adsorption	$2,519,700
RAA	3:	Groundwater Collection and On-Site Treatment	$3,000,500

Figure 5-1 graphically displays a comparison of costs for RAAs 2, 3, 4, and 5.

5.2.8 USEPA/State Acceptance

The USEPA and NE DEHNR have indicated their concurrence with the RAAs developed under this FS, in general, and with RAA 5 as the proposed alternative, in particular. The ROD also identified RAA 3 as the proposed alternative should RAA 5 be determined to be technically infeasible based on the results of a field pilot test.

5.2.9 Community Acceptance

Based on the lack of community participation at a public meeting held on May 10, 1995, no adverse community reaction to the proposed remedial action is anticipated.

SECTION 5.0 TABLES

TABLE 5 - 1

ESTIMATED COSTS

RAA 2: INSTITUTIONAL CONTROLS WITH GROUNDWATER MONITORING
SITE 35 - CAMP GEIGER AREA FUEL FARM
MCB CAMP LEJEUNE, NORTH CAROLINA
O & M AND CAPITAL COST ESTIMATE

7 - EXISTING MONITORING WELLS
+ 2 - NEW MONITORING CLUSTER WELLS

COST COMPONENT	UNIT	QUANTITY	UNIT COST	SUBTOTAL COST	TOTAL COST	SOURCE	BASIS / COMMENTS
O & M COST ESTIMATE (SEMI-ANNUAL SAMPLING YEARS 1 - 30)							Cluster Well: 1-25' deep well, 1-40' deep well
Groundwater Monitoring							
Labor	Hours	110	$ 40	$ 4,440		Engineering Estimate	Semi-annual sampling of 6 locations (11 wells): 2 samplers, 5 hours (avg.) each location, 2 events per year.
Laboratory Analyses - TCL VOCs	Sample	32	$ 175	$ 5,600		Baker Average 1994 BOAs	Semi-annual sampling of 11 wells: GW Samples - 11 from wells, 5 QA/QC = 16 samples
Misc. Expenses	Sample Event	2	$ 2,780	$ 5,560		1994 JTR, Vendor Quotes	Includes travel, lodging, air fare, supplies, truck rental, equipment, cooler shipping
Report	Sample Event	2	$ 1,500	$ 3,000		Engineering Estimate	1 - report per sampling event
Well Maintenance	Year	1	$ 500	$ 500		Engineering Estimate	Includes repainting and annualized cost of replacing 1 - well every 5 - years
					$ 19,100		
CAPITAL COST ESTIMATE							
New Monitoring Wells	Cluster Well	2	$ 3,100	$ 6,200		Engineering Estimate	Cluster Well: 1 - 25' deep 2" well & 1 - 40' deep 2" well
Revise Base Master Plan				$ -			No cost - by Camp Lejeune EMD
					$ 6,200		
ANNUAL GROUNDWATER MONITORING O & M COSTS (Years 1 - 30)					**$ 19,100**		
GROUNDWATER MONITORING CAPITAL COSTS					**$ 6,200**		
TOTAL COST (PW) - RAA 2 (5 YEAR TREATMENT PLANT OPERATION)					**$ 88,900**		
TOTAL COST (PW) - RAA 2 (30 YEAR TREATMENT PLANT OPERATION)					**$ 299,800**		

TABLE 5 - 2

ESTIMATED COSTS

RAA 3: GROUNDWATER COLLECTION WITH ON-SITE TREATMENT
SITE 35 - CAMP GEIGER AREA FUEL FARM
MCB CAMP LEJEUNE, NORTH CAROLINA
O & M AND CAPITAL COST ESTIMATE

BIOPOLYMER TRENCH
7 - EXISTING MONITORING WELLS
+ 2 - NEW MONITORING CLUSTER WELLS

COST COMPONENT	UNIT	QUANTITY	UNIT COST	SUBTOTAL COST	TOTAL COST	SOURCE	BASIS / COMMENTS
O & M COST ESTIMATE (SEMI-ANNUAL SAMPLING YEARS 1 - 30)							Cluster Well: 1-25' deep well, 1-40' deep well
Groundwater Monitoring							
Labor	Hours	110	$ 40	$ 4,440		Engineering Estimate	Semi-annual sampling of 6 locations (11 wells) 2 samplers, 5 hours (avg.) each location, 2 events per year.
Laboratory Analyses - TCL VOCs	Sample	32	$ 175	$ 5,600		Baker Average 1994 BOAs	Semi-annual sampling of 11 wells: GW Samples - 11 from wells, 5 QA/QC = 16 samples
Misc. Expenses	Sample Event	2	$ 2,780	$ 5,560		1994 JTR, Vendor Quotes	Includes travel, lodging, air fare, supplies, truck rental, equipment, cooler shipping
Report	Sample Event	2	$ 1,500	$ 3,000		Engineering Estimate	1 - report per sampling event
Well Maintenance	Year	1	$ 500	$ 500		Engineering Estimate	Includes repainting and annualized cost of replacing 1 - well every 5 - years
					$ 19,100		
CAPITAL COST ESTIMATE							
New Monitoring Wells	Cluster Well	2	$ 3,100	$ 6,200		Engineering Estimate	Cluster Well: 1 - 25' deep 2" well & 1 - 40' deep 2" well
Revise Base Master Plan				$ -			No cost - by Camp Lejeune EMD
					$ 6,200		

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TABLE 5 - 2

ESTIMATED COSTS

(CONTINUED)

RAA 3: GROUNDWATER COLLECTION WITH ON-SITE TREATMENT
SITE 35 - CAMP GEIGER AREA FUEL FARM
MCB CAMP LEJEUNE, NORTH CAROLINA
O & M AND CAPITAL COST ESTIMATE

BIOPOLYMER TRENCH
7 - EXISTING MONITORING WELLS
+ 2 - NEW MONITORING CLUSTER WELLS

COST COMPONENT	UNIT	QUANTITY	UNIT COST	SUBTOTAL COST	TOTAL COST	SOURCE	BASIS / COMMENTS
O & M COST ESTIMATE							
Treatment Plant O & M (Years 1 - 30)							
Electricity	Month	12	$ 150	$ 1,800		Means 010-034-0160 & Engineering Estimate	24 hr/day, 365 days/year operation
Carbon Regeneration/ Replacement	Unit	6	$ 875	$ 5,250		Engineering Estimate	Four 350 #/GAC Unit@$2.50/# = $875/unit Based on approx. 8-month carbon "life".
Chemicals - Polymer, Caustic	Month	12	$ 100	$ 1,200		Engineering Estimate	
Analytical (Effluent)	Sample	24	$ 200	$ 4,800		Engineering Estimate	1 sample/month/GAC unit
(Air)	Sample	24	$ 300	$ 7,200		Engineering Estimate	1 sample/month/GAC unit
Sludge Disposal	Month	12	$ 300	$ 3,600		Engineering Estimate	2 drums/month at $150/drum disposal costs.
Labor							
Operating	Week	52	$ 120	$ 6,200		Engineering Estimate	4 hr/week, 52 weeks/year, at $30/hr.
Plant Maintenance & Sampling	Month	12	$ 240	$ 2,900		Engineering Estimate	8 hr/month, 12 months/year, at $30/hr.
Administration & Reports	Hour	100	$ 50	$ 5,000		Engineering Estimate	25 hrs/quarter at $50/hr
					$ 38,000		

(Continued Next Page)

TABLE 5 - 2

ESTIMATED COSTS

(CONTINUED)

RAA 3: GROUNDWATER COLLECTION WITH ON-SITE TREATMENT
SITE 35 - CAMP GEIGER AREA FUEL FARM
MCB CAMP LEJEUNE, NORTH CAROLINA
O & M AND CAPITAL COST ESTIMATE

BIOPOLYMER TRENCH
7 - EXISTING MONITORING WELLS
+ 2 - NEW MONITORING CLUSTER WELLS

COST COMPONENT	UNIT	QUANTITY	UNIT COST	SUBTOTAL COST	TOTAL COST	SOURCE	BASIS / COMMENTS
CAPITAL COST ESTIMATE (BIOPOLYMER TRENCH)							
SITE PREPARATION							
Equipment Mobilization	LS	1	200	200		Rental company & Means	1 trailer, 1 forklift, 1 utility tractor w/backhoe
Personnel Mobilization	LS	1	860	860		1994 JTR, Eng'r.Est.	(Does not include biopolymer trench subcontractor mob/demob.)
Pre-Construction Submittals	LS	1	14,830	14,830		Engineering Estimate	
Office Trailer Setup	LS	1	120	120		Engineering Estimate	
Laydown Area / Staging Area	LS	1	7,950	7,950		Engineering Estimate	60' x 100' staging/laydown area
Decontamination Area	LS	1	1,580	1,580		Means & Eng'r. Estimate	Steel pans
Site Access	LS	1	69,490	69,490		Means & Eng'r. Estimate	3,000 ft access road parallel to highway
Miscellaneous	LS	1	81,440	81,440		Means & Eng'r. Estimate	Utilities Materials and Hookup, (incl. Treatment Bldg. and Wells) Erosion Control, Safety Fencing, Sediment Fencing
GROUNDWATER COLLECTION / ON-SITE TREATMENT / DISCHARGE / SOIL DISPOSAL							
Biopolymer Trench Construction	LS	1	1,148,650	1,148,650		Means, Vendor & Eng'r. Est.	Includes sub mob/demob, soil disposal.
Groundwater Collection	LS	1	23,380	23,380		Means, Vendor & Eng'r. Est.	
Treatment Plant Construction	LS	1	193,170	193,170		Means, Vendor & Eng'r. Est.	
SITE RESTORATION							
General Site Cleanup	LS	1	1,500	1,500		Engineering Estimate	
Wetlands Revegetation	LS	1	14,810	14,810		Engineering Estimate	
Equipment Decon	LS	1	500	500		Engineering Estimate	
DEMOBILIZATION							
Equipment & Trailer Demob	LS	1	200	200		Rental company & Means	Same as Mobilization
Personnel Demob	LS	1	860	860		1994 JTR, Eng'r.Est.	Same as Mobilization
Post-Construction Submittals	LS	1	7,240	7,240		Engineering Estimate	
Miscellaneous	LS	1	9,750	9,750		Engineering Estimate	Remove Utilities (not incl. Treatment Bldg.), Erosion Control,Safety Fencing

(Continued Next Page)

TABLE 5 - 2

ESTIMATED COSTS

(CONTINUED)

RAA 3: GROUNDWATER COLLECTION WITH ON-SITE TREATMENT
SITE 35 - CAMP GEIGER AREA FUEL FARM
MCB CAMP LEJEUNE, NORTH CAROLINA
O & M AND CAPITAL COST ESTIMATE

BIOPOLYMER TRENCH
7 - EXISTING MONITORING WELLS
+ 2 - NEW MONITORING CLUSTER WELLS

COST COMPONENT	UNIT	QUANTITY	UNIT COST	SUBTOTAL COST	TOTAL COST	SOURCE	BASIS / COMMENTS
CAPITAL COST ESTIMATE (BIOPOLYMER TRENCH Continued)							
DISTRIBUTIVE COSTS							
Supervision	LS	1	56,880	56,880		Engineering Estimate	Site Supervisor, Foreman (3 months) Mechanical Engineer (2 weeks)
Per Diem	LS	1	20,720	20,720		Engineering Estimate	at $66/day: Site Supervisor, Foreman, Mechanical Engineer, Plant Operators
Home Office/Eng'r/H & S/QA/QC	LS	1	8,530	8,530		Engineering Estimate	15 % of Supervision
Trailer, Portable Toilet Rental	LS	1	540	540		MEANS, 1994: 015-904-1350 MEANS, 1994: 016-420-7200	Trailer 3 months at $102/month Portable toilet 3 months at $78/month
Vehicles	LS	1	3,330	3,330		MEANS, 1994: 016-420-7200	Pickup Trucks - 2 @ $555/month each (3 months)
SUBTOTAL CAPITAL COST					$ 1,666,500		
Engineering & Design @ 12 %		0.12		200,000			
Contingencies @ 15 %		0.15		250,000			
TOTAL CAPITAL COST					$ 2,116,500		

ANNUAL GROUNDWATER MONITORING O & M COSTS (Years 1 - 30)	$ 19,100
ANNUAL TREATMENT PLANT O & M COSTS (YEARS 1 - 30)	$ 38,000
GROUNDWATER MONITORING CAPITAL COSTS	$ 6,200
TREATMENT PLANT CAPITAL COSTS	$ 2,116,500
TOTAL CAPITAL COSTS	$ 2,122,700
TOTAL COST (PW) - RAA 3 (5 YEAR TREATMENT PLANT OPERATION)	$ 2,580,800
TOTAL COST (PW) - RAA 3 (30 YEAR TREATMENT PLANT OPERATION)	$ 3,000,500

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TABLE 5 - 3

ESTIMATED COSTS

RAA 4: IN SITU AIR SPARGING AND OFF - GAS CARBON ADSORPTION
SITE 35 - CAMP GEIGER AREA FUEL FARM
MCB CAMP LEJEUNE, NORTH CAROLINA
O & M AND CAPITAL COST ESTIMATE

43 - NEW AIR INJECTION WELLS
\+ 43 - NEW AIR EXTRACTION WELLS
7 - EXISTING MONITORING WELLS
\+ 2 - NEW MONITORING CLUSTER WELLS

COST COMPONENT	UNIT	QUANTITY	UNIT COST	SUBTOTAL COST	TOTAL COST	SOURCE	BASIS / COMMENTS
O & M COST ESTIMATE (SEMI-ANNUAL SAMPLING YEARS 1 - 30)							Cluster Well: 1-25' deep well, 1-40' deep well
Groundwater Monitoring							
Labor	Hours	110	$ 40	$ 4,440		Engineering Estimate	Semi-annual sampling of 6 locations (11 wells) 2 samplers, 5 hours (avg.) each location, 2 events per year.
Laboratory Analyses - TCL VOCs	Sample	32	$ 175	$ 5,600		Baker Average 1994 BOAs	Semi-annual sampling of 11 wells: GW Samples - 11 from wells, 5 QA/QC = 16 samples
Misc. Expenses	Sample Event	2	$ 2,780	$ 5,560		1994 JTR, Vendor Quotes	Includes travel, lodging, air fare, supplies, truck rental, equipment, cooler shipping
Report	Sample Event	2	$ 1,500	$ 3,000		Engineering Estimate	1 - report per sampling event
Well Maintenance	Year	1	$ 500	$ 500		Engineering Estimate	Includes repainting and annualized cost of replacing 1 - well every 5 - years
					$ 19,100		
CAPITAL COST ESTIMATE							
New Monitoring Wells	Cluster Well	2	$ 3,100	$ 6,200		Engineering Estimate	Cluster Well: 1 - 25' deep 2" well & 1 - 40' deep 2" well
Revise Base Master Plan				$ -			No cost - by Camp Lejeune EMD
					$ 6,200		

(Continued Next Page)

TABLE 5 - 3

ESTIMATED COSTS

(CONTINUED)

RAA 4: IN SITU AIR SPARGING AND OFF - GAS CARBON ADSORPTION
SITE 35 - CAMP GEIGER AREA FUEL FARM
MCB CAMP LEJEUNE, NORTH CAROLINA
O & M AND CAPITAL COST ESTIMATE

43 - NEW AIR INJECTION WELLS
+ 43 - NEW AIR EXTRACTION WELLS
7 - EXISTING MONITORING WELLS
+ 2 - NEW MONITORING CLUSTER WELLS

COST COMPONENT	UNIT	QUANTITY	UNIT COST	SUBTOTAL COST	TOTAL COST	SOURCE	BASIS / COMMENTS
O & M COST ESTIMATE							
Treatment Plant O & M (Years 1 - 30)							
Electricity	Month	12	$ 250	$ 3,000		Means 010-034-0160 & Engineering Estimate	24 hr/day, 365 days/year operation
Carbon Regeneration/ Replacement	Unit	3	$ 875	$ 2,625		Engineering Estimate	Two 350 #/GAC Unit@$2.50/# = $875/unit Based on approx. 8-month carbon "life".
Analytical (Water)	Sample	12	$ 200	$ 2,400		Engineering Estimate	1 sample/month
(Air)	Sample	72	$ 300	$ 21,600		Engineering Estimate	6 samples/month/GAC unit
Labor							
Operating	Week	52	$ 240	$ 12,500		Engineering Estimate	8 hr/week, 52 weeks/year, at $30/hr.
Plant Maintenance & Sampling	Month	12	$ 480	$ 5,800		Engineering Estimate	16 hr/month, 12 months/year, at $30/hr.
Disposal of Water							
Hazardous	Gal.	1500	$ 5	$ 7,500		Engineering Estimate	Assume $5/gal.
Non-Hazardous	Gal.	1500	$ 5	$ 7,500		Engineering Estimate	Assume $0.50/gal.
Transport Costs	Load	6	$ 500	$ 3,000		Engineering Estimate	Assume $500/trip
Administration & Reports	Hour	100	$ 50	$ 5,000		Engineering Estimate	25 hrs/quarter at $50/hr
					$ 71,000		

(Continued Next Page)

TABLE 5 - 3

ESTIMATED COSTS

(CONTINUED)

RAA 4: IN SITU AIR SPARGING AND OFF - GAS CARBON ADSORPTION
SITE 35 - CAMP GEIGER AREA FUEL FARM
MCB CAMP LEJEUNE, NORTH CAROLINA
O & M AND CAPITAL COST ESTIMATE

43 - NEW AIR INJECTION WELLS
\+ 43 - NEW AIR EXTRACTION WELLS
7 - EXISTING MONITORING WELLS
\+ 2 - NEW MONITORING CLUSTER WELLS

COST COMPONENT	UNIT	QUANTITY	UNIT COST	SUBTOTAL COST	TOTAL COST	SOURCE	BASIS / COMMENTS
CAPITAL COST ESTIMATE (AIR SPARGING)							
SITE PREPARATION							
Equipment Mobilization	LS	1	200	200		Rental company & Means	1 trailer, 1 forklift, 1 utility tractor w/backhoe (Does not include biopolymer trench subcontractor mob/demob.)
Personnel Mobilization	LS	1	860	860		1994 JTR, Eng'r.Est.	
Pre-Construction Submittals	LS	1	14,830	14,830		Engineering Estimate	
Office Trailer Setup	LS	1	120	120		Engineering Estimate	
Laydown Area / Staging Area	LS	1	7,950	7,950		Engineering Estimate	60' x 100' staging/laydown area
Decontamination Area	LS	1	1,580	1,580		Means & Eng'r. Estimate	Steel pans
Site Access	LS	1	69,490	69,490		Means & Eng'r. Estimate	3,000 ft access road parallel to highway
Miscellaneous	LS	1	26,410	26,410		Means & Eng'r. Estimate	Utilities Materials & Hookup (incl. Treatment Bldg.), Erosion Control, Safety Fencing, Sediment Fencing
VAPOR COLLECTION / VAPOR - WATER SEPARATION / DISPOSAL							
Treatment Plant Construction	LS	1	369,900	369,900		Means, Vendor & Eng'r. Est.	
Vapor Collection	LS	1	146,270	146,270		Means, Vendor & Eng'r. Est.	
SITE RESTORATION							
General Site Cleanup	LS	1	1,500	1,500		Engineering Estimate	
Wetlands Revegetation	LS	1	14,810	14,810		Engineering Estimate	
Equipment Decon	LS	1	500	500		Engineering Estimate	
DEMOBILIZATION							
Equipment & Trailer Demob	LS	1	200	200		Rental company & Means	Same as Mobilization
Personnel Demob	LS	1	860	860		1994 JTR, Eng'r.Est.	Same as Mobilization
Post-Construction Submittals	LS	1	7,240	7,240		Engineering Estimate	
Miscellaneous	LS	1	9,750	9,750		Engineering Estimate	Remove Utilities (not incl. Treatment Bldg.), Erosion Control,Safety Fencing

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TABLE 5 - 3

ESTIMATED COSTS

(CONTINUED)

RAA 4: IN SITU AIR SPARGING AND OFF - GAS CARBON ADSORPTION
SITE 35 - CAMP GEIGER AREA FUEL FARM
MCB CAMP LEJEUNE, NORTH CAROLINA
O & M AND CAPITAL COST ESTIMATE

43 - NEW AIR INJECTION WELLS
+ 43 - NEW AIR EXTRACTION WELLS
7 - EXISTING MONITORING WELLS
+ 2 - NEW MONITORING CLUSTER WELLS

COST COMPONENT	UNIT	QUANTITY	UNIT COST	SUBTOTAL COST	TOTAL COST	SOURCE	BASIS / COMMENTS
CAPITAL COST ESTIMATE (Continued)							
DISTRIBUTIVE COSTS							
Supervision	LS	1	56,880	56,880		Engineering Estimate	Site Supervisor, Foreman (3 months) Mechanical Engineer (2 weeks)
Per Diem	LS	1	20,720	20,720		Engineering Estimate	at $66/day: Site Supervisor, Foreman, Mechanical Engineer, Plant Operators
Home Office/Eng'r/H & S/QA/QC	LS	1	8,530	8,530		Engineering Estimate	15 % of Supervision
Trailer, Portable Toilet Rental	LS	1	540	540		Means, 1994: 015-904-1350 Means, 1994: 016-420-7200	Trailer 3 months at $102/month Portable toilet 3 months at $78/month
Vehicles	LS	1	3,330	3,330		Means, 1994: 016-420-7200	Pickup Trucks - 2 @ $555/month each (3 months)
SUBTOTAL CAPITAL COST					$ 762,500		
Engineering & Design @ 12 %		0.12		91,500			
Contingencies @ 15 %		0.15		114,400			
Treatment Study				100,000			
TOTAL CAPITAL COST					$ 1,068,400		

ANNUAL GROUNDWATER MONITORING O & M COSTS (Years 1 - 30)	$ 19,100
ANNUAL TREATMENT PLANT O & M COSTS (YEARS 1 - 30)	$ 71,000
GROUNDWATER MONITORING CAPITAL COSTS	$ 6,200
TREATMENT PLANT CAPITAL COSTS	$ 1,068,400
TOTAL CAPITAL COSTS	$ 1,074,600
TOTAL COST (PW) - RAA 4 (5 YEAR TREATMENT PLANT OPERATION)	$ 1,675,600
TOTAL COST (PW) - RAA 4 (30 YEAR TREATMENT PLANT OPERATION)	$ 2,459,600

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TABLE 5 - 4

ESTIMATED COSTS

RAA 5: IN WELL AERATION AND OFF - GAS CARBON ADSORPTION
SITE 35 - CAMP GEIGER AREA FUEL FARM
MCB CAMP LEJEUNE, NORTH CAROLINA
O & M AND CAPITAL COST ESTIMATE

? - NEW AERATION WELLS
7 - EXISTING MONITORING WELLS
+ 2 - NEW MONITORING CLUSTER WELLS

COST COMPONENT	UNIT	QUANTITY	UNIT COST	SUBTOTAL COST	TOTAL COST	SOURCE	BASIS / COMMENTS
O & M COST ESTIMATE (SEMI-ANNUAL SAMPLING YEARS 1 - 30)							Cluster Well: 1-25' deep well, 1-40' deep well
Groundwater Monitoring							
Labor	Hours	110	$ 40	$ 4,440		Engineering Estimate	Semi-annual sampling of 6 locations (11 wells): 2 samplers, 5 hours (avg.) each location, 2 events per year.
Laboratory Analyses - TCL VOCs	Sample	32	$ 175	$ 5,600		Baker Average 1994 BOAs	Semi-annual sampling of 11 wells: GW Samples - 11 from wells, 5 QA/QC = 16 samples
Misc. Expenses	Sample Event	2	$ 2,780	$ 5,560		1994 JTR, Vendor Quotes	Includes travel, lodging, air fare, supplies, truck rental, equipment, cooler shipping
Report	Sample Event	2	$ 1,500	$ 3,000		Engineering Estimate	1 - report per sampling event
Well Maintenance	Year	1	$ 500	$ 500		Engineering Estimate	Includes repainting and annualized cost of replacing 1 - well every 5 - years
					$ 19,100		
CAPITAL COST ESTIMATE							
New Monitoring Wells	Cluster Well	2	$ 3,100	$ 6,200		Engineering Estimate	Cluster Well: 1 - 25' deep 2" well & 1 - 40' deep 2" well
Revise Base Master Plan				$ -			No cost - by Camp Lejeune EMD
					$ 6,200		

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TABLE 5 - 4

ESTIMATED COSTS

(CONTINUED)

RAA 5: IN WELL AERATION AND OFF - GAS CARBON ADSORPTION
SITE 35 - CAMP GEIGER AREA FUEL FARM
MCB CAMP LEJEUNE, NORTH CAROLINA
O & M AND CAPITAL COST ESTIMATE

? - NEW AERATION WELLS
7 - EXISTING MONITORING WELLS
+ 2 - NEW MONITORING CLUSTER WELLS

COST COMPONENT	UNIT	QUANTITY	UNIT COST	SUBTOTAL COST	TOTAL COST	SOURCE	BASIS / COMMENTS
O & M COST ESTIMATE							
Independent Off-Gas Treatment Systems O & M (Years 1 - 30)							
Electricity	Month	12	$ 200	$ 2,400		Means 010-034-0160 & Engineering Estimate	24 hr/day, 365 days/year operation
Carbon Regeneration/ Replacement	Unit	9	$ 440	$ 3,960		Engineering Estimate	175#/GAC Unit@$2.50/# = $440/unit Based on approximately 8-month carbon "life".
Analytical (Air)	Sample	72	$ 300	$ 21,600		Engineering Estimate	1 sample/month/independent GAC unit
Labor							
Sampling	Month	12	$ 480	$ 5,760		Engineering Estimate	16 hr/month, 12 months/year, at $30/hr.
Aeration Equipment by Subcontractor	Event	2	$ 11,500	$ 23,000		Vendor Quote & Engineering Estimate	2 days maintenance by subcontractor - includes labor & travel costs
Disposal of Water							
Hazardous	Gal.	200	$ 5	$ 1,000		Engineering Estimate	Assume $5/gal.
Transport Costs	Load	1	$ 500	$ 500		Engineering Estimate	Assume $500/trip
Administration & Reports	Hour	100	$ 50	$ 5,000		Engineering Estimate	25 hrs/quarter at $50/hr
					$ 63,200		

(Continued Next Page)

TABLE 5 - 4

ESTIMATED COSTS

(CONTINUED)

RAA 5: IN WELL AERATION AND OFF - GAS CARBON ADSORPTION
SITE 35 - CAMP GEIGER AREA FUEL FARM
MCB CAMP LEJEUNE, NORTH CAROLINA
O & M AND CAPITAL COST ESTIMATE

? - NEW AERATION WELLS
7 - EXISTING MONITORING WELLS
+ 2 - NEW MONITORING CLUSTER WELLS

COST COMPONENT	UNIT	QUANTITY	UNIT COST	SUBTOTAL COST	TOTAL COST	SOURCE	BASIS / COMMENTS
CAPITAL COST ESTIMATE (IN WELL AERATION)							
SITE PREPARATION							
Equipment Mobilization	LS	1	200	200		Rental company & Means	1 trailer, 1 forklift, 1 utility tractor w/backhoe (Does not include biopolymer trench subcontractor mob/demob.)
Personnel Mobilization	LS	1	860	860		1994 JTR, Eng'r.Est.	
Pre-Construction Submittals	LS	1	14,830	14,830		Engineering Estimate	
Office Trailer Setup	LS	1	120	120		Engineering Estimate	
Laydown Area / Staging Area	LS	1	7,950	7,950		Engineering Estimate	60' x 100' staging/laydown area
Decontamination Area	LS	1	1,580	1,580		Means & Eng'r. Estimate	Steel pans
Site Access	LS	1	69,490	69,490		NC DOT Budget Quote	3,000 ft access road parallel to highway
Miscellaneous	LS	1	64,770	64,770		Means & Eng'r. Estimate	Utilities Hookup (incl. Treatment Bldg.), Erosion Control, Safety Fencing, Sediment Fencing
VAPOR COLLECTION / VAPOR - WATER SEPARATION / DISPOSAL							
Individual Off-Gas Treatment Systems	UNIT	6	12,600	75,600		Means, Vendor & Eng'r. Est.	Includes: Knockout Tank, Activated Carbon Unit, 5 HP Blower
In Well Aeration Wells	UNIT	6	91,887	551,320		Means, Vendor & Eng'r. Est.	UVB Custom Wells, 30' deep
SITE RESTORATION							
General Site Cleanup	LS	1	1,500	1,500		Engineering Estimate	
Wetlands Revegetation	LS	1	7,400	7,400		Engineering Estimate	
Equipment Decon	LS	1	500	500		Engineering Estimate	
DEMOBILIZATION							
Equipment & Trailer Demob	LS	1	200	200		Rental company & Means	Same as Mobilization
Personnel Demob	LS	1	860	860		1994 JTR, Eng'r.Est.	Same as Mobilization
Post-Construction Submittals	LS	1	7,240	7,240		Engineering Estimate	
Miscellaneous	LS	1	9,740	9,740		Engineering Estimate	Remove Utilities (not incl. Treatment Bldg.), Erosion Control,Safety Fencing

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TABLE 5 - 4

ESTIMATED COSTS

(CONTINUED)

RAA 5: IN WELL AERATION AND OFF - GAS CARBON ADSORPTION
SITE 35 - CAMP GEIGER AREA FUEL FARM
MCB CAMP LEJEUNE, NORTH CAROLINA
O & M AND CAPITAL COST ESTIMATE

? - NEW AERATION WELLS
7 - EXISTING MONITORING WELLS
+ 2 - NEW MONITORING CLUSTER WELLS

COST COMPONENT	UNIT	QUANTITY	UNIT COST	SUBTOTAL COST	TOTAL COST	SOURCE	BASIS / COMMENTS
CAPITAL COST ESTIMATE (Continued)							
DISTRIBUTIVE COSTS							
Supervision	LS	1	56,880	56,880		Engineering Estimate	Site Supervisor, Foreman (3 months) Mechanical Engineer (2 weeks)
Per Diem	LS	1	20,720	20,720		Engineering Estimate	at $66/day: Site Supervisor, Foreman, Mechanical Engineer, Plant Operators
Home Office/Eng'r/H & S/QA/QC	LS	1	8,530	8,530		Engineering Estimate	15 % of Supervision
Trailer, Portable Toilet Rental	LS	1	540	540		MEANS, 1994: 015-904-1350 MEANS, 1994: 016-420-7200	Trailer 3 months at $102/month Portable toilet 3 months at $78/month
Vehicles	LS	1	3,330	3,330		MEANS, 1994: 016-420-7200	Pickup Trucks - 2 @ $555/month each (3 months)
SUBTOTAL CAPITAL COST					$ 904,200		
Engineering & Design @ 12 %		0.12		108,500			
Contingencies @ 15 %		0.15		135,600			
Treatment Study				100,000			
TOTAL CAPITAL COST					$ 1,248,300		

ANNUAL GROUNDWATER MONITORING O & M COSTS (Years 1 - 30)	$ 19,100
ANNUAL TREATMENT PLANT O & M COSTS (YEARS 1 - 30)	$ 63,200
GROUNDWATER MONITORING CAPITAL COSTS	$ 6,200
TREATMENT PLANT CAPITAL COSTS	$ 1,248,300
TOTAL CAPITAL COSTS	$ 1,254,500
TOTAL COST (PW) - RAA 5 (5 YEAR TREATMENT PLANT OPERATION)	$ 1,821,700
TOTAL COST (PW) - RAA 5 (30 YEAR TREATMENT PLANT OPERATION)	$ 2,519,700

TABLE 5 - 4

ESTIMATED COSTS

RAA 5: IN WELL AERATION AND OFF - GAS CARBON ADSORPTION
SITE 35 - CAMP GEIGER AREA FUEL FARM
MCB CAMP LEJEUNE, NORTH CAROLINA
O & M AND CAPITAL COST ESTIMATE

6 - NEW AERATION WELLS
7 - EXISTING MONITORING WELLS
+ 2 - NEW MONITORING CLUSTER WELLS

COST COMPONENT	UNIT	QUANTITY	UNIT COST	SUBTOTAL COST	TOTAL COST	SOURCE	BASIS / COMMENTS
O & M COST ESTIMATE (SEMI-ANNUAL SAMPLING YEARS 1 - 30)							Cluster Well: 1-25' deep well, 1-40' deep well
Groundwater Monitoring							
Labor	Hours	110	$ 40	$ 4,440		Engineering Estimate	Semi-annual sampling of 6 locations (11 wells): 2 samplers, 5 hours (avg.) each location, 2 events per year.
Laboratory Analyses - TCL VOCs	Sample	32	$ 175	$ 5,600		Baker Average 1994 BOAs	Semi-annual sampling of 11 wells: GW Samples - 11 from wells, 5 QA/QC = 16 samples
Misc. Expenses	Sample Event	2	$ 2,780	$ 5,560		1994 JTR, Vendor Quotes	Includes travel, lodging, air fare, supplies, truck rental, equipment, cooler shipping
Report	Sample Event	2	$ 1,500	$ 3,000		Engineering Estimate	1 - report per sampling event
Well Maintenance	Year	1	$ 500	$ 500		Engineering Estimate	Includes repainting and annualized cost of replacing 1 - well every 5 - years
					$ 19,100		
CAPITAL COST ESTIMATE							
New Monitoring Wells	Cluster Well	2	$ 3,100	$ 6,200		Engineering Estimate	Cluster Well: 1 - 25' deep 2" well & 1 - 40' deep 2" well
Revise Base Master Plan				$ -			No cost - by Camp Lejeune EMD
					$ 6,200		

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TABLE 5 - 4

ESTIMATED COSTS

(CONTINUED)

RAA 5: IN WELL AERATION AND OFF - GAS CARBON ADSORPTION
SITE 35 - CAMP GEIGER AREA FUEL FARM
MCB CAMP LEJEUNE, NORTH CAROLINA
O & M AND CAPITAL COST ESTIMATE

6 - NEW AERATION WELLS
7 - EXISTING MONITORING WELLS
+ 2 - NEW MONITORING CLUSTER WELLS

COST COMPONENT	UNIT	QUANTITY	UNIT COST	SUBTOTAL COST	TOTAL COST	SOURCE	BASIS / COMMENTS
O & M COST ESTIMATE							
Independent Aeration Well Off-Gas Treatment Systems O & M (Years 1 - 30)							
Electricity	Month	12	$ 200	$ 2,400		Means 010-034-0160 & Engineering Estimate	24 hr/day, 365 days/year operation
Carbon Regeneration/ Replacement	Unit	9	$ 440	$ 3,960		Engineering Estimate	175# / GAC Units @ $2.50 / # = $440/unit Based on approximately 8 -month carbon "life".
Analytical (Air)	Sample	72	$ 300	$ 21,600		Engineering Estimate	1 sample/month/independent GAC unit
Labor							
Sampling	Month	12	$ 480	$ 5,760		Engineering Estimate	16 hr/month, 12 months/year @ $30/hr.
Aeration Equipment Maintenance by Subcontractor	Event	2	$ 11,500	$ 23,000		Vendor Quote & Engineering Estimate	2 days maintenance by subcontractor - includes labor & travel costs
Disposal of Water							
Hazardous	Gal.	200	$ 5	$ 1,000		Engineering Estimate	Assume $5/gal.
Transport Costs	Load	1	$ 500	$ 500		Engineering Estimate	Assume $500/trip
Administration & Reports	Hour	100	$ 50	$ 5,000		Engineering Estimate	25 hrs/quarter at $50/hr
					$ 63,220		

(Continued Next Page)

TABLE 5 - 4

ESTIMATED COSTS

(CONTINUED)

RAA 5: IN WELL AERATION AND OFF - GAS CARBON ADSORPTION
SITE 35 - CAMP GEIGER AREA FUEL FARM
MCB CAMP LEJEUNE, NORTH CAROLINA
O & M AND CAPITAL COST ESTIMATE

