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FINAL

**TREATABILITY STUDY WORK PLAN
PILOT-SCALE EVALUATION OF
IN-SITU AIR SPARGING
OPERABLE UNIT NO. 10
(SITE 35)
MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA**

CONTRACT TASK ORDER 0323

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1.0 INTRODUCTION

This Treatability Study Work Plan has been prepared by Baker Environmental, Inc. (Baker) under the United States Department of the Navy (DON), Atlantic Division, Naval Facilities Engineering Command (LANTDIV) Comprehensive Long-Term Environmental Action Navy (CLEAN) Program for Contract Task Order 0323, Operable Unit (OU) No. 10, Site 35 - Camp Geiger Area Fuel Farm, Marine Corps Base (MCB), Camp Lejeune, North Carolina. The treatability study is being conducted as part of the Remedial Design (RD) for surficial groundwater at Site 35. This document has been prepared in accordance with the requirements of the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) for remedial actions [40 Code of Federal Regulations (CFR) 300.430]. The NCP regulations were promulgated under Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), commonly referred to as Superfund, and amended by the Superfund Amendments and Reauthorization Act (SARA) signed into law on October 17, 1986. The USEPA's document Guide for Conducting Treatability Studies Under CERCLA (USEPA, 1992) has been used as guidance for preparing this document.

MCB Camp Lejeune was placed on the CERCLA National Priorities List (NPL) on October 4, 1989 (54 Federal Register 41015, October 4, 1989). The United States Environmental Protection Agency (USEPA) Region IV, the North Carolina Department of Environment, Health and Natural Resources (NC DEHNR) and the DON then entered into a Federal Facilities Agreement (FFA) for MCB, Camp Lejeune. The primary purpose of the FFA is to ensure that environmental impacts associated with past and present activities at the MCB, Camp Lejeune are thoroughly investigated and appropriate CERCLA response/Resource Conservation and Recovery Act (RCRA) corrective action alternatives are developed and implemented as necessary to protect public health and the environment.

1.1 Purpose and Organization

This document presents Baker's approach to executing the pilot-scale Treatability Study of Air Sparging technology at Site 35. Its purpose is to detail the objectives and methodologies for conducting this work.

Section 1.0 of this document includes this introduction and site background information. Section 2.0 contains a description of in situ air sparging (IAS) technology and its limitations along with a discussion of remedial design/remedial action implementation considerations. The objectives of the treatability study are presented in Section 3.0. Test procedures are detailed in Section 4.0. Community relations efforts are discussed in Section 5.0. The proposed reports to be prepared as part of this project are discussed in Section 6.0, and, finally, the project schedule is presented in Section 7.0.

1.2 Site Background

1.2.1 Site Location and Description

Marine Corps Base (MCB), Camp Lejeune is a training base for the U.S. Marine Corps, located in Onslow County, North Carolina. The Activity, as the base is referred to, covers approximately 236 square miles and includes 14 miles of coastline. MCB, Camp Lejeune is bounded to the southeast by the Atlantic Ocean, to the northeast by State Route 24, and to the west by U.S. Route 17. The town of Jacksonville, North Carolina, is located north of the Activity (see Figure 1-1).

Camp Geiger is located at the extreme northwest corner of MCB, Camp Lejeune. The main entrance to Camp Geiger is off U.S. Route 17, approximately 3.5 miles southwest of the city of Jacksonville, North Carolina. Site 35, the decommissioned Camp Geiger Area Fuel Farm, refers primarily to five, 15,000-gallon aboveground storage tanks (ASTs), a pump house, and a fuel unloading pad formerly situated within Camp Geiger just north of the intersection of Fourth and G Streets (see Figure 1-2).

Site 35 is contained within Operable Unit (OU) No. 10, one of 17 operable units at MCB, Camp Lejeune. An "operable unit," as defined by the National Oil and Hazardous Substances Pollution Contingency Plan (NCP), is a discrete action that comprises an incremental step toward comprehensively addressing site problems.

The Interim Feasibility Study (FS) study area consists of a portion of OU No. 10 measuring approximately 18 acres. More specifically, the study area consists of contaminated groundwater in the portion of the surficial aquifer that is located roughly between the Fuel Farm and Brinson Creek (see Figure 1-2).

1.2.2 Site History

Construction of Camp Geiger was completed in 1945, four years after construction of MCB, Camp Lejeune was initiated. Originally, the 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. The ASTs at the site are reported to be the original tanks. Demolition of the Fuel Farm ASTs was completed in 1995.

Product was dispensed from the ASTs via trucks and underground piping. Routinely, the ASTs at Site 35 supplied fuel to an adjacent dispensing pump. A leak in the underground line from the ASTs to the dispensing island 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 were 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 until the spring of 1995. The ASTs were supplied by commercial carrier trucks which delivered product to fill ports located on the fuel unloading pad at the southern end of the facility. Six short-run (120 feet maximum), underground fuel lines were utilized to distribute the product from the unloading pad to the ASTs.

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 cannot be located. 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 had been discovered by Camp Geiger personnel along the unnamed drainage channels north of the Fuel Farm. Apparently, the source of the fuel, believed to be diesel or jet fuel, was an unauthorized discharge from a tanker truck that was never identified. The Activity reportedly initiated an emergency clean-up action that included the removal of approximately 20 cubic yards of soil.

Decommissioning of the Fuel Farm began in the spring of 1995 and was completed in July 1995. The ASTs were cleaned, dismantled and removed along with associated concrete foundations, slabs on grade, berms, and underground piping. The Fuel Farm was removed to make way for a six-lane, divided highway proposed by the North Carolina Department of Transportation (NC DOT) (see Figure 1-2).

In addition to the Fuel Farm dismantling, soil remediation activities began in August 1995 along the highway right-of-way as per an Interim Record of Decision (ROD) executed on September 15, 1994. To date, all identified contaminated soil has been excavated and removed from the site.

1.2.3 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); Addendum Report of Underground Fuel Investigation and Comprehensive Site Assessment (Law, 1993); Interim Remedial Action Remedial Investigation/Feasibility Study for Soil (Baker, 1994); Comprehensive Remedial Investigation Report (Baker, 1995); and Interim Feasibility Study for Surficial Groundwater (Baker, 1995).

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. In April 1996, Baker performed a supplemental field investigation to characterize the vertical and horizontal extent of fuel- and solvent-related contamination along the proposed IAS curtain boundary. This investigation consisted of installation and sampling of a total of 36 temporary monitoring wells. These wells were installed at 12 locations and as 3-well clusters designed to monitor the upper, middle, and lower regions of the surficial aquifer (see Figure 2-3).

Several areas of fuel- and solvent-related groundwater contamination were identified in the surficial aquifer in the area north of Fourth Street. Organic contaminant concentrations detected in the upper and lower portions of the surficial aquifer during the May 1994 sampling round, conducted by Baker, are shown in Figures 1-3 and 1-4, respectively. Additional figures depicting the nature and extent of groundwater contamination are provided in the Final RI Report (Baker, 1995). A water table contour map indicating general groundwater flow directions in the surficial aquifer is provided in Figure 1-5. As shown in Figures 1-6 and 1-7, a hydrogeologic cross-section was developed for the area paralleling Brinson Creek, which shows the various soil types for the area in which the IAS system would be installed. An additional hydrogeologic cross-section was developed from the temporary well boring logs, which is provided in Appendix A. This cross-section indicates that the

soil lithologies vary significantly between the southern and northern portions of the site. As shown in Appendix A, the surficial aquifer in the northern region north of temporary well TW-19 is comprised mainly of medium and fine-grained sands, whereas the region to the south of TW-19 contains at least one significant silt/clay lens of varying thickness.

Two additional areas of solvent-related groundwater contamination have been identified adjacent to Site 35. The extent and sources of this contamination have not been identified and additional RI activities are planned. In addition, significant levels of organic and inorganic contamination were identified in sediment samples.

Following the completion of the RI, a Final Interim Proposed Remedial Action Plan (PRAP) and Final Interim ROD for surficial groundwater at Site 35 were prepared (Baker, 1995). These documents detailed five potential Remedial Action Alternatives (RAAs) developed in the FS for the remediation of organic chemical contaminated surficial groundwater at Site 35. More specifically, the following Remedial Action Objectives (RAOs) were developed in the FS for the surficial aquifer:

- 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 contaminants of concern.

The remediation levels established for the contaminated of concern are provided in Table 1-1. These levels were based on the NC DEHNR Water Quality Standards for Groundwater (15A NCAC 2L.0202).

RAA 5, In Well Aeration with Off-Gas Carbon Adsorption, was selected in the Final Interim ROD contingent upon the successful execution of preliminary field pilot-scale tests. This RAA is interim in nature because it represents only one phase of a comprehensive investigation and remediation at Site 35 and is not intended to represent the final solution for OU No. 10. This particular interim action focuses on containment and remediation of organic groundwater contamination in the surficial aquifer located in the vicinity of the Fuel Farm and extending downgradient towards Brinson Creek. A remediation system installed in this area would be designed to mitigate the migration of groundwater contamination from OU No. 10 prior to its discharge into Brinson Creek.

Other media of concern such as sediment and groundwater in the upgradient portion of the surficial aquifer will be addressed during subsequent RI/FS activities that are scheduled to commence later this year. Soil contamination at Site 35 was excavated and removed as part of a separate Interim Remedial Action.

The viability of in-well aeration technology (RAA 5) at Camp Lejeune is being evaluated by means of a field pilot test currently underway at another site (OU No. 14, Site 69). Whether or not in-well aeration is applied at Site 35 is dependent on the results of the field pilot test at Site 69 and, subsequently, on field pilot testing at Site 35. If it is determined, based on the results of the field pilot test, that in-well aeration cannot perform as required, RAA 3 (Groundwater Collection and On-Site Treatment) will be selected as the Interim Preferred Remedial Action. To date, the field

pilot test of an in-well aeration technology has experienced delays in being implemented at Site 69 which further delays field pilot-scale tests at Site 35. In the meantime, EPA, NC DEHNR, LANTDIV, Camp Lejeune, and Baker staff agreed that a field pilot test of in-situ air sparging (IAS) technology would be appropriate at this site. If the results of this test are sufficiently positive, a request may be made to prepare an Explanation of Significant Differences (ESD) document to modify the selected alternative.

2.0 INITIAL FEASIBILITY EVALUATION

2.1 Technology Description

IAS is a technology in which air is bubbled through a contaminated aquifer. Air bubbles traverse horizontally and vertically through the soil column, creating an underground stripper that removes contaminants by volatilization and, for some contaminants, particularly fuel-related compounds, by biodegradation. The air bubbles carry the contaminants upward until they can be recovered by a vapor extraction system or released to the atmosphere.

IAS is a commercially available technology for removing volatile organic chemicals from groundwater. Various technical papers have been published documenting its effectiveness at sites across the U.S. In general, the available literature indicates that IAS is most frequently used to remediate shallow groundwater (i.e., less than 20 feet below the ground surface bgs); however, in theory there is no limit to its application.

At Site 35, the area east of the former Fuel Farm, between Brinson Creek and the proposed divided highway, is located, for the most part, within the limits of the Brinson Creek 100-year floodplain. The area is characteristically marshy with the groundwater surface generally situated within three feet of the ground surface throughout the year. This type of site does not avail itself to vapor extraction due to the lack of a sufficiently thick unsaturated soil zone. Consequently, the contaminants removed from the shallow groundwater at Site 35 via IAS will be discharged to the atmosphere directly.

2.2 Technology Limitations

The effectiveness of IAS generally increases with increasing intrinsic permeability (k , cm^2). Soils should have an intrinsic permeability of at least 10^{-9} in order for air sparging to be effective (EPA/510/B-94/003). Silty sands generally have k values in the range of 10^{-10} to 10^{-8} . Therefore, the soils at Site 35, which are predominantly silty sands, are potentially amenable to IAS. Organic compounds with Henry's law constants greater than $0.01 \text{ atm}\cdot\text{m}^3/\text{mol}$ (EPA/542/B-94/013) or 100 atm (EPA/510/B-94/003) are typically considered amenable to stripping. All of the VOCs of concern have Henry's constants that are greater than these values.

As previously indicated, IAS is generally applied to remediate contamination in shallow groundwater (i.e., less than 20 feet bgs). At Site 35, the area of contamination is distributed throughout a shallow groundwater zone that varies in depth from approximately 32 to 40 feet. Lighter molecular weight fuel contaminants are more prevalent near the groundwater surface, while heavier halogenated compounds are concentrated atop a semi-confining layer at the base of the shallow groundwater zone. In general, the lighter contaminants near the groundwater surface should be easier and less costly to remove than the heavier contaminants at the base of the shallow zone. This is due, in part, to the higher volatility of the lighter compounds and, in part, because of the greater energy required to inject air in the deeper zone.

The track record for IAS shows that it has indeed been applied more at sites contaminated with fuels rather than solvents. This is probably due in part to the larger number of fuel-related versus solvent-contaminated sites, the biodegradability of fuel-related contaminants, and the fact that the majority of fuel-related sites are characterized by contamination at or near the groundwater surface. One IAS pilot study was performed in 1995 on solvent-related contamination (TCE) at Hill AFB in

Utah (Wheless, et al., 1995). Significant contaminant removals were achieved by the IAS system, which was applied at a depth similar to Site 35. A copy of this paper, which discusses the results of this study, is included in Appendix B.

IAS systems utilize injected air and are often combined with vapor extraction systems to control the migration of contaminants. At Site 35, between Brinson Creek and the proposed divided highway, the groundwater surface is generally within three feet of the ground surface throughout the year. The available unsaturated soil zone is insufficiently thick to afford the application of vapor extraction. Without vapor extraction, the migration of contaminants in the vadose zone is uncontrolled. However, as illustrated by the following example calculations, vapor emissions are anticipated to be low and should not pose an unacceptable risk to human health or the environment.

To provide a conservative estimate, or upper bound, of the vapor emission rate prior to performing the pilot test, it can be assumed that, at steady-state, the contaminant vapor emission rate will equal the dissolved contaminant migration rate to the IAS system. Thus, this upper bound can be calculated from an estimate of the groundwater specific discharge q [ft/d], width of the IAS barrier W [ft], the depth below the groundwater table to the injection point H [ft], and dissolved contaminant concentration C_{gw} [lb/ft³] as follows:

$$\text{Emissions}_{\text{max}} = q \text{ [ft/d]} \times W \text{ [ft]} \times H \text{ [ft]} \times C_{\text{gw}} \text{ [lb/ft}^3\text{]}$$

Based on the available Site 35 data from the RI Report, conservative estimates for these parameters are as follows: $q = 0.06$ ft/d (based on $K = 0.001$ cm/s, $I = 0.02$), $W = 200$ ft, $H = 25$ ft, $C_{gw} = 0.00006$ lb/ft³ ($\approx 1,000$ $\mu\text{g/L}$). Inserting these values into the above emissions equation results in a maximum surficial emission rate of approximately 0.02 lb/d.

Assuming four sparging wells are installed over the 200-foot wide capture zone with a combined air flow rate of 40 cubic feet per minute (cfm) (i.e., four wells spaced 50 feet apart with 10 cfm per well), the resulting contaminant air concentration passing through the vadose zone would be 3.5×10^{-7} lb/ft³ or 5.6 mg/m³. For a qualitative risk assessment, this value can be compared to the threshold limit value (TLV) for an 8-hour exposure (i.e., time-weighted average (TWA)) for benzene and TCE, which are 32 mg/m³ and 269 mg/m³, respectively. Additional risk assessment analyses will be performed based on the air sampling results from the pilot tests.

Another potential concern associated with the IAS system is the amount of contamination that will be retained in the soils (i.e., resulting contaminant concentrations) since implementation of a soil vapor extraction system to collect volatilized contaminants in the vadose zone may not be possible. Based on an vapor contaminant concentration of 5.6 mg/m³ and assuming an equilibrium soil-vapor partitioning coefficient of 3.3 L/kg for benzene and 2.5 L/kg for TCE (see calculations provided in Appendix C), the degree of soil contamination resulting from this contaminated air is approximately 0.018 mg/kg for benzene and 0.014 mg/kg for TCE. The acceptable U.S. EPA risk-based concentrations (RBCs) for exposure to contaminated soil (i.e., accidental ingestion) under a residential use scenario are 22 mg/kg and 58 mg/kg for benzene and TCE, respectively. Thus, the IAS system should not create soil contamination that poses an unacceptable risk to human health or the environment.

2.3 Technology Implementation/Design Basis

The IAS alternative in the Interim FS (Baker, 1995), Remedial Action Alternative (RAA) 4, included installation of an IAS "curtain," or barrier, to contain and treat contaminated groundwater as it flows towards Brinson Creek. The conceptual design for RAA 4 included a total of 43 sparging (i.e., air injection) wells spaced approximately 25 feet apart. As shown in Figure 2-1, a total capture zone approximately 1000 feet in width was assumed based on available data. The capture zone width was based on containing groundwater contaminated above the NC DEHNR-based groundwater standards (Table 1-1). As shown in Figure 2-1, the sparging curtain is expected to be located approximately 25 feet downgradient, or east, of the highway's eastern right of way. A soil vapor extraction system was included in the FS as part of RAA 4, since it is typically required for an IAS system as a safeguard measure for controlling vapor emissions. RAA was not selected because of the high water table conditions in the capture zone area along Brinson Creek.

One of the goals of the pilot-scale test is to refine the conceptual design in the FS using test data as well as additional groundwater contaminant data obtained during the Phase II RI at Site 35. The Phase II RI is scheduled to be completed prior to the initiation of the pilot test. A summary of the available groundwater data through the 1994 RI for the fuel-related (i.e., benzene, toluene, ethylbenzene, and xylenes (BTEX)) and solvent-related (i.e., total chlorinated hydrocarbons (CHCs)) contamination in the vicinity of Brinson Creek is provided in Figure 2-2. Total concentrations of BTEX and CHCs detected during the April 1996 field investigation are shown in Figure 2-3.

Groundwater sampling results from the most recent field investigation and previous studies conducted by ESE (1986), NUS (1990), Law (1991 and 1993), and Baker (1994), indicate three primary areas of contamination that intercept the proposed sparging curtain boundary. Hypothetical contaminant plumes for these areas were developed (Figure 2-4) to estimate capture zones and to identify additional data needs. These plumes have been identified as plumes A, B, and C for purposes of this report. These plumes are considered hypothetical since it is unknown if each plume originates from a single source area or if it is actually a composite of two or more plumes originating from multiple sources. The two northern plumes (A and B) represent BTEX contamination associated with monitoring wells MW-20 and MW-16, respectively. The southern plume (plume C) consists of chlorinated solvent contamination, primarily TCE and 1,2-DCE, associated with monitoring well MW-19. A fourth potential area of solvent contamination (not shown), plume D, is located south of plume C near wells 35MW-34B, 35MW-35B, and 35MW-36B (see Figures 1-3 and 1-4). This zone of contamination does not appear to have encroached as near to Brinson Creek as plumes A, B, and C. The concentrations in plume D are three orders of magnitude less than the plume C contamination and appear to represent a separate contaminant source.

Of the three or four plumes intercepting the sparging curtain boundary, plumes B and C contain the bulk of the contaminant mass in the groundwater and pose the most risk to receptors in Brinson Creek. The significance of these two plumes with respect to the remedial design/action is discussed later in this section. Groundwater data (Figure 2-2) show that BTEX levels associated with plume A attenuate rapidly in the downgradient direction, suggesting natural attenuation mechanisms (i.e., biodegradation) are preventing appreciable contamination from reaching the creek. With respect to plume D, contaminant levels in this area only slightly exceed established cleanup levels. Therefore, with containment/treatment of the upgradient source area, natural attainment of the cleanup levels in plumes A and D may be possible through dilution and dispersion.

Conceptually, the shallow aquifer can be divided into two regions; an upper region in which the majority of the BTEX contamination resides, and a lower region that contains the bulk of the solvent-related contamination. The thickness of the shallow aquifer is approximately 30 to 35 feet, with the water table located approximately two to three feet bgs along the sparge curtain boundary. BTEX compounds were generally detected in the upper 0 to 15 feet of aquifer; whereas, the highest concentrations of chlorinated compounds were detected in the lower 20 to 35 feet of aquifer (i.e., above the semi-confining layer). BTEX concentrations in the upper aquifer are generally about two orders of magnitude higher in the upper aquifer than in the lower aquifer.

Plume B is generally a shallow BTEX plume with contamination in the center of the plume extending into the middle portion of the shallow aquifer (approximately 25 feet bgs) and contamination near the edges of the plume extending only to about 15 feet bgs. Plume B is approximately 300 feet in width. The centerline of the plume appears to be located near well TW-23. Soil conditions across Plume B appear more uniform compared to those across Plume C. Most of the saturated aquifer material across Plume B is composed of medium- and fine-grained sands. Thin silt/clay stringers were observed in some of the borings, however, the soils are predominantly sands. Therefore, there is a good chance of success for implementing IAS in Plume B.

In contrast to Plume B, Plume C is generally a deeper chlorinated solvent plume (mainly TCE and 1,2-DCE) with contamination generally absent in the upper 10 feet of aquifer and then increases dramatically with depth to the confining layer located 30-35 feet bgs. Plume C appears to be at least 450 feet in width. As shown in Figure 2-4, part of plume C overlaps with plume B. The highest concentrations of the TCE and 1,2 DCE contamination are centered near well locations TW-16 and TW-17. Soil boring logs from the wells installed along Plume C indicate a much more heterogeneous condition. Boring log TW-16 indicates either silty clay or clayey silt from 6.5 to 25 feet bgs. Silt and clay was also apparent in boring TW-17 down to 18.5 feet bgs with silty sand down to about 24.5 feet bgs. Borings TW-16 and TW-17 contained the highest concentrations of TCE and 1,2-DCE. The thicknesses of the silt/clay and clay/silt lenses appear to dramatically decrease in the northwestern direction along the sparge curtain boundary. A silt/clay lens was only detected from about 8.5 to 9.5 feet in boring TW-18. The thickness of the silt/clay lens may also attenuated in the southeastern direction. Upon implementation of IAS, air flow channels will likely be dependent on the extent and shape of the silt/clay material. Depending on these factors, as well as the permeability and heterogeneity of the sandy and shell hash materials below the silt/clay layer, injected air could travel in a uniform lateral direction beneath the layer, preferentially travel in one direction, or become trapped beneath the silt/clay layer.

