**U.S. NAVY ENGINEERING FIELD ACTIVITY, NORTHEAST
REMEDIAL ACTION CONTRACT (RAC)
CONTRACT NO. N62472-99-D-0032
CONTRACT TASK ORDER NO. 0089**

DRAFT CONSTRUCTABILITY EVALUATION FOR FULL-SCALE IMPLEMENTATION OF ERH THERMAL TREATMENT

NAVAL WEAPONS INDUSTRIAL RESERVE PLANT BEDFORD, MASSACHUSETTS

May 11, 2005

Prepared by

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Revision	Date	Prepared by	Approved by	Pages Affected
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N62472-99-D-0032	**0089**	**Naval Weapons Industrial Reserve Plant - Bedford, MA**

PROJECT TITLE:
Constructability Evaluation for Full-Scale Implementation of ERH Thermal Treatment Project

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Tetra Tech EC, Inc.: Program QC Manager Thomas Kelly	May 11, 2005
TO: **T. Bober (CD-Copy)**	DATE May 11, 2005

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1	SD-18, Records; Draft Constructability Evaluation for Full-Scale Implementation of ERH Thermal Treatment	Amy Karaskevicus			

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LIST OF ACRONYMS AND ABBREVIATIONS

1,1,1-TCA	1,1,1-trichloroethane
1,1-DCA	1,1-dichloroethane
1,1-DCE	1,1-dichloroethene
1,2-DCA	1,2-dichloroethane
1,2-DCE	1,2-dichloroethene
AMRAD	Advanced Medium Range Air to Air Missile Development
bgs	below ground surface
BTEX	benzene, toluene, ethylbenzene and xylene
°C	Degrees Celsius
CPE	Crossed-Linked Polyethylene
CPVC	chlorinated polyvinyl chloride
CTO	Contract Task Order
cy	cubic yard
DNAPL	Dense Non-Aqueous Phase Liquid
EFANE	Engineering Field Activity, Northeast
ENSR	ENSR International
ERH	Electrical Resistance Heating
°F	Degrees Fahrenheit
FS	Feasibility Study
GAC	Granular Activated Carbon
GWTP	groundwater treatment plant
K	Thousand
kg	kilograms
kW	kilowatt
lb	pound
LEL	lower explosive limit
LNAPL	Light Non-Aqueous Phase Liquid
M	Million
MADEP	Massachusetts Department of Environmental Protection
NAPL	non-aqueous phase liquid
NWIRP	Naval Weapons Industrial Reserve Plant
O&M	Operation and Maintenance
PCE	tetrachloroethene
PCU	power control unit
PE	Polyethylene
ppb	parts per billion
PVC	polyvinyl chloride
RAC	Remedial Action Contract
SDR	Standard Dimensional Ratio
sf	square foot/feet
SVOC	Semi-Volatile Organic Compound
TCE	trichloroethene
TMP	Temperature Monitoring Point
TRS	Thermal Remediation Services, Inc.
TtEC	Tetra Tech EC, Inc.
TtNUS	Tetra Tech NUS, Inc.
ug/L	micrograms per liter
VOC	Volatile Organic Compound
VR	Vapor Recovery

1.0 INTRODUCTION

Tetra Tech EC, Inc. (TtEC) has prepared this Constructability Evaluation for Full-Scale Implementation of Electrical Resistance Heating (ERH) Thermal Treatment under Contract Task Order (CTO) No. 0089, United States Navy Engineering Field Activity, Northeast (EFANE) Remedial Action Contract (RAC) N62472-99-D-0032. This Constructability Evaluation briefly reviews the recently completed (2003) pilot study and describes the proposed full-scale approach for the implementation of ERH, a thermal treatment technology, for the remediation of Site 3 groundwater at the Naval Weapons Industrial Reserve Plant (NWIRP) located in Bedford, Massachusetts (the Site). The estimated costs and implementability issues associated with full-scale ERH remediation are also identified and discussed.

1.1 Site Background and History

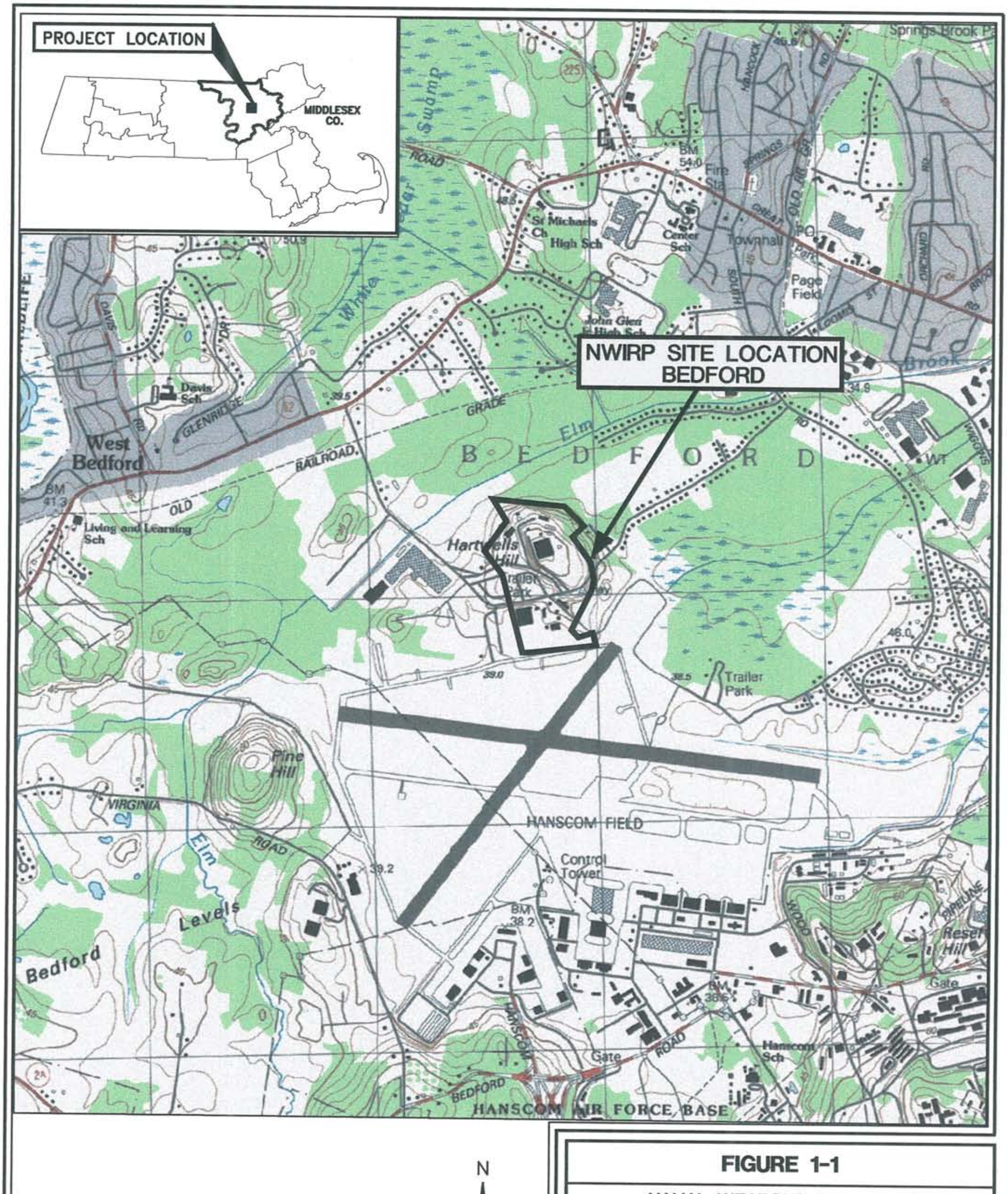
In 1983 and 1984, concentrations of benzene, trichloroethene (TCE), tetrachloroethene (PCE), and 1,2-dichloroethene (1,2-DCE) were detected in three water supply wells operated by the Town of Bedford at the Hartwells Road Well Field, located to the northwest of NWIRP Bedford (Figure 1-1). During subsequent investigations, chlorinated volatile organic compounds (VOCs) were observed in groundwater at the northern portion of the Site, near the Facility Storage Building and the Components Laboratory (located at the top of Hartwells Hill). This area of chlorinated solvent detections was adopted as Site 3 in subsequent investigations of the Site.

The northern portion of the Site is located on Hartwells Hill where the pilot study was located. The northern slope of Hartwells Hill drops steeply at the northern-most property boundary. Elm Brook and associated wetlands are present to the west and north of the facility, near the base of Hartwells Hill. A residential area and additional wetlands are located to the east and northeast. Other properties abutting the Site include Raytheon Missile Systems Division facilities to the west, and Hanscom Field (formerly Hanscom Air Force Base) to the south.

Site 3 consists of a subsurface source area, and dissolved-phase constituents that emanate from this source area. A dissolved-phase plume starts at the upgradient source area near the Facility Storage Building and Components Laboratory and migrates in a northwesterly direction across the Site and into an off-site wetland area (Figure 1-2).

Previous reports have documented one release of 1,1,1-trichloroethane (1,1,1-TCA) at the Site. Potential other sources of chlorinated solvent releases at Site 3 include the Components Laboratory, the Facility Storage Building print shop, a storm drain connected to the Facility Storage Building, the Antenna Range Building, the former Transportation Building, the former Advanced Medium Range Air to Air Missile Development (AMRAD) building, and the chemical storage building (Figure 1-2). TCE and 1,1,1-TCA were both reportedly used in the Components Laboratory, and could have been released to the ground in this area. Floor drains and, prior to 1980, the sink drains in the AMRAD building were connected to a storm drain that runs beneath this building. Solvents used during painting could have been discharged to these lines and leaked into the groundwater.

From July through October of 2003 a pilot test of the ERH technology was performed at Site 3. Final subsurface temperature readings and water levels were measured in January 2005. The pilot test was performed in an area located approximately 50 feet north of the Components Laboratory, as shown on Figure 1-3. The pilot test area was 40 feet wide by 80 feet long with a treatment volume of 112,000 cubic feet or 4,148 cubic yard (cy). The treatment depth and heating zone for the pilot study was from 20 to 55 feet below ground surface (bgs). The depth to groundwater in this area of the Site ranges from 20 to 30 feet bgs.