6 - NEW AERATION WELLS
7 - EXISTING MONITORING WELLS
+ 2 - NEW MONITORING CLUSTER WELLS

COST COMPONENT	UNIT	QUANTITY	UNIT COST	SUBTOTAL COST	TOTAL COST	SOURCE	BASIS / COMMENTS
CAPITAL COST ESTIMATE (IN WELL AERATION)							
SITE PREPARATION							
Equipment Mobilization	LS	1	200	200		Rental company & Means	1 trailer, 1 forklift, 1 utility tractor w/backhoe
Personnel Mobilization	LS	1	860	860		1994 JTR, Eng'r.Est.	
Pre-Construction Submittals	LS	1	14,830	14,830		Engineering Estimate	
Office Trailer Setup	LS	1	120	120		Engineering Estimate	
Laydown Area / Staging Area	LS	1	7,950	7,950		Engineering Estimate	60'x100' laydown/staging area
Decontamination Area	LS	1	1,580	1,580		Means & Eng'r. Estimate	Steel pans
Site Access	LS	1	46,320	46,320		NC DOT Budget Quote	Access road and culvert
Miscellaneous	LS	1	64,770	64,770		Means & Eng'r. Estimate	Utilities Hookup (incl. Treatment Systems), Erosion Contl, Safety & Sediment Fencing.
VAPOR COLLECTION / VAPOR - WATER SEPARATION / DISPOSAL							
Individual Off-Gas Treatment Systems	UNIT	6	12,600	75,600		Means, Vendor & Eng'r. Est.	Includes: Activated Carbon Unit and 12'x8' Building for Entire System
In Well Aeration Wells	UNIT	6	91,887	551,320		Vendor & Eng'r. Est.	Custom In Well Aeration Wells, 35' deep Includes 5 hp Blower, Moisture Knockout Tank, and All Connections
SITE RESTORATION							
General Site Cleanup	LS	1	1,500	1,500		Engineering Estimate	
Wetlands Revegetation	LS	1	7,400	7,400		Engineering Estimate	
Equipment Decon	LS	1	500	500		Engineering Estimate	
DEMOBILIZATION							
Equipment & Trailer Demob	LS	1	200	200		Rental company & Means	Same as Mobilization
Personnel Demob	LS	1	860	860		1994 JTR, Eng'r.Est.	Same as Mobilization
Post-Construction Submittals	LS	1	7,240	7,240		Engineering Estimate	
Miscellaneous	LS	1	9,740	9,740		Engineering Estimate	Remove Utilities (not incl. Treatment System.), Erosion Control,Safety Fencing

(Continued Next Page)

TABLE 5 - 4

ESTIMATED COSTS

(CONTINUED)

RAA 5: IN WELL AERATION AND OFF - GAS CARBON ADSORPTION
SITE 35 - CAMP GEIGER AREA FUEL FARM
MCB CAMP LEJEUNE, NORTH CAROLINA
O & M AND CAPITAL COST ESTIMATE

6 - NEW AERATION WELLS
7 - EXISTING MONITORING WELLS
+ 2 - NEW MONITORING CLUSTER WELLS

COST COMPONENT	UNIT	QUANTITY	UNIT COST	SUBTOTAL COST	TOTAL COST	SOURCE	BASIS / COMMENTS
CAPITAL COST ESTIMATE (Continued)							
DISTRIBUTIVE COSTS							
Supervision	LS	1	56,880	56,880		Engineering Estimate	Site Supervisor, Foreman (3 months) Mechanical Engineer (2 weeks)
Per Diem	LS	1	20,720	20,720		Engineering Estimate	at $66/day: Site Supervisor, Foreman, Mechanical Engineer, Plant Operators
Home Office/Eng'r/H & S/QA/QC	LS	1	8,530	8,530		Engineering Estimate	15 % of Supervision
Trailer, Portable Toilet Rental	LS	1	540	540		Means, 1994: 015-904-1350 Means, 1994: 016-420-7200	Trailer 3 months at $102/month Portable toilet 3 months at $78/month
Vehicles	LS	1	3,330	3,330		Means, 1994: 016-420-7200	Pickup Trucks - 2 @ $555/month each (3 months)
SUBTOTAL CAPITAL COST					$ 881,000		
Engineering & Design @ 12 %		0.12		105,720			
Contingencies @ 15 %		0.15		132,200			
Treatment Study				100,000			
TOTAL CAPITAL COST					$ 1,218,900		

ANNUAL GROUNDWATER MONITORING O & M COSTS (Years 1 - 30)	$ 19,100
ANNUAL TREATMENT PLANT O & M COSTS (YEARS 1 - 30)	$ 63,220
GROUNDWATER MONITORING CAPITAL COSTS	$ 6,200
TREATMENT PLANT CAPITAL COSTS	$ 1,218,900
TOTAL CAPITAL COSTS	$ 1,225,100
TOTAL COST (PW) - RAA 5 (5 YEAR TREATMENT PLANT OPERATION)	$ 1,792,400
TOTAL COST (PW) - RAA 5 (30 YEAR TREATMENT PLANT OPERATION)	$ 2,490,400

TABLE 5-5

SUMMARY OF DETAILED ANALYSIS
OPERABLE UNIT NO. 10 (SITE 35)
INTERIM FEASIBILITY STUDY, CTO-0232
MCB CAMP LEJEUNE, NORTH CAROLINA

Evaluation Criteria	RAA 1 No Action	RAA 2 No Action with Institutional Controls	RAA 3 Groundwater Collection and On-Site Treatment	RAA 4 In Situ Air Sparging and Off-Gas Carbon Adsorption	RAA 5 In Well Aeration and Off-Gas Carbon Adsorption
OVERALL PROTECTIVENESS					
• Human Health	Potential risks associated with groundwater exposure will remain. Some reduction in contaminant levels may result from natural attenuation.	Aquifer-use restrictions mitigate risks from direct groundwater exposure.	Active collection and treatment will reduce contaminant levels in groundwater within capture zone of interceptor trench (estimated at 100 feet upgradient maximum). Aquifer-use restrictions will also mitigate risks from direct groundwater exposure.	Active in situ volatilization and biodegradation will reduce contaminant levels in groundwater within radius of influence of wells (estimated at 25 feet). Aquifer-use restrictions will also mitigate risks from direct groundwater exposure.	Active in-well volatilization and in situ biodegradation will reduce contaminant levels in groundwater within radius of influence of wells (estimated at 45 to 60 feet). Aquifer-use restrictions will also mitigate risks from direct groundwater exposure.
• Environment	Contaminated groundwater will continue to be a source of future contamination to Brinson Creek.	Contaminated groundwater will continue to be a source of future contamination to Brinson Creek.	Interceptor trench serves as a barrier to contaminated groundwater discharge to Brinson Creek.	Air sparging wells and SVE wells serve as a barrier to contaminated groundwater discharge to Brinson Creek.	Aeration wells serve as a barrier to contaminated groundwater discharge to Brinson Creek.
COMPLIANCE WITH ARARs					
• Chemical-Specific	No active effort made to reduce groundwater contaminant levels to below federal or state ARARs.	No active effort made to reduce groundwater contaminant levels to below federal or state ARARs.	Reductions in groundwater contaminant levels to below federal or state ARARs can be expected within capture zone of interceptor trench. Reductions upgradient will be less substantial if at all.	Reductions in groundwater contaminant levels to below federal or state ARARs can be expected within radius of influence of wells. Reductions upgradient will be less substantial if at all.	Reductions in groundwater contaminant levels to below federal or state ARARs can be expected within radius of influence of wells. Reductions upgradient will be less substantial if at all.
• Location-Specific	Not Applicable.	Not Applicable.	Wetlands and alligators (endangered species) are concerns because of proposed location of interceptor trench. It is assumed that necessary approvals can be obtained.	Wetlands and alligators (endangered species) are concerns because of proposed location of interceptor trench. It is assumed that necessary approvals can be obtained.	Wetlands and alligators (endangered species) are concerns because of proposed location of interceptor trench. It is assumed that necessary approvals can be obtained.
• Action-Specific	Not Applicable.	Not Applicable.	Can be designed to meet these ARARs.	Can be designed to meet these ARARs.	Can be designed to meet these ARARs.

TABLE 5-5 (Continued)

SUMMARY OF DETAILED ANALYSIS
OPERABLE UNIT NO. 10 (SITE 35)
INTERIM FEASIBILITY STUDY, CTO-0232
MCB CAMP LEJEUNE, NORTH CAROLINA

Evaluation Criteria	RAA 1 No Action	RAA 2 No Action with Institutional Controls	RAA 3 Groundwater Collection and On-Site Treatment	RAA 4 In Situ Air Sparging and Off-Gas Carbon Adsorption	RAA 5 In Well Aeration and Off-Gas Carbon Adsorption
LONG-TERM EFFECTIVENESS AND PERFORMANCE					
• Magnitude of Residual Risk	Any long-term effect on contamination will be the result of natural attenuation processes only.	Any long-term effect on contamination will be the result of natural attenuation processes only. Aquifer-use restrictions will provide a permanent means for protection against direct exposure to the contaminated surficial groundwater.	Provides an effective means of intercepting contaminated groundwater and blocking its discharge to Brinson Creek for as long as it remains in operation. Aquifer-use restrictions will provide a permanent means for protection against direct exposure to the contaminated surficial groundwater.	Provides an effective means of intercepting and treating contaminated groundwater prior to its discharge to Brinson Creek for as long as it remains in operation. Toxic vapors escaping to the air due to poor vapor extraction may increase risk to community. Aquifer-use restrictions will provide a permanent means for protection against direct exposure to the contaminated surficial groundwater.	Provides an effective means of intercepting and treating contaminated groundwater prior to its discharge to Brinson Creek for as long as it remains in operation. Aquifer-use restrictions will provide a permanent means for protection against direct exposure to the contaminated surficial groundwater.
• Adequacy and Reliability of Controls	Not Applicable.	Aquifer-use restrictions are reliable if enforced. Enforcement is likely as Camp Geiger is a controlled military installation. The proposed highway right-of-way will continue to be controlled by the Marine Corps, indefinitely, under lease to NCDOT.	Interceptor trench involves basic technology and should be adequate and reliable for an indefinite period.	Air sparging has a long track record of commercial use and should be able to be controlled adequately and reliably for an indefinite period. High levels of metals in groundwater could short circuit the system prompting frequent maintenance. Well replacement over several years may result.	In well aeration is a relatively new technology without a substantial commercial track record. High levels of metals could short circuit the system prompting frequent maintenance. Well replacement over several years may result.
• Estimated Period of Operation	30 Years	30 Years	30 years unless additional active treatment actions are implemented upgradient.	30 years unless additional active treatment actions are implemented upgradient.	30 years unless additional active treatment actions are implemented upgradient.
• Need for 5-Year Review	Review required because no active treatment is included	Review required because no active treatment is included.	Review required because area impacted by treatment will be limited.	Review required because area impacted by treatment will be limited.	Review required because area impacted by treatment will be limited.

TABLE 5-5 (Continued)

SUMMARY OF DETAILED ANALYSIS
OPERABLE UNIT NO. 10 (SITE 35)
INTERIM FEASIBILITY STUDY, CTO-0232
MCB CAMP LEJEUNE, NORTH CAROLINA

Evaluation Criteria	RAA 1 No Action	RAA 2 No Action with Institutional Controls	RAA 3 Groundwater Collection and On-Site Treatment	RAA 4 In Situ Air Sparging and Off-Gas Carbon Adsorption	RAA 5 In Well Aeration and Off-Gas Carbon Adsorption
REDUCTION OF TOXICITY, MOBILITY, OR VOLUME THROUGH TREATMENT					
• Treatment Process Used	No active treatment process applied.	No active treatment process applied.	On-site groundwater treatment includes filtration, metals precipitation, air stripping, air and water carbon adsorption.	In situ volatilization and biodegradation. Off-gas carbon adsorption.	In situ volatilization and biodegradation. Off-gas carbon adsorption.
• Reduction of Toxicity, Mobility or Volume	No reduction except by natural attenuation.	No reduction except by natural attenuation.	Reduction of organic and inorganic contaminants expected within capture zone of trench.	Reduction of organic contaminants expected within radius of influence of wells.	Reduction of organic contaminants expected within radius of influence of wells.
• Residuals Remaining After Treatment	No active treatment process applied.	No active treatment process applied.	Residuals include metals sludge and spent carbon which would have to be disposed of properly.	Residuals requiring disposal include spent carbon and a small volume of condensed contaminated vapor (water).	Residuals requiring disposal include spent carbon and a small volume of condensed contaminated vapor (water).
• Statutory Preference for Treatment	Not satisfied.	Not satisfied.	Satisfied except that area impacted by treatment is limited and does not include entire plume of contaminated surficial groundwater.	Satisfied except that area impacted by treatment is limited and does not include entire plume of contaminated surficial groundwater.	Satisfied except that area impacted by treatment is limited and does not include entire plume of contaminated surficial groundwater.
SHORT-TERM EFFECTIVENESS					
• Community Protection	Risks to community not increased by remedy implementation.	Risks to community not increased by remedy implementation.	Minimal, if any, risks during collection and treatment.	Possible migration of toxic vapors through ground surface because vapor extraction is difficult to control when groundwater surface is within several feet of ground surface.	Minimal, if any, risks during operation and treatment.
• Worker Protection	None.	Protection required during well installation and sampling.	Trench installation procedure limits worker exposure by design.	Minimal potential for worker exposure.	Minimal potential for worker exposure.

TABLE 5-5 (Continued)

SUMMARY OF DETAILED ANALYSIS
OPERABLE UNIT NO. 10 (SITE 35)
INTERIM FEASIBILITY STUDY, CTO-0232
MCB CAMP LEJEUNE, NORTH CAROLINA

Evaluation Criteria	RAA 1 No Action	RAA 2 No Action with Institutional Controls	RAA 3 Groundwater Collection and On-Site Treatment	RAA 4 In Situ Air Sparging and Off-Gas Carbon Adsorption	RAA 5 In Well Aeration and Off-Gas Carbon Adsorption
• Environmental Impacts	Continued impacts from unchanged existing conditions.	Continued impacts from unchanged existing conditions.	Wetlands disturbance during installation could be significant. Trench will serve as a barrier for contaminated groundwater discharge to Brinson Creek.	Minimal wetlands disturbance. System will serve as a barrier for contaminated groundwater discharge to Brinson Creek.	Minimal wetlands disturbance. System will serve as a barrier for contaminated groundwater discharge to Brinson Creek.
• Installation Period	Not Applicable.	Less than 30 days required to install additional groundwater monitoring wells.	60 to 90 days estimated to install trench and treatment system.	60 to 90 days estimated to install sparging and SVE wells and treatment system.	60 to 90 days estimated to install aeration wells and treatment system.
IMPLEMENTABILITY					
• Ability to Construct and Operate	No construction or operation activities.	Involves standard well installation and sampling only.	Soft ground in wetlands areas may hamper construction and result in delays. Once installed, operating is straightforward using commercially proven technology. Approximately 2,000 to 3,000 cubic yards of potentially contaminated soil excavated from the trench will require disposal. Lack of access may be a significant lost factor.	Construction of activities involve primarily well installation which has been previously executed successfully in this area. Disposal of drill cuttings required. Thin vadose zone may hamper effective vapor extraction which could result in the release of toxic vapors to atmosphere. High metals in groundwater could clog well screens which would require frequent maintenance or well replacement.	Construction of activities involve primarily well installation which has been previously executed successfully in this area. Disposal of drill cuttings required. High metals in groundwater could clog well screens which would require frequent maintenance or well replacement.
• Ability to Monitor Effectiveness	No monitoring.	Proposed monitoring will provide an indication of effects of natural attenuation and progress of contaminants migration.	Proposed monitoring will give notice of failure so that system can be adjusted before a significant contaminant release occurs.	Proposed monitoring will give notice of failure so that system can be adjusted before a significant contaminant release occurs.	Proposed monitoring will give notice of failure so that system can be adjusted before a significant contaminant release occurs.
• Availability of Services and Equipment	None required.	Well installation and sampling services available from multiple vendors.	Biopolymer trench technology available from a limited number of vendors.	Air sparging technology is available from multiple vendors.	In well aeration is a patented priority technology currently available from only one vendor.

TABLE 5-5 (Continued)

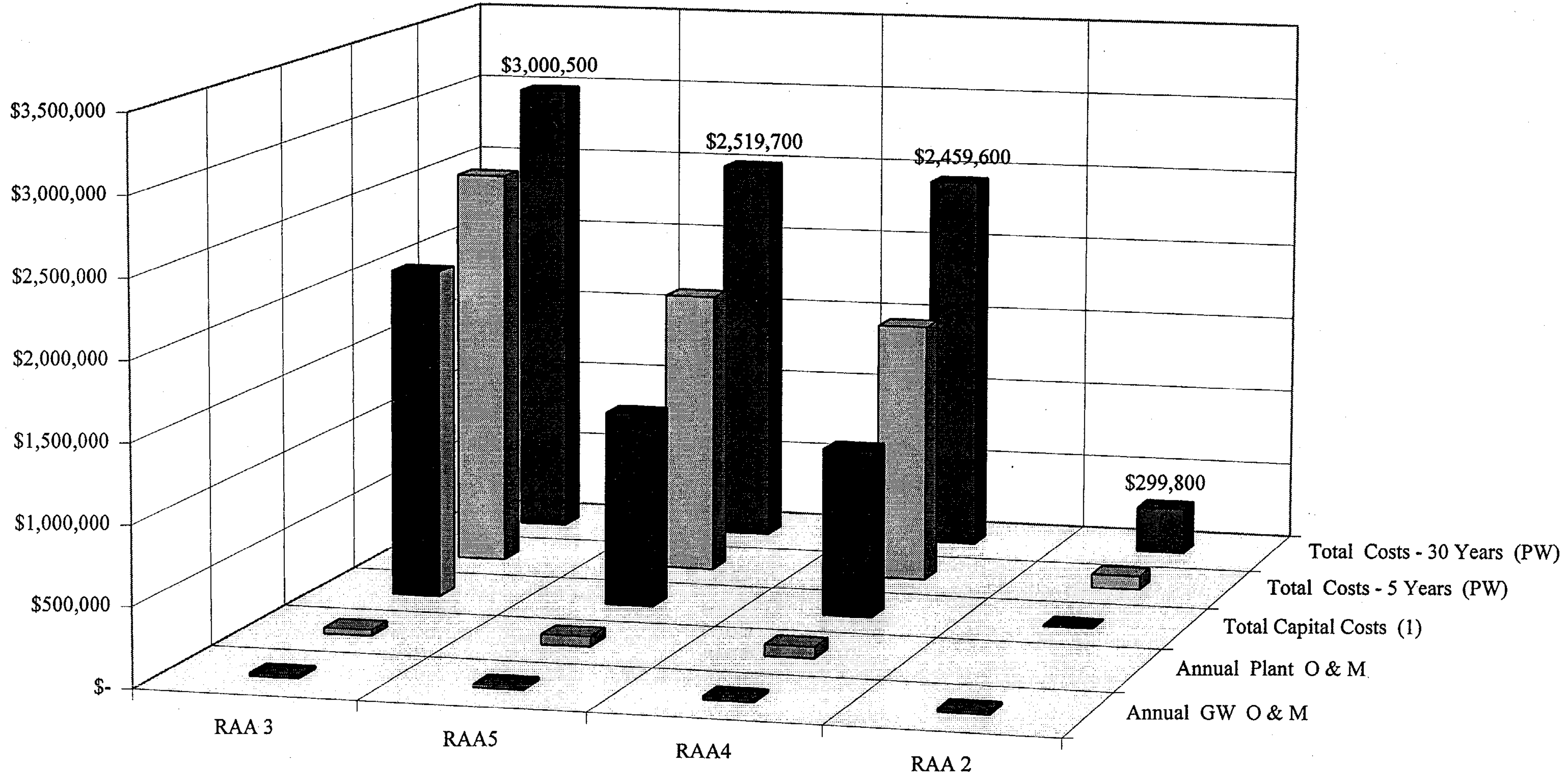
SUMMARY OF DETAILED ANALYSIS
OPERABLE UNIT NO. 10 (SITE 35)
INTERIM FEASIBILITY STUDY, CTO-0232
MCB CAMP LEJEUNE, NORTH CAROLINA

Evaluation Criteria	RAA 1 No Action	RAA 2 No Action with Institutional Controls	RAA 3 Groundwater Collection and On-Site Treatment	RAA 4 In Situ Air Sparging and Off-Gas Carbon Adsorption	RAA 5 In Well Aeration and Off-Gas Carbon Adsorption
• Requirements for Agency Coordination	None required.	Must submit semi-annual reports to document sampling reports.	None required, provided the intent of wetland and air and water discharge permits are met.	None required, provided the intent of wetland and air and water discharge permits are met.	None required, provided the intent of wetland and air and water discharge permits are met.
COSTS					
• Net Present Worth (30 years)	$0	$299,800	$3,000,500	$2,459,600	$2,519,700

SECTION 5.0 FIGURES

FIGURE 5 - 1

COMPARISON OF COSTS
RAAs 2, 3, 4, and 5
SITE 35 - CAMP GEIGER FUEL FARM
MCB CAMP LEJEUNE, NC



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APPENDIX A
RISK-BASED ACTION LEVEL CALCULATIONS

INGESTION OF GROUNDWATER ACTION LEVEL
FEASABILITY STUDY
CTO-0232
MCB CAMP LEJEUNE
FUTURE ADULT RESIDENT

*C = TR or THI * BW * ATc or ATnc * DY / IRw * EF * ED * CSF or 1/RfD*

Where:	INPUTS
C = contaminant concentration in water ((ug/L)	
TR = total lifetime risk	1E-04
THI = total hazard index	1
CSF = carcinogenic slope factor	specific
RfD = reference dose	specific
IRw = daily water ingestion rate (L/Day)	2
EF = exposure frequency (days/yr)	350
ED = exposure duration (yr)	30
BW = body weight (kg)	70
ATc = averaging time for carcinogen (yr)	70
ATnc = averaging time for noncarcinogen (yr)	30
DY = days per year (day/year)	365

Note: Inputs are scenario and site specific

Contaminant	Concentration Carcinogen (ug/l)	Ingestion Rate (L/day)	Exposure Frequency (day/year)	Exposure Duration (year)	Body Weight (kg)	Average Carc Time (years)	Days per year (day/yr)	Slope Factor (mg/kg-day)-1	Target Excess Risk
Trichloroethene	774	2	350	30	70	70	365	1.10E-02	1.0E-04
Benzene	294	2	350	30	70	70	365	2.90E-02	1.0E-04
Arsenic	5	2	350	30	70	70	365	1.70E+00	1.0E-04
Beryllium	2	2	350	30	70	70	365	4.30E+00	1.0E-04

Contaminant	Concentration Noncarcinogen (ug/L)	Ingestion Rate (L/day)	Exposure Frequency (day/year)	Exposure Duration (year)	Body Weight (kg)	Average Noncarc Time (years)	Days per year (day/yr)	Reference Dose (mg/kg-day)	Target Hazard Index
Trichloroethene	219	2	350	30	70	30	365	6.00E-03	1
cis-1,2-Dichloroethene	365	2	350	30	70	30	365	1.00E-02	1
trans-1,2-Dichloroethene	730	2	350	30	70	30	365	2.00E-02	1
Ethyl Benzene	3650	2	350	30	70	30	365	1.00E-01	1
Methyl Tertiary Butyl Ether	183	2	350	30	70	30	365	5.00E-03	1
Toluene	7300	2	350	30	70	30	365	2.00E-01	1
Xylenes	73000	2	350	30	70	30	365	2.00E+00	1
Naphthalene	1460	2	350	30	70	30	365	4.00E-02	1
Antimony	15	2	350	30	70	30	365	4.00E-04	1
Arsenic	11	2	350	30	70	30	365	3.00E-04	1
Barium	2555	2	350	30	70	30	365	7.00E-02	1
Beryllium	183	2	350	30	70	30	365	5.00E-03	1
Cadmium	18	2	350	30	70	30	365	5.00E-04	1
Cobalt	2190	2	350	30	70	30	365	6.00E-02	1
Copper	1354	2	350	30	70	30	365	3.71E-02	1
Manganese	183	2	350	30	70	30	365	5.00E-03	1
Mercury	11	2	350	30	70	30	365	3.00E-04	1
Nickel	730	2	350	30	70	30	365	2.00E-02	1
Selenium	183	2	350	30	70	30	365	5.00E-03	1
Vanadium	256	2	350	30	70	30	365	7.00E-03	1
Zinc	10950	2	350	30	70	30	365	3.00E-01	1

File Name: GWIC.WQ1

INGESTION OF GROUNDWATER ACTION LEVEL
FEASABILITY STUDY
CTO-0232
MCB CAMP LEJEUNE
FUTURE CHILD RESIDENT

C = TR or THI * BW * ATc or ATnc * DY / IRw * EF * ED * CSF or 1/RfD

Where:	INPUTS
C = contaminant concentration in water ((ug/L)	
TR = total lifetime risk	1E-04
THI = total hazard index	1
CSF = carcinogenic slope factor	specific
RfD = reference dose	specific
IRw = daily water ingestion rate (L/Day)	1
EF = exposure frequency (days/yr)	350
ED = exposure duration (yr)	6
BW = body weight (kg)	15
ATc = averaging time for carcinogen (yr)	70
ATnc = averaging time for noncarcinogen (yr)	6
DY = days per year (day/year)	365

Note: Inputs are scenario and site specific

Contaminant	Concentration Carcinogen (ug/l)	Ingestion Rate (L/day)	Exposure Frequency (day/year)	Exposure Duration (year)	Body Weight (kg)	Average Carc Time (years)	Days per year (day/yr)	Slope Factor (mg/kg-day)-1	Target Excess Risk
Trichloroethene	1659	1	350	6	15	70	365	1.10E-02	1.0E-04
Benzene	629	1	350	6	15	70	365	2.90E-02	1.0E-04
Arsenic	11	1	350	6	15	70	365	1.70E+00	1.0E-04
Beryllium	4	1	350	6	15	70	365	4.30E+00	1.0E-04

Contaminant	Concentration Noncarcinogen (ug/L)	Ingestion Rate (L/day)	Exposure Frequency (day/year)	Exposure Duration (year)	Body Weight (kg)	Average Noncarc Time (years)	Days per year (day/yr)	Reference Dose (mg/kg-day)	Target Hazard Index
Trichloroethene	94	1	350	6	15	6	365	6.00E-03	1
cis-1,2-Dichloroethene	156	1	350	6	15	6	365	1.00E-02	1
trans-1,2-Dichloroethene	313	1	350	6	15	6	365	2.00E-02	1
Ethyl Benzene	1564	1	350	6	15	6	365	1.00E-01	1
Methyl Tertiary Butyl Ether	78	1	350	6	15	6	365	5.00E-03	1
Toluene	3129	1	350	6	15	6	365	2.00E-01	1
Xylenes	31286	1	350	6	15	6	365	2.00E+00	1
Naphthalene	626	1	350	6	15	6	365	4.00E-02	1
Antimony	6	1	350	6	15	6	365	4.00E-04	1
Arsenic	5	1	350	6	15	6	365	3.00E-04	1
Barium	1095	1	350	6	15	6	365	7.00E-02	1
Beryllium	78	1	350	6	15	6	365	5.00E-03	1
Cadmium	8	1	350	6	15	6	365	5.00E-04	1
Cobalt	939	1	350	6	15	6	365	6.00E-02	1
Copper	580	1	350	6	15	6	365	3.71E-02	1
Manganese	78	1	350	6	15	6	365	5.00E-03	1
Mercury	5	1	350	6	15	6	365	3.00E-04	1
Nickel	313	1	350	6	15	6	365	2.00E-02	1
Selenium	78	1	350	6	15	6	365	5.00E-03	1
Vanadium	110	1	350	6	15	6	365	7.00E-03	1
Zinc	4693	1	350	6	15	6	365	3.00E-01	1

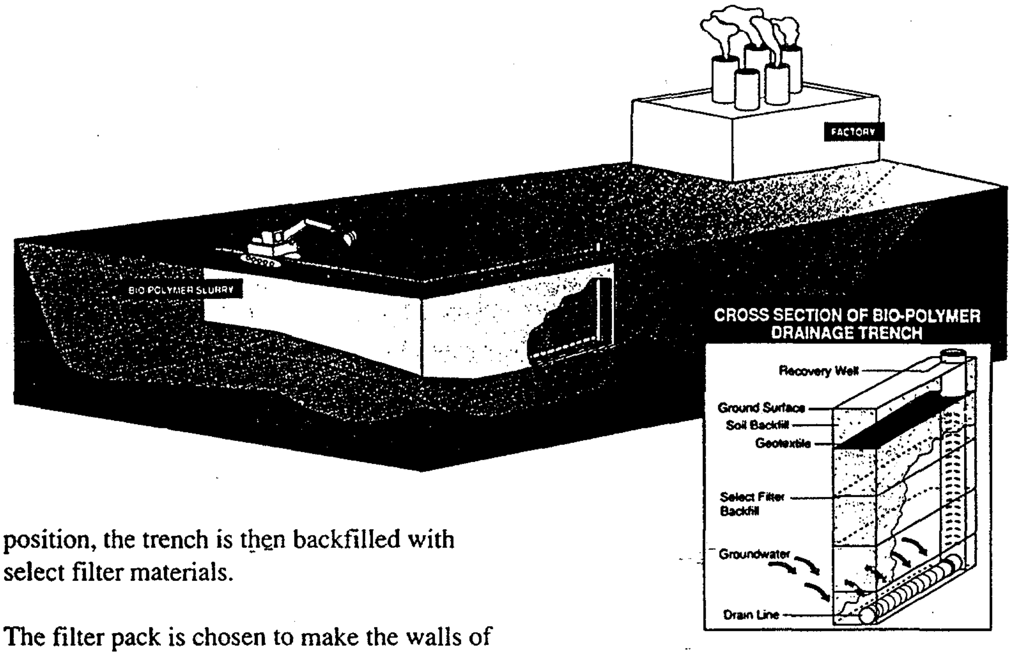
File Name: GWIC.WQ1

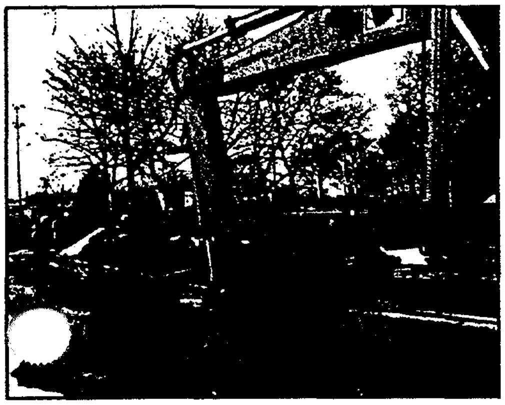
APPENDIX B
INTERCEPTION TRENCHES

Bio-Polymer Slurry Drainage Trenches

SER

The Bio-Polymer Slurry Drainage Trench method is used to install deep drainage trenches to collect or remove contaminated groundwater for treatment and/or disposal. Through the use of a natural, biodegradable slurry, the walls of a trench excavation can be supported without the traditional and expensive use of sheeting, shoring, or dewatering. This allows personnel to install the proper drainage structures without entering the trench. Compared to other trenching methods, this technique is safer and extremely cost-effective in areas with a high groundwater table and unstable soil conditions.





(ABOVE) Workers place a perforated drain line into position through the Bio-Polymer slurry.

Trench Construction

A Bio-Polymer Slurry Drainage Trench is constructed in much the same manner as a typical slurry cut-off wall. However, unlike a bentonite-clay slurry, a biodegradable Bio-Polymer slurry supports the walls of the trench temporarily while excavated materials are removed and drainage structures are installed. The Bio-Polymer slurry then naturally biodegrades after the trench is backfilled. Hence, a permeable wall is left intact.

The Bio-Polymer Slurry Drainage Trench is constructed by excavating a narrow trench which is supported by the simultaneous pumping of the slurry into the excavation. [illegible] the excavation of the trench, the drainage and/or extraction structures (well casings, perforated pipes, etc.) can be installed through the slurry to required depths. When these structures are in position, the trench is then backfilled with select filter materials.

The filter pack is chosen to make the walls of the natural formation more permeable and to minimize the migration of silt into the drainage system. The filter pack materials are selected to assure good porosity and hydraulic conductivity. In situations where silt migration is a factor, a geotextile can be installed over the filter material to prevent silt from entering into the trench.

After the trench is completely installed and backfilled, the remaining Bio-Polymer slurry is converted back to a water/carbohydrate solution by the inclusion of a breaker agent or by the natural enzymes existing in the soil.

(ABOVE) The crew positions a geotextile in the trench, which will then be backfilled. The geotextile will prevent silt migration into the trench.

Advantages & Applications

- Cost-effective for use in high groundwater and unstable soil conditions
- Contain plumes of contaminated groundwater
- Eliminate expensive cost of sheeting and shoring
- Recovery of contaminated groundwater
- Contain seepage or leakage from ponds and lagoons
- Eliminate dangers of personnel working in trench
- Biodegradable - environmentally safe
- Provides flexibility in engineering groundwater recovery systems
- Eliminate dewatering and treatment of dewatering liquids
- Narrower trench produces savings in the quantities of excavation/ backfill material, and lowers disposal costs

GRS

Griffin Remediation Services
an affiliated company of Griffin Dewatering Corp.

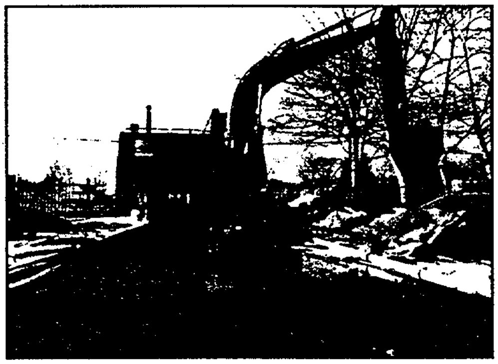
The Importance of Trench Development

Any method of trench excavation, whether employing an earth support system such as sheeting or a Bio-Polymer slurry, causes damage to the recovery system by clogging the pores of the aquifer trench walls and accumulating suspended fines in the gravel backfill. The result is a reduction in the porosity and permeability of the formation and a lessening of the hydraulic conductivity of the gravel backfill.

Trench development procedures are the final and most important step in trench installation. The objectives of development are to clear the fine material from the trench walls, clean the damaged aquifer and remove the fine material from the trench. Trench development procedures are similar to water well development procedures used in artificially packed wells. The drainage trench, in essence, is a horizontal well with the same high yielding characteristics of a water well.

A[illegible] the drainage lines or extraction wells are successfully developed, recovered groundwater can be pumped to an on-site treatment facility or to a storage tank for disposal. ■

(ABOVE) After excavation of the trench, a drain pipe is attached to a well casing. It is then placed through the Bio-Polymer slurry to the specified depths.



(ABOVE) A hydraulic excavator constructs the trench, while the Bio-Polymer slurry supports the walls of the excavation.

(ABOVE) Workers hold drainage pipe and well casing in position, while the trench is backfilled with a filter material.

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To find out more about GRS's specialty contractor services or to discuss specific projects, call a representative at one of the following regional offices:

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  (402) 331-5000
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- Ontario, CA
  (714) 986-4498
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- Jacksonville, FL
  (904) 781-8790

Project Profile: Groundwater Interception Trenches and Wells Utilizing the Bio-Polymer Slurry Drain Technique

GRS recently completed a major groundwater recovery system installation using the Bio-Polymer Slurry Drain Technique at an East Coast manufacturing facility. Site assessments revealed that the soil and groundwater were contaminated with TCE, vinyl chlorides, volatile organics and heavy metals as a result of previous manufacturing processes.

The project required GRS to install eight separate interception trenches to various depths along with several recovery wells at numerous locations throughout the site. The trench excavations were supported by the Bio-Polymer Slurry method. The slurry was premixed at a central location and then stored temporarily in tanks prior to excavation. When excavation began, the slurry was pumped through 6-inch PVC pipe to correct trench locations.

[illegible] the excavation of [illegible] trench, a [illegible] drain pipe attached to a well [illegible] through the slurry to [illegible] pipe and [illegible] position [illegible] backfilled with [illegible] Site conditions warranted [illegible] over the filter material [illegible] the trench.

The drain lines were developed after each trench was completely backfilled and the geotextile liners installed. Development discharge water was pumped into a temporary storage area to await proper disposal. All GRS work was performed in level "D" conditions.

