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Final
Technology Evaluation
Operable Unit 21
Site 73

Marine Corps Base
Camp Lejeune, North Carolina

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QC Review Page

Technology Evaluation

Site 73, Operable Unit No. 21

MCB Camp Lejeune

Jacksonville, North Carolina

Contract Task Order Number - 0253
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TABLE OF CONTENTS

TABLE OF CONTENTS
(Continued)

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ACRONYMS AND ABBREVIATIONS

AST	above ground storage tank
ATEC	ATEC Environmental Consultants
Baker	Baker Environmental, Inc.
bgs	below ground surface
BTEX	benzene, toluene, ethylbenzene, and xylenes
COC	Contaminant of Concern
DCA	dichloroethane
DCE	dichloroethene
DNAPL	dense, non-aqueous phase liquid
DUS	Dynamic Underground Stripping
ERH	Electrical Resistance Heating
ESE	Environmental Science and Engineering
gpd	gallons per day
gpm	gallons per minute
GSI	Groundwater Services, Inc.
HRC®	Hydrogen Release Compound®
LTM	Long-Term Monitoring
MCB	Marine Corps Base
MDL	Method Detection Limit
µg/L	micrograms per liter
mg/L	milligram per liter
NA	Natural Attenuation
NAE	Natural Attenuation Evaluation
NAPL	Non-Aqueous Phase Liquid
ORC®	Oxygen Release Compound®
ORP	oxidation/reduction potential
OU	Operable Unit
PRB	Permeable Reactive Barrier
RI	Remedial Investigation
SVE	Soil Vapor Extraction
TCE	trichloroethene
UST	Underground Storage Tank
VOC	Volatile Organic Compound
VC	Vinyl Chloride
WAR	Water and Air Research

1.0 INTRODUCTION

1.1 Purpose of the Technology Evaluation

The purpose of this document is to provide a review of potential groundwater remedial options at Site 73 that may be used to facilitate the selection of a cost-effective approach for treatability or pilot testing at Site 73. This document is not intended to be a "feasibility study" or "corrective measures study." One or more of the remedial options presented in this document will be used to address "hot spot" area reduction of contamination in the groundwater. Innovative, in-situ, approaches that show promise for the treatment of "hot spots" in the groundwater are considered. After a review of this document and selection of the technology is made, a work plan will be developed to implement the chosen technology.

1.2 Report Organization

This document is organized into seven sections. The purpose of the technology evaluation is given in the introduction. Site information, including geology, hydrogeology, and contaminant distribution is given in Section 2.0. Section 3.0 contains the identification of the "hot spot." Section 4.0 describes various remedial technologies and their associated costs. Section 5.0 contains the results of modeling of the various remedial scenarios. Sections 6.0 and 7.0 provide conclusions and references.

2.0 SITE INFORMATION

Operable Unit 21, Site 73, the Amphibious Vehicle Maintenance Facility, is bounded by State Route 172 (Sneads Ferry Road) to the north, Courthouse Bay to the south, and unnamed tributaries of Courthouse Bay to the east and west (see Figure 2-1). Courthouse Road, which bisects the study area, is used to enter the complex. The terrain is primarily flat. Stormwater run-off tends to drain directly south to Courthouse Bay or to two small, unnamed tributaries located east and west of the facility, ultimately discharging to Courthouse Bay. A broad marshy area is associated with the western tributary. Directly north of the site is another large marsh and a stream that discharges north into the New River. The latter marsh is separated from the site by State Route 172 which represents a local topographical high and surface water runoff divide.

The study area contains numerous buildings, aboveground storage tanks (ASTs), underground storage tanks (USTs), vehicle wash racks, and oil/water separators. Most of the USTs are or were located (some USTs have been removed) within the fenced area around Building A47. Non-petroleum type wastes are routinely handled at an active Hazmat Storage Area located near UST A47/3. Other USTs are or were located near Buildings A1, A2, and A10. The Remedial Investigation (RI) (Baker, 1997) contains profiles of the various USTs.

Previous environmental investigations at Site 73 date back to 1983. A listing of those performed prior to Baker's involvement (1992) at the site is provided below.

- Initial Assessment Study (Water and Air Research [WAR], 1983)
- Confirmation Study (Environmental Science and Engineering [ESE], 1990)
- UST SA-21 Investigation (ATEC, 1991)
- UST A47/3 Investigation (Groundwater Services, Inc. [GSI], 1993)
- UST A47/3 Investigation (Law-Catlin, 1993)

Baker Environmental, Inc. (Baker) performed additional investigations on UST SA-21 in 1992 and 1993. In addition, Baker conducted an Aerial Photography Review in 1993, the results of which are included in the RI Report (1997). Recent investigations/studies conducted by Baker include:

- Preliminary Investigation (1994, included in the RI)
- Remedial Investigation/Feasibility Study Work Plan (1995)

- Remedial Investigation Report (1997)
- Feasibility Study (1998a)
- Groundwater Modeling Report (1998)
- Letter Report for New Deep Well Installation (August, 2001)
- Draft Natural Attenuation Evaluation (NAE) Report (2000, revised 2002)
- Long Term Monitoring (LTM) Reports (2000- current)

The results of the above investigations/studies have been summarized in each document previously prepared by Baker and, consequently, are only referenced in this section.

2.1 Site History

The Amphibious Vehicle Maintenance Facility started operations in 1946 and is still active. Available information indicates that an estimated 400,000 gallons of waste oil was discharged directly onto the ground surface at this facility, primarily near Building A47. In addition to the waste oil, approximately 20,000 gallons of waste battery acid was also reportedly disposed in the area northeast of A47. The waste battery acid was poured into shallow, hand-shoveled holes, which were immediately backfilled. Neither area of disposal is visually apparent. Much of the area where waste disposal reportedly took place is covered with concrete, building and/or roads. A previous report (Law-Catlin, 1993) indicated that solvents may have also been disposed at this site although no specific disposal locations or dates were identified.

2.2 Geology and Hydrogeology

2.2.1 Geology

Geologic cross-sections were constructed using boring information from the RI and the NAE Study to correlate the relationships among subsurface soil beneath the site. Figure 2-2 shows the cross-section locations while Figures 2-3 through 2-7 contain the cross-sections themselves.

Four sections have been located in a somewhat radial pattern across the site. This pattern was selected to allow the sections to be perpendicular to the groundwater flow direction in the upper portion of the surficial aquifer (see Section 2.2.2). It should be noted that the sections were also strategically placed to provide the ability to overlay contaminant occurrence and concentration on the subsurface geology. The end result is a three-dimensional understanding of site dynamics.

Cross-section A-A' (Figure 2-3) trends southeast to northwest from near Courthouse Bay, through Building A-47 ending at monitoring well A47/MW16. The soils underlying this portion of the site consist of very fine to fine sands with occasional peat layers. The sands are approximately 14 feet thick in the southeast and thicken to approximately 17 feet in the northwest. Underlying the sands is the gray confining clay between the surficial and Castle Hayne aquifers. The clay unit was not found in the bottom of the shallow borings between IR73-IS03 and A47-MW16 and may not be laterally continuous along the section.

Cross-section B-B' (Figure 2-4) trends almost due south-north across the site from near the washdown areas to the northernmost edge of Site 73. The section exhibits three slightly different stratigraphies.

The southern 350-400 feet of the section exhibit a stratigraphy similar to that seen on cross-section A-A'. Very fine grained sand (to silty sand) overlays the confining clay layer. The sands are five feet thick on average while the clay layer is one and one-half to two and one-half feet thick to the point at which it pinches out somewhere between 73-MW14 and 73-MW43DW. Underlying the clay are the sands of the Castle Hayne aquifer.

The central 400 feet of the cross-section shows the semi-confining clay layer to be absent. Stratigraphically, the very fine sands of the top unit grade to greenish gray, silty, sand that in turn grades to gray to white, silty, sand with cemented nodules.

The northernmost 100 feet of the section line evidences the return of the clay layer at a depth of approximately two and one-half feet. Since the clay layer occurs at the end of the section (which corresponds to the edge of the site), it is not known if the clay is continuous farther north or whether the clay seen is a relatively small pocket.

Cross-section C-C' (Figure 2-5) trends slightly southwest to northeast from Courthouse Bay to near the "HazMat" storage shelter. Two different stratigraphies are represented in this cross-section. The southwestern half of the cross-section shows a considerable thickness (up to 16 feet) of the confining clay layer. Above the clay, very fine-grained sand is present. Somewhere between wells IR73-MW50DW and A47/3-8 the clay rather abruptly disappears. Where the clay layer is absent, and below the clay where it is present, are the sands typical of the stratigraphy seen in other portions of the site.

Cross-section D-D' (Figure 2-6) trends southwest to northeast paralleling the Courthouse Bay shoreline. The stratigraphy exhibited along this section is very similar to that seen in cross-section C-C' with some variations. In the southwest, the confining layer is present at a thickness ranging from 12 to 18 feet. Immediately below the clay is silty sand with trace clay. This unit grades into very fine-grained sand with traces of silt. Below this is the fine-grained sand with nodules that is typical of the Castle Hayne aquifer.

The northeastern portion of section D-D' shows a substantially different stratigraphy. The uppermost unit is clayey sand approximately seven feet thick. A localized peat layer is present below the clayey sand in the two north easternmost borings. This is underlain by very fine-grained sand with traces of silt and clay. Immediately below this is the greenish gray, very fine-grained sand that is continuous across the site. This unit overlies the sand of the Castle Hayne aquifer. The confining unit is notably absent in the northeast portion of the cross-section area.

Cross-section E-E' (Figure 2-7) is a west-east cross-section drawn perpendicular to groundwater flow in the Castle Hayne aquifer. This section shows the sub-horizontal layering of the Coastal Plain sediments. The confining clay layer is continuous across this section and provides a barrier to groundwater and contaminants from moving directly downward at this location. The consistent presence of shells and limestone layers likely provides the conductive zones within the Castle Hayne aquifer.

2.2.2 Hydrogeology

The following sections describe the site hydrogeologic conditions for the surficial (water table) and Castle Hayne aquifers underlying Site 73, with a brief discussion of the Castle Hayne confining unit. Hydrogeologic characteristics in the vicinity of the site were evaluated by reviewing existing information and installing a network of shallow, shallow-intermediate, intermediate, and deep monitoring wells during the RI and NAE investigations.

Groundwater was encountered at varying depths during the drilling programs. The variation was primarily attributed to topographical changes. In general, the groundwater was encountered between 1.0 and 6.5 feet below ground surface (bgs) during, the RI and NAE field activities.

Typically at Marine Corps Base (MCB) Camp Lejeune, a higher water table is observed in the winter and spring and a lower water table is noted in the summer and fall. According to historical rainfall data provided by the Naval Oceanography Command Detachment, rainfall increases throughout the summer with July recording the largest quantity per year on average. A decrease in amount of rain is usually observed in August.

2.2.2.1 Surficial Aquifer

Although the surficial aquifer is classified as GA (i.e., existing or potential source of drinking water supply for humans), it is not used as a potable water source at MCB, Camp Lejeune because of its low yielding production rates (typically less than three gallons per minute [gpm]).

Surficial groundwater elevations and flow patterns are depicted on Figures 2-8. These contours are from the April 2002 LTM event. The data indicate that the surficial groundwater flow is radial toward Courthouse Bay with an average gradient of 1.32×10^{-2} ft/ft. The groundwater contours appear to somewhat parallel the topography of the site with the highest groundwater elevations corresponding to the highest surface elevations. Shallow groundwater is suspected to discharge to Courthouse Bay (south), the eastern and western unnamed tributaries, and the New River (north). The steepest gradient observed at the site appears to be in the vicinity of monitoring wells 73-MW06, 73-MW07, 73-MW09 and 73-MW25 sloping toward the east. This area corresponds to a relatively steep decline in ground surface elevation as well as a discharge area for surficial groundwater into Courthouse Bay. The concrete pad and wall located south of Buildings A-1 and A-2, provide a barrier for groundwater to discharge into the bay, hence the higher groundwater elevations in the wells in this area as opposed to the elevations recorded in wells 73-MW06 and 73-MW15.

2.2.2.2 Castle Hayne Aquifer

The principal water supply aquifer for MCB, Camp Lejeune is the Castle Hayne aquifer. This aquifer consists of sand, cemented shells and limestone. The upper portion of the aquifer is primarily comprised of calcareous sands with some thin clay and silt beds. The sand becomes increasingly more limey with depth. The lower portion of the aquifer is comprised of partially unconsolidated limestone and sandy limestone interbedded with clay and sand. Also, buried paleostream channels containing various deposits exist within the aquifer. The top of the aquifer ranges from 10 feet above sea level to 70 feet below sea level and is irregular over most of the northern portion of MCB, Camp Lejeune. The aquifer is more regular in areas southeast of the New River, where it slopes southeastward. The Castle Hayne thickens to the east, from 160 feet in the Camp Geiger area to over 400 feet at the eastern boundary of MCB, Camp Lejeune.

Estimated transmissivity, hydraulic conductivity and storage coefficient values for the Castle Hayne aquifer range from 6,100 to 183,300 gallons per day (gpd)/ft, 14 to 91 feet/day and $2x10^{-4}$ to $1.9x10^{-3}$, respectively. An aquifer pump test conducted by ESE (1988) in the Hadnot Point Industrial Area, using an existing water supply well (HP-642), indicates an average transmissivity and storage coefficient of 9,600 gpd/ft and $8.8x10^{-4}$, respectively (ESE, 1988).

Groundwater elevations and flow patterns for the upper portion of the Castle Hayne aquifer are depicted on Figures 2-9. Again, these are from the April 2002 LTM sampling event. Groundwater appears to flow in a southeastern direction over most of the site at an average gradient of 0.001 ft/ft.

Hydraulic conductivity tests were performed at the site on May 22 and 23, 1995 and February 26, 1996. The geometric average conductivity recorded for the surficial unit was 1.3 ft/day ($4.6 x10^{-4}$ cm/sec) and the geometric average for the upper portion of the Castle Hayne aquifer (below the confining clay) was 3.6 ft/day (1.3×10^{-3} cm/sec). These values were calculated using the Geraghty and Miller, Aquifer Test Solver (AQTESOLV) program that uses the Bouwer and Rice (1976) method for unconfined aquifers. The average values are consistent with expected values of hydraulic conductivity for the well sorted fine sands observed at the site (Fetter, 1989).

Additional slug tests were performed in the surficial aquifer during the May 1999 NAE investigation. Results from this testing indicated on average horizontal hydraulic conductivity of approximately 12 ft/day (4.23×10^{-3} cm/sec.). These values are about an order of magnitude higher than those obtained during the RI (Baker, 1997).

2.2.2.3 Castle Hayne Confining Unit

The Castle Hayne confining unit in the MCB, Camp Lejeune area is characterized as less permeable beds overlying the Castle Hayne Aquifer that have been partly eroded or incised in places. This unit is composed of clay, silt, and sandy clay, with vertical hydraulic conductivity estimates of 1.4×10^{-3} to 0.41 feet/day. The range in vertical hydraulic conductivity of the semi-confining layers determines the degree to which the semi-confining unit transmits flow.

The thickness of the semi-confining unit ranges from zero to 26 feet and averages about nine feet where present. As noted on the geologic cross-sections, this layer is discontinuous within Site 73.

2.3 Site Contamination

The primary contaminants of concern at this site are the chlorinated solvent compounds trichloroethene (TCE), and its daughter products of reductive dechlorination, including cis 1,2-dichloroethene (DCE), and vinyl chloride (VC). Benzene is also found in the two aquifers. Figures 2-10 and 2-11 depict the horizontal extent of these four compounds in the surficial aquifer and the Castle Hayne aquifer. The concentration values contoured on these drawings are the maximum concentrations found during the period of July 2001 and April 2002, which represents four sampling events. The areal extent of the primary VOC plume is approximately 19 acres.

The vertical extent of the various compounds were depicted in the Final NAE Report (Baker, 2002). These vertical profiles are seen in Figures 2-12, 2-13, and 2-14. The cross-section locations are the same ones depicted in Figure 2-2. Only TCE, cis 1,2-DCE and vinyl chloride are shown in these cross-sections. Cross-section D-D' is not shown because of the limited concentrations along the shore of Courthouse Bay. These cross-sections depict the maximum concentrations observed from 1998 through July 2001 and are within the same general order of magnitude as recent concentrations detected during the LTM events. Although contaminants extend to a depth below 90 feet bgs, the highest concentrations are present between 60 and 75 feet bgs, which is also the anticipated treatment depth.

2.4 Site Characterization Data Gaps

There are still two areas of the site where the groundwater contamination has not been clearly delineated. The first area is to the east of monitoring well 73-GW44DW. There is a lack of information with depth in this direction, but its significance may be limited since the edge of Courthouse Bay is within 200 feet of the last well. The second data gap is the horizontal and vertical extent of the plume to the west of the wells, 73-GW44DW and 73-GW49DW. The information from these areas of the site will be obtained through a focused data collection investigation prior to implementing a pilot study. Three deep transects (approximately 100 feet) with multiple sample locations and sample depths are envisioned for this investigation.

3.0 LOCATION OF "HOT SPOTS" FOR TECHNOLOGY EVALUATION

3.1 Discussion of "Hot Spot" Definition

"Hot spots" were identified by contaminant type and concentration. No set criteria for "hot spot" identification were used rather, a qualitative approach was taken. This approach involved reviewing site information and selecting areas for active remediation based on site-specific factors. An important aspect of this was to identify "typical" areas that were representative of other "hot spots" across the Base. Doing this will allow pilot studies to be performed that will provide data on the effectiveness of a given technology that can be applied throughout MCB, Camp Lejeune. This selection process is described more fully in Section 4.0.

3.2 Identification of "Hot Spot" Used in This Technology Evaluation

Based on the previous field investigations in support of remedial and natural attenuation evaluations at Site 73, two plumes of volatile organic compound (VOC) contamination are present at this site, one in the surficial aquifer and one in the Castle Hayne aquifer (see Figures 2-10 and 2-11). The primary contaminants of concern are TCE, cis-1,2-DCE, vinyl chloride, and benzene.

In the surficial aquifer, the concentrations of all chemicals of interest are not high enough to warrant active remediation. During the past year, the highest VOC concentration in the surficial aquifer was 50 micrograms per liter (µg/L) of cis 1,2 DCE at monitoring well 73-GW13. The NAE Study (Baker, 2002) indicates that these concentrations will be naturally attenuated and, therefore, they will not be considered in this technology evaluation.

In the Castle Hayne aquifer, the concentration of TCE is above 1,000 ug/L in 73-GW49DW. Well 73-GW44DW has also had historically high levels of TCE. The area within this TCE 1,000 ug/L contour will be considered a "hot spot" for the purpose of this evaluation and represents an area of higher contaminant mass. Other chemicals within this plume are cis 1,2-DCE, trans 1,2-DCE, benzene, and vinyl chloride. A small amount of 1,1-DCE and 1,1-dichloroethane (DCA) (estimated below the quantification limit) is also present. Table 3-1 summarizes relevant information for this treatment area.

4.0 REMEDIAL TECHNOLOGIES EVALUATION

4.1 Factors in Selecting a Remedial Technology

This section of the report describes potentially applicable remedial technologies and evaluates their projected ability to address "hot spot" contamination at Site 73. Included is a discussion of the general and site-specific factors that need to be taken into account when evaluating remedial options.

There are a number of factors that need to be considered in evaluating remedial technologies and their applicability to a particular site. These factors include:

- Environmental media to be remediated;
- Purpose of remedial action;
- Contaminant characteristics and concentrations; and
- Site constraints.

Each of these factors is discussed below.

Environmental Media

The first thing to establish is which environmental media requires remediation. Technologies differ for soil, soil gas and groundwater. Some technologies are able to address multiple media while others are medium specific. It is also important to understand that some technologies will cause impact to another medium that may not have required cleanup. An example of this would be air sparging where, during the course of groundwater remediation, soil gases are increased to levels that may need to be managed with a separate remedial system.

At Site 73, the medium of interest is groundwater. Investigations performed to date do not indicate that there is significant soil contamination at the site. Based on this, only technologies that address groundwater have been evaluated in this report.

Purpose of the Remedial Action

The remediation goal must be understood prior to reviewing specific technologies. If it is the purpose of the project to reach hard cleanup standards, different technologies will need to be employed than those used in a remedial scenario where contaminant mass needs only to be reduced in a target area within the plume.

The goal of active remediation at Site 73 is to address "hot spot" contamination; therefore, only areas within the contaminant plume that exhibit significantly higher concentrations of contaminants or contaminant mass will be subjected to active remediation. The concept is to reduce contaminant mass in the "hot spots" that is serving as a continuing source for the dissolved plume. By doing this, it is expected that the plume will reach equilibrium sooner and that natural attenuation can be used as a polishing approach to address residual contamination.

Contaminant Characteristics and Concentrations

There are three basic points to consider under this topic.

1. Chemical Characteristics - This includes toxicity of the contaminant, the way in which the contaminant is degraded or destroyed and, in the case of co-mingled plumes containing multiple contaminants, how contaminants interact.

2. Physical Characteristics of the Contaminants - Includes vapor pressure, miscibility, specific gravity, etc.

3. Contaminant Concentration - Often the concentration of contaminants within the plume will drive remedial option selection. Low concentrations will challenge some options while high concentrations exceed the capacity of others.

The profiles of the contaminant plumes present at Site 73 were discussed in Section 2.

Site Constraints

Site constraints are those site physical conditions that limit the ability to implement particular technologies. These would include such things as depth of contamination, presence of buried infrastructure, nearby surface water bodies, buildings, roads and other impediments to access.

The constraints at Site 73 are severe and do impact selection of remedial approaches. There are four primary site constraints that affect the implementability of some remedial options. These are:

- The presence of buildings, large paved areas, and other structures;
- The depth of the higher contaminant mass;
- The presence of numerous underground utilities; and
- The intensive use of the areas, including recent construction activities.

Most of the area at Site 73 where the highest concentration plume resides is covered with parking areas and amphibious vehicles and is a high use area. There are underground utilities at various locations in the area of interest. Because of the high use nature of the site, in-situ technologies are favored over ex-situ technologies.

4.2 Classes of Technologies

There are three classes of remedial technologies that are applicable to groundwater cleanup. They are: 1) mechanical, 2) chemical oxidation/destruction, and 3) biodegradation.

Mechanical

Mechanical means of remediation involve affecting some physical aspect of the aquifer or groundwater in order to reduce the contaminant concentration. Examples include:

- Pump and treatment;
- Air sparging, biosparging, or cometabolic air sparging;
- Electrical Resistance Heating (ERH);
- In Situ Steam Stripping; and
- Dynamic Underground Stripping (DUS).

ERH and DUS are primarily used for the removal of Dense Non-Aqueous Phase Liquid (DNAPL) from an aquifer but have also been applied to the dissolved phase with success.