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Source:
USGS 7.5 Minute Series Topographic Map: Maynard, MA1987.

FIGURE 1-1

NAVAL WEAPONS INDUSTRIAL RESERVE PLANT (NWIRP) BEDFORD, MASSACHUSETTS

SITE AREA MAP

SCALE: AS SHOWN

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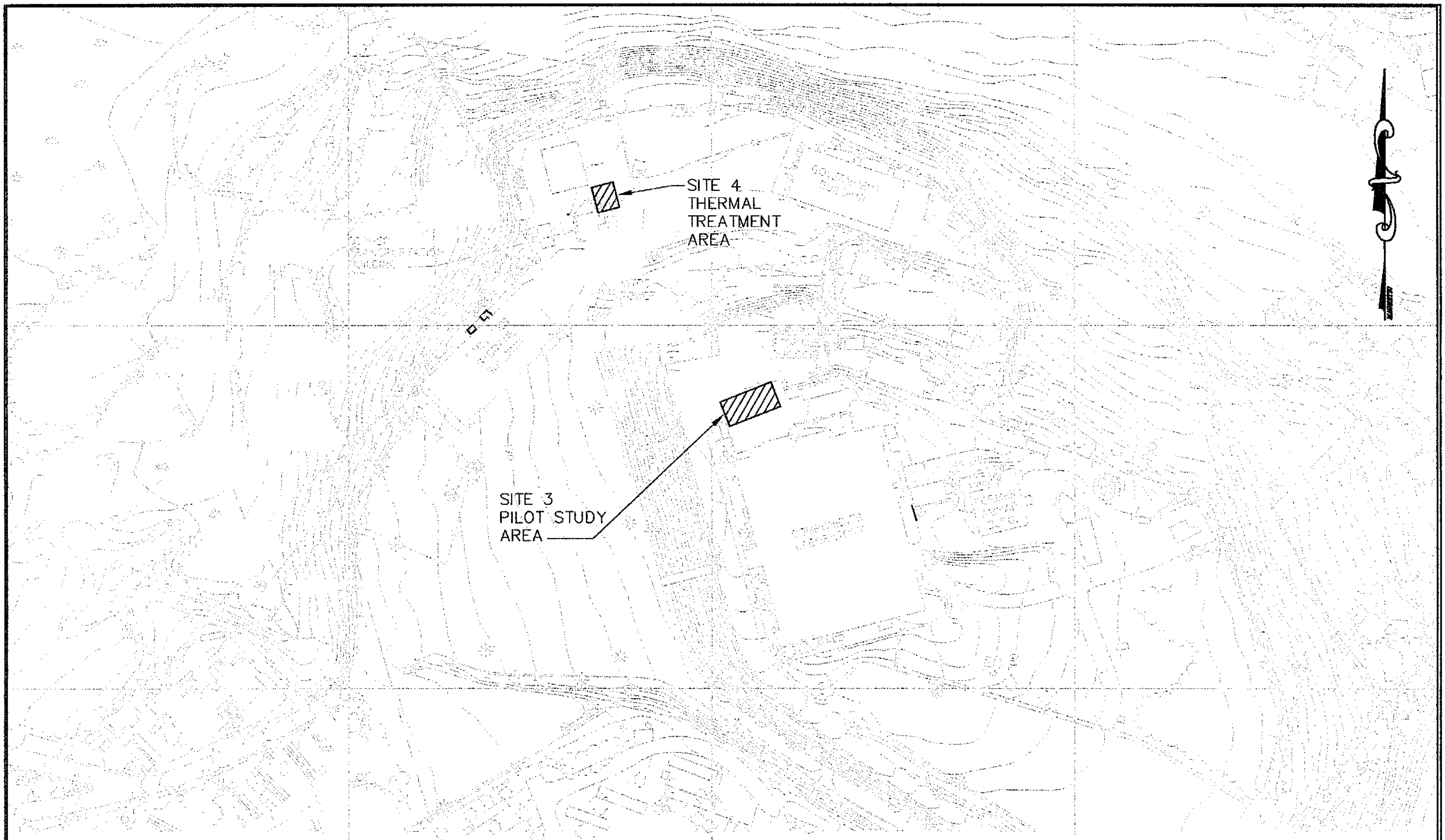


LEGEND

	THREAD OF STREAM
	FENCE
	CONDUIT
	GUARD RAIL
	STONE WALL
	TREE LINE
	TREE OR SCHRUB
	SEWER MANHOLE
	DRAIN MANHOLE
	UNDETERMINED MANHOLE
□ or ■	CATCH BASIN
	UTILITY POLE
	LIGHT POLE
	UNKNOWN STRUCTURE (PROBABLE POST OR POLE)
	WETLANDS

0 200 400
SCALE IN FEET

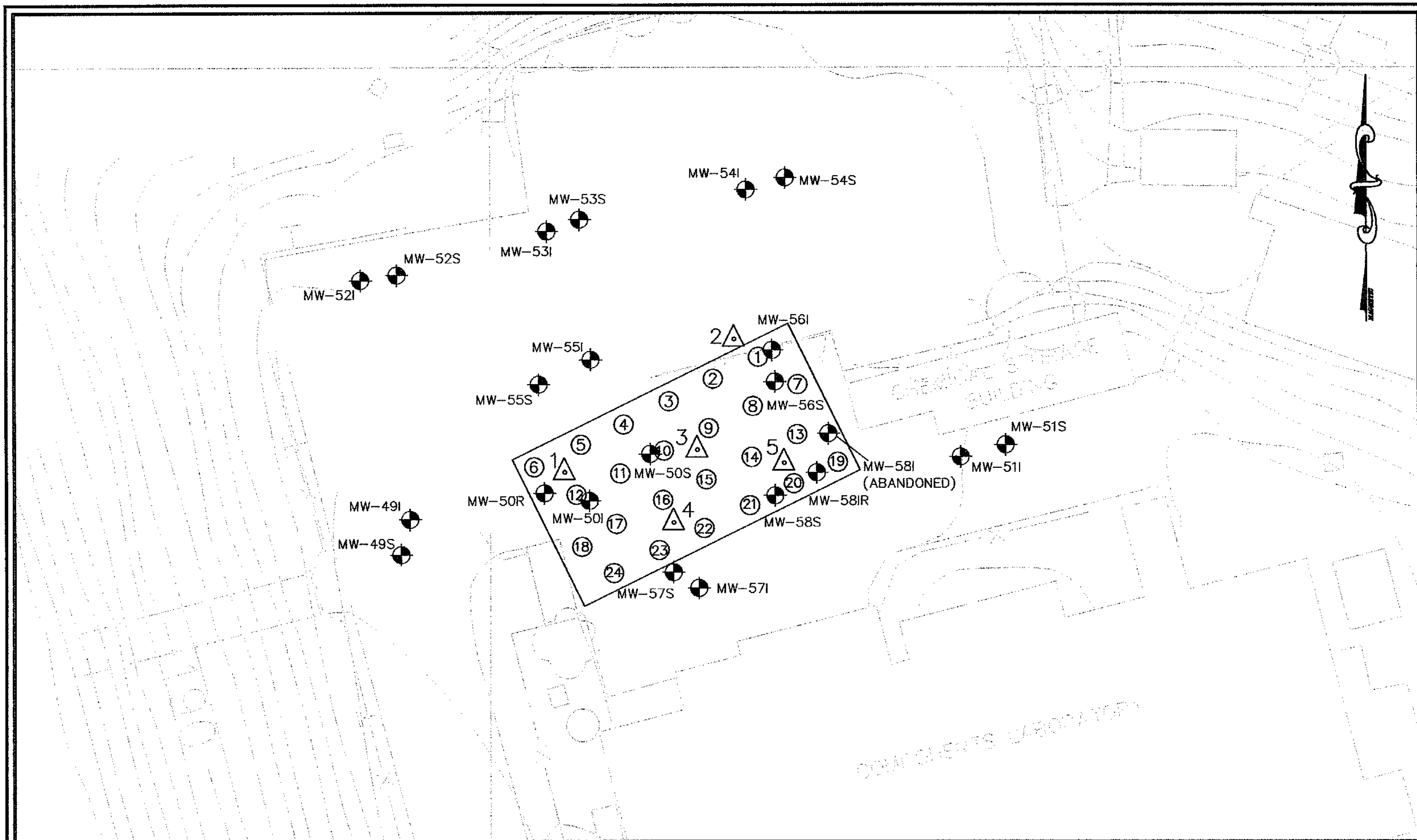
FIGURE 1-2

NAVAL WEAPONS INDUSTRIAL RESERVE PLANT
BEDFORD, MASSACHUSETTS

SITE PLAN

SCALE: AS SHOWN

CAD FILE: 22820424_A010.DWG



LEGEND:

(17) ELECTRODE

3△ TEMPERATURE MONITORING POINT

⊕ MONITORING WELL

0 400 800
SCALE IN FEET

FIGURE 1-3

NAVAL WEAPONS INDUSTRIAL RESERVE PLANT
BEDFORD, MASSACHUSETTS

PILOT STUDY LAYOUT WITH WELLS

SCALE: AS SHOWN

CAD FILE: 22820424_A011.DWG

A total of 24 electrodes with collocated vapor recovery (VR) wells were installed to a depth of 60 feet bgs (i.e., 5 feet beyond the bottom of the treatment interval). The electrode design allowed subsurface power application and VR to be performed simultaneously at each electrode. Subsurface temperatures were measured at four temperature monitoring points (TMPs) located within the treatment area and one additional TMP located immediately outside the treatment perimeter. Recovered groundwater, soil vapors, and steam were separated in the condenser unit of the ERH process treatment system. Contaminants were removed from the vapor stream by four, 1,000-pound (lb) granular activated carbon (GAC) vessels. Condensate and recovered groundwater were treated using a single 30-gallon liquid GAC vessel and were either returned to the subsurface via drip lines installed in each electrode boring or were evaporated via the on-site condenser cooling tower.