Since plumes B and C essentially represent two distinct sites with different types of contamination and soils, two short-term (6-day) pilot-scale tests are proposed for Site 35, one for plume B and one for plume C. The pilot test for plume B will be conducted first since the soil lithology is more homogeneous and contains more sand and less silt than the aquifer materials located further south in the plume C area. Thus, the plume B area is more conducive to IAS technology and has the greatest chance of success. If the plume B pilot test appears successful (i.e., air can be effectively injected into the aquifer with no signs of entrapment below confining layers), then the plume C pilot test will be performed. This area contains the highest levels of solvent-related contamination and poses the greatest treatment challenge with respect to IAS. It is anticipated that the scope of work for the plume C pilot test will be very similar to the first plume B pilot test. However, modifications and adjustments may be made to the plume C study based on data obtained and lessons learned from the first test.

To accommodate the two different types and zones of contamination, two sparging wells are proposed for the plume B treatability study, as shown in Figure 2-5. The upper sparging well would be screened approximately 14 to 16 feet bgs, whereas the lower sparging well would be screened from approximately 32 to 34 feet bgs. Exact screen placements would be determined in the field based on actual conditions. As shown in Figure 2-6, only one deep sparging well is proposed for plume C because of the silt/clay and clay silt lenses present from approximately 7 to 23 feet bgs. Air injected into the plume C sparging well is expected to travel horizontally within the lower sand layer and beneath the silt/clay lenses. The air will gradually travel upward as the silt/clay lenses become thinner and eventually disappear.

As shown in Figures 2-5 and 2-6, as the injected air exits the well screen and travels upward towards the water table, it fans out radially, forming a parabolic-shaped zone of influence (under homogeneous conditions). Soil heterogeneities, however, such as silt stringers or very permeable sand lenses, can dramatically alter this flow regime by trapping air and forcing it to move laterally and/or by creating preferential flow paths. Thus, changes in lithology may preclude the sparge curtain from treating certain zones of contamination. Because of the "fanning-out" effect, the length of the radius of influence (ROI) of a sparging well is typically least at the bottom of the well and greatest near the water table. Since the sparging wells cannot be placed below the semi-confining layer, chlorinated hydrocarbons located immediately above this layer may pass beneath and/or between the sparging wells. To minimize this problem, sparging wells may need to be tightly spaced in the deep zones of contamination (i.e., plume C). In areas with mainly shallow contamination, a longer spacing may be feasible, depending on lithology.

Depending on the results of the test and the observed vertical distributions of BTEX compounds and chlorinated hydrocarbons, the full-scale design could include any of the following sparging well combinations:

- Shallow sparging wells for BTEX
- Shallow and deep sparging wells for BTEX
- Deep sparging wells for chlorinated hydrocarbons
- Shallow and deep wells for chlorinated hydrocarbons

The results of the short-term pilot tests will provide key information concerning the effectiveness and implementability of IAS technology at the Site 35 plumes. However, the short-term tests will not provide conclusive evidence as to the effectiveness of the sparge curtain to mitigate long-term contaminant migration. Furthermore, since the plume B pilot test will only be performed for a short duration, it will not provide data regarding potential enhancement of biodegradation rates in this area. For these reasons, a long-term (i.e., 12 to 18-month) barrier effectiveness test is proposed for plumes B and C, provided the short-term pilot test(s) yield(s) promising results. The long-term test would essentially represent the first phase of the interim remedial action, in which permanent, full-scale equipment and utilities would be installed by the Remedial Action Contract (RAC) contractor and operated at the site. During this period, new and existing monitoring wells located up-, down-, and cross-gradient of the sparge curtain boundary would be monitored to track contamination in both untreated and treated areas. Near the end of this time frame, one of the following decisions would be made based on sampling results:

- Continue operation of the existing system

- Expand the existing IAS system to include additional areas if necessary (e.g., plume A and/or plume D)
- Discontinue use of the sparging system in plume B and/or plume C in favor of an alternate technology (i.e., in-well aeration)

Should the short-term tests demonstrate that IAS is a potentially feasible technology for both the BTEX and solvent-related plumes, Baker proposes to proceed with the design of the full-scale interim system based on the collected data and following receipt of review comments on the Treatability Study Report.

3.0 TREATABILITY STUDY OBJECTIVES

At Site 35 IAS is proposed as part of an interim remedial action. The focus of this interim action is the contaminated surficial groundwater in the area located east of the former Site 35 Fuel Farm, between Brinson Creek and the proposed divided highway. As this represents only a portion of the contaminated shallow groundwater identified at the site, this action is referred to as an Interim Remedial Action. That is, it represents only a portion of a more comprehensive investigation and remediation at Site 35 and will not necessarily be the final solution for OU No. 10.

The objectives of the pilot-scale treatability study are as follows:

- Assess the applicability of IAS technology in addressing shallow groundwater contamination at Site 35 by evaluating the effectiveness, implementability, and cost of a full-scale treatment system.
- Obtain sufficient data to afford the development of a full-scale system remedial design.
- Assess the impact of air emissions on human health and the environment, and verify that air emissions will not impact the proposed highway project.

4.0 TESTING PROCEDURES

A Final Remedial Investigation Work Plan, Sampling and Analysis Plan (SAP), Quality Assurance Project Plan (QAPP), and site-specific Health and Safety Plan (HASP) were prepared by Baker (December, 1993) for various field activities at Site 35, including monitoring well installation and soil and groundwater sampling. These project plans will be used for the monitoring well installation and groundwater sampling activities described herein for the pilot-scale test.

4.1 Mobilization

Mobilization will include site preparation, site clearing, and mobilization of drilling crew and rig.

4.1.1 Site Preparation/Site Clearing

Since the treatability study area is located in a heavily-wooded, low-lying area, site-preparation and site-clearing activities will be required to provide access and a stable working surface.

The existing dirt access road is generally accessible for a drilling rig and 4-wheel drive vehicles. However, the treatability study areas are in a low-lying portion of the site, which are subject to occasional flooding and are generally soft. Therefore, the areas will need to be improved prior to treatability study mobilization activities. A small staging area (approximately 15'x 15') will be prepared in each area by placing a 1-foot thick compacted gravel layer over a geofabric. Limited site-clearing, which includes cutting small trees and removing shrubs, may be required to install the staging areas and treatability study monitoring wells.

4.1.2 Installation of Temporary Utilities

The compressor for the IAS system will be operated using a 20-hp gas-powered engine. Therefore, installation of temporary power will not be required.

4.1.3 Temporary Facilities

Baker's existing office and storage trailers near Site 41 will be used during the study due to its short duration. Trash will be collected in garbage bags and disposed of in the dumpster located at Site 41. Baker will have a mobile phone on site during the well installation and treatability study effort.

4.2 Drilling and Well Construction

This section describes the procedures for the construction and installation of groundwater monitoring wells (two-inch diameter PVC casings two-inch diameter, No. 10 slot, well screened), IAS wells, and the soil gas monitoring probes. All drilling activities will be performed using hollow-stem augering methods under the direct supervision of a licensed well driller in accordance with the procedures provided in the Baker SAP. Oversight will be provided by a Baker geologist.

4.2.1 PVC (2-inch) Monitoring Wells

Plan views of the proposed IAS and groundwater monitoring wells for each test are shown in Figure 4-1. As shown in Figure 4-1, six pairs of shallow/deep monitoring well clusters are proposed for the pilot test for plume B. For the plume C test, four pairs of shallow/deep monitoring well clusters

are planned with an additional four deep monitoring wells. Thus, a total of 12 new monitoring wells will be installed for each test. All new monitoring wells will be installed and developed immediately prior to performance of each treatability study.

To optimize data collection for the plume B study, each pair of wells will not be located immediately adjacent to one another as is done with a typical well cluster. However, the cluster well numbering terminology will be used to maintain consistency with previous investigations. The purpose of the two-well cluster concept is to provide the means for obtaining groundwater data at the shallow groundwater surface and above the underlying semi-confining layer. These intervals are monitored by existing double-nested shallow wells. According to the results of previous investigations, the shallow groundwater surface can be expected to be encountered across the treatability study area at two to three feet bgs. Data provided in previous investigations indicates that the top of the semi-confining layer is located about 35 feet bgs.

Each well in the two-well clusters will be provided with either an "A" or "B" designation (e.g., MW-45A and MW-45B). The "A" will identify the well screened at the groundwater surface, whereas "B" will identify the well screened at the top of the underlying confining layer. Existing monitoring wells are currently numbered up to 35MW-43A/B. Therefore, wells installed for the treatability studies will begin with number 35MW-44A/B.

Each well will be constructed with two-inch diameter, schedule 40 PVC casings and No. 10 slot, 2-inch diameter PVC screens. All air sparging wells (35MW-44A/B and 35MW-51B) will be installed using two-foot long screens. The shallow sparging well will be installed to a depth of approximately 16 feet bgs. The deep air sparging well will be installed just above the clayey silt semi-confining layer at a depth of approximately 34 feet bgs.

For the plume B test, a 10-foot screened interval for the groundwater surface monitoring wells will be used from about two to 12 feet bgs. For the deep monitoring wells in plume B, a five-foot long screen will be set approximately three feet higher than the screen depth used for the deep sparging well (i.e., 31 feet). These monitoring wells are placed higher than the sparge wells for the purpose of intercepting the air flow channels rising from the injection well. Detailed well construction information and well installation procedures are provided in Section 5.0 of the SAP.

Because of the presence of the silt/clay lenses, the shallow wells for the plume C test will actually be screened within the lower sand stratum just above (i.e., 1-2 feet) the deep well casing (i.e., within a range of approximately 20 to 30 feet bgs). For all deep monitoring wells which are part of a well cluster (35MW-52B, 35MW-53B, 35MW-54B, and 35MW-55B), a five-foot long screen will be set at a depth that is either equal to, or slightly higher (i.e., 1 to 3 feet) than the screen depth used for the deep sparging well, depending on the thickness of the sand stratum. Thus, the screens for these deep monitoring wells will be placed within a depth range of 26 to 34 feet bgs. For the remaining deep monitoring wells which are not part of a cluster (35MW-56B, 35MW-57B, 35MW-58B, and 35MW-59B), 15-foot long screens will be set for an interval from 19 to 34 feet bgs. The purpose of these 15-foot screens is to capture a greater section of the aquifer to allow for more effective monitoring of the horizontal movement of air at large distances from the sparge well.

Continuous split-spoon sampling using 2-foot long, 2.5- or 3-inch I.D. spoons will be performed during installation of several of the deep wells to determine soil types and well screen placements. Selected soil samples will be collected for possible future geotechnical analysis (e.g., grain size analysis), if deemed necessary following completion of the treatability study.

4.2.2 Soil Gas Probes

For each test, a total of six soil gas probes will be installed at various locations surrounding the air sparging wells as shown in Figure 4-2. The probes will be placed approximately 1 foot above the water table (i.e., 1 to 1.5 feet bgs). The probes will be constructed of 2.5-foot long, 1/2-inch diameter schedule 40 PVC piping with retractable or disposable tips. They will be manually pushed into the soil and removed upon completion of the test.

4.3 Pilot Test Design and Operation

Once the soil gas probes and monitoring wells are installed, as described in Section 4.2, each IAS test and associated air and groundwater sampling/monitoring activities will commence as follows:

- Day 1: Pre-Test Sampling (Baseline Conditions)
- Days 2-3: Phase I IAS Test (5 scfm flow rate)
- Days 4-5: Phase II IAS Test (20 scfm flow rate)
- Day 6: Post-Test Sampling

During each phase of the pilot test, air will be simultaneously injected into both the shallow and deep sparging wells. In other words, approximately 5 scfm will be injected into each well during Phase I; whereas, approximately 20 scfm will be injected into each well during Phase II. The text will be revised to clarify this point. As discussed below, the length of Phase I and/or Phase II could be expanded based on field observations.

Changes in the following parameters will be measured to evaluate the radius of influence (ROI) of the IAS system:

- Dissolved oxygen (D.O.) in groundwater
- Oxygen concentration (by volume) in soil (vadose zone)
- Contaminant levels in vadose zone (soil gas)
- Contaminant levels in groundwater
- Helium concentrations in vadose zone
- Vadose zone pressure
- Groundwater pressure (water table elevation)

All measurements in the vadose (i.e., unsaturated) zone will be taken using the soil gas probes, and all groundwater parameters will be measured using the upper and lower aquifer monitoring wells.

Of the above parameters, oxygen concentration is the key parameter that will be used to assess the zone of influence of the sparging system, particularly D.O. concentrations in the surficial aquifer. Background dissolved oxygen levels are expected to be at concentrations less than 2 mg/L in the aquifer and possibly in the range of 10 - 15 percent in the vadose zone, depending on the amount of biological activity in the area. Once the IAS system is turned on, D.O. levels in the monitoring wells may rise to various levels up to the saturation point of about 9 mg/L, and oxygen levels in the vadose zone may increase to about 20 percent. The duration of Phase I and/or Phase II could be increased an additional 12 to 24 hours if D.O. measurements indicate that the system has not reached steady-state and more time is needed to obtain an accurate ROI estimate.

In addition to oxygen, a helium tracer will be used to help determine the IAS radius of influence. Procedures for the helium tracer test as well as the other data collection methods and frequencies are discussed for each test phase in the following sections.

All samples collected during this investigation, including QA/QC samples, will be designated with a unique number. The number will serve to identify the investigation, the site, the area within the site, the sample medium, a sampling location, depth or round (pre-test, test, post-test) of sample, and QA/QC qualifiers.

The sample designation format is as follows:

Site # - Medium - Location - Depth/Round - Time (QA/QC)

An explanation of each of these identifiers is given below.

Site # This investigation includes Site 35.

Medium GW = Groundwater
 SG = Soil Gas
 WT = Waste

Location The location numbers identify the sampling location. This would include station number for soil location or monitoring well number for groundwater. Each grid station will be identified with a unique identification number.

Depth/Round Depth indicators will be used for soil samples. The number will refer to the depth of the top of the sampled interval. For example:

00 = top of sample at ground surface
01 = top of sample is 1 foot below surface
07 = top of sample is 7 feet below surface

Round indicator will be used for groundwater samples as follows:

01 = Pre-test sampling round
02 = Pilot test (Phase I)
03 = Pilot test (Phase II)
04 = Post-test sampling round

Time Time indicators will be used to identify the time (in hours) of sample collection during each phase as follows:

00 = Initial baseline sampling or immediately after system startup (i.e., t = 10 minutes)
02 = t = 2 hours
24 = t = 24 hours
48 = t = 48 hours

QA/QC	(FB)	=	Field Blank
	(D)	=	Duplicate Sample
	(TB)	=	Trip Blank
	(ER)	=	Equipment Rinsate

Under this sample designation format the sample number 35-GW-48A-01-24D refers to:

<u>35</u> -GW-48A-01-24D	Site 35
35- <u>GW</u> -48A-01-24D	Groundwater Sample
35-GW- <u>48A</u> -01-24D	Monitoring well 48A
35-GW-48A- <u>01</u> -24D	Pre-test sampling round
35-GW-48A-01- <u>24</u> D	Sample collected after 24 hours
35-GW-48A-01-24 <u>D</u>	duplicate (QA/QC) sample

This sample designation format will be followed throughout the project. Required deviations to this format in response to field conditions will be documented.

The types and quantities of QA/QC samples associated with the groundwater sampling are indicated in Tables 4-1, 4-2, and 4-3 discussed in the following sections. Additional information concerning the QA/QC samples is provided in the Site 35 QAPP. Sample bottle and holding time requirements for the groundwater samples are also provided in the QAPP.

4.3.1 Pre-Test Sampling

Prior to startup of the IAS system, a 24-hour pre-test sampling event will be conducted to obtain a baseline data set of the natural physical/chemical conditions in the aquifer and vadose. The pre-test sampling matrix outlining all test parameters, methods, and sampling frequencies is provided in Table 4-1. Specific sampling methodologies are described below.

4.3.1.1. Soil Gas Sampling and Monitoring

With the exception of the SUMMA canisters, all soil gas samples will be collected using a Dawson electric high volume air sampling pump connected to the soil gas probes. The high volume air sampler is designed to provide a variable flow setting between 3 to 20 liters/min. The air sampler will be connected to the soil gas probes using 1/4" flexible tubing (i.e., tygon, PVC, polyethylene, or polypropylene). Specific methods and equipment are given below.

Oxygen Concentrations

Oxygen concentrations in the vadose zone will be measured using a portable Sentinel Model 503-A O₂/LEL meter, or equivalent. The measurement will be taken by drawing air from the air pump discharge line into the intake tube on the O₂/LEL meter.

Organic Contaminant Concentrations

The majority of the total organic compound concentrations in soil gas will be measured using an HNu Model PI-101 or DL-101 photoionization detector (PID) with a 10.2 eV lamp. The measurement will be taken by holding the PID probe the in the discharge from the air pump.

In addition to PID readings, a limited number (Table 4-1) of vapor samples will be collected using 6-liter SUMMA canisters. The inlet to the SUMMA canisters (i.e., swagelock), which are supplied under vacuum, will be connected to the soil gas probes using 1/4" flexible tubing (i.e., tygon, PVC, polyethylene, or polypropylene) and shipped to an off-site laboratory certified by NFESC or the U.S. Army Corps of Engineers for EPA Method TO-14 analysis. A list of the constituents detected by the TO-14 analysis is provided in Appendix D. There is no holding time for the SUMMA canisters; however, it is anticipated that all canisters will be shipped to the laboratory within a few days of sampling and analyzed within a two-week time frame.

Pressure Measurements

Pressure measurements will be taken using magnehelic differential pressure gauges (e.g., Dwyer Series 2000, 0-20" H₂O) hard-piped to dedicated 1/4-inch diameter soil gas probes.

4.3.1.2. Groundwater Sampling

Oxygen Concentrations

D.O. concentrations in the aquifer will be measured using a portable YSI Model 57 D.O. meter, or equivalent. The measurement will be taken by using the peristaltic pump to pump water into a small jar in which the D.O. sensor is placed. The D.O. measurement will be taken after the sensor reading stabilizes. The collected water will be disposed in the decontamination water container.

Organic Contaminant Concentrations

Groundwater samples will be collected for VOC analysis as indicated in Table 4-1. The peristaltic pump will be used to purge three to five well volumes from the well and to obtain a turbidity reading less than 10 NTUs prior to collecting the sample. Additional sampling collection protocols are provided in the SAP. The samples will be analyzed using EPA SW 846 Method 8240 (plus xylenes) by an off-site laboratory certified by NFESC or the U.S. Army Corps of Engineers.

Pressure Measurements

Water table levels will be automatically recorded on an hourly basis in four shallow wells throughout the pre-test, pilot test, and post-test periods using pressure transducers linked to a data logger (4-channel In Situ, Inc. Hermit Model SE2000).

4.3.2 Pilot Test Operation

As previously noted, each pilot test will consist of two, 2-day phases (Phase I and Phase II) in which air injection flow rates (per well) of approximately five standard cubic feet per minute (SCFM) and 20 SCFM will be used. The phases will be performed in series without discontinuing air injection. IAS systems typically operate within the range of three to 20 SCFM, with the majority of systems operating around 10 SCFM per well. Thus, the five and 20 SCFM flow rates were selected to provide the optimal data on which to base a full-scale system design.

4.3.2.1 Pilot Test Equipment

A process flow schematic showing the equipment and instrumentation to be used for the IAS tests is provided in Figure 4-3. The equipment shown in Figure 4-3 will be pre-assembled on a single-axle flat bed trailer (5 feet by 8 feet), which will be transported to the site by a van or pickup truck. Since a soil vapor extraction (SVE) test will not be performed in conjunction with the IAS test due to the high water table, the major equipment item to be used in the IAS will be an oil-free rotary vane air compressor. The compressor will be equipped with a pressure relief valve, check valve, and pressure gauge and will be plumbed to a section of 1-inch diameter schedule 40 steel pipe with a bleed valve to control air flow and sampling port to monitor helium concentrations. Schedule 40 0.5-inch diameter high temperature hose will be used to connect the steel pipe to the injection well head. The following parameters will be measured on the compressor discharge:

- Temperature
- Pressure
- Air flow rate

These parameters will be monitored periodically and any changes/adjustments recorded in the field log book as appropriate.

4.3.2.2 Pilot Test Sampling

The test sampling matrix outlining all test parameters, methods, and sampling frequencies is provided in Table 4-1. The sampling procedures are identical to those described in Section 4.3.1, except that helium concentrations will be measured in the soil as part of the helium tracer test discussed in the next section.

4.3.2.3 Helium Tracer Test

As air injection is initiated after the baseline sampling, helium will be blended with the injection air at a concentration of about two percent. A series of pressurized helium tanks will be manifolded together and piped into the air injection line. Helium air flow will be adjusted manually by sampling the injected air. Pressure and flow gauges will also be provided on the helium line. The helium will be used as a conservative tracer to identify where the injected air reaches the vadose zone, and to identify if the injected air is traveling to any location of concern. Helium concentrations in the vadose zone will be measured using a portable battery-operated helium detector (Mark 9821 or equivalent). The measurement will be taken by drawing air from the air pump discharge line into the intake tube on the helium detector.