Chemical Oxidation/Destruction

In this class, only the source area or areas of highest contamination are treated with various agents in order to reduce any residual Non-Aqueous Phase Liquid (NAPL) phase contaminant. Permeable reactive barriers (PRBs) also fall under this classification. The remediation relies on actual physical contact between the oxidizing/reducing agent and the contaminant of concern (COC), whether by injection in the actual source area or by relying on groundwater flow to provide contact between the oxidizing agent or reactive barrier. Examples include:

- Fenton's reaction;
- Oxygen Release Compound® (ORC®);
- Ozone;
- Potassium or sodium permanganate; and
- Zero-Valent Iron.

Biodegradation

Enhanced biodegradation is used to promote the destruction of COCs through the use of microbial action. Its application usually involves the addition of some material or microbes to the aquifer that stimulates microbial growth or augments it. Depending on what environment is needed for the biodegradation of the site COC, different agents are added. Examples include:

- Hydrogen Release Compound®(HRC®)/ORC®;
- Hydrogen/propane/methane injection via sparging;
- Oxygen via electrolysis;
- Bioaugmentation;
- Toluene/molasses/vegetable oil/lactic acid/nutrients; and
- Heat.

Technology Delivery Options

With the exception of ERH, these technologies rely on accurate delivery of reagents or biostimulants to the aquifer. The most common method of delivery is direct push injection. Another method of delivery is the use of pneumatic fracturing in soils that are resistant to flow. This enhances the delivery of the reagents and increases the likelihood of successful contact between the reagent and the COC. A third method of delivery is the use of horizontal wells. Historically, horizontal wells have been used primarily for delivery of gases, but chemical/substrate delivery can also be accomplished through their use. The use of horizontal wells may be employed where delivery will occur near or under buildings. Recirculating wells, either horizontal or vertical, increase the gradient and flow rate of the groundwater in the area of concern, thereby increasing the likelihood of prolonged contact between reagent or biostimulant and the affected groundwater.

4.3 Selected Technologies

Based on the type of contamination (primarily the chlorinated compounds), the desired clean up goals, hydrogeologic and geologic conditions, and the site constraints at the proposed treatment area, five different technologies were further evaluated for this technology evaluation. These are:

1. oxidation of the primary COCs with potassium permanganate;
2. reduction with colloidal iron injection;
3. enhanced biodegradation with HRC®;
4. bioaugmentation; and
5. sparging with hydrogen, cometabolic sparging with air and propane, or sparging with ozone using horizontal wells. Each of these uses a different mechanism to destroy the COCs.

These technologies will be discussed below.

4.3.1 Potassium Permanganate

In situ oxidation using potassium permanganate is a technology that may provide a fast and low-cost solution for the destruction of chlorinated solvents under certain site conditions. Potassium permanganate chemically oxidizes a wide range of organic compounds to innocuous end products over a wide pH range. Potassium permanganate reacts with the double bonds in chlorinated compounds and may be effective for the remediation of dissolved-phase contaminants under certain site conditions. The reaction produces breakdown products such as carbon dioxide, chloride ions, and manganese dioxide.

A permanganate solution at concentrations of about 4 percent typically is applied through injection wells. The solution is non-toxic and non-hazardous. The solution color (purple) makes it easy to track the zone of injection influence. Chemically stable in water, permanganate degrades very slowly, staying in solution until it reacts with organic material. Groundwater subjected to permanganate treatment can be visually observed to change color from purple to brown to clear upon complete oxidation (the soluble permanganate ion is purple, and forms a brown colloid that ultimately settles out of solution).

Permanganate is a strong oxidant used to destroy TCE and its daughter products. In addition to oxidizing VOCs, it can also oxidize naturally occurring organic carbon and minerals in soil. Oxidation of naturally occurring minerals can potentially be of concern. Specifically, the oxidation of trivalent chromium (Cr^{+3}) to the more soluble and toxic hexavalent chromium (Cr^{+6}), as well as the oxidation of selenium from Se^{+4} to the more soluble Se^{+6}, are undesirable reactions that may occur (Clayton, et al., 2000). However, the oxidation of chromium and selenium is reversible if reducing conditions re-establish over time in treated areas and as groundwater containing the oxidized compounds migrates into untreated areas with reducing conditions. Therefore, the transient occurrence of oxidized metals may be an acceptable "side effect", unless human or environmental receptors may be affected prior to the reduction of the oxidized metals.

As with most technologies that rely on fluid injection and contact with target contaminants, low permeability and heterogeneity of soils present a challenge. Permanganate oxidation is generally most effective at sites that are relatively homogenous and have relatively high permeability soil (in the range of 10^{-3} cm/sec or higher permeability). If the soil matrix permeability is generally low, and/or low permeability layers or lenses are present, these zones eventually will leach contaminants, causing a gradual increase or "rebound" in levels of groundwater contamination. Rebound effects are quite common with in situ oxidation technologies (Moes, et al., 2000; Roberts, 2000).

The effectiveness of the in situ injection of potassium permanganate is a function of the reaction kinetics, the transport and contact between potassium permanganate and the contaminant, as well as competitive reactions with other oxidizable species (e.g., iron, other inorganics, and natural organics) (Tarr, et al., 2000).

The reported effectiveness of chemical oxidation in groundwater has been widely variable, and there are widely varying opinions regarding its effectiveness and future potential for cleanup of contaminated sites. It may not be effective on TCE with concentrations over 10 milligrams per liter (mg/L) and may require several injections. However, it appears to be promising for dissolved-phase plumes under certain site conditions. Drawbacks include the potential for rebound. In one case study, rebound of concentrations to within 50 to 90 percent of the initial TCE concentrations occurred during the first four weeks after injection in areas of highest concentrations (1400 to 1600 ug/L) (Lowe, et al., 2002).

Applicability to Site 73

This technology was evaluated for the given "hot spot" of 1000 ug/L of TCE. Based on calculations performed to determine the amount of potassium permanganate necessary for oxidation of the TCE and other volatile organics in the "hot spot," it was determined that a volume of 12.5 percent of the actual pore volume in the "hot spot" would have to be injected (also considering fracture injection). This large injection volume would cause movement of the contaminants away from the source zones, thereby spreading out the contamination from the target zone. Accordingly, this option was removed from consideration due to the mass/volume injection requirements and will not be discussed further.

4.3.2 Zero Valent Iron / Colloidal Iron Injection with Pneumatic Fracturing

Permeable reactive barriers (PRBs) made of zero-valent iron (Fe^0) are gaining acceptance and are being used to treat groundwater contaminated with chlorinated solvents. This technology uses zero-valent iron to reductively dehalogenate hydrocarbons, converting TCE into non-toxic chloride ions and ethenes, for example. The reactions that take place within the PRBs are dependent on parameters such as pH, oxidation-reduction potential (ORP), contaminant concentrations, and reaction kinetics.

Removal rates of 90 percent or more of chlorinated compounds are common with properly designed systems using zero-valent iron. It has been shown to be effective at relatively high VOC concentrations (e.g., 600 to 700 mg/L); however, when concentrations are higher than about

100 mg/L, the reaction rates through a PRB are lower due to saturation kinetics (insufficient surface area on the iron), costs increase significantly, and effectiveness generally decreases.

Using an alternative placement technology, zero-valent iron in a powdered form (Ferox®) can be injected into a source area in order to reduce source concentrations. This technique employs pneumatic fracturing of the source area to increase formation permeability and disperse the iron powder. Preliminary results using this technology indicate substantial reduction of chlorinated solvents in the source area during a three-month post-monitoring period.

Applicability to Site 73

The PRB implementation of zero-valent iron is not applicable to Site 73 because of the focus on "hot spot" treatment and the depth required for installation of a PRB.

Direct injection of the iron to the "hot spot" can be implemented, however, allowing prolonged contact between the reducing agent (iron) and the chlorinated compounds. Pneumatic fracturing is used to inject the iron in order to spread the iron out evenly through the aquifer formation in the treatment area. This technology does not address benzene, which is one of the target treatment compounds at Site 73.

4.3.3 Hydrogen Release Compound (HRC) ®

HRC® is a patented polylactate ester used to remediate chlorinated hydrocarbons that biodegrade anaerobically. Upon contact with water, HRC® slowly releases lactic acid. Microbes metabolize the lactic acid, releasing hydrogen to enhance anaerobic bioremediation. Microbes called "reductive dechlorinators" are capable of biological dechlorination of chlorinated hydrocarbons using the generated hydrogen. HRC® slowly releases lactic acid over time, providing a steady supply of hydrogen, essential for anaerobic dechlorination, for a period of six months to one year. HRC® is a viscous fluid substance that typically is heated and injected into the treatment zone using direct push (Geoprobe®) methods. It can be applied in a grid across a zone of contamination or in the form of a barrier wall.

As with most technologies that rely on fluid injection and contact with target contaminants, low permeability and heterogeneity of soils present a formidable challenge. HRC® is generally most effective at sites that are relatively homogenous and have relatively high soil permeability (in the range of 10^{-3} cm/sec or higher permeability). If the soil matrix permeability is generally low, and/or low permeability layers or lenses are present, these zones will leach contaminants, causing a gradual increase or "rebound" in levels of groundwater contamination.

When field conditions are conducive to HRC® remediation, results from applications of HRC® have shown significant reduction in chlorinated hydrocarbons in a relatively rapid timeframe. Field studies to date have shown HRC® to effectively reduce concentrations of chlorinated hydrocarbons when initial concentrations were as high as 100 mg/L.

Daughter products of TCE dechlorination (Cis-1,2-DCE and vinyl chloride) will increase as the parent compounds are being degraded. Vinyl chloride degrades aerobically and generally is not degraded by the HRC® process. This can be problematic, especially if vinyl chloride accumulates because vinyl chloride is relatively toxic and highly mobile in the environment. Therefore, increasing concentrations of vinyl chloride are of concern if generated in close proximity to human or environmental receptors. Typically, ORC® (injected in a second remedial event) is used to remediate the vinyl chloride that accumulates from the HRC® process.

Applicability to Site 73

As stated previously, the reductive dechlorination process is already occurring at the treatment location. Regenesis, Inc. has provided software for preliminary design and cost purposes. Using this software, over one hundred injection locations with an injection rate of 5.1 pounds per foot over a twenty-foot thickness are necessary to dose the entire treatment area with HRC®. Pneumatic fracturing with HRC® injection is also applicable here, resulting in a reduction in the number of injection points through a temporary increase in permeability. A potential drawback of this technology is its longevity in the aquifer. Repeated applications may be necessary to complete treatment. As stated above, vinyl chloride may accumulate and require remedial actions through sparging or ORC®. Also, this technology does not address benzene and may require a follow up injection of ORC®.

4.3.4 Bioaugmentation

This technology, essentially adding a microbial culture to the aquifer, is used in conjunction with the addition of electron donor. Addition of the microbial culture "KB-1" is most typically used to promote complete reduction of the chlorinated compounds after the process has been observed to stall following cis 1,2-DCE production. It can, however, also be used to accelerate the biodegradation process.

Applicability to Site 73

Because ethene is present at this site, the addition of microbes would accelerate the reductive dechlorination process already in place. However, since the addition of electron donor is also required, this technology should not be considered until it is determined that the addition of electron donor alone does not adequately treat the "hot spot" areas to reasonable levels. Accordingly, this option was removed from consideration and will not be discussed further.

4.3.5 Sparging

Sparging with various gases is a potentially viable technology at Site 73. Different gases perform different actions on the contaminants. Air, hydrogen, cometabolic, and ozone sparging may be applicable and are discussed below. Because of previous applications of soil vapor extraction and sparging at Camp Lejeune and their limited success rate, and because of the location with depth of the treatment area, vertical sparge wells will not be considered here. Rather, it is proposed that horizontal sparge wells be considered for delivery of this technology.

The air sparging technique uses air as the driving force for "stripping" of volatile organics from groundwater. Soil vapor extraction is required following sparging to collect the volatilized gases.

Hydrogen injection, a variation of biosparging, is a recently developed method to directly stimulate anaerobic halorespiration, a form of reductive dechlorination. For dechlorination to occur, halorespirators must compete successfully with other hydrogen utilizers for available hydrogen at low concentrations. Increased hydrogen availability will result in increased halorespiration. This technology was tested with favorable results at Cape Canaveral Air Station (Newell, et al., 2001).

Cometabolic sparging involves injection of air, amended with a nutrient or donor gas, typically propane or methane. The objective of cometabolic sparging is not to promote volatilization, rather to enhance halorespiration. Although a relatively new methodology, cometabolic sparging has seen impressive results in several field demonstrations for TCE plumes (ESTCP, 2001).

It is generally accepted that direct halorespiration does not occur under aerobic conditions. However, if conditions are favorable, cometabolism may occur. During cometabolism, microorganisms gain carbon and energy for growth from metabolism of a primary substrate, and chlorinated solvents are degraded fortuitously (i.e. non-selectively) by enzymes present in the metabolic pathways (Weidemeier, 1999). The organism obtains no known benefit from the biodegradation of the chlorinated solvent. Literature review indicates that TCE can be cometabolized, and "daughter products" such as DCE and VC can be degraded aerobically.

Ozone is a strong oxidant, second only to fluorine and the hydroxyl radical in oxidation potential, and slightly more powerful than hydrogen peroxide. Ozone is typically produced on-site from pure oxygen gas using an ozone generator, which is subsequently injected at a ratio of approximately 5 percent by weight in air. Ozone is an unstable molecule, with a half-life of approximately two minutes in air and 20 minutes dissolved in water. This characteristic of ozone can be considered either a drawback or a benefit, depending on subsurface characteristics. Since the persistence of ozone in the environment is short, it must be delivered to the treatment area quickly and efficiently; residual oxidation potential within several hours of delivery is generally negligible. However, ozone can be used to reduce chlorinated solvent concentrations within a relatively short period of time, provided conditions are favorable (i.e. high permeability, relatively homogeneous soils).

Since ozone reacts quickly and degrades into harmless molecular oxygen, there is little possibility of fugitive gas accumulation or production of by-products. Oxygen produced by ozone decomposition benefits aerobic biodegradation of less highly oxidized chlorinated solvents, such as DCE and vinyl chloride (Newell, 2001). By contrast, common liquid oxidants such as those used in Fenton's chemistry and permanganate leave behind residual insoluble precipitates. These precipitates may adversely affect water quality over the long term, particularly in the case of aquifers that may be considered potential drinking water sources.

Applicability to Site 73

Addition of gases to the treatment area through sparging is a viable remedial option at this site through the use of horizontal wells. Because of the limited success with sparging at Camp Lejeune based on its extensive use at both IR and UST sites, sparging with air will not be evaluated further.

The addition of propane as a gaseous organic growth substrate (ESTCP, 2001) along with air to the target area would promote aerobic cometabolic biodegradation of the contaminants without resulting in significant volatilization, theoretically eliminating the need for soil vapor extraction.

The addition of hydrogen directly would provide the halorespirators the necessary hydrogen to perform reductive dechlorination. Its addition would promote biodegradation directly through halorespiration. Therefore, hydrogen sparging is preferred over cometabolic air sparging.

Sparging with ozone in the treatment area would result in oxidation of the COC, reducing contaminant mass directly, rather than through biodegradation. This method also destroys the microbial population through oxidation, resulting in a lag time before natural reductive dechlorination re-establishes itself.

The benefits of each of these four sparging options were compared and the following recommendation is made. Pulsed hydrogen sparging appears to be the best suited to the conditions at this site, because of the already active reductive dechlorination occurring as discussed in the NAE Study Report (Baker, 2002). In addition, the use of horizontal wells would eliminate many of the problems of gas delivery associated with sparging at Camp Lejeune sites. Typically, a very small radius of influence and channelization occur in the sparge and/or soil vapor extraction (SVE) area with vertical wells. Horizontal wells have a larger radius of influence and are more effective in a deeper target zone. Non-uniform flow over the screen length may occur, but can be overcome with proper design. The site constraints of the parking lot with amphibious vehicles located over the treatment area would be overcome with a horizontal well because the equipment for installation and operation could be located in an area that would not be disruptive to site activities.

4.4 Cost Analyses

A cost analysis was performed on three technologies at Site 73 for the purpose of comparison of treatability study costs. The technologies selected for cost analyses were 1) HRC® using regular Geoprobe® injection and injection with pneumatic fracturing; 2) zero valent iron (Ferox®) injection with pneumatic fracturing; and 3) sparging with a horizontal well using hydrogen; and 4) sparging with horizontal well using air and propane to promote cometabolic degradation. Potassium permanganate oxidation and bioaugmentation were eliminated from further consideration, as were sparging with air, propane, and ozone. Cost back up information is provided in Appendix A.

As shown on Table 4-1, the costs for the various technologies along with the different delivery options are shown. The costs range from a low of $314,000 for a normal Geoprobe® injection of HRC® to a high of $666,510 for cometabolic sparging with a horizontal well. It should be noted that the cost estimate prepared for HRC® assumes only one injection since this action is considered a pilot test of the technology. Multiple injections of HRC® or follow up injections of ORC® may be required; however, it is not practical at this time to evaluate these potential costs because it is not possible to predict the quantities of HRC® and/or ORC® materials that would be required for treatment.

4.4.1 Cost Estimate Sensitivity

A sensitivity analysis of the cost estimates provided above is necessary to understand which assumptions made in developing costs affect the project totals most significantly. There are three areas in which changed assumptions or concepts cause the widest variation in costs. These are:

1. Cost estimate was prepared prior to design of the remedial action;
2. Implementation of the proposed technology to the required depth;
3. Unknown site conditions.

Pre-Design Estimate

The cost estimate has been prepared prior to design of the remedial action. This primarily applies to the horizontal well construction option. Gross assumptions regarding the sequencing of the construction and the implementation of the hydrogen sparging will be refined during a detailed design. The resulting cost may differ substantially from the pre-design cost estimate. This may also apply to the HRC® injection option if Regenesis, Inc. recommendations for safety factor and grid spacing vary significantly from the pre-design.

Implementation of the Proposed Technology to the Required Depth

It is assumed that a Geoprobe® rig can attain the depths required for injection of HRC®. If it is not feasible, alternative methods of delivery will have to be employed and the cost will increase.

Unknown Site Conditions

Current site conditions are fairly well understood. However, the identified data gaps may impact the cost of the remedial technology by enlarging the area of the "hot spot." The underground geology has been extensively investigated; so unknown geologic conditions are unlikely. The location of underground utilities at the site is less well known, however, and may cause reconfiguration of the remedial options resulting in increased cost.

5.0 PREDICTIVE MODELING

5.1 Purpose and Objectives

The reactive transport model, BIOCHLOR (Aziz, 2001) was used to predict reductive dechlorination with time of TCE and its daughter products under different source configurations and degradation rates. It assumes a one-dimensional groundwater flow regime with dispersion in three dimensions.

The primary cleanup criteria available in North Carolina for groundwater or surface water are the 2L Standards. Unfortunately, cleaning up the groundwater to the 2L Standards is neither physically nor economically feasible for most contaminants. This is especially true when a particular 2L Standard (e.g., vinyl chloride) is below the method detection limit (MDL).

Therefore, the objective of this preliminary modeling effort is to predict the length of time to reach the 2L Standards under various combinations of active and passive remediation scenarios. The type of remediation is not specifically modeled, but the results of a particular remedial effort can be assumed and used as input in the BIOCHLOR model. This type of prediction is necessary to determine the level to which to remediate groundwater in the most contaminated areas of Site 73, while leaving the rest for natural attenuation (NA). These areas or "hot spots" contain TCE, 1,2-DCE (total) and vinyl chloride concentrations up to 4,600, 1,200, and 47 ug/L, respectively. If these "hot spots" are cleaned up to a certain "cleanup level," NA processes may be able to remediate the remaining dissolved concentrations within a reasonable timeframe.

Because of the preliminary nature of this modeling effort it is premature to predict or guarantee the success of any single or combination of remedial approaches described herein. At best, the results should be viewed qualitatively and any conclusions drawn carefully.

5.2 Modeling Approach and Methodology

The objective of this preliminary modeling effort is to predict the length of time to reach the 2L Standards under various combinations of active and passive remediation scenarios. Therefore, under each remedial scenario there was an assumed constant source concentration (worst-case assumption). Maximum concentrations were used in the BIOCHLOR modeling such that the highest TCE, cis-1,2-DCE and vinyl chloride concentrations were used as input to the model, regardless of their locations (either 73-MW44DW or 73-MW49DW). Other input parameters were assumed to be the same as those determined for the NAE (Baker, 2002). Table 5-1 presents the basic input parameters for BIOCHLOR 2.2 that were used for NAE Study Report (Baker, 2002).

Four scenarios were modeled. The first scenario is a no action scenario, while scenarios 2 and 3 represent source reduction by an order of magnitude. That is, the 1,000 ug/L TCE "hot spot" was assumed to be remediated to 1,000 ug/L of TCE within its entirety (with similar reductions in the daughter products) and a larger 100 ug/L TCE "hot spot" was remediated to 100 ug/L within its entirety (again with similar reduction in the daughter products). The last scenario (Scenario 4) represents active remediation of the hot spot area with enhanced biodegradation such as would be expected with the addition of a carbon source/donor to the aquifer. In this scenario, the original degradation rates were increased by an order of magnitude, while the source concentrations were held at their original level.

5.3 Modeling Results

Table 5-2 depicts the results of the modeling exercise. Appendix B contains the input and output pages of the model.

As shown in Table 5-2, under a no-action scenario, the time to steady state is approximately 35 years, with the maximum reach of TCE extending into Courthouse Bay, off-site. The extent of the vinyl chloride is 420 feet.

Under the source reduction scenarios, 2 and 3, the time to reach steady state is 25 years for both scenarios. The extent of the plume is reduced from the no-action scenario, to 500 feet and 300 feet for TCE and vinyl chloride in scenario 2, and 300 feet and 100 feet, respectively, in scenario 3.

In the enhanced biodegradation scenario (scenario 4), the time to reach steady state is reduced to 5 years and the extent of the plume is reduced to 120 feet for TCE and 80 feet for vinyl chloride. Both of these distances are within the extent of the "hot spot" area, indicating that treatment of only the hot spot area with an enhanced biodegradation approach would be sufficient to reduce the steady state plume size.

The modeling results of these different scenarios would seem to favor the last approach if the enhanced biodegradation remedial effort was continued for the full five years. HRC® is an example of the enhanced biodegradation approach, although it does not last for five years in an aqueous environment and reapplication would have to occur.

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Site 73 has one identifiable "hot spot" where a relatively localized area of higher concentration of contaminants is present. TCE and the daughter products of its reductive dechlorination are the primary COC in this "hot spot". It is approximately 200 feet by 200 feet in area, and located approximately 65 feet below the ground surface in the Castle Hayne aquifer. Significant contaminant mass could be removed from this location using appropriate technologies.