The following goals were established for the pilot test:

- Achieve a 95% reduction (minimum) of total VOC concentrations in pilot test area groundwater from pre-treatment (baseline) levels.
- Determine the potential effectiveness of the technology over the entire source area.
- Determine the implementability of the technology over the entire source area.
- Determine costs for implementing the technology across the entire source area.

The first two bulleted goals were addressed in the Closeout Report for Site 3 Thermal Treatment Pilot Test (TtEC, 2005), while the other objectives are covered in more depth in this Constructability Evaluation.

During the operational period of the Site 3 thermal treatment pilot test, a small-scale remediation of soil and groundwater using ERH thermal treatment was also conducted simultaneously in an area identified as Site 4. Site 4 is within close proximity to Site 3 and the thermal treatment at Site 4 was performed to remove benzene, toluene, ethylbenzene and xylene (BTEX) contamination in soil and groundwater in the defined area. Remediation activities and project results pertinent to the Site 4 work are included in the Closeout Report for Site 4 Thermal Treatment Remediation, and will not be discussed in this Constructability Evaluation for Full-Scale Implementation. Site 4 is not included as part of the proposed full-scale ERH since no further remediation is considered necessary at this time. Where appropriate, this Constructability Evaluation for Full-Scale Implementation may reference the Closeout Report for Site 3, or discuss results from joint operations between Site 3 and Site 4, including a combined VR and treatment system as well as a combined waste disposal system.

2.0 SITE CHARACTERIZATION

2.1 Clean-Up Objectives

The ultimate site remediation goal is to reduce the concentration of contaminants in groundwater to below their respective drinking water standards. In this case the contaminant driving the clean up is TCE since it is present in the highest concentration and has the lowest corresponding drinking water standard of 5 parts per billion (ppb).

Previous modeling indicated that reducing the source area concentration by 95% or greater could potentially allow the plume to naturally attenuate over time and eventually fall below the 5 ppb groundwater standard for TCE. A 95% reduction of the average concentration across the source area would result in a clean-up objective of 218 ppb.

The latest modeling completed by Tetra Tech NUS, Inc. (TtNUS) for the Feasibility Study (FS) for Site 3 (TtNUS, 2005) indicates that a 95% or greater reduction in the mass of TCE is still required to potentially achieve the drinking water standards. In addition, it was determined that the 95% reduction was based upon the mass of TCE, not the concentration. Therefore, using the model, the source area was approximated at the 218 ppb contour and then the mass of TCE was calculated within this contour as 77.51 kilograms (kg). The average concentration within the 218 ppb contour was also calculated by the model as 1,550 ppb. In order to achieve a 95% reduction the mass within the source area would need to be reduced to 3.88 kg. This corresponds to an average TCE concentration of 75 ppb.

Remediation at the site is directed towards achieving the drinking water standards in groundwater. No clean-up objective has been established for soil contamination since the majority of the Site 3 plume is considered to be in the dissolved phase. In areas where there may be contamination present as dense non-aqueous phase liquid (DNAPL) in the soil, ERH treatment will be able to reduce the levels of contamination to at least the level established for the groundwater clean-up objective

2.2 Assessment of Clean-Up Objectives for Full-Scale ERH

Achievement of the clean-up objectives will be determined primarily from the collection of pre- and post-treatment groundwater samples. Other secondary objectives may also be established for energy input, subsurface temperature, and boiling duration. Concentration of the extracted soil vapor may also be used to assess the performance of full-scale ERH.

Groundwater samples collected from monitoring wells within the treatment area will be assessed on an individual basis as well as collectively to determine whether the clean-up objectives have been met. The clean-up objective will be considered satisfied as long as the concentration of TCE has been reduced by 95% or greater from pre-treatment levels in each individual monitoring well and the average groundwater concentration of TCE from all the wells within the treatment area does not exceed 75 ppb. Post-treatment groundwater samples will be collected immediately after heating using procedures established for hot groundwater sampling so long as it is safe to do so. The collection of pre- and post-test soil samples will also be conducted at approximately 24 locations across the treatment area in case the collection of post-treatment groundwater samples is not feasible.

2.3 Nature and Extent of Contamination

The Site 3 plume consists primarily of the following contaminants in groundwater: TCE, PCE, 1,2-DCE, 1,1-dichloroethene (1,1-DCE) and 1,2-dichloroethane (1,2-DCA). As previously stated, the contaminant driving the clean-up is TCE based on its present concentration and the corresponding regulatory standard. Concentrations of TCE in groundwater have been detected at a maximum concentration of 240,000 micrograms per liter (ug/L) at MW-55Il.

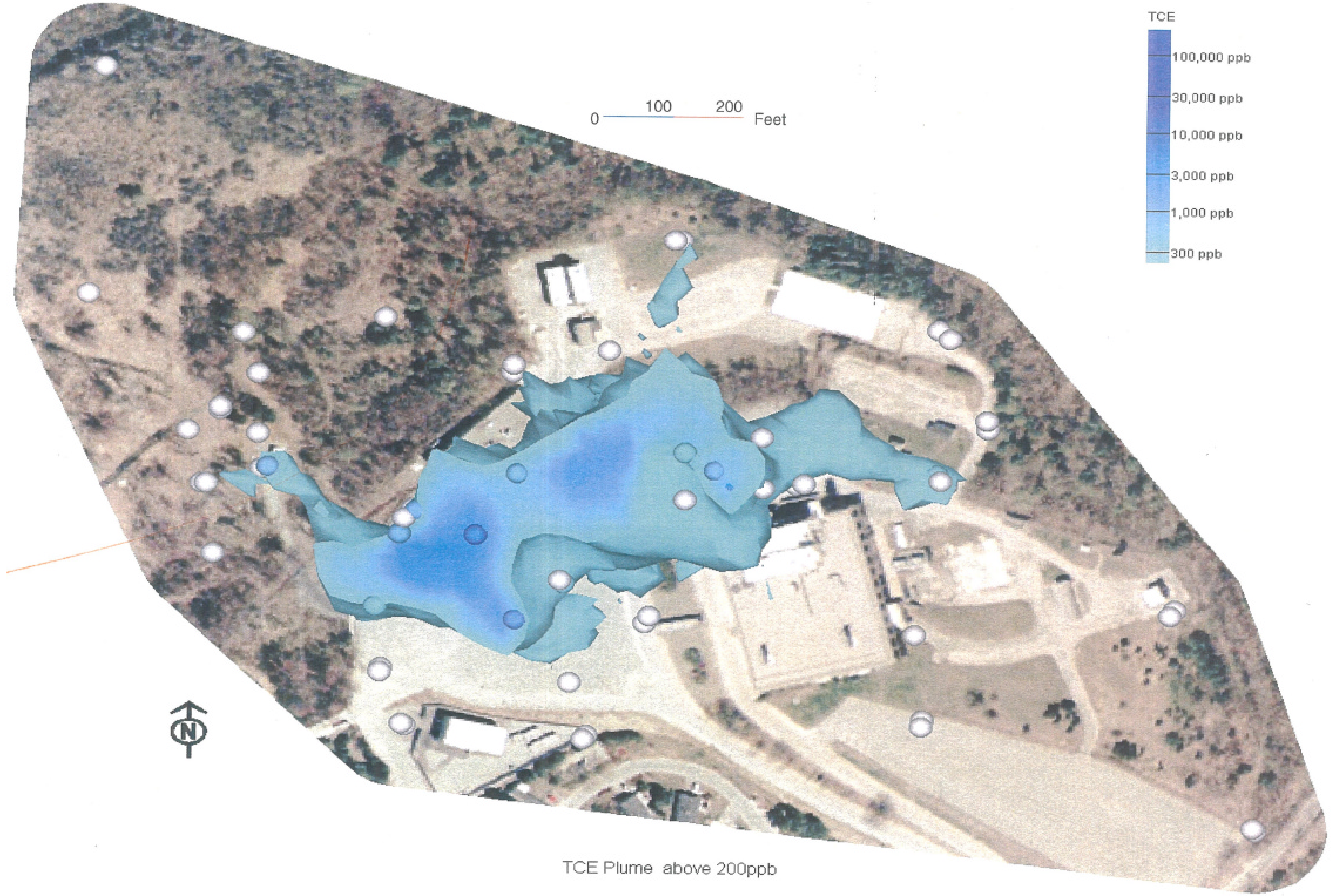
Site 3 has been characterized in previous documents submitted to the Navy, and most recently in the FS for Site 3 (TtNUS, 2005). Detailed information pertaining to the characterization of the Site 3 plume can be found in this FS for Site 3 (TtNUS, 2005). As part of the FS for Site 3 (TtNUS, 2005) the existing groundwater plume model based upon TCE was updated. The modeled TCE plume greater than 200 ppb is presented in Figure 2-1. This plume estimate was the starting point for area selection to be targeted during full-scale ERH remediation.

Figure 2-1 represents the approximate location of the source area and has the following characteristics:

- Surface Area: 205,212 square feet (sf)
- Average Depth Interval: 34 feet
- Volume: 261,700 cy
- Average TCE concentration: 1,550 ppb
- TCE Mass: 77.51 kg

Bedrock contamination was not included in this estimate.

For the purposes of this Constructability Evaluation, several areas of the plume were not considered practical to treat. These areas consisted of contamination under major buildings and contamination off of the Bedford NWIRP property. For further details of the proposed ERH treatment regions refer to Section 4.1. Eliminating the aforementioned areas reduces the source area and volume by less than 10% to 189,490 sf and 241,424 cy. It is assumed that this reduction of the source area will not present a significant impact to the overall remediation of the Site 3 plume.



SOURCE:
ENSR FIGURE 2-9, CONTRACT NO. N62467-94-D-0888, DECEMBER 2004.

FIGURE 2-1

NAVAL WEAPONS INDUSTRIAL RESERVE PLANT
BEDFORD, MASSACHUSETTS

PLAN VIEW, LOCATION OF SOURCE AREA
SITE 3 FS

SCALE: AS SHOWN

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3.0 ERH CONCEPTUAL APPROACH

3.1 Introduction

The purpose of this Constructability Evaluation is to provide the strategy, work requirements and specific activities for implementing an ERH remediation at the Site. This Constructability Evaluation will evaluate the feasibility of implementing ERH under Bedford Site conditions and determine the effectiveness of ERH for enhancing the performance of VR in the removal of the "source" of contaminants at the Site.