Once the soil gas data has been collected, contaminant emission rates will be estimated by multiplying the air injection flow rate Q_{air} [ft^3/min] with some average of the measured shallow soil gas concentrations C_{sq} [lb/ft^3]:

$$Emissions = Q_{air} [ft^3/min] \times C_{sq} [lb/ft^3]$$

As a check on the accuracy of the estimate, an estimate of the helium emission rate will be calculated using the same procedure. The helium emission estimate will then be compared with the known helium injection rate to check the accuracy of the contaminant emission rate estimate.

4.3.3 Post-Test Sampling

Following completion of Phase II air injection period, a 24-hour post-test sampling event will be conducted to evaluate how the aquifer and vadose zone return to their natural pre-test conditions. The post-test sampling matrix outlining all test parameters, methods, and sampling frequencies is provided in Table 4-3. The sampling methodologies are identical to those described in Section 4.3.1 for the pre-test sampling round.

4.4 Equipment Decontamination Procedures

All drilling and sampling equipment will be decontaminated before use, between each sampling station, and at the completion of the sampling program in accordance with the EPA Region IV ECBSOPQAM. Specific decontamination procedures are provided in the SAP (Baker, 1993).

4.5 Residuals Management

Investigation derived wastes (IDW) will be generated during the drilling and sampling activities associated with the treatability study. The IDW to be generated will include soil cuttings, purge and development groundwater, spent decontamination fluid, and personal protective equipment (PPE) and clothing (PPC). Procedures for IDW disposal are included in the SAP (Baker, 1993).

5.0 COMMUNITY RELATIONS

Community relations activities and requirements are outlined in the Base-wide Community Relations Plan prepared by Baker for the CERCLA RI/FS activities being performed on-Base. A Technical Review Committee (TRC) has been established for the MCB Camp Lejeune CERCLA activities, which includes LANTDIV, the Activity, USEPA, NC DEHNR personnel, and local citizens. The TRC reviews CERCLA documents and participates in periodic meetings with Baker to discuss ongoing CERCLA activities.

6.0 REPORTS

Two main reports are associated with the treatability study effort include this Treatability Study Work Plan and the Treatability Study Report, which will document the treatability study results and conclusions. Submission and review of these two reports are discussed in the following sections.

6.1 Treatability Study Work Plan

This Draft Treatability Study Work Plan, which details the scope of the treatability study activities to be performed, is being submitted to LANTDIV, the Activity, USEPA Region IV, and NC DEHNR for review. Comments received from the NC DEHNR and USEPA Region IV, will be addressed and incorporated, as appropriate, into the Final Treatability Study Work Plan. Baker will distribute the appropriate number of copies of the Final Treatability Study Work Plan to LANTDIV, the Activity, USEPA Region IV, NC DEHNR, and the other members of the TRC.

6.2 Treatability Study Report

Upon completion of the on-site pilot study, a Treatability Study Report will be prepared in accordance with USEPA's "Guide for Conducting Treatability Studies under CERCLA" (USEPA, October 1992). The Treatability Study Report will provide a presentation and evaluation of the treatability study test results. The Treatability Study Report will also include engineering and design-related information needed for evaluating the short- and long-term effectiveness, implementability (including long-term operation and maintenance requirements), and cost (both capital and operation and maintenance) of implementing a full-scale IAS system on site.

Two versions of the Treatability Study Report will be prepared as follows: a Draft Treatability Study Report for review by the Navy, USEPA, and NC DEHNR; and a Final Treatability Study Report, which will incorporate review comments from the Navy and regulatory agencies. Upon completion, Baker will distribute the appropriate number of copies of the Final Treatability Study Report to LANTDIV, the Activity, USEPA Region IV, NC DEHNR, and the other members of the TRC.

7.0 SCHEDULE

A preliminary schedule depicting the treatability study process is provided in Figure 7-1. As shown in Figure 7-1, the on-site operational period for the pilot system, including installation of monitoring wells and demobilization efforts, is approximately three weeks, whereas, the entire treatability study process, which includes development and review of the Treatability Study Work Plan and Treatability Study Report, is expected to require a total of eight months to complete.

8.0 PROJECT MANAGEMENT AND STAFFING

The proposed management and staffing of this Treatability Study is graphically depicted in Figure 8-1. The primary participants in this project will include:

- Mr. Matthew D. Bartman, Activity Coordinator
- Mr. Daniel Bonk, P.E., Project Manager
- Mr. Gordon J. Ruggaber, P.E., Lead Engineer
- Mr. Mark Kimes, Site Manager/Project Engineer

Mr. Daniel L. Bonk will serve as the Project Manager. He will be responsible for the overall technical preparation of the report and will serve as the client contact representative from Baker. Lead technical assistance will be provided by Mr. Gordon J. Ruggaber. All field activities will be managed and coordinated by Mr. Mark Kimes, who will serve as the Site Manager. Mr. Kimes will be responsible for coordinating with on-site subcontractors. Senior review and technical guidance will be provided by the MCB, Camp Lejeune Activity Coordinator, Mr. Matthew D. Bartman.

Overall field and reporting QA/QC will be the responsibility of Mr. Daniel L. Bonk. Mr. Ray Wattras will provide program-level technical and administrative support.

TABLES

TABLE 1-1

**ORGANIC COCs THAT EXCEED REMEDIATION LEVELS
OPERABLE UNIT NO. 10 (SITE 35)
CTO-0323
MCB CAMP LEJEUNE, NORTH CAROLINA**

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

Notes:

⁽¹⁾ RL = Remediation Level

⁽²⁾ Groundwater RLs expressed as $\mu\text{g/L}$ (ppb)

NC WQS = North Carolina Water Quality Standard

TABLE 4-1

PRE-TEST SAMPLING MATRIX
 SITE 35
 MCB CAMP LEJEUNE, NORTH CAROLINA

Matrix	Location	Analysis	Frequency	Method	Total Samples
Soil gas	All probes	Oxygen	t = 0, 8, 24 hrs	O ₂ /LEL meter	18
Soil gas	All probes	VOCs	t = 0, 8, 24 hrs	Vapor analyzer	18
Soil gas	SG1, SG2, SG4, SG7, SG8, SG9	VOCs	t = 0 hrs	SUMMA, TO-14	3
Soil gas	All probes	Pressure	t = 0, 8, 24 hrs	Pressure gauge	18
Groundwater	All wells	D.O.	t = 0, 8, 24 hrs	D.O. meter	18
Groundwater	46A/B, 50A/B, 53A/B, 54A/B	VOCs	t = 0, 24 hrs	Lab, SW 846 8240	8 + 3*
Groundwater	45A, 46A, 48A, 50A, 52A, 53A, 54A, 55A	Water Level	Hourly for 24 hrs	Data logger	96

Notes:

* Includes following QA/QC samples:

1 Trip blank

1 Equipment rinsate (sampling pump tubing)

1 Field duplicate

TABLE 4-2

PILOT TESTING SAMPLING MATRIX
SITE 35, MCB CAMP LEJEUNE, NORTH CAROLINA

Matrix	Location	Analysis	Frequency	Method	Total Samples
Phase I, Air Flow Rate = 5 SCFM					
Soil gas	All probes	Oxygen	t=0, 2, 4, 6, 8, 12, 24, 28, 32, 36, 48 hrs	O ₂ /LEL meter	66
Soil gas	All probes	VOCs	t = 0, 8, 24, 32, 48 hrs	Vapor analyzer	30
Soil gas	SG1, SG2, SG4, SG7, SG8, SG9	VOCs	t = 48 hrs	SUMMA, TO-14	3
Soil gas	All probes	Pressure	t = 0, 8, 24, 32, 48 hrs	Pressure gauge	30
Soil gas	All probes	Helium	t=0, 2, 4, 6, 8, 12, 24, 28, 32, 36, 48 hrs	Portable analyzer	60
Groundwater	All wells	D.O.	t=0, 2, 4, 6, 8, 12, 24, 28, 32, 36, 48 hrs	D.O. meter	66
Groundwater	46A/B, 50A/B, 53A/B, 54A/B	VOCs	t = 24, 48 hrs	Lab, SW 846 8240	8
Groundwater	45A, 46A, 48A, 50A, 52A, 53A, 54A, 55A	Water Level	Hourly for 48 hrs	Data logger	192
Phase II, Air Flow Rate = 20 SCFM					
Soil gas	All probes	Oxygen	t=0, 2, 4, 6, 8, 12, 24, 28, 32, 36, 48 hrs	O ₂ /LEL meter	66
Soil gas	All probes	VOCs	t = 0, 8, 24, 32, 48 hrs	Vapor analyzer	30
Soil gas	SG1, SG2, SG4, SG7, SG8, SG9	VOCs	t = 48 hrs	SUMMA, TO-14	3
Soil gas	All probes	Pressure	t = 0, 8, 24, 32, 48 hrs	Pressure gauge	30
Soil gas	All probes	Helium	t=0, 2, 4, 6, 8, 12, 24, 28, 32, 36, 48 hrs	Portable analyzer	60
Groundwater	All wells	D.O.	t=0, 2, 4, 6, 8, 12, 24, 28, 32, 36, 48 hrs	D.O. meter	66
Groundwater	46A/B, 50A/B, 53A/B, 54A/B	VOCs	t = 24, 48 hrs	Lab, SW 846 8240	8 + 3*
Groundwater	45A, 46A, 48A, 50A, 52A, 53A, 54A, 55A	Water Level	Hourly for 48 hrs	Data logger	192

Notes:

- * Includes following QA/QC samples:
- 1 Trip blank, 1 Field duplicate
- 1 Equipment rinsate (sampling pump tubing)

TABLE 4-3

POST-TEST SAMPLING MATRIX
 SITE 35
 MCB CAMP LEJEUNE, NORTH CAROLINA

Matrix	Location	Analysis	Frequency	Method	Total Samples
Soil gas	All probes	Oxygen	t = 4, 8, 12, 24 hrs	O ₂ /LEL meter	24
Soil gas	All probes	VOCs	t = 4, 8, 12, 24 hrs	Vapor analyzer	24
Soil gas	SG1, SG2, SG4, SG7, SG8, SG9	VOCs	t = 24 hrs	SUMMA, TO-14	3
Soil gas	All probes	Pressure	t = 4, 8, 12, 24 hrs	Pressure gauge	24
Soil gas	All probes	Helium	t = 4, 8, 12, 24 hrs	Portable analyzer	4
Groundwater	All wells	D.O.	t = 4, 8, 12, 24 hrs	D.O. meter	24
Groundwater	46A/B, 50A/B, 53A/B, 54A/B	VOCs	t = 24 hrs	Lab, SW 846 8240	4 + 1*
Groundwater	45A, 46A, 48A, 50A, 52A, 53A, 54A, 55A	Water Level	Hourly for 24 hrs	Data logger	96

Notes:

* Includes following QA/QC samples:
 1 Trip blank

FIGURES

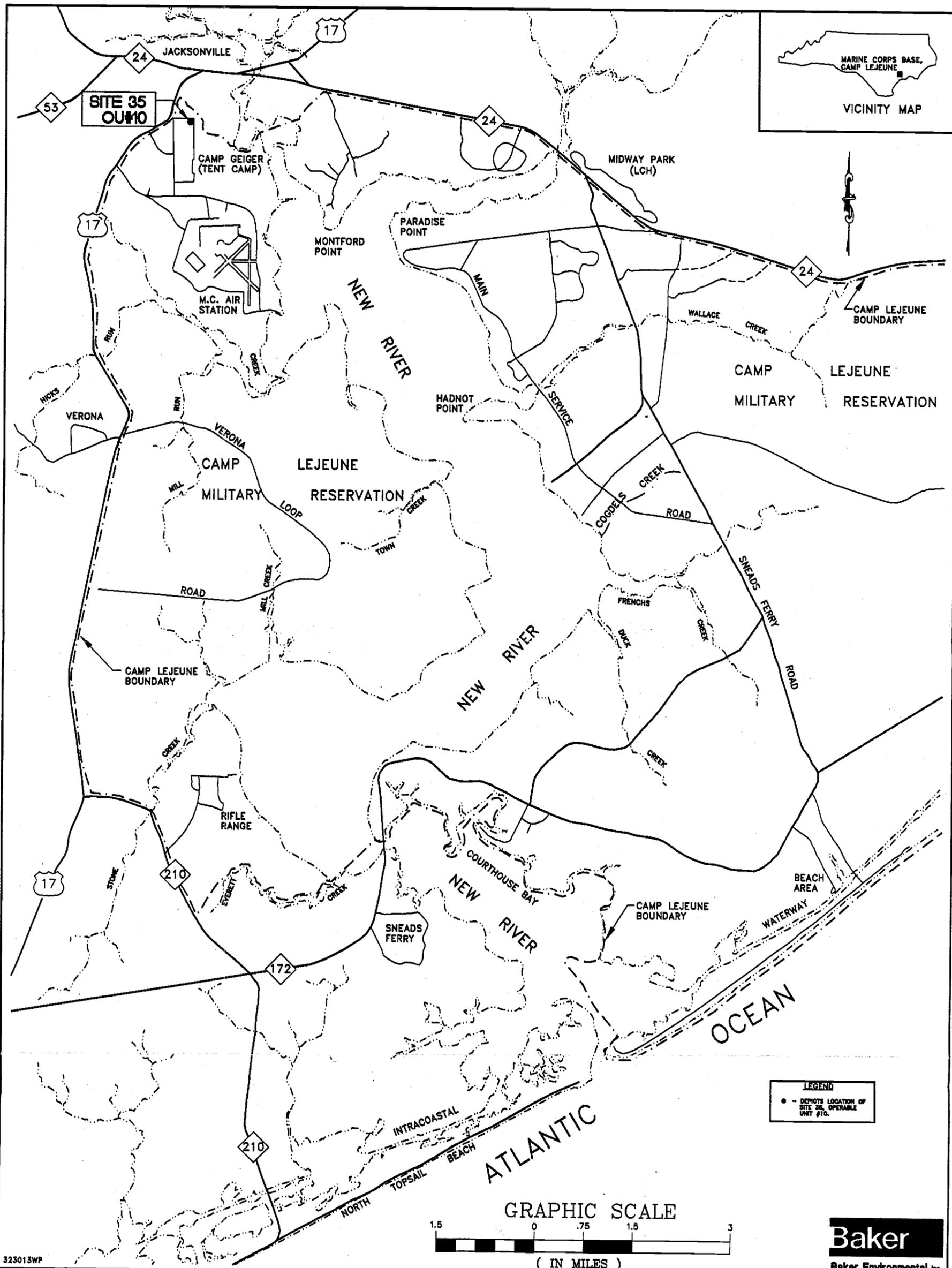
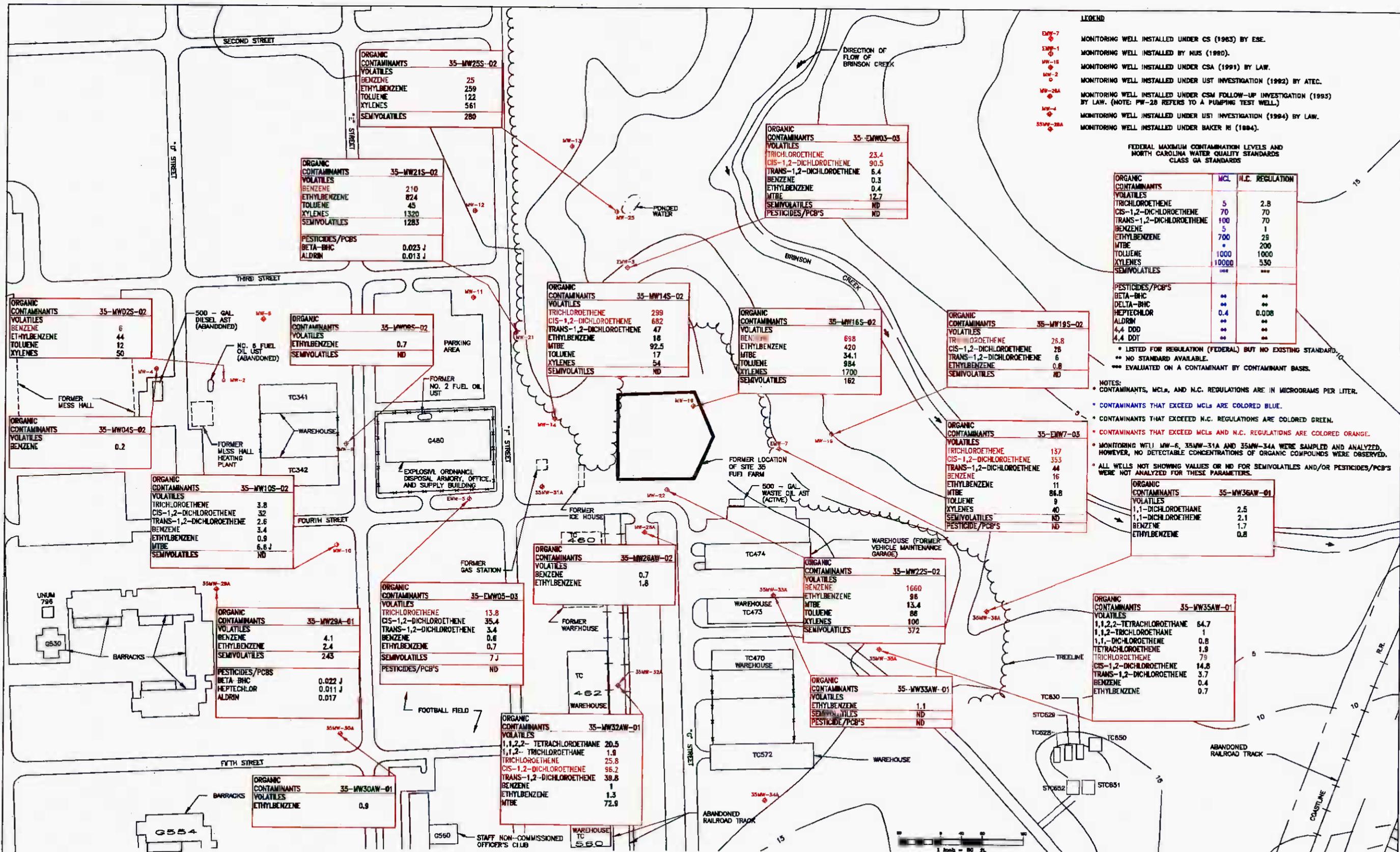


FIGURE 1-1
 CAMP LEJEUNE AND SITE 35
 LOCATION MAP
 SITE 35, CAMP GEIGER AREA FUEL FARM
 CONTRACT TASK ORDER - 0323
 MARINE CORPS BASE, CAMP LEJEUNE
 NORTH CAROLINA

01586CC B12



LEGEND - - - FENCE LINE - - - CONTOUR LINES DEPICTING SURFICIAL RELIEF LEGEND CONTINUED IN UPPER RIGHT HAND CORNER.	DATE: OCT. 1984 SCALE: 1" = 80' DRAWN: W.JH REVIEWED: JSC S.O.#: 62479-325-0000-07000 CADD#: 523006WP	NORTH 	SITE 35, IAS TREATABILITY STUDY MARINE CORPS BASE, CAMP LEJUNE NORTH CAROLINA BAKER ENVIRONMENTAL, Inc. Coraopolis, Pennsylvania		DETECTED ORGANICS IN UPPER PORTION OF SURFICIAL AQUIFER CONTRACT TASK ORDER - 0323	FIGURE No. 1-3
	SCALE: 1" = 80' DATE: OCT. 1984					

01586 CC B2Y

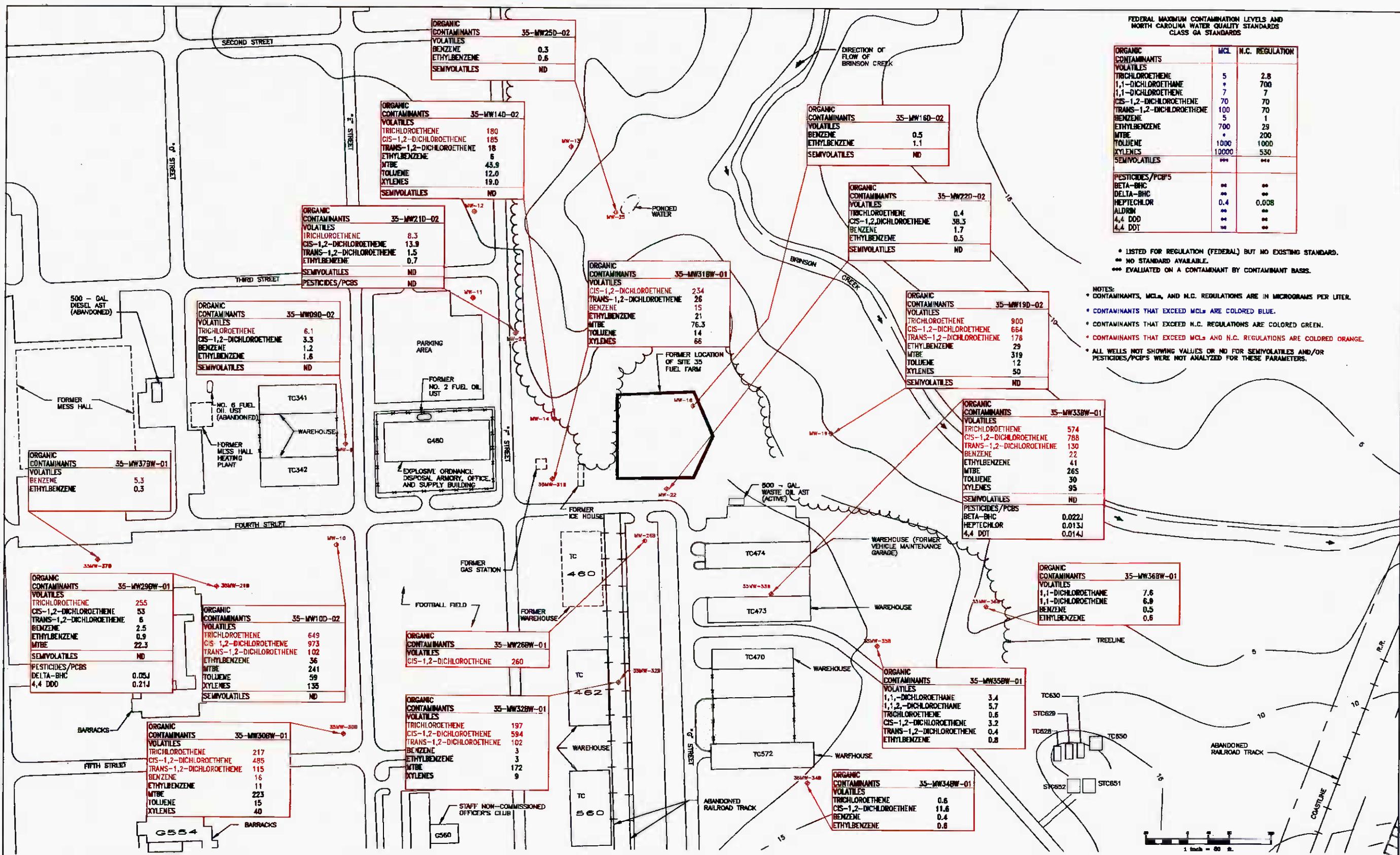
FEDERAL MAXIMUM CONTAMINATION LEVELS AND NORTH CAROLINA WATER QUALITY STANDARDS CLASS GA STANDARDS

ORGANIC CONTAMINANTS	MCL	N.C. REGULATION
VOLATILES		
TRICHLOROETHENE	5	2.8
1,1-DICHLOROETHANE	7	700
1,1-DICHLOROETHENE	7	7
CIS-1,2-DICHLOROETHENE	70	70
TRANS-1,2-DICHLOROETHENE	100	70
BENZENE	5	1
ETHYLBENZENE	700	29
MTBE	*	200
TOLUENE	1000	1000
XYLENES	10000	530
SEMIVOLATILES		

PESTICIDES/PCB'S		
BETA-BHC	**	**
DELTA-BHC	**	**
HEPTACHLOR	0.4	0.008
ALDRIN	**	**
4,4 DDD	**	**
4,4 DDT	**	**

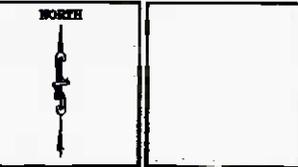
* LISTED FOR REGULATION (FEDERAL) BUT NO EXISTING STANDARD.
 ** NO STANDARD AVAILABLE.
 *** EVALUATED ON A CONTAMINANT BY CONTAMINANT BASIS.