EXTRACTION/INTERCEPTION TRENCHES BY THE BIO-POLYMER SLURRY DRAINAGE TRENCH TECHNIQUE

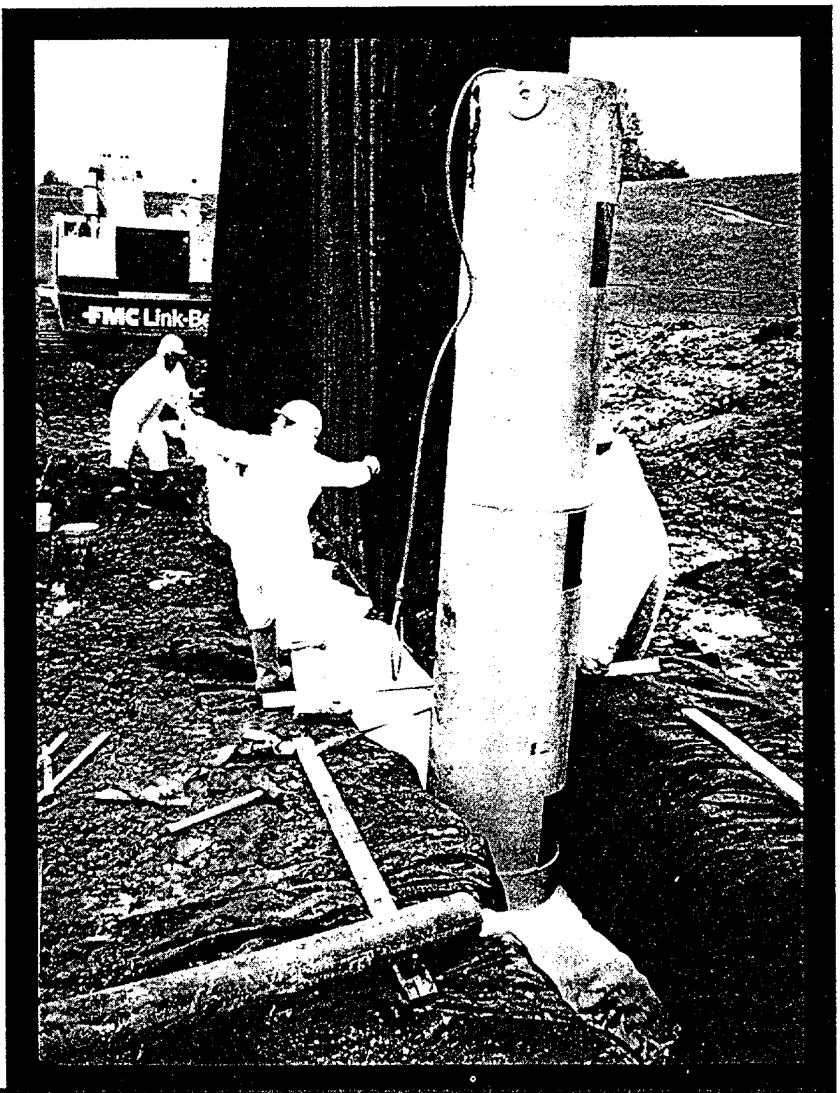
Steven R. Day

The installation of deep drainage trenches has long been a risk-filled and costly endeavor.Conventional installation techniques involve dewatering, sheeting, and shoring; in addition, personnel working in the trench face the danger of trench collapse. Recently, there has been an increased demand for deeper and more sophisticated groundwater extraction and interception trenches. These trenches are even more difficult to construct because of the volatilization of toxins and increased groundwater and trench spoil disposal restrictions and costs.

The introduction of a new construction method, the Bio-Polymer Slurry Drainage Trench (B-P drain), offers a quicker, safer, more cost-effective method to install deep drainage trenches. This method is a modification of the well-known slurry trench method, and uses a biodegradable trenching slurry to temporarily support the trench walls and control trench width. Using the B-P drain method, the usual drainage structures (wells, perforated pipes, and free-draining aggregates) can be placed without dewatering, sheeting or shoring, or the risk of having personnel working in the trench. Experienced personnel and quality control are especially critical in constructing B-P drains.

Construction methods

Trench excavation and support. Slurry trench construction is a well-established



Installation of geofabric in Bio-Polymer trench; tremie pipe in foreground technique for installing groundwater control and/or deep foundation systems to great depths at a minimum cost. Generally, a bentonite-clay slurry fills the excavation to support the side walls and permit the creation of a narrow, vertical trench. In the typical slurry trench, the bentonite-clay slurry cakes on the trench walls and plugs porous formations creating a hydraulic barrier. A slurry wall is formed by replacing the slurry with a permanent, engineered backfill. Trench stability is maintained during construction by controlling slurry properties (density, viscosity, etc.) and by keeping the level of slurry in the trench above the groundwater table.

With the B-P drain method, a biodegradable slurry is used in a manner similar to the bentonite-clay slurry technique, except that the B-P slurry does not form a cake or permanently impede groundwater flow. After excavation and backfilling are complete, the B-P slurry can be treated with additives to convert it to water and a very small amount of natural carbohydrate.

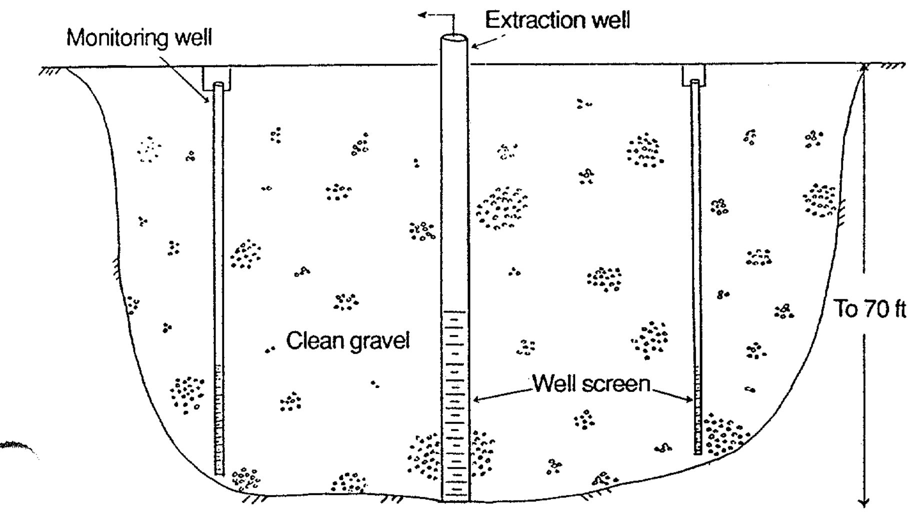
Compared with more traditional trenching methods, B-P drain construction is simpler, safer, faster, and usually less costly. Trench support is provided by the slurry, eliminating sheeting and shoring, trench shields, and bracing. Since the trench is filled with slurry, no workers can enter the trench. The slurry trench method also eliminates dewatering and the necessity of treating dewatering liquids. B-P drains can be constructed much narrower than trenches constructed by traditional methods, because internal supports are unnecessary. This provides an additional savings in excavation, disposal, and backfill material volumes and costs.

B-P drains usually are excavated with a hydraulic excavator. Depths to 70 ft are possible using custom-built hydraulic excavators with extended reach capabilities. The design width of the trench (usually 18 to 36 inches) is ensured by using a back hoe bucket of the same width. An earthen pad (working platform) is created prior to trenching by leveling the trench alignment to provide room for the temporary storage and drainage of trench spoil removed during excavation. A level working platform is required to maintain the slurry level in the trench at an acceptable elevation. In the case of highly contaminated soils, the working platform may be lined to prevent additional contamination. All excavation is carried out under slurry; continuity, depth, and soil conditions are determined by observations of the construction process and soils discharged from the excavator bucket.

Drain backfill and structures. Depending on the purpose and design of the drainage trench, different materials and structures can be placed through the slurry into the trench. The simplest systems involve the placement of a coarse aggregate (pea gravel) around well casings spaced in the trench (Figure 1). Well casings are lowered vertically into the trench, through the slurry, with the pea gravel tremie placed around the well to maintain the alignment of the casing. The trench between wells is also filled with pea gravel by end-dumping backfill down the backfill slope to ensure proper displacement of the slurry. If a finer or graded aggregate (sand or gravel) is used, it must be wetted first with slurry to permit tremie placement. Filter fabrics and geomembranes (geofabrics) also can be placed through the slurry into the trench to line the trench walls. The placement of geofabrics is facilitated by attaching weights to the geofabric to provide ballast. Continuity of the geofabrics is provided by overlapping the geofabric sheets by at least 5 ft.

FIGURE 1

Profile of typical B-P trench



When design considerations dictate that a horizontal drain pipe be used along the bottom of the trench, it can be installed by the B-P drain method. Using a flexible pipe, corrugated for strength, a separate pipe laying machine travels behind the hydraulic excavator laying the pipe through the slurry while simultaneously bedding and backfilling around the pipe. Additional backfill can be placed by end loader to bring the backfill to grade. Small diameter sumps or wells (4 to 24 inch diameter) are either attached directly to the drain pipe or placed directly beside the drain pipe perforations for continuity.

Since the backfill is placed through slurry, the aggregate must extend to near the surface to displace the slurry and maintain trench stability. The top 3 to 5 ft of the drainage trench usually are backfilled with excess trench spoil or other soil to cap the trench. This zone may also support buried vaults, discharge piping and pump controls so that all drainage structures are buried and hidden from view.

Design and quality control

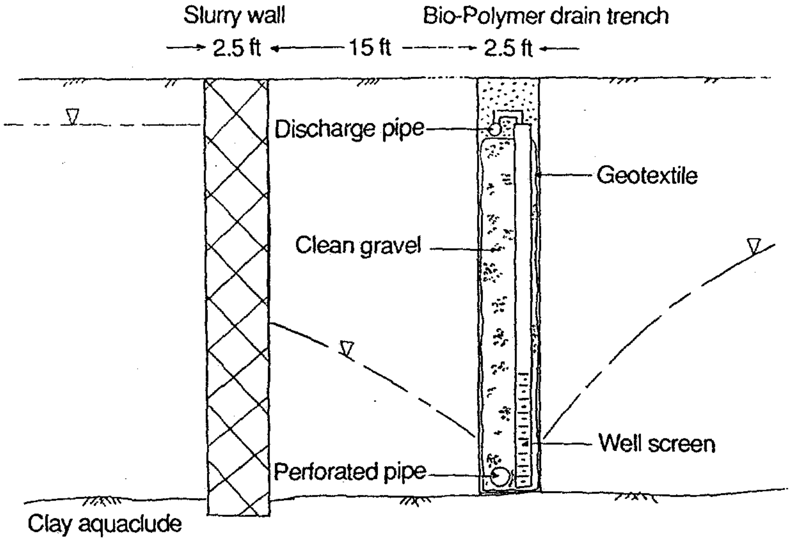
Design considerations. The design of a B-P drain should combine the project requirements, soil conditions, pollutant characteristics, and installation procedure into a reasonable solution. A B-P drain can serve as a groundwater cutoff, plume extraction trench, groundwater interceptor trench, injection trench, and/or shallow groundwater skimmer. In some cases, well points or conventional deep wells may not function effectively or efficiently; often a B-P drain with a single well can replace an entire array of conventional wells.

The continuity provided by a B-P drain can be especially advantageous. Soils that typically produce poor groundwater yield can be effectively drained by B-P drains; preferential groundwater conduits such as sand seams, buried conduits, and root holes that are difficult to intercept with other methods can be effectively intercepted and collected.

Groundwater conditions and pollutant characteristics may dictate the depth of the drainage trench. A high groundwater table and a floating pollutant (e.g., petroleum) may permit the design of a relatively shallow drainage trench that intercepts the groundwater table at an elevation sufficiently deep to overcome seasonal groundwater fluctuations. A deep groundwater table or a pollutant heavier than water may require a much deeper trench.

FIGURE 2

Cross-section of groundwater contaminant and extraction system



Soil conditions affect both the type of drainage structures and the backfill requirements. Silty soils can migrate to a drain and plug the backfill, thus limiting *the drain's effectiveness or fouling* pumps. A filter fabric can be used to protect an open graded backfill, or a backfill with an engineered gradation can be designed for the trench based on filter criteria.

When the drainage trench is designed to provide a positive groundwater cutoff in highly permeable *soils, a perforated pipe on the bottom of* the trench may be necessary. Alternatively, the drain can be installed deeper to allow a lower operating head. In many cases, a slurry cutoff wall can be economically combined with the B-P drain for a positive cutoff and more efficient groundwater collection (Figure 2).

In general, conventional manholes or lift stations are not recommended for a number of reasons. First, conventional manholes typically used for sanitary sewers constitute a confined space that can allow unintentioned access. The presence of contaminated groundwater makes entry into such an environment potentially hazardous even for the well-trained worker. Second, pumps, control facilities, and access can be provided through conventional well equipment at a much lower installation cost. Duplex systems can be provided using multiple well casings for backup pumps. Third, conventional manholes must be constructed by conventional means (sheeting, shoring, and dewatering) negating a significant portion of the savings and time provided by the B-P drain installation. Finally, concrete manholes are sealed structures attached to the drain field only through the perforated pipe. A much larger radius of influence can be provided by using a perforated sump or well and in the case of failure of the drainage pipe, the perforated sump or well provides a safety factor for ensuring the continued service of the drainage trench.

Quality control. The control and monitoring of construction quality for a B-P *drain installation focus on the* properties of the bio-polymer slurry. Adequate control of the slurry is required to support the trench and permit the proper placement of the backfill during construction. In addition, the safe and effective treatment of the slurry after construction is necessary to ensure that the drain is activated and fully functional.

The bio-polymer slurry consists of ground guar beans, water, and proprietary degradable additives. A suspension of the guar and water at very low percentages (approximately 1%) creates a viscous, pseudoplastic slurry capable of supporting an earthen trench. Additives are used to control and extend the life of the slurry. Without additives, enzymes in the soil will quickly cause the slurry to "break"—or degrade and become ineffective— in approximately one day.

Primary quality control parameters for the slurry are viscosity, density, filtrate loss, and pH. All monitoring and testing should be performed by an experienced bio-polymer slurry engineer. Chemical adjustments to the slurry are made to both fresh and trench slurry to extend the working life. Depending on the grade of guar, a target viscosity of 40 cP is typically used to ensure adequate guar content. Titrations of the slurry are performed as needed to calculate additive requirements. The slurry pH is maintained at 8.0 or higher to limit enzyme action during excavation. Tests on the filtrate properties of the slurry indicate that the slurry does temporarily seal off the trench wall, but instead of a filter cake (as with bentonite slurry), a very thin, slimy, gelatin-like substance bridges over porous formations to support the trench with its high gel strength.

Once construction is complete, the slurry must be broken and the drain developed much like a water well is developed. First, the pH of the slurry is reduced to below 7 to initiate enzyme action, then a proprietary enzyme breaker solution is added to ensure biodegradation. The drain is now functional, but residue from the guar can degrade slowly or incompletely due to toxins in the groundwater causing anaerobic digestion in the trench and/or an unpleasant odor. To alleviate this problem and to ensure that the drain is fully functional, the drain is continuously pumped and recirculated while metering in additives to inhibit anaerobic digestion. Chlorine, typically used in water well development, can be used to help develop a B-P drain, but only under the strictest controls, as untimely or over-application of chlorine can produce toxic byproducts. Pumping and flushing continue for one day or several days depending on the size of the drain and the permeability of the native soils.

When the drain is fully developed, the flush water should be clear and free of slurry and the trench continuity obvious. Excess waters usually have been disposed of through a municipal wastewater treatment plant or held for priority pollutant testing and flushed into the storm water sewer system.

Evidence from past projects has shown that construction creates a small groundwater mound around the trench which temporarily limits the inflow of contaminated water. Usually, pollutants in the groundwater are absent in the recovered B-P slurry. With continued pumping, the drain installation results in a line sink and pollutants are again collected in the groundwater.

Applications

Over the past decade there have been several dozen B-P drains constructed in the United States and Europe. Most applications in Europe were intended for the interception of groundwater to stabilize and dewater slopes along highways, while applications in this country have concentrated on contaminated groundwater remediation. The following recently completed projects illustrate recent applications in the United States and the variety and magnitude of projects now being pursued.

Pilot project in New Jersey. An older pharmaceutical manufacturing plant in a highly developed urban area had leaked vinyl chloride, trichloro-ethylene (TCE), PCBs and other toxins into the groundwater. The congestion of the site and cost of conventional construction provided encouragement for the engineers to seek a solution to the groundwater extraction problem by using a B-P drain. The pilot project design called for a 100-ft long trench, 2 to 3 ft wide and 27 ft deep constructed through silts, peat, and a groundwater table within 2 ft of the surface. Because TCE is heavier than water, the drain used a 6-in. perforated corrugated pipe along the bottom of the trench, which terminated in an 18-inch diameter polyethylene sump. The B-P drain was installed in approximately one week, flushed, developed, and ready for pumping into an on-site treatment plant. Monitoring wells were placed inside the trench and alongside the trench perimeter.

More than a year of monitoring and testing have proven the success of this drainage trench. Pumping rates of 3 to 10 gpm are currently used. The pea gravel backfill used has shown no plugging or fouling problems to date. Due to the success of the pilot project, 10 more short deep B-P drains are planned to fully remediate the hot spots on the two square block area at the site.

One of the most significant advantages of the installation was the complete lack of toxic volatilization. Monitoring wells within 4 ft of the trench alignment gave consistently high readings of volatiles. The B-P slurry temporarily blocked these toxins during construction and permitted the safety level of the work to be down graded from Level B (supplied air respirators) to Level D (street clothes).

Interceptor trench in Missouri. At a munitions plant in Missouri, solvents used in the manufacturing process—including TCE—had escaped the property, and the plume was traveling toward a nearby river. Soils at the site consisted of clay over gravel over bedrock, with the plume traveling on top of the bedrock. Conventional well spacing design was found to be so close that a deep drainage trench became a practical necessity. The trench was 250 ft long, 3 ft wide, and 30 ft deep with a woven geotextile envelope around a pea gravel backfill. A 6-in. diameter stainless steel well casing was placed in the center of the trench for pumping with six-in. diameter PVC monitoring wells on each end of the trench. The trench was installed in approximately one week. The B-P slurry was broken and the drainage trench developed by pumping. Prior to completion, the continuity of the installation was demonstrated by pumping the central well and observing the immediate response of the monitoring wells.

Extraction trench in central California. An oil company in central California owned a service station found to be leaking gasoline into two aquifers under the site. Silty sands and cemented sands limited the effectiveness and continuity of conventional extraction well systems. In addition, the groundwater gradients in the two aquifers flowed in different directions making two deep trenches with different alignments a distinct advantage. Two trenches were constructed with 18-in. diameter stainless steel wells placed in a graded filter backfill. The deeper trench was 65 ft deep and 170 ft long, and had an impervious backfill material placed over the graded filter backfill zone to maintain the separation between the aquifers. The second trench was 35 ft deep and 240 ft long. Total construction time for both trenches—including earthwork to level the site topography—was approximately three weeks.

Collection trench in northern California. The operators of a major manufacturing plant feared that spills of processing chemicals might have leaked into the groundwater and affected the pending sale of the property. An on-site treatment and containment system was designed which called for 2,000 ft of B-P drain and a soil-bentonite slurry wall to provide a downgradient groundwater recovery system.

The B-P drain was constructed through clays and silts approximately 15 ft upgradient and parallel to the cutoff wall. The trench was constructed 3 ft wide and approximately 30 ft deep and lined with a woven geotextile. The pipe laying machine laid and bedded a 6-in. diameter perforated pipe through the slurry. Pumping wells 12 inches in diameter and 4-in. diameter monitoring wells were placed in the trench alongside the perforated pipe. Construction time for the entire project was less than two months.

Conclusion

The Bio-Polymer Slurry Drainage Trench method represents a significantly improved method for the construction of deep drainage trenches. The primary advantages are in safety, cost and the ability to employ deep trench applications in problem soils and polluted groundwater. The quality control requirements of the B-P slurry demand that all projects be supervised by experienced, competent experts.

The design of deep drainage trenches by the B-P method should recognize the advantages and limitations of the B-P drain method in design. Most conventional drainage structures and systems can be employed, although large diameter manholes and rigid piping are impractical. The most critical aspects of quality control are in extending the slurry's life during construction and then eliminating the residues of the slurry when the drain is developed.

The B-P drain projects illustrated in this paper show the method to be practical in a variety of soil types, applications, project sizes and with different pollutants. Construction is generally rapid and quite cost-effective.

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Steven R. Day[1] and Christopher R. Ryan[1]

STATE OF THE ART IN BIO-POLYMER DRAIN CONSTRUCTION

REFERENCE: Day, S. R. and Ryan, C. R., "State of the Art in Bio-Polymer Drain Construction," Slurry Walls: Design, Construction, and Quality Control, ASTM STP 1129, David B. Paul, Richard R. Davidson, and Nicholas J. Cavalli, Eds., American Society for Testing and Materials, Philadelphia, 1992.

ABSTRACT: A common feature of civil engineering design is the "french drain," a trench intended to intercept and collect groundwater and transfer it laterally to a sump. The environmental marketplace has created a larger demand for these drains for the purpose of the collection of contaminated groundwater. Traditional construction methods that use trench boxes or shoring, sometimes in combination with dewatering systems, present a number of problems, particularly if the trenches have depths in excess of about five meters.

The Bio-Polymer Slurry Drain (BP Drain) has provided a new method for constructing deep drains that eliminates shoring and dewatering. It does not require a wide excavation, reducing spoil disposal and does not require trench entry by workers, improving safety.

The system uses basic slurry trench technology but, instead of bentonite clay slurry, a guar-gum based slurry is used to maintain the open trench. Once the trench is dug to full depth, it is backfilled with a pervious material such as gravel. Wells can be inserted, pipe laterals can be placed and filter fabric inserted, all under slurry. When the trench is filled, the slurry is chemically and biologically "broken", allowing the slot to collect water.

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This paper reviews the current practice as illustrated by these case studies: a collection trench for oil, another for a chemical containment, and a drain constructed inside a slurry wall at a landfill site. The authors believe that this methodology will be subject to wide application once all of its features and advantages are fully realized.

KEYWORDS: Bio-Polymer, drains, groundwater, collector wells, slurry, construction

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INTRODUCTION

One of the most difficult civil engineering projects has always been the construction of deep drains. By definition, these are constructed through soil profiles with flowing groundwater. Control of the excavation side slopes and construction dewatering are difficult problems. Trench collapse is a leading cause of construction worker injury and death.

The concept of trenching under a slurry has been an intriguing technology. The use of slurries to hold open trenches for impervious barriers and structural concrete slurry walls has been common practice for more than thirty years. In a drain application, however, the bentonite clay slurries commonly used would seal the trench walls from water inflow and defeat the purpose of the drain.

Use of biodegradable slurries has changed the technology. Now trenches can be excavated under slurry, backfilled with a pervious mixture, and the slurry degraded to allow for water infiltration.

To the authors' knowledge, the first U.S. use was a project in San Jose, California. A BP Drain, 17m deep and 200m long, was constructed to collect a diesel spill (Hanford and Day, 1988). Numerous additional applications have been completed in the U.S. market, almost all for environmental cleanups (Day, 1990). A similar process had apparently earlier been used to construct drains for dewatering and slope stabilization in France (Bachy, 1982).

The BP Drain technique provides numerous advantages over conventional construction, some of which are listed below:

<u>Economy</u>—Because the technique does not require dewatering nor sheeting and shoring, it is considerably cheaper to install. Typically it costs less than half of conventional construction.

<u>Schedule</u>—For the same reasons, the time of construction is much less than for conventional trenching methods.

Safety--Since no one enters the excavation with the BP Drain method, the method is much safer. There is also less potential for damage to surrounding structures from excavating or dewatering activities.

Environmental--Since most applications are on contaminated sites, another important advantage of the BP Drain is that it is narrower and generates less excavation spoil. There is also no water generated by temporary dewatering systems.

In the following sections, we look at construction methods, technical factors, and several example case studies.

CONSTRUCTION METHODS

A bio-polymer slurry drainage trench (or BP Drain) is constructed using a modified version of the slurry trench technique. The trench is excavated under slurry using an extended reach hydraulic excavator creating relatively narrow (0.5 to 1.0 meters) trenches up to 20 meters deep. Trench stability is temporarily provided by a polymer based slurry. A permeable backfill (gravel) and extraction structures (wells) are placed in the trench, through the slurry, to complete the construction. Later, the slurry degrades, permitting groundwater to flow through the trench for extraction or injection.

Polymer Slurry

Critical to successful BP Drain construction is the maintenance and control of the slurry. Guar gum based slurries normally remain effective for only about one day unless treated with additives. Slurry life is affected by atmospheric conditions, soil types and construction expertise. Typically, a mud engineer or slurry trench specialist trained in the use and control of bio-polymer systems directs the slurry mixing. Standard tests include viscosity and filtrate (API 13B) along with other slurry tests specified by ASTM D4380. Slurry treatment primarily consists of the addition of pH modifiers and preservatives which can extend the life of the slurry to as much as a few weeks.

Guar gum-based slurries provide a high gel strength (viscosity >40cP) and low water loss (filtrate < 25 ml) which permits the efficient transfer of the elevated hydrostatic head of the slurry to the trench walls thereby providing stability. Most soil types can be supported, as long as a slurry head of 1 meter or more can be maintained in the trench over the local groundwater table.

As an alternative to the guar slurries, there are some synthetic polymers that can be degraded in a similar fashion. To date, synthetic polymers have seen only limited use and only in applications where trench stability is not critical. Synthetic polymers have a very low gel strength (viscosity <15cp) and high water loss (filtrate >50 ml); therefore, they are limited to cases with more stable trench geometry and inherently stable soils. Care must be used in the selection of synthetic polymers since some create toxic byproducts when degraded. With continued research, synthetic polymers may prove useful on a wider variety of sites.

After the trench is backfilled, the bio-polymer slurry must be treated to initiate degradation and the trench flushed to develop the drain. The efficiency of trench flushing is a function of site conditions and the efforts of the contractor. A highly permeable soil and warm weather will encourage rapid flushing and result in limited excess slurry for disposal. Usually, degraded slurry is used to flush and develop the drain by pumping and recirculating at least three pore volumes of the trench. Simple drawdown tests can be used to demonstrate the effectiveness of the development.

In most cases, a small proportion of degraded slurry will remain as excess and must be evaporated, solidified, or disposed of at a waste water treatment facility. The BOD (biological oxygen demand) and COD (chemical oxygen demand) of the degraded slurry are similar and initially in the range of 3000 to 6000 mg/l. As the degradation continues and with successful initial degradation, the BOD may decrease to 1000 mg/l in a week and eventually (about six months) to background levels.

Backfill

Depending on the purpose and design of the drainage trench, different materials can be placed through the slurry into the trench to serve as the permanent, permeable backfill. A typical backfill is a clean, washed gravel such as pea gravel or crushed stone. A backfill with an engineered gradation or a filter fabric envelope can be used when the surrounding soil conditions would cause plugging or silting.

The backfill is placed through the slurry via tremie pipe or by sliding the backfill down the slope of the previously placed backfill to displace the slurry and minimize segregation. Sands and finer backfills must be prewetted to be tremied while coarser backfills, such as pea gravels, can be placed dry. Tremie placement should be used around wells and other structures to ensure accurate alignment.

Woven filtration fabrics are preferred over other geotextiles since the degraded slurry can be flushed from the weave. Placement of geotextiles in a slurry-filled trench requires special equipment and procedures. Geotextiles will naturally float and so they must be weighted to be placed through slurry. Concrete weights and temporary frames are most often used to facilitate placement and provide ballast. End tubes may also be used to still wave action in the trench which can disturb placement efforts. Continuity of the geotextiles is provided by overlapping the sheets.

Usually, the backfill is extended up to near the surface and always above the water table. Typically, the top 1 to 2 meters of the trench is backfilled with excess trench spoil or other soil to cap the trench and limit surface water infiltration. This zone may also support buried vaults, discharge piping and pump controls.

Extraction Structures

The most economical means of removing collected groundwater in a BP Drain is through well casings with pumps. With a permeable backfill, wells can be spaced about 100 meters apart. Stainless steel, galvanized steel, polyvinylchloride and polyethylene well casings have all been used successfully. Groundwater chemistry may dictate the selection of nonmetallic materials or other special considerations in extremely corrosive groundwaters. Inexpensive submersible, progressive cavity, or ejector pumps are available which can operate in corrosive groundwaters and pump at the very low extraction rates (35 lpm or less) required in most applications.

For a limited number of cases, a horizontal drainage pipe may be required along the bottom of the trench. The utility of horizontal pipes for groundwater collection is often overestimated. Drain pipes must have perforations which may be more restrictive than gravel alone in transmitting groundwater. Closer well spacing and deeper trenches can almost always provide equal performance and a lower initial cost and with reduced maintenance costs. In most groundwater extraction applications, the presence of pipe in a gravel-filled trench does not affect the performance of the system and is redundant.

In those few instances where a drainage pipe is required, special pipe-laying equipment of a design similar to cable-laying equipment is used. The pipe, of course, must be fully flexible and corrugated for strength. A separate pipe-laying machine travels over the slurry-filled trench behind the excavator, laying the pipe through the slurry while simultaneously bedding and backfilling around the drain pipe through a tremie. Pipe grade is controlled by survey control of the pipe laying boom. Small diameter sumps or wells (100 to 600 mm diameter) are either attached directly to the drain pipe or placed directly beside the drain pipe perforations for continuity.

Experience has shown that laying a drain pipe using weighted sections can also be used but only in very short (15 meters or less) trenches which can be placed in a single step. In longer sections the buoyancy of the flexible pipe creates folds at the end of each weight, which become crimped when the trench is backfilled. Since all work is performed in the blind, under slurry, breaks in the pipe cannot be easily detected and repairs are extremely difficult and costly. Purpose-built pipe-laying equipment is recommended for all but the shortest trenches.

In general, conventional manholes or lift stations are not recommended for a number of reasons. First, conventional manholes constitute a confined space which can allow unauthorized access. Second, pumps, control facilities and access to same can be provided through conventional well equipment at a much lower installation cost. Duplex systems can be provided using multiple well casings for backup pumps. Third, conventional manholes must be constructed by conventional means (sheeting, shoring and dewatering) negating a significant portion of the savings provided by the BP Drain installation. Finally, concrete manholes are sealed structures which are only attached to the drain field through the perforated pipe. A much larger radius of influence can be provided by using a perforated sump or well, and in the case of failure of the drainage pipe, the perforated sump or well provides a safety factor for ensuring the continued service of the drainage trench.

CASE STUDIES

Most BP Drains are installed to collect contaminated groundwater where the depth of the excavation makes conventional trenching impractical and soil conditions make well fields ineffective. A wider application of the BP Drain method is possible when the designer and the specialty contractor work together to fully exploit the advantages of the technique. The following case studies portray some of the more complicated systems installed to date and illustrate the potential for BP Drains on other sites.

Oil Skimmer in South Texas

A refinery had to collect floating waste oil which was leaving the site and appearing as a sheen on the adjoining Houston Ship Channel. A high water table, numerous utility lines, fill soils and limited working space made conventional excavation difficult and expensive. The BP Drain method was selected to create a deep trench in which was placed a geomembrane barrier to block oil seepage, while still allowing clean groundwater to pass under and into the waterway. Wells were placed in the trench to remove floating product which was collected by the barrier. Figure 1 shows a schematic of the completed system.

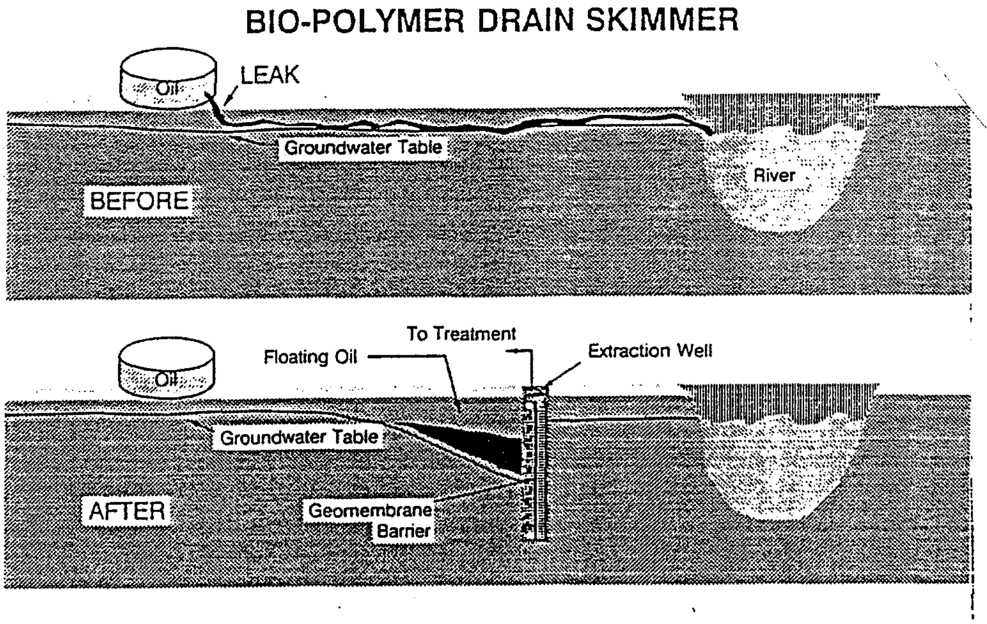


FIG. 1—Schematic of Oil Skimmer Interceptor Trench

Geomembrane panels were prefabricated and HDPE joints welded to the membrane. The panels were stretched over frames which held the geomembrane during installation and jointing. An interlocking dovetail joint was used which was later grouted to complete the seal.

A trench 400 meters long and 6 meters deep was constructed between the waterway and the plant access roadway. The installation sequence for placing the geomembrane panels is shown in Figures 2 and 3. Due to the presence of the geomembrane, extensive development of the drain was required to ensure adequate flushing behind the barrier. The installation schedule was about one month.

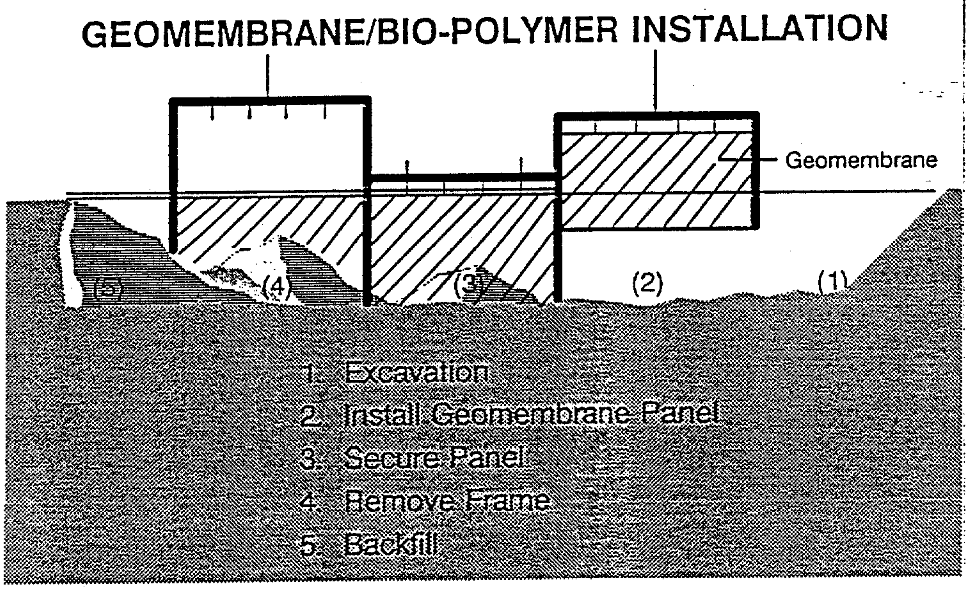


FIG. 2—Sequence for Installation of Geomembrane in Bio-Polymer Trench

Collection Trench in Northern California

A major manufacturing plant needed to contain a plume of spilled processing chemicals. An onsite treatment and containment system was designed which called for a down-gradient, soil-bentonite slurry wall and BP Drain. Due to regulatory requirements, a horizontal drainage pipe was included in the design. Well casings were placed at 100 m intervals, and cleanouts for the pipe were provided near the wells. A cross-section of the parallel trenches is shown in Figure 4.