The goal of this remedy for the Site is to reduce VOCs in groundwater by 95% of the existing containment mass. From the FS for Site 3 (TtNUS, 2005), it was established that a 95% reduction in modeled source concentration was required to achieve the clean-up goal of 5 ppb throughout most of the plume. Following a successful pilot test at the Site in 2003, the ERH remedial technique was identified as having the potential ability to attain groundwater clean-up levels while at the same time assist in the current Site Management of Migration activities. Successful demonstration of ERH in this area identified a remediation technology that will contribute significantly to the overall remediation of site groundwater.

The general pilot test strategy was to install an ERH system that would heat the site groundwater for a set period of time while collecting VOC laden vapors in a conventional VR system with treatment using on-site GAC filters. Monitoring of various parameters, such as soil temperature, electrical voltage, induced vacuum, extracted vapor flow rates, extracted vapor concentrations, GAC efficiency, and groundwater concentrations, was performed to provide measurements of effectiveness.

3.2 ERH

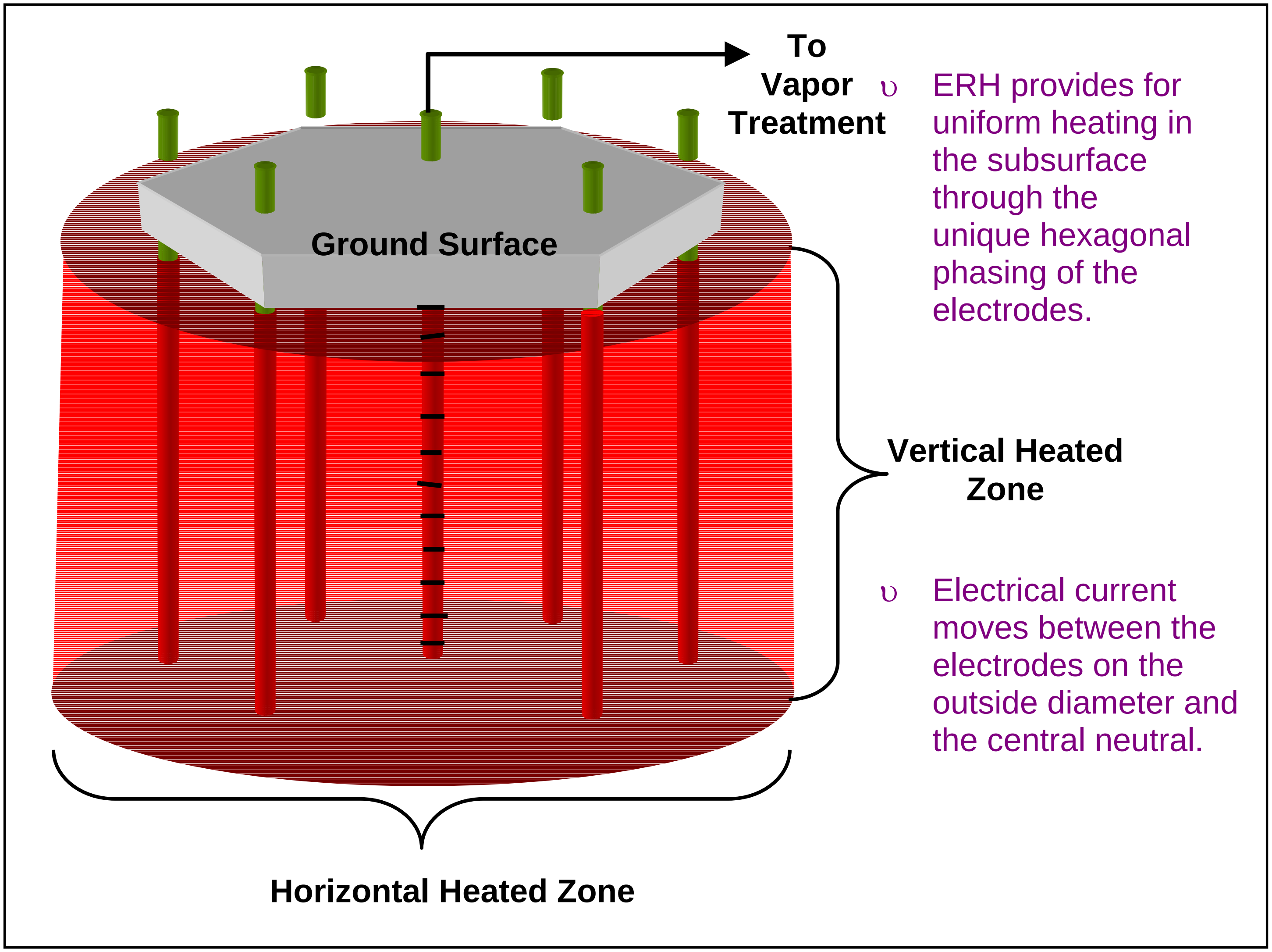
3.2.1 Technology Overview

ERH is a polyphase electrical technology that uses in-situ ERH and subsequent steam stripping to remediate subsurface soil and groundwater. Heating is accomplished through the resistive dissipation of the electrical energy in the soil. The technology takes common three-phase electricity and directs it into the subsurface through electrodes. Contamination released from soil and groundwater by heating is removed via a conventional VR system. For tightly bound soils, such as exist at the Bedford Site, conventional VR alone is ineffective and therefore thermal enhancements are necessary for significant contaminant removal.

During ERH operations, the temperatures achieved in treated soil reach approximately 100 degrees Celsius (°C), increasing vapor pressures and liberating contaminants from the subsurface. This increase in vapor pressures increases the rate of volatilization, thus transferring more of the contaminant to the vapor-phase allowing facilitated removal through VR points. Unlike conventional VR, ERH does not require the dewatering of the treatment area for remediating saturated soils.

The application of ERH at a given site typically involves the installation of steel pipes that serve as electrodes to conduct electrical current throughout the target treatment volume. A typical heating array is made up of several electrodes that double as VR wells and conduct electricity into the subsurface. A target treatment volume includes the area within the array down to the depth of the installed electrode (Figure 3-1). Multiple electrode arrays can be installed and operated simultaneously to remediate larger site-specific areas of concern.

Figure 3-1
ERH Cross Section



Note: Each thermal well can also be used as a VR well as necessary.

ERH has been pilot tested and installed as a full-scale remedial technology for applications involving:

- Low permeability and heterogeneous lithologies.
- Unsaturated and saturated zones.
- Light Non-Aqueous Phase Liquid (LNAPL) and DNAPL sites involving hydrocarbons and chlorinated solvents.

3.2.2 Applicability of ERH to the Bedford Site

Heating groundwater and soils contaminated with VOCs and semi-volatile organic compounds (SVOCs) using in-situ methods can have several beneficial effects on the performance of VR:

- Raising the temperature of the soil results in vaporizing both pore water and organics. Heating generally doubles the organics' vapor pressure for every 14°C rise in temperature; this approximately doubles the rate of extraction (Beyke, 1994).

- Vaporization and removal of pore water and organics opens soil pores and increases permeability to soil vapor transport.

- Raising the temperature of water containing dissolved organics generally increases the Henry's Law constant, thereby concentrating the organic in the vapor-phase relative to the liquid-phase. This results in increasing the rate of recovery of the organic relative to that of water.

Further consideration of the type of in-situ thermal technology resulted in the selection of ERH for pilot testing during summer/fall 2003. The main reason for ERH’s selection and applicability over other in-situ thermal technologies was that the variation in horizontal and vertical extent of VOCs composition (including at depth in the saturated zone) did not present difficulties for ERH. Other criteria reviewed regarding its applicability included:

- Overall treatment effectiveness at sites with low permeability soils.
- Effectiveness in remediation of saturated zone and DNAPL contamination.
- Comparable capital and operation and maintenance (O&M) costs for a thermal technology.
- Low aesthetic impacts for the site.
- Regulatory acceptance at other similar sites.

3.3 Design Results from Pilot Test

3.3.1 Required Spacing of Electrodes Based on Site-Specific Conditions

The effectiveness of ERH to transmit electricity at the Site is dependent on the electrode spacing and directly reflects the ability to heat the treatment zone. Determining the maximum electrode spacing was based on thermocouple monitoring data and provides the design basis for the full-scale ERH arrays. The required spacing will also be one of the major cost factors in the development cost for full-scale implementation. Thermal Remediation Services, Inc. (TRS) concludes that the electrodes were very efficient at coupling power to the soil resulting in adequate spacing (15 feet between electrodes) during the pilot test. Following analysis by the ERH Subcontractor (TRS), it was determined that the ideal spacing for electrodes during full-scale remediation could be increased to 22 feet between electrodes. Based on the performance of the electrodes during the pilot test, increasing the spacing of the electrodes for full-scale ERH application is warranted.

3.3.2 Collection, Controlling and Treating of Vapors

During the pilot test operational period, the ability to collect, control, and treat the extracted vapors was a high priority objective. This is because it was necessary to take all measures that ensured that the test was performed safely without downtime due to control, collection and treatment of vapors. However, several problems with silt entrainment were discovered during pilot test operations. For the full-scale installation, the electrodes will be redesigned to surmount this problem.

GAC was utilized for the vapor treatment system. This treatment media worked well, and due to low expected concentrations of contaminants, GAC will also be recommended as the vapor treatment method for full-scale operations. Based on the pilot test results, it is estimated that approximately 36,000 lbs of GAC will be required to treat the 300 lbs of VOC mass projected to be extracted during full-scale operations.

3.3.3 Basis for Full-Scale Capital and O&M Costs

Costs were developed for scale-up to full-scale implementation per cy of treated soil. The goal for the cost estimate was to confirm that the costs of implementing the technology on a full-scale per cy basis would be less than $100/cy. The $100/cy cost level is just above the high end cost range made by vendors promoting the ERH technology. Costs greater than $100/cy will need to be reviewed more carefully versus other applicable and feasible treatment alternatives. Estimated costs for a full-scale application at the Site are detailed in Section 8.0 and confirm that costs are expected to be below the $100/cy threshold.