The most promising technologies applicable to Site 73 are those that enhance the reductive dechlorination process that is already in place at this site. Delivery of the technologies presents a challenge because of the depth of the contaminant plume at this location. The technologies evaluated were HRC® injection using Geoprobe injection and pneumatic fracturing, Ferox® zero-valent iron injection using pneumatic fracturing, and hydrogen sparging using a directionally drilled horizontal well. HRC® and hydrogen sparging both enhance the currently active biodegradation occurring at the site, while Ferox® injection reduces the source concentrations of the contaminant plume. The costs for these technologies ranged from about $300,000 to $700,000.

Modeling with BIOCHLOR of the resulting reduction in source concentration predicted a decrease in time to steady state and plume length over a no-action scenario. Enhanced biodegradation modeling predicted a much shorter plume length and time to steady state because of the increased activity of the microbes. Because the time modeled in the enhanced biodegradation scenario was five years, it is implied that the proposed technology(s) would last for five years.

6.2 Recommendations

It is recommended that a one year pilot study be performed using one of the technologies discussed in this report. As stated above, the enhanced bioremediation approach would seem to provide the most favorable results because the reductive dechlorination is already occurring to a large extent across the site.

Based on effectiveness, hydrogen sparging with a horizontal well for one year is recommended at Site 73. The advantage of the horizontal well would be minimal disruption to any site activities. The disadvantage would be the initial capital cost. However, future costs, if this technology was chosen, would be minimal, only operation and maintenance. While it is premature to predict the length of time required for hydrogen sparging, it is reasonable to assume five years.

Equally as effective would be HRC® injection. This injection can be done using regular Geoprobe® injection with a tight injection point spacing or pneumatic fracturing with a larger spacing. The advantage of the Geoprobe® injection is that current site conditions would remain unchanged after the injections were complete. The advantage of the pneumatic fracturing injection is that the casings through which the pneumatic fracturing is done would be able to be reused for subsequent injections, if desired. A one-time injection at Site 73 and monitoring would yield valuable information for the use of this technology in the Castle Hayne aquifer.

In order of the preferred alternatives for the pilot testing, the recommendations are:

1.	Hydrogen sparging with horizontal well	$639,510
2.	HRC injection with regular Geoprobe®	$313,892
3.	HRC injection with pneumatic fracturing	$467,092
4.	Cometabolic sparging with horizontal well	$666,510
5.	Ferox® injection with pneumatic fracturing	$609,205

It is expected that any of these technologies would address most of the contamination in the "hot spot" area. Once a pilot test is complete and the results have been evaluated, a decision can be made on either full-scale implementation of the technology or monitored natural attenuation with Long Term Monitoring at Site 73.

7.0 REFERENCES

ATEC Environmental Consultants. 1991. Underground Storage Tank Site Check Investigation Report Building A-47 UST SA-21, Camp Lejeune, Marine Corps Base, Jacksonville, North Carolina.

Aziz, C.E., C.J. Newell, J.R. Gonzales, P. Haas. 2001. BIOCHLOR, Natural Attenuation Decision Support System, Version 2.0, User' s Manual, March, 2001.

Baker Environmental, Inc. 1995. Remedial Investigation/Feasibility Study Work Plan Operable Unit No. 9). Final. Prepared for the Department of the Navy, Naval Facilities Engineering Command, Atlantic Division, Norfolk Virginia.

Baker Environmental, Inc. 1997. Remedial Investigation Report, Operable Unit No. 9 (Site 73), Marine Corps Base, Camp Lejeune, North Carolina. Final. Contract Task Order 0312. Prepared for the Department of the Navy Atlantic Division, Naval Facilities Engineering Command, Norfolk, Virginia. November, 1997.

Baker Environmental, Inc. 1998a. Feasibility Study, Operable Unit No. 9, Site-73, Amphibious Vehicle Maintenance Facility, Marine Corps Base, Camp Lejeune, North Carolina. Final. Contract Task Order 0312. Prepared for the Department of the Navy Atlantic Division, Naval Facilities Engineering Command, Norfolk, Virginia. July, 1998.

Baker Environmental, Inc. 1998b. Sample Strategy Plan - Corrective Action Plan/Natural Attenuation Evaluation Study, Operable Unit No. 9, Site 73, Amphibious Vehicle Maintenance Facility, Marine Corps Base, Camp Lejeune, North Carolina. Final. Contract Task Order 0312. Prepared for the Department of the Navy Atlantic Division, Naval Facilities Engineering Command, Norfolk, Virginia. November 6, 1998.

Baker Environmental, Inc. July 1999 to June 2000. Annual Monitoring Report, Draft, OU 21, Site 73, MCB, Camp Lejeune, North Carolina, Reporting Period July 1999-June 2000. Contract Task Order 0120. Prepared for Department of the Navy, Atlantic Division, Naval Facilities Engineering Command, CH2MHILL/Baker Environmental, Inc.

Baker Environmental, Inc. 2001a. Letter Work Plan for Deep Well Installation. Contract Task Order 0130. Prepared for the Department of the Navy Atlantic Division, Naval Facilities Engineering Command, Norfolk, Virginia. March 20, 2001.

Baker Environmental, Inc. 2001b. Letter Report for Deep Well Installation. Contract Task Order 0130. Prepared for the Department of the Navy Atlantic Division, Naval Facilities Engineering Command, Norfolk, Virginia. August 23, 2001.

Baker Environmental, Inc. 2001. Work Plans for Long Term Monitoring and Natural Attenuation Monitoring. Prepared for the Department of the Navy Atlantic Division, Naval Facilities Engineering Command, Norfolk, Virginia.

Baker Environmental, Inc. February, 2002. Final Natural Attenuation Evaluation, Operable Unit No. 21, Site 73, Marine Corps Base, Camp Lejeune, North Carolina. Contract Task Order 0130. Prepared for Department of the Navy, Atlantic Division, Naval Facilities Engineering Command, CH2MHILL/Baker Environmental, Inc.

Clayton, W.S., et al. 2000. A Multisite Field Performance Evaluation of In-Situ Chemical Oxidation Using Permanganate. Second International Conference on Remediation of chlorinated and Recalcitrant Compounds, G.B. Wickramanayake and A.R. Gavaskar, eds., Battelle Press.

Environmental Science and Engineering (ESE). May 1998. Characterization Step Report for Hadnot Point Industrial Area Confirmation Study to Determine Existence and Possible Migration of Specific Chemical In Situ. Marine Corps Base, Camp Lejeune, North Carolina. Prepared for the Department of the Navy Atlantic Division, Naval Facilities Engineering Command. ESE Project No. 49-02036.

Environmental Science and Engineering (ESE). September 1990. Site Summary Report Final. Marine Corps Base, Camp Lejeune, North Carolina. Prepared for the Department of the Navy Atlantic Division, Naval Facilities Engineering Command. ESE Project No. 49-02036.

ESTCP Cost and Performance Report. 2001. Use of Cometabolic Air Sparging to Remediate Chloroethene-Contaminated Groundwater Aquifers. U.S. Department of Defense.

Fetter, C.W., Jr. 1989. Applied Hydrogeology. Charles E. Merrill Publishing Company, Columbus, Ohio. p. 64, p. 75, and p. 116.

Groundwater Services, Inc. (GSI). 1993. Underground Storage Tank Investigation, Building A47-3, Marine Corps Base, Camp Lejeune, North Carolina.

Law-Catlin Associates, Inc. 1993. Leaking Underground Storage Tanks Comprehensive Site Assessment, Building A-47 Pumps, Marine Corps Base, Camp Lejeune, North Carolina. Draft. December 29, 1993. Volumes I and II.

Lowe, K.S., Gardner, F.G. and Siegrist, R.L. Winter. 2002. Field Evaluation of In Situ Chemical Oxidation Through Vertical Well-to-Well Recirculation of $NaMnO_4$. Groundwater Monitoring and Remediation, pp. 106-115.

Moes, M., et al. 2000. Permanganate Injection for Source Zone Treatment of TCE DNAPL. Second International Conference on Remediation of Chlorinated and Recalcitrant Compounds, G.B. Wickramanayake and A.R. Gavaskar, eds., Battelle Press.

Newell, C.J., et al. 2001. Two Novel Methods for Enhancing Source Zone Bioremediation: Direct Hydrogen Addition and Electron Acceptor Diversion. Anaerobic Degradation of Chlorinated Solvents, 6(7), The Sixth International In Situ and On-Site Bioremediation Symposium, Battelle Press.

Roberts, E.P. and N. Bauer. 2000. In-Situ Chemical Oxidation Limited by Site Conditions: A Case Study. Second International Conference on Remediation of chlorinated and Recalcitrant Compounds, G.B. Wickramanayake and A.R. Gavaskar, eds., Battelle Press.

Tarr, M.A., et al. 2000. Fenton Oxidation: Bringing Pollutants and Hydroxyl Radicals Together. Second International Conference on Remediation of chlorinated and Recalcitrant Compounds, G.B. Wickramanayake and A.R. Gavaskar, eds., Battelle Press.

U. S. Environmental Protection Agency. September 2001. Remediation Technology Cost Compendium-Year 2000. Office of Solid Waste and Emergency Response, EPA-542-R-01-009.

U. S. Environmental Protection Agency. September 2001. Use of Bioremediation at Superfund Sites. Office of Solid Waste and Emergency Response, EPA-542-R-01-019.

Water and Air Research (WAR). April, 1983. Initial Assessment Study of Marine Corps Base Camp Lejeune, North Carolina. Marine Corps Base, North Carolina. Prepared for the Naval Energy and Environmental Support Activity.

Weidemeier, T.H., Rifai, H.S., Newell, C.J., and Wilson, J.T. 1999. Natural Attenuation of Fuels and Chlorinated Solvents in the Subsurface. John Wiley and Sons, New York.

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TABLES

TABLE 3-1
HOT SPOT SUMMARY
TECHNOLOGY EVALUATION - CTO -0253
OPERABLE UNIT NO. 21, SITE 73
MCB, CAMP LEJEUNE, NORTH CAROLINA
SEPTEMBER 2002

Location	Vicinity of 73-MW44DW and 73-MW49DW, southeast of Building A-47
Contaminants of Concern	TCE, DCE, vinyl chloride, benzene
Other contaminants present	1,1 -DCE, 1,1 -DCA
Maximum concentrations (ug/L)	
TCE	4600
1,2 DCE	1200
vinyl chloride	47
Benzene	13
1,1 -DCE	9
1,1 -DCA	4
Depth BGS to maximum concentration (ft)	70
Approximate horizontal extent of 1000 ug/L contour	200 feet by 200 feet
Approximate height of 1000 ug/L contour (ft)	10
Approximate cylindrical volume of affected aquifer (cubic feet)	400,000
Approximate pore space volume (cubic feet)	120,000

TABLE 4-1
COST COMPARISON
TECHNOLOGY EVALUATION, CTO - 0253
OPERABLE UNIT 21, SITE 73
MCB CAMP LEJEUNE, NORTH CAROLINA
SEPTEMBER 2002

Technology	Delivery	Cost of Technology	Other costs (1)	Total Cost
HRC, one injection	Geoprobe injection	$99,312	$214,580	$313,892
HRC, one injection	Pneumatic fracturing	$252,512	$214,580	$467,092
Ferox	Pneumatic fracturing	$394,625	$214,580	$609,205
Cometabolic sparging	Horizontal Well	$451,930	$214,580	$666,510
Hydrogen sparging	Horizontal Well	$424,930	$214,580	$639,510

(1) other costs include one year of operation and maintenance, if applicable; installation of monitoring wells; one year of sampling; surveying; utility locating; and all reporting, including work plans.

TABLE 5-1
BIOCHLOR INPUT PARAMETERS
TECHNOLOGY EVALUATION, CTO -0253
OPERABLE UNIT NO. 21, SITE 73
MCB, CAMP LEJEUNE, NORTH CAROLINA
SEPTEMBER 2002

	Scenario				
Input Parameter	**All 1, 2, 3, 4**	**1 No action**	**2 1000 ug/L hot spot**	**3 100 ug/L hot spot**	**4 Enhanced Biodegradation**
Hydraulic Conductivity (cm/sec)	0.0018				
hydraulic gradient	0.00075				
effective porosity	0.25				
seepage velocity (ft/year)	55.9				
dispersion coefficient, alpha x (ft)	19.811				
alpha y/ alpha x	0.333				
alpha z/ alpha x	0.04				
soil bulk density (kg/L)	1.7				
fraction organic carbon	0.0071				
Koc -TCE (L./kg)	130				
Koc - DCE (L/kg)	50				
Koc - vinyl chloride (L/kg)	30				
Koc - ethene (L/kg)	302				
decay coefficient, TCE to DCE (1/yr)		0.87	0.87	0.87	8.7
decay coefficient, DCE to vinyl chloride (1/yr)		1.93	1.93	1.93	19.3
decay coefficient, VC to ethene (1/yr)		17.33	17.33	17.33	173.3
Source information					
source thickness (ft)		50	50	50	50
source width (ft)		200	200	300	200
source concentrations (mg/L)					
TCE		4.6	1	0.1	4.6
DCE		1.2	0.12	0.012	1.2
Vinyl chloride		0.04	0.004	0.001	0.04
Ethene		0	0	0	0

TABLE 5-2
BIOCHLOR MODELING RESULTS
TECHNOLOGY EVALUATION, CTO - 0253
OPERABLE UNIT NO. 21, SITE 73
MCB, CAMP LEJEUNE, NORTH CAROLINA
SEPTEMBER 2002

	Time to steady state	Distance to 2L Standard (ft)	
Scenario	(years)	TCE	Vinyl Chloride
1	35	off site	420
2	25	500	300
3	25	300	100
4	5	120	80

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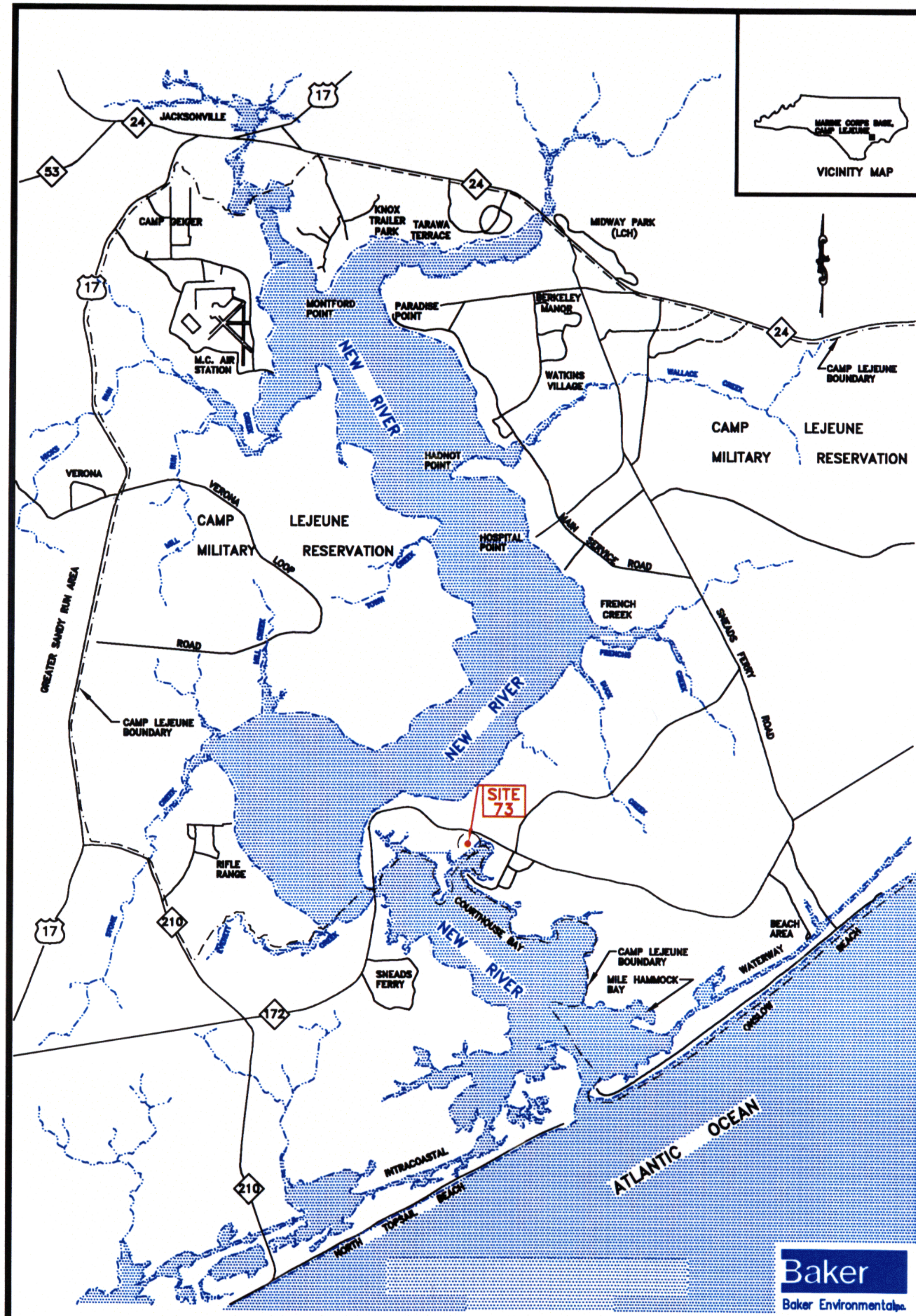
FIGURES



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NOT TO SCALE

2253TE04

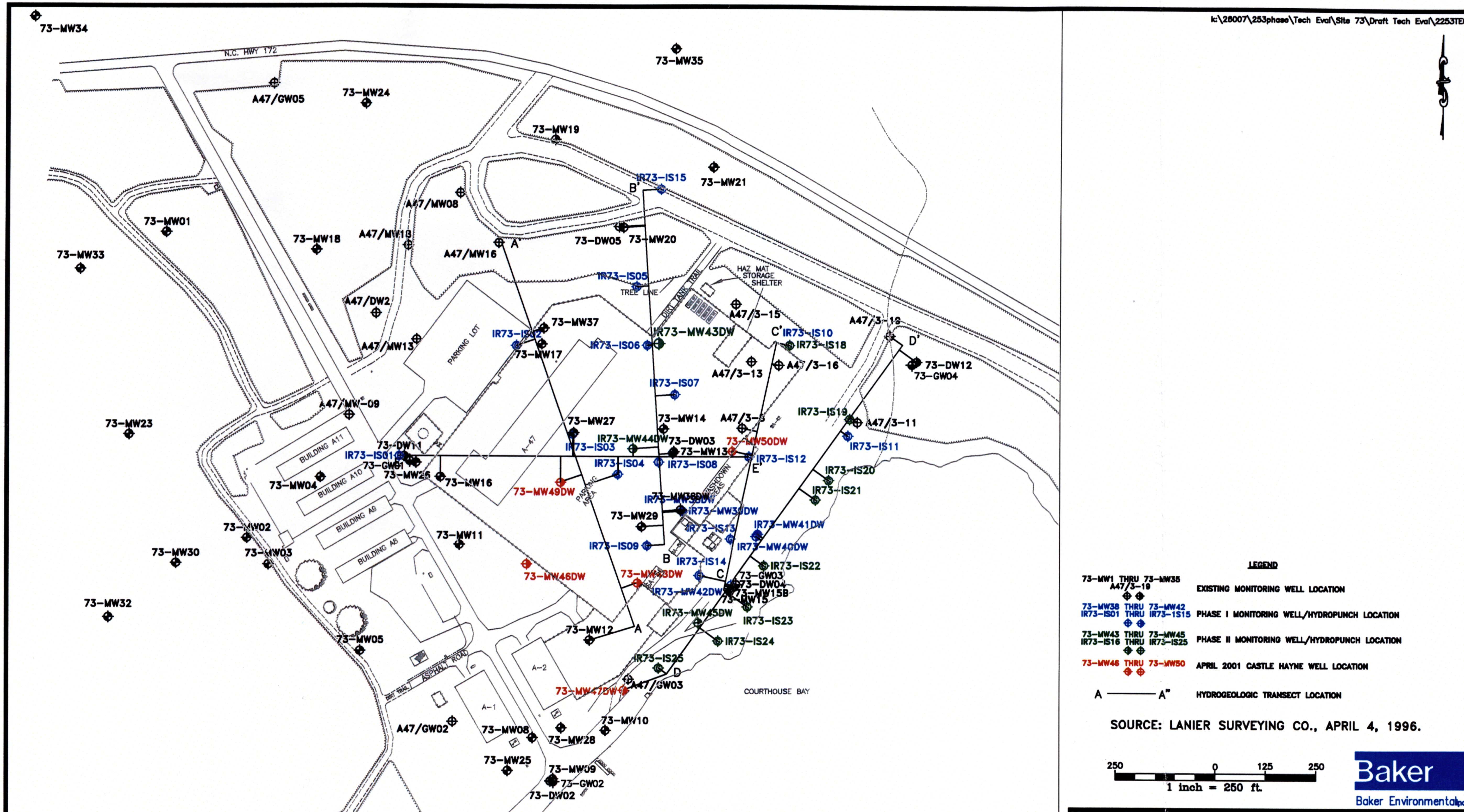
SITE 73

NOT TO SCALE

SOURCE: AERIAL FLY OVER 1996

FIGURE 2-1
SITE LOCATION
SITE 73, OU 21
AMPHIBIOUS VEHICLE MAINTENANCE FACILITY
TECHNOLOGY EVALUATION, CTO-0253
SEPTEMBER 2002

MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA



SOURCE: LANIER SURVEYING CO., APRIL 4, 1996.