NOTES:
 • CONTAMINANTS, MCLs, AND N.C. REGULATIONS ARE IN MICROGRAMS PER LITER.
 • CONTAMINANTS THAT EXCEED MCLs ARE COLORED BLUE.
 • CONTAMINANTS THAT EXCEED N.C. REGULATIONS ARE COLORED GREEN.
 • CONTAMINANTS THAT EXCEED MCLs AND N.C. REGULATIONS ARE COLORED ORANGE.
 • ALL WELLS NOT SHOWING VALUES OR ND FOR SEMIVOLATILES AND/OR PESTICIDES/PCB'S WERE NOT ANALYZED FOR THESE PARAMETERS.



LEGEND
 MW-299 - MONITORING WELL INSTALLED UNDER BAKER IN (1994).
 MW-18 - MONITORING WELL INSTALLED UNDER CSA (1991) BY LAW.
 --- FENCE LINE
 -15- CONTOUR LINES DEPICTING SURFICIAL RELIEF

DATE: OCT. 1994
 SCALE: 1" = 80'
 DRAWN: W.J.H.
 REVIEWED: J.S.C.
 S.O.#: 62470-323-0000-07000
 CAUD#: 323009WP



SITE 35, IAS TREATABILITY STUDY
 MARINE CORPS BASE, CAMP LEJUNE
 NORTH CAROLINA

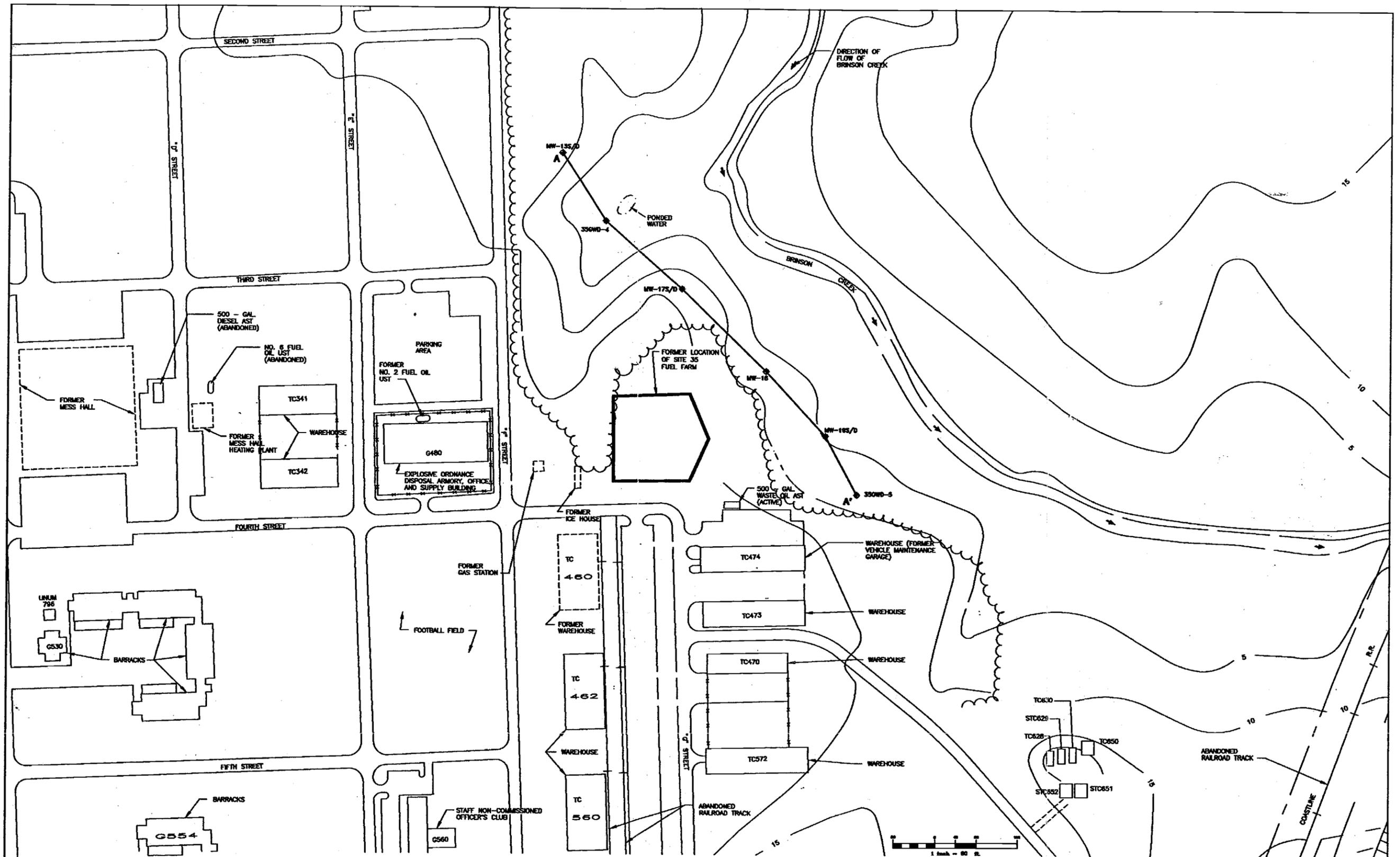
Baker Environmental, Inc.
 Coraopolis, Pennsylvania



DETECTED ORGANICS IN LOWER PORTION OF SURFICIAL AQUIFER
 CONTRACT TASK ORDER - 0323

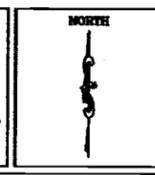
SCALE: 1" = 80'
 DATE: OCT. 1994

FIGURE No.
1-4



LEGEND	
	- FENCE LINE
	- CONTOUR LINES DEPICTING SURFICIAL RELIEF
	- MONITORING WELL LOCATION AND DESCRIPTION

DATE	OCT. 1984
SCALE	1" = 80'
DRAWN	W.H.
REVIEWED	JSC
S.O.#	62470-325-0000-07000
CAID#	325015WP



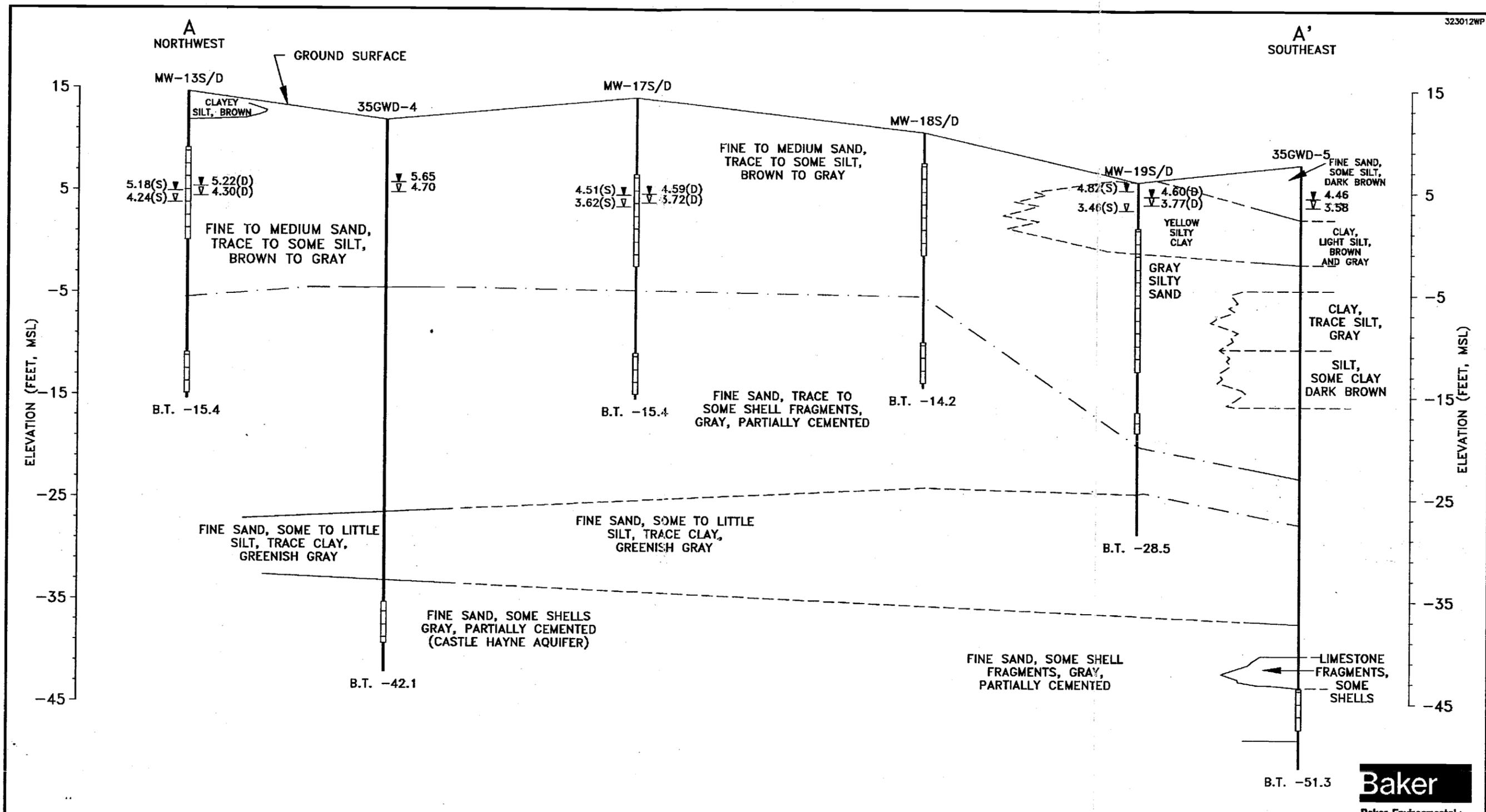
SITE 35, IAS TREATABILITY STUDY
MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA
 BAKER ENVIRONMENTAL, Inc.
 Coraopolis, Pennsylvania

Baker
 Baker Environmental, Inc.

CROSS-SECTION LOCATION SITE 35, IAS TREATABILITY STUDY CONTRACT TASK ORDER - 0323	
SCALE	1" = 80'
DATE	SEPT. 1984

FIGURE No.
1-6

01586CCB3Z



LEGEND

	GROUNDWATER ELEVATION (X)
	GROUNDWATER ENCOUNTERED DURING DRILLING
	BORING TERMINATED, ELEVATION MSL
	BENZENE CONCENTRATIONS (ug/L) IN GROUNDWATER
	TOTAL VOC CONCENTRATIONS (ug/L) IN GROUNDWATER
	TPH CONCENTRATIONS (mg/kg) IN SOILS
	WELL SCREEN INTERVAL
	NOT DETECTED AT METHOD DETECTION LIMITS
	ESTIMATED BY BAKER BORING
	PROJECTED BETWEEN KNOWN POINTS
	INFERRED FROM OTHER CONSULTANT BORINGS

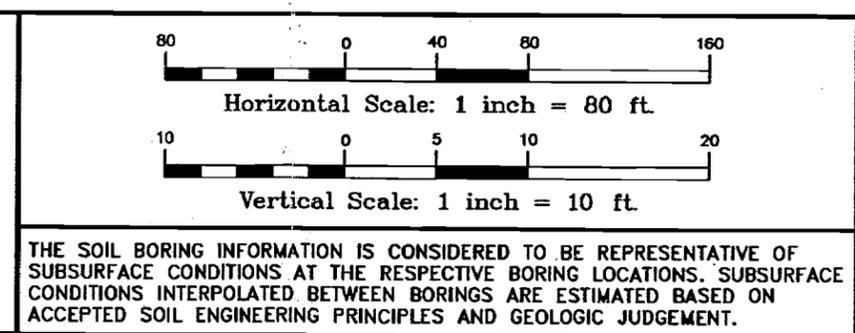
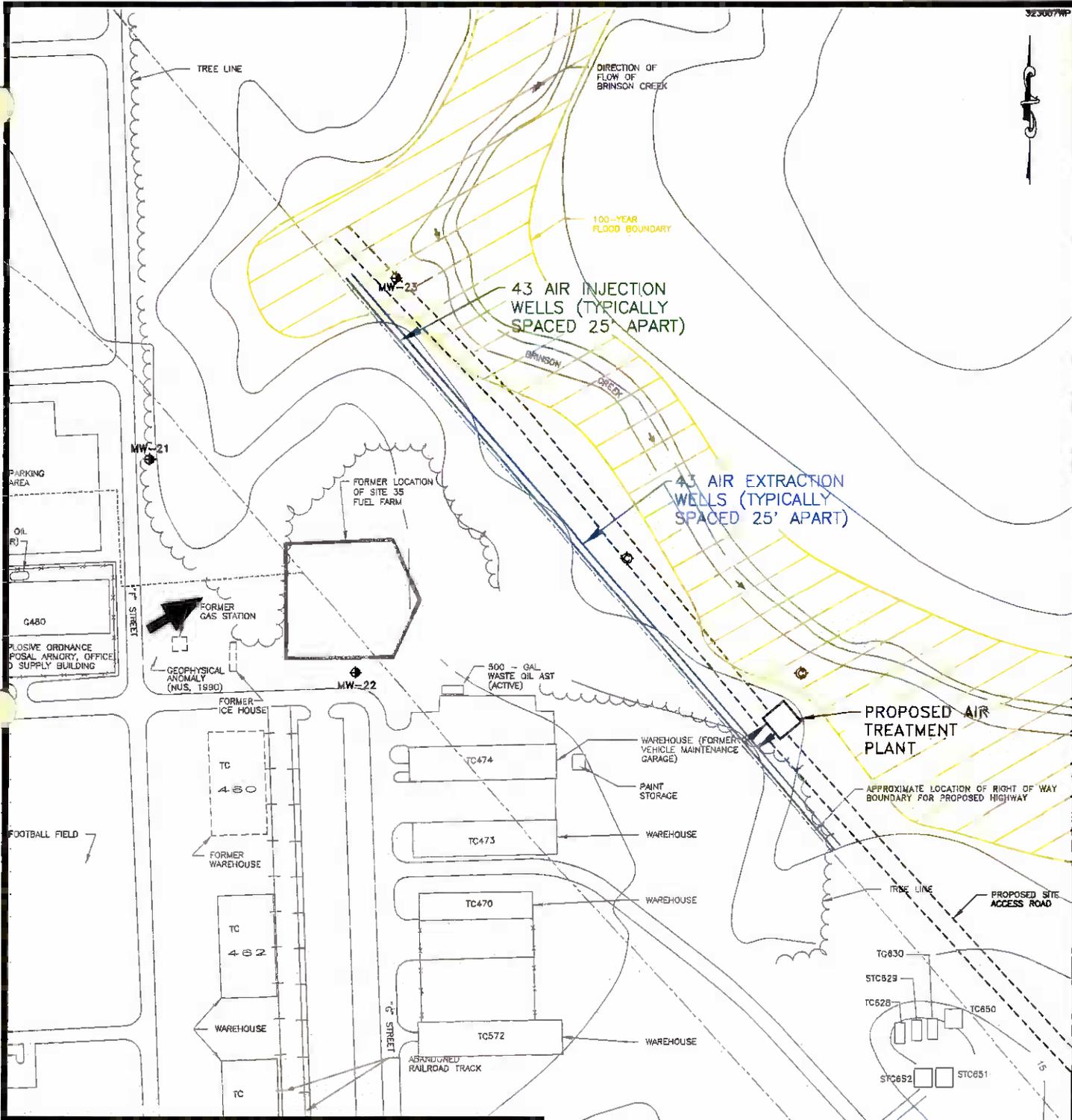


FIGURE 1-7
HYDROGEOLOGIC CROSS-SECTION A-A'
SITE 35, IAS TREATABILITY STUDY
CTO-0323

MARINE CORPS BASE, CAMP LEJEUNE
 NORTH CAROLINA

Baker
 Baker Environmental, Inc.



LEGEND

- *---*--- 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
- AIR EXTRACTION CONVEYANCE LINE
- AIR INJECTION CONVEYANCE LINE
- APPROXIMATE GROUNDWATER FLOW DIRECTION
- 100 YEAR FLOOD BOUNDARY (ref. FIRM FLOOD INSURANCE RATE MAP, ONSLOW COUNTY, NORTH CAROLINA; FEMA COMMUNITY PANEL NUMBER 3 70340 0305C.
- - - - - PROPOSED LOCATION OF SITE ACCESS ROAD
- MW-23 EXISTING WELL CLUSTER IN THE SURFICIAL AQUIFER
- 35GWD-3 EXISTING WELL IN THE DEEP AQUIFER
- PROPOSED WELL CLUSTER IN THE SURFICIAL AQUIFER

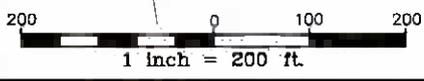
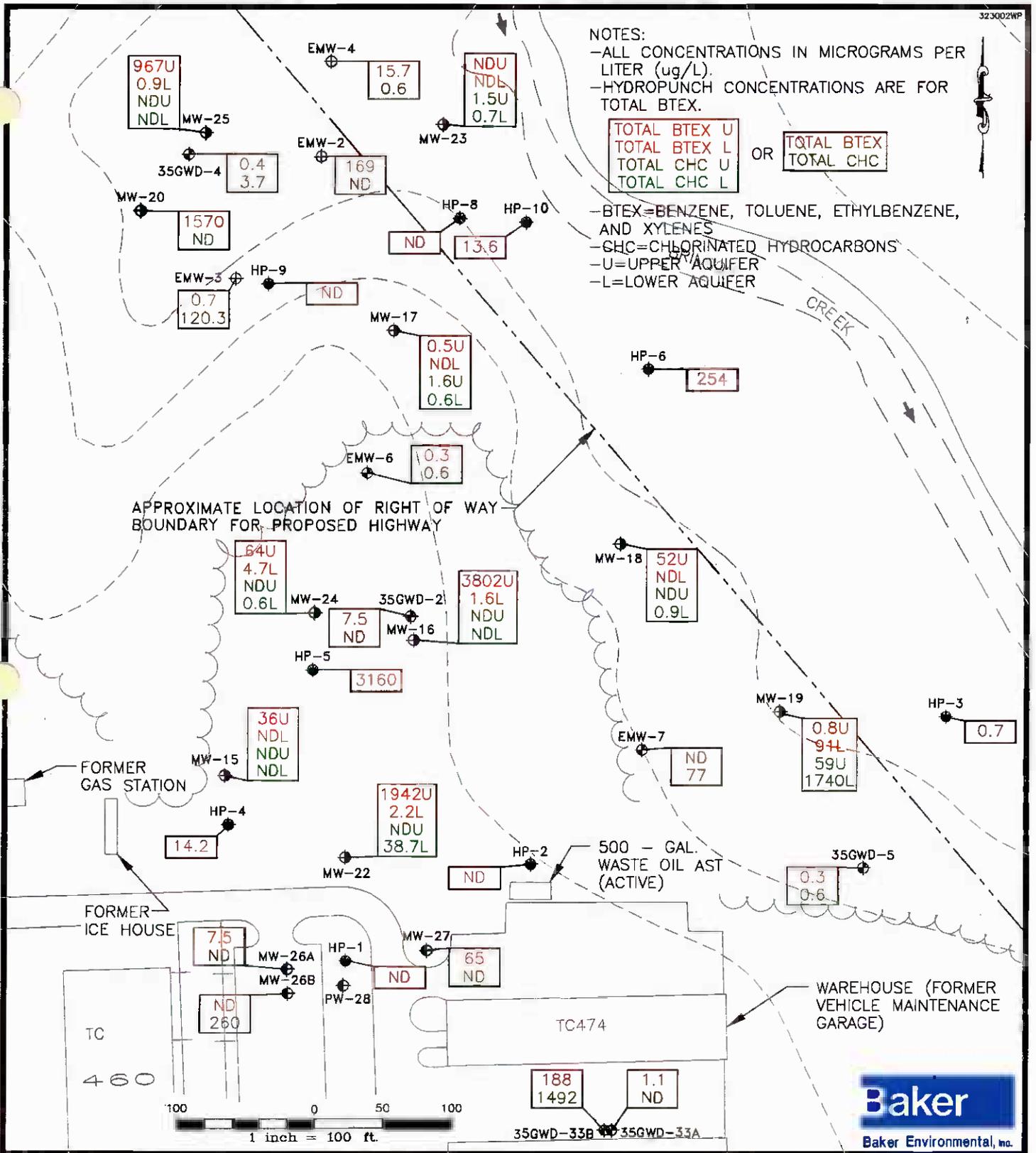