The costs of implementing the ERH technology include:

- Site preparation (including infrastructure impacts).
- ERH well installation.
- VR system installation.
- ERH O&M.
- Utility requirements.
- Vapor treatment.

3.4 Overview of Pilot Testing

The ERH pilot test was performed in a location adjacent to the Components Building where previous site characterization had identified relatively high groundwater contamination levels. The location and layout of the pilot test area is shown in Figure 1-2, Site Plan.

Pre-Test site characterization activities are described in the Closeout Report for Site 3 Thermal Treatment Pilot Test (TtEC, 2005) and included groundwater sampling, providing the baseline by which later testing and operations were compared. VR was also monitored for the entire installed VR system.

The demonstration of ERH was then performed by ramping up the subsurface temperature via the installed electrodes to the target treatment temperature (groundwater boiling point). The time to heat up the treatment volume required approximately one month. Once the targeted temperature was reached, the treatment volume remained heated at the boiling point for an additional twenty days. During this time, variations were made in the operational parameters to help maintain and define optimum performance. During the ERH pilot testing, soil temperature measurements were made continuously along with the performance parameters of the VR system to ensure that as the soil liberated the VOCs, the VR system was effectively collecting all the vapors.

At the conclusion of the ERH treatment period, the groundwater was sampled to assess treatment effectiveness. The groundwater monitoring wells were also available for further sampling during subsequent months after pilot test shut down, and additional samples were collected as described in the Closeout Report for Site 3 Thermal Treatment Pilot Test (TtEC, 2005). Based on the pre-and post-test characterization sampling no hazardous by-products were identified in the analytical data.

A more detailed discussion of the pilot testing operations is provided in the Closeout Report for Site 3 Thermal Treatment Pilot Test (TtEC, 2005).

4.0 ERH FULL-SCALE DISCUSSION

Implementation of ERH at a full-scale level will be dependent on a number of considerations with each having cost implications for implementing the technology. The considerations identified in this section will provide the basis for costing the options for implementing a full-scale ERH at the site and assist the Project Team in selection of the appropriate method of implementation. The most important consideration prior to selection of any option will be defining the primary end goal acceptable to allow attainment of Site closure.

4.1 Selection of Target Treatment Area

Site groundwater contamination has been characterized in the past through several sampling events and has been compiled into the site conceptual model. This model was most recently updated and presented in the FS for Site 3 (TtNUS, 2005). Subsequently, this remediation has been focused on groundwater as shown in Figure 2-1 of the FS for Site 3 (TtNUS, 2005). The FS for Site 3 (TtNUS, 2005) defines the Site 3 plume zone as extending from the top of Hartwells Hill to the west, and northwest to the NWIRP Bedford property boundary. Accordingly, areas to be remediated have been divided into three specific areas as shown in Figure 4-1. The three proposed distinct areas in Figure 4-1 are described as follows:

- Upper Treatment Region – Consists of the upgradient area adjacent to the Components Building, (an extension of where the Site 3 Pilot Test was located). This area is estimated to be 39,645 sf.

- Sloped Treatment Region – Consists of the sloped area from the Upper Treatment Region to the Lower Treatment Region. This area is sloped at an approximate 10% grade and is estimated to consist of 27,712 sf plus an additional 11,561 sf which requires clearing of vegetated growth for a total area of 39,273 sf.

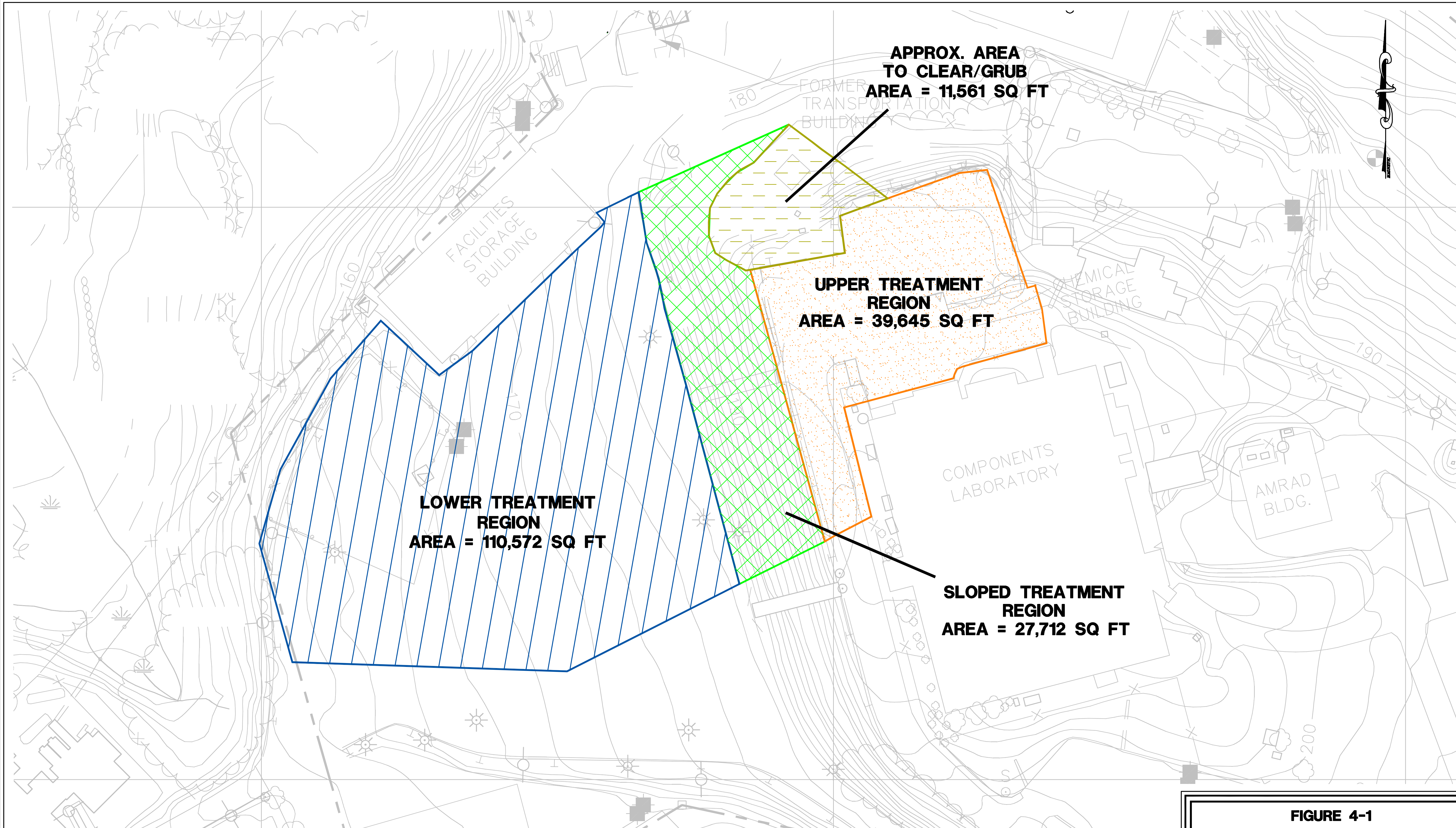
- Lower Treatment Region – Consists of the downgradient parking lot area from the Sloped Treatment Region to the northwestern property boundary. This area is estimated to be 110,572 sf.

Therefore the total treatment area proposed for groundwater remediation is approximately 189,500 sf. It should be noted that 205,212 sf was estimated by TtNUS and used by TRS for their cost estimate. This area is larger than the proposed area because the proposed area does not include technically infeasible areas such as under existing buildings or areas outside property boundaries. It has also been proposed to treat the entire area simultaneously as this will be the most cost-effective approach with regards to logistics and O&M effort.

4.2 Selection of Target Treatment Depth

The selection of the target treatment depth to assist with the management of migration remedy requires a review of site-specific hydrogeologic and contaminant conditions. The presence and location of groundwater contamination at levels considered to be sources of continuing contamination such as non-aqueous phase liquid (NAPL) must be considered and targeted, if possible, by this technology

The goal of the ERH remediation at the Site has been defined to reduce VOCs in groundwater by 95% as measured for TCE. The groundwater depth was defined as the top of the water table (~10 feet bgs). The use of ERH to strictly treat to this depth is possible and has been successfully accomplished at other similar sites. From this proposed depth interval and total area as described above, the proposed remediation volume is approximately 234,500 cy.



SOURCE:
ENSR GIS FILE SITE3_PILOTSTUDY.APR, FIGURE 2-5, DATED 5/02, ENTITLED "INTERMEDIATE GROUNDWATER CONTOURS MARCH 2002, SITE 3 PILOT STUDY WORK PLAN NWIRP BEDFORD, MA.

FIGURE 4-1

NAVAL WEAPONS INDUSTRIAL RESERVE PLANT
BEDFORD, MASSACHUSETTS

PROPOSED ERH TREATMENT REGIONS

SCALE: AS SHOWN

CAD FILE: 22820424_A014.DWG

4.3 ERH Implementation Logistics

Implementation of ERH requires a review of the potential effects caused by the magnitude of heat and voltage introduced into the subsurface. A brief review of the potential effects has been performed during the Final Work Plan for Site 3 Thermal Treatment Pilot Test (Foster Wheeler, 2003). However, further advances in the ERH technology and actual full-scale implementation projects have allowed a better understanding of these effects with regard to surface and subsurface features at the Site. A discussion of the potential effects on subsurface and surface features is provided below.

Supplementing this knowledge will be the observations and monitoring data obtained during the ERH pilot test. Based on the impacts or implementation logistics, cost estimates for implementing ERH across the site have been developed and are detailed in Appendix A of this Constructability Evaluation.

4.3.1 Subsurface Structures

<u>Subsurface piping/conduit/wiring temperature tolerance</u>: Subsurface piping, conduit and wiring at the Site do not present problems because the heating will take place at much lower elevations, therefore the ability of the materials of construction to tolerate elevated temperatures due to the heat introduced into the soil is not of concern. Examples of some of piping, conduit and wiring installed at the Site includes:

- Polyvinyl Chloride (PVC)/Polyethylene (PE)/Cross-Linked Polyethylene (CPE) (electrical wiring insulation).
- CPE with PVC jacket (electrical power cable insulation).
- Ductile iron with gaskets (potable water piping).
- PVC Standard Dimensional Ration (SDR) 35 (sewer and drain piping).