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FIGURE 2-2
HYDROGEOLOGIC CROSS-SECTION LOCATION MAP
SITE 73, AMPHIBIOUS VEHICLE MAINTENANCE FACILITY
TECHNOLOGY EVALUATION, CTO - 0253
SEPTEMBER 2002

MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

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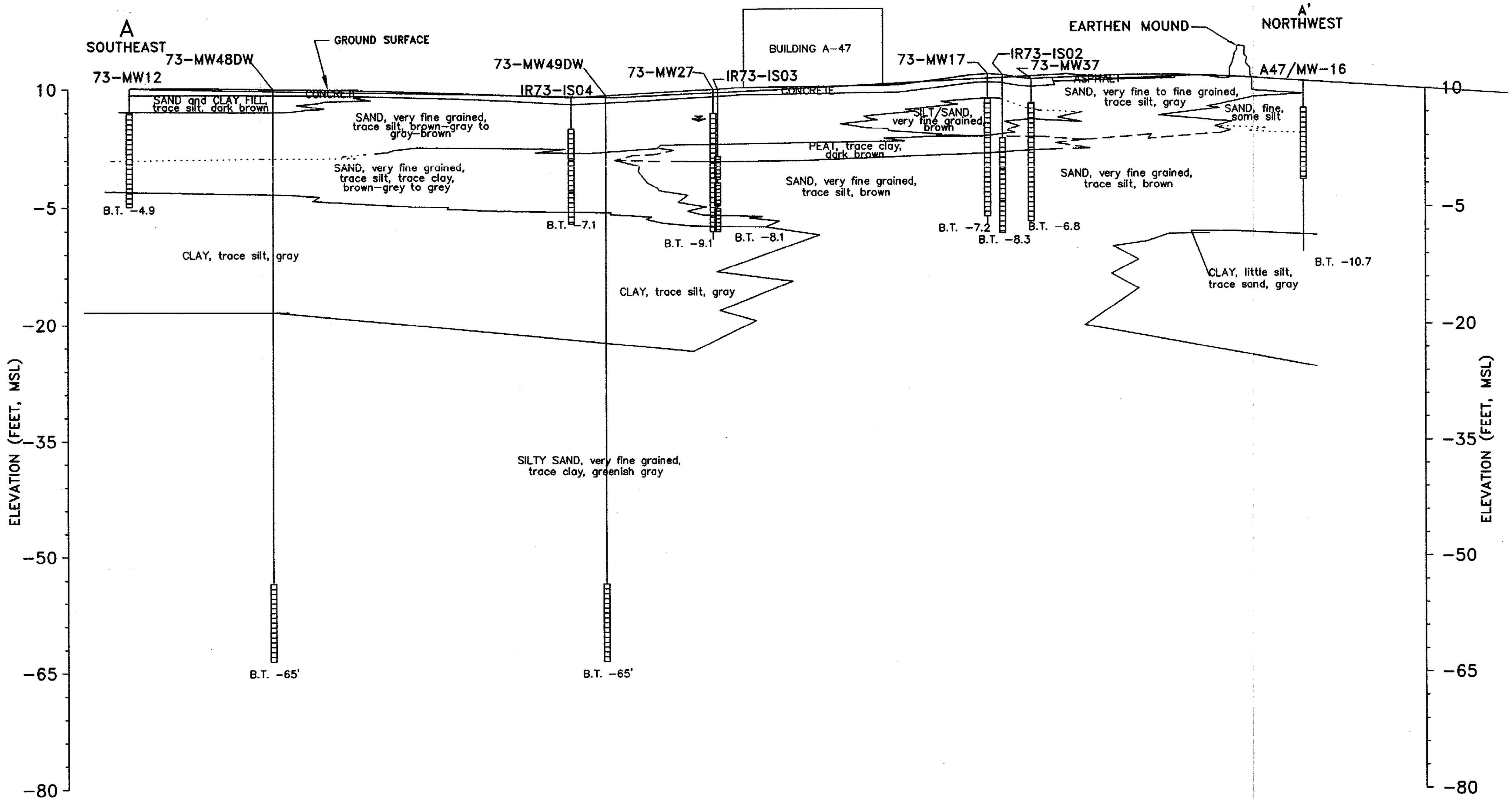


Baker
Baker Environmental Inc.

LEGEND

———	ESTIMATED CONTACT
— — —	PROJECTED CONTACT
········	GRADATIONAL CONTACT
▯	WELL SCREEN INTERVAL
B.T. -4.9'	BORING TERMINATED, ELEVATION MSL, UNLESS OTHERWISE NOTED
▼	GROUNDWATER LEVEL

100 0 50 100 200

Horizontal Scale: 1 inch = 100 ft.

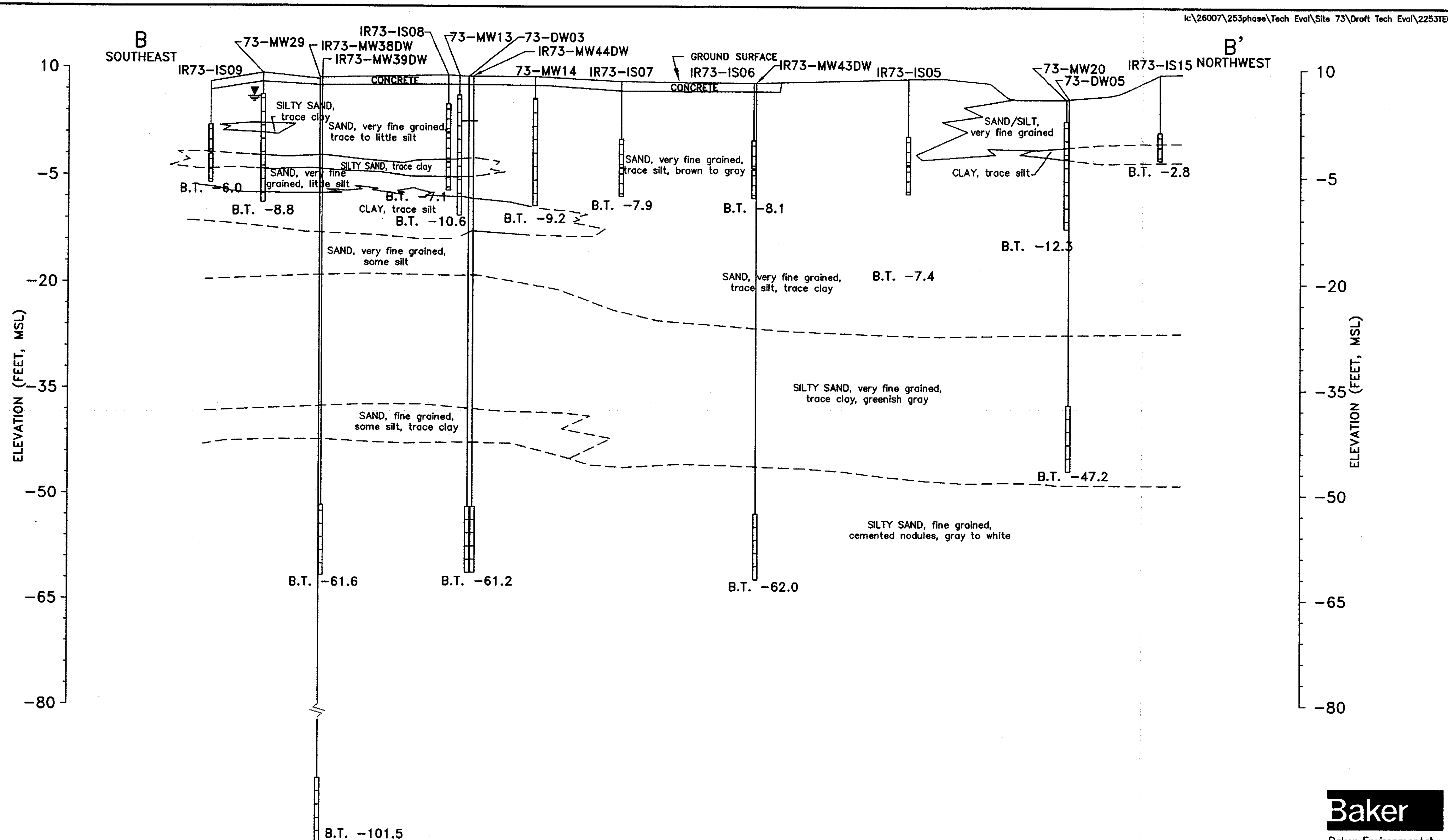
15 0 7.5 15 30

Vertical Scale: 1 inch = 15 ft.

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

FIGURE 2-3
HYDROGEOLOGIC CROSS-SECTION A-A'
SITE 73, AMPHIBIOUS VEHICLE MAINTENANCE FACILITY
TECHNOLOGY EVALUATION, CTO - 0253
SEPTEMBER 2002

MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA



LEGEND

- ——— ESTIMATED CONTACT
- — — — PROJECTED CONTACT
- ▯ WELL SCREEN INTERVAL
- B.T. -2.8' BORING TERMINATED, ELEVATION MSL
- ▼ GROUNDWATER LEVEL

100 0 50 100 200

Horizontal Scale: 1 inch = 100 ft.

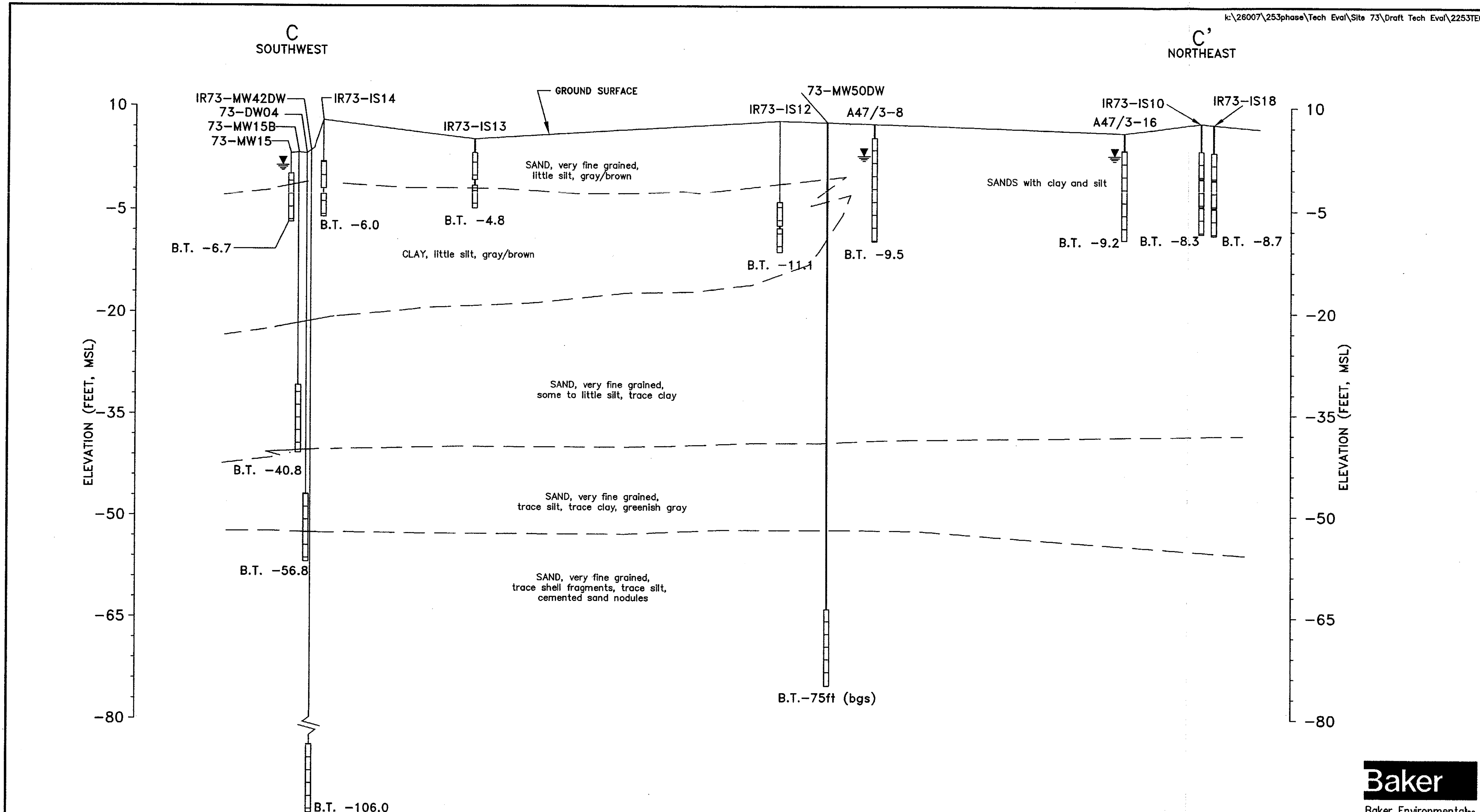
15 0 7.5 15 30

Vertical Scale: 1 inch = 15 ft.

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

FIGURE 2-4
HYDROGEOLOGIC CROSS-SECTION B-B'
SITE 73, AMPHIBIOUS VEHICLE MAINTENANCE FACILITY
TECHNOLOGY EVALUATION - CTO - 0253
SEPTEMBER 2002

MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA



LEGEND

- ESTIMATED CONTACT
- PROJECTED CONTACT
- WELL SCREEN INTERVAL
- B.T. X' — BORING TERMINATED, ELEVATION MSL, UNLESS OTHERWISE NOTED
- GROUNDWATER LEVEL

70 0 35 70 140

Horizontal Scale: 1 inch = 70 ft.

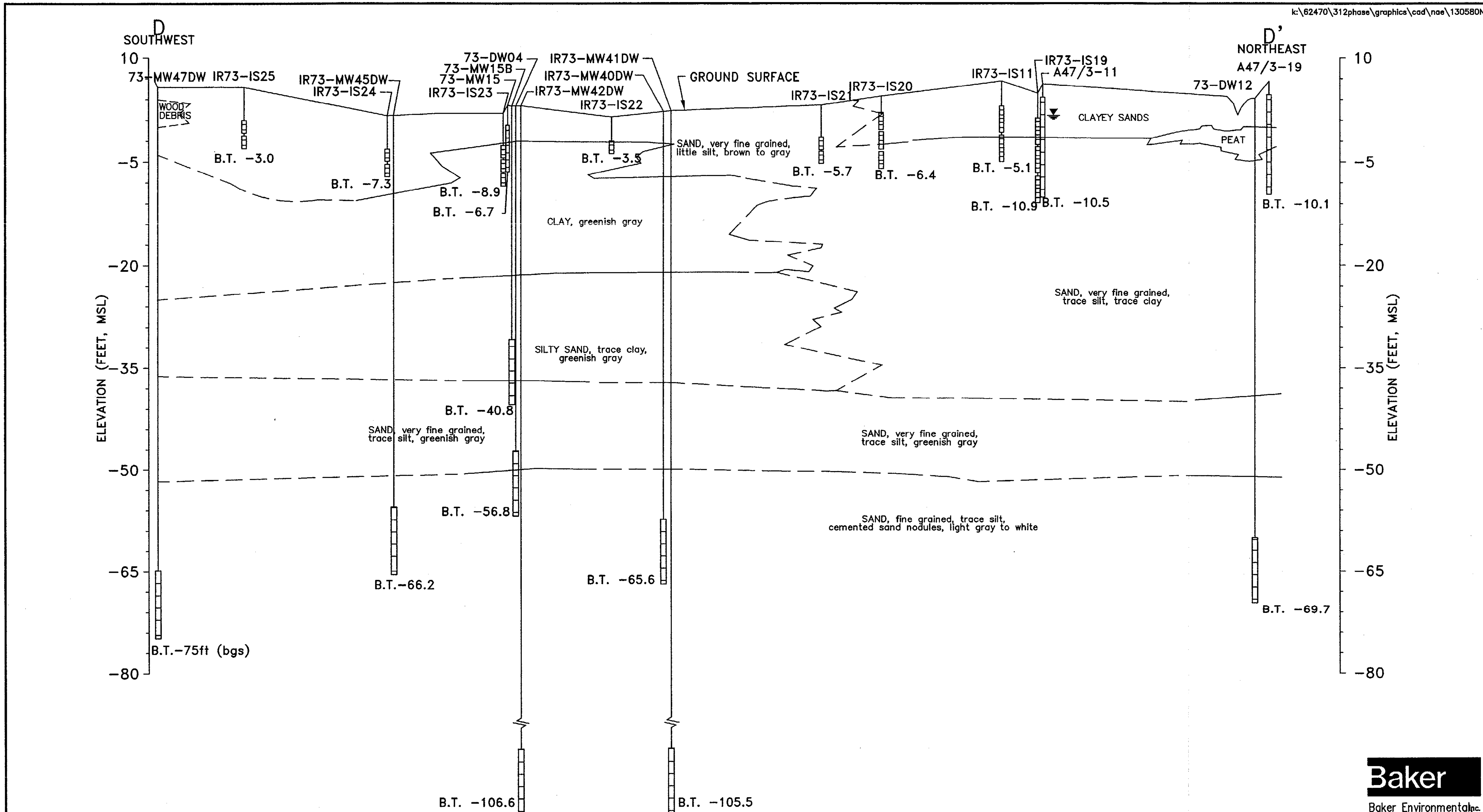
15 0 7.5 15 30

Vertical Scale: 1 inch = 15 ft.

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

FIGURE 2-5
HYDROGEOLOGIC CROSS-SECTION C-C'
SITE 73, AMPHIBIOUS VEHICLE MAINTENANCE FACILITY
TECHNOLOGY EVALUATION, CTO – 0253
SEPTEMBER 2002

MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA



LEGEND

———	ESTIMATED CONTACT
— —	PROJECTED CONTACT
▯	WELL SCREEN INTERVAL
B.T. 3.0'	BORING TERMINATED, ELEVATION MSL, UNLESS OTHERWISE NOTED
▽	GROUNDWATER LEVEL

100 0 50 100 200

Horizontal Scale: 1 inch = 100 ft.

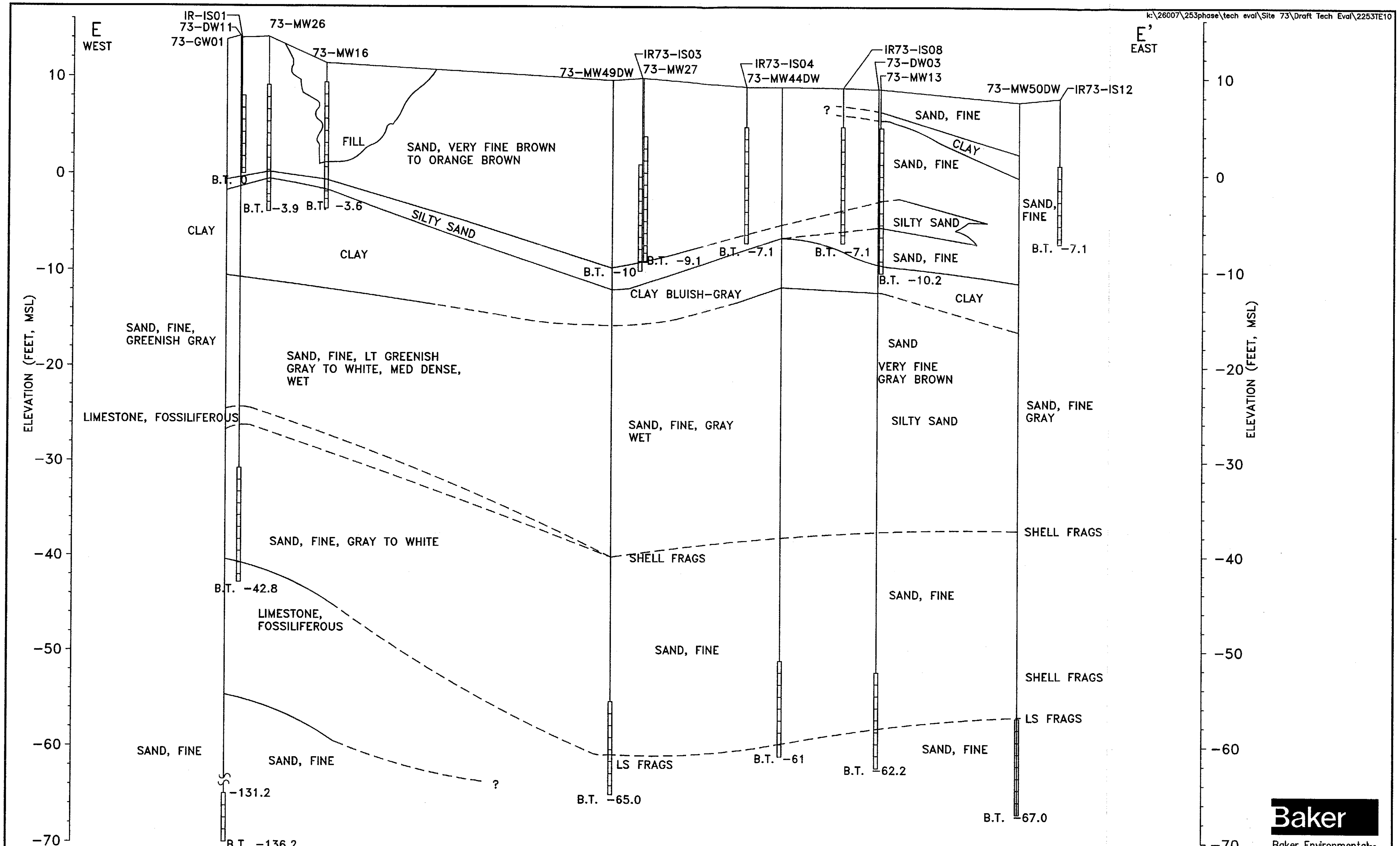
15 0 7.5 15 30

Vertical Scale: 1 inch = 15 ft.

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

FIGURE 2-6
HYDROGEOLOGIC CROSS-SECTION D-D'
SITE 73, AMPHIBIOUS VEHICLE MAINTENANCE FACILITY
TECHNOLOGY EVALUATION, CTO - 0253
SEPTEMBER 2002

MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA



Baker
Baker Environmental, Inc.

LEGEND

———	ESTIMATED CONTACT
— — —	PROJECTED CONTACT
▯	WELL SCREEN INTERVAL
B.T. -2.8'	BORING TERMINATED, ELEVATION MSL

100 0 50 100 200

Horizontal Scale: 1 inch = 100 ft.