A drought in the area made it necessary to use runoff water as the slurry mixing water. The water had to be sterilized to limit biological growth and along with the hot summer weather increased additive requirements to protect the slurry from premature degradation.

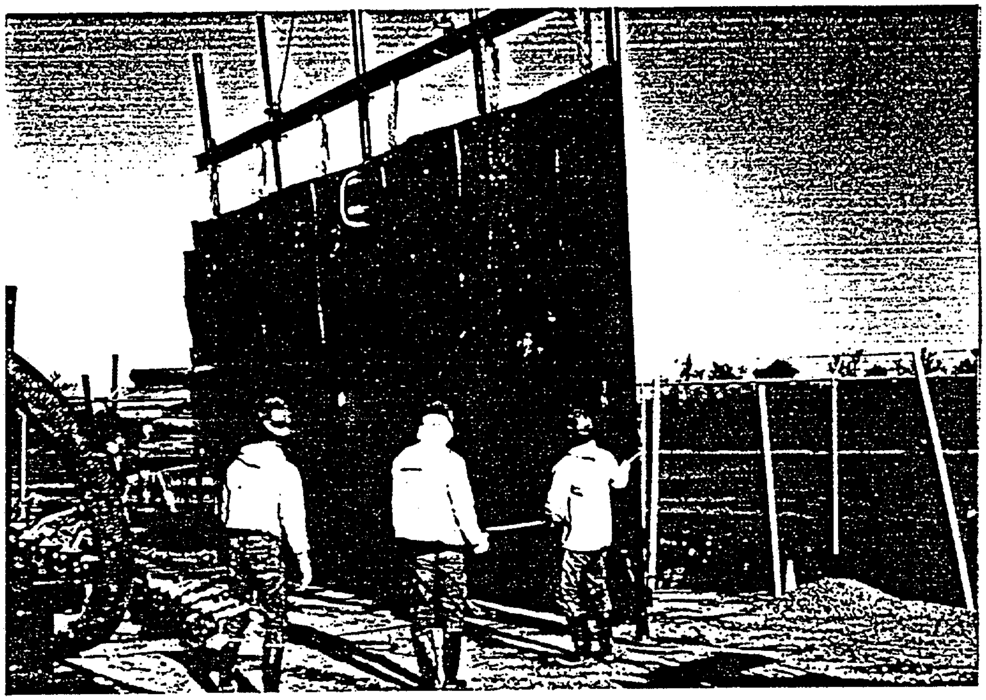


FIG. 3—Installation of Geomembrane Panel

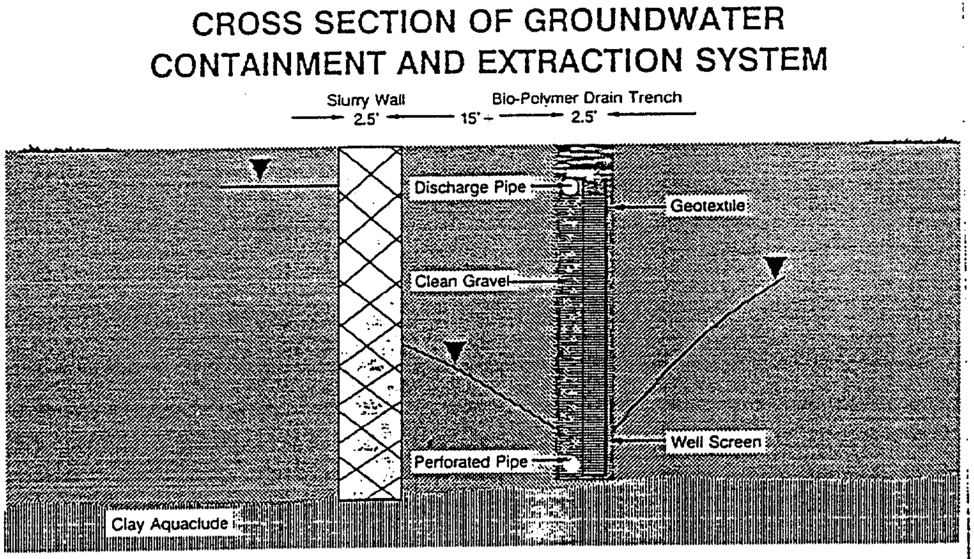


FIG. 4—Cross Section of Groundwater Containment System

The BP Drain was constructed through clays and silts up gradient and parallel to the cutoff wall. The trench was excavated 0.75 meters wide and about 9 meters deep and lined with a woven geotextile. The pipe laying machine (Figure 5) laid and bedded a 150 mm diameter perforated pipe through the slurry. Extraction wells 300 mm in diameter and 100 mm diameter monitoring wells were placed in the trench alongside the perforated pipe. Construction time for the project was less than two months.

FIG. 5—View of Pipe Installation in Bio-Polymer Trench

Landfill Dewatering in Ohio

A nuclear fuels processing plant had a mixed waste landfill that required closure. Plumes of contaminates were caused by the fluctuations in the groundwater table saturating the base of the landfill. The remedy was to construct a soil-bentonite slurry wall up gradient and a BP Drain parallel to the landfill to divert groundwater and finally cap the landfill to prevent infiltration. A schematic of the dewatering plan is shown in Figure 6.

Regulatory deadlines made it imperative to perform the construction in the winter. The cold weather made it difficult to pump and mix the slurry and complicated efforts to degrade the slurry.

A soil-bentonite slurry wall 250 meters long and two 125 meter long BP Drains were constructed up to 15 meters deep. Each BP Drain was one meter wide, lined with a woven geotextile, and equipped with a single extraction well. After nearly a year of operation, each trench produces a steady 19 lpm (5 gpm). A photo of the installation is shown in Figure 7. Construction of all trenches required less than one month.

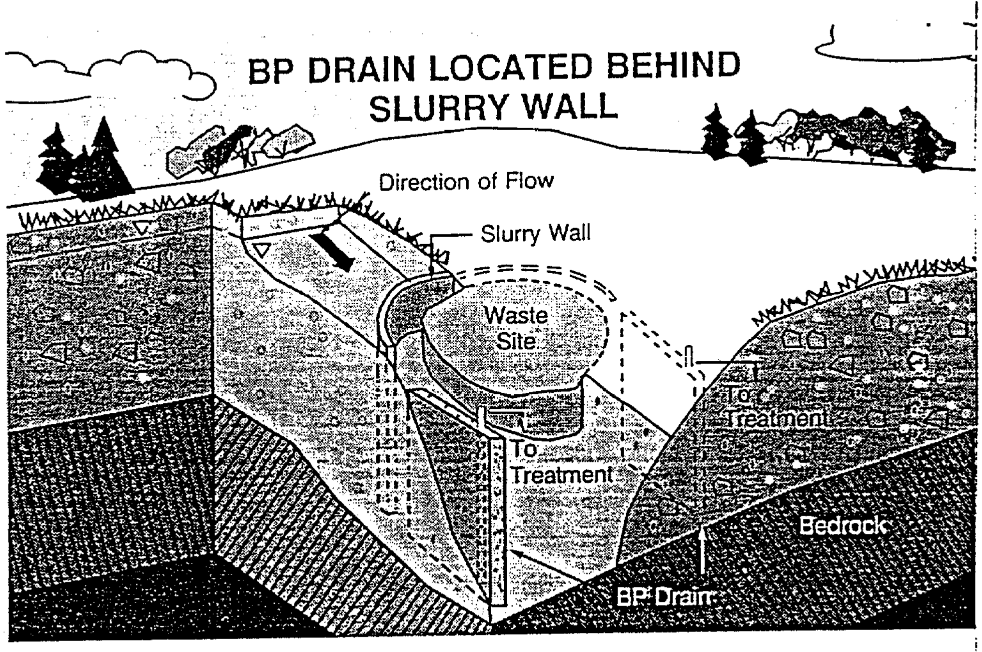


FIG. 6—Schematic of Slurry Wall and Bio-Polymer System to Dewater Landfill

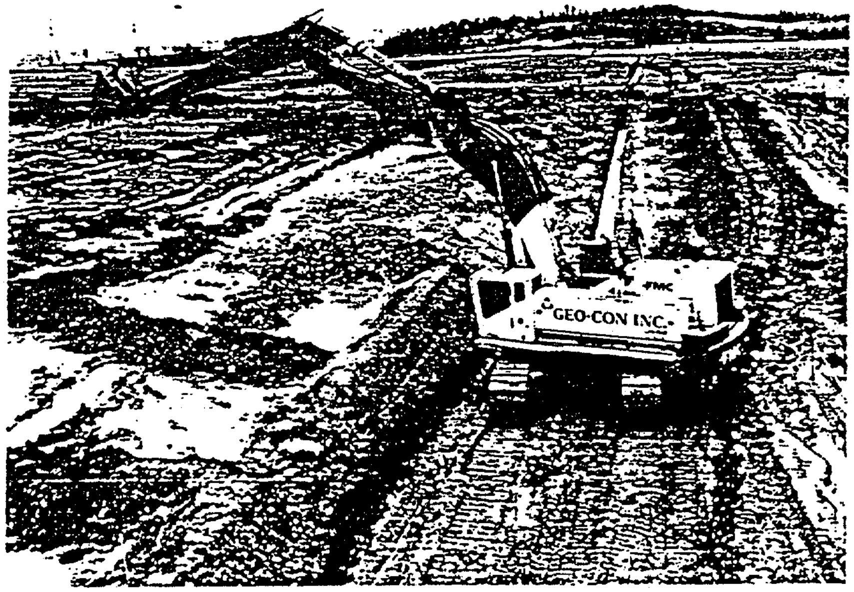


FIG. 7—View of Slurry Trench Installation

CONCLUSION

The BP Drain methodology provides a new means for constructing difficult deep drains. Where appropriate, they also provide significant savings of time and money, as well as improving worker safety and general environmental exposure. The projects completed to date have generally been for environmental containment purposes, although the process lends itself to civil works as well. We see a considerable potential for future applications of this technique.

REFERENCES

[1] Hanford, R. W. and Day, S. R., Installation of a Deep Drainage Trench by the Bio-Polymer Slurry Drain Technique, National Water Well Association Conference Proceedings, Las Vegas, NV, May, 1988.
[2] Day, S. R., Deep Groundwater Collection Trenches by the Bio-Polymer Drain Method, HMCRI Superfund Conference Proceedings, November, 1990.
[3] Bachy, Deep Draining Trench Brochure, SIF Bachy, Levallois Perret, France, 1982.
[4] American Petroleum Institute, "Recommended Practice for Standard Procedure for Field Testing Water-Based Drilling Fluids", Specification RP13B-1, Washington, D.C., First Edition, June 1, 1990.

MICHAEL BAKER JR., INC.

PHONE CALL REPORT

PROJECT/LOCATION: OU No. 10, Site 35, Camp Geiger Area Fuel Farm, MCB Camp Lejeune.

S.O. No.: 62470-232-0000-09500

DATE: 11-16-94

CONTRACT NO.: N62470-89-D-4814

To:

Repres.: Envirotrench Co.

Phone No.: 914-738-4880

Fax: 914-738-4804

From: Tara Beckman

Repres.: BEI

Phone No.: 269-2040

Subject:

The rough cost for installing a biopolymer trench is $10-30/sq.ft. ($15/sq.ft is a good average value)

This cost includes excavation, backfill with aggregate, wells, perforated pipe, and geotextile installation.

PREPARED BY Tara Beckman TITLE Asst. Engr. I PAGE 1 OF 1

OP-3C
10/92

APPENDIX C
FLOW QUANTITY CALCULATIONS

S.O. No. CTO 232

Subject: Interim FS, OU No. 10, Site 35, Camp Geiger Area Fuel Farm, MCB Camp Lejeune

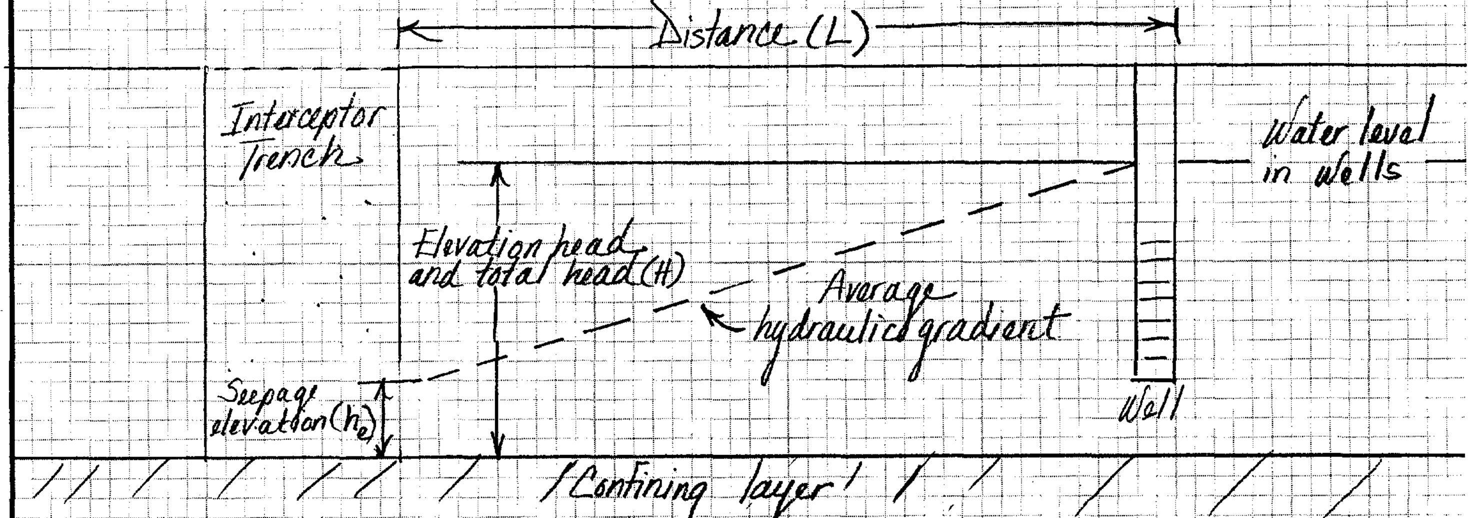
Sheet No. 1 of 3

Drawing No.

Computed by TLB Checked By

Date 11-15-94

ESTIMATED FLOW QUANTITIES:



Determine maximum, minimum, and average flow to trench under equilibrium conditions.

References:
- Leonards, "Foundation Engineering", Section 3-16, Flow to a fully penetrating slot from a single line source, unconfined flow.
- Harr, "Groundwater and Seepage," Section 2-2, equation 5 - Dupuit's formula

Assumptions:
- Assume one-sided trench, geomembrane on back and ends
- Assume equilibrium conditions, after drawdown
- Assume equal gradient with depth below free surface
- Assume infinite trench length, due to very small zone of influence per pump tests.

From Leonards, Equation 3-11

$$Q = \frac{kx}{2L}(H^2 - h_e^2)$$

where: Q = Flow
k = coefficient of permeability
x = trench length
Other symbols as noted.

S.O. No. 62470-232-0000-09400

Subject: Interim FS, OU No. 10, Site 35, Camp Geiger Area Fuel Farm, MCB Camp Lejeune

Baker

Sheet No. 2 of 3

Drawing No.

Computed by TLB Checked By CVJ Date 11·15·94

$Q = \frac{kx}{2L}(H^2 - h_e^2)$

$k = \frac{0.628 + 5.16}{2} = 2.89$ ft/d (average of shallow & intermediate well hydraulic conductivities)

$X = 700'$ = trench length

The confining layer is at 27.5' below MSL

$h_{e\,max} = 4.02 - (-27.5) = 31.5$

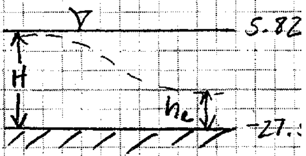
$h_{e\,avg} = 16.3'$

$h_{e\,min} = 1'$

} based on well 35GW/D-5

.0052 gpm/cfd

$\boxed{L_1 = 175'}$



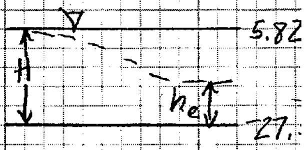
$H_1 = 4.17 - (-27.5) = 31.7'$

$Q_{min} = \frac{(2.89)(1080)}{2(175)}(31.7^2 - 31.5^2) = 112.7$ cfd $= 0.59$ gpm

$Q_{avg} = \frac{1560}{175}(31.7^2 - 16.3^2) = 6590$ cfd $= 34$ gpm

$Q_{max} = \frac{1560}{175}(31.7^2 - 1^2) = 8950$ cfd $= 46$ gpm

$\boxed{L_2 = 350'}$



$H_2 = 5.82 - (-27.5) = 33.3'$

$Q_{min} = \frac{1560}{350}(33.3^2 - 31.5^2) = 520$ cfd $= 2.7$ gpm

$Q_{avg} = \frac{1560}{350}(33.3^2 - 16.3^2) = 3758$ cfd $= 20$ gpm

$Q_{max} = \frac{1560}{350}(33.3^2 - 1^2) = 4938$ cfd $= 26$ gpm

S.O. No. 62470-232-0000-09400

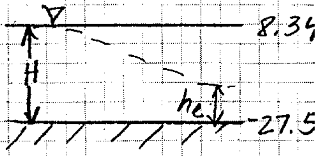
Subject: Interim FS, OU No. 10, Site 35, Camp Geiger Area Fuel Farm, MCB Camp Lejeune

Sheet No. 3 of 3

Drawing No.

Computed by TLB Checked By CVJ Date 11.15.94

$\boxed{L_3 = 650'}$



$H_3 = 8.34 - (-27.5) = 35.8'$

$Q_{min} = \frac{1560}{650}(35.8^2 - 31.5^2) = 694 \text{ cfd} = 3.6 \text{ gpm}$

$Q_{avg} = \frac{1560}{650}(35.8^2 - 16.3^2) = 2438 \text{ cfd} = 13 \text{ gpm}$

$Q_{max} = \frac{1560}{650}(35.8^2 - 1^2) = 3073 \text{ cfd} = 16 \text{ gpm}$

SUMMARY OF ESTIMATED FLOW QUANTITIES:

Distance L	Qmin	Qavg	Qmax (gpm)
175'	0.59	34	46
350'	2.7	20	26
650'	3.6	13	16

$Q = kiA$

$Q = (2.89)(1.7(10)^{-2})(29)(1080) = 1540 \text{ cfd} = 8.0 \text{ gpm}$

APPENDIX D
IN SITU AIR SPARGING

FOCUS

An Overview of In Situ Air Sparging

by R.L. Johnson, P.C. Johnson, D.B. McWhorter, R.E. Hinchee, and I. Goodman

Abstract

In situ air sparging (IAS) is becoming a widely used technology for remediating sites contaminated by volatile organic materials such as petroleum hydrocarbons. Published data indicate that the injection of air into subsurface water saturated areas coupled with soil vapor extraction (SVE) can increase removal rates in comparison to SVE alone for cases where hydrocarbons are distributed within the water saturated zone. However, the technology is still in its infancy and has not been subject to adequate research, nor have adequate monitoring methods been employed or even developed. Consequently, most IAS applications are designed, operated, and monitored based upon the experience of the individual practitioner.

The use of in situ air sparging poses risks not generally associated with most practiced remedial technologies: air injection can enhance the undesirable off-site migration of vapors and ground water contamination plumes. Migration of previously immobile liquid hydrocarbons can also be induced. Thus, there is an added incentive to fully understand this technology prior to application.

This overview of the current state of the practice of air sparging is a review of available published literature, consultation with practitioners, a range of unpublished data reports, as well as theoretical considerations. Potential strengths and weaknesses of the technology are discussed and recommendations for future investigations are given.

Introduction

In situ air sparging (IAS) is a technique in which air is injected into water saturated zones for the purpose of removing organic contaminants by a combination of volatilization and aerobic biodegradation processes. It is typically used in conjunction with soil vapor extraction (SVE) to eliminate the off-site migration of vapors. Its use for the remediation of gasoline and chlorinated solvent spill sites has been reported. Air sparging has broad appeal because, like SVE, it is relatively simple to implement and capital costs are modest. However, like most subsurface remediation activities, in situ air sparging relies on the interactions between complex physical, chemical, and biological processes, many of which are not well understood.

This paper discusses several issues related to in situ air sparging. First, the current state of the practice of air sparging is described. Second, physical and biological processes that control the performance of IAS systems are discussed. Finally, a review of design criteria for implementing IAS is presented. The material that follows is primarily a review and critical evaluation of currently available literature on this subject. Because the available information is somewhat limited, the authors have drawn upon their own experience to provide a context for interpreting reported IAS performance data. This overview is not intended to be exhaustive, nor is it the final word on in situ air sparging. Instead, it is anticipated that this paper will raise

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some important questions and stimulate further research, discussion, and writing on this increasingly popular remediation approach.

State of the Practice of In Situ Air Sparging

The goal of an IAS system is to remove volatile and/or aerobically biodegradable hydrocarbons from both ground water and unsaturated subsurface zones. To accomplish this, air sparging systems commonly consist of the following components (Figure 1): (1) air injection well(s); (2) an air compressor; (3) air extraction well(s); (4) a vacuum pump; (5) associated piping and valving for air movement systems; and (6) an off-gas treatment system (e.g., activated carbon, combustion). Depending upon characteristics of the subsurface and the IAS/SVE system, practitioners may select injection air rates ranging from a few to several standard cubic feet per minute (scfm) per well (Table 1). Air injection wells are generally placed a few meters below the water table in the hope of inducing lateral spreading of air away from the injection well. To date, most decisions on injection well placement and flow rates have been based on operator experience.

As air moves up through the ground water zone, contaminants partition into the gas phase and are swept out of the ground water zone to the vadose zone. At the same time, oxygen in the injected sparge air partitions into the ground water. This oxygen may then serve to stimulate the aerobic microbial degradation of contaminants. To prevent the unintended migration of contaminant vapors, sparging systems are integrated with an SVE system at most sites. In general, the rate of air removal by the SVE system should be substantially greater than the injection rate for the IAS system. Current practice among some practitioners is to adjust rates empirically to ensure overall negative air pressure throughout the remediation zone.

Physical and Biological Processes that Control IAS

Conceptual Model of Injected Air Flow in the Saturated Zone

The flow of air from an injection well toward the vadose zone is the central feature of IAS operations. For the purposes of this discussion, the flow of injected air through the well screen and through the saturated zone toward the unsaturated zone is best discussed in terms of a conceptual model. In this section such a model is presented as the context for discussing processes important to IAS as well as those important for monitoring field performance of IAS systems.

When air is injected into a well, standing water in the well bore is displaced downward and through the well screen until the air/water interface reaches the top of the well screen. The minimum air pressure required for this displacement is the hydrostatic pressure P_H corresponding to the water column height that is displaced:

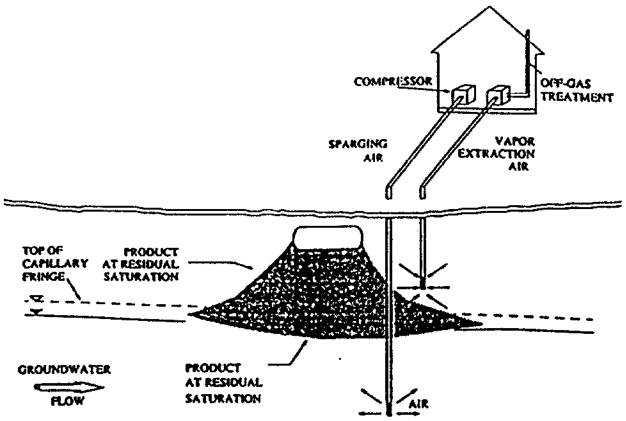

Figure 1. Schematic drawing showing the components of an in situ air sparging/soil vapor extraction system.

$$P_H = r_w g (L_s - L_{gw})$$

where:

r_w = the density of water (= 1000 kg/m^3)
g = the acceleration due to gravity (= 9.8 m/s^2)
L_s = the depth to the top of screen (m)
L_{gw} = the depth to ground water (m).

For the injected air to penetrate the aquifer, air pressure in excess of the hydrostatic pressure is required. This excess air pressure is commonly known as the "air-entry pressure" for the formation, P_{entry}. It is the minimum capillary pressure (air pressure minus water pressure) necessary to induce air to flow into a saturated porous medium. Air-entry pressures (expressed as equivalent water "heads") can range from a few centimeters for coarse sandy soils to several meters in low-permeability clayey soils. If specialized diffuser screens are used to enhance air distribution, then the minimum bubbling pressure for the diffuser ($P_{diffuser}$) must be overcome for air to enter the formation.

As injected air enters the saturated aquifer, it rises due to both its buoyancy in water and the pressure gradient induced by the vapor extraction system. As water is necessarily displaced when air is injected into the formation, a slight rise in the ground water level in the vicinity of the injection well is likely to be observed. However, contrary to some published reports, it is unlikely that the air injection by itself will result in a sustained mound of water within the porous medium. It is more likely that any observed sustained mounding is a result of the vapor extraction system, which can cause sustained ground water upwelling. The water level changes observed in monitoring wells may also be the result of preferential air movement to the wells, and not a reflection of conditions in the formation.

It is virtually impossible to predict the flow path that air channels will take between the injection point and the vadose zone for real field settings. It is well known that water displacement by the invasion of air is remarkably sensitive to even subtle changes in soil structure. Under experimental conditions (Ji et al. 1993; Johnson 1993), the formation of individual air channels occurring at spacings on the order of centimeters, or greater, have been observed. The equivalent diameter of individual air channels is estimated to be, at most, on the order of a few grain diameters. It is important to note that, for realistic scenarios, the air occupying the individual air channels is continuous; in no sense does air flow occur as a sequence of rising bubbles (Figure 2).

Small variations in permeability, or soil structure, at the scale of even a few grain diameters will cause air channels to form. Larger scale heterogeneity, such as stratification, also affects air flow patterns, as demonstrated by Ji et al. (1993) in laboratory visualization studies. For example, if air is injected into a stratum lying below a more fine-grained (higher air-entry pressure) water saturated zone, then the injected air will accumulate beneath the finer grained stratum and form a thin, relatively continuous "bubble" as shown in Figure 3. Lateral spreading of the air will continue until the pressure within the bubble exceeds the air-entry pressure of the finer grained stratum, or until a vertical pathway, such as a monitoring well or fracture, is reached. Field observation of bubbles in monitoring wells has often been interpreted as an indication of air distribution within the medium, while it is more likely an indication of the type of flow described above. It is important to note that flow of this type will also likely cause enhanced transport of hydrocarbons away from the source area.

Processes Controlling the Removal of Contaminants

Air sparging depends on two basic processes for contaminant removal: volatilization and aerobic biodegradation. Similar factors control both processes. This section compares these processes for several areas of the subsurface, including the air flow channels, saturated soils surrounding the air channels, capillary fringe, and vadose zone. Within these areas, contaminants targeted for remediation may be dissolved in the ground water, be adsorbed onto soils, or occur as globules of immiscible non-aqueous-phase liquid (NAPL).

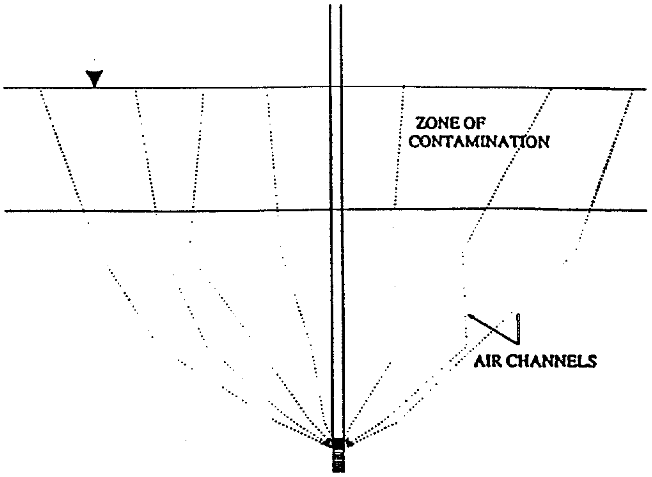

Figure 2. Schematic drawing showing air channels formed during in situ air sparging.

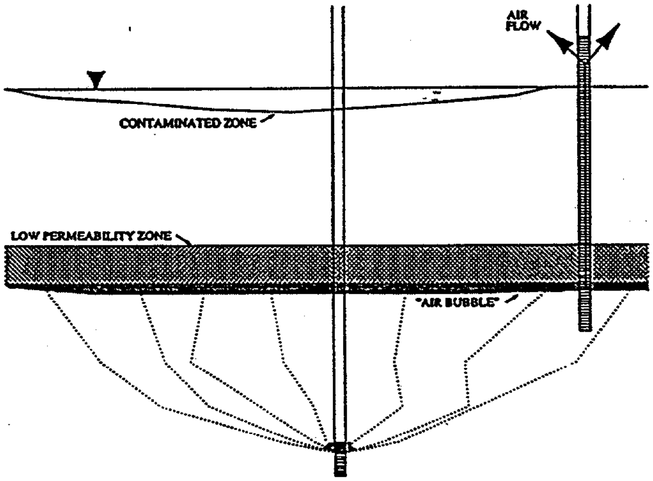

Figure 3. Schematic drawing showing air "short-circuiting" through a monitoring well and around the zone of contamination.

Volatilization

For contaminants initially located within the air channels, volatilization due to air sparging is analogous to vadose zone SVE, and similar removal rates and remedial efficiencies can be anticipated. Where NAPL is in contact with an air channel, contaminants will volatilize by direct evaporation from the NAPL surface. Given the postulated conceptual flow model, the greater contaminant mass will likely be located beyond the air channels in water saturated zones. Removal of this mass will depend upon diffusive transport to the air-water interface, which is inherently a slow process. This analysis leads to the conclusion that the effectiveness of air sparging could be limited, unless the air flow also induces some degree of mixing within the water saturated zone. The injected air eventually moves across the capillary fringe and into the vadose zone, unless it intercepts some preferential conduit to the ground surface, such as a monitoring well. As a result, this might enhance remediation of capillary fringe soils not otherwise affected by SVE, or may simply accelerate remediation of the portion of the capillary fringe that SVE would treat more slowly. Neither possibility can be confirmed with available data. IAS has been used at sites where hydrocarbon removal by conventional soil vapor extraction has reached "asymptotic" levels. Some studies have reported an initial, short-term increase in hydrocarbon removal rates when air sparging is initiated. However, it should be noted that the cumulative mass of contaminant removed by volatilization during this phase of the remediation is typically a small fraction of the total amount removed over the entire duration of remediation.

Biodegradation

Many compounds in hydrocarbon fuels will biodegrade aerobically; at most fuel-contaminated sites, oxygen is the primary factor limiting biodegradation rates (other potentially limiting factors will not be considered here). IAS is one of a number of methods for delivering oxygen to the saturated zone, and it therefore has the potential to stimulate aerobic biodegradation. Conventional in situ oxygen delivery processes have either used the injection of oxygenated water, water containing hydrogen peroxide, or soil vapor extraction to increase subsurface oxygen levels. Air-saturated water contains 8 to 10 mg-O_2/L. Oxygen-saturated water increases this level to about 40 mg-O_2/L, and as much as 500 mg-O_2/L can be supplied by water containing hydrogen peroxide. The difficulty in injecting oxygenated water is the relatively high oxygen demand of aerobic hydrocarbon degradation. Between 3 and 3.5 g of O_2 per gram of hydrocarbon is required for complete mineralization, and, at concentrations typical of NAPL-contaminated soils, hundreds or even thousands of pore volumes of water may be required to treat aquifer soils. Practitioners are now beginning to realize the advantage of supplying oxygen through vapor transport. For example, the practice of "bioventing" takes advantage of this feature for vadose zone soils, but it does little to supply significant oxygen to aquifer solids unless the solids are dewatered first. From this perspective, IAS has the potential to be an oxygen delivery method that is at least competitive with current practices.

As previously discussed, contamination in the air channels will be treated much like soils undergoing vapor extraction in the vadose zone, and current experience with bioventing should be applicable. In these channels oxygen will be supplied relatively efficiently and aerobic biodegradation will be stimulated. This may result in the biodegradation of some part of the more volatile fraction and much of the less volatile, higher molecular weight compounds. At fuel-contaminated sites, bioventing of vadose zone soils typically results in biodegradation rates of 2 to 20 mg/kg-d (Hoeppel et al. 1991). Similar rates may be anticipated in the air channels.

Biodegradation of contaminants outside the air channels will be affected by the same mechanisms that control their removal by volatilization. The rate of biodegradation is likely controlled by the rate of oxygen transfer to the ground water, which, as previously stated, is probably limited by diffusion.

Few well-documented air sparging demonstrations have been published. Billings (1991) has applied air sparging to numerous fuel-contaminated sites and, at some, observed concentrations of dissolved hydrocarbons in monitoring wells to decrease in excess of 99 percent in six to 12 months. At other sites, decreases have been less dramatic. Marley et al. (1992) have reported the remediation of a small site where concentrations remained low for a sustained period following IAS shutdown. However, there are few reported cases in which ground water cleanup levels have been achieved and maintained for several years. It also appears that confirmatory soil sampling has been limited at most IAS sites.

Design, Operation, and Monitoring of Air Sparging Systems

In situ air sparging systems should be designed and operated to optimize volatilization and biodegradation processes and to minimize the probability of adverse consequences, such as off-site migration of vapor or contaminated ground water. As mentioned previously, there is limited design and operation information available in the form of published reports. The guidelines given below, therefore, also include theoretical considerations, empirical results, and practical engineering and economic limitations.

Design Considerations

It is important to recognize that the design of most IAS systems will be based on relatively limited site-specific information. Given this reality and a knowledge of the wide range of behavior that can occur, it is imperative that the potential for flexible operation and system expansion be incorporated into any system design.

Table 1 lists some design specifications for basic air sparging systems and a range of values summarized from published reports. These and other critical design specifications are discussed later on in more detail.

Table 1
Design Parameters for Air Sparging Systems (based on literature values)

Parameter	Reported Value
Injection Well Specifics	
• screen depth below water table (ft):	16[1], 3[3,5], 9[3], 15-40[3], 5[6], 10-39[8]
• screen interval width (ft):	2[1,3,5,8], 300[4], 6[6]
• number of wells:	14[1], 5[2], 13[3,5], 1[4,6,8]
• injection air flow rate (ft^3/min):	6[2], 2-6[3,5], 170-270[4], 56[6], 7-16[8], 3-4[10]
• injection air pressure (psig):	1-2[3], 1-8[3,5], 3-4[10]
• operation (pulsed or continuous):	continuous[1,2,6,8,9,10], pulsed[3,5]
• other information:	nested injection/extraction wells[1,9,10] individual wells[2,3,4,5,6,10] horizontal wells[4]
Vapor Extraction Well Specifics	
• # extraction wells/# injection wells:	8/14[1], 1/1[6,9,10], 2/13[3,5], 0/1[8]
• extraction flow rate/injection flow rate [ft^3/min]:	475/30[2], 580/170 - 580/270[4], 160/100[6], 2/1[10]

1. Brown and Fraxedas 1991
2. Middleton and Hiller 1990
3. Marley et al. 1990
4. Kaback et al. 1991
5. Marley 1991
6. Bohler et al. 1990
7. Wehrle 1990
8. Griffin et al. 1990
9. Ardito and Billings 1990
10. Billings 1991

Air Injection Wells

Air injection wells are usually similar in construction to standard ground water monitoring wells; the main difference is that the screened (perforated) section of an air sparging well must be located entirely within the saturated zone. One such construction is depicted in Figure 4. Here the air injection well is placed within a borehole, a relatively permeable packing material surrounds the well screen, and grout seals the annulus above the well screen to inhibit short-circuiting of the injected air. While Figure 4 illustrates a well placed within a borehole, it should be noted that wells may be installed in some soils by driving the casing into the soil. Most published air sparging application summaries report the use of vertical wells (Ardito and Billings 1990; Bohler et al. 1990; Griffin et al. 1990; Marley et al. 1990; Middleton and Hiller 1990; Wehrle 1990; Billings 1991; Brown and Fraxedas 1991; Marley 1991); however, this predominance should be regarded as a reflection of current drilling and well installation procedures rather than an indication that vertical wells offer maximum or unique performance. The use of horizontal wells, which may offer some advantages relative to vertical wells, is reported by Kaback et al. (1991). Other authors report dual vapor extraction/air injection wells constructed by installing separate injection and extraction wells in the same borehole or casing (Ardito and Billings 1990; Billings 1991; Brown and Fraxedas 1991).