In addition, five PVC monitoring wells (MW-58I, MW-13R/S, MW-21R/S) in the target area have a maximum allowable temperature before failure of 150 degrees Fahrenheit (°F). The costs for removing and replacing the wells will need to be estimated if heating is to take place in adjacent areas.

4.3.2 Above Ground Structures

<u>Existing Buildings</u>: For an expanded, full-scale system, the remediation of the soil underlying the existing buildings will be a challenge due to the limitation to access. Existing buildings within the proposed remediation area include the Components Building, the Facilities Storage Warehouse and the Vitro Tower. Therefore these areas have not been considered as part of the proposed remediation areas. However, two existing abandoned chemical storage sheds are minor structures and would be recommended for demolition prior to installing the treatment system. If necessary, the options for installing vertical or horizontal electrodes to remediate areas beneath existing buildings could be added for cost estimating purposes.

<u>Metal fences</u>: The site fence is not expected to be a problem as far as acting as a pathway to electrical current as reported by ERH vendors on other projects. To confirm this assumption, the fence in the vicinity of the pilot test area will be monitored for stray voltage during operations.

4.4 Vapor Collection and Off-Gas Treatment

4.4.1 Vapor Collection

Vapor collection at an ERH system is typically accomplished by a conventional VR system using the vertical electrode wells screened within and above the treatment zone. For conventional VR systems the requirement of a surface seal is dependant on depth of the treatment zone and the degree of shortcircuiting that may occur. For implementation of ERH at the Site, the collection of vapors via vertical wells will not require supplementing by the installation of a surface cover due to the depth of heating. As was shown during the pilot test, the vertical VR wells (electrodes) will provide enough VR control during ERH full-scale operations without having a requirement for surface sealing.

It should be noted that the rate at which soil gas must be removed is directly correlated to the rate at which energy is injected into the subsurface. If during ERH operations it is found that maintaining containment of the soil gases is difficult, the heating process can be scaled back to accommodate the extraction capabilities of the system.

4.4.2 Off-Gas Treatment

The use of ERH is expected to remove most of the contaminant mass from a given treatment area over a relatively short period of time. As was utilized during the pilot test, the full-scale operations will rely on GAC system and off-site thermal regeneration for collection and treatment of the VOCs.

4.4.3 Safe Operating Conditions

It is estimated that the concentration of extracted vapors may be above the lower explosive limit (LEL). Therefore, the design both mechanically and operationally will take this possibility into account. Ambient air dilution points will be as near to the VR points as possible. This minimizes the concern for the above ground system. Monitoring of the subsurface gas concentrations can be accomplished using single extraction wellpoints (for a point source measurement) and using the combined extracted soil gas stream (for an "average" measurement).

During the operations, sufficient tertiary GAC units will be maintained as a backup for the primary GAC units to ensure that Massachusetts Department of Environmental Protection (MADEP) emission guidelines are not exceeded (Policy #WS-94-150, Off-Gas Treatment of Point Source Remedial Air Emissions). If necessary, power can be promptly shut off to the ERH electrodes. Immediately following electrode shutdown, the VR system will be operated to maintain minimum vacuum in the treatment area. Additionally, a review of the current state of the estimated GAC treatment capacity will be completed to enable a decision to fast-track the change out of one or more GAC vessels. Therefore, monitoring of breakthrough of the primary GAC units will not present an emissions problem.

4.5 Power Requirements

Power requirements are discussed in Section 5.1 to employ a full-scale ERH system and will be reviewed for practicality with the electrical utility (NSTAR), which serves the site.

4.6 Post-Test Characterization

When the operations have been completed, characterization will be performed to determine the groundwater contaminant concentrations. These measurements will allow an assessment of the total contaminant removal and the percentage of the clean-up goal achieved. Additionally, contaminant concentrations may result in the recommendation that the ERH system is restarted for an additional period of time.

Because of the hazards associated with subsurface heating, post characterization sampling will not be performed until the treated zone has cooled to levels that allow safe sampling (typically one day for groundwater and one month for soils). Cooling of the subsurface is a function of a number of environmental factors. Both vapor flow and groundwater influx will influence the cooling of the treated volume. Post characterization groundwater sampling will occur as soon as possible after shutdown. However, due to the heat remaining in the subsurface following completion of power input, the VR system must continue to extract soil gas, which may pull in additional contaminated vapor from outside the treated zone. Recontamination and continued removal of contaminants via VR are competing mechanisms, which will vary within different parts of the subsurface at different rates.

4.7 Recontamination

The assessment of contaminant mobilization from the ERH treatment is nearly impossible to discern based on the monitoring performed during the pilot test and the location surrounded by known contaminated soils and groundwater. Based on the groundwater monitoring program there has been a moderate level of recontamination at the target treatment area.

It may be possible to limit the extent of recontamination of the unsaturated zone due to soil vapor migration by using VR to continually sweep away the contaminant vapor entering the treated zone. Although some partitioning from the vapor to the soil phase will occur as a function of contact time, the use of VR will minimize this contact time and will provide a transport mechanism for the contaminant from the soil particle surface. Additionally, VR will serve as a polishing step to facilitate the diffusion of contaminants, which remain following ERH operations.

4.8 Vendor Procurement

TtEC will procure an experienced ERH subcontractor to design, install and operate the full-scale ERH treatment system. The selected ERH vendor will not necessary be the same as the subcontractor who performed the pilot test, following evaluation of competing bids to provide best value to the Navy.

The ERH vendor procurement document will specify the division of roles and responsibilities between TtEC and the ERH Subcontractor. The Work Plan will also highlight the specific roles and responsibilities. Table 4-1 provides a summary of the major roles and responsibilities of TtEC versus the ERH Subcontractor for completion of the full-scale ERH remediation.

Table 4-1
Summary of Roles and Responsibilities

Task	TtEC	ERH Subcontractor
Work Area and treatment location	Lead role	Review role
Design of ERH Wells and layout	Review role	Lead role
Design of Monitoring Scheme	Lead role	Review role
ERH System Design and Installation	Review role; to supply power connection and install electrode wells	Lead role; responsible for complete system installation
VR System Design and Installation	Review role; assist in installation of VR system	Lead role
Vapor Treatment System Installation	Review role; procure and install vapor treatment equipment	Lead role
Environmental Sampling	Lead role	Review role
ERH system start-up and shakedown	Review role	Lead role
ERH O&M	Lead on-site role	Lead overall ERH operations monitoring
Data analysis and reporting	Lead role	Review role

5.0 ERH SYSTEM

5.1 Power Supply

The local electrical utility (NSTAR) has verified that they will be able to provide the estimated maximum of 8,000 kilowatts (kW) power to be required for the full-scale ERH application. The average ERH power input is estimated to be just over 5,000 kW, and the design remediation energy is estimated to be just above 33,000,000 kW-hr. New Utility poles will be required to be installed from an existing source to the treatment area. Transformers and an electrical panel will be installed as necessary to several power control units (PCUs) which will consist of four 13 kv services with fused disconnects located adjacent to the remediation area. The service will extend to the security fence. The cable will be installed in a galvanized steel conduit as a protective measure. The ERH Subcontractor will be responsible for providing the power accessibility and connecting their equipment (PCUs) to the available power lines.

5.2 Water Supply

As was performed during the pilot test operations, water will be added at the electrodes, as necessary, to continually assist in the conduction of current into the subsurface. The temporary water supply will be taken from the groundwater treatment plant (GWTP). The water will be transmitted by flexible hosing over the ground to a manifold located in the remediation area.

Alternatively, the water supply may originate from the collected condensate storage tank. This alternate supply will be dependent on condensate sampling results and regulatory acceptance for the reinjection of recycled water. It should be noted that during the pilot test, the collected water was required (by MADEP) to be treated with GAC prior to discharge.

5.3 ERH Equipment

ERH equipment will be similar to that utilized during the pilot test and include voltage control systems, instrumentation and data acquisition systems. Further discussion on the ERH equipment will be provided in the Work Plan.

5.3.1 Vapor Extraction and Treatment System

In summary, the ERH system will use vertical wells for collection of soil vapor (and steam). The electrode wells will be designed to include the ability to recover soil vapor while heating. It is envisioned that 60% of the wells will be installed by pile driving and 40% will be installed by rotosonic drilling methods, as described in Section 6.0. A condenser will be used to separate the soil vapor from the soil moisture/steam and the collected water will be pumped to condensate storage tanks. The condensate water will either be stored or recycled back to the electrode wells. As was performed during the pilot test, the extracted soil vapor will be treated using GAC.

5.3.2 Layout Area

Because of the duration of the remediation (up to 9 months) a secure area will be required. The layout area will also allow ready access to the equipment for operation and monitoring. This layout area will be within the treatment area, similar to the pilot test area, and completely secured with chain link fencing.

5.3.3 Wellfield Piping and Manifolds

Wellfield piping will be used to convey the extracted soil vapor to the vapor treatment units. This piping will be chlorinated polyvinyl chloride (CPVC) from the wellheads to the extraction points. A manifold will be constructed to connect all the extraction points prior to the condenser unit. An ambient air dilution valve will be utilized to reduce the contaminant concentration to below 25% of the LEL.

Because of the temporary nature of the remediation, it is anticipated that all hose and piping will be allowed to rest on the ground surface without the need for more permanent setup or frost protection. Any above ground piping will be protected at several points for vehicle access where necessary.

5.3.4 VR Equipment

The VR equipment provided by the ERH Subcontractor will, at a minimum, include the following:

- Vacuum Blower with ancillary features such as an air filter, pressure and vacuum relief valves.
- Air Water separator.
- Condensing skid.
- Flow meters (liquid and vapor).
- Valves.
- Sampling ports.