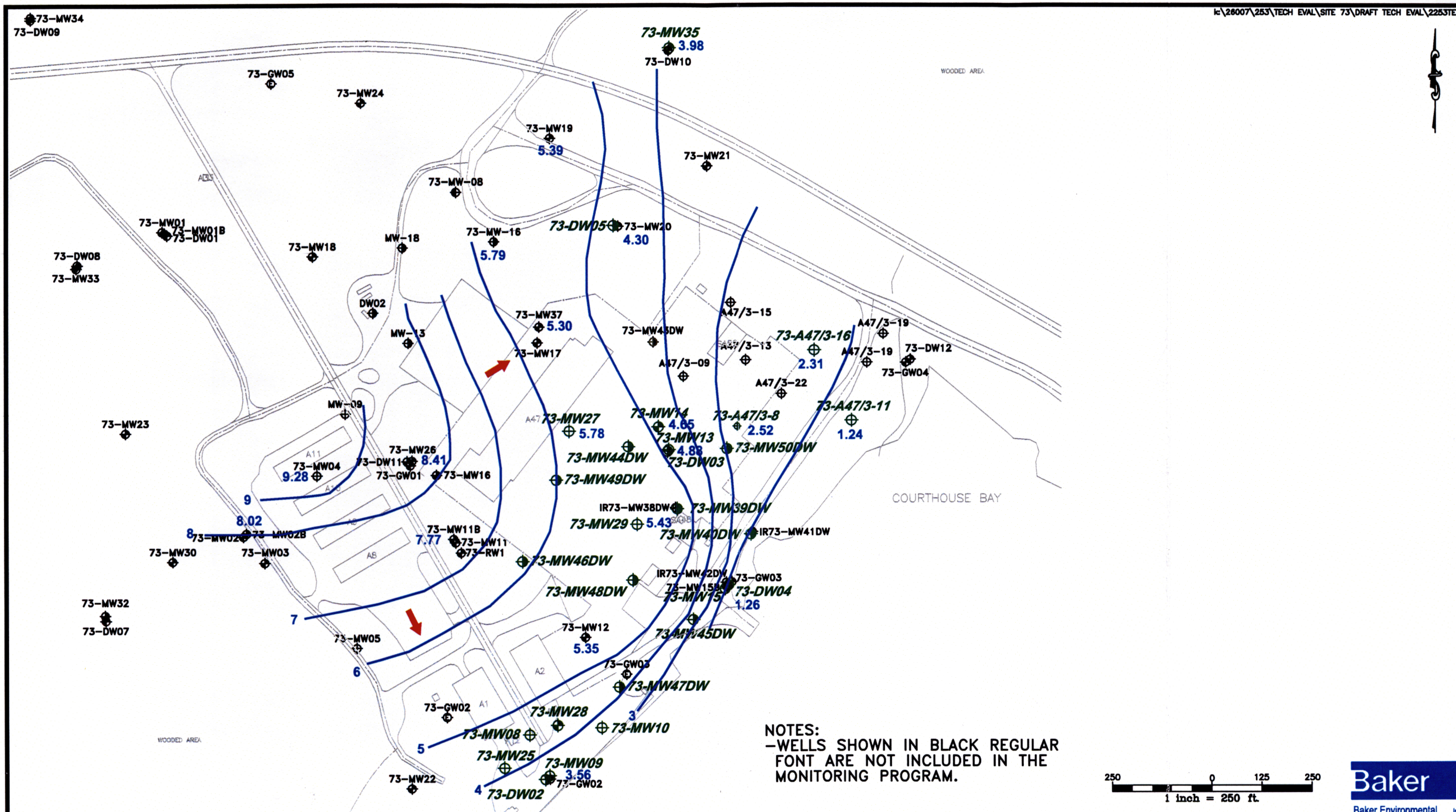
10 0 5 10 20

Vertical Scale: 1 inch = 10 ft.

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

FIGURE 2-7
HYDROGEOLOGIC CROSS-SECTION E-E'
SITE 73, AMPHIBIOUS VEHICLE MAINTENANCE FACILITY
TECHNOLOGY EVALUATION, CTO- 0253
SEPTEMBER 2002

MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA



NOTES:
-WELLS SHOWN IN BLACK REGULAR FONT ARE NOT INCLUDED IN THE MONITORING PROGRAM.

LEGEND

Symbol	Description
73-MW04	SHALLOW MONITORING WELL
9.28	STATIC WATER LEVEL COLLECTED ON 4/17/02
73-DW02	DEEP MONITORING WELL
(red arrow)	SHALLOW GROUNDWATER FLOW DIRECTION
(blue line)	GROUNDWATER CONTOUR LINE

SOURCE: MCB, CAMP LEJEUNE MARCH 2000

FIGURE 2-8
GROUNDWATER CONTOUR MAP
SURFICIAL AQUIFER – APRIL 2002
OPERABLE UNIT NO. 21 – SITE 73
TECHNOLOGY EVALUATION, CTO -0253
SEPTEMBER 2002
MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

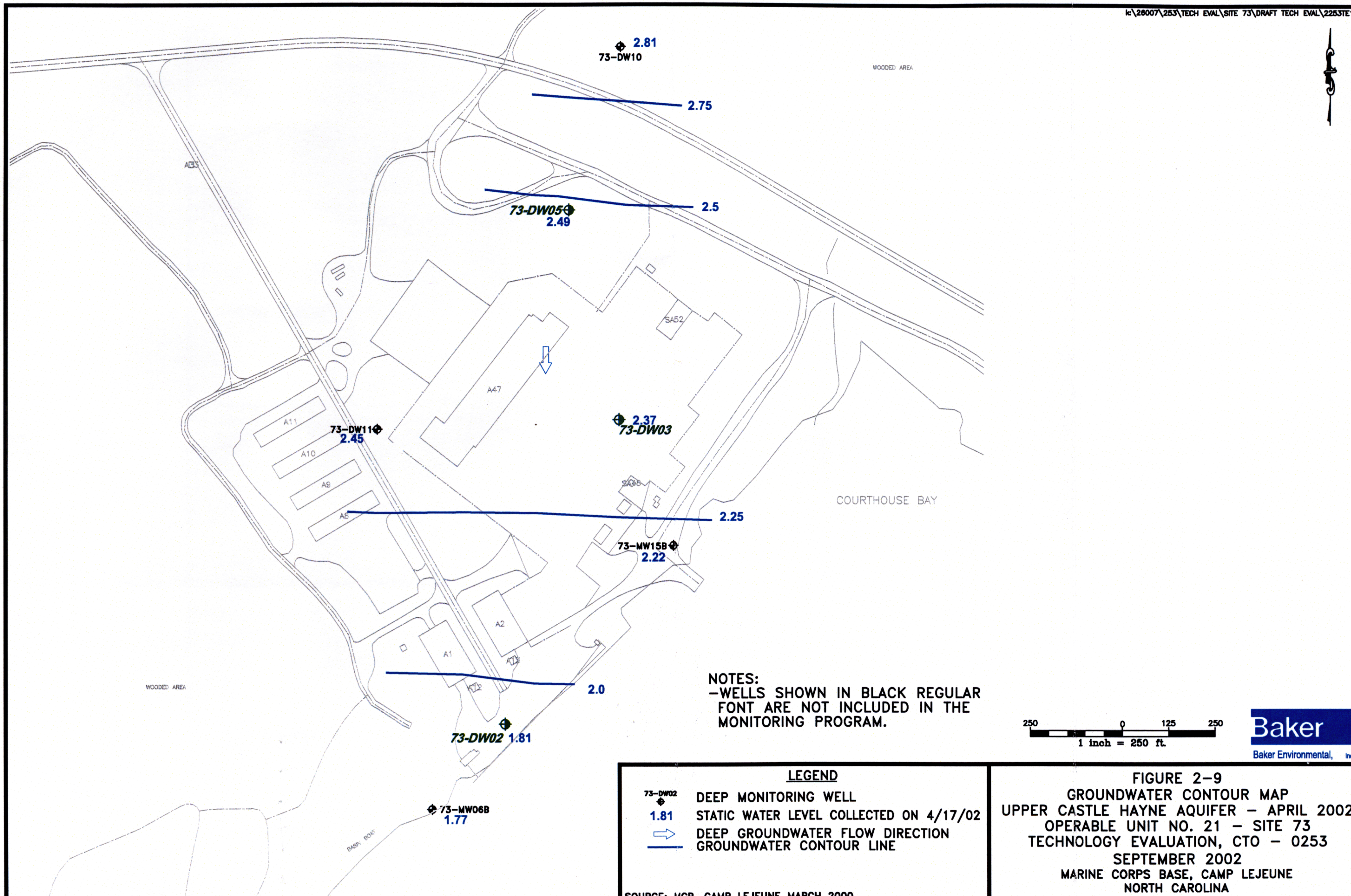
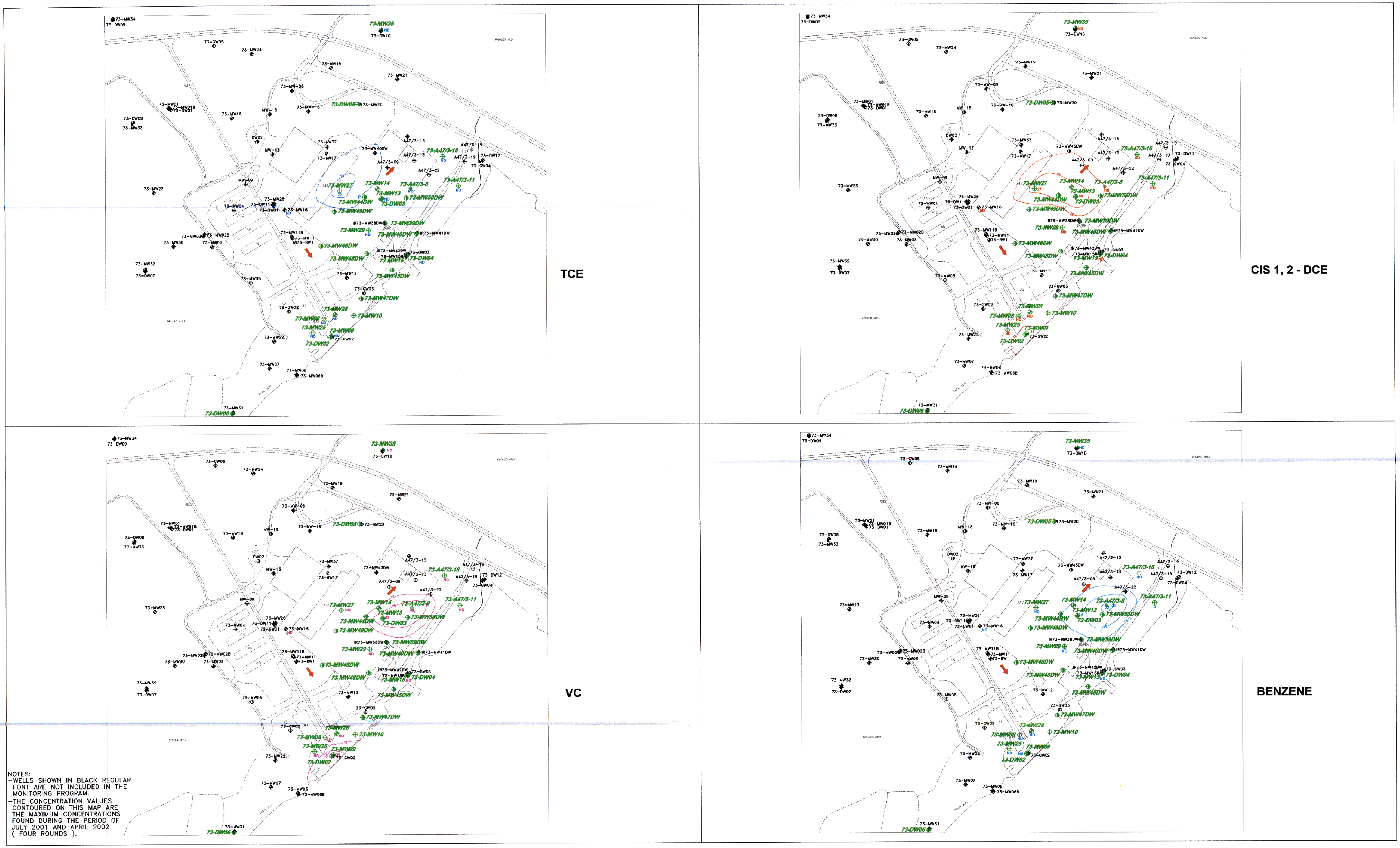


FIGURE 2-9
GROUNDWATER CONTOUR MAP
UPPER CASTLE HAYNE AQUIFER – APRIL 2002
OPERABLE UNIT NO. 21 – SITE 73
TECHNOLOGY EVALUATION, CTO – 0253
SEPTEMBER 2002
MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA



NOTES:
- WELLS SHOWN IN BLACK REGULAR FONT ARE NOT INCLUDED IN THE MONITORING PROGRAM.
- THE CONCENTRATION VALUES CONTOURED ON THIS MAP ARE THE MAXIMUM CONCENTRATIONS FOUND DURING THE PERIOD OF JULY 2001 AND APRIL 2002 (FOUR ROUNDS).

NOTE:
- 73-MW04 – SHALLOW MONITORING WELL
- 73-DW02 – DEEP MONITORING WELL
- → – SHALLOW GROUNDWATER FLOW DIRECTION
- ND – NOT DETECTED
- ~25~ – CONCENTRATION CONTOUR (ug/L)

SOURCE: MCB, CAMP LEJEUNE MARCH 2000

DRAWN	RRR/
REVIEWED	CLH\REB
S.O.#	26007-253
CADD#	2253TE11

K:\26007\253\TECH EVAL\SITE 73\DRAFT TECH

NORTH

MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

BAKER ENVIRONMENTAL, Inc.
Coraopolis, Pennsylvania

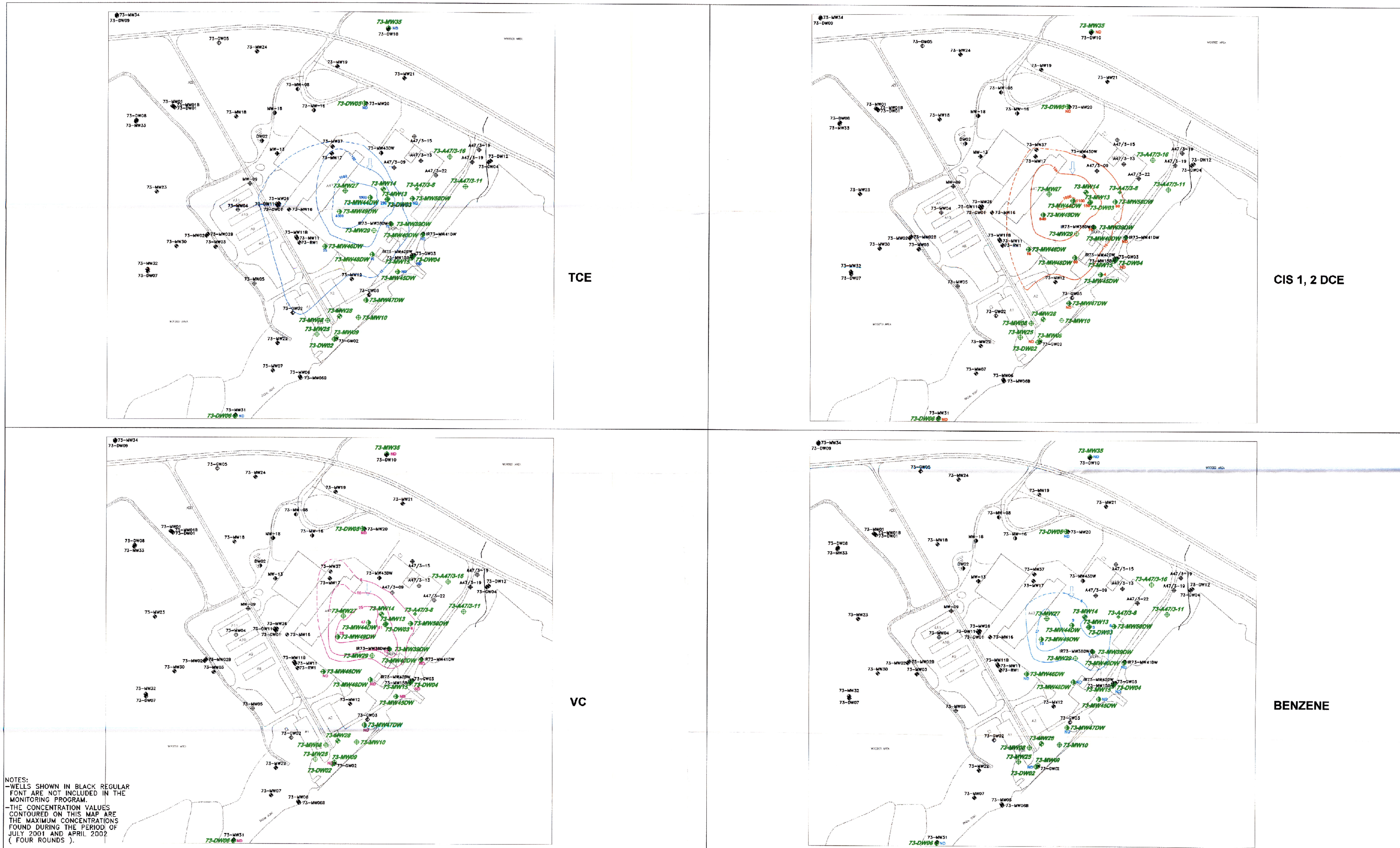
Baker

**GROUNDWATER CONCENTRATIONS
SURFICIAL AQUIFER
OPERABLE UNIT 21, SITE 73
TECHNOLOGY EVALUATION, CTO -0253, SEPT 2002**

SCALE 250 0 125 250 — 1 inch = 250 ft.

DATE September 12, 2002

FIGURE **2-10**



NOTE:
- SHALLOW MONITORING WELL
- DEEP MONITORING WELL
- DEEP GROUNDWATER FLOW DIRECTION
ND – NOT DETECTED
25 – CONCENTRATION CONTOUR (ug/L)

SOURCE: MCB, CAMP LEJEUNE MARCH 2000

DRAWN	RRR/
REVIEWED	CLH/REB
S.O.#	26007-253
CADD#	2253TE12

K:\26007\253\TECH EVAL\SITE 73\DRAFT TECH

NORTH

MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

BAKER ENVIRONMENTAL, Inc.
Coraopolis, Pennsylvania

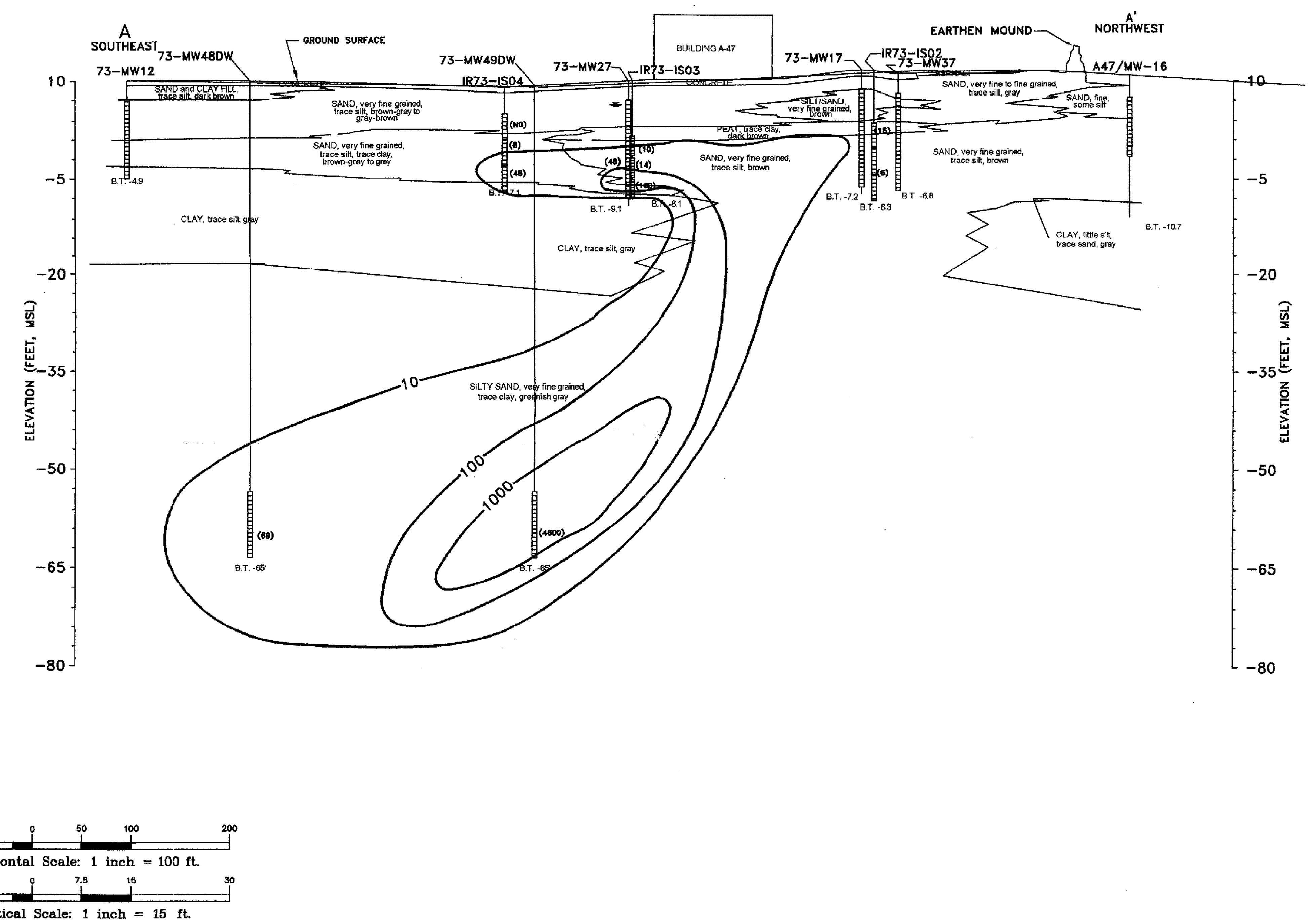
Baker Environmental, Inc.