FIGURE 2-1
RAA 4: IN SITU AIR SPARGING AND
OFF-GAS CARBON ADSORPTION
SITE PLAN - SITE 35
CTO-0323
MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

01586.00 BLV

NOTES:

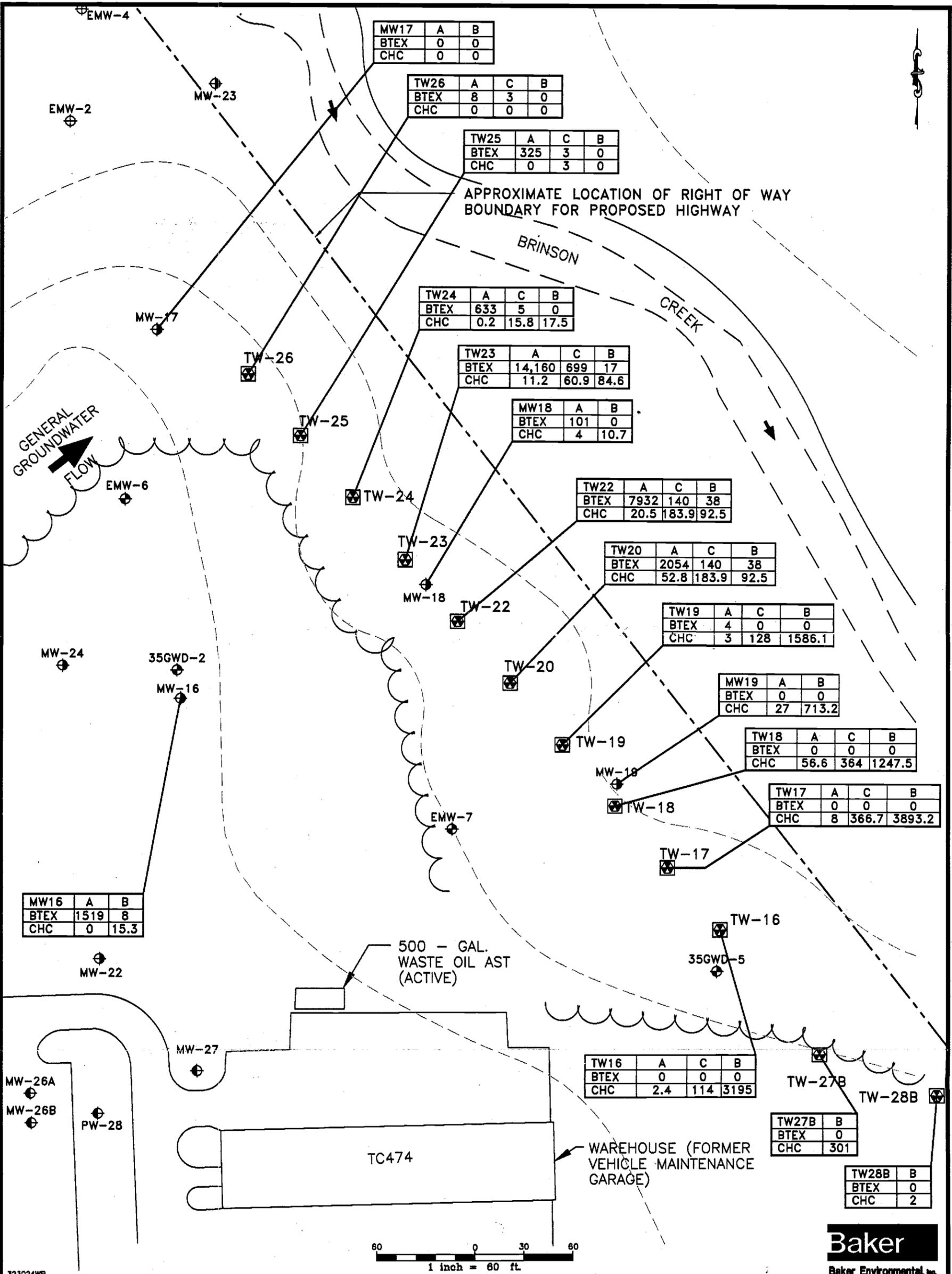
- ALL CONCENTRATIONS IN MICROGRAMS PER LITER (ug/L).
 - HYDROPUNCH CONCENTRATIONS ARE FOR TOTAL BTEX.
- | | | |
|--------------|----|------------|
| TOTAL BTEX U | OR | TOTAL BTEX |
| TOTAL BTEX L | | TOTAL CHC |
| TOTAL CHC U | | |
| TOTAL CHC L | | |
- BTEX=BENZENE, TOLUENE, ETHYLBENZENE, AND XYLENES
 - CHC=CHLORINATED HYDROCARBONS
 - U=UPPER AQUIFER
 - L=LOWER AQUIFER



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-26 MONITORING WELL INSTALLED UNDER CSM FOLLOW-UP INVESTIGATION (1993) BY LAW. (NOTE: PW-28 REFERS TO A PUMPING TEST WELL.)
- HP-18 "HYDROPUNCH" SAMPLING POINT UNDER CSA (1991) BY LAW.
- 35GWD-4 MONITORING WELL INSTALLED UNDER RI (1994) BY BAKER.

FIGURE 2-2
 SUMMARY OF SURFICIAL AQUIFER CONTAMINATION
 IN TREATABILITY STUDY AREA
 SITE 35
 CTO-0323
 MARINE CORPS BASE, CAMP LEJEUNE
 NORTH CAROLINA



MW17	A	B
BTEX	0	0
CHC	0	0

TW26	A	C	B
BTEX	8	3	0
CHC	0	0	0

TW25	A	C	B
BTEX	325	3	0
CHC	0	3	0

TW24	A	C	B
BTEX	633	5	0
CHC	0.2	15.8	17.5

TW23	A	C	B
BTEX	14,160	699	17
CHC	11.2	60.9	84.6

MW18	A	B
BTEX	101	0
CHC	4	10.7

TW22	A	C	B
BTEX	7932	140	38
CHC	20.5	183.9	92.5

TW20	A	C	B
BTEX	2054	140	38
CHC	52.8	183.9	92.5

TW19	A	C	B
BTEX	4	0	0
CHC	3	128	1586.1

MW19	A	B
BTEX	0	0
CHC	27	713.2

TW18	A	C	B
BTEX	0	0	0
CHC	56.6	364	1247.5

TW17	A	C	B
BTEX	0	0	0
CHC	8	366.7	3893.2

MW16	A	B
BTEX	1519	8
CHC	0	15.3

TW16	A	C	B
BTEX	0	0	0
CHC	2.4	114	3195

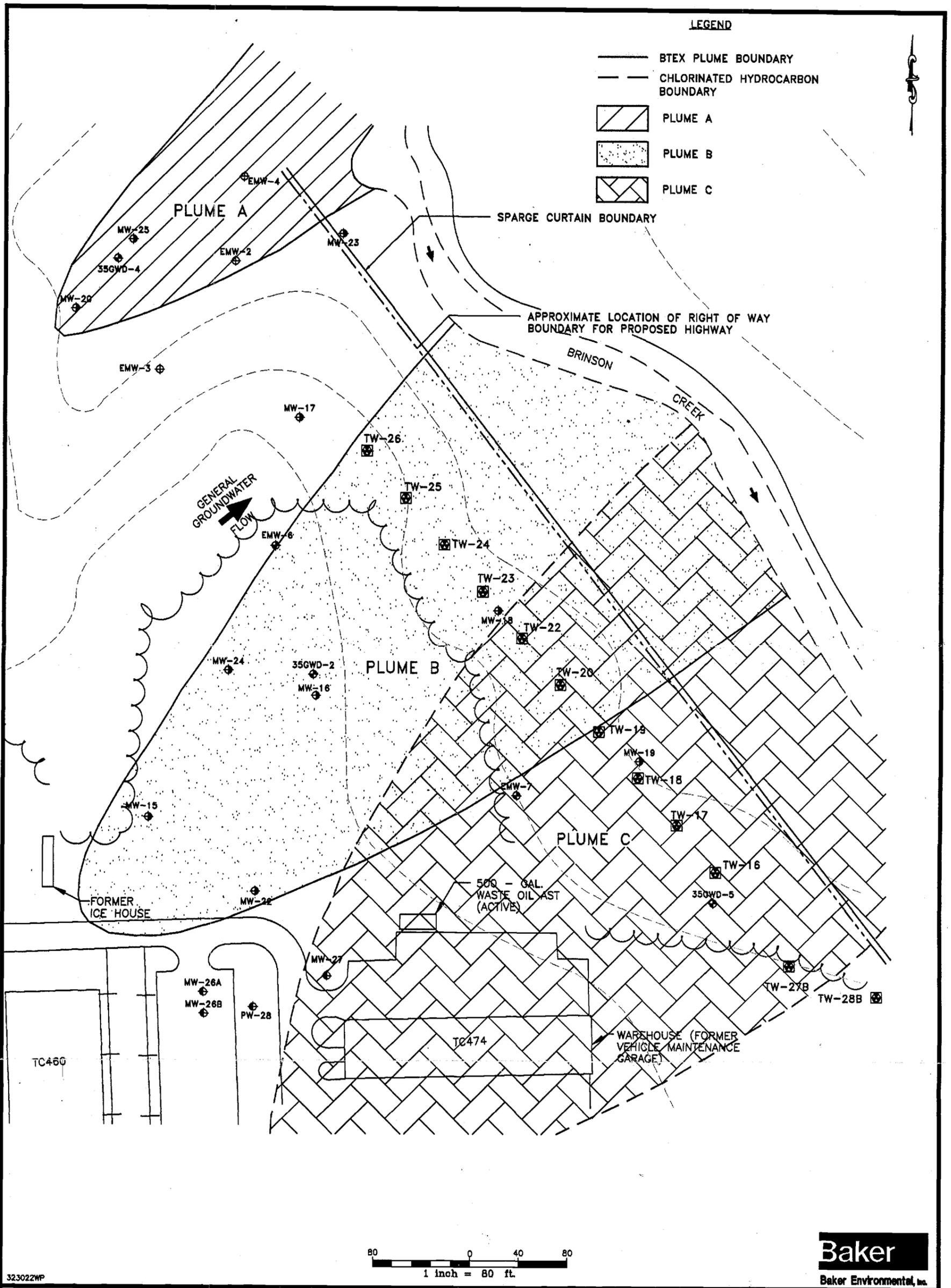
TW27B	B
BTEX	0
CHC	301

TW28B	B
BTEX	0
CHC	2

- 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-26 MONITORING WELL INSTALLED UNDER CSM FOLLOW-UP INVESTIGATION (1993) BY LAW. (NOTE: PW-26 REFERS TO A PUMPING TEST WELL).
 - TEMPORARY WELL CLUSTER
 - CHC TOTAL CHLORINATED HYDROCARBONS
 - BTEX TOTAL BTEX
 - A WELLS WITH 10' SCREEN LENGTH PLACED 5'-15' BGS, ACROSS THE WATER TABLE.
 - C WELLS WITH 5' SCREEN LENGTH PLACED WITHIN A 18 1/2' - 27 1/2' BGS INTERVAL.
 - B WELLS WITH 5' SCREEN LENGTH PLACED WITHIN A 30' - 40' BGS INTERVAL (SCREENED ON TOP OF THE CONFINING UNIT).

FIGURE 2-3
DETECTED BTEX AND
TOTAL CHLORINATED SOLVENTS
IN SURFICIAL AQUIFER (APRIL 1996)
SITE 35, CAMP GEIGER
MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

01586CCB5Z



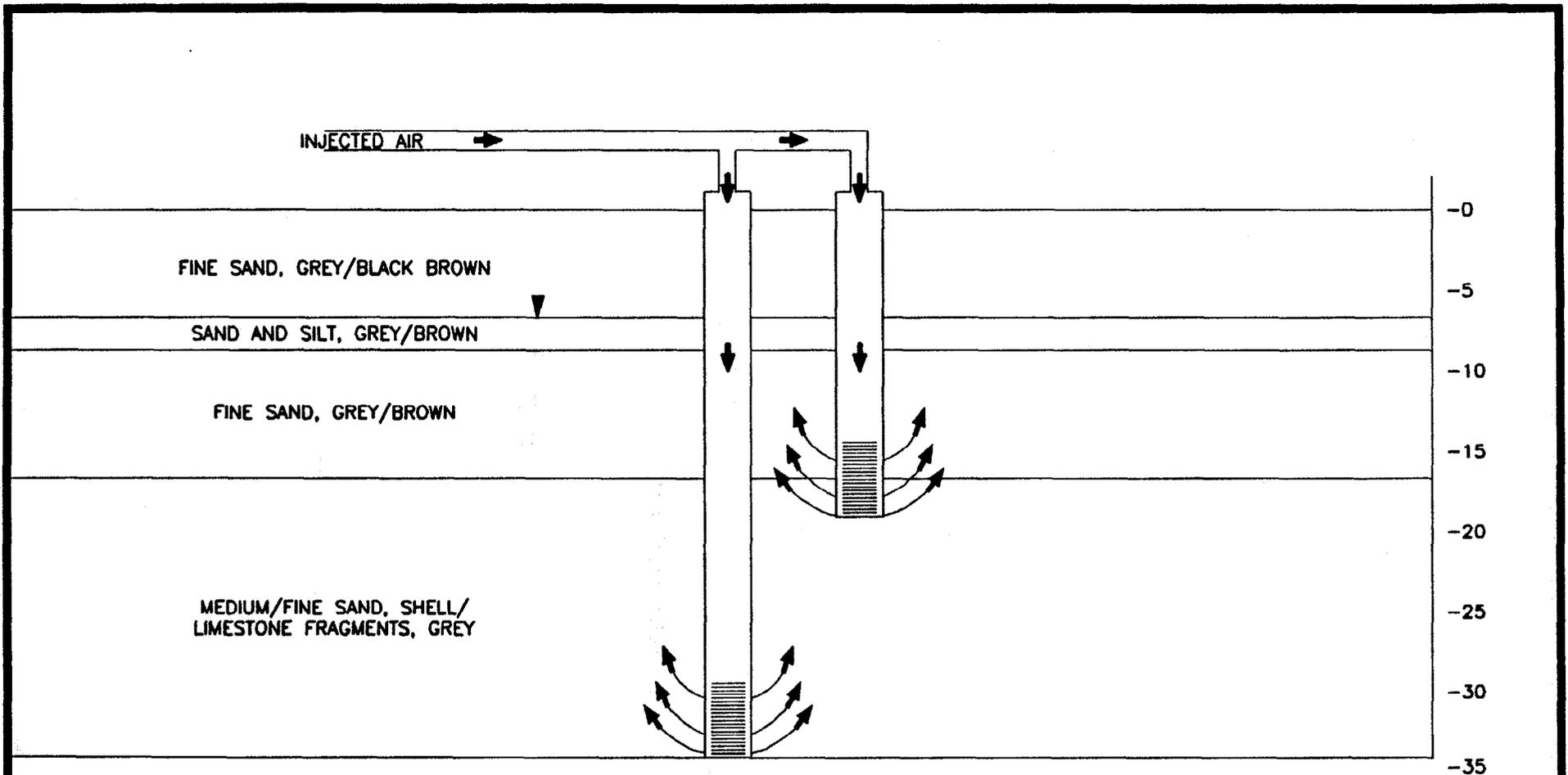
323022WP

LEGEND

EMW-7	MONITORING WELL INSTALLED UNDER CS (1986) BY ESE.
EMW-1	MONITORING WELL INSTALLED BY NUS (1980).
MW-1	MONITORING WELL INSTALLED UNDER CSA (1991) BY LAW.
MW-26	MONITORING WELL INSTALLED UNDER CSM FOLLOW-UP INVESTIGATION (1993) BY LAW. (NOTE: PW-26 REFERS TO A PUMPING TEST WELL.)
⊠	TEMPORARY WELL CLUSTER
CHC	TOTAL CHLORINATED HYDROCARBONS
BTEX	TOTAL BTEX
A	WELLS WITH 10' SCREEN LENGTH PLACED 5'-15' BGS, ACROSS THE WATER TABLE.
C	WELLS WITH 5' SCREEN LENGTH PLACED WITHIN A 18 1/2' - 27 1/2' BGS INTERVAL.
B	WELLS WITH 5' SCREEN LENGTH PLACED WITHIN A 30' - 40' BGS INTERVAL (SCREENED ON TOP OF THE CONFINING UNIT).

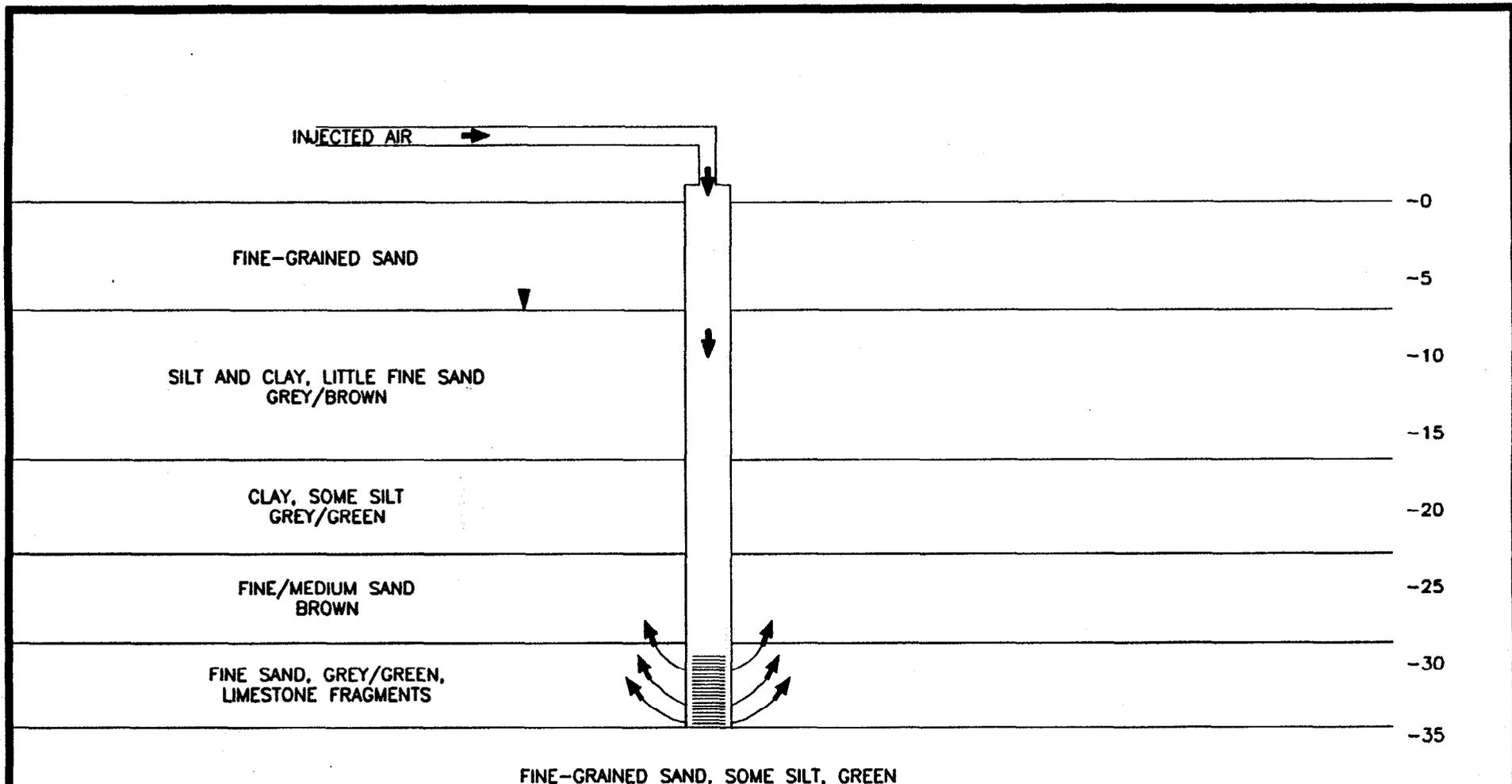
FIGURE 2-4
CONCEPTUAL CONTAMINANT PLUMES
INTERCEPTING SPARGING CURTAIN
SITE 35
CTO - 0323
MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA





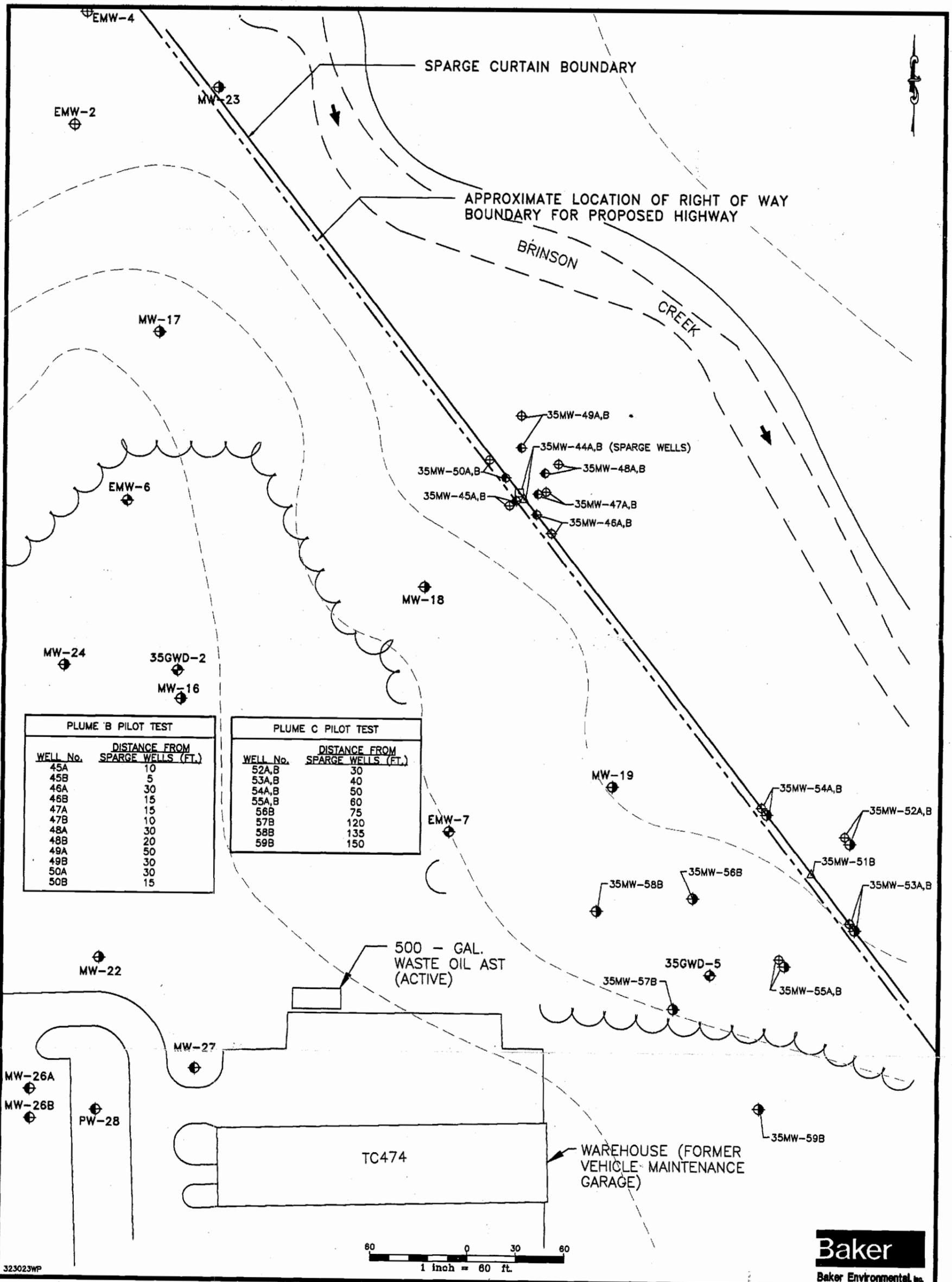
Baker
Baker Environmental, Inc.

FIGURE 2-5
PLUME B PILOT TEST
PROPOSED SPARGING WELLS
SITE 35
CTO-0323
MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA



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Baker Environmental, Inc.

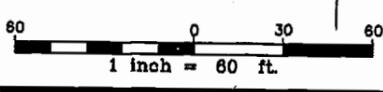
FIGURE 2-6
PLUME C PILOT TEST
PROPOSED SPARGING WELLS
SITE 35
CTO-0323
MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA



PLUME B PILOT TEST	
WELL No.	DISTANCE FROM SPARGE WELLS (FT.)
45A	10
45B	5
46A	30
46B	15
47A	15
47B	10
48A	30
48B	20
49A	50
49B	30
50A	30
50B	15

PLUME C PILOT TEST	
WELL No.	DISTANCE FROM SPARGE WELLS (FT.)
52A,B	30
53A,B	40
54A,B	50
55A,B	60
56B	75
57B	120
58B	135
59B	150

323023WP



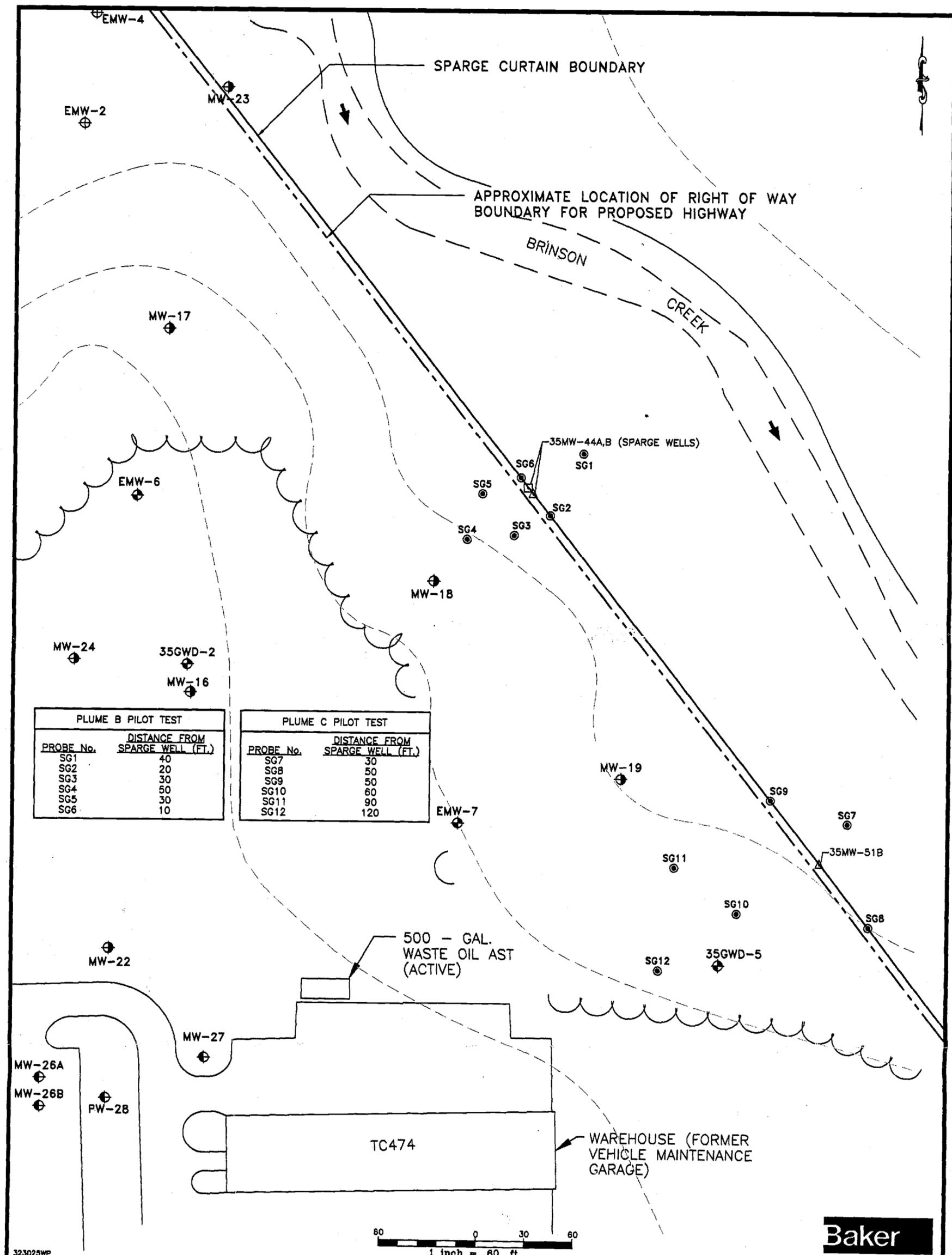
Baker
Baker Environmental, Inc.

LEGEND

- EMW-7 MONITORING WELL INSTALLED UNDER CS (1988) BY ESE.
- EMW-1 MONITORING WELL INSTALLED BY NUS (1990).
- MW-1 MONITORING WELL INSTALLED UNDER CSA (1991) BY LAW.
- MW-28 MONITORING WELL INSTALLED UNDER CSM FOLLOW-UP INVESTIGATION (1993) BY LAW. (NOTE: PW-28 REFERS TO A PUMPING TEST WELL.)
- TEMPORARY WELL CLUSTER
- SHALLOW SPARGE WELL (18' DEEP)
- △ DEEP SPARGE WELL (34' DEEP)
- ⊕ SHALLOW MONITORING WELL
- ⊙ DEEP MONITORING WELL

FIGURE 4-1
IAS PILOT TEST WELL LAYOUTS
SITE 35
CTO - 0323
MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

01586CCB6Z



PLUME B PILOT TEST	
PROBE No.	DISTANCE FROM SPARGE WELL (FT.)
SG1	40
SG2	20
SG3	30
SG4	50
SG5	30
SG6	10

PLUME C PILOT TEST	
PROBE No.	DISTANCE FROM SPARGE WELL (FT.)
SG7	30
SG8	50
SG9	50
SG10	60
SG11	90
SG12	120

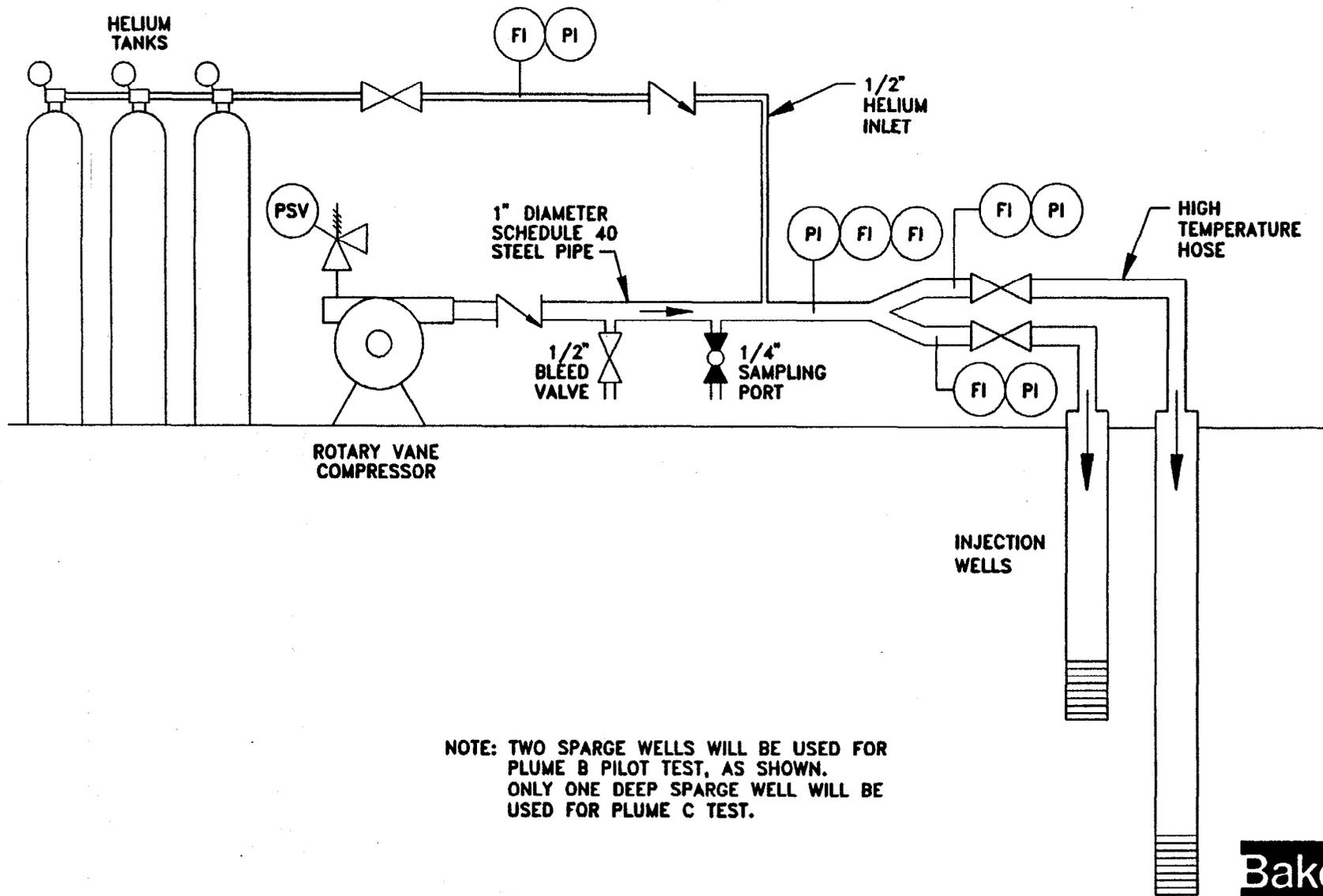
323025WP

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-26 MONITORING WELL INSTALLED UNDER CSM FOLLOW-UP INVESTIGATION (1993) BY LAW. (NOTE: PW-26 REFERS TO A PUMPING TEST WELL.)
- TEMPORARY WELL CLUSTER
- SHALLOW SPARGE WELL (18' DEEP)
- DEEP SPARGE WELL (34' DEEP)
- SHALLOW MONITORING WELL
- DEEP MONITORING WELL



FIGURE 4-2
IAS PILOT TEST SOIL GAS PROBE LAYOUTS
SITE 35
CTO - 0323
MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA



NOTE: TWO SPARGE WELLS WILL BE USED FOR PLUME B PILOT TEST, AS SHOWN. ONLY ONE DEEP SPARGE WELL WILL BE USED FOR PLUME C TEST.

Baker

Baker Environmental, Inc.

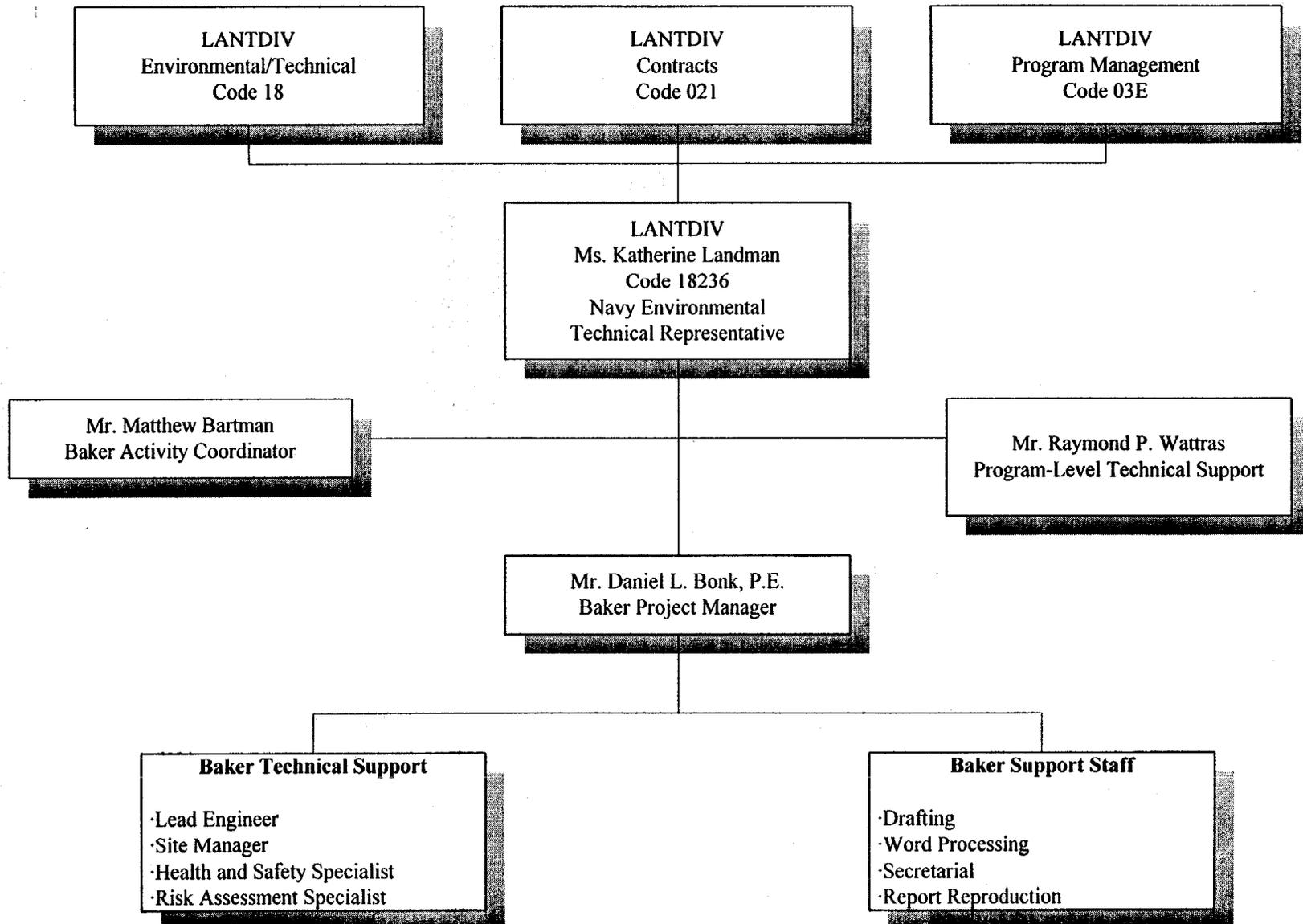
LEGEND

	GATE VALVE		CHECK VALVE
	BALL VALVE (OPEN)	PI - PRESSURE INDICATOR	
	BALL VALVE (CLOSED)	FI - FLOW INDICATOR	
	PRESSURE SAFETY VALVE (PSV)	TI - TEMPERATURE INDICATOR	

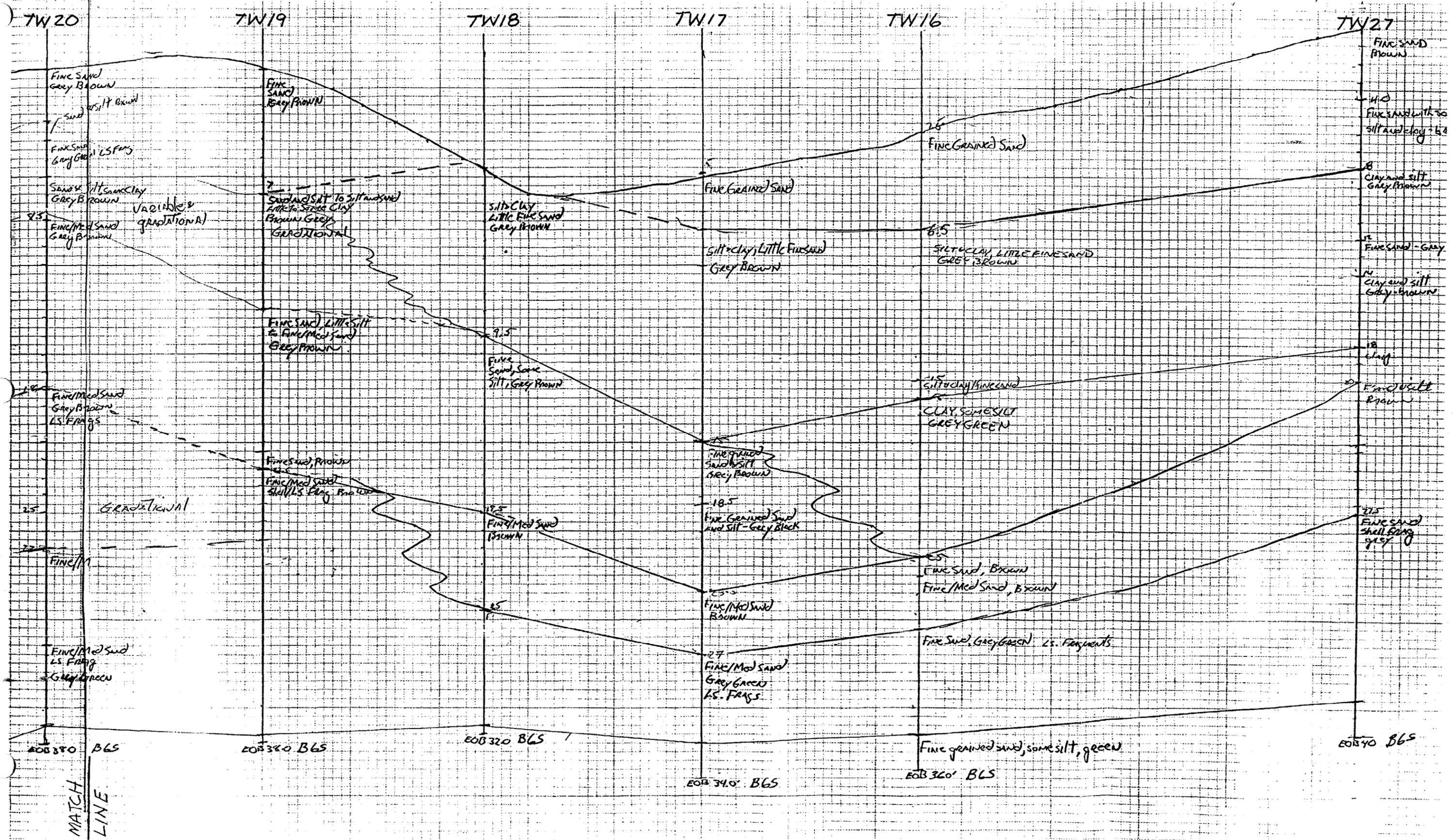
FIGURE 4-3
IAS PROCESS FLOW SCHEMATIC
IAS TREATABILITY STUDY
SITE 35
CTO-0323
MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