5.3.5 Extracted Soil Vapor Treatment Equipment

The soil vapor extracted during the remediation will be treated with GAC. The GAC vapor treatment system will include three large vessels placed in series with each vessel containing up to 8,000 lbs of GAC. The estimated maximum VOC loading rate is 10 lbs/day. The effluent from the GAC canisters will be released through a stack to atmosphere.

During the remediation operations, the tertiary GAC units will allow primary GAC units to be changed out as necessary. A procured GAC subcontractor will complete the GAC change out.

Each GAC vessel will have sampling ports to monitor its contaminant removal efficiency. Once the GAC is spent, the GAC will be removed and properly transported off-site for regeneration. The spent GAC vessel will be refilled with regenerated GAC.

5.3.6 Instrumentation

As was accomplished during the pilot test, the data acquisition for the ERH system will be performed both automatically and manually. The instruments to be used are flow meters, pressure gauges, thermometers, water level gauges, and voltmeters.

5.3.6.1 Wellfield Instrumentation

The induced vacuum in the subsurface will be monitored at soil vapor piezometer wells and shallow monitoring wells with vacuum indicators (magnehelic type).

The water level measurements will be made manually by inserting a water level probe into a well through a port located at the wellhead. Water level measurements in the active treatment area will not be made during ERH operations due to health and safety concerns.

Thermocouples installed in the subsurface will be connected to a process control system to monitor and log subsurface temperatures on a daily basis.

6.0 ERH SYSTEM INSTALLATION, OPERATIONS AND MONITORING

This section provides a discussion of the installation, operations, and monitoring of the ERH system. The construction/installation program will follow the guidance and specifications described in a Work Plan and a Construction Quality Control Plan to be developed for the full-scale ERH remediation.

6.1 Wellfield Installation and Pre-Test Characterization

TtEC will procure subcontractors to assist in the installation of the subsurface remediation components. A drilling subcontractor will install the electrodes, monitoring wells, piezometers and temperature monitoring points. Rotosonic drilling techniques, as used during the pilot study installation, will be used for installation of electrodes in the Upper Treatment Region due to the depth of treatment and difficult soil conditions. For the Sloped Treatment Region and the Lower Treatment Region, pile driven electrodes are recommended as this is an easier installation method for shallow soils. These electrodes will be installed by a crane stationed at level locations at both the Upper and Lower Regions to allow access.

Drill cuttings and other soils generated by installation activities will be temporarily staged in appropriate containers at the Site. The materials will ultimately be characterized and properly disposed of by TtEC.

6.1.1 Site Preparation

The northeastern portion of the Sloped Treatment Region will be cleared of overgrown vegetation that could have an impact on the wellfield installation prior to ERH system installation. Locations for subsurface remediation components will be field located and staked prior to installation.

6.1.2 Electrode Wells Installation

It is estimated that a total number of 490 electrodes will be required in order to effectively remediate the specified areas. The spacing between electrodes is estimated to be 22 feet and maximum installation depths for the electrodes are estimated to be 45.5 feet.

As described above, the electrode wells will be installed using a combination of rotosonic drilling and pile driven techniques. The rotosonic drilling technique will be utilized for deeper electrodes in the Upper Treatment Region based on its success during the pilot test installation and pile driven electrodes will be installed at the Sloped and Lower Treatment Regions where it is anticipated that this technique will be applicable (shallower installation depths required).

6.1.3 Monitoring Wells Installation

New groundwater monitoring wells are not planned to be installed, however if requested, monitoring wells may be installed within the treatment area using rotosonic drilling techniques.

Groundwater samples will be obtained from existing monitoring wells using a peristaltic pump. Groundwater sampling procedures including purging and sampling will be detailed in the Work Plan and will be similar to those utilized during the pilot test sampling events.

6.1.4 TMPs Installation

An estimated 49 subsurface TMPs will be required for the remediation. The TMPs will be installed and be constructed in the same manner as was employed during the pilot study.

6.2 ERH System, VR System, and Instrumentation Installation

The ERH Subcontractor will be responsible for the installation of the ERH system, the VR system, process instrumentation and the security fence. The layout of equipment and final positioning of the security fence will consider access requirements for the supplied equipment and the condensate storage and vapor treatment vessels.

The major components are expected to be skid-mounted equipment owned by the ERH Subcontractor. The piping, fittings, and valves; and instrumentation will be field fitted by the ERH Subcontractor with the piping located on the ground surface. TtEC will monitor the construction and installation of the system by the ERH subcontractor at the Site

6.3 Vapor Treatment System Installation

TtEC will complete the installation of the GAC vapor treatment system for the ERH remediation. TtEC will also procure a GAC subcontractor to supply the necessary vessels and GAC and will include provisions for the changeout of the spent GAC. It is envisioned that large GAC vessels (8,000-lb GAC) will be setup and positioned adjacent to the pilot test area. Details regarding management of the vapor treatment system will be provided in the Work Plan.

6.4 Shakedown of System/Readiness Review

Following construction and installation of ERH and VR components, shakedown and startup will be performed. Prior to system shakedown, a walk down of the entire system will be performed. During the walk down, the system will be configured for the shakedown test, all valves/tags will be checked, an electrical inspection will be completed, and instruments/meters will be calibrated.

For the VR System, shakedown/startup will involve individually starting up and testing each system component using 100% ambient air, beginning at the extraction wells and working back to the VR blower. Shakedown will include testing each system component (blowers, pumps, tanks, motors, piping, valves, etc.) for proper operations and leaks, testing system interlocks and alarm conditions, and testing and calibrating system instrumentation.

6.5 ERH Operation

Upon completion of the shakedown and startup, the ERH operations will be initiated. The system operation is planned for an approximate 280-day period of operation in order to reach the 95% groundwater contamination reduction target. Actual system end of operations will be determined based on evaluations conducted during the operation period.

6.5.1 Initial Heat Up Period

The ERH operations will be initiated by introducing the electricity to the electrodes and monitoring the ramp up of the subsurface temperatures. The goal of the initial heat up period is to achieve uniform heating across the treatment volume while ensuring that the vapor control and collection system is functioning as designed. The achievement of the boiling point of water is the heat up period milestone for the saturated zone. For areas with NAPLs present the target boiling point temperature will be determined by based on contaminant levels. Temperature goals for the unsaturated zone will be 90°C. Once reached, the treatment volume will be maintained above the boiling point of water until the decision to complete post-test characterization. The decision to complete post-operations characterization will be mutually derived.

6.5.2 Monitoring Period

Monitoring will be conducted throughout the ERH operations, similar to monitoring conducted during the pilot test. Subsurface temperature is the critical ERH process monitored. Other monitoring will be performed throughout the operations, such as induced vacuum, VR flow rates, and vapor concentrations.

Because ERH is expected to remove most of the contaminant mass from the treatment area over a relatively short period of time, a substantial mass of contaminant will be removed quickly. This requires a close review of the VOC mass loading on the vapor treatment system to ensure that the GAC is achieving required performance treatment standards. Vapor samples will be collected with testing performed with on-site field instruments and at an off-site analytical laboratory.

The monitoring of the off-gas removed during the operations (influent mass to the treatment system) will also be used to gauge the level of treatment achieved in the subsurface at the treatment area. The monitoring data is expected to show declining VOC mass removal rates over time. The decline in VOC removal will be tracked and will be one of the criteria used to determine shut down of the ERH operation.

The extracted soil vapor and soil moisture will be separated in a condenser. The collected water will be pumped to the water storage tank for sampling and storage. Sampling results will be used to determine the ability to recycle the water to the electrode wells or sent for off-site disposal. During the pilot test, the collected water was treated through liquid-phase GAC prior to disposal.

7.0 POST REMEDIATION CHARACTERIZATION

Following the ERH remediation, characterization will be performed to determine both soil and groundwater contaminant concentrations. These measurements will allow an assessment of the total contaminant removal and the percentage of the clean-up goal achieved.

It is expected that the VR system will remain operational during the post-remediation period. The VR system will continue to control and collect liberated vapors and assist in cooling the heated subsurface soils.

7.1 Field Sampling and Off-Site Analysis

A sampling plan will provide the protocols and guidance on soil and groundwater sampling locations for the post-remediation characterization. During the post-remediation period, vapor samples will continue to be collected and analyzed to document the change in extracted soil vapor concentrations and to assess the efficiency of the GAC vapor treatment system. Vapor and groundwater samples will be collected and analyzed in an off-site analytical laboratory.

7.1.1 Subsurface Temperature Monitoring

Continuous temperature monitoring will be performed after system shut down. Temperature monitoring is necessary because post-operations sampling will be contingent on reaching levels that allow safe sampling procedures.

7.1.2 Confirmatory Sampling and Analysis

Groundwater samples will be collected upon reaching the post-operations target sampling temperature. Groundwater samples will be collected from available monitoring wells in the treatment area.

Additionally, groundwater level measurements will be performed at the monitoring wells, if possible, during groundwater sampling and periodically thereafter to monitor groundwater gradients in the treatment area. However, monitoring may be deemed to be unsafe due to subsurface pressure or steam generation at the wellhead. Soil samples may be collected to help access the removal of contaminants in some areas.

7.2 Field Measurements

VR process monitoring and wellfield vapor monitoring will continue during post-remediation characterization. The process monitoring will be similar to the ERH pilot test operational period, as long as the VR remains operational. The VR will remain operational to continue to control and collect liberated vapors, as appropriate based on off-gas measurements and wellfield monitoring results.

Soil temperature will continue to be monitored throughout the post-remediation period at each of the TMPs. These measurements will be used to monitor when the post-remediation groundwater sampling will be performed.

Similar to the pilot test period monitoring, data will be collected to monitor the vapor collection and treatment system. This includes flow, vacuum and vapor concentrations throughout the system.

8.0 FULL-SCALE COSTS

ERH implementation costs for a full-scale application have been developed for the treatment regions as described in Section 4.0. The preliminary cost estimates were developed in conjunction with TRS and are detailed for this proposed application. Additional information on cost estimate developed by TRS is provided in Appendix A – Estimated Remediation Parameters and Cost.