The most common material for well construction appears to be PVC, although more heat resistant materials are required if the injected air is warmed too much by the air compressor. Injection well diameters range from 1 to 4 inches; performance is not expected to be affected significantly by changes in well diameter, although as the diameter of the conduit is reduced, the pressure drop due to flow through the piping increases and may become significant. All other factors being equal, economic considerations favor smaller diameter wells (1 to 2 inches), because these are typically less expensive to install and in many cases may be driven into the soil.

Based on the previous discussion concerning the behavior of air injected into an aquifer and the resulting vaporization and biological processes, the well screen location and length should be chosen to maximize the flow of air through the zone of contamination. The top of the well screen, therefore, should always be placed below the lowest suspected level of contamination. This requirement applies equally to vertical and horizontal wells. In relatively homogeneous soils, increasing the depth will tend to expand the zone through which air flows. However, in more heterogeneous and layered soils, increasing the depth beyond the zone of contamination may cause the air flow to circumvent contaminated soils as it seeks the path of least resistance. In either case, water table fluctuations must be considered and the top of the well screen must be placed at a depth where it will not become exposed if the water table drops. Reported well screen length (vertical wells) are 0.5 to 2 m in many cases (Bohler et al. 1990; Marley et al. 1990; Billings 1991; Brown and Fraxedas 1991; Griffin et al. 1990; Marley 1991), and theoretical considerations indicate that there may be little advantage to expanding the screened interval beyond this value.

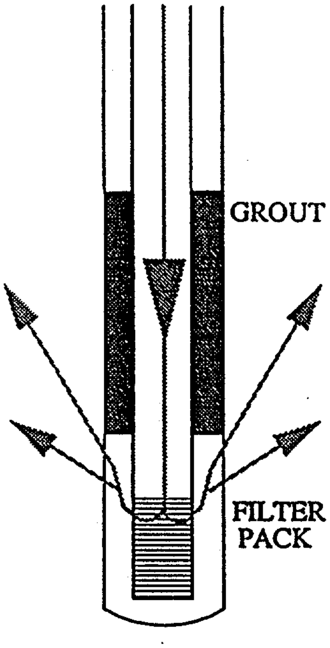

Figure 4. Schematic drawing showing air flow in a well screen and filter pack.

Vapor Extraction Wells

Vapor extraction is typically used in conjunction with air sparging systems in order to remove and treat contaminant vapors liberated by the air sparging process, and to minimize the potential for contaminant vapor migration to nearby structures and conduits. In some cases it may be argued that vapor recovery systems are not necessary: i.e., in remote locations where total potential emission rates are below acceptable levels, or in cases where the injected air flow rate is so low that contaminant vapors are degraded as they pass through the unsaturated zone.

Vapor extraction wells for air sparging applications are usually constructed in the same manner as those used in traditional soil venting applications; vertical wells resemble the air sparging well in Figure 4, with the exception that the screened section of the well must extend at least partially into the unsaturated zone. Horizontal wells or trenches may also be used. Some authors report dual vapor extraction/air sparging wells that incorporate extraction and injection abilities in the same borehole or well casing. This configuration offers obvious economic advantages relative to placing extraction and injection wells in separate boreholes.

At some sites the IAS/SVE system has been designed to remediate soils in both the unsaturated and saturated zones. In such cases the vapor extraction wells should be designed to optimize vapor flow through the contaminated soils above the water table and ensure collection of vapors liberated by air sparging. The reader is referred to Johnson et al. (1990) for some vapor extraction system design considerations. For IAS system designs requiring vapor extraction wells screened near the capillary fringe and water table, it is important to consider ground water level fluctuations when choosing the location of the well screen and screen width.

Well Placement

The number and placement of air injection wells should be chosen to maximize air flow through the contaminated zone. Literature reports often allude to the "radius of influence" or "zone of influence" of an air sparging well; the number of air injection wells is then chosen to ensure that the contaminated zone is encompassed by the zone of influence of the collective system of individual wells. Unfortunately, radius of influence estimates are empirically based, and it is not clear how this quantity should be measured in the field. Some authors claim to have measured it via indirect measurements, such as pressure responses in the unsaturated zone and the bubbling of air in monitoring wells, but the reported evidence is not very defensible. Based on the preceding fundamental discussion of air flow, the zone through which air flows is sensitive to aquifer properties, and a wide range of behavior is possible. Theoretical and experimental analyses of the concept of radius of influence in homogeneous and heterogeneous media are needed to provide a baseline for understanding the spacing and depth of injection of air injection wells.

In the absence of any proven guidelines, it is useful to examine reported injection well spacings: Ardito and Billings (1990) and Billings (1991) seem to prefer to space wells 10 to 20 feet apart, Brown and Fraxedas (1991) appear to have placed wells 50 to 75 feet apart, and 30 to 150 feet spacings are reported in Bohler et al. (1990). It should be noted that these data correspond to vertical well installations, and horizontal wells may prove to be more effective. Theoretical considerations indicate that increasing the number of wells (decreasing the spacing) should increase the rate of remediation in most cases; thus as many wells as possible should be installed, within economic constraints.

The number of vapor extraction wells should be chosen to maximize the recovery of liberated contaminant vapors and to prevent the intrusion of vapors into nearby buildings, conduits, or other enclosed spaces. Table 1 summarizes the relative numbers of extraction and injection wells for some reported applications. Relative to other reported applications, the approach used by Ardito and Billings (1990), Billings (1991), and Brown and Fraxedas (1991) might be regarded as conservative. They utilize dual vapor extraction/air injection well nests; therefore, there is one extraction well for each injection well. These designs are apparently based on the premise that the area of influence of the vapor extraction well will extend beyond the zone where air flow channels emerge from the saturated zone.

Aboveground Components

Given vapor extraction and air injection flow rates (discussed below), one can choose an appropriate blower, compressor, or vacuum pump by finding a unit capable of producing the desired flow rate at an estimated operating pressure or vacuum. The minimum operating pressure for the air injection blower or compressor is equal to the pressure head at the top of the well screen (2.3 feet below water table equals 1 psig) plus the air entry pressure required to overcome capillary forces. One should be careful to consider potential water table fluctuations when estimating this minimum operating pressure. The operating vacuum for vapor extraction systems can be estimated with simplistic screening model calculations, such as those given by Johnson et al. (1990). Following are other considerations regarding air flow in IAS systems: (1) air injection equipment must produce a contaminant-free vapor stream (many compressors utilize oil for seals) to avoid introducing new contaminants to the aquifer; and (2) safety considerations dictate that air sparging/vapor extraction systems be constructed in such a manner that air injection ceases automatically whenever the vapor extraction system malfunctions.

The use of heated air injection has been reported. The purpose is to heat soils and increase degradation and volatilization rates. Heating probably has limited effectiveness, at least for enhanced biodegradation. The volumetric heat capacity of dry air at standard temperature and pressure is 0.00028 cal/cm^3, whereas the heat capacity of saturated soils is approximately 0.7 cal/cm^3. Consequently, at feasible air flow rates and temperature differences, it is not possible to significantly warm soils. For example, an air sparging system injecting 20 scfm of 80 C air into an aquifer at 10 C, 10 feet below the water table affecting a radius of about 20 feet (assuming 12,500 feet^3 of soil uniformly impacted), would result in a maximum temperature rise of approximately 0.06 C per day. This is at or below the level of heating expected from enhanced biodegradation processes. Higher air injection temperatures are possible, but would be detrimental to biodegradation.

Operating Considerations

As previously discussed, increases in air injection flow rate will increase the rate of remediation in most cases. Based on this observation, the air injection system should be operated at the maximum flow rate. However, five other factors limit the rate of air injection:

1. **Mechanical limitations:** Increased flow rates require larger operating pressures and may exceed the capacity of the IAS hardware.
2. **Soil matrix considerations:** As already mentioned, the operating pressure increases as the air injection rate is increased. When this pressure becomes comparable to the overburden of soil above the well, it can cause deformations of the soil matrix or upheaval (fluidization) of the soil above the air injection point. Performance is expected to be best for well-graded medium to coarse sands. This is because less pressure will be required to sustain air injection than required in less permeable soils. In addition, preferential air channeling and poor air distribution are expected to increase significantly as permeability decreases and/or soil heterogeneity increases.
3. **Vapor extraction limitations:** In situations where vapor recovery systems are required, the air injection flow rate must always be less than that of the extraction system flow rate. The extraction system is in

turn limited by characteristics of the vapor extraction blower, or vacuum pump, and the vapor treatment system.

4. To the extent that remediation is diffusion-limited, increased air flow will serve primarily to increase diffusion gradients (by replacing contaminated or deoxygenated air). At higher air flow rates, a diminishing return may be observed.
5. If a sparging system is operated to maximize the remediation contribution due to biodegradation rather than volatilization (for example to reduce off-gas treatment costs), high air flow rates may be problematic. With bioventing systems in the unsaturated zone it has been found that lower air flow rates will enhance biodegradation while minimizing volatilization (Miller et al. 1991; Dupont et al. 1991).

Table 1 contains a summary of relative vapor extraction/air injection flow rates reported in the literature. Most reported air injection flow rates are less than 10 scfm per injection well.

There are at least three distinct approaches to operating IAS systems. These can be referred to as "staged," "continuous," and "pulsed" operating strategies. In the staged approach the unsaturated soil zone is remediated first, followed by air sparging. At this time there appears to be no benefit to operating in this fashion, unless the goal is to quantify the relative contribution of air sparging to the overall remediation. Continuous and pulsed systems are differentiated by whether or not the air injection is continuous or intermittent. The available data are too limited to determine which approach is best. If mass transfer limitations prove to govern air sparging system behavior, continuous operation will probably be the preferred option. Should the pulsing of the air injection flow rate enhance mixing in the subsurface, a properly timed pulsed operation could deliver enhanced performance.

Health, safety, and compliance issues will also affect the operating conditions of IAS/SVE systems. For example, discharge of extracted vapors must be in compliance with local air discharge standards. This may require the use of off-gas treatment equipment such as carbon beds or thermal or chemical oxidizers.

Monitoring Considerations

Monitoring data can be used to assess the performance of current operating conditions, to help determine if system adjustments or expansions are necessary, and to determine if off-site migration of contaminant vapors and contaminated ground water is occurring. Table 2 lists a number of items that can be monitored. The aboveground system performance items listed in Table 2 (flow rate, concentration, composition) can be used to estimate the net rate of removal due to volatilization. In some cases it may also be used to quantify the rate of biodegradation induced by air sparging (based on proper interpretation of O_2 and CO_2 data).

In situ response data (e.g., pressure, air flow, water quality) are often puzzling and subject to a wide range of interpretations concerning validity and meaning. For example, consider the case where a monitoring well intersects a large subsurface "air bubble" (formed in response to stratified soil conditions). Air will bubble up through water in the monitoring well, thereby causing contaminant concentrations in the well water to be lower, and dissolved oxygen levels higher, than concentrations in the surrounding aquifer. Other equally likely scenarios lead to the conclusion that monitoring well samples analyzed during operation of an air sparging system will always be suspect. It is recommended, therefore, that ground water samples collected for the purpose of assessing remediation only be obtained weeks or months after system shut-down. Ground water samples can also be collected utilizing driven devices, or by means other than a conventional monitoring well. It does not appear that monitoring wells are useful in determining ground water oxygen concentrations. As with any in situ remediation technique, soil sampling before and after treatment must be done to confirm effectiveness. This is particularly true with IAS, because conventional monitoring well data are suspect.

Soil gas pressure/vacuum and concentration/composition analyses are relatively reliable indicators of condi-

Table 2
Potential System Monitoring Requirements

Parameter	How Measured
Aboveground System Performance	
• extraction well flow rate:	flowmeter (rotameter, orifice plate, etc.)
• injection well flow rate:	flowmeter (rotameter, orifice plate, etc.)
• extraction well vacuum:	vacuum gauge or manometer
• injection well pressure:	pressure gauge or manometer
• extraction gas concentration:	flame ionization detector (FID) or explosimeter
• extraction well composition*:	gas chromatography with FID
• respiratory gas concentrations*:	electrochemical cell (oxygen) infrared detector (carbon dioxide)
In Situ Response [illegible]	
• contaminant levels in soil:	analyze soil sample by appropriate method
• soil gas concentrations:	FID or explosimeter
• soil gas composition:	gas chromatography with FID**
• respiratory gas concentrations:	electrochemical cell (oxygen) infrared detector (carbon dioxide)
• soil gas pressure/vacuum:	pressure/vacuum gauge or manometer**
• ground water elevation:	pressure transducer or tape in monitoring well
• contaminant levels in ground water:	analyze ground water sample by appropriate method
• dissolved oxygen levels:	analyze ground water sample

*includes compositional analyses of hydrocarbon (boiling point fractionation or individual species).

**requires vadose monitoring installations or soil gas probes.

tions in the vicinity of the monitoring point. These can be collected with the use of permanent vadose zone monitoring installations (Johnson et al. 1990) or driven soil gas probes. In most cases, a measurable vacuum is interpreted as an indication that the monitoring point lies within a zone where vapors are flowing toward the vapor extraction well(s). Unfortunately, in heterogeneous systems, the relationship between vacuum and air velocity is not straightforward, and it may be necessary to have some more direct measurement of velocity if remediation effectiveness is to be predicted. Finally, vadose monitoring locations should be placed near any buildings or conduits if there is concern over the potential migration of contaminants to these locations.

Summary

In situ air sparging systems are more frequently being proposed and installed for remediating aquifers contaminated with volatile organic compounds. The rapid, widespread application of this technology is occurring because it is relatively simple and cost-effective to implement, and because potential risks can be overcome if systems are operated properly. However, for the following reasons, interpretation of IAS performance data is quite difficult and misinterpretation is quite common:

1. The physics of air movement in saturated porous media are not widely understood. Nearly all published reports incorrectly show air movement occurring as bubbles. This will rarely be the case; air flow will almost always occur in small continuous air channels.
2. Air movement within the saturated zone is extremely sensitive to formation structure. Small variations in permeability may control the air pathways within the medium. In this manner, large portions of the targeted remediation zone may be bypassed by the sparge air. The movement of air within the formation is difficult to predict and to monitor.
3. Monitoring of IAS performance is most commonly accomplished using conventional monitoring wells. Unfortunately, the design of these wells often adversely affects the data obtained from them. For example, if sparge air enters the monitoring well, then contaminant and oxygen concentrations within the well may not reflect those concentrations in the formation due to sparging within the well. New monitoring techniques must be developed to allow IAS performance to be effectively monitored.

The effectiveness of IAS in remediating ground water and aquifer solids in the saturated zone is not understood. If the process is diffusion limited, and saturated zone remediation is primarily to air flow channels, most of the remedial benefits of IAS are likely to occur in the capillary fringe and vadose zone. To address this issue, future studies need to focus on mass transfer and remedial processes in the saturated zone. Total removal data and monitoring well data as typically collected do not address this important issue.

Despite these problems, in situ air sparging has potential as a remediation tool, when applied in a safe manner and when its limitations are understood. Given its increasing use, it is essential that the technique be examined in detail so that its strengths and weaknesses can be better understood.

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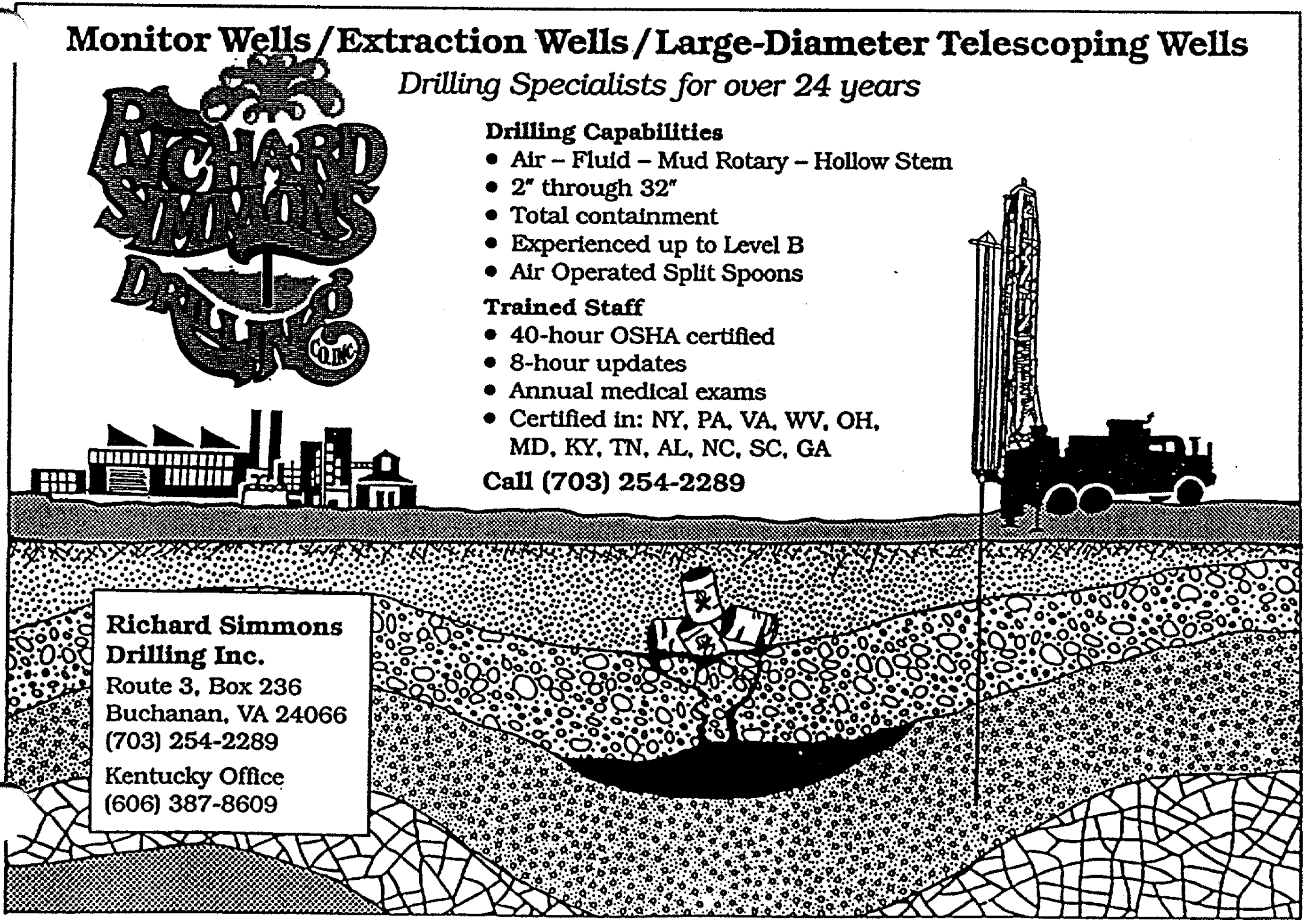

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In Situ Remedial Methods:

AIR SPARGING

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As remedial technologies advance, traditional remedial methods have given way to innovative techniques to reduce both the cost and time associated with remediation. One of these techniques, air sparging, is an emerging in situ technology that enhances desorption and bioremediation of contaminants in saturated soils by forcing air under pressure into the saturated zone. Since remediation of adsorbed and dissolved-phase contamination is often the longest and most expensive part of site cleanup, the application of air sparging in a multi-phase cleanup program can save both time and money.

Background

Soil and groundwater contamination have been traditionally treated by excavating contaminated soils and by pumping and treating contaminated groundwater. Too frequently, however, soil excavation is neither practical nor cost-effective, and groundwater treatment is often required following soil excavation. Groundwater pumping, while effective at containing contamination migration, can be extremely slow due to the equilibrium achieved between the dissolved and adsorbed phases of contamination.

The amount of a compound that sorbs to the soil relative to that dissolved is represented by the partition coefficient, K_d, which is the product of the organic carbon/water partition coefficient, K_{oc}, and the fraction of organic carbon in the soil, f_{oc}. When K_d exceeds 1, contamination resides principally in the soil matrix, rather than in the groundwater, thus rendering a groundwater treatment system ineffective. Since f_{oc} is in the range of 1 to 3 percent for most soils, K_d usually exceeds 1 in situations where K_{oc} exceeds 50.

K_{oc} values for several common volatile constituents are listed below.

Contaminant	**Partitioning Coefficient, K_{oc}**
Acetone	1.0
Benzene	97.0
Tetrachloroethylene	303.0
Trichloroethylene	152.0
Trans-1,2-Dichloroethylene	169.0
Naphthalene	1,300.0

The distribution between adsorbed and dissolved contamination affects groundwater remediation in two ways. First, organic compounds that sorb to soils are retarded in their water phase transport relative to groundwater movement. This means that more water must be pumped to collect contaminants. The effect of pumping groundwater at a greater rate leads to the second effect. At high pumping rates, the leaching of contaminants from soil into groundwater becomes transport-limited—resulting in lower groundwater concentrations—because the contact time between the groundwater and soil is insufficient to allow enough of the compound to diffuse through the soil and into the groundwater to equilibrium. When a pumping system is turned off, contact time is increased and the groundwater concentration of the contaminant increases because the groundwater flow rate has been slowed; the dissolution of contaminants is then equilibrium-controlled, rather than transport-controlled.

Since natural subsurface formations are rarely homogenous and isotropic units, the interlayering of high and low permeability sediments often results in significant variations in local groundwater velocity (advection) within the aquifer. Virtually all groundwater flow under pumping conditions occurs through the higher permeability sediments, and contaminants are rapidly removed from these zones. In contrast, very little flow is induced in the low permeability sediments, and contaminants are released from this zone primarily through the relatively slow mechanism of diffusive transport. This diffusion process involves molecular movement along a concentration gradient from areas of high contaminant concentration to areas of low contaminant concentration.

A pump-and-treat system that maintains low concentrations in the high permeability sediments provides an avenue for transport of contaminants from contaminated low permeability sediments to high permeability sediments and ultimately to recovery wells. Unfortunately, the physical limitations of diffusive transport result in an extremely slow recovery rate under this scenario. Remediation efficiency is further impaired due to the fact that the majority of the total contaminant mass is usually present in the low permeability sediments. Since low permeability sediments have a surface area per unit volume orders of magnitude greater than the surface area per unit vol-

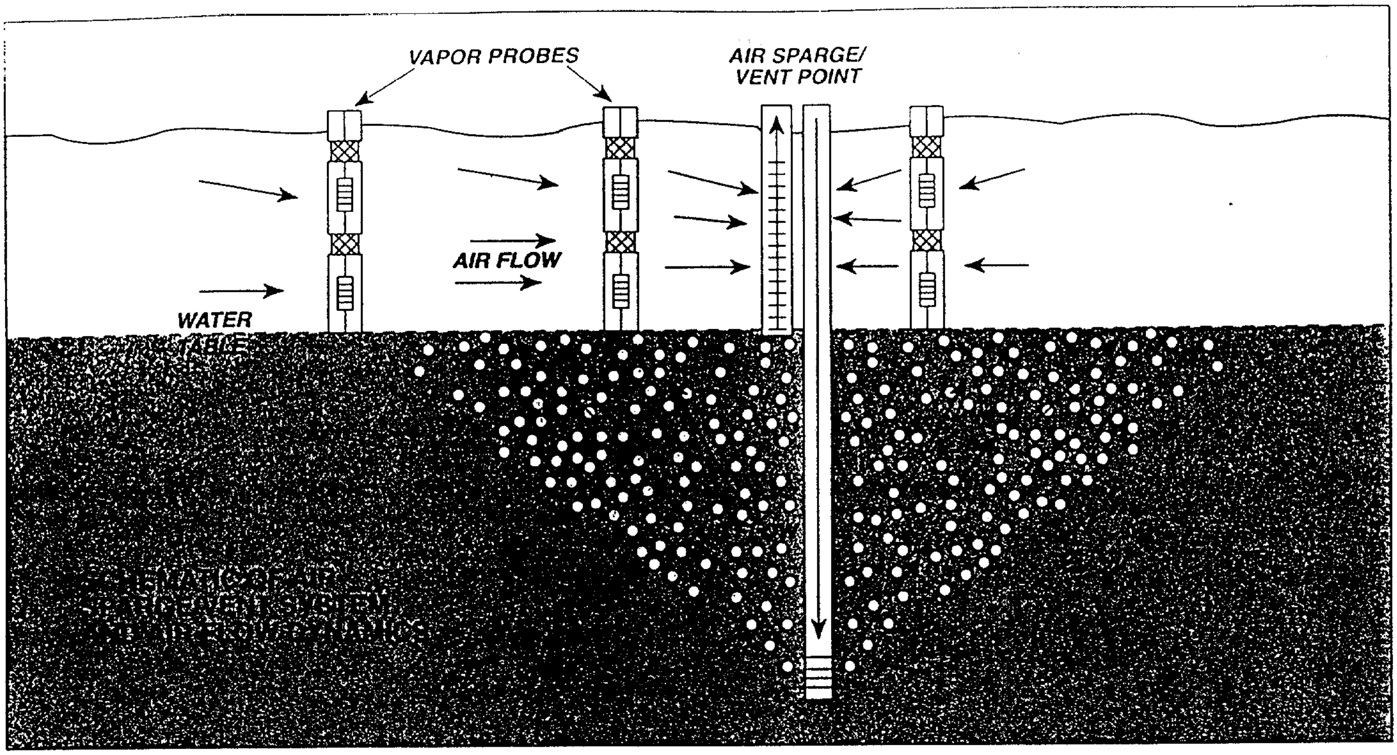

FIGURE 1

ume of coarser sediments, they have a capacity to adsorb a much greater quantity of contaminants. Therefore, in a heterogeneous aquifer contaminated by volatile organics, most contaminants are adsorbed to fine sediments that can only release contaminants slowly by diffusive transport.

Remediation times can be estimated by calculating the number of pore volumes of contaminated water needed at equilibrium concentrations to remove the total estimated contaminant mass. The most cost-effective application for pump-and-treat remediation systems is achieved by minimizing the volume of groundwater pumped and maximizing the concentration of contaminants. This scenario typically provides the lowest lifetime operating costs.

Unfortunately, a more common scenario for pump-and-treat systems is to pump relatively large volumes of water with relatively low contaminant concentrations. This is due to the effect of groundwater velocity on partitioning between adsorbed or pure-phase contaminants and groundwater. Conventional pump-and-treat wellfields generally create local groundwater velocities that are considerably faster than natural flow velocities under static conditions. These faster flow velocities may not allow sufficient contact time between contaminated sediments and groundwater to reach equilibrium concentrations before the water is advected away from the contaminated zone. As a result, groundwater is replaced by clean upgradient water, and large volumes are pumped at less than equilibrium concentrations.

If, as an alternative to groundwater extraction, the dissolved/adsorbed contamination could be removed in place, accelerated remediation of the site, reduced costs, and long-term protection of potential downgradient receptors could be achieved. Several such in situ technologies are currently being developed, including in situ vitrification and bioremediation. One of the more promising approaches has been soil and aquifer aeration.

Two aeration approaches are used to treat volatile organic compound (VOC)-contaminated soils: venting and sparging. The more common is physical contaminant removal by venting (vacuum extraction). This approach, however, is only applicable to unsaturated soils. Volatilization can also be accomplished in saturated zones by sparging air through soils below the water table. This process removes volatiles from the sorbed and dissolved phases, thereby treating both soils and groundwater in the saturated zone.

Not only do aeration systems remove VOCs directly, they enhance degradation of VOCs as well. Because vacuum extraction and air sparging increase air flow through contaminated areas, oxygen availability is enhanced and natural biodegradation stimulated, further increasing the remediation rate.

Air Sparging Technology

Air sparging essentially creates a crude air stripper in the subsurface, with the saturated soil column acting as the packing. Injected air flows through the water column over the packing, and air bubbles contacting dissolved/adsorbed-phase contaminants cause the VOCs to volatilize (see *Figure 1*). The entrained organics are then carried by the air bubbles into the vadose zone where they can be captured by a vapor extraction system, or if permissible, allowed to escape through the ground surface. As a bonus, the sparged air maintains high dissolved oxygen, which enhances natural biodegradation.

The effectiveness of the air sparger system on VOC contaminants is roughly indicated by the contaminants'

Henry's Law constants, with K_H A K_H of $>10^{-5}$ atm-m^3/mole indicating a "stripable" volatile constituent. The Henry's constant for several VOCs is shown below.

Constituent	Henry's Constant KK_H (atm-m^3mole^{-1})
Benzene	5.6×10^{-3}
Toluene	6.3×10^{-3}
Xylene	5.7×10^{-3}
Tetrachloroethylene	1.5×10^{-2}
Trans-1,2,Dichloroethene	9.4×10^{-3}
Trichloroethylene	9.9×10^{-3}

Air sparging creates turbulence and increased mixing in the saturated zone, which increases the contact between groundwater and soil. When the leaching of contaminants from soil into groundwater is transport-limited, higher transport rates (and therefore higher concentrations of VOCs) result.

The key to successful air sparging is good contact between the injected air and contaminated soil and groundwater. Below the water table, the air bubbles need to travel vertically through the aquifer in order to strip the VOCs. In addition, A permeability differential (i.e., clay barrier) above the air injection zone can reduce the effectiveness of air sparging, and must be addressed through a pilot study. There are two primary concerns with air sparging: 1) the spread of dissolved contamination, and 2) the acceleration of vapor-phase transport and the subsequent accumulation of vapors in buildings.

Where geology constricts vertical air flow, sparging can push the dissolved contamination concentrically from the injection point. As a result, in certain low permeable heterogeneous formations, sparging requires a groundwater recovery system to prevent the spread of dissolved contamination.

Since air sparging increases pressure in the vadose zone, any exhausted vapors can be drawn into building basements, which are generally low pressure areas; this can lead to preferential vapor migration and accumulation in basements. As a result, in areas with potential vapor receptors, air sparging should be evaluated with a concurrent vent system.

Air Sparging vs. Pump-and-Treat

When comparing in situ groundwater aeration programs with pump-and-treat alternatives, it is evident that air injection is subject to many of the same physical flow processes described above. However, air injection offers several clear advantages over a conventional pump-and-treat approach:

- Increased volumetric flow rate for air vs. water, due to higher permeability of soil to air.
- Simple, inexpensive installation of air injection points vs. costly installation of groundwater recovery wells.
- Increased mass transfer characteristics for contaminant removal by air rather than water.

An increased volumetric flow rate provides an advantage for heterogeneous formations where diffusive transport from low permeability sediments may be an issue. In this environment, the physical movement of air occurs preferentially through high permeability sediments in the same route as water. However, the greater volumetric flow rate for air ensures that contaminant concentrations in the air remain low, thus maximizing the concentration gradient that drives contaminants out of the low permeability zones. This low concentration in the air could be an additional cost factor for systems in areas that require off-gas treatment prior to discharge; however, it represents a distinct advantage for enhancing the rate of contaminant mass removal from the subsurface under diffusion controlled conditions.

TYPICAL AIR SPARGE/VENT POINT CONSTRUCTION (ASVPI-ASVP7)

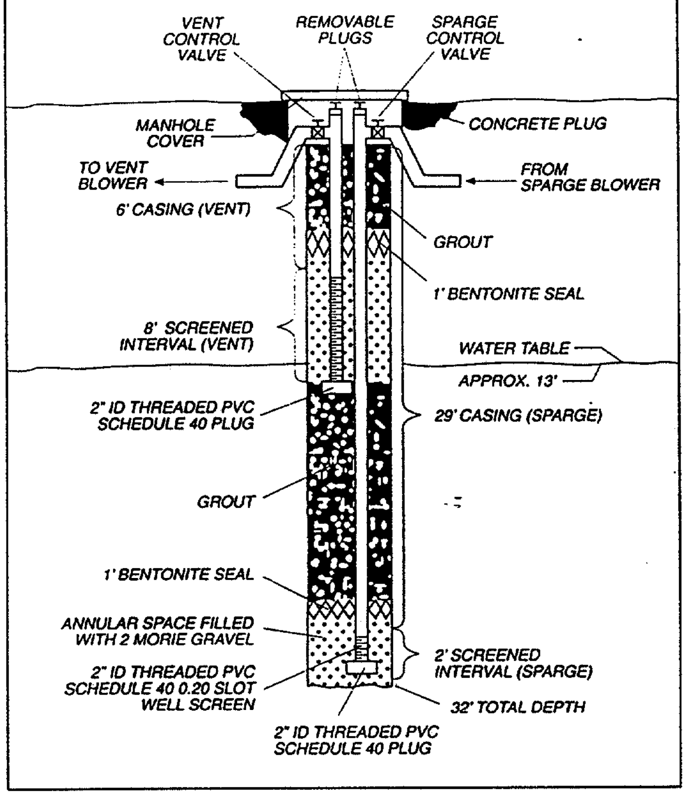

FIGURE 2

Air Sparging and Vacuum Extraction

Above the water table, VOCs can be removed by inducing air flow through areas of contamination by application of a vacuum (see *Figure 1* for air flow dyanmics; see *Figure 2* for detailed construction of an air/sparge/vent point). The air flow volatilizes and removes VOCs and supplies oxygen to support biodegradation. Nutrients, if needed, can be added periodically by percolation into the vent tubes. As long as the air flow contacts the contaminated soils, the system is effective. Proper air flow is ensured by properly spacing vapor extraction points, and by locating the contamination horizon and screening the vapor extraction well(s) accordingly.

The ventability of a compound is related to its vapor pressure, or the pressure of its vapor in equilibrium with its pure liquid or solid phase. The temperature at which the vapor pressure of a liquid is equal to atmospheric pressure is the boiling point of that compound. As a rule of thumb, a contaminant can be effectively removed by vacuum extraction only when its vapor pressure exceeds 1.0 mm Hg.

For a fixed flow rate of venting air, the maximum rate at which a contaminant can be extracted is derived by assuming the partial pressure of the contaminant in the vented gas is equal to the vapor pressure of the contaminant. The molar density of the contaminant in the gas phase is equal to its partial pressure, assuming ideal behavior. The vapor pressure at 40°F and maximum extraction rates of some common VOCs are shown in the table to the above right.

Actual extraction rates are generally less than the calculated maximum for two reasons. First, the contact time between the venting air and the contaminated soil may be insufficient to allow enough contamination to diffuse through the soil and into the air stream to establish the equilibrium vapor pressure. Second, because soil is generally not uniformly contaminated, not all the vented air will have passed through a contaminated zone. Thus, even if air passing through a contaminated zone were saturated with VOCs, it would be diluted by clean air which had only passed through uncontaminated soil. Proper design of a vacuum extraction system can maximize air/soil contact in the contaminated zone and maximize extraction efficiency.

Maximum – Vapor Extractability*

Compound	Vapor Pressure @ 40°F (mm Hg)	lb/100 ft^3	lb/day @ 100 SCFM
Benzene	28.0	7.9	1134
Chlorobenzene	3.8	1.5	221
Chloroform	77.0	33.2	4782
1,1 DCA	89.0	31.7	4564
Methylene Chloride	198.9	59.9	8622
Naphthalene	0.1	0.05	7
PERC	7.5	4.49	646
1,1,1 TCA	4.6	21.9	3154
TCE	28.0	13.1	1891
Toluene	9.0	3.0	430
Xylenes	3.0	1.1	165

*Assumes continuous vapor saturation

Design Principles

Two factors are critical to the effective design and operation of soil vapor extraction systems: the extraction system itself and the vapor abatement system. The extraction system includes the number, spacing and location of extraction wells, manifold layout, and the size and type of blowers. A properly designed extraction system operates with minimal adjustment. A poorly designed system requires the repeated installation of additional wells, piping, and blowers.Vapor abatement systems, often required by regulatory agencies, can consist of carbon or thermal treatment. Carbon is generally easy and cheap to install and permit, but can be expensive to use for high VOC levels. Thermal systems, on the other hand, require higher capital expenditures, take time to permit, but are relatively inexpensive to operate.