FIGURE 8-1

PROJECT ORGANIZATION



APPENDIX A
HYDROGEOLOGIC CROSS SECTIONS



01586CCB7Z

CROSS SECTION TW26 - TW27

Drawing No. 1/2

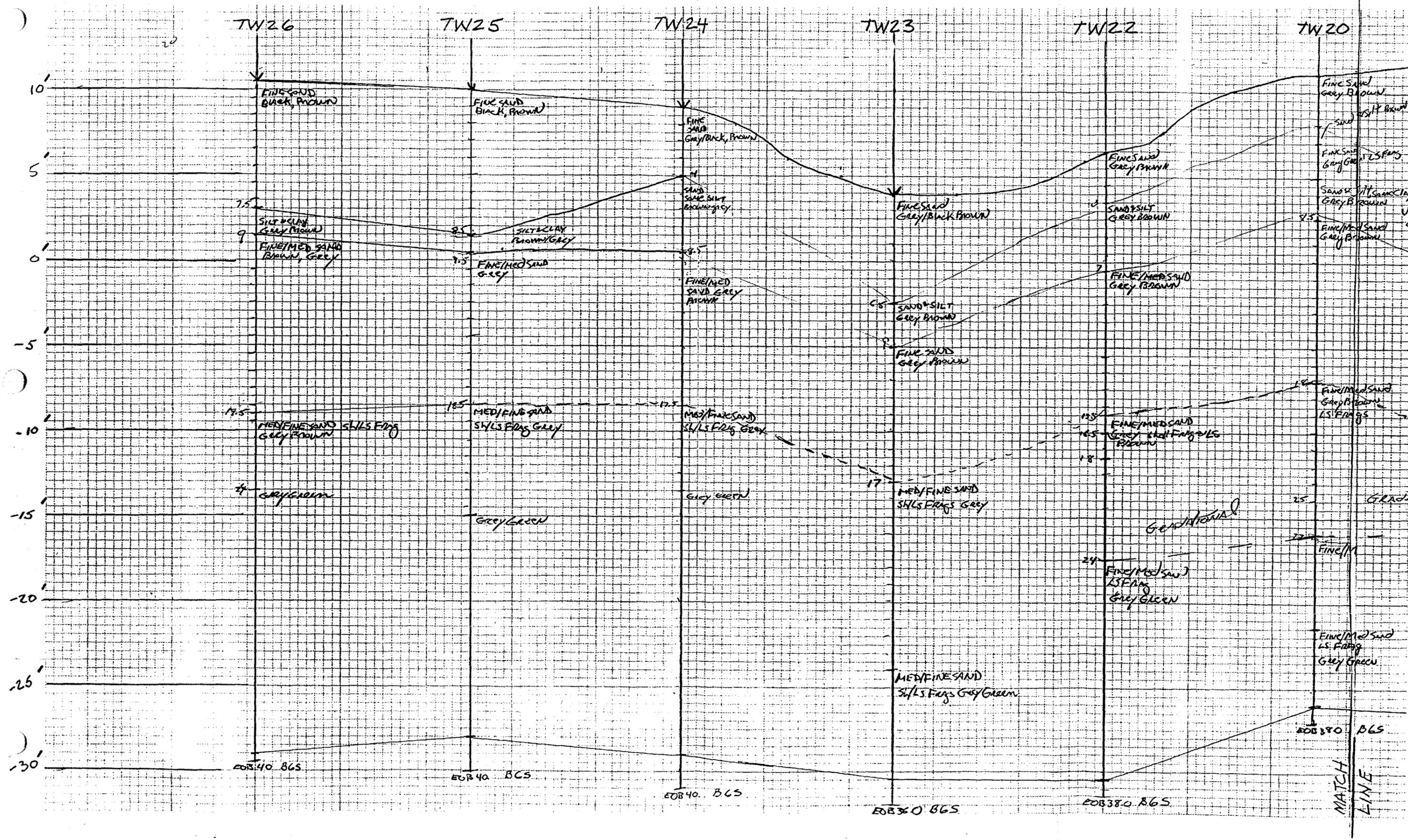
MICHAEL BAKER, JR., INC.

Subject _____ S.O. No. _____

Computed by RPA Checked by _____ Date _____

DESIGN PAD

Sheet No. _____ of by R



APPENDIX B
HILL AFB TECHNICAL PAPER

In Situ Air Sparging—Technology Demonstration for Remediating Groundwater Contaminated with Dissolved-Phase Constituents at Hill Air Force Base

Whitney Wheelless, Radian Corporation

Steve Hicken, Hill Air Force Base

Carrie Beitler, Jim Rowe, Mark A. Robbins, Radian Corporation

Robert E. Hinchee, Parsons Engineering Science

Paul C. Johnson, Arizona State University

Richard L. Johnson, Oregon Graduate Institute of Science & Technology

David E. McWhorter, Colorado State University

Abstract

In-situ air sparging (IAS), in conjunction with soil vapor extraction (SVE), is becoming a widely used technology for remediating groundwater contaminated with volatile organic compounds. As part of a technology demonstration conducted at Hill AFB, the authors evaluated IAS technology for remediating groundwater contaminated with dissolved-phase chlorinated organic compounds. The primary objective of the demonstration was to determine whether IAS could effectively serve as a control barrier technology and remediate the contaminant plume at Operable Unit 6, where trichloroethene is the major constituent of concern. Another objective was to establish the physical and chemical monitoring parameters and the types of sampling needed to conclusively determine the treatment effectiveness of IAS.

The investigators determined the effectiveness of IAS technology by evaluating the reduction of trichloroethene from the groundwater, as measured in hydropunch and monitor well samples of the groundwater collected before and after the twelve-week demonstration period. In addition, they used the results of a helium tracer study to determine the efficiency of the SVE system in capturing the air sparged into the aquifer. The investigators also used the results from monitor well purge tests to determine the representativeness of monitor well data for evaluating IAS systems. The zone of influence and the effect of the IAS system on the aquifer was determined on the basis of field measurements, such as water levels, subsurface pressures, and water quality parameters.

Both the monitor well and hydropunch sample results showed significant reductions of TCE concentrations during the IAS test—generally from 150 to 300 µg/L at baseline to 1 to 50 µg/L after 12 weeks of IAS operation. Significant reductions were observed at most depths for all downgradient monitor wells. These reductions are believed to be a result of a relatively uniform distribution of air flow throughout the aquifer at OU 6 during IAS treatment. The observed lateral movement of air is likely caused by the lower permeability sands within the aquifer that divert upward movement of air and force air to flow laterally. Under the flow regime at the OU 6 TD site, the aquifer as a whole was treated by the IAS system.

Introduction

In situ air sparging (IAS) is an innovative technology for remediating groundwater, where air is injected into the saturated zone for the purpose of removing organic contaminants. The vertical and horizontal air flow enables the contaminants in the groundwater to volatilize into the air stream. After the contaminated air has migrated to the unsaturated zone, it is typically collected through soil vapor extraction (SVE) for treatment or emission.

Figure 2 shows the known extent of contaminated groundwater. The contaminant plume is elongated in the direction of groundwater flow and extends from a maintenance area on Base to beneath a residential area off Base. Minimal lateral spreading is seen in the plume because of the lower-permeability materials that border the sand to silty-sand aquifer in which the contamination is migrating. Because the TCE has not appreciably spread laterally, the average peak concentration in the center of the plume is relatively consistent (generally between 200 and 300 $\mu\text{g/L}$). The location of the TD site relative to the plume and Base boundary is also shown in Figure 2.

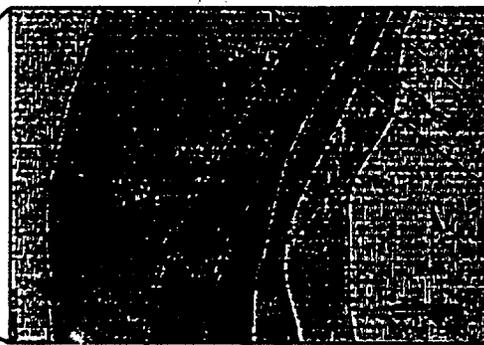
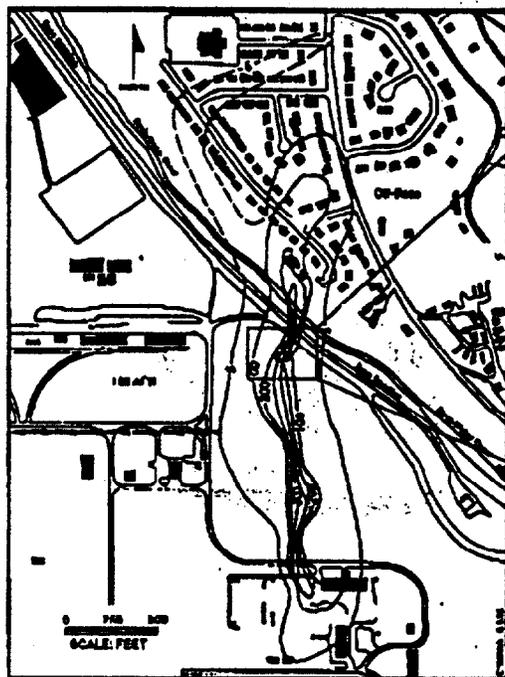


Figure 2. TCE Contaminant Plume at Operable Unit 6 and Location of the Technology Demonstration

Technical Approach

The IAS test was conducted for a 12-week period from February to May 1995 to evaluate the performance of the system in removing chlorinated dissolved-phase contaminants from the groundwater. Baseline groundwater characteristics and organic concentrations were determined.

Treatment System

The IAS/SVE system includes a single row of four nested sparging and SVE wells. Figure 3 shows a schematic of the treatment system installed at OU 6. The IAS process equipment was sized to provide a 90% minimum stripping efficiency using relationships developed by Pankow et al. (1993). The resulting compressor specifications were 15 scfm per well at 20

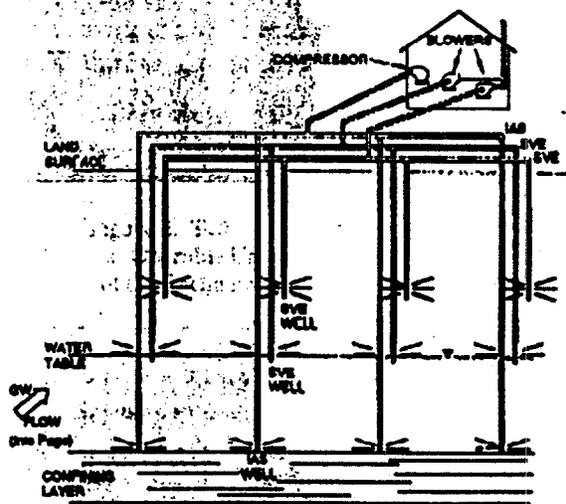


Figure 3. Schematic Diagram of the IAS System at OU 6

psig. The SVE blowers were then sized to capture the sparged air with a safety factor of three to four.

Figure 4 shows a plan of the site and the locations of the treatment and monitor wells. Each treatment well contains an IAS well at the bottom of the aquifer, a deep SVE well screened at the water table, and a shallow SVE well screened 20 ft above the water table. Ten nested monitor wells were also installed at the site at the TD site. Each cluster contains two vapor probes and three monitor wells with 5-ft screened intervals and bentonite seals between the screens. Figure 5 shows a schematic of the IAS/SVE dual wells and the nested monitor well installations.

Sampling and Analysis

To observe the impact of the treatment system on the aquifer and the unsaturated zone, numerous parameters were monitored at varying frequencies, as outlined in Table 2. Baseline samples and measurements were collected to

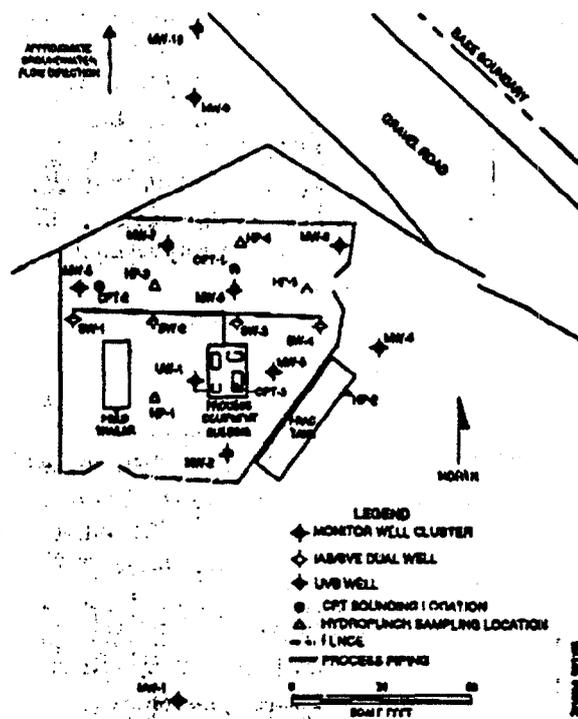
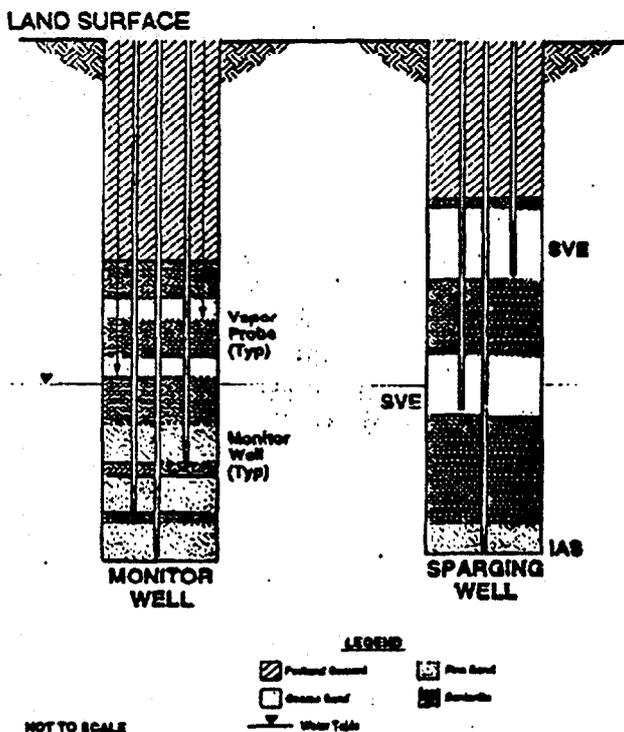


Figure 4. Treatment System Layout at the TD Site



NOT TO SCALE

Figure 5. Schematic Diagram for the Monitor Well Clusters and the Sparging Well

characterize the aquifer for chlorinated organics and water quality parameters prior to the system startup. A CPT rig was used to collect hydropunch samples of groundwater at three discrete intervals at five locations within the anticipated zone of influence. The hydropunch samples were viewed as critical for quantifying the contaminant reduction from IAS because the representativeness of monitor well data is suspect. Previous studies have shown that IAS causes preferential flow to monitor wells which leads to preferential treatment at the wells (Johnson et al., 1993).

After startup, weekly, monthly, and final samples were collected to monitor the treatment and the impact of the system on the subsurface. Final samples were collected from the monitor wells and at the hydropunch locations after the system had been shut off a week; these sample results were used to evaluate the effectiveness of the IAS system for removing TCE from the aquifer.

Table 2. Summary of Parameters Monitored During the IAS/SVE Test

Matrix	Parameter	Frequency	Location
Groundwater	Chlorinated volatile organic compounds	Baseline and final	Hydropunch locations
	Chlorinated volatile organic compounds	Monthly	Monitor wells
	Anions and cations		
	Alkalinity		
	Water level		
	Dissolved oxygen	Weekly or monthly	
	pH		
	Specific conductance		
	Redox potential		
Temperature	Continuously		
Soil gas	Pressure	Continuously	Vapor probes
Air	Volatile organic compounds	Monthly	System off-gas and venting monitor well

Performance testing was also conducted to further evaluate the test results. A helium tracer recovery test was performed to determine the efficiency of the SVE system in recovering the air sparged into the aquifer. During the test, helium was added to the air sparging system, and the concentration of helium was measured in the SVE off-gas streams and also in the air flow out the venting monitor wells. The recovery of helium was calculated from the injected and recovered helium volumetric flow rates.

Additionally, a monitor well purge test was performed to evaluate the representativeness of the monitor well samples for quantifying IAS treatment. A continuous low-flow purge (0.15 gpm) was performed on three monitor wells within the treatment zone (5M, 7M, and 8M) to remove 800 gallons from each well. The TCE concentration was monitored over time to determine a stabilized concentration at each well; these concentrations were compared to the final sample results for the monitor well.

Test Results

TCE Reductions

Concentrations measured after the 12-week treatment period showed the greatest reduction from baseline levels at locations downgradient of the sparging lines. Table 3 provides the baseline and final TCE concentrations for the monitor well and hydropunch samples. These results are organized by depth since the contamination at the site varies by depth, with the shallow-medium and medium zones of the aquifer having the highest concentrations of TCE.

Although there was quite a bit of variability in baseline and final concentrations across the site, generally TCE concentration reductions in the 80% to 90% range were observed within and downgradient of the treatment zone. A portion of the test data are plotted on the contour map in Figure

Table 3. TCE Reduction by Depth for Monitor Well and Hydropunch Samples

Location	Shallow ^a				Shallow-Medium ^a				Medium ^a				Deep ^a			
	TCE Concentration (µg/L)		Percent Reduction	Absolute Reduction (µg/L)	TCE Concentration (µg/L)		Percent Reduction	Absolute Reduction (µg/L)	TCE Concentration (µg/L)		Percent Reduction	Absolute Reduction (µg/L)	TCE Concentration (µg/L)		Percent Reduction	Absolute Reduction (µg/L)
	Baseline	Final			Baseline	Final			Baseline	Final			Baseline	Final		
Monitor Well Samples^b																
MW-1	5.99	20.9	-249	-14.9	NA	NA	NA	NA	202	170	15.8	32	46.6	18.5	60.3	28.1
MW-2	4.76	25.5	-436	-20.7	NA	NA	NA	NA	169	174	-3	-5	12	1.3	89.2	10.7
MW-3	84.7	26.6	68.6	58.1	NA	NA	NA	NA	80.9	72.8	10	8.1	0.21	0.99	-374	-0.8
MW-4	18.5	46.9	-154	-28.4	NA	NA	NA	NA	37.4	23.2	38	14.2	0.35	0.41	-19	-0.1
MW-5	35.7	68.7	-92	-33.0	NA	NA	NA	NA	222	36.8	83.4	185.2	175	71.4	59.2	103.6
MW-6	82.8	0.38	99.5	82.4	NA	NA	NA	NA	188	0.3	99.8	187.7	21.4	0.63	97.1	20.8
MW-7	120	27.2	77.3	92.8	NA	NA	NA	NA	194	32.7	83.1	161.3	186	44.3	76.2	141.7
MW-8	15.4	36	-134	-20.6	NA	NA	NA	NA	93.3	3.16	96.6	90.1	0.11	0.24	-121	-0.1
MW-9	46.7	6.38	86.3	40.3	NA	NA	NA	NA	129	38.6	70.1	90.4	60.8	15	75.3	45.8
MW-10	122	38.5	68.4	83.5	NA	NA	NA	NA	194	55.8	71.2	138.2	79.5	17.9	77.5	61.6
UW-1S	2.85	NS	NC	NC	NA	NA	NA	NA	NA	NA	NA	NA	4.81	1.47	69.4	-3.3
Hydropunch Samples^b																
HP-1	3.08	NS	NC	NC	169	29.6	82.5	139.4	300	29.4	90.2	270.6	NA	NA	NA	NA
HP-2	30.9	20.4	34	10.5	110	12.5	88.6	97.5	67	66	1.49	1	NA	NA	NA	NA
HP-3	6.08	NS	NC	NC	71	14.5	79.6	56.5	130	16	87.7	114	NA	NA	NA	NA
HP-4	15.1	NS	NC	NC	60	1.58	97.4	58.4	162	4.85	97	157.2	NA	NA	NA	NA
HP-5	8.73	4.11	52.9	4.6	186	0.61	99.7	185.4	24.6	1.08	95.6	23.5	NA	NA	NA	NA

NA = Not applicable.

NC = Not calculated.

NS = Not sampled (no water at shallow depth).

^a Refers to relative depth of sample.^b Upgradient of sparging line: MW-1, MW-2, MW-3, HP-1, and HP-2.

Cross-gradient of sparging line: MW-4.

Downgradient of sparging line: MW-5 through MW-10, HP-3, HP-4, and HP-5.

^c Results are unreliable due to improper development of UW-1S and UW-1D.