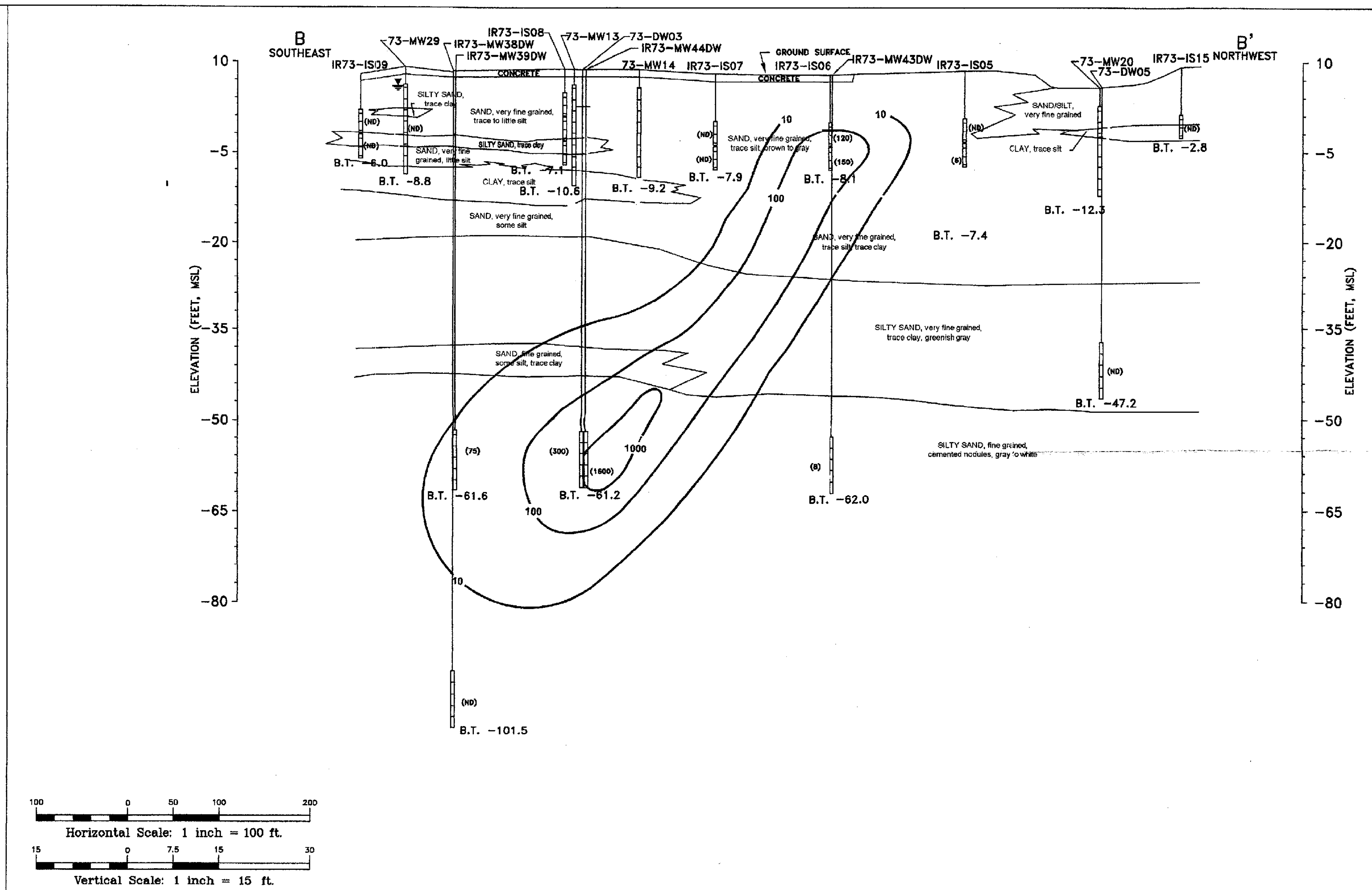
GROUNDWATER CONCENTRATIONS
CASTLE HAYNE AQUIFER
OPERABLE UNIT 21, SITE 73
TECHNOLOGY EVALUATION, CTO -0253

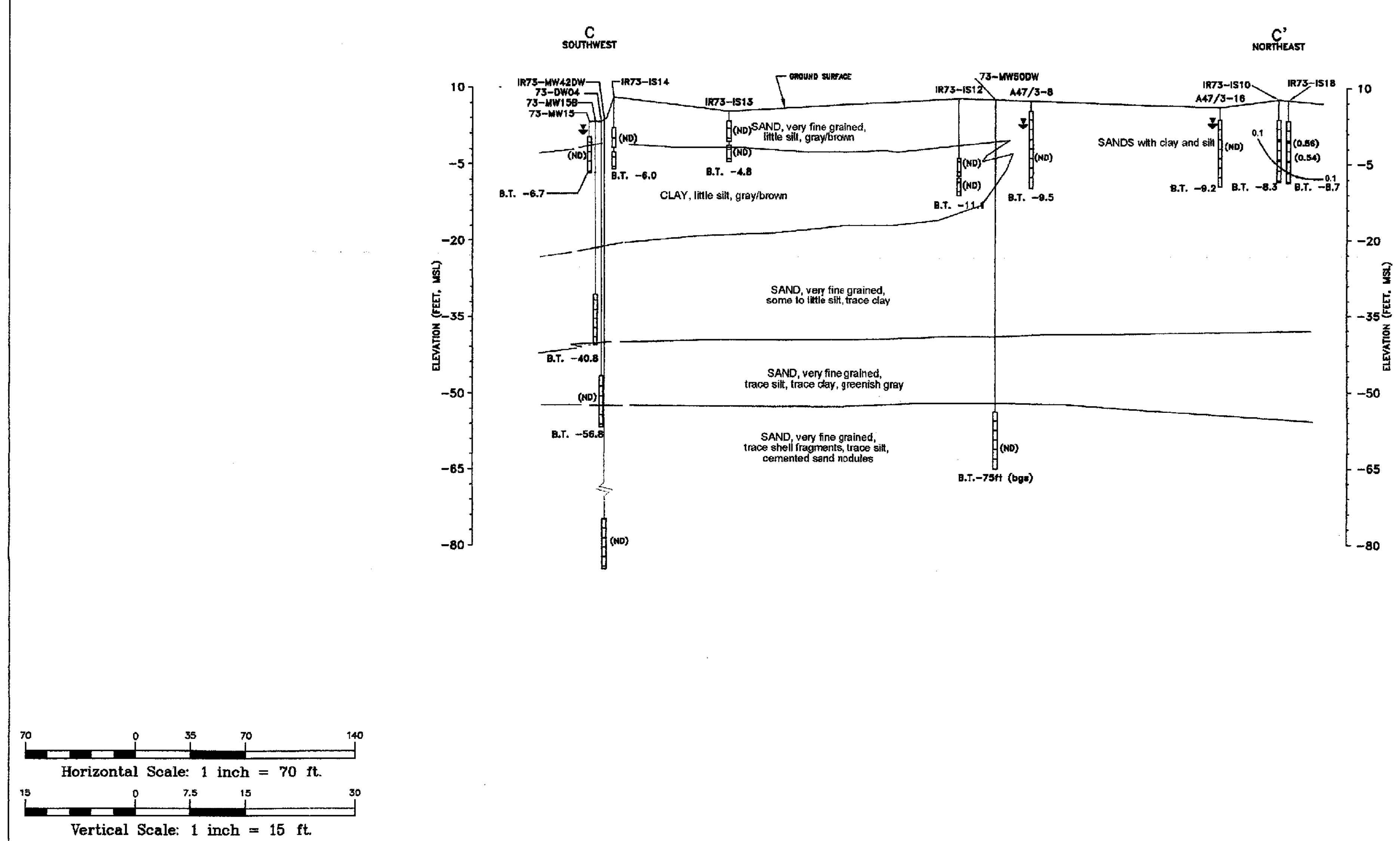
FIGURE 2-11

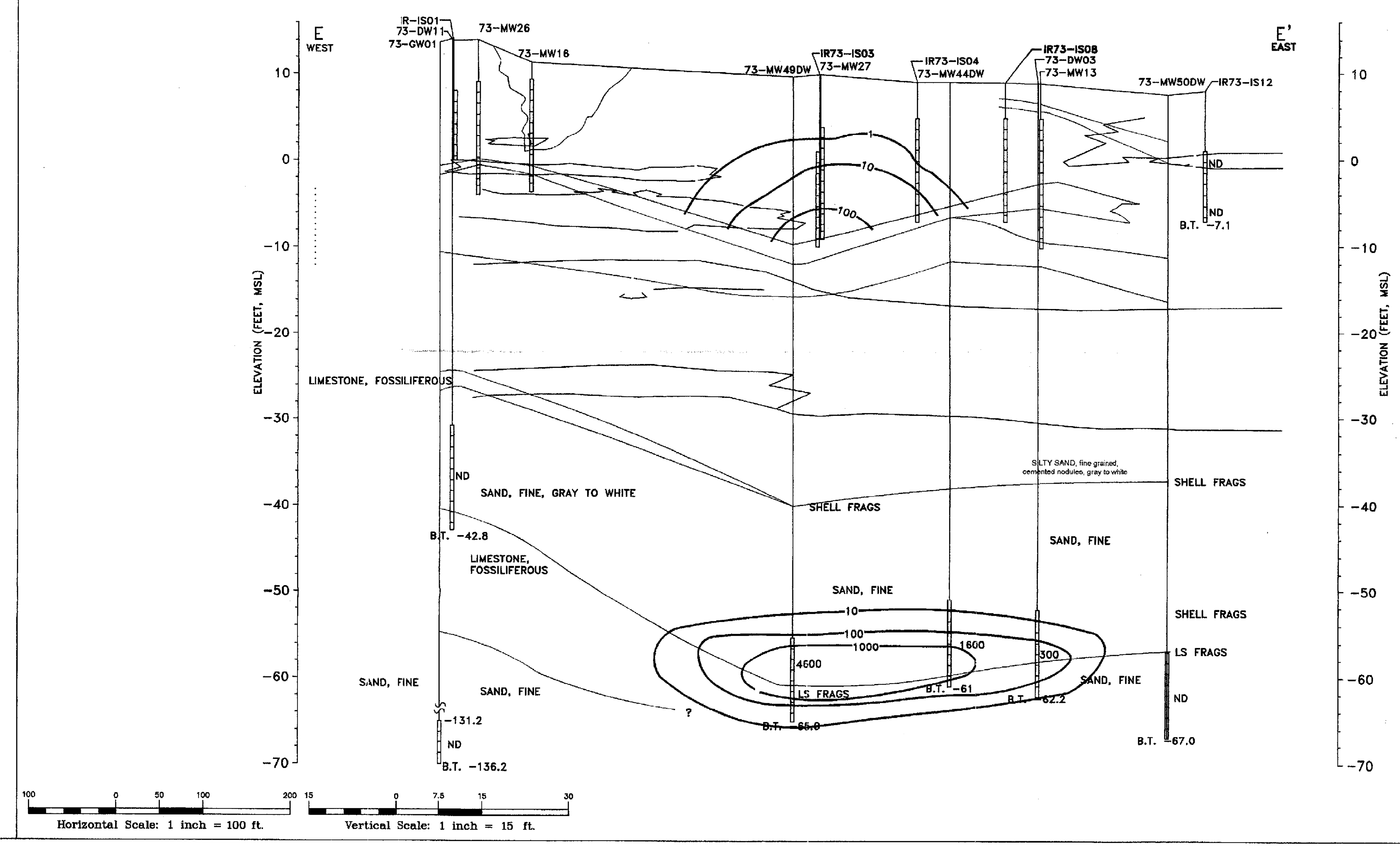
SCALE 1 inch = 250 ft.

DATE September 25, 2002









NOTE: CONCENTRATIONS SHOWN ARE THE MAXIMUM FOUND FROM 1998-2001 AND ARE IN ug/L.

LEGEND

- ESTIMATED CONTACT
- PROJECTED CONTACT
- WELL SCREEN INTERVAL
- B.T. -4.9' BORING TERMINATED, ELEVATION MSL, UNLESS OTHERWISE NOTED
- GROUNDWATER LEVEL

DRAWN	RRR/
REVIEWED	CLH\
S.O.#	26007-253
CADD#	2253TE01

K\26007\253\Tech Evaluation\site73\ Draft tech eval\

NORTH

MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

BAKER ENVIRONMENTAL, Inc.
Coraopolis, Pennsylvania

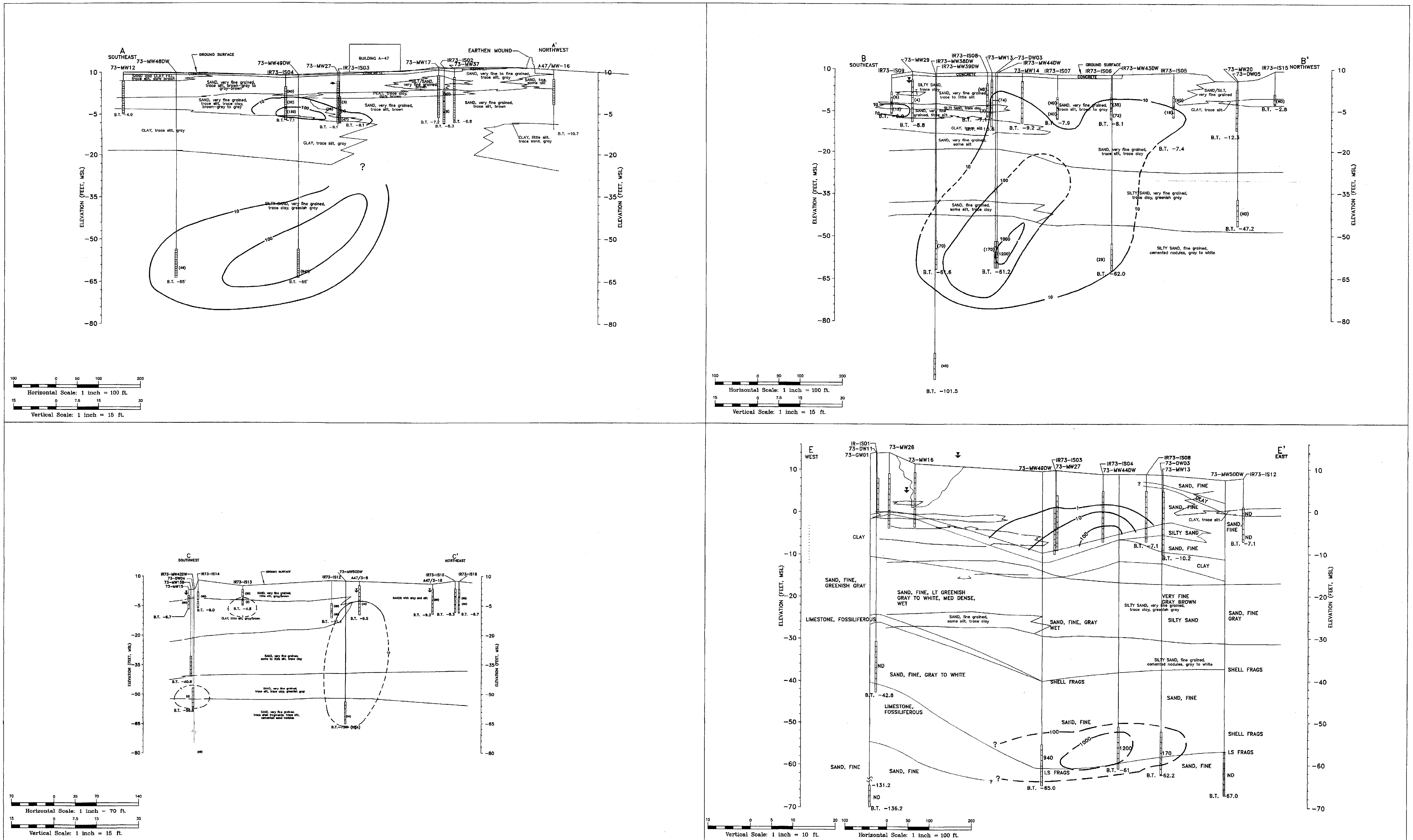
Baker

TRICHLOROETHENE
SITE 73, OU 21
AMPHIBIOUS VEHICLE MAINTENANCE FACILITY
TECHNOLOGY EVALUATION, CTO-0253
SEPTEMBER 2002

SCALE 1 inch = 250 ft.

DATE September 12, 2002

FIGURE
2-12



NOTE: CONCENTRATIONS SHOWN ARE THE MAXIMUM FOUND FROM 1998–2001 AND ARE IN ug/L.

LEGEND

- ESTIMATED CONTACT
- PROJECTED CONTACT
- WELL SCREEN INTERVAL
- B.T. -4.9' BORING TERMINATED, ELEVATION MSL, UNLESS OTHERWISE NOTED
- GROUNDWATER LEVEL

DRAWN	RRR/
REVIEWED	CLH\
S.O.#	26007-253
CADD#	2253TE02

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NORTH

MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

BAKER ENVIRONMENTAL, Inc.
Coraopolis, Pennsylvania

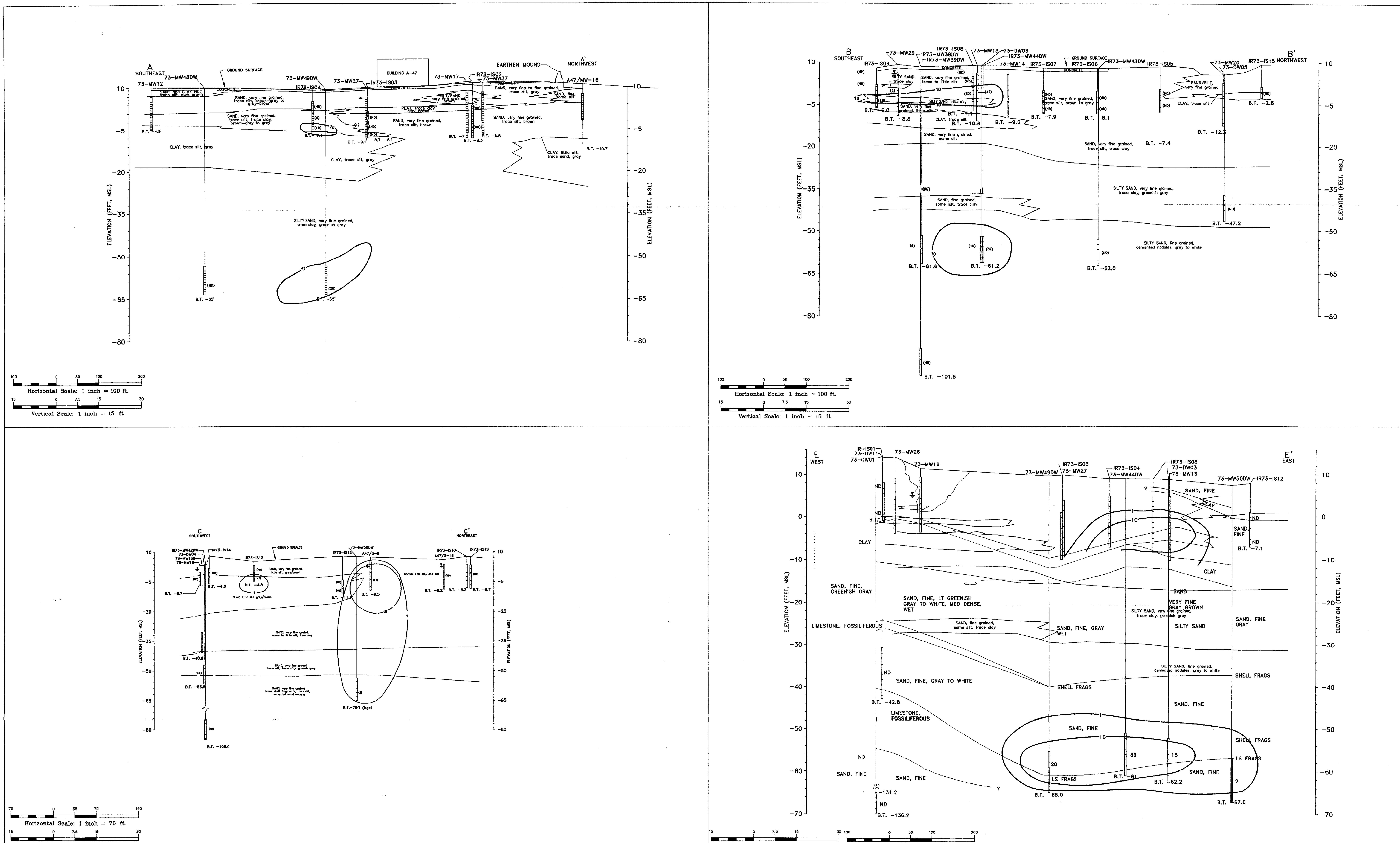
Baker

CIS 1,2-DICHLOROETHENE
SITE 73, OU 21
AMPHIBIOUS VEHICLE MAINTENANCE FACILITY
TECHNOLOGY EVALUATION, CTO-0253
SEPTEMBER 2002

SCALE AS NOTED

DATE September 12, 2002

FIGURE
2-13



NOTE: CONCENTRATIONS SHOWN ARE THE MAXIMUM FOUND FROM 1998-2001 AND ARE IN ug/L.

LEGEND

- ESTIMATED CONTACT
- PROJECTED CONTACT
- WELL SCREEN INTERVAL
- B.T. -4.9' BORING TERMINATED, ELEVATION MSL, UNLESS OTHERWISE NOTED
- GROUNDWATER LEVEL

DRAWN	RRR/
REVIEWED	CLH\
S.O.#	26007-253
CADD#	2253TE03

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NORTH

MARINE CORPS BASE, CAMP LEJEUNE
NORTH CAROLINA

BAKER ENVIRONMENTAL, Inc.
Coraopolis, Pennsylvania

Baker

VINYL CHLORIDE
SITE 73, OU 21
AMPHIBIOUS VEHICLE MAINTENANCE FACILITY
TECHNOLOGY EVALUATION, CTO-0253
SEPTEMBER 2002

SCALE AS NOTED

DATE September 12, 2002

FIGURE
2-14

Baker

Baker Environmental, Inc.

Appendix A: Cost Backup

MONITORING WELL INSTALLATION COST ESTIMATE

for

CAMP LEJEUNE, NC, SITE 73

Block B

Baker

MICHAEL BAKER JR., INC.
CONSULTING ENGINEERS
CORAOPOLIS, PENNSYLVANIA

Computed By: MKD | Date: September 16, 2002
Checked By: | Date:

ITEM NO.	ITEM	QTY.	UNIT	UNIT PRICE	ITEM PRICE	SOURCE
1	Mobilization/Demobilization (truck-mounted rig)	1	each	$500.00	$500.00	Based on Parratt-Wolff BOA costs
2	Drilling Hollow Stem Augers - 8-1/4" (0-20 Ft)	160	L.F.	$28.00	$4,480.00	Based on Parratt-Wolff BOA costs
3	Mud Rotary - 6" (20-50 Ft)	240	L.F.	$13.00	$3,120.00	Based on Parratt-Wolff BOA costs
4	Mud Rotary - 6" (>50 Ft)	160	L.F.	$25.00	$4,000.00	Based on Parratt-Wolff BOA costs
5	Split Spoon Sample (0-50 Ft)	80	each	$15.00	$1,200.00	Based on Parratt-Wolff BOA costs
6	Split Spoon Sample (>50 Ft)	32	each	$25.00	$800.00	Based on Parratt-Wolff BOA costs
7	6" Casing, Installed	160	L.F.	$30.00	$4,800.00	Based on Parratt-Wolff BOA costs
8	Monitoring Well Construction (Type III Well)	560	L.F.	$16.50	$9,240.00	Based on Parratt-Wolff BOA costs
9	2" Dia. PVC, Schedule 40, Well Casing, Standard Length 10'	520	L.F.	$1.25	$650.00	Based on Parratt-Wolff BOA costs
10	2" Dia. PVC, Schedule 40, Well Screen (10ft.)	8	each	$20.00	$160.00	Based on Parratt-Wolff BOA costs
11	Flush-mount Protective cover (for 2" well)	8	each	$140.00	$1,120.00	Based on Parratt-Wolff BOA costs
12	Well Development (labor & equip)	16	hour	$65.00	$1,040.00	Based on Parratt-Wolff BOA costs
13	55-Gallons Drums	20	each	$65.00	$1,300.00	Based on Parratt-Wolff BOA costs
14	Per diem (2 man crew)	16	day	$95.00	$1,520.00	Based on Parratt-Wolff BOA costs
15	Drum Management	4	hour	$150.00	$600.00	Based on Parratt-Wolff BOA costs
16	Temporary Decon Pad	1	each	$200.00	$200.00	Based on Parratt-Wolff BOA costs
	BUDGETARY MONITORING WELL INSTALLATION ESTIMATE				**$34,730**	

Monitoring Well Installation costs and material estimates are based on the following assumptions:

- * Assuming the depth of all eight wells will be 70 foot deep Type III wells
- * Assuming a backhoe will not be needed for the site
- * Assuming 8 monitoring wells will take 16 days to install
- * Shaw Environmental will handle IDW sampling and disposal
- 2 Auger to confining layer for casing installation
- 3 & 4 Assuming mud rotary for remainder of hole
- 5 & 6 For geologic classification
- 7 Assuming time and materials
- 8 Monitoring well construction is assembling the well
- 10 Assuming 10 ft of screen for each well. Price is for material only.