The maximum venting efficiency is attained in a soil vent system when:

- The induced air flow directly contacts the contaminated soil,
- The radius of influence of the vent well(s) matches the area of contamination, and
- The correct size vacuum blower is chosen based on site-specific soil permeability conditions such as moisture content, texture, and mineralogy.

The following information is needed for effective air sparge system design.

- The location of potential groundwater and vapor receptors,
- The geological conditions of the site (permeability, lithology, heterogeneity),
- The contaminant mass distribution within the area to be treated in both soil and groundwater (should be "superimposed" over the site lithology), and
- The radius of influence of the sparge well(s) at various flow rates/pressures.

The best sparge system design requires a field test that includes monitoring the following parameters.

- Pressure vs. distances; this indicates radius.
- VOC concentrations in groundwater; these indicate what is being removed and areas being affected and should be done before, during (with and without the system running), and after test.
- CO_2 and O_2 levels in soil vapor; these indicate biological activity and should be done before, during, and after test for petroleum contamination sites, under static as well as pumping conditions.
- Dissolved oxygen levels in water; these indicate effect and may be slower to see than air flow.
- Water levels before and during test; air flow will cause some mounding.

The ease and affordability of installing small-diameter air injection points allows considerable flexibility in the design and construction of a remediation system. The ability to install a dense grid of injection points without major site disruption or expense means that many of the problems associated with stagnation zones in wellfields may be avoided simply by completely covering the contaminated zone with injection points. Construction of the air injection points also allows fairly precise targeting of the aeration effect. The screened zone for these points is typically very short, providing a single point of aeration. If site investigation activities have identified zones or layers of either high contamination or aquifer heterogeneity, injection points may be dedicated to concentrate remediation activities on a specific zone. This ability to tightly focus remediation efforts alleviates the problem of aquifer heterogeneities influencing flow patterns in a pump-and-treat system. ☐

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EXCERPTS FROM . . .

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A TECHNOLOGY ASSESSMENT OF SOIL VAPOR EXTRACTION AND AIR SPARGING

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SECTION 2
AIR SPARGING

PROCESS DESCRIPTION

Air sparging, also called "in situ air stripping" and "in situ volatilization," is a technology utilized to remove VOCs from the subsurface saturated zone. It introduces contaminant-free air into an impacted aquifer system, forcing contaminants to transfer from subsurface soil and groundwater into sparged air bubbles. The air bubbles are then transported into soil pore spaces in the unsaturated zone where they can be removed by SVE.

Air sparging systems must operate in tandem with SVE systems that capture volatile contaminants stripped from the saturated zone. Using air sparging without accompanying SVE could create a net-positive, subsurface pressure extending contaminant migration to as-yet-unaffected areas. Thus the treatment could increase the overall zone of contamination. Without SVE, uncontrolled contaminated soil vapor could also flow into buildings (i.e., basements) or utility conduits (i.e., sewers), creating potential explosion or health hazards.

REMEDIATION MECHANISMS

The SVE system alone may affect the rate of volatilization of VOCs from the saturated zone [Marley, Walsh and Nangeroni, 1990]. However, transport of immiscible contaminants from the saturated zone to the vadose zone necessitates channeling them to the air/water interface for removal by an SVE system. Thus, the rate of contaminant transport from groundwater to soil vapor phase has increased with the addition of air sparging to an SVE system.

The effectiveness of combined SVE/air sparging systems results from two major mechanisms: contaminant mass transport and biodegradation. Depending on the system configuration, the operating parameters, and contaminant types found on-site, one mechanism usually predominates. In both remediation mechanisms, oxygen transport in the saturated and unsaturated zones plays a key role.

Although the exact nature of the saturated zone vapor phase is not completely understood, sparging seems to create air bubbles, which move through the groundwater to the unsaturated soil, like bubbles in an aeration basin [Ardito and Billings, 1990; Brown and Fraxedas,1991]. Other theories trace the movement of air through irregular pathways in the saturated zone and, ultimately, to the surface of the water table [Middleton and Hiller, 1990]. These theories suggest that the air would move as pockets through soil pathways, rather than forming bubbles, because groundwater travels in a porous medium.

The nature of air transport affects mass transfer to and from the groundwater regime. Bubbles exhibit higher surface area for transfer of oxygen to the groundwater and for volatile migration to the unsaturated zone, than the area provided by continuous, irregular air-flow pathways.

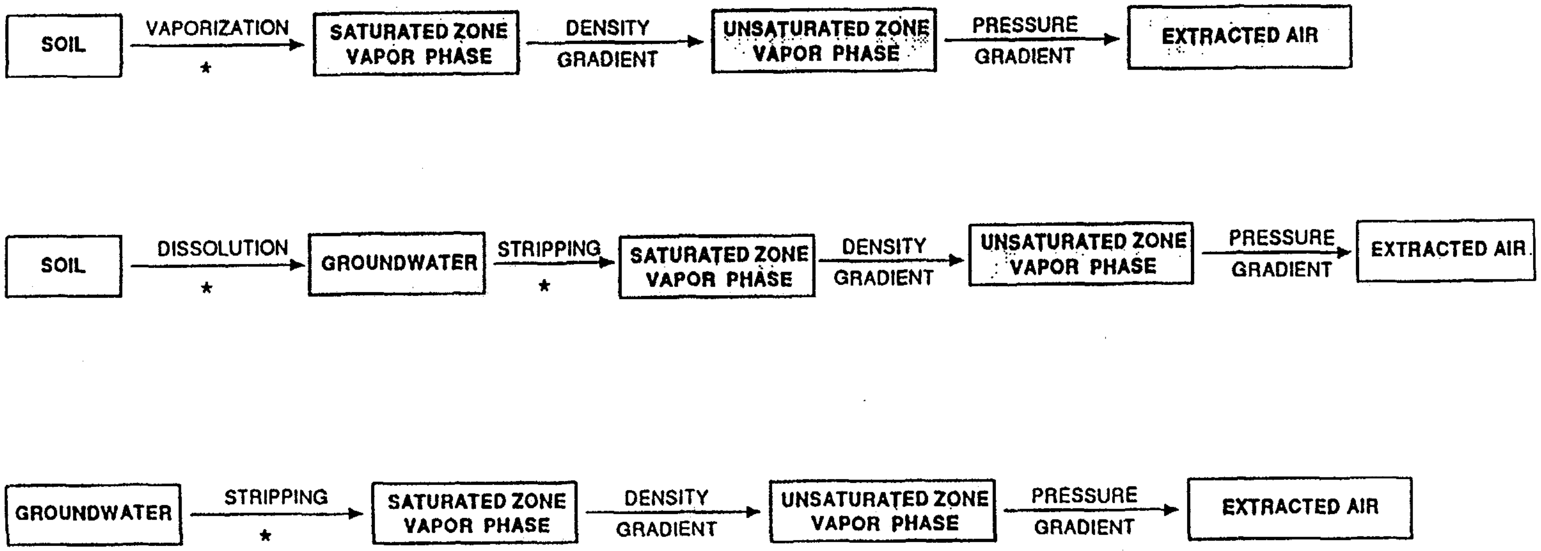
Mass Transfer

Mass transfer employs several mechanisms that move contaminants from saturated zone groundwater to unsaturated soil vapors. Figure 1 illustrates the following major mechanisms: (a) dissolving soil-sorbed contaminants from the saturated zone to groundwater; (b) displacing water in soil pore spaces by introducing air; (c) causing soil contaminants to desorb; (d) volatilizing them, and (e) enabling them to enter the saturated zone vapor phase. Due to the density difference between air and water, the sparged air migrates upwards in the aquifer. The pressure gradient resulting from the creation of a vacuum in the unsaturated zone pulls the contaminant vapors toward and into the SVE wells.

The action of the air passing through the saturated zone in response to sparging leads to turbulence and mixing of the groundwater. This in turn increases the rate at which contaminants adsorbed to the saturated zone soils dissolve into the groundwater. Light non-aqueous phase liquids (LNAPLs) floating on the water table are also subject to increased rate of transfer to the unsaturated zone because they are volatilized by the air sparging process.

In summary, air sparging increases the speed at which the following occur:

- volatilization of contaminants from the groundwater to the vadose zone;
- desorption and dissolution of adsorbed contaminants from the soil into the groundwater; and
- dissolution of NAPLs due to mechanical mixing.



* = Mechanisms enhanced by air sparging

Figure 1. Mechanisms of mass transport during air sparging.

The mass transfer of contaminants may be further enhanced by heating the air prior to sparging. The increase in air temperature will increase the rate of volatilization of contaminants.

Biodegradation Mechanism

Aerobic biodegradation of contaminants by indigenous microorganisms requires the presence of a carbon source, nutrients, and oxygen. Air sparging increases the oxygen content of the groundwater thus enhancing aerobic biodegradation of contaminants in the subsurface. Certain organic contaminants, such as petroleum constituents, serve as a carbon source for microorganisms under naturally occurring conditions. The rate of biodegradation can be enhanced by optimizing nutrient status of the system.

Remediation of an aquifer via the biodegradation mechanism has distinct advantages since a portion of the contaminants will be biologically degraded to carbon dioxide, water, and biomass -- yielding a lower level of VOCs in the extracted air. This in turn can substantially reduce vapor treatment costs. The possibility of off-site contaminant vapor migration is also reduced when sparged vapors entering the vadose zone contain lower levels of contaminants.

Certain contaminants, such as chlorinated solvents, can undergo biodegradation under anaerobic conditions. Air sparging, in these instances, could adversely affect this biodegradation process.

TECHNOLOGY APPLICABILITY

Although air sparging is a relatively new technology for contaminated subsurface soil remediation, it has been applied at hundreds of sites in the United States and Europe since 1985. However, the design of these systems has been, for the most part, empirically based [Marley, 1991].

The effectiveness of air sparging depends on various site conditions. Table 1 lists these factors, which are discussed below.

Depth to Groundwater

Air sparging has been effective in an aquifer 150 ft below surface [Looney, Kaback and Corey, 1991]. There appears to be no depth limit at which air sparging would not be effective, but significant cost implications may accompany the installation of an air sparging system in a very deep aquifer. However, a

TABLE 1. CONDITIONS AFFECTING APPLICABILITY OF AIR SPARGING

Air sparging applicability factor	Favorable conditions	Unfavorable conditions
Depth to groundwater	>5 ft	<3 ft
Volatility of contaminants	High volatility	Low volatility
Solubility of contaminants	Low solubility	High solubility
Biodegradability	High biodegradability	Low biodegradability
Permeability	$>10^{-3}$ cm/sec	$<10^{-3}$ cm/sec
Aquifer type	Unconfined	Confined
Soil type	Sandy soils	Clays, high organic soils
Presence of LNAPL	None or thin layer	Thick layer of LNAPL
Bedrock aquifer contamination	Highly fractured bedrock	Unfractured bedrock

water table located at a shallow depth (<5 ft), may increase the difficulty of recovering vapors with SVE. It could release VOC emissions to the atmosphere. Capping such a site with pavement or other impervious material might reduce atmospheric emissions.

Volatility of Contaminants

Enhancing mass transfer of contaminants from the soil and groundwater into the vapor phase, a key mechanism of the air sparging process, requires highly volatile contaminants. Volatility is directly related to the Henry's Law Constant of a compound and its vapor pressure -- the higher the Henry's Law constant, the higher the volatility. In general, compounds which are effectively removed from contaminated water by air stripping are sufficiently volatile for adequate air sparging treatment. Compounds with Henry's Law Constants of 10^5 atm-m^3/mole or greater can be air stripped or sparged [Brown et al., 1991]. Due to their high volatility, petroleum compounds (e.g., benzene and toluene), and solvents (e.g., trichloroethylene) are very amenable to air sparging technology.

Solubility of Contaminants

The solubility of a contaminant in water determines its ability to be stripped by air sparging. In general, the more soluble a contaminant is in water, the greater the difficulty there is in using air sparging.

Biodegradability of Contaminants

Since biodegradation is enhanced by air sparging, compounds that are readily aerobically degraded are amenable to remediation by air sparging. Biodegradation of petroleum hydrocarbons, such as those found in gasoline and diesel leaks from USTs, has been significantly increased with air sparging. Prior to designing an air sparging system for bioremediation, electrolytic respirometry should be used to analyze samples of the soils and groundwater. This will make it possible to gauge the effectiveness of the indigenous microorganisms and their energy sources to metabolize the petroleum hydrocarbons.

Soil Permeability

Soil permeability, which measures the ease of fluid flow through the soil column, is a critical parameter in the design of air sparging systems. Injected air must flow freely throughout the aquifer to achieve adequate removal rates. In most aquifers, horizontal permeability is greater, by a factor of ten, than vertical permeability. Successful sparging systems require air flow in both horizontal and vertical directions [Brown and Fraxedas, 1991]. Vertical flow is particularly important since the contaminant must migrate to the vadose zone for removal by SVE.

If the geology restricts the vertical flow, contaminants may migrate laterally into previously uncontaminated areas. Hydraulic conductivity of 0.001 cm/sec or greater is required to obtain sufficient subsurface air flow [Middleton, 1990]. Bench-scale experiments have shown coarse sand (d_{50} = 0.8 mm) forming the dividing line between soils, which permits injected air to rise by hydraulic uplift alone from soil that required additional pressure to inject air and through which air escaped at only a few points [Wehrle, 1990].

Due to the heterogeneity of soils at all sites, it may be necessary to concentrate wells in areas with lower permeability. The spacing of the wells depends on the radius of influence. In general, highly permeable soils will have larger radii of influence and higher air flow rates than lower permeable soils.

Screen placement requires a good understanding of the stratigraphy of a site. Well layout should overlap the radii of influence. This will ensure the treatment of all soil areas.

Clogging of the injection well screen or the aquifer in the vicinity of the sparging wells could reduce permeability and, therefore, decrease the effectiveness of the method. Clogging may result from enhanced bacterial growth under increased oxygen levels. In addition, oxidation at sites with high iron and manganese levels could cause further clogging. Some applications have injected nitrogen instead of ambient air to minimize problems associated with fouling [MWR, 1990]. However, the use of nitrogen also prevents the enhancement of aerobic biodegradation.

Confining Layers

Some air sparging proponents point out that it can only achieve success at sites with water table (i.e. unconfined) aquifers. Confined aquifers, where a low permeability layer lies above the water-bearing zone, would inhibit the flow of air upward from the saturated zone to the vadose zone. The injected air in these situations would flow radially away from the injection point; the vapor extraction system would not recover it. Such a situation could build up pressure in the aquifer.

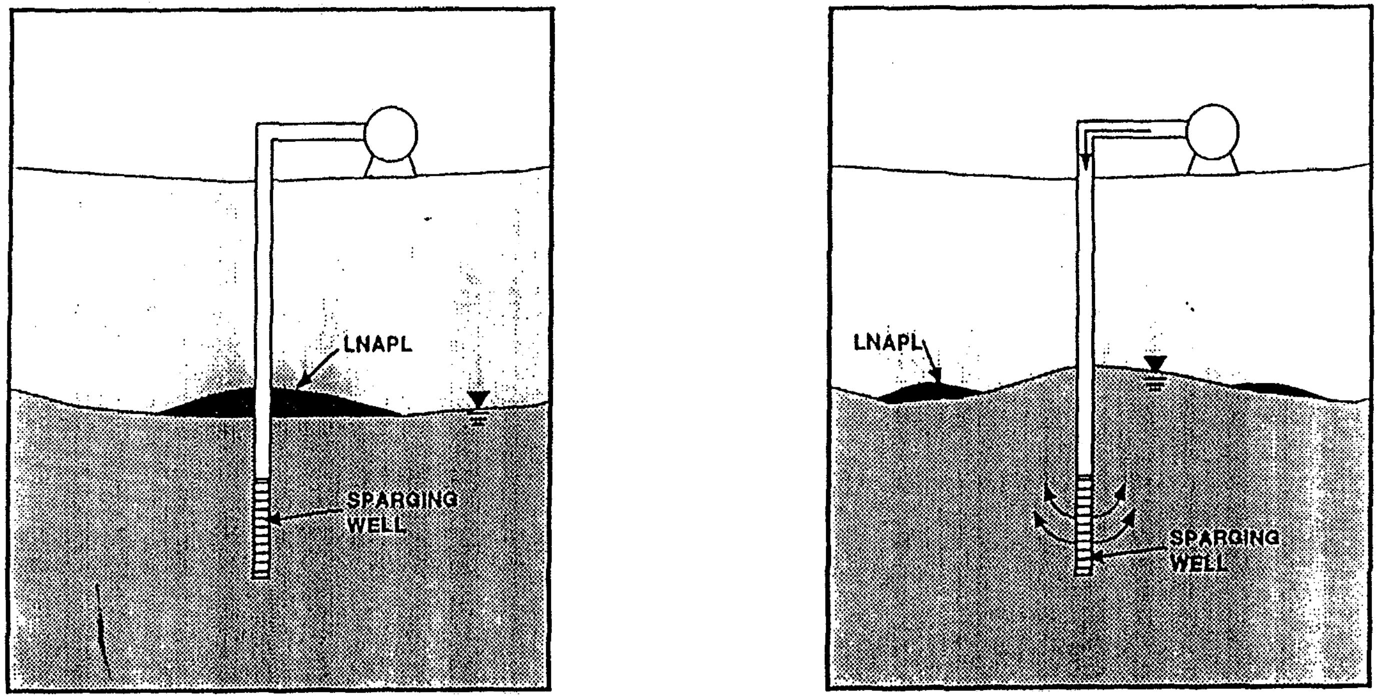
For unconfined aquifers, stratigraphic layers with different permeabilities will also affect air and water flow patterns as well as influence the air sparging system. In such situations, optimal air flow will occur in the more permeable zones [Wehrle, 1990]. Air flow may travel horizontally away from the injection point and create a wider zone of influence than would otherwise be expected [Bohler et al., 1990].

Soil Characteristics

Air sparging systems are most applicable for sites with sandy soil, due to its permeability. Soil containing a large organic carbon fraction may impede the desorption of volatile organic contaminants, thus reducing air sparging effectiveness. In extraction wells, the presence of a large amount of monomers in the soil may cause clogging of well screens possibly due to polymerization.

Presence of LNAPL

Low-density (or light) nonaqueous phase liquids (LNAPL) floating on the water table presents a particular problem during air sparging. As Figure 2 shows, the air sparging action creates a mounding effect



SUBSURFACE CONDITIONS PRIOR TO SPARGING

SUBSURFACE CONDITIONS DURING SPARGING

Figure 2. Migration of light non-aqueous phase liquids during air sparging.

in the proximity of the sparge well. In sites with steep hydraulic gradients, this mounding effect may be sufficient to move a plume of LNAPL, possibly contaminating clean areas. While it is possible to prevent the plume movement by modulating the sparged air pressure, it is more important to recover the mobile portion of the LNAPL to a residual saturation phase.

Contamination in Bedrock Aquifer

The effectiveness of air sparging hinges on the mass transfer of air to the groundwater and movement of the contaminants' vapor through the saturated zone upward into the unsaturated zone where they can be extracted. Unless the rock formation is highly fractured, with fractures vertically oriented, this technology will not provide sufficient mass transfer to effectively remediate a bedrock aquifer.

Metals in Groundwater

In addition to the possibilities of clogged well screens resulting from oxidation of metals in groundwater and the growth of bacteria previously discussed, precipitation of metals can also be an inhibiting factor. Since ambient air contains carbon dioxide, calcium carbonate precipitation may occur in some aquifers during air sparging. This may also reduce the air flow through the system.

Contaminant Location

Air sparging targets contaminants in the saturated zone and the capillary fringe. For compounds with a density less than water such as many petroleum constituents, much of the contamination may lie in the capillary fringe and just below the water table, depending on such factors as water table fluctuations, the amount of product released, contaminant density, and contaminant solubility. Dense non-aqueous phase liquids (DNAPL), such as trichloroethylene, often migrate through the aquifer to a lower confining unit and to greater depths. For dissolved contaminants in the aqueous phase, groundwater flow and direction will control the distribution of contaminants throughout the site. Depending on soil characteristics, air sparging would remediate DNAPL-contaminated soil as well.

Combination with Other Technologies

Air sparging is always used in conjunction with SVE. The implementation of SVE addresses the vadose zone contamination, and incorporates air sparging wells to treat saturated zones.

Groundwater extraction at air sparging sites may serve as a hydraulic control. Injected air may mobilize contaminants adsorbed to soil, either by displacement from the soil matrix or through increased dissolution of the adsorbed contaminant into the groundwater during mixing caused by air injection [Middleton and Hiller, 1990]. If this occurs and the rate of volatilization is insufficient, downgradient groundwater concentrations could actually increase. Air sparging may have fallen into disfavor in Germany due to increased downgradient dissolved contamination [Brown and Fraxedas, 1991]. To prevent this situation, a groundwater pumping system could hydraulically contain the site groundwater flow.

SECTION 3

AIR SPARGING CASE STUDIES

Air sparging technology is a relatively recent remediation method, applied at contaminated sites only within the past half decade. Early applications of this technique apparently occurred in Germany during the mid-1980's [Middleton and Hiller, 1990]. Due to the technology's short track record, the delay in publishing the results of field work, and the reluctance of some experts in revealing details about the technology for proprietary and competitive reasons, a relatively sparse body of information is available on air sparging. With increased application, the quantity and quality of this data should improve, disseminating helpful information to the remedial community.

Not surprisingly, documented air sparging experience has not been limited to one chemical group or soil type. The sites vary in contaminant treated, soil type, geological features, additional techniques used at the site, and other factors. A study of these sites, however, reveals that some share common characteristics, from which important insights can be drawn.

AIR SPARGING EXPERIENCE

Reviews of case histories for air sparging sites and visits to active sites in New Mexico contributed to the preparation of this report. A summary of the information gathered during these activities follows below. Table 2 lists 21 sites remediated by air sparging. It provides data on soil types, contaminant types, groundwater concentrations (initial and final), and the time needed to achieve those final levels. Table 3 presents construction and operations information for these case studies. Brief treatments of four case studies from the United States and nine European installations will illustrate how air sparging successfully remediates the saturated zone.

Contaminants Treated

At the sites studied, air sparging has been used exclusively to treat VOCs, including petroleum constituents and chlorinated solvents. Gasoline and industrial solvent applications targeted trichloroethylene (TCE) and perchloroethylene (PCE). In many instances such contamination originated in releases from USTs at service stations, tank farms, dry cleaners, manufacturing plants, and other industrial facilities. Among the case histories reviewed, nine sites were contaminated with gasoline, and twelve were impacted by the release of solvents. One of the nine gasoline-contaminated sites contained both gasoline and diesel fuel contamination.

Contaminant Magnitude

Table 2 lists the initial contaminant concentration for each case history site. There appears to be no upper limit for expectations of air sparging effectiveness. Indeed, as the contaminant levels increase, air sparging should exceed the results achieved by groundwater pump-and-treat approaches, since the volatilization mechanism depends on a concentration gradient between the groundwater concentration and that of the (contaminant-free) introduced air.

Soil Characteristics

Like many in situ remediation technologies, the effectiveness of air sparging is significantly affected by soil characteristics. Table 2 shows the soil properties found at each site listed. Most of these sites contained permeable soil types, such as sand, silt, and gravel. The Nordrhein, Westfalen site presented fractured limestone. Such sites, with highly fractured rock formations, may also provide sufficient permeability for air sparging application, as noted before.

Depth to Groundwater Table

Air sparging has operated at sites where the depth to groundwater ranges from just two ft [Harress, 1989] to 135 ft [Looney, 1991]. Most of the sites studied, however, measured this depth from 8 to 20 ft (Table 3).

TABLE 2. SUMMARY OF PUBLISHED AIR SPARGING SITES

Site	Citation	Soil type	Contaminants	Cleanup time** (months)	Initial GW concentration (ppm)	Final GW concentration (ppm)
Isleta	Ardito & Billings, 1990	Alluvial sands, silts, clays	Leaded gasoline	2	MW-1 BTEX ~4 MW-3 BTEX ~18 MW-5 BTEX ~25	MW-1 BTEX ~0.25 MW-3 BTEX ~8 MW-5 BTEX ~6
Conservancy	Billings, 1990	Silty sand Interfering clay layer	Gasoline	5	Benzene 3 - 6	59% average benzene reduction after 5 months
Buddy Beene	Billings, 1991	Clay	Gasoline	2	*	8.5% reduction/month
Bernalillo	Billings, 1990	*	Gasoline	17	*	BTEX & MTBE <5.5
Los Chavez	Billings, 1990	Clay	Gasoline	9	*	40% benzene, xylenes reduction, 60% toluene reduction, 30% ethyl benzene reduction
Arenal	Billings, 1990	*	Gasoline	10	Benzene >30	Benzene <5
Dry cleaning facility	Brown, 1991	Coarse sand Natural clay barrier	PCE, TCE, DCE, TPH	4	Total VOCs - 41	Total VOCs - 0.897
Berlin	Harress, 1989	Sand, silty lenses Aquitard-clay	c-1,2-DCE, TCE, PCE	24	c-1,2-DCE - >2	c-1,2-DCE - <0.440
Bielefeld, Nordrhein - Westfalen	Harress, 1989	Fill, sand, silt Aquitard-siltstone	PCE, TCE, TCA	11	PCE 27; TCE 4.3; TCA 0.7	Total VOCs - 1.207
Munich, Bavaria	Harress, 1989	Fill, gravel, sand Aquitard-clayey silt	PCE, TCE, TCA	4	PCE 2.2; TCE 0.4; TCA 0.15	PCE 0.539; TCE 0.012; TCA 0.002
Nordrhein, Westfalen	Harress, 1989	Clayey silt, sand Aquitard-siltstone	Halogenated hydrocarbons	4 6	Location A: THH 1.5-4.5 Location B: THH 10-12	Location A: THH 0.010 Location B: THH 0.200
Bergisches Land	Harress, 1989	Fractured limestone	Halogenated hydrocarbons	15	THH - 80	THH - 0.4
Pluderhausen, Baden - Wurttemburg	Harress, 1989	Fill, silt, gravel Aquitard-clay	TCE	2	1.20	0.023

TABLE 2. (Continued)

Site	Citation	Soil type	Contaminants	Cleanup time** (months)	Initial GW concentration (ppm)	Final GW concentration (ppm)
Mannheim - Kaefertal	Herrling, 1991	Sand	PCE, chlorinated hydrocarbons	*	*	*
Gasoline service station	Kresge, 1991	Sand and silt	Gasoline	24	Total BTEX - 6-24	Total BTEX - 0.380-7.6
Savannah River	Looney, 1991	Sand, silt, and clay	TCE, PCE	3	TCE 0.5-1.81 PCE 0.085-0.184	TCE 0.010-1.031 PCE 0.003-0.124
Gasoline service station	Marley, 1990	Fine-coarse sand, gravel	Gasoline	2	Total BTEX - 21	Total BTEX <1
Solvent spill	Middleton, 1990	Quaternary sand and gravel	TCE, PCE	3	Total VOCs - 33	Total VOCs - 0.27
Solvent leak at degreasing facility	Middleton, 1990	Fill, sandy and clayey silts	TCE	2	0.200-12	<0.010-0.023
Chemical manufacturer	Middleton, 1990	Sandy gravel Aquitard-clay	Halogenated hydrocarbons	9	THH - 1.9-5.417	THH - 0.185-0.320
Truck distribution facility	MWR, 1990	Sands	Gasoline & diesel fuel	On-going	Total BTEX - 30	*

c-1,2-DCE	- 1,2-cis-Dichloroethylene	BTEX	- Benzene, toluene, ethyl benzene, xylenes
TPH	- Total petroleum hydrocarbons	MTBE	- Methyl tert-butyl ether
TCE	- Trichloroethylene	THH	- Total halogenated hydrocarbons
PCE	- Tetrachloroethylene	*	- Not specified
TCA	- Trichloroethane		

**** Cleanup times indicate the time interval between the initial and final groundwater concentrations reported in this table. Total site remediation time may have been longer.**

TABLE 3. PUBLISHED AIR SPARGING CONSTRUCTION DETAILS

Site	Citation	Depth to groundwater (ft)	No. of air spargers	Screen depth (ft)	Injection pressure (in H_2O)	Injection flow rate (cfm)	No. of vacuum wells	Other
Isleta	Ardito & Billings, 1990	6.5-16	27	•	•	•	27	Nested injection & extraction wells
Conservancy	Billings, 1990	6.5	35	•	•	•	35	Nested injection & extraction wells
Buddy Beene	Billings, 1991	•	67	•	•	•	67	Nested injection & extraction wells
Bernalillo	Billings, 1990	•	16	•	•	•	16	Nested injection & extraction wells
Los Chavez	Billings	•	•	•	•	•	•	Nested injection & extraction wells
Arenal	Billings, 1990	•	11	•	•	•	11	Nested injection & extraction wells
Dry cleaning facility	Brown, 1991	13	7 sparge only; 7 nested sparge/vacuum	2' sparge 8'vacuum	277	225	1 extraction only 7 nested	40 in. H_2O, vacuum extraction flow rate - 500 cfm, (2) 1,800 lb GAC vapor treatment
Berlin	Harress, 1989	15-18	3	•	•	•	1	
Bielefeld, Nordrhein - Westfalen	Harress, 1989	2-8	5	•	•	•	2	
Munich, Bavaria	Harress, 1989	15	7	•	•	•	1	
Nordrhein - Westfalen	Harress, 1989	6-9	10	•	•	•	2	
Bergisches Land	Harress, 1989	90	8	•	•	•	2	
Pluderhausen, Baden - Wurttemberg	Harress, 1989	11	5	•	•	•	1	
Mannheim-Kaefertal	Herrling, 1991	33	1 w/gw recirc. and extract.	•	•	•	1 combo inj. & ext. w/gw recirculator	19.7 in H_2O, vacuum extraction flow rate 300 - cfm, activated carbon vapor treatment
Gasoline service station	Kresge, 1991	8-13	8	2.5	•	•	•	20-30 in H_2O, vacuum extraction flow rate - 200 cfm, air injection - 8 hr/day
Savannah River	Looney, 1991	135	1 (horiz.)	300 (sparge) 205 (vacuum)	•	165-185	1 (horiz.)	130-145 in H_2O, vacuum extraction flow rate 935-1,020 cfm

TABLE 3. (Continued)

Site	Citation	Depth to groundwater (ft)	No. of air spargers	Screen depth (ft)	Injection pressure (in H_2O)	Injection flow rate (cfm)	No. of vacuum wells	Other
Gasoline service station	Marley, 1990	15.5-16	7 shallow 6 deep	18-20 25-27	28-55 166-222	3-6 2-6	2	Deep wells 6 hr on, 6 hr off, extraction flow rate - 100 cfm
Solvent spill	Middleton, 1990	27	5	*	*	30	2	Extraction flow rate - 475 cfm
Solvent leak at degreasing facility	Middleton, 1990	18-20	5	*	*	*	1	
Chemical *manufacturer*	Middleton, 1990	8	8	*	*	*	4	
Truck distribution center	MWR, 1990	12-14	13	*	*	*	4	

** Not available or reported.*

Analyses for groundwater sampling cost $125 (TPH), $225 (VOCs), $100 (BTEX), $425 (ABNs), and $50 for general groundwater quality parameters, respectively. Soil gas analysis using a GC determines total hydrocarbons and other specific contaminants; it may cost as much as $250 at a laboratory.

Biological assay tests can monitor biological activity in the soil. Dissolved oxygen in groundwater should be measured on-site with a D.O. probe, which costs about $1,000.

CONCEPTUAL ESTIMATE FOR AN SVE AND AIR SPARGING INSTALLATION

Following is a conceptual estimate for a leaking underground storage tank site remediation using the air sparging technology. The site is contaminated in both the saturated and unsaturated zones by gasoline. The equipment that will be included for site remediation will be sufficient to act on a total of up to 10,000 cubic yards of contaminated soil. The depth to the water table is assumed to be 60 feet.

The capital costs are based on a configuration that includes two (2) vapor extraction wells, one (1) air injection well, and four (4) groundwater monitoring wells. The system also consists of a 25 HP rotary lobe vacuum pump, a 15 HP rotary lobe air injection compressor, two (2) air/water separators, a collection header and various piping connections. An off-gas emissions control system will be required to capture the BTEX hydrocarbon compounds. This will consist of canisters filled with granular activated carbon adsorbent. The size of the site dictates that on-site regeneration of the carbon will not be practical. The cost of carbon will be based on regeneration or reactivation off-site. The canisters containing the carbon will be rented from the supplier, so that the costs for the emissions control system will appear as an operations and maintenance cost.

Table 6 contains the equipment specifications required for the site remediation, Table 7 outlines the capital costs of the equipment items, and Table 8 contains a summary of the annual operating and maintenance costs.

TABLE 6. EQUIPMENT SPECIFICATIONS

A. Vacuum Blower	
Size	25 HP
Rating	500 scfm @ 10" Hg vac
Electrical	440 V, 3 phase
Compression ratio	1.52
Type	Straight lobe rotary (positive displacement), constant volume - variable discharge pressure
B. Air Compressor	
Size	15 HP
Rating	160 scfm, disch. press. 15 psig
Electrical	440 V, 3 phase
Type	Rotary lobe, positive displacement V-belt dirve with inlet filter, inlet silencer and discharge silencer
C. Air/Water Separators	
Size	800 gallons
Type	Stainless steel
Accessories	Sight glass 2-4" NPT connections (top) 1-4" NPT connection (bottom sealed to atmosphere)
D. Piping Network	
Type	4" PVC
Length	500 ft
Elbows	20
Caps	5
Valves (2")	6
Reducers	10
Type	2" PVC
Length	70 ft
E. Vacuum Well Construction	
Type	Rotary auger
No. of wells; Screen	Depth
3 10'	20'
3 15'	60' (to water table)
Hole size	6"
Casing	4"
F. Air Sparging Well Construction	
Type	Rotary auger
No. of wells	One
Depth	60'
Hole size	6"
Casing size	4"
Air line	2" PVC, well complete with bottom cap, bentonite seal and inflatable packer
G. Valve Boxes (4)	
Type	Below grade/cast iron construction
Size	2' x 2' x 1'
Additional features	Gravel packed bottom
H. Trench Construction	
Type	Cut and cover
Depth	1 foot below grade
Layout	4" PVC pipe
Length	50 feet
Cover	Concrete

TABLE 7. CAPITAL COSTS

Item/description	Install/labor cost ($)	Equip./matl. cost ($)	Total cost ($)
1. WELLS			
Air sparging well	2,000	1,000	3,000
Extraction wells	4,000	1,600	5,600
Monitoring wells	3,000	1,900	4,900
Valve boxes	1,500	1,000	2,500
SUBTOTAL	$10,500	$5,500	$16,000
2. EQUIPMENT			
Air compressor	1,500	3,000	4,500
Vacuum blower	2,500	9,500	12,000
Separators	11,600	23,200	34,800
Blower housing	2,500	5,000	7,500
SUBTOTAL	$18,100	$41,700	$59,800
3. MECHANICAL/PIPING			
Wellhead pits (4)	2,000	1,200	3,200
Well pipe & fittings	3,000	1,500	4,500
Pipe	5,500	4,000	9,500
Valves & fittings	1,500	2,100	3,600
Testing	500	500	1,000
SUBTOTAL	$12,800	$14,700	$27,500
4. ELECTRICAL/INSTRUMENTS			
Elec. & instr. - wells	1,000	1,500	2,500
Elec. & instr. - equip.	2,500	3,000	5,500
Elec. distribution	2,000	4,000	6,000
Main control panel	1,000	2,000	3,000
SUBTOTAL	$6,500	$10,500	$17,000
TOTAL	$47,900	$72,400	$120,300

TABLE 8. OPERATION AND MAINTENANCE COSTS

	Annual costs
Power	8,000
Off-gas emissions control[1]	120,000
Maintenance	5,000
Monitoring[2]	34,000
Labor	15,000
Contingency	10,000
TOTAL	$192,000

[1] Assumes an average usage of 2,000 lb per month of granular activated carbon. The price includes transportation and off-site regeneration.

[2] Assumes twice a month evaluation of extraction well concentrations with a portable GC.