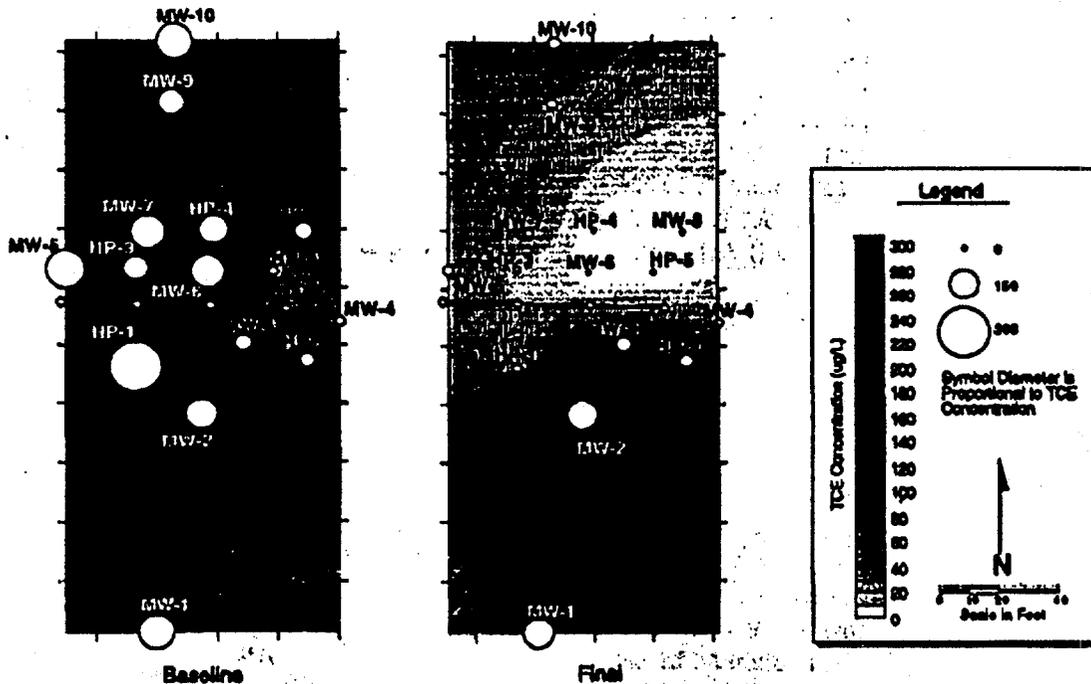


Figure 6. Contour Plot of Baseline and Final TCE Concentrations for the Medium-Depth Hydropunch and Monitor Well Samples

6 that represents baseline and final concentrations at the medium depth for both hydropunch and monitor well samples. As the figures illustrate, following the test the concentrations of TCE declined downgradient of the sparging line to concentrations ranging from 0.3 $\mu\text{g/L}$ at MW-6 to 55.8 $\mu\text{g/L}$ at MW-10. Statistical analysis of the baseline-to-final reductions and final concentrations confirmed that the reductions observed were statistically significant.

The higher concentration observed at MW-10 may be due to the position of the well approximately 95 ft downgradient of the sparge line. The average linear velocity at the site is low (0.5 to 1.8 ft/day), and during the course of the test, groundwater treated at the sparging line may not have had sufficient time to migrate to MW-10 by the time the final samples were collected. Evidence for this was provided in subsequent sampling at the site two months after the test period, where concentrations of TCE at MW-10M were measured at 7.8 $\mu\text{g/L}$.

The data were evaluated to determine whether the measured reductions are real. Mass balances were performed using the liquid phase and gas phase sample results. The mass of TCE removed from the groundwater (0.29 to 3.4 lb) compared well with the mass removed from the SVE and monitor well off-gas (0.80 lb). An air-to-water ratio was calculated as 30 to 60 vol/vol depending on the groundwater velocity. A theoretical air-to-water ratio was calculated as 12 vol/vol. Both of these analyses indicate that the observed reductions are physically possible.

External factors (i.e., other than treatment) that could potentially affect TCE concentrations during the TD were also evaluated. These factors included normal concentration fluctuations in the aquifer and changes in groundwater gradient or flow direction. Periodic monitoring of the contaminant plume since 1993 has shown that concentrations in the center of the plume have never been measured below 150 $\mu\text{g/L}$. Groundwater level surveys taken before, during, and after the treatment show that

groundwater flow direction has remained consistently to the north. Neither of these factors affected TCE concentrations or treatment at the site.

Purge Test

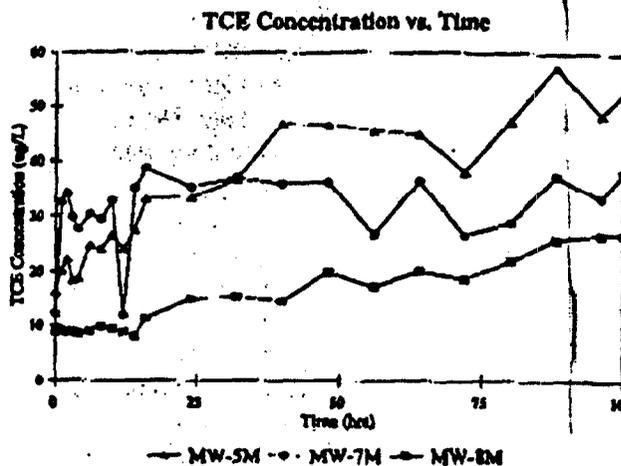
The results of the purge test at monitor wells 5, 7, and 8 are shown in Figure 7. The TCE concentrations at MW-7M remained essentially constant during the test around 30 µg/L, which agreed well with the final sample result of 32.7 µg/L. However, concentrations did show increases during pumping at MW-5M and MW-8M. The cause of this rise is uncertain. The observed gradual rise could be caused by mixing effects from untreated groundwater entering the wells' zones of influence or by preferential treatment at the monitor well. Mixing effects are especially relevant for monitor wells 5 and 8 since they are on the edge of the treatment zone.

Even though these results were inconclusive, the monitor well data showed good correlation with the hydropunch sample results. This correlation does not mean, however, that sampling interferences do not exist with either sampling technique, such as preferential flow or volatilization. The uncertainties in the purge test data do create questions concerning the results, but the consistent concentration reductions across the treatment zone, utilizing three different sampling techniques, appear to be indicative of treatment as a whole.

Flow Model

Because the reductions measured during the test were significant and appeared to be relatively consistent across the TD site, a conceptual physical model was necessary to account for the observed reductions. Besides the TCE concentrations, several other pieces of data collected during the test were important for evaluating the effect of IAS on the aquifer, including dissolved oxygen readings, pH measurements, the potentiometric surface and water level changes, air flow measurements from the monitor wells, and the lithology at the site.

The DO concentrations were recorded prior to and during the test, as presented graphically in Figure 8. These data show that DO concentrations increased, relative to baseline, within a week of startup. This rapid rise in DO was observed at most depths for all downgradient wells; elevated DO is indicative of oxygen transfer to the aquifer from the sparged air. Particularly noteworthy are the measurements at MW-9 and MW-10, which are located 70 and 95 ft from the sparging line, respectively, because they showed elevated DO after 4 weeks of operation (during the first sampling event). The groundwater flow at the site is approximately 0.5 to 1.8 ft/day, so it is not likely that the treated groundwater plume migrated to these locations within the first four weeks of operation.



Well	Sampling Event	
	Baseline	Final
MW-5M	222	36.8
MW-7M	194	32.7
MW-8M	93.3	3.16

Figure 7. TCE Concentrations During the Monitor Well Purge Test and Concentrations Measured During the Baseline and Final Sampling Events

Therefore, some degree of direct air flow was observed up to 95 ft downgradient of the sparging line. The elevated DO measurements observed at deep, medium, and shallow depths at many of the wells indicate that the air flow is distributed relatively uniformly across the entire site.

Another indication of the even distribution of air at the site was the change in pH observed at numerous wells downgradient of the treatment area. A gradual rise from baseline conditions ranging from 0.15 to 1 pH units was observed in the pH measurements within 4 to 8 weeks of startup. This rise was likely caused by the stripping of CO₂ from the aquifer by the sparged air. Because the alkalinity of the groundwater is high and the CO₂ concentration in the sparged (ambient) air is low, CO₂ is stripped out of the groundwater into the air, thus raising the pH. These results indicate that stripping is occurring across much of the TD site.

This uniform treatment of the aquifer is governed by the lithology at the OU 6 TD site. Although the aquifer framework is predominantly sands, as shown in the CPT logs, there are slight changes in grain size and density and, thus, permeability throughout the saturated zone. It appears that these variations in permeability have a significant effect on the air pathways in the treatment area and, as a result, TCE removal rates. The lower permeability sands divert the upward movement of air and force the air to flow laterally. This "pancake" flow mechanism causes a laterally extensive distribution of air in the aquifer and results in treatment of the groundwater as a whole.

IAS appears to have significantly reduced dissolved-phase TCE concentrations at OU 6, however, two important questions remained: 1) Was groundwater simply diverted around the site? and

2) Was the sparged air adequately recovered by the SVE system? These points are important for understanding the impact and effectiveness of the IAS/SVE system.

When the IAS system was started at the beginning of the test, a pressure field developed in the TD area. This was seen as a significant rise in pressure measured by pressure transducers in the deep monitor wells. Figure 9 shows the general response of the submersible pressure transducers during the performance of the test.

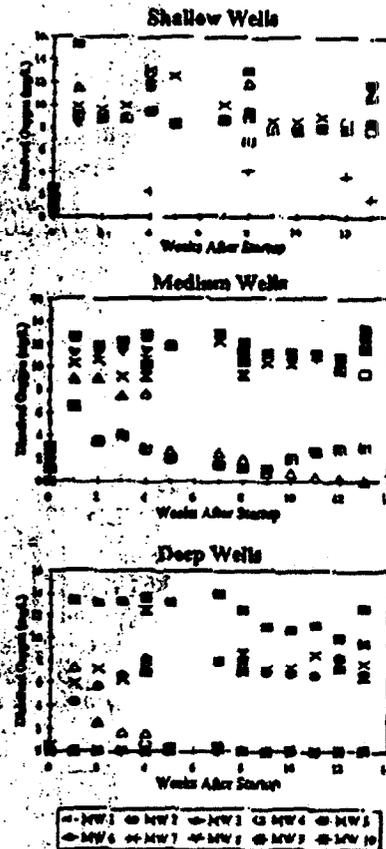


Figure 8. DO Concentrations Measured at the Monitor Wells During the Weekly and Monthly Sampling Events

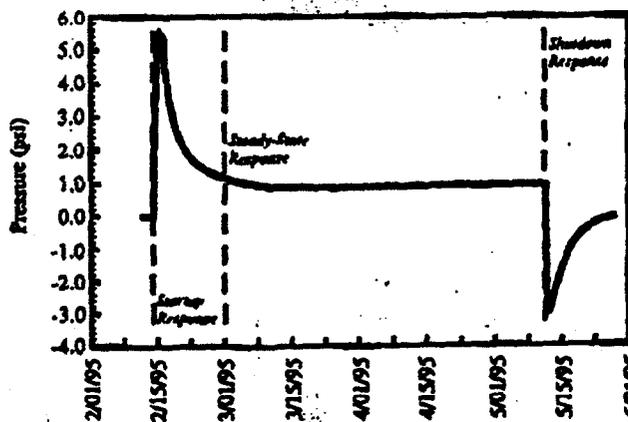


Figure 9. General Pressure Response as Measured by the Submersible Pressure Transducers During the IAS Test

Figure 10 presents a schematic of the conceptual air flow pathways at steady state in the OU 6 aquifer system. As the figure shows, the less permeable sands have the effect of spreading the air flow laterally through the aquifer. Unique to this site are the confining layers that restrict the air flow and create a locally extensive pressure field during treatment. The deep SVE wells and some of the shallow monitor wells penetrate the confining layers thus providing a release point for the pressure field developed because of these layers.

Conclusions

The in situ sparging system installed at Hill AFB OU 6 did appreciably remove contaminants, specifically TCE, from the groundwater. Both the monitor well and hydropunch sample results showed significant reductions of TCE concentrations during the IAS test—generally from 150 to 300 µg/L at baseline to 1 to 50 µg/L after 12 weeks of IAS operation.

Significant reductions were observed at most depths for all downgradient monitor wells. These reductions are believed to be a result of a relatively uniform distribution of air flow throughout the aquifer at OU 6 during IAS treatment. This conclusion is supported by the rapid rise in dissolved oxygen at wells up to 95 ft from the sparging line and the consistently elevated dissolved oxygen concentrations in the aquifer both laterally and vertically from the sparging wells. The lateral movement of air is likely caused by the lower permeability sands within the aquifer that divert the upward movement of air and force air to flow laterally. In contrast to a vertical channeling flow mechanism where discrete channels of air provide a relatively small air-water interface, the pancake flow of air in the OU 6 system provided air movement laterally and vertically throughout the aquifer. Since the primary removal mechanism for chlorinated organics is the stripping of contaminants caused by air movement, it appears that under the flow regime at the OU 6 TD site the aquifer as a whole was treated by the IAS system.

It was also found that subsurface lithology drastically affected the ability of the designed system to remove sparged air. The confining layers at or near the water table caused air to accumulate and a pressure field to develop in the treatment area after sparging began. These layers caused the majority of sparged air (80%) to be vented through the shallow monitor wells.

To better understand the impact and effectiveness of IAS at a site, it is recommended that submersible pressure transducer measurements, dissolved oxygen, pH, and contaminant concentrations be monitored before, during, and after the testing period.

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APPENDIX C
CONTAMINANT CONCENTRATION CALCULATIONS

S.O. No. CTD-0323

Subject: Soil-Vapor Contaminant Concentration Estimates

MCB Camp Lejeune, D.U. No 10 Sheet No. 1 of 3

Site 35 Drawing No. _____

Computed by GJR Checked By RPA Date 4-26-96

Baker

Vapor Emission and Resulting Soil Contamination - Site 35 IAS A lot Test

$$\text{Emissions}_{\text{Max}} = q \times W \times H \times C_{\text{gw}} \quad \text{Emission in pounds/day}$$

where q = groundwater flow rate (ft/d)

W = width of IAS barrier (ft)

H = depth below water table to injection point (ft)

C_{gw} = dissolved contaminant concentration (lb/ft³)

Assume: $q = 0.06$ ft/d, based on hydraulic conductivity, K , of 0.001 cm/s and hydraulic gradient, I , of 0.02

$$H = 25 \text{ ft}$$

$$W = 200 \text{ ft}$$

$$C_{\text{gw}} = 6.0 \times 10^{-5} \text{ lb/ft}^3 \quad (\approx 1,000 \text{ } \mu\text{g/L})$$

$$\text{Emissions}_{\text{max}} = (0.06 \text{ ft/d})(200 \text{ ft})(25 \text{ ft})(6.0 \times 10^{-5} \text{ lb/ft}^3)$$

$$\text{Emissions}_{\text{max}} = 0.02 \text{ lb/d of contaminant}$$

$$C_{\text{vapor}} = \text{Emissions}_{\text{max}} / Q_{\text{IAS}} \quad \text{Vapor emission contaminant concentration}$$

Assume: 4 IAS wells spaced 50 ft apart with flowrate = 10 ft³/min each

$$\text{Total Flow, } Q = 4 \text{ wells} \times 10 \text{ ft}^3/\text{min}/\text{well}$$

$$Q = 40 \text{ ft}^3/\text{min}$$

$$C_{\text{vapor}} = (0.02 \text{ lb/day}) / [(40 \text{ ft}^3/\text{min})(1440 \text{ min/d})]$$

$$C_{\text{vapor}} = 3.5 \times 10^{-7} \text{ lb/ft}^3 = 5.6 \times 10^{-3} \text{ g/m}^3, \text{ } \mu\text{g/L}$$

S.O. No. CTD-0323

Subject: Soil-Vapor Contaminant Concentration Estimates

MCB Camp Lejeune, D.V. No 10 Sheet No. 2 of 3

Site 35 Drawing No. _____

Computed by GJR Checked By RPA Date 4-26-96

Baker

Vapor Emission and Resulting Soil Contamination - Site 35 IAS Pilot Test

$$\text{Total soil concentration, } C_{\text{Total}} = C_{\text{sorbed}} + C_{\text{moisture}} \theta_m + C_{\text{vapor}} \theta_v / \rho_s$$

where C_{sorbed} = contaminants sorbed directly onto soil (mg/kg)

C_{moisture} = contaminants dissolved in soil moisture (mg/L)

θ_m = soil moisture content (L-H₂O/kg-soil)

C_{vapor} = contaminants in soil vapor (mg/L)

θ_v = vapor void fraction

ρ_s = soil bulk density (kg/L)

In Equilibrium:

$$C_{\text{moisture}} \times H = C_{\text{vapor}}$$

where H = Henry's Law Constant

$$C_{\text{moisture}} \times K_d = C_{\text{sorbed}}$$

where K_d = partitioning coefficient (L/kg)

$K_d = K_{oc} \times f_{oc}$, K_{oc} = adsorption coefficient for o.c.

f_{oc} = organic carbon (o.c.) content

$$\therefore C_{\text{sorbed}} = C_{\text{vapor}} (K_d/H)$$

$$C_{\text{moisture}} = C_{\text{vapor}} (1/H)$$

$$C_{\text{Total}} = C_{\text{vapor}} \left[\frac{K_d}{H} + \frac{\theta_m}{H} + \frac{\theta_v}{\rho_s} \right]$$

S.O. No. CTO-0323



Subject: Soil-Vapor Contaminant Concentration Estimates

MCB Camp Lejeune, P.O. No 10 Sheet No. 3 of 3

Site 35 Drawing No. _____

Computed by GJR Checked By RPA Date 4-26-96

Vapor Emission and Resulting Soil Contamination - Site 35 IAS Pilot Test

Assume: $\theta_m \approx 0.1 \text{ L-H}_2\text{O/kgsoil}$

$\theta_v \approx 0.2 \text{ L-air/L-soil}$

$\rho_s \approx 1.7 \text{ kg/L}$

$f_{oc} \approx 0.01 \text{ g O.C./g-soil}$

For Benzene, $H = 0.22$, $K_{oc} = 60 \text{ L/kg}$

For TCE, $H = 0.44$, $K_{oc} = 94 \text{ L/kg}$

$$C_{\text{Total-Benzene}} = C_{\text{Vapor}} \left[\frac{(60 \text{ L/kg})(0.01)}{0.22} + \frac{0.1 \text{ L/kg}}{0.22} + \frac{0.2}{1.7 \text{ kg/L}} \right]$$

$$C_{\text{Total-Benzene}} = C_{\text{Vapor}} [2.73 \text{ L/kg} + 0.45 \text{ L/kg} + 0.12 \text{ L/kg}]$$

$$C_{\text{Total-Benzene}} = C_{\text{Vapor}} [3.3 \text{ L/kg}]$$

$$C_{\text{Vapor}} = 5.6 \times 10^{-3} \text{ mg/L}$$

$$C_{\text{Total-Benzene}} = (5.6 \times 10^{-3} \text{ mg/L})(3.3 \text{ L/kg})$$

$$C_{\text{Total-Benzene}} = 0.018 \text{ mg/kg}$$

$$C_{\text{Total-TCE}} = C_{\text{Vapor}} \left[\frac{(94 \text{ L/kg})(0.01)}{0.44} + \frac{0.1 \text{ L/kg}}{0.44} + \frac{0.2}{1.7 \text{ kg/L}} \right]$$

$$C_{\text{Total-TCE}} = C_{\text{Vapor}} [2.14 \text{ L/kg} + 0.23 \text{ L/kg} + 0.12 \text{ L/kg}]$$

$$C_{\text{Total-TCE}} = C_{\text{Vapor}} [2.5 \text{ L/kg}]$$

$$C_{\text{Total-TCE}} = (5.6 \times 10^{-3} \text{ mg/L})(2.5 \text{ L/kg})$$

$$C_{\text{Total-TCE}} = 0.014 \text{ mg/kg}$$

APPENDIX D
CONSTITUENTS DETECTED BY EPA METHOD TO-14

TABLE 1. VOLATILE ORGANIC COMPOUND DATA SHEET

COMPOUND (SYNONYM)	FORMULA	MOLECULAR WEIGHT	BOILING POINT (°C)	MELTING POINT (°C)	CAS NUMBER
Freon 12 (Dichlorodifluoromethane)	Cl ₂ CF ₂	120.91	-29.8	-158.0	
Methyl chloride (Chloromethane)	CH ₃ Cl	50.49	-24.2	-97.1	74-87-3
Freon 114 (1,2-Dichloro-1,1,2,2-tetrafluoroethane)	ClCF ₂ CClF ₂	170.93	4.1	-94.0	
Vinyl chloride (Chloroethylene)	CH ₂ =CHCl	62.50	-13.4	-1538.0	75-01-4
Methyl bromide (Bromomethane)	CH ₃ Br	94.94	3.6	-93.6	74-83-9
Ethyl chloride (Chloroethane)	CH ₃ CH ₂ Cl	64.52	12.3	-136.4	75-00-3
Freon 11 (Trichlorofluoromethane)	CCl ₃ F	137.38	23.7	-111.0	
Vinylidene chloride (1,1-Dichloroethene)	C=CH ₂ Cl ₂	96.95	31.7	-122.5	75-35-4
Dichloromethane (Methylene chloride)	CH ₂ Cl ₂	84.94	39.8	-95.1	75-09-2
Freon 113 (1,1,2-Trichloro-1,2,2-trifluoroethane)	CF ₂ ClCCl ₂ F	187.38	47.7	-36.4	
1,1-Dichloroethane (Ethylidene chloride)	CH ₃ CHCl ₂	98.96	57.3	-97.0	74-34-3
cis-1,2-Dichloroethylene	CHCl=CHCl	96.94	60.3	-80.5	
Chloroform (Trichloromethane)	CHCl ₃	119.38	61.7	-63.5	67-66-3
1,2-Dichloroethane (Ethylene dichloride)	ClCH ₂ CH ₂ Cl	98.96	83.5	-35.3	107-06-2
Methyl chloroform (1,1,1-Trichloroethane)	CH ₃ CCl ₃	133.41	74.1	-30.4	71-55-6
Benzene (Cyclohexatriene)	C ₆ H ₆	78.12	80.1	5.5	71-43-2
Carbon tetrachloride (Tetrachloromethane)	CCl ₄	153.82	76.5	-23.0	56-23-5
1,2-Dichloropropane (Propylene dichloride)	CH ₃ CHClCH ₂ Cl	112.99	96.4	-100.4	78-87-5
Trichloroethylene (Trichloroethene)	ClCH=CCl ₂	131.29	87	-73.0	79-01-6
cis-1,3-Dichloropropene (cis-1,3-dichloropropylene)	CH ₃ CCl=CHCl	110.97	76		

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