GROUNDWATER MONITORING EVENT
BUDGETARY COST ESTIMATE
MARINE CORPS BASE, CAMP LEJEUNE, NORTH CAROLINA

Cost Item	Quantity	Units	Unit Cost	Total Cost	Assumptions (Basis of Cost Estimate)
ANNUAL GROUNDWATER MONITORING COSTS					
I. Groundwater Monitoring (One Event)					
A. Groundwater Sampling - Labor	1	event	$4,717	$4,717	2 geologists @$45/hr; 10 hrs per day; for 3 days, plus travel expenses. Refer to Block A for itemized costs.
B. Equipment Costs	1	event	$1,000	$1,156	Pumps, tubing, and other equipment needed to sample wells. Refer to Block B for itemized costs.
B. Sample Analysis	12	Ea	$90	$1,080	TCL VOC, analysis; 10 samples plus 1 MS/MSD and 1 duplicate and trip blanks
C. Data Management				$375	25 hours at T2 level
TOTAL PROJECT COST SUMMARY				**$7,328**	

Notes:

Cost estimates are based on previous groundwater monitoring work at Camp Lejeune and engineering judgement.
Costs are for sampling 10 monitoring wells at MCB, Camp Lejeune.

BLOCK A
GROUNDWATER SAMPLING EVENT TRAVEL AND LABOR COSTS
MARINE CORPS BASE, CAMP LEJEUNE, NORTH CAROLINA

Monitoring Event Travel Costs

		People/units		Rate		Days/trips		Total
Perdiem @ $30 per day		2	x	$30.00	x	3	=	$180.00
Airfares		2	x	$500.00	x	1	=	$1,000.00
Hotel nights		2	x	$55.00	x	3	=	$330.00
Cargo van/Car rentals		1	x	$65.00	x	1	=	$65.00
Aiport Parking		2	x	$7.00	x	3	=	$42.00
								$1,617.00

Monitoring Event Labor Costs

		People/units		Rate		Hour		Days		Total
Geologist		2	x	$45.00	x	10	x	3	=	$2,700.00
										$2,700.00

Miscellaneous Travel and Labor Costs

		People/units		Rate		Total
Miscellaneous		2	x	$200.00	=	$400.00
						$400.00

Total Travel and Labor Field Costs = $4,717.00

BLOCK B
GROUNDWATER SAMPLING EVENT EQUIPMENT COSTS
MARINE CORPS BASE, CAMP LEJEUNE, NORTH CAROLINA

Equipment	**Rate**	**Units**	**Subtotal**
Peristaltic Pump	$7.00	2	$14.00
Horiba	$20.00	2	$40.00
Redox meter	$6.00	2	$12.00
Water Level Meter	$4.00	2	$8.00
H&S Expendables	$40.00	12	$480.00
Two-Way Radio	$7.00	2	$14.00
Log-Book	$4.00	2	$8.00
per sample			
Sampling Expendables	$15.00	12	$180.00
Site Totals			$756.00
Miscellaneous Costs			$400.00

Total $1,156.00

HRC Design Software for Plume Area/Grid Treatment

Regenesis Technical Support: USA (949) 366-8000, www.regenesis.com

Site Name: Site 78
Location: Plume 3A
Consultant:

Site Conceptual Model/Extent of Plume Requiring Remediation

Width of plume (intersecting gw flow direction)	200	ft		
Length of plume (parallel to gw flow direction)	200	ft	=	40,000
Depth to contaminated zone	55	ft		
Thickness of contaminated saturated zone	20	ft		
Nominal aquifer soil (gravel, sand, silty sand, silt, clay)	silty sand			
Total porosity	0.3		Eff. porosity:	0.25
Hydraulic conductivity	50	ft/day	=	1.8E-02
Hydraulic gradient	0.00075	ft/ft		
Seepage velocity	54.8	ft/yr	=	0.150
Treatment Zone Pore Volume	240,000	ft^3	=	1,795,440

Dissolved Phase Electron Donor Demand

	Contaminant Conc (mg/L)	Contaminant Mass (lb)	Stoich. (wt/wt) contam/H_2
Tetrachloroethene (PCE)	0.00	0.0	20.7
Trichloroethene (TCE)	3.00	44.9	21.9
cis-1,2-dichloroethene (DCE)	1.00	15.0	24.2
Vinyl Chloride (VC)	0.05	0.7	31.2
Carbon tetrachloride	0.00	0.0	19.2
Chloroform	0.00	0.0	19.9
1,1,1-Trichloroethane (TCA)	0.00	0.0	22.2
1,1-Dichlorochloroethane (DCA)	0.01	0.1	24.7
Hexavalent Chromium	0.00	0.0	17.3
User added, also add stoichiometric demand	0.00	0.0	0.0
User added, also add stoichiometric demand	0.00	0.0	0.0

Sorbed Phase Electron Donor Demand

Soil bulk density	1.76	g/cm^3	=	110
Fraction of organic carbon: foc	0.005	range: 0.0001 to 0.01		

(Values are estimated using Soil Conc=foc*Koc*Cgw)
(Adjust Koc as nec. to provide realistic estimates)

	Koc (L/kg)	Contaminant Conc (mg/kg)	Contaminant Mass (lb)	Stoich. (wt/wt) contam/H_2
Tetrachloroethene (PCE)	263	0.00	0.0	20.7
Trichloroethene (TCE)	107	1.61	141.1	21.9
cis-1,2-dichloroethene (DCE)	80	0.40	35.2	24.2
Vinyl Chloride (VC)	2.5	0.00	0.1	31.2
Carbon tetrachloride	110	0.00	0.0	19.2
Chloroform	34	0.00	0.0	19.9
1,1,1-Trichloroethane (TCA)	183	0.00	0.0	22.2
1,1-Dichlorochloroethane (DCA)	183	0.01	0.7	24.7
User added, also add stoichiometric demand	0	0.00	0.0	0.0
User added, also add stoichiometric demand	0	0.00	0.0	0.0

Competing Electron Acceptors

	Electron Acceptor Conc (mg/L)	Electron Acceptor Mass (lb)	Stoich. (wt/wt) elec acceptor/H_2
Oxygen	0.10	1	8.0
Nitrate	0.00	0	12.4
Est. Mn reduction demand (potential amt of Mn2+ formed)	5.00	75	27.5
Est. Fe reduction demand (potential amt of Fe2+ formed)	5.00	75	55.9
Estimated sulfate reduction demand	30.00	449	12.0

Microbial Demand Factor	3	Recommend 1-4x
Safety Factor	3	Recommend 1-4x

Injection Point Spacing and Dose:

Injection spacing within rows (ft)	15.0	# points per row:	14
Injection spacing between rows (ft)	25.0	# of rows:	8
Advective travel time bet. rows (days)	167	Total # of points:	112
		Minimum req. HRC dose per foot (lb/ft)	5.1

Project Summary			
Number of HRC delivery points (adjust as nec. for site)			112
HRC Dose in lb/foot (adjust as nec. for site)			5.1
Corresponding amount of HRC per point (lb)			101
Number of 30 lb HRC Buckets per injection point			3.4
Total Number of 30 lb Buckets			379
Total Amt of HRC (lb)			11,370
HRC Cost		$	5.50
Total Material Cost		**$**	**62,535**
Shipping and Tax Estimates in US Dollars			
Sales Tax	rate: 6%	$	3,752
Total Matl. Cost		$	66,287
Shipping of HRC (call for amount)		$	-
Total Regenesis Material Cost		**$**	**66,287**

September 16, 2002

Christine L. Harwood
Baker Environmental, Inc.
Airport Office Park
420 Rouser Rd.
Coraopolis, PA 15108

RE: Budgetary Estimate for Injection of Zero Valent Iron and HRC®
Baker Environmental, Inc.
Camp Lejeune, North Carolina

Dear Ms. Harwood:

ARS is pleased to provide Baker Environmental Inc. (Baker), with this budgetary cost estimate for our patented Pneumatic Fracturing (PF) and Liquid Atomization Injection (LAI) services. ARS has provided herein budgetary estimates using treatment alternatives for both zero-valet iron (ZVI) and HRC® for full-scale application at the above referenced site.

The budgetary estimates provided herein are based upon data provided to us, using the following major assumptions:

- An area of approximately 40,000 square feet (200 ft by 200 ft) is targeted for treatment and the treatment depth interval is from 65 to 75 ft bgs.
- The main contaminants are TCE, cis-1,2-DCE and VC at concentrations of 3,000 ug/L, 1,200 ug/L and 40 ug/L, respectively.
- The geology at the 65 to 75 ft depth interval consists of saturated, fine sand with an assumed porosity of 0.25 (Freeze and Cherry, 1979).
- At pressures ranging from approximately 100 to 300 psi and nitrogen gas injection flow rates of approximately 1,000 cfm, an injection radius of influence (ROI) of 25 ft is achievable, resulting in the need for 21 injection points.
- An iron to total VOC mass (TCE, cis-1,2-DCE and VC) ratio of 4000:1 was used to calculate the iron dosage, resulting in 109,000 lbs of iron.
- 12,000 lbs of HRC® are required, according to calculations performed by Baker. Baker will provide all HRC®, the cost of which is not included herein.

- Baker will install the injection points using a direct push method, in accordance with ARS guidelines, the costs of which are not included herein. Baker will also conduct all necessary grouting and surveying of boreholes.
- All pre- and post-monitoring will be conducted by Baker
- Building structures are not present within the immediate vicinity of the injection locations.
- All utilities will be located and marked by Baker.
- 120V power and a potable water source are available at the site.
- Baker will conduct all permitting.
- All soil cuttings and waste generated during the project will the responsibility of Baker.
- Complete and unhindered access to the project site is available.
- The work will be conducted during normal working hours, in Level D PPE and any time period except June 1 through September 14.
- The budgetary costs provided include work plans, health and safety plans, project management, reporting, royalty charges associated with the PF technology and all necessary labor, equipment and materials (except those outlined) needed to complete the project.

The budgetary cost for completing the HRC® injections is roughly $145,000 (does not include HRC®) and for completing the Ferox^{SM} application is roughly $355,000 (includes ZVI). Although there appears to be a significant difference in the two budgetary estimates, it should be noted that Ferox^{SM} applications typically require only one injection while HRC® applications may require two or more injections.

Factors that may impact the above budgetary cost estimates include the following:

- The quantity of ZVI powder required to reduce contaminant concentrations can impact costs. ARS has significant experience using ZVI to reduce TCE and has found historically that anywhere from 400:1 to 4000:1 iron to mass ratio results in the desired contaminant reduction. A design incorporating a laboratory treatability study may better indicate where the dosage ratio falls in this range. Since the iron powder cost comprises a significant portion of the technology cost (approx. 1/3 the cost), optimization through a design and treatability testing, along with a pilot test will ensure the full-scale system is applied cost effectively. The treatability test and design costs $15,000 to $25,000, depending upon the duration of the study, how much QA/QC is required, how many iron to mass ratios are tested and reporting requirements.

- The injection point spacing, ROI and drilling method also impact the cost. ARS has been able to achieve a ROI in similar materials and depths ranging from 40 to 50 feet using the Ferox^{SM} process. ARS achieved an injection ROI of 40 ft at a DOD site in Alabama, where an overlying clay unit was present. The type of drilling method also plays an important role with respect to cost. ARS typically uses a direct-push method, which keeps drilling costs to a minimum. The implementation of a field pilot study will generate data to optimize the site-specific injection ROI, injection spacing, drilling method, nitrogen usage, and installation timeframe. A field pilot study would cost roughly $40,000 to $60,000 depending upon how many points are tested, how many injection pressures and flows are tested, the amount of ZVI used, the amount of nitrogen used, ROI verification methods and other factors.

We hope this information satisfies your needs. If you have any questions or concerns regarding this budgetary estimate, please feel free to contact John Liskowitz (732 296-6620) or myself (919 969 9961).

We appreciate the opportunity to be of service to you.

Sincerely,

David Wagner, P.G.
Southeast Regional Manager

c: John Liskowitz

C:Proposals/Baker/Deep Zone Ferox Estimate

HRC with GEOPROBE INJECTION COST BACKUP
SITE 73 TECHNOLOGY EVALUATION
CTO- 0253
SEPTEMBER 2002

HRC		
HRC material, 12,000 lbs	$66,287	Regenesis spreadsheet
HRC shipping	$1,600	verbal quote from Regenesis
HRC total	$67,887	
Geoprobe--15 Days	$28,500	based on verbal quote from Vironex, 800 lbs per day, $1900/day
Geoprobe--per diem	$2,625	Vironex, $175/day
Geoprobe--mob/demob	$300	Vironex verbal quote, from Raleigh, NC
Geoprobe total	$31,425	
Total	**$99,312**	

Other costs		
monitoring wells--8 new	$34,730	based on BOA from Parratt-Wolfe
sampling for one year	$36,640	based on 5 sampling events on 10 wells using LTM costs
reporting--work plan	$25,000	based on IPFP for CTO 253 for Site 78
labor, travel and ODC's--implementation	$73,210	based on IPFP for CTO 253 for Site 78
reporting--interim report	$15,000	based on IPFP for CTO 253 for Site 78
reporting --final report	$25,000	based on IPFP for CTO 253 for Site 78
surveying	$3,000	based on IPFP for CTO 253 for Site 78
utility locator	$2,000	based on IPFP for CTO 253 for Site 78
Total	**$214,580**	
Grand Total	**$313,892**	

HRC with PNEUMATIC FRACTURING COST BACKUP
SITE 73 TECHNOLOGY EVALUATION
CTO- 0253
SEPTEMBER 2002

HRC		
HRC material, 12,000 lbs	$66,287	Regenesis spreadsheet
HRC shipping	$1,600	verbal quote from Regenesis
HRC total	$67,887	
Pneumatic Fracturing with HRC		
installation of points with mud rotary	$39,625	based on installation of 21 HW casings, 70 feet deep, $25/ linear ft. Including per diem and mob/demob
Pneumatic Fracturing	$145,000	ARS quote
Pneumatic Fracturing Total	$184,625	
Other costs		
monitoring wells--8 new	$34,730	based on BOA from Parratt-Wolfe
sampling for one year	$36,640	based on 5 sampling events on 10 wells using LTM costs
reporting--work plan	$25,000	based on IPFP for CTO 253 for Site 78
labor, travel and ODC's--implementation	$73,210	based on IPFP for CTO 253 for Site 78
reporting--interim report	$15,000	based on IPFP for CTO 253 for Site 78
reporting --final report	$25,000	based on IPFP for CTO 253 for Site 78
surveying	$3,000	based on IPFP for CTO 253 for Site 78
utility locator	$2,000	based on IPFP for CTO 253 for Site 78
Total	$214,580	
Grand Total	**$467,092**	

HYDROGEN SPARGING WITH HORIZONTAL WELL COST BACKUP
SITE 73 TECHNOLOGY EVALUATION
CTO- 0253
SEPTEMBER 2002

Hydrogen Sparging with one Horizontal Well		
Equipment prep, mob, demob	$70,000	Based on verbal estimate from Starr Environmental
Conceptual Design Report	$10,000	
Installation of Horizontal well assume 200 feet in length, with 500 feet of entry, no exit drilling to achieve target depth of about 70 feet below grade 700 feet total, $180 / foot	$126,000	Based on verbal estimate by Starr Environmental, and Longbore Drilling Company also compared to costs in GWRTAC Technology Status Report: A Catalogue of Horizon Environmental Wells in the US, January 2002.
per diem for drilling company	$8,850	59 days at $150 / day
Protective Enclosure	$18,000	
Misc field piping/manifolding	$5,000	
Hydrogen Biosparging Equipment and Installation	$123,000	Based on lump sum estimate by Groundwater Science, Inc.
One year O and M includes labor for technician, hydrogen gas, supplies, and electrical usage	$44,080	
Project Management	$20,000	
Total	$424,930	
Other costs		
monitoring wells--8 new	34730	based on BOA from Parratt-Wolfe
sampling for one year	36640	based on 5 sampling events on 10 wells using LTM costs
reporting--work plan	25000	based on IPFP for CTO 253 for Site 78
labor, travel and ODC's--implementation	73210	based on IPFP for CTO 253 for Site 78
reporting--interim report	15000	based on IPFP for CTO 253 for Site 78
reporting --final report	25000	based on IPFP for CTO 253 for Site 78
surveying	3000	based on IPFP for CTO 253 for Site 78
utility locator	2000	based on IPFP for CTO 253 for Site 78
Total	214580	
Grand Total	**$639,510**	

COMETABOLIC SPARGING WITH HORIZONTAL WELL COST BACKUP
SITE 73 TECHNOLOGY EVALUATION
CTO- 0253
SEPTEMBER 2002

Cometabolic Sparging with one Horizontal Well		
Equipment prep, mob, demob	$70,000	Based on verbal estimate from Starr Environmental
Conceptual Design Report	$10,000	
Installation of Horizontal well assume 200 feet in length, with 500 feet of entry, no exit drilling to achieve target depth of about 70 feet below grade 700 feet total, $180 / foot	$126,000	Based on verbal estimate by Starr Environmental, and Longbore Drilling Company Also compared to costs in GWRTAC Technology Status Report: A Catalogue of Horizoı Environmental Wells in the US, January 2002.
per diem for drilling company	$8,850	59 days at $150 / day
Protective Enclosure	$18,000	
Misc field piping/manifolding	$5,000	
Rotary Screw Air compressor and Control System	$22,000	
Gas Blending Equipment and Installation	$128,000	Based on lump sum estimate by Groundwater Science, Inc.
One year O and M includes labor for technician, propane gas, supplies, and electrical usage	$44,080	
Project Management	$20,000	
Total	$451,930	
Other costs		
monitoring wells--8 new	34730	based on BOA from Parratt-Wolfe
sampling for one year	36640	based on 5 sampling events on 10 wells using LTM costs
reporting--work plan	25000	based on IPFP for CTO 253 for Site 78
labor, travel and ODC's--implementation	73210	based on IPFP for CTO 253 for Site 78
reporting--interim report	15000	based on IPFP for CTO 253 for Site 78
reporting --final report	25000	based on IPFP for CTO 253 for Site 78
surveying	3000	based on IPFP for CTO 253 for Site 78
utility locator	2000	based on IPFP for CTO 253 for Site 78
Total	214580	
Grand Total	**$666,510**	

FEROX with PNEUMATIC FRACTURING COST BACKUP
SITE 73 TECHNOLOGY EVALUATION
CTO- 0253
SEPTEMBER 2002

Pneumatic Fracturing with Ferox		
installation of points with mud rotary	$39,625	based on installation of 21 HW casings, 70 feet deep, $25/ linear ft. Including per diem and mob/demob
Pneumatic Fracturing with Ferox	$355,000	based on ARS quote
Total	$394,625	

Other costs		
monitoring wells--8 new	$34,730	based on BOA from Parratt-Wolfe
sampling for one year	$36,640	based on 5 sampling events on 10 wells using LTM costs
reporting--work plan	$25,000	based on IPFP for CTO 253 for Site 78
labor, travel and ODC's--implementation	$73,210	based on IPFP for CTO 253 for Site 78
reporting--interim report	$15,000	based on IPFP for CTO 253 for Site 78
reporting --final report	$25,000	based on IPFP for CTO 253 for Site 78
surveying	$3,000	based on IPFP for CTO 253 for Site 78
utility locator	$2,000	based on IPFP for CTO 253 for Site 78
Total	$214,580	
Grand Total	**$609,205**	

Baker

Baker Environmental, Inc.

Appendix B: BIOCHLOR Modeling Input and Output

BIOCHLOR Natural Attenuation Decision Support System

Version 2.2
Excel '97

Site 73
NA constant source

Run Name

Data Input Instructions:

115 → 1. Enter value directly....or
↑ or 2. Calculate by filling in gray
0.02 cells. Press Enter, then (C)
(To restore formulas, hit "Restore Formulas" button)
Variable* → Data used directly in model.