APPENDIX E
IN WELL AERATION

BIOREMEDIATION BY GROUNDWATER CIRCULATION USING THE VACUUM-VAPORIZER-WELL (UVB) TECHNOLOGY: BASICS AND CASE STUDY

W. Buermann and G. Bott-Breuning

INTRODUCTION

Not only in the industrialized countries, but worldwide, the numbe of known groundwater and soil air contaminations by hydrocarbons benzene, toluene, ethylbenzene, and xylenes (BTEX); pesticides; nitrates etc., increases. Efficient, low-cost remediation techniques are needed.

A new method for the in situ remediation of groundwater and soi air is the vacuum-vaporizer-well (UVB) technology (German: Unterdruck Verdampfer-Brunnen [UVB]; invented by B. Bernhardt; patents: IEG mbH D-7410 Reutlingen). The disadvantages of groundwater remediatio applying current pumping methods (groundwater lowering, limited yield insufficient remediation) may be avoided if pumping and recharge tak place in the same well. The UVB technology applies this circulation wel concept.

The basics of hydromechanical theory are outlined in some detai (Buermann 1990, Bürmann 1991). Results of the field measurement conducted in Karlsruhe, Germany, to verify the UVB technology hav been published briefly (Bürmann 1992, Bürmann & Wagner 1992) and are presented.

A case study on the bioremediation of pesticide (triazines)-contaminated groundwater is presented. Activated carbon is placed within the UV well as a biofilter. A decrease in triazine concentrations in the ground-water is documented. An increase in the number of bacteria in the aquife was observed and suggests a stimulation of biological processes. Develop-ment of metabolites within the activated carbon filter provides evidence of triazine biotransformation.

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Operation of the Vacuum-Vaporizer-Well: UVB Technology. The UVB produces a circulation flow within the surrounding groundwater, directed from the upper to the lower screening, as seen in Figure 1. Water is sucked into the lower screening, transported upwards inside the UVB by the water pump (air lift pump), and cleaned by fresh air in the stripping zone under below-atmospheric pressure before flowing out of the UVB through the upper screening. This all takes place without the water leaving the aquifer. If necessary, the groundwater is cleaned on site and directed back to the well. Soil air from the unsaturated zone of the aquifer may be sucked into the UVB through the upper screening and thus also may be cleaned. The contaminants in the stripping air are adsorbed by activated carbon. To avoid precipitation, the stripping air loop is closed. Thus contaminants that are not adsorbed can be kept from escaping into the atmosphere (Herrling et al. 1992).

In resting groundwater, circulation creates a permanent flow and consequently cleans the soil within the zone of the well, as all the circulating water flows through the well. Natural groundwater flow, which exists in most cases, deforms the circulation flow so that a portion of the water flowing toward the intake zone of the well may pass the well several times, due to the continual circulation flow, whereas the remainder of the water flows through the well only once. Therefore, the cleaning equipment of the UVB must be dimensioned so that one flow through the well is sufficient to ensure decontamination of the water.

Groundwater Flow around the UVB. The circulation flow depends on the natural groundwater flow, the water flowrate through the well, the water-saturated thickness of the aquifer (corresponding to the length of the well), the lengths of the lower and upper screenings, the outer radius of the well, and the horizontal and vertical conductivities of the aquifer (Buermann 1990).

The circulation flow may be influenced only by the design of the well itself, and in particular by the water flowrate. If existing wells must be used, water flowrate is the only means of control of the circulation flow.

In resting groundwater, the investigations give a theoretically unlimited zone of effect of the well. For a realistic judgment of the zone of effect, a radius around the well is chosen that contains a specific percentage of the total quantity of water flowing inside the well. The influence of the screening length is small. For realistic values of the anisotropy of the aquifer, the radius of effect is approximately 1.5 to 2 times the water-saturated aquifer thickness.

The circulation flow in moving groundwater shows two separating streamlines, at the bottom and at the top of the aquifer, similar to the

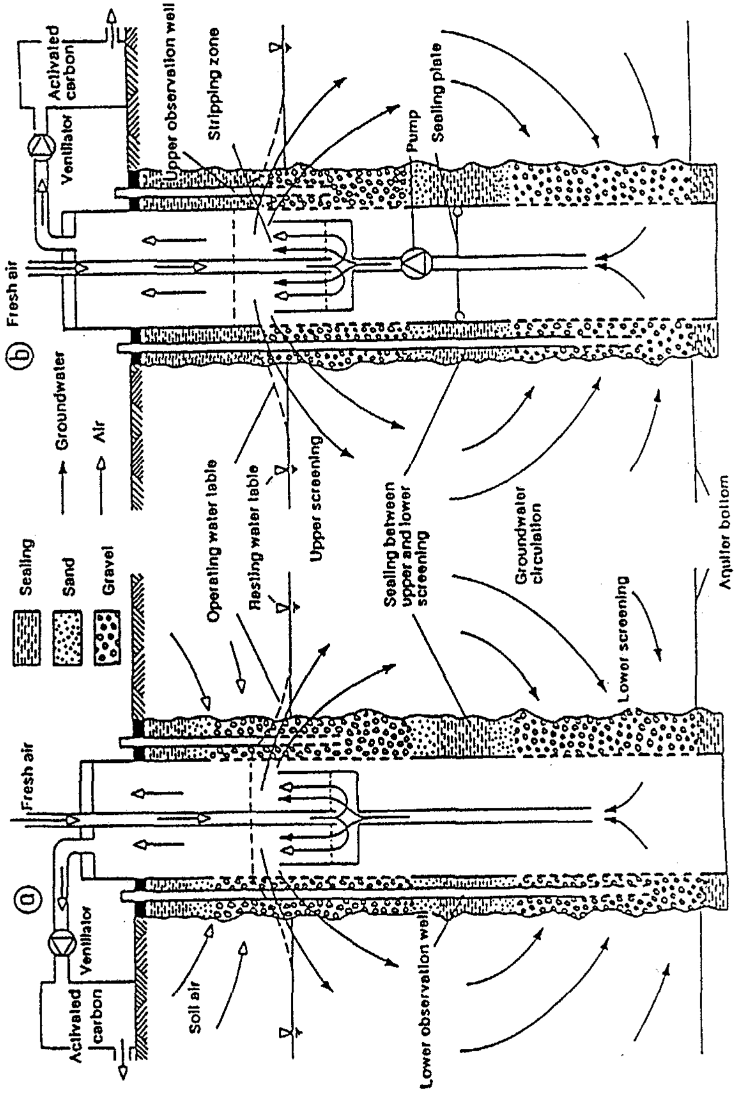

FIGURE 1. Typical vacuum-vaporizer-well (UVB)

perfect well (Figure 2). In a well with upward flow, the lower separating streamline corresponds to the withdrawal well and the upper one to the infiltration well. Between these two separating streamlines at the lower and upper boundaries of the aquifer lies the separating stream surface of the flow around the well in the natural groundwater. This surface consists of spatial streamlines and shows a different contour in each horizontal section.

The dimension of the separating stream surface is characterized by the distance of the stagnation point S from the well. Figure 3 shows the water flowrate over the stagnation point distance of the upper separating streamline. The lower stagnation point distance gives the same curves for equal lengths in the lower and upper screening, and the curves remain essentially the same even for very different screening lengths. The smaller the ratio of vertical and horizontal conductivity, the greater the stagnation point distance and the influence zone of the well.

The water flowrate through the well rises more than proportional with the stagnation point distance. Therefore, instead of one single well of a large water flowrate, several wells of small rates may be useful.

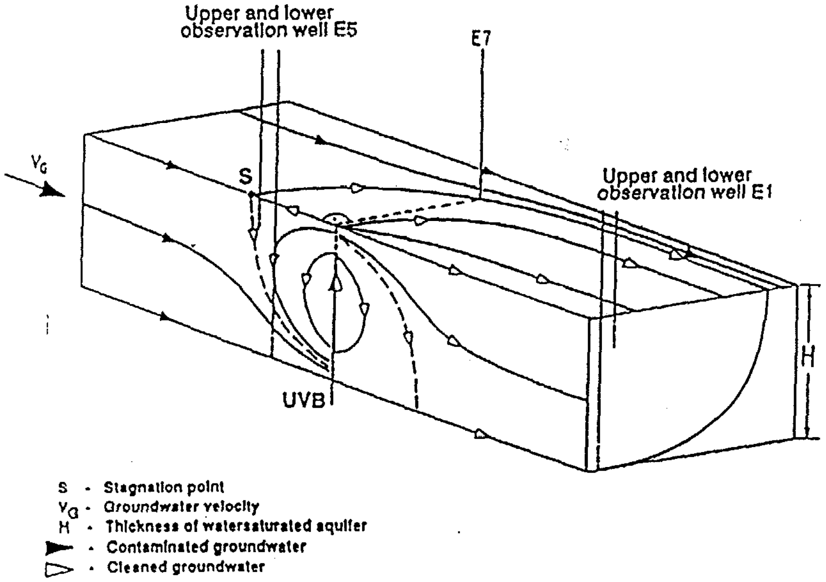

FIGURE 2. Typical flow pattern of the vacuum-vaporizer-well (UVB) in natural groundwater flow.

CASE STUDY OF A BIOLOGICAL REMEDIATION

The UVB technology offers not only an innovative method of physically remediating contaminated sites, but also makes in situ biological remediation of groundwater possible. As a case study, a combined physical and biological remediation of groundwater containing pesticides (triazines) is presented (Figure 4).

The darcy velocity of the natural groundwater flow of 0.17 m/d, the water-saturated thickness of the aquifer of 6.6 m, the anisotropy k_V/k_H of 0.1, the screening length of 2 m, and the water flowrate inside the UVB of 4 m^3/h give the stagnation point distance of about 13 m in Figure 3.

Principle of Bioremediation. The principle behind every bioremediation is optimizing the environmental conditions for the naturally existing, already adapted microorganisms. Oxygen often is a limiting factor for aerobic degradation. The part of the aquifer where the UVB creates a continuous circular flow is regarded as an in situ bioreactor and is constantly supplied with oxygen-enriched water. Additional nutrients needed by the bacteria can easily be injected into the circulation flow that

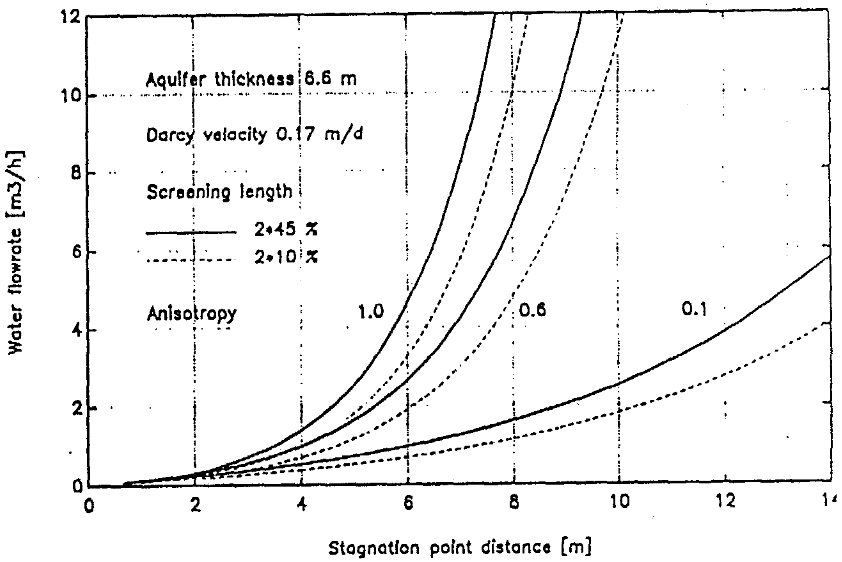

FIGURE 3. Water flowrate over stagnation point distance of the vacuum-vaporizer-well (UVB) in natural groundwater flow.

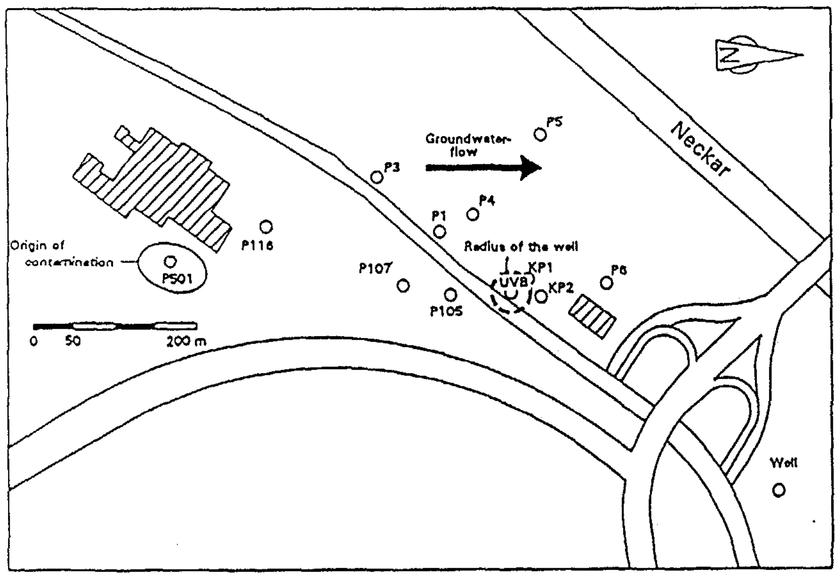

FIGURE 4. Schematic map of the contaminated site.

the UVB creates within the aquifer. These nutrients enable optimal conditions to be created for the microorganisms bound on grain surfaces. In the case study presented in this paper, activated carbon was used as a biofilter within the UVB. The two variations shown in Figure 5 were tested. In both cases the contaminants and the triazine-degrading bacteria are adsorbed onto the activated carbon by constant circulation of contaminated groundwater in the well. This accumulation is a special advantage in cases with low contaminant concentrations or few bacteria in the groundwater. Adding specific nutrient supply for the bacteria to the biofilter is possible.

Results of the Triazine Remediation. In Figure 6, the concentration curves of the total triazines (atrazine, propazine, simazine, and triazine metabolites) entering and leaving the biofilter are depicted. The amount of triazines in the groundwater entering the activated carbon is higher than that leaving the biofilter. This decontamination is the result of adsorption of triazines onto and biological degradation processes within the activated carbon.

During biodegradation of triazines, various intermediates are formed (Cook 1987). These were detected in the aquifer before remediation with the UVB technique began. Figure 7 shows the concentration curve of one

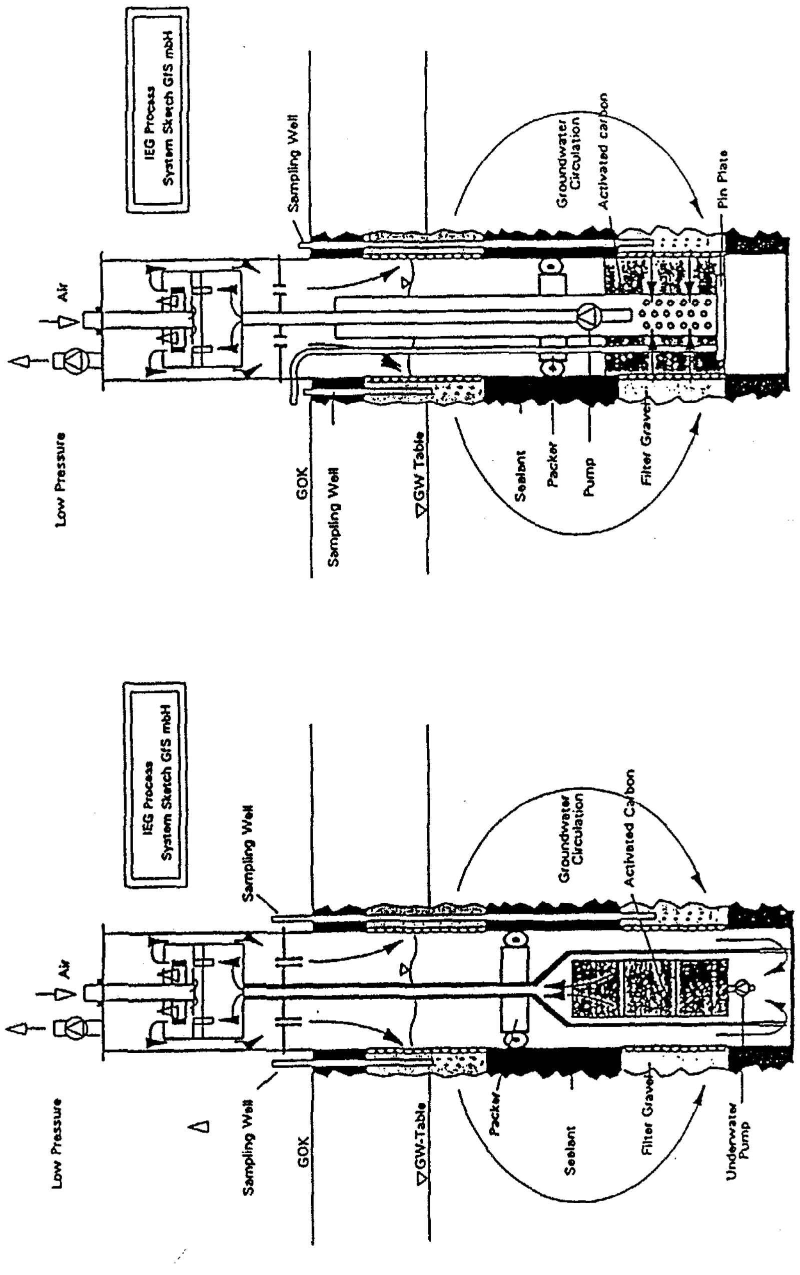

FIGURE 5. Version 1 (left) and version 2 (right) with the biofilter implemented (schematic).

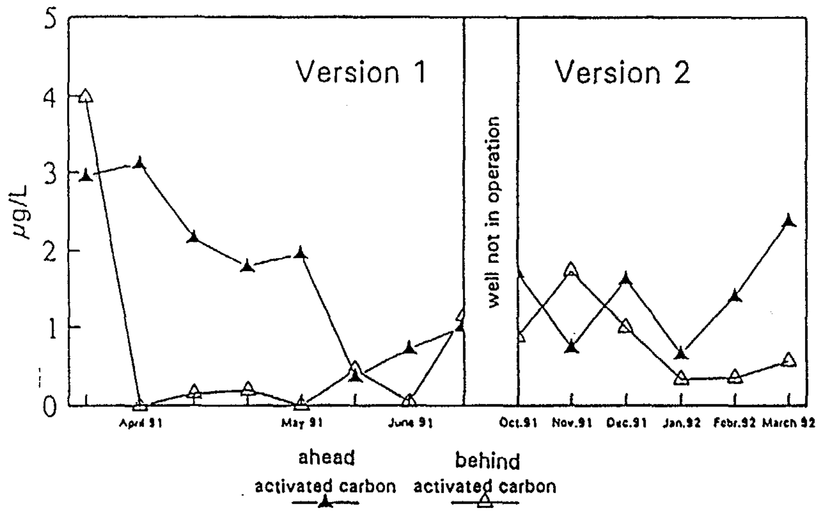

FIGURE 6. Concentration curve of triazines in groundwater entering and leaving the biofilter.

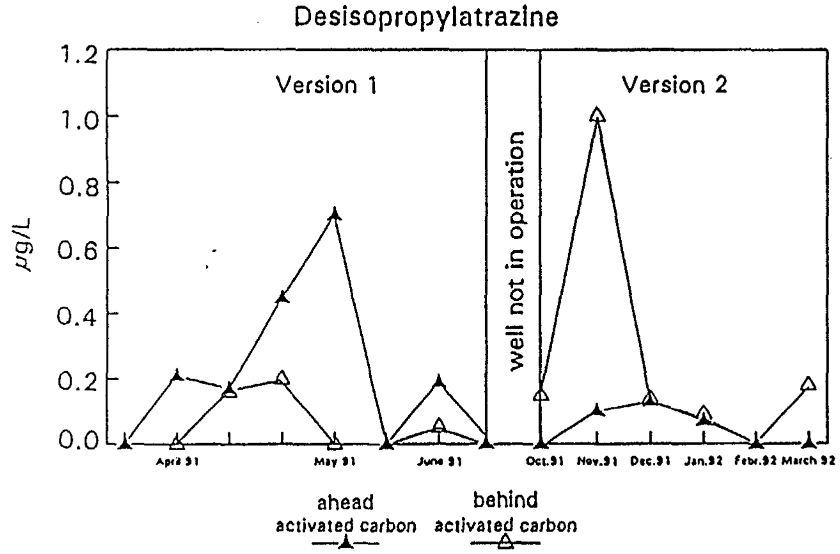

FIGURE 7. Metabolite concentration (desisopropylatrazine) in groundwater entering and leaving the biofilter.

of these metabolites, desisopropylatrazine, in groundwater before and after treatment by the activated carbon. The higher metabolite concentration behind the activated carbon indicates that further biological transformation of triazines occurs in the biofilter. This intermediate is further reduced by biodegradation. Figure 8 depicts the decrease of triazine concentrations in groundwater of the monitoring well KP1.

In addition to using intermediates as an indication of biodegradation it is possible to count the number of bacteria in a sample. This was carried out by the colony-forming-units (CFU) method, in which bacteria are cultivated under aerobic conditions on a defined standard nutrien supplier. Table 1 shows the development of the number of bacteria in samples taken from various wells. Within 3 months the number of bacteria in monitoring well KP1 increased by a factor of 1,000, and the triazine concentration decreased accordingly. A biofilm developed on the activated carbon from April to June 1991. It was analyzed qualitatively and quantitatively. The number of CFUs was 7.7 × 10^4/g activated carbon, which is an enrichment compared to the number of bacteria (470 CFU/mL groundwater) ahead of the activated carbon biofilter.

CONCLUSIONS

The combined physical and biological remediation of triazine-contaminated groundwater using the UVB technology shows good success

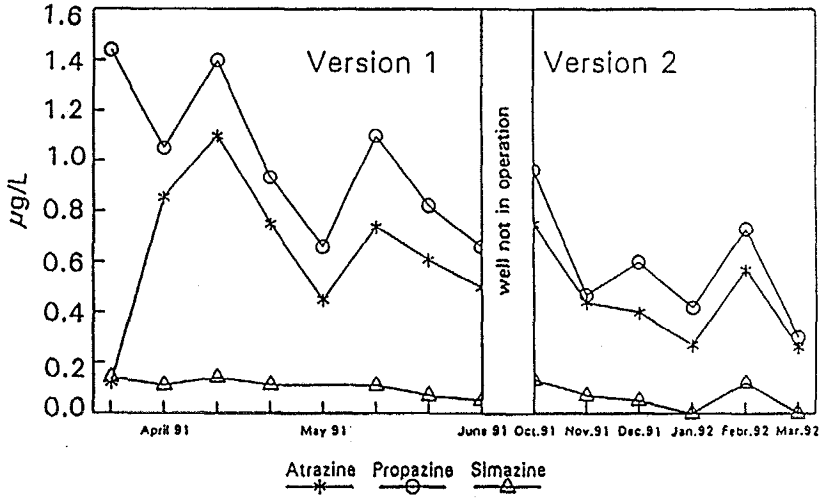

FIGURE 8. Triazine concentrations in the groundwater at monitoring well KP1.

TABLE 1. Development of bacteria (CFU/mL groundwater).

Date	Entering Activated Carbon	Leaving Activated Carbon	Monitoring Well KP1	Monitoring Well KP2
October 1991	$4.7*10^2$		$2.5*10^3$	
January 1992	$1.8*10^3$	$3.1*10^4$	$3.5*10^6$	$7.5*10^3$

in decreasing the triazine concentrations during remediation to date. The simultaneous increase in the number of bacteria in the aquifer suggests stimulation of biological processes. The development of metabolites and the increasing remediation rate within the activated carbon are evidence of biological triazine transformation. Further investigations include determination of degradation rate, looking for proof of specific triazine-degrading bacteria both in the aquifer and in the biofilter, and optimizing the biofilter.

ACKNOWLEDGMENTS

The authors gratefully acknowledge IEG mbH, D-7410 Reutlingen, for funding the investigations, and in particular, B. Bernhardt, IEG mbH, and many others for their work and their numerous helpful discussions and contributions concerning the UVB technology.

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PROFESSIONAL QUALIFICATIONS FOR

BIOREMEDIATION TECHNOLOGY

SBP Technologies, Inc.

A Subsidiary of The EICON Group, Inc.

UVB-Microbiological Remediation

Due to the minimal environmental impact and low cost of implementation, biological remediation technologies have become increasingly popular during the last few years.

In an ideal case, depending on the type of contaminants on the site, naturally occurring microorganisms degrade organic compounds to carbon dioxide and water. The rate of biodegradation is determined by the existing chemical and physical conditions.

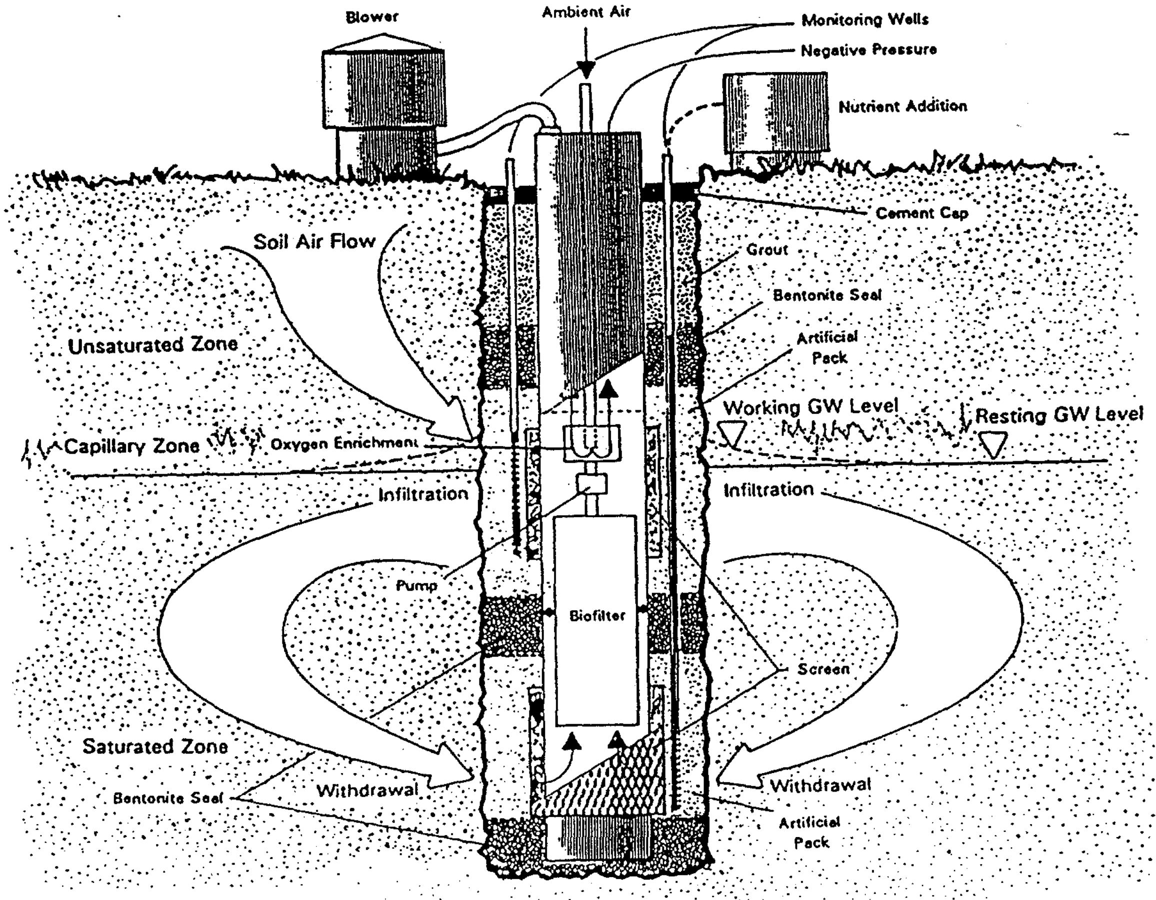
The goal of in situ biological remediation technologies we implement is to optimize the existing degradation potential. By improving the environmental conditions needed by the degrading bacteria, an effective reduction of contaminants is achieved.

Biological/Physical In Situ Groundwater Remediation Using the UVB

The UVB Technology is especially suitable for eliminating biologically degradable contaminants (e.g. hydrocarbons, phenols, pesticides, etc.) from the groundwater without having to pump the groundwater to the ground surface.

The specially designed UVB produces a groundwater convection cell in the aquifer around the remediation well. The circulating groundwater constantly transports both contaminants and existing degrading bacteria to the well. When flowing through the well the contaminants are adsorbed onto the material inside the bio-reactor; simultaneously the bacteria settle in the same area. If necessary, the accumulated microorganisms can be supplied with nutrients.

Another advantage of the UVB is the oxygen enriched groundwater, which enhances the population growth of the microorganisms in the aquifer, thus accelerating the degradation process. System variations include discontinuous circulation flow, reversing the circulation direction, installing different bioreactor configurations and materials, and using a combination of physical, chemical and/or biological methods. These variations enable the technology to easily adapt to different contamination sites.



Technologies Corp.
[illegible] Drive Charlotte, NC 28217

UVB (Vacuum Vaporizer Well)
in situ Groundwater/Circulation/Soil Flushing

Possible Areas of Application

The UVB is an in situ system for remediation of contaminated aquifers, especially those contaminated with volatile and semi-volatile hydrocarbons or heavy metals, and uses a combination of chemical, physical and biological processes. UVB is a process patented by IEG mbH, Reutlingen, Germany.

Description of Method

Primary Components

A UVB system consists of a specially adapted groundwater well, a negative pressure stripping reactor, an above-ground mounted blower, and a waste air decontamination system, for example disposable filters or regenerative activated carbon filters.

Principle of Operation

The water level rises inside the well due to a negative pressure generated by a blower. Fresh air is drawn into the system through a pipe leading to the stripping reactor and pearls up through the raised water. The rising air bubbles enhance the suction effect at the well bottom (air-lift-pump).

Dry Air

As a result of the concentration gradient, the contaminants vaporize into the air bubbles and are removed from the well by the air flow.

The continuous expansion of the air bubbles when passing through the stripping zone causes adiabatic cooling, which results in a decrease of the relative humidity of the withdrawn air.

Efficient Use of Activated Carbon Filter

When the contaminated exhaust air passes through the activated carbon filter, no water condensation occurs due to the low humidity of the air. Therefore, a significantly greater part of the activated carbon filter can be utilized for adsorption of pollutants as compared to conventional air stripping.

Air-Lift-Effect

The rising of the air bubbles supplements the lifting effect of the negative pressure and further elevates the groundwater within the well. The subsequent fall of the groundwater along the walls of the well produces a significant hydraulic pressure.

Transport within the Well

By adding a support pump to the UVB System, a specific flow direction can be induced, which produces a vertical flow either upward or downward within the well. The oscillating hydraulic pressure forces the water horizontally into the aquifer through the top screened segment of the well. In the surrounding aquifer, a circulation develops with water entering at the base of the well and leaving through the upper screened segment or vice versa, depending on the desired flow direction.

Sphere of Influence

A flow pattern with a calculable horizontal and vertical component is produced in the aquifer to compensate for the directed water flow within the UVB well. Non linear frequencies produced by the bursting air bubbles inside the well are transmitted as pressure waves to the surrounding subsoil. They enhance diffusion of contaminants into the groundwater, which are subsequently incorporated into the UVB circulation and then treated in the well.

Thus, treated groundwater circulates through the sphere of influence (within the aquifer) before returning to the well.

Simultaneous Soil Air Venting

The UVB-method is capable of extracting soil air during ground water treatment. The amount of soil air and groundwater passing through the decontamination system can be adjusted according to the type of contamination and the well construction.

EUROPEAN UVB SITES

PROJECT → INFORMATION ↓	Rhein-Ruhr-Area UVB I	Rhein-Ruhr-Area UVB II	Berlin	Köppern UVB I	Köppern UVB II
Company	GfS	GfS	Hydrodata	Protec	Protec
UVB-circulation	*standard*	*standard*	*standard*	*standard*	*standard*
Diameter of well [mm]	600 23.6 in	400 15.7	400	400	400
Depth of well [m]	12	33,7	10.2	6.8	5.9
Air-lift (AL); additional hydraulic pump (HP)	HP	HP	AL	AL	AL
Pump rate [m^3/h]	5	5	est. 6	est. 1	est. 0.5
Volume of off-air [m^3/h]	350	450	350 266 cfm	410	410
Soil air extraction (Yes/No; m^3/h)	Y	N	Y, 110 64 cfm	N	N
Aquiferstructure/ Geology	Fine to medium grained sand, sandy gravel	Fine to medium grained sand, sandy gravel	Fine to medium grained sands, low gravel content	Silt with quartzite lenses	Silt with quartzite lenses
Hydraulic conductivity: k_f [m/s]	$1 \times 10^{-3} - 5 \times 10^{-4}$	$1 \times 10^{-3} - 5 \times 10^{-4}$	$1 \times 10^{-4} - 1 \times 10^{-6}$	$5 \times 10^{-5} - 1 \times 10^{-7}$	$5 \times 10^{-5} - 1 \times 10^{-7}$
Type of contamination	Trichloroethylene	Trichloroethylene	1,1,1-trichloroethane and methyl chloride	Trichloroethylene and tetrachloroethylene	Trichloroethylene and tetrachloroethylene
Highest concentration in groundwater [$\mu g/l$]	5000	650	Total CHC: 3092	Total CHC: 45987	Total CHC: 43570
Beginning contaminant extraction rate [g/d]	ca. 1 600	375	2835	390	88
Total contaminants extracted to date [g]	1700000	68300	1310000	51.8	11.7
Start of operation	October 1988	November 1990	April 1989	July 1992	July 1992
Comments/remarks	System has self-regenerating activated carbon unit.	System has self-regenerating activated carbon unit.	Remediation ended July 1990; March 1992 local authorities declared the groundwater remediated.	System has separate valve for controlled soil air extraction	System has separate valve for controlled soil air extraction

EUROPEA JVB SITES

PROJECT → INFORMATION ↓	Military Barracks UVB I	Military Barracks UVB II	Schelklingen	Nürnberg	Heslach
Company	GfS	GfS	Hydrodata	Hydrodata	IEG/HPC
UVB-circulation	reverse	reverse	standard	standard	standard
Diameter of well [mm]	400	400	400	150	400
Depth of well [m]	11.0	11.0	20.5	7.0	15.8
Air-lift (AL); additional hydraulic pump (HP)	HP	HP	AL	HP	AL
Pump rate [m^3/h]	6	6	?	0.4	---
Volume of off-air [m^3/h]	300	450	840	130	340
Soil air extraction (Yes/No; m^3/h)	Y	Y	Y, 600	Y, 65	Y, 40
Aquiferstructure/ Geology	Fine sand and gravel with silt lenses	Fine sand and gravel with silt lenses	Gravel	Sandstone with fractures	Clay and siltstone
Hydraulic conductivity: k_f [m/s]	3×10^{-3}	3×10^{-3}	1×10^{-3}	est. 2×10^{-5}	1×10^{-5}
Type of contamination	BTEX and diesel fuel	BTEX and diesel fuel	CHC, heavy metals	1,1,1-trichloroethane	CHC
Highest concentration in groundwater [µg/l]	BTEX: 280000 diesel f.: 1080	BTEX: 1.8 diesel f.: 164	Total CHC: 1800	Total CHC: 3831	Total CHC: 47000
Beginning contaminant extraction rate [g/d]	21600	0.8	125	1800	---
Total contaminants extracted to date [g]	ca. 200000	---	data not available	15000	data not available
Start of operation	Oct. 1990	Oct. 1991	January 1990	July 1990	February 1988
Comments/remarks	On-site reactor; free product found on aquifer	On-site reactor	---	Remediation complete; only monitoring of GW over time being conducted	---

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INITIAL COST ESTIMATE
FOR
BAKER ENVIRONMENTAL
CAMP LEJEUNE, NC
(SBP #S5112)

1.0 INTRODUCTION

Baker Environmental, Inc. requested that SBP Technologies, Inc. (SBP) and IEG Technologies, Inc. review the design of an initial remediation concept to reduce and remove petroleum fuel hydrocarbons and TCE from the groundwater and soils at Area Fuel Farm Site 35 at Camp Lejeune, NC. SBP will provide a final cost estimate following review of the site documents, exact UVB location, petroleum hydrocarbon concentrations and completion of the remedial design phase.