Test if Biotransformation is Occurring → Natural Attenuation Screening Protocol

TYPE OF CHLORINATED SOLVENT: Ethenes ● Ethanes ○

1. ADVECTION

Seepage Velocity*	Vs	55.9	(ft/yr)
or			
Hydraulic Conductivity	K	1.8E-02	(cm/sec)
Hydraulic Gradient	i	0.00075	(ft/ft)
Effective Porosity	n	0.25	(-)

2. DISPERSION

Alpha x*	19.811	(ft)
(Alpha y) / (Alpha x)*	0.333	(-)
(Alpha z) / (Alpha x)*	4.E-02	(-)

Calc. Alpha x

3. ADSORPTION

Retardation Factor* → R
or

Soil Bulk Density, rho	1.7	(kg/L)		
FractionOrganicCarbon, foc	7.1E-3	(-)		
Partition Coefficient	Koc			
PCE	426	(L/kg)	21.57	(-)
TCE	130	(L/kg)	7.28	(-)
DCE	50	(L/kg)	3.41	(-)
VC	30	(L/kg)	2.43	(-)
ETH	302	(L/kg)	15.58	(-)

Common R (used in model)* = 3.40

4. BIOTRANSFORMATION -1st Order Decay Coefficient*

Zone 1	λ (1/yr)	half-life (yrs)	Yield
PCE → TCE	0.000		0.79
TCE → DCE	0.870		0.74
DCE → VC	1.930		0.64
VC → ETH	17.330		0.45

Zone 2	λ (1/yr)	half-life (yrs)
PCE → TCE	0.000	
TCE → DCE	0.000	
DCE → VC	0.000	
VC → ETH	0.000	

λ HELP

5. GENERAL

Simulation Time*	35	(yr)
Modeled Area Width*	500	(ft)
Modeled Area Length*	600	(ft)
Zone 1 Length*	600	(ft)
Zone 2 Length*	0	(ft)

L, W
Zone 2= L - Zone 1

6. SOURCE DATA

TYPE: Continuous Single Planar

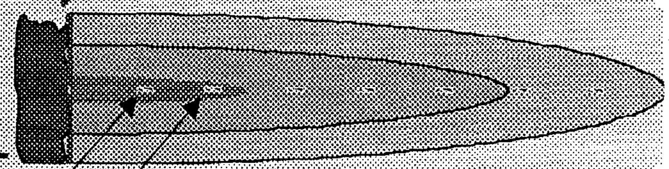
Source Options

Source Thickness in Sat. Zone* 50 (ft)

Y1
Width* (ft) 200

Conc. (mg/L)*	C1	k_s* (1/yr)
PCE	.0	0
TCE	4.6	0
DCE	1.2	0
VC	.04	0
ETH	0	0

Vertical Plane Source: Determine Source Well Location and Input Solvent Concentrations



View of Plume Looking Down

Observed Centerline Conc. at Monitoring Wells

7. FIELD DATA FOR COMPARISON

PCE Conc. (mg/L)											
TCE Conc. (mg/L)											
DCE Conc. (mg/L)											
VC Conc. (mg/L)											
ETH Conc. (mg/L)											
Distance from Source (ft)	0	560	650	930							
Date Data Collected	1998										

8. CHOOSE TYPE OF OUTPUT TO SEE:

RUN CENTERLINE

RUN ARRAY

Help

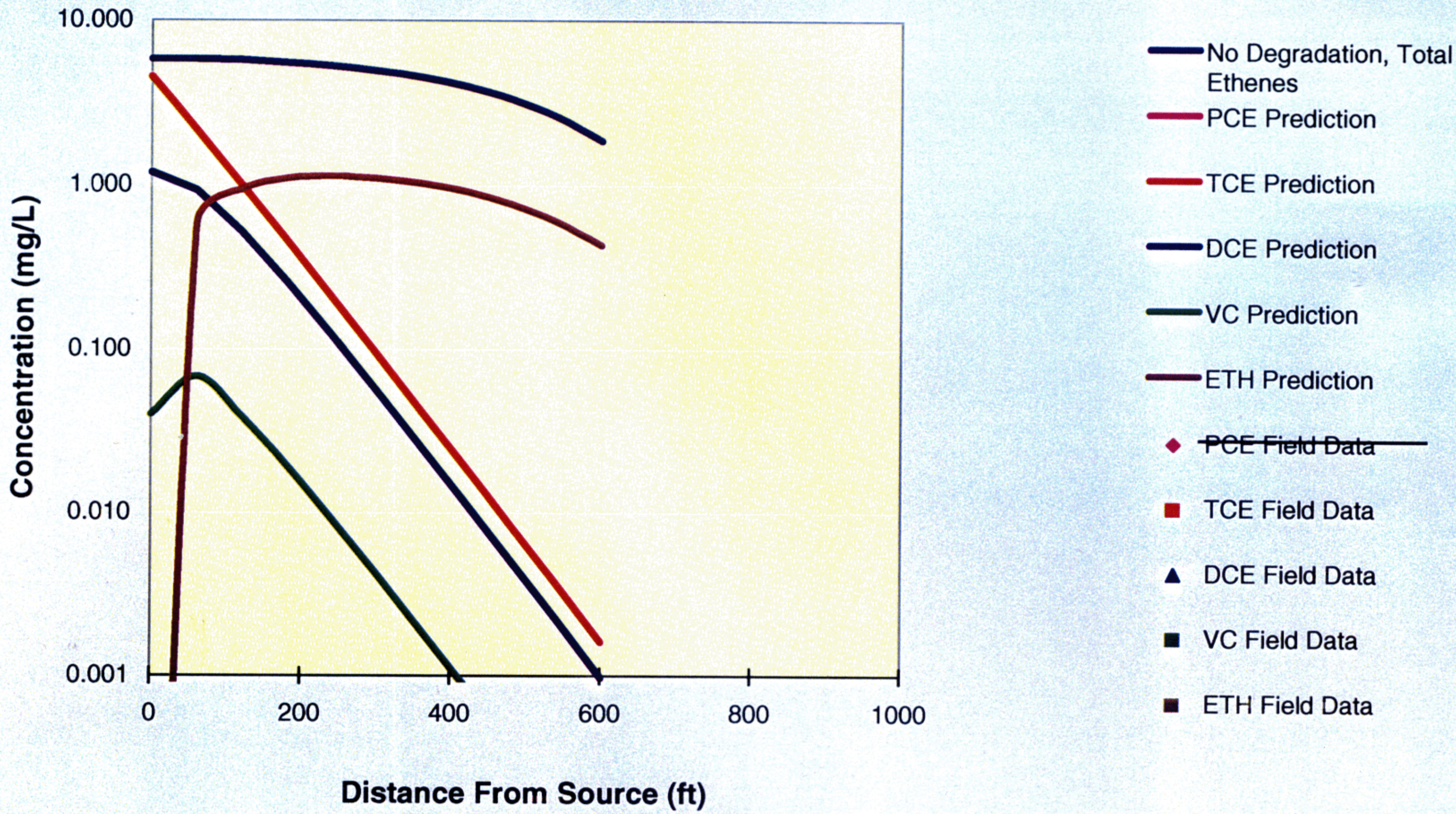
Restore Formulas

RESET

SEE OUTPUT

Paste Example

No action- constant source



BIOCHLOR Natural Attenuation Decision Support System

Version 2.2
Excel '97

Site 73
1000 ug/L hot spot
Run Name

Data Input Instructions:

115 → 1. Enter value directly....or
↑ or ↗ 2. Calculate by filling in gray
0.02 cells. Press Enter, then (C)
(To restore formulas, hit "Restore Formulas" button)
Variable* → Data used directly in model.

Test if Biotransformation is Occurring → Natural Attenuation Screening Protocol

TYPE OF CHLORINATED SOLVENT: Ethenes ● Ethanes ○

1. ADVECTION

Seepage Velocity*	Vs	55.9	(ft/yr)
or			
Hydraulic Conductivity	K	1.8E-02	(cm/sec)
Hydraulic Gradient	i	0.00075	(ft/ft)
Effective Porosity	n	0.25	(-)

2. DISPERSION

Alpha x*	19.811	(ft)
(Alpha y) / (Alpha x)*	0.333	(-)
(Alpha z) / (Alpha x)*	4.E-02	(-)

Calc. Alpha x

3. ADSORPTION

Retardation Factor* → R
or
Soil Bulk Density, rho 1.7 (kg/L)
FractionOrganicCarbon, foc 7.1E-3 (-)
Partition Coefficient Koc

	Koc		R	
PCE		(L/kg)	1.00	(-)
TCE	130	(L/kg)	7.28	(-)
DCE	50	(L/kg)	3.41	(-)
VC	30	(L/kg)	2.43	(-)
ETH	302	(L/kg)	15.58	(-)

Common R (used in model)* = 3.41

4. BIOTRANSFORMATION -1st Order Decay Coefficient*

Zone 1

	λ (1/yr)	half-life (yrs)	Yield
PCE → TCE	0.000		0.79
TCE → DCE	0.870		0.74
DCE → VC	1.930		0.64
VC → ETH	17.330		0.45

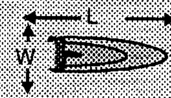
Zone 2

	λ (1/yr)	half-life (yrs)
PCE → TCE	0.000	
TCE → DCE	0.000	
DCE → VC	0.000	
VC → ETH	0.000	

λ HELP

5. GENERAL

Simulation Time*	25	(yr)
Modeled Area Width*	500	(ft)
Modeled Area Length*	600	(ft)
Zone 1 Length*	600	(ft)
Zone 2 Length*	0	(ft)



Zone 2= L - Zone 1

6. SOURCE DATA TYPE: Continuous Single Planar

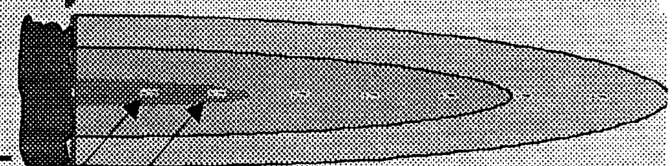
Source Options

Vertical Plane Source: Determine Source Well Location and Input Solvent Concentrations

Source Thickness in Sat. Zone* 50 (ft)

Y1
Width* (ft) 200

Conc. (mg/L)*	C1	k_s* (1/yr)
PCE	.0	0
TCE	1.0	0
DCE	.1	0
VC	.01	0
ETH	0	0



View of Plume Looking Down

Observed Centerline Conc. at Monitoring Wells

7. FIELD DATA FOR COMPARISON

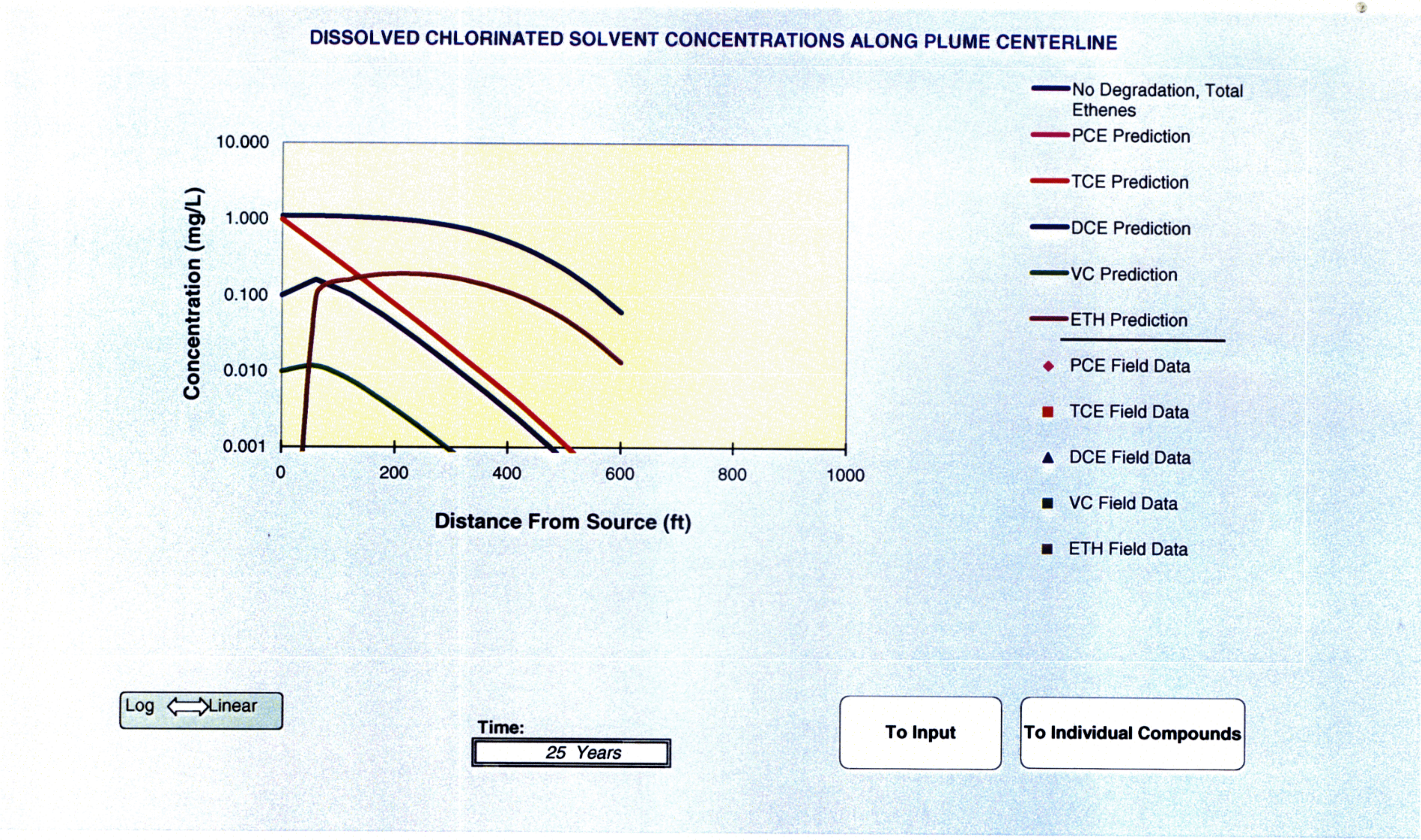
PCE Conc. (mg/L)											
TCE Conc. (mg/L)											
DCE Conc. (mg/L)											
VC Conc. (mg/L)											
ETH Conc. (mg/L)											
Distance from Source (ft)	0	560	650	930							
Date Data Collected	1998										

8. CHOOSE TYPE OF OUTPUT TO SEE:

RUN CENTERLINE | RUN ARRAY | Help | Restore Formulas | RESET | SEE OUTPUT | Paste Example

3

1000 ug/L hot spot reduction



BIOCHLOR Natural Attenuation Decision Support System

Version 2.2
Excel '97

Sit e73
100 ug/L hot spot
Run Name

Data Input Instructions:

115 → 1. Enter value directly....or
or 0.02 → 2. Calculate by filling in gray cells. Press Enter, then (C)
(To restore formulas, hit "Restore Formulas" button)
Variable* → Data used directly in model.

Test if Biotransformation is Occurring → Natural Attenuation Screening Protocol

TYPE OF CHLORINATED SOLVENT: Ethenes ● Ethanes ○

1. ADVECTION

Seepage Velocity*	Vs	55.9	(ft/yr)
or			
Hydraulic Conductivity	K	1.8E-02	(cm/sec)
Hydraulic Gradient	i	0.00075	(ft/ft)
Effective Porosity	n	0.25	(-)

2. DISPERSION

Alpha x*	19.811	(ft)
(Alpha y) / (Alpha x)*	0.333	(-)
(Alpha z) / (Alpha x)*	4.E-02	(-)

Calc. Alpha x

3. ADSORPTION

Retardation Factor* → R
or
Soil Bulk Density, rho 1.7 (kg/L)
FractionOrganicCarbon, foc 7.1E-3 (-)
Partition Coefficient

	Koc		R	
PCE	426	(L/kg)	21.57	(-)
TCE	130	(L/kg)	7.28	(-)
DCE	50	(L/kg)	3.41	(-)
VC	30	(L/kg)	2.43	(-)
ETH	302	(L/kg)	15.58	(-)

Common R (used in model)* = 3.40

4. BIOTRANSFORMATION -1st Order Decay Coefficient*

Zone 1

	λ (1/yr)	half-life (yrs)	Yield
PCE → TCE	0.000		0.79
TCE → DCE	0.870		0.74
DCE → VC	1.930		0.64
VC → ETH	17.330		0.45

Zone 2

	λ (1/yr)	half-life (yrs)
PCE → TCE	0.000	
TCE → DCE	0.000	
DCE → VC	0.000	
VC → ETH	0.000	

λ HELP

5. GENERAL

Simulation Time*	25	(yr)
Modeled Area Width*	500	(ft)
Modeled Area Length*	600	(ft)
Zone 1 Length*	600	(ft)
Zone 2 Length*	0	(ft)

L, W; Zone 2= L - Zone 1

6. SOURCE DATA TYPE: Continuous Single Planar

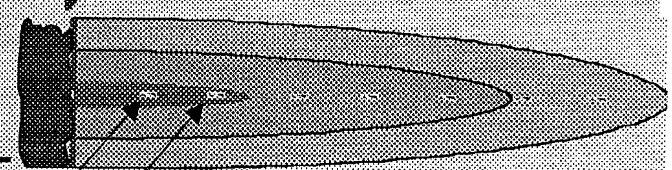
Source Options

Vertical Plane Source: Determine Source Well Location and Input Solvent Concentrations

Source Thickness in Sat. Zone* 50 (ft)

Y1 Width* (ft) 300

Conc. (mg/L)*	C1	k_s* (1/yr)
PCE	.0	0
TCE	.1	0
DCE	.01	0
VC	.001	0
ETH	0	0



View of Plume Looking Down

Observed Centerline Conc. at Monitoring Wells

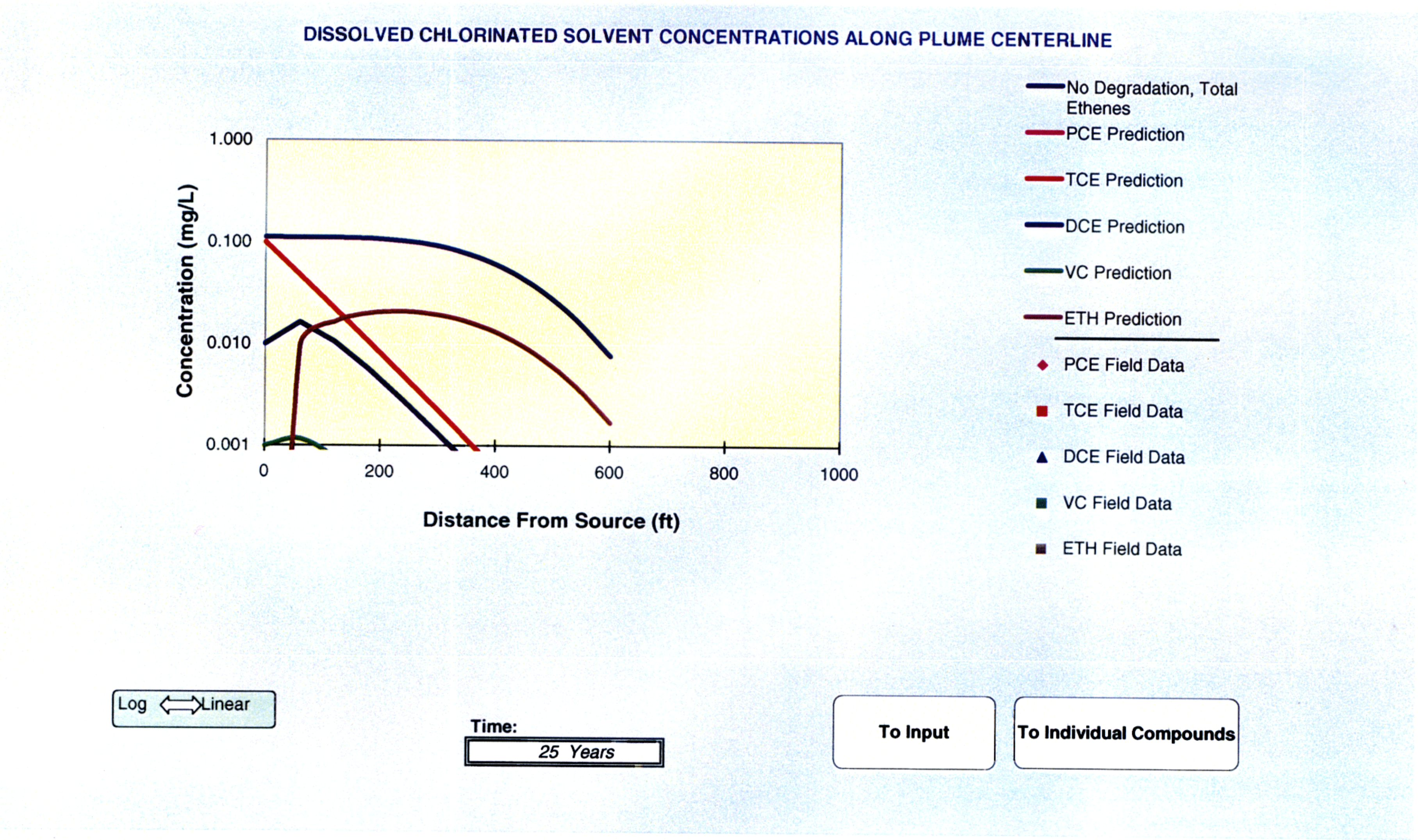
7. FIELD DATA FOR COMPARISON

PCE Conc. (mg/L)											
TCE Conc. (mg/L)											
DCE Conc. (mg/L)											
VC Conc. (mg/L)											
ETH Conc. (mg/L)											
Distance from Source (ft)	0	560	650	930							
Date Data Collected	1998										

8. CHOOSE TYPE OF OUTPUT TO SEE:

RUN CENTERLINE | RUN ARRAY | Help | SEE OUTPUT | Restore Formulas | Paste Example | RESET

100 ug/L hot spot



BIOCHLOR Natural Attenuation Decision Support System

Version 2.2
Excel '97

Run Name
Site 73-
10 x decay

Data Input Instructions:

115 → 1. Enter value directly...or
↑ or
0.02 → 2. Calculate by filling in gray cells. Press Enter, then (C)
(To restore formulas, hit "Restore Formulas" button)
Variable* → Data used directly in model.

Test if Biotransformation is Occurring → Natural Attenuation Screening Protocol

TYPE OF CHLORINATED SOLVENT: Ethenes ● Ethanes ○

1. ADVECTION

Seepage Velocity*	Vs	55.9	(ft/yr)
or			
Hydraulic Conductivity	K	1.8E-02	(cm/sec)
Hydraulic Gradient	i	0.00075	(ft/ft)
Effective Porosity	n	0.25	(-)

2. DISPERSION

Alpha x*	19.811	(ft)
(Alpha y) / (Alpha x)*	0.333	(-)
(Alpha z) / (Alpha x)*	4.E-02	(-)

Calc. Alpha x

3. ADSORPTION

Retardation Factor* → R

or

Soil Bulk Density, rho	1.7	(kg/L)
FractionOrganicCarbon, foc	7.1E-3	(-)

Partition Coefficient

	Koc		R	
PCE	426	(L/kg)	21.57	(-)
TCE	130	(L/kg)	7.28	(-)
DCE	50	(L/kg)	3.41	(-)
VC	30	(L/kg)	2.43	(-)
ETH	302	(L/kg)	15.58	(-)

Common R (used in model)* = **3.40**

4. BIOTRANSFORMATION

-1st Order Decay Coefficient*

Zone 1

	λ (1/yr)	half-life (yrs)	Yield
PCE → TCE	0.000		0.79
TCE → DCE	8.700		0.74
DCE → VC	19.300		0.64
VC → ETH	170.000		0.45

Zone 2

	λ (1/yr)	half-life (yrs)
PCE → TCE	0.000	
TCE → DCE	0.000	
DCE → VC	0.000	
VC → ETH	0.000	

λ HELP

5. GENERAL

Simulation Time*	5	(yr)
Modeled Area Width*	500	(ft)
Modeled Area Length*	600	(ft)
Zone 1 Length*	600	(ft)
Zone 2 Length*	0	(ft)

Zone 2= L - Zone 1

6. SOURCE DATA

TYPE: Continuous Single Planar

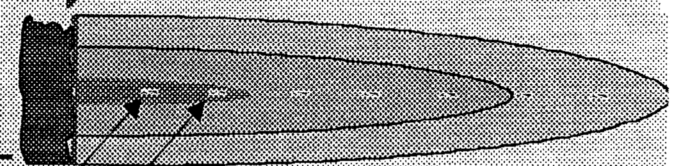
Source Options

Source Thickness in Sat. Zone* 50 (ft)

Y1
Width* (ft) 200

Conc. (mg/L)*	C1	k_s* (1/yr)
PCE	.0	0
TCE	4.6	0
DCE	1.2	0
VC	.05	0
ETH	0	0

Vertical Plane Source: Determine Source Well Location and Input Solvent Concentrations



View of Plume Looking Down

Observed Centerline Conc. at Monitoring Wells

7. FIELD DATA FOR COMPARISON

PCE Conc. (mg/L)											
TCE Conc. (mg/L)											
DCE Conc. (mg/L)											
VC Conc. (mg/L)											
ETH Conc. (mg/L)											
Distance from Source (ft)	0	560	650	930							
Date Data Collected	1998										

8. CHOOSE TYPE OF OUTPUT TO SEE:

RUN CENTERLINE

RUN ARRAY

Help

SEE OUTPUT

Restore Formulas

Paste Example

RESET

enhanced decay rate-- 10 times natural