2.0 OPERATIONAL CHARACTERISTICS AND PERFORMANCE STANDARDS

UVB System General Operation

The vacuum vaporizing well (UVB, in German) is an *in situ* groundwater and soil remediation system, which remediates the contaminants in the impacted aquifer using a combination of both physical and biological processes. The UVB system creates a circulation cell that mobilizes the mobile phase and residual solid phase hydrocarbons to a central well casing for treatment. The treatment methodology is primary air stripping, and secondarily bioremediation for light fraction hydrocarbons. The UVB system can include an *in situ* or ex *situ* bioreactor.

The UVB system consists of a specially adapted groundwater well, with double cased and bridge slot screens, floating horizontal stripping reactor, a support pump, and a centrifugal above-ground blower.

During operation, the water level rises inside the air tight UVB well due to a reduced atmospheric pressure generated by a blower. Atmospheric air enters the well through a fresh air pipe connected to the stripping reactor, which floats on the raised groundwater level, and creates a pressure equilibrium. The incoming fresh air creates bubbles as it is jetted through the pin hole plate of the stripping reactor, into the groundwater in the well casing. The raising air bubbles leaving the pin hole plate create an air lift "pump" that creates the suction effect pulling water upward from the well bottom. In some cases, a support pump replaces the air lift "pump" and allows for a known amount of water to pass into the stripping reactor.

The groundwater elevation in the well casing is also amplified by the rising of air bubbles (air-lift effect). The reduced pressure in the well casing above the stripping reactor accelerates that rise of the bubbles by allowing for an increased rate of expansion. When the bubbles reach the water-air interface inside the well casing, they burst and allow the VOCs to be transported upwards through the well shaft to the atmosphere. After the bubbles burst, the groundwater then falls along the walls of the well and produces a significant hydraulic pressure, forcing the water horizontally into the aquifer through the upper screen section at the top of the aquifer.

Groundwater flows into a lower part of the well to compensate for the water removal from the upper section. Thus, a vertical circulation develops with water entering the screen in the lower part of the well, or the base of the well shaft and leaving through the upper screen segment. The expected VOC concentrations, based on empirical data, are 90 to 99 percent of the influent hydrocarbon concentration. As the system functions over time the VOC concentrations are represented by a reduction curve which eventually reaches an asymptotic level.

The majority of the treated groundwater leaving the upper section of the well circulates through the entire sphere of influence, and returns to the lower screen a number of times before exiting the circulation cell. Since the treated groundwater leaving the UVB well is almost saturated with oxygen, the effluent groundwater enriches the phreatic zone with dissolved oxygen thus enhancing aerobic biodegradation throughout the circulation cell.

Operation Characteristics of the UVB-400

The stripping efficiency of the UVB is based on the air to water ratio. The UVB 400 usually draws in approximately 200 cubic meters/hour of air, and in some cases 2 cubic meters/hour of water are being pumped into the stripping reactor, producing a water to air ratio of 1:100, and an approximate stripping efficiency ranging from 90 to > 99%.

Based on an assumed bedrock and saprolite flow of 0.306 cubic meters/hour, and an internal UVB flow rate of 2 cubic meters/hour, the UVB 400 will be able to recirculate 84.7 percent of the influent more than once through the circulation cell. Assuming complete mixing, 15.3 percent of the effluent that moves downstream will have passed once through the stripping reactor, while the remaining 84.7 percent of the effluent will have passed through the stripping reactor at least twice.

Capture Zone and Circulation Cell of the UVB

The capture zone and circulation cell will be estimated for the UVB 400 and 200 systems for Site 35 at Camp Lejeune using equations and graphical solutions developed by Dr. Bruno Herrling (1992) of the Groundwater Research Group, Hydromechanic Institute, University of Karlsruhe, Germany.

3.0 BACKGROUND INFORMATION

The information given to SBP by Baker Environmental on March 17, 1995 provided the background for this equipment selection:

1) Groundwater flows to the northeast.

2) Horizontal hydraulic conductivity is 1.8 x 10^{-3} cm/sec.

3) Vertical hydraulic conductivity is 1.8 x 10^{-4} cm/sec.

4) Water table gradient is 0.017.

5) Groundwater was 5.5 to 8.5 feet below land surface.

6) Darcian velocity is calculated to range from 3.06 x 10^{-5} cm/sec.

7) The saturated zone thickness containing dissolved petroleum fuel hydrocarbons and TCE is estimated to range from 30 to 40 feet.

4.0 INITIAL REMEDIATION CONCEPT

SBP/IEG recommends two UVB-400 air lift systems and four UVB 200 air lift systems to cover the distance of proposed aeration wells in Figure 4-8 (Baker Environmental). The distance the UVB will cover is estimated to be at least 1080 feet. The systems are to be installed to a depth of approximately 35 feet. The UVB system will be located 180 feet apart. The UVB-400 systems will address the hot spots and the UVB-200 systems the areas of lower concentrations.

The UVB system may be placed in a building, or the vacuum lines may be run to the system from a remotely placed blower unit.

UVB 200 : 400

5.0 COST ESTIMATE FOR ~~ONE UVB-400~~ SYSTEMS

5.1 Preparation of Remedial Design- (includes information review, two trips and remedial design)	$ 32,860.58
5.2 Equipment-	
Two air lift UVB-400 systems, including blower(5 hp, 208v, 3-phase), HDPE blower enclosure with moisture knockout, air stripper, bridge slot screens and all connections for installation within 5 ft. of the well head	133,430.00
Four air lift UVB-200 systems, including blower(5 hp, 208v, 3-phase), HDPE blower enclosure with moisture knockout, air stripper, bridge slot screens and all connections for installation within 5 ft. of the well head	176,000.00

5.3 Installation of six UVB systems
system installation and start-up
(includes travel time and
travel costs) 31,885.51

NOT INCLUDED IN PRICE
1. Borehole drilling
2. Drilling six UVB wells
3. Electrical installation and electricity
4. Buildings (if required)
5. Off gas treatment installation and carbon units (if required)
6. Slab for units
7. Disposal of contaminated soil and groundwater
8. Living expenses for construction
9. Safety supplies (level ?)
10. Analytical/sampling
11. Permits

5.4 Maintenance for six UVB systems
Four quarterly maintenance
visits for two people; 3-6-9-12
months following installation;
quarterly reporting –
(includes travel costs) 46,076.83

NOT INCLUDED IN PRICE
1. Analytical/sampling
2. Off-gas treatment (if required)

TOTAL $420,252.92

6.0 **TRAVEL COSTS AND OUT OF SCOPE SERVICES** (e.g., reports, meetings, drilling oversight, etc.) charged according to time invested and expenses incurred and based on listed rates

Professional Service Fees Effective January 1, 1995 (includes professional and support labor, equipment usage, and others)

Design	$185/hr
Project Management	150/hr
Technical Installation	120/hr
Geologic Supervision	120/hr
Maintenance	Price on request

EXPENSES

Air Travel, Rent Car/Truck, Hotel, and Meals	At cost plus 10%
Freight	At cost plus 10%
Travel Time billed	At 2.50 multiple
Materials, outside services, Special equipment and supplies purchased on clients behalf	At cost plus 10%

7.0 SERVICES PROVIDED BY SBP/IEG:

- design UVB system
- installing the remediation system according to the results obtained from the borehole log
- introduction to different modes of operation of UVB system
- adjustment of UVB system at time of installation
- quarterly maintenance and adjustment of UVB system
- data management and reporting

8.0 SERVICES NOT PROVIDED FOR INCLUDE:

- supervising drilling of the borehole
- drilling of pilot hole
- drilling of borehole and providing custom-made well installation equipment (casing, etc.) not included in the UVB system
- obtaining of permits for drilling, remediation, and off-gas treatment, if required
- hook-up of adequate electricity, plus wire

- construction of building or fence, if required
- construction of off-gas treatment system and service, if required
- electricity
- overall project management

9.0 TERMS

Fifty percent of UVB systems must be received by SBP prior to ordering the systems from IEG.

Professional service fee and expenses will be billed monthly or upon completion of tasks, whichever comes first.

Terms are Net 30 days with 1.5% per month late charge on unpaid balance of overdue accounts.

Prices are good for 90 days.

Allow 6 (six) weeks for manufacture and shipping (depending on standard or explosive-proof blower).

Submitted to Karl Thomas, Baker Environmental, by fax on March 29, 1995.

SITE35: (S5112.00)

United States
Environmental Protection
Agency

Office of Research and
Development
Washington DC 20460

EPA/540/R-93/526
November 1993

EPA

Superfund Innovative Technology Evaluation Program

Technology Profiles
Sixth Edition

SITE
SUPERFUND INNOVATIVE
TECHNOLOGY EVALUATION

IT CORPORATION
(In Situ Groundwater Treatment System)

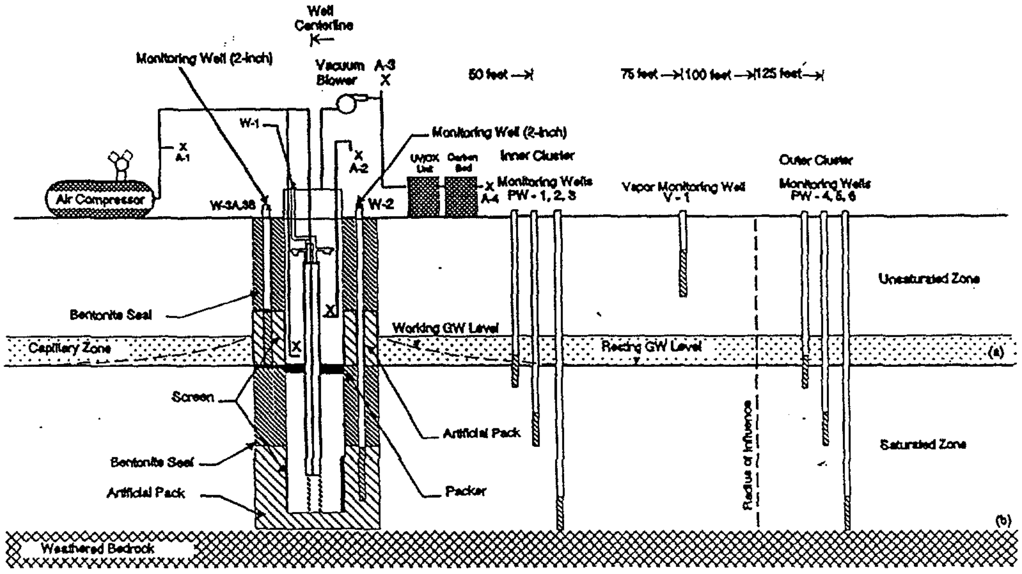
TECHNOLOGY DESCRIPTION:

The in situ groundwater treatment system removes volatile organic compounds (VOC) from groundwater by transferring them to a vapor phase and destroying them with a photocatalytic oxidation (PCO) unit, possibly followed by treatment with granular activated carbon. The organic compounds may be halogenated or nonhalogenated.

The process consists of three stages: (1) an air lift pumping technique, (2) an in situ vapor stripping method, and (3) air sparging. An extraction unit well is installed to the bottom of the contaminated aquifer. Air is injected into an eductor pipe, lifting the contaminated groundwater up through the pipe. The lifting action causes displacement of groundwater from the lower section of the well, which is replaced by contaminated groundwater from the lower aquifer.

In the first stage, air bubbles and water mix as they move up the eductor pipe. As the bubbles travel upward, partial transfer of chlorinated VOCs from the water phase to the vapor phase occurs. The vapor phase of the contaminants is then drawn off by the vacuum system.

In the second stage, water that has been lifted to the top of the well is sprayed as fine droplets



(a) Depth to water: 55.5 feet
(b) Depth to bedrock: 155 to 161 feet
V-1 set at 75-feet from system well, screened at 15 to 25 feet (bgs)
PW-1 screened from 46.7 to 66.7 feet (bgs)
PW-2 screened from 114 to 124 feet (bgs)
PW-3 screeend from 140 to 156 feet (bgs)
PW-4 screened from 50.3 to 70.3 feet (bgs)
PW-5 screened from 120 to 130 feet (bgs)
PW-6 screened from 160 to 166 feet (bgs)
All cluster wells are set 5 feet apart

NOT TO SCALE

Schematic Diagram of In Situ Groundwater Treatment System inside the well casing. Countercurrent air flow strips additional chlorinated VOCs from the water, similar to standard air stripping systems.

Water is sparged as it collects at the water table, in the upper well. A packer separates the upper well from the lower, forcing water to recharge at the water table. Fine bubble aerators transfer high volumes of air through the water, aerating and stripping off remaining VOCs. This air sparging step is the third and final treatment step prior to recharge into the upper aquifer. Throughout this process, a slight vacuum is maintained on the upper well, which draws stripped VOCs to the PCO unit.

Water from the lower portion of the aquifer flows into the well to replace the air-lifted water, causing drawdown. Thus, water is circulated from the lower portion of the aquifer into the well and then back to the upper portion of the aquifer, establishing a recirculating treatment zone. Multiple treatment stages are used to achieve maximum cleanup efficiencies. The system is designed to remove chlorinated VOCs below maximum contaminant levels in the first pass. Therefore, water reintroduced to the upper aquifer should not degrade water quality.

WASTE APPLICABILITY:

The in situ groundwater treatment system is designed to remove VOCs, including trichloroethene, benzene, and chloroform, from groundwater.

STATUS:

This technology was accepted into the SITE Demonstration Program in 1993. The demonstration is on hold pending selection of a new location at Site 2 on March Air Force Base, California.

FOR FURTHER INFORMATION:

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EG&G ENVIRONMENTAL

A TECHNOLOGY AND SYSTEMS INTEGRATION COMPANY

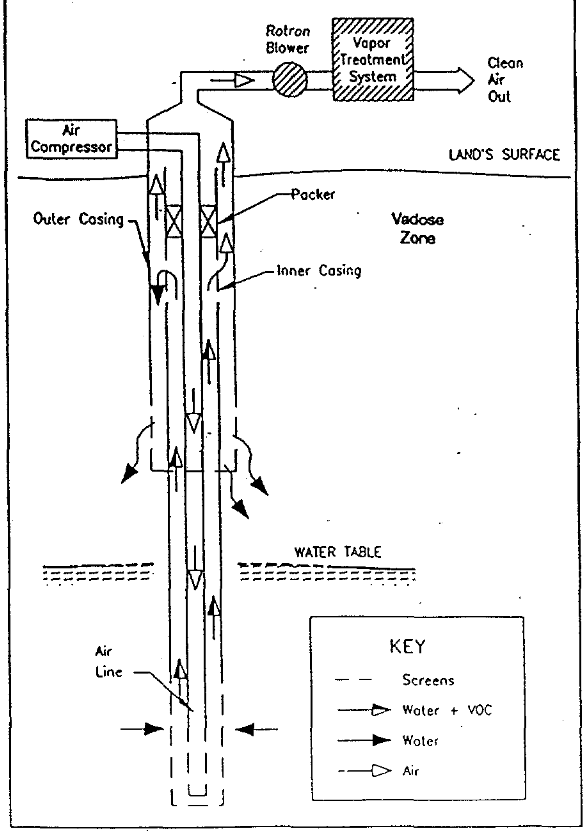
NoVOCs SYSTEM: IN-WELL STRIPPING OF VOCs FROM GROUNDWATER

THE CONCEPT

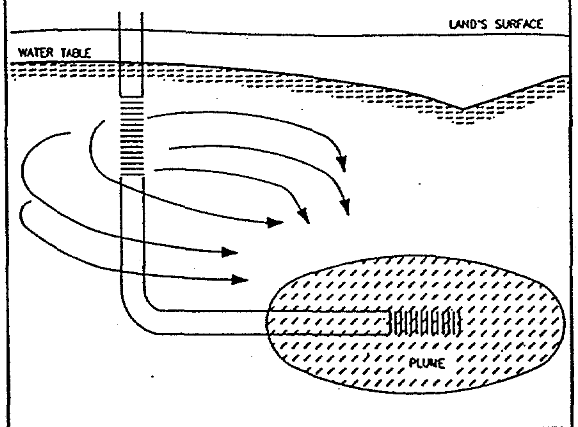
EG&G Environmental, Inc., through its NoVOCs division, offers a cost-effective new technology for removing volatile organic compounds (VOCs) from contaminated groundwater (US Patent No. 5,180,503). Traditional remedies for removing petroleum hydrocarbons and chlorinated solvents in the groundwater have relied upon extraction wells to bring contaminated water to the surface, followed by one of several treatment alternatives to remove contaminants from the aqueous phase. These options include: air stripping, activated carbon, and UV-peroxide oxidation.

In-well stripping, however, simplifies the process and results in significant savings by eliminating separate above-ground aqueous phase treatment.

OPERATION OF A NoVOCs WELL



HORIZONTAL NoVOCs WELL



In-well stripping operates on the same principle as the aerator in an aquarium. A compressor is used to deliver air or an inert gas such as nitrogen to the water column within an extraction well. The resulting bubbles in the water constitute an air lift pump. Because the water with bubbles has a lower density than water outside the well, a pressure gradient is established which causes water outside the well to flow into it through the lower screened section. The bubble-water mixture rises in the well. At the same time, VOCs in the water volatilize into the bubbles. The bubble-water mixture is allowed to rise to a point where optimum volatilization has occurred. The casing is screened at that point and sealed with a deflector plate.

When the mixture encounters the deflector plate, the bubbles break and combine. Water then flows through the upper screen and is allowed to reinfiltrate into the vadose (above water table) zone. A larger casing placed over the top of the well is maintained under vacuum; it allows coalesced bubbles to be drawn off for treatment above ground. Reinfiltrating water creates a torroidal circulation pattern around the well so that waters can be treated through multiple cycles to achieve the desired level of removal.

EG&G ENVIRONMENTAL

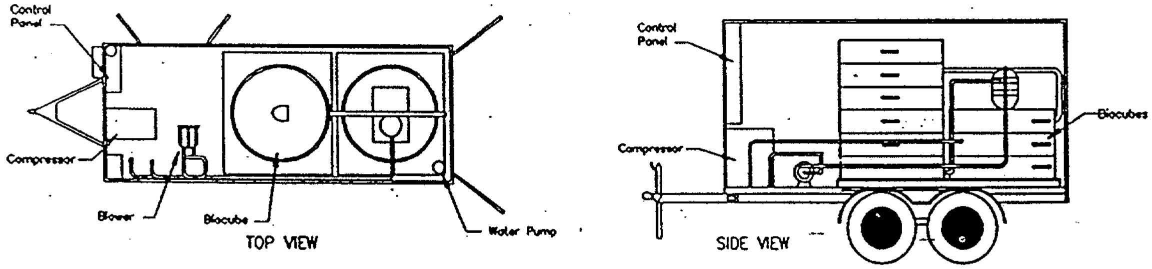
ADVANTAGES

In-well stripping offers a number of advantages over traditional pump and treat technologies:

- *Reduces Capital Costs*
- *Reduces Operating Costs Associated With Pumping Vapor, Not Water, to the Surface*
- *Accelerates Restoration Due to Disruption of Free Phase Product in the Capillary Fringe*
- *Enhances Bioremediation of Hydrocarbons as a Result of Aeration/Recirculation of Treated Water*
- *Eliminates Need for Reinjection Wells, Discharge Lines and Discharge Fees*
- *Facilitates Coupling with Soil Vapor Extraction Systems*
- *Minimizes Installation Time/Cost Through Use of Integrated System Mobile Unit*

In-well technology is available with a full set of related services, including consultation, design, installation, operation and monitoring. Designs include new installation and retrofits for existing extraction wells.

MOBILE UNIT FOR HYDROCARBON RECOVERY WITH NoVOCs SYSTEM



ABOUT EG&G ENVIRONMENTAL, INC.

EG&G Environmental is a wholly-owned subsidiary of EG&G, Inc., a Fortune 200 company. EG&G Environmental was formed in January 1994 to harness the recognized strengths of the parent corporation, build on them, and apply them in environmental problem solving. EG&G Environmental offers services and products in four strategic areas: *1) Consulting Services; 2) Technology Products; 3) Systems Integration; and 4) Integrated Environmental Management.*

For further information on in-well stripping technology or other products and services from EG&G Environmental, contact the Pittsburgh headquarters office or the Richland, Washington office.

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APPENDIX F
PASSIVE TREATMENT WALL

enviro**metal**
technologies
inc.

the enviro**metal** process

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metal-enhanced abiotic degradation of chlorinated organic compounds

the
envirometal
process

THE COMPANY

[illegible]roMetal Technologies Inc. (ETI) is a Canadian owned company, [illegible]mitted to providing its clients with cost effective, long-term solutions for the remediation of water contaminated with halogenated organic compounds, through the application of the envirometal process developed at the Waterloo Centre for Groundwater Research. The University of Waterloo, as a partner in ETI and through the Waterloo Centre for Groundwater Research, will be developing application enhancements to this patented process.

ETI's team of Associates and Technical Advisors specialize in the study of contaminent movement in the vadose and groundwater zones, and the remediation of halogenated volatile organic compounds (VOCs) in groundwater.

TECHNOLOGY DESCRIPTION

The envirometal process uses a metal formulation to degrade dissolved halogenated (e.g., chlorinated) organic chemicals from groundwater. The envirometal formulation induces conditions that cause substitution of halogen atoms by hydrogen atoms. The end products of the process are completely dehalogenated and non-toxic. Examples of end-products for chlorinated VOCs degraded by the envirometal process are, ethene, ethane, methane and chloride ions.

ADVANTAGES

The envirometal process is a mechanically simple, long term, and cost effective technology for treating groundwater containing VOCs. The simplicity of the process applied in either an *in-situ* or [illegible]ove ground configuration will greatly reduce operating and [illegible]aintenance costs such as:

- energy consumption;
- water processing and disposal charges; and
- activated carbon regeneration or disposal.

It is a destructive treatment technology and therefore does not simply transfer chemicals from one medium to another as is the case with air stripping and activated carbon systems.

Because the VOCs are degraded, the envirometal process is superior to barrier technologies which simply contain the chemicals.

In-situ installations require no ongoing energy inputs because groundwater is treated while migrating in the natural hydrogeologic system (i.e., there is no extraction and discharge of treated groundwater).

In-situ installations made upgradient of the property lines will enable maximum concentration limits (MCLs) to be met at the property boundary.

The process will effectively combine with other groundwater remedial and control technologies for full treatment of groundwater contaminants.

It does not produce toxic end products or sludge.

APPLICATION CONFIGURATIONS

In-Situ envirometal Permeable Treatment Walls

An *in-situ* envirometal treatment wall consists of a permeable metal formulation installed across the flow path of a plume of VOC-bearing groundwater (Figure 1). The VOCs are degraded as they migrate slowly through the wall under natural groundwater flow conditions.

By utilizing alternating sections of impermeable sheet pile or slurry wall constructed so as to funnel the VOC bearing groundwater through permeable treatment sections, large plumes of VOCs can be degraded as groundwater passes through the envirometal formulation (Figure 2).

Above-Ground envirometal Treatment Canisters

Specifically-designed above ground envirometal treatment units can replace air strippers and activated carbon canisters in existing groundwater treatment systems. Components that increase the amount of time that the VOCs are in contact with the envirometal treatment mixture may allow these canisters to treat significant quantities of extracted groundwater over short periods of time (tens to hundreds of gallons per minute). Data collected during field tests of the envirometal canister shows that the process may effectively replace air stripping and activated carbon as methods of removing halogenated VOCs from extracted groundwater.

Figure 1: Schematic Plan View of an *In-Situ* Permeable Treatment Wall

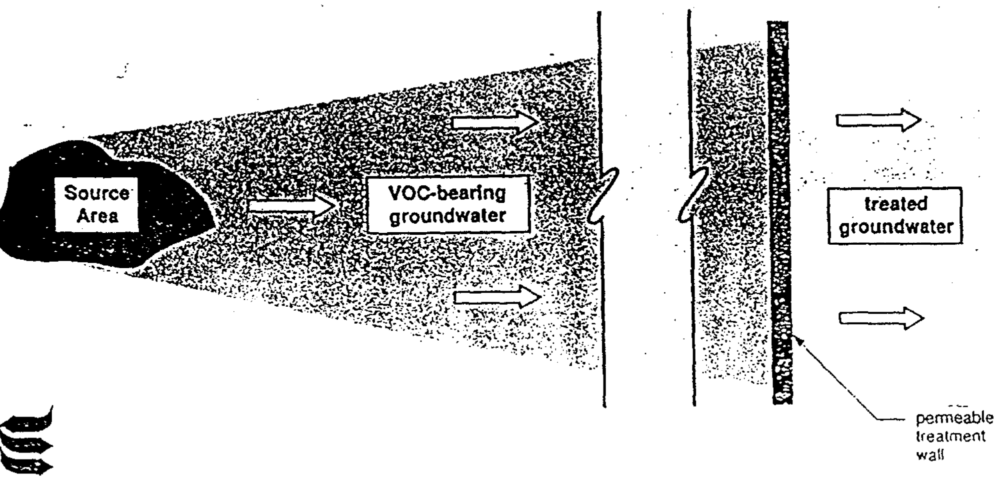
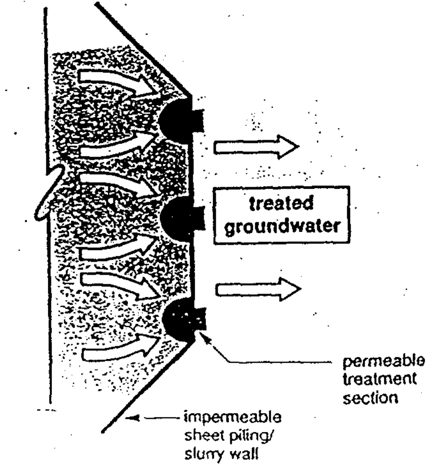
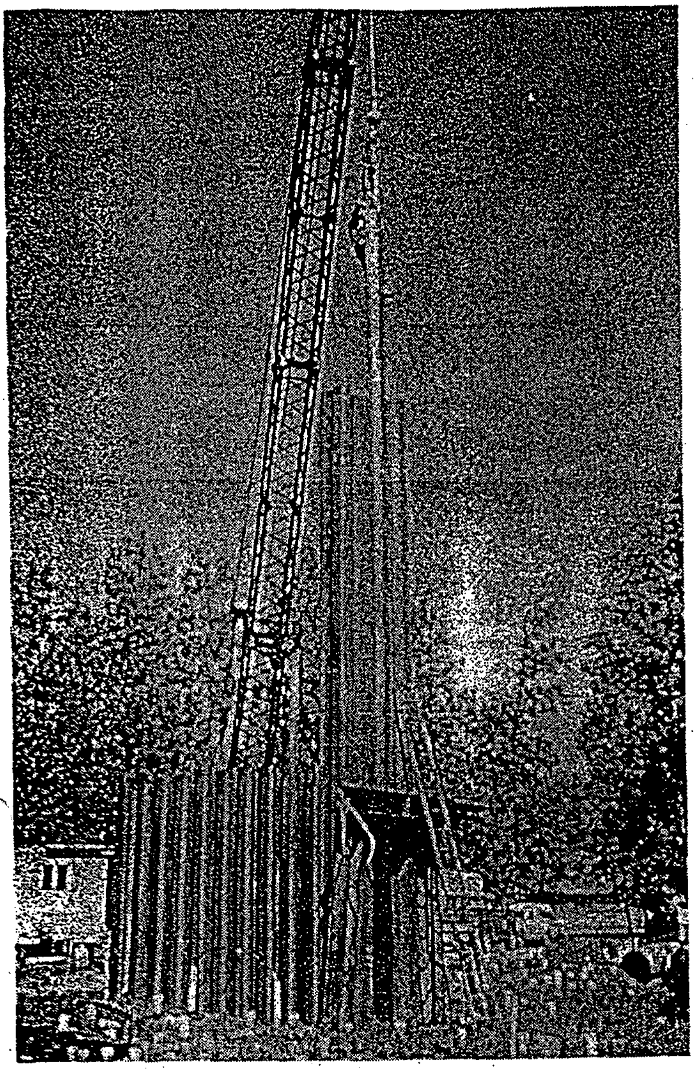


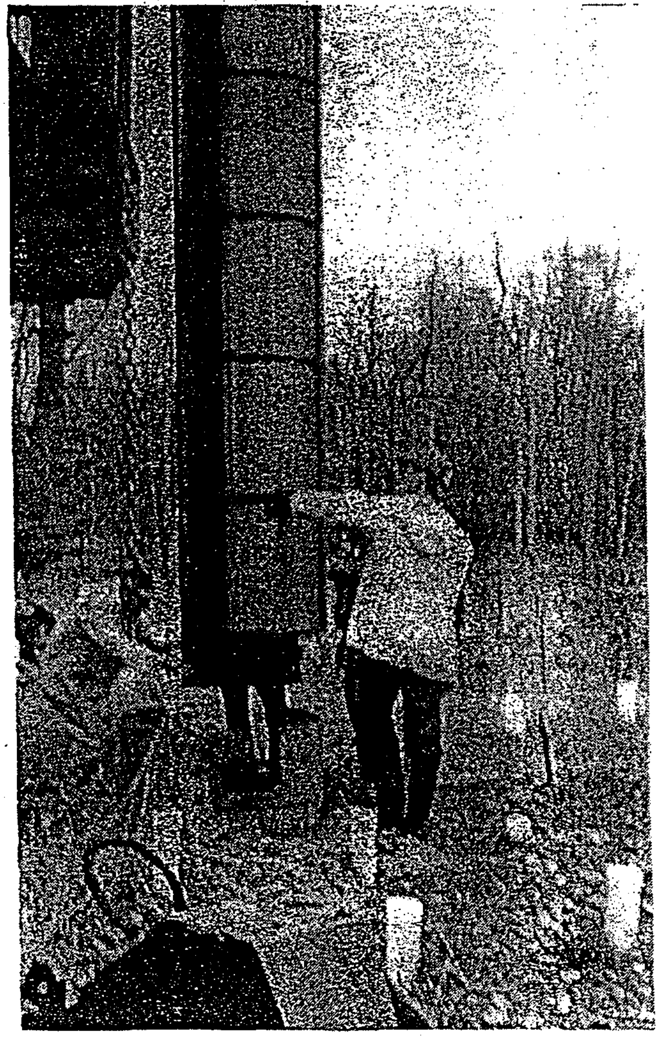
Figure 2: Schematic Plan View of *In-Situ* Permeable Treatment Sections Installed in Conjunction with an Impermeable Barrier



Sealable sheet piling being used to construct a permeable treatment wall.



Installation of permeable treatment section using screened caisson. Impermeable sheet piles funnel groundwater through treatment section.



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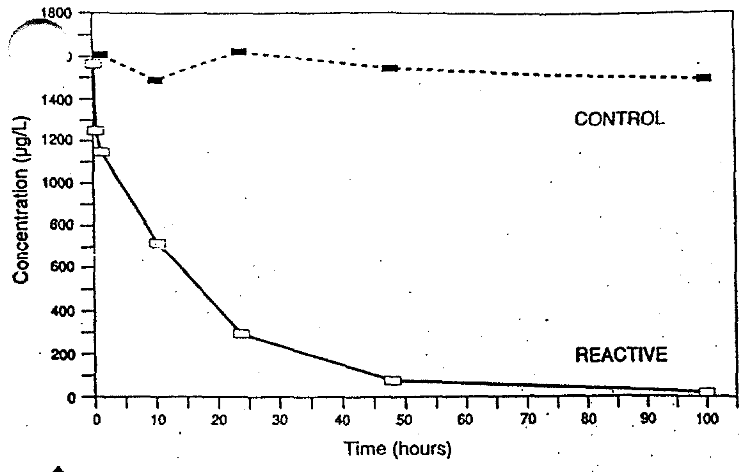

Figure 3: Typical Batch Degradation Curve for TCE

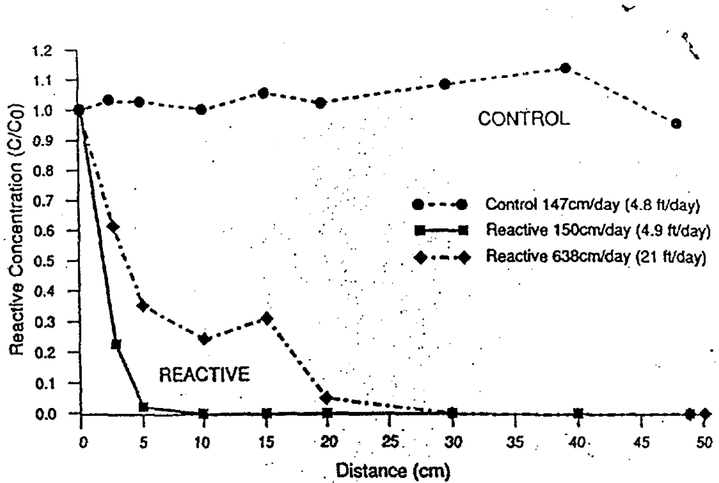

Figure 4: Typical Steady State, Control & Reactive Columns for TCE

IMPLEMENTATION PROCEDURE

The complex nature of the remediation of halogenated organic compounds requires a phased approach to the application of the **envirometal** process. The phases are described below:

Phase 1 - Preliminary Assessment

The purpose of Phase 1 is to review existing site data to screen the site relative to the current knowledge level of the technology, i.e. conditions that affect the process and its application. On the basis of this review the site will fall into one of two categories.

The first category includes sites that have common attributes, such as physical setting and groundwater chemistry, similar to other sites at which the **envirometal** process is effective. The **envirometal** process has a high probability of success at these sites.

The second category are sites having unique physical and geochemical properties that may affect the application of the **envirometal** process. They have in common an unknown probability for the successful application of the technology.

Data that are necessary to assess a site include:

- Groundwater inorganic and organic chemistry;
- VOC characteristics: compounds, concentration and distribution;
- Site geology and soils: depth to water table, aquifer and aquitard thickness;
- Source type: free phase, dissolved or residual;
- Source location: vadose or groundwater zone;
- Hydrogeological data, such as: porosity, hydraulic conductivity and groundwater velocity; and
- Site history and current remedial activities.

Phase 2 - Feasibility Evaluation

If the site falls into the first category, a site Feasibility Evaluation is recommended. The purpose of Phase 2 is to evaluate the efficiency of the process, under simulated site conditions, through laboratory tests using representative groundwater samples taken from the site. Groundwater flow and geochemical models may be used to assist in the feasibility evaluation.

The tests will define the:

- Rates of reaction;
- The possible degradation products; and
- Associated inorganic chemical reactions.

The Phase 2 report will provide data interpretation and evaluation, and a preliminary cost estimate for a pilot scale field test. Examples of typical data from a feasibility evaluation are shown in Figures 3 and 4.

Figure 3 shows a typical laboratory batch test degradation curve for TCE. Figure 4 shows a typical column test result for TCE under steady state conditions and two flow rates. Column tests are performed to assess the process under dynamic conditions representative of groundwater flow through the treatment media. This figure shows that the process is effective even with flow rates of 638 cm/day (21 ft/day).

The feasibility evaluation recommended for second category sites will incorporate additional testing to evaluate the effects of the unique attributes of the site.

Phase 3 - Pilot Scale Field Test

Following successful laboratory tests, a Pilot Scale field test will collect the data required for a full scale application of the process. Results of Phase 2 tests are used to design the pilot scale system. The system may be installed *in-situ* or above ground (depending on the potential full scale application and site conditions). This field verification of the **envirometal** process design provides data concerning full scale costs, long term performance and operation, and maintenance requirements. Of specific concern are those conditions that could affect the long term performance of the system, such as, biofouling or mineral precipitation that could lead to a decrease in permeability and the effectiveness of the process. The Phase 3 report will present a field test evaluation, and a detailed cost estimate for a Full Scale system.

Phase 4 - Full Scale Implementation

Phase 4 is the design and installation of a Full Scale system. The results from Phase 3 provide the basis for Full Scale design.

Phase 5 - Long Term Performance Monitoring

Routine performance monitoring and reporting will be undertaken according to regulatory requirements, and will include an ongoing comparison of field results to design criteria.