A cost estimate developed for the proposed implementation is presented in Appendix A - Table A-1 for the complete area (189,500 sf) representing approximately 235,000 cubic yard. The preliminary cost estimate was divided into major activities including ERH subcontractor, overall design, drilling and sampling, CTO administration, field staff, sample analysis, vapor treatment, utilities, waste disposal, and miscellaneous site work. It is important to note that the actual cost estimate would be more accurately refined once the proposed plan of action for full-scale implementation is identified.

Major costs related to the ERH installation include ERH vendor subcontract, drilling/installation subcontract, electrical power, sampling and analysis, GAC regeneration, waste disposal, and associated labor costs for field and home office support. The largest single cost is for ERH vendor subcontract, which is presently estimated to be $6.1 million (M), including approximately $2.4M in subsurface installation costs, approximately $1.7M in surface installation costs, and approximately $1.5M in system operation costs. Other significant costs are estimated to be approximately $3.7M in electrical power costs, approximately $630 thousand (K) in field staff costs and approximately $420K in project management and administrative costs. Pre- and post-test sampling and site restoration are estimated to be approximately $150K, GAC usage and regeneration are estimated to be approximately $70K, and waste disposal is estimated to be approximately $201K. The overall cost for a full-scale ERH implementation at the Site is estimated to be approximately $11.4M, resulting in an approximate cost of $50 per treated cy.

9.0 SUMMARY

The results of the 2003 ERH Pilot Study at the Bedford NWIRP Site have been used to develop a full-scale approach for implementing ERH at the Site. The overall results indicate that ERH is a viable technology for attaining the groundwater clean-up goals at the Site, potentially leading to overall site closure.

Based on findings from the pilot study, full-scale ERH constructability is feasible and can be implemented as outlined in this Constructability Evaluation. Past experience and lessons learned from the pilot study are invaluable in designing for potential full-scale implementation at the Site and will allow potential problems to be surmounted. The three treatment regions outlined herein provide the most cost-effective and beneficial implementation to reach the targeted clean-up goals for the Site. Application of ERH as described would allow for the removal of the majority of the contaminant source from over four acres of the Site at a cost that would not be prohibitive. Total remediation cost of $11.4M and overall unit costs of approximately $50 per treated cy are within acceptable values for typical site remediation costs.

Prior to full-scale implementation, a detailed work plan and more accurate cost estimate must be developed, covering all the possible variations from the proposed application. However, before any remedial action is selected, the primary end goals must be decided upon and regulatory acceptance must be attained.

10.0 REFERENCES

Foster Wheeler Environmental Corporation. April 2003. *Final Work Plan for Site 3 Thermal Treatment Pilot Test, Naval Weapons Industrial Reserve Plant, Bedford, Massachusetts, Rev. 0.*

Tetra Tech NUS, Inc.. January 2005. *Draft Final Feasibility Study for Site 3, Naval Weapons Industrial Reserve Plant, Bedford, Massachusetts.*

Tetra Tech EC, Inc.. April 2005. *Closeout Report for Site 3 Thermal Treatment Pilot Test, Naval Weapons Industrial Reserve Plant, Bedford, Massachusetts, Rev. O.*

APPENDIX A

Estimated Remediation Parameters and Cost

Table A-1
Bedford ERH - Full Scale Site 3

ERH total area (sf) =	189,500
unit cell area (sf) =	189,500
total # unit cells =	1
total # electrodes =	490
total # TMPs =	49
depth (ft) =	45.4
total duration (dy) =	282
treated volume (cy) =	234,419

ERH Subcontractor Est. (TRS):	$	6,101,000
PROJECT TOTAL:	**$**	**11,429,170**
cost per treated cy =		$49

	Qty.	Unit		Unit Price		Total Cost
Design						
Work Plan/Cost Proposal	1	ea.	$	50,000	$	50,000
QAPP	1	ea.	$	25,000	$	25,000
SSHP update	1	ea.	$	15,000	$	15,000
SOWs	7	ea.	$	3,500	$	24,500
				TOTAL:	**$**	**114,500**
Waste Disposal						
Drill Cuttings	613	per ton	$	235	$	144,272
Waste Water	421,000	per gal.	$	0.13	$	56,625
				TOTAL:	**$**	**200,896**
Task Order Admin						
PM	12	per mo.	$	12,000	$	144,000
MIS	12	per mo.	$	4,500	$	54,000
Procurement	4	per mo.	$	7,500	$	30,000
QC	10	per mo.	$	19,200	$	192,000
				TOTAL:	**$**	**420,000**
Field Staff						
Installation - 3 field staff	6	per mo.	$	51,000	$	306,000
Installation support	6	per mo.	$	8,500	$	51,000
O&M - 1 field staff	9	per mo.	$	15,000	$	135,000
O&M support	9	per mo.	$	7,500	$	67,500
Procurement	12	per mo.	$	5,000	$	60,000
Demob	2	per mo.	$	15,000	$	30,000
				TOTAL:	**$**	**649,500**
Miscellaneous						
PVC MW replacement	5	ea.	$	8,500	$	42,500
Security fence	800	per ft.	$	25	$	20,000
Site restoration & disposal	10	per dy	$	3,400	$	34,000
				TOTAL:	**$**	**96,500**

	Qty.	Unit		Unit Price		Total Cost
Pre-Sample Analysis						
Soil VOCs	24	ea.	$	94	$	2,256
Soil TOC	6	ea.	$	55	$	330
Groundwater VOCs	140	ea.	$	85	$	11,900
				TOTAL:	**$**	**14,486**
During-Sample Analysis						
Summa TO-14	45	ea.	$	285	$	12,825
Summa Methane	45	ea.	$	65	$	2,925
Groundwater VOCs	30	ea.	$	85	$	2,550
				TOTAL:	**$**	**18,300**
Post-Sample Analysis						
Soil VOCs	24	ea.	$	94	$	2,256
Soil TOC	6	ea.	$	55	$	330
Groundwater VOCs	140	ea.	$	85	$	11,900
				TOTAL:	**$**	**14,486**
Vapor Treatment						
GAC vessel mob	1	ea.	$	3,550	$	3,550
GAC vessel rental	44	per wk.	$	585	$	25,740
GAC usage	56,000	lbs.	$	0.44	$	24,640
GAC changeout	4	ea.	$	2,080	$	8,320
GAC demob	1	ea.	$	5,892	$	5,892
				TOTAL:	**$**	**68,142**
Utilities						
Electric install	1	ea.	$	60,000	$	60,000
Electricity	33,376,000	kWh	$	0.11	$	3,671,360
				TOTAL:	**$**	**3,731,360**

Estimated Remediation Parameters and Cost

Site Name: **Bedford NWIRP Steaming**

Electrical Resistance Heating Treatment Area:	205,212 sq. ft.	
Shallow Extent of Electrical Resistance Heating:	10 ft	
Deep Extent of Electrical Resistance Heating:	44.4 ft	
Typical Depth to Groundwater:	10 ft	
Treatment Volume:	261,700 cu yds	
Soil Organic Carbon Content:	0.10%	Based on provided TOC data.
	About 40% of the electrodes would be installed by boring (deep electrodes) and about 60% of the electrodes would be installed by pile driving.	
Estimated Number of Electrodes:	490	
Estimated Distance Between Electrodes:	22 ft	
Total Depth of Electrodes	45.4 ft	
Depth to Top of Electrodes	12 ft	
Estimated Number of Vapor Recovery Wells:	490	
Number of Temperature Monitoring Points:	49	Each TMP has 8 thermocouples.
Number of New Monitoring Wells:	0	
Piping and Well Installation:	5% is below grade completion to provide access routes	
Is a New Surface Cap Required?	no	
Controlling Contaminant:	TCE	
Overall Clean-up Percent:	95%	E.g., reduce 1,550 ug/l to 78 ug/l
Assumed VOC Mass:	170 lbs	Assumes avg. VOC conc. of 0.2 mg/kg.
Vapor Recovery Air Flow Rate (scfm):	2450 scfm	
Minimum Vapor Recovery Blower:	180 horsepower	
Condensate Production Rate:	25.9 gpm	(when the site is at full steam production)
Liquid Groundwater Pumping Rate:	0 gpm	
Vapor Treatment Method:	carbon	
Assumed Activated Carbon Required:	16,000 lbs	
Power Control Unit (PCU) Capacity:	8000 kW	
Average Electrical Heating Power Input:	5428 kW	

THERMAL REMEDIATION services inc.

The entire treatment volume is heated simultaneously.

Total Heating Treatment Time:	231 - 282 days	
Design Remediation Energy (kW-hr):	33,376,000	
Number of Confirmatory Soil Borings Included:	49	Analysis of 7 soil samples per boring

The above parameters are estimated +/- 20%. Final parameters will be determined during system design.

Approximate Costs (+/- 20%)

Thermal Remediation Services Costs

		Percent	
Design, Work Plans, Permits:	$86,000	1%	
Subsurface Installation:	$2,365,000	23%	
Surface Installation and Start-up:	$1,684,000	17%	
Remediation System Operation:	$1,488,000	15%	
Demobilization and Final Report:	$478,000	5%	
Total TRS Costs	**$6,101,000**		

Estimated Costs by Others

Site Preparatory Work:	$0	0%	
Drill Cuttings and Waste Disposal:	$87,000	1%	assumes $250 per ton
Electrical Utility Connection to PCU:	$60,000	1%	
Electrical Energy Usage:	$3,751,000	37%	assumes $0.11 per kW-hr
Carbon Usage, Transportation & Regeneration:	$29,000	0%	assumes $1.80 per pound
Water/Condensate Disposal:	$2,000	0%	
Other Operational Costs:	$72,000	1%	includes vapor sampling

Total Remediation Cost:	**$10,102,000**
Total Cost per Cubic Yard:	$39

	Volume (cu.yd.)	Plan Area (sq.ft.)	Average Depth Interval (ft.)	Percent of Total Volume	Average TCE (ppb)	TCE Mass (kg)	TCE Reduction	Average Final TCE (ppb)	Final TCE Mass (kg)
Bio (218-1000 ppb)	158,045	98,315	43	60%	516	15.57	80%	103	3.11
Steam (>1000 ppb)	103,655	106,897	26	40%	3,126	61.94	99%	31	0.62
Overall (>218 ppb)	261,700	205,212	34	100%	1,550	77.51		75	3.73
									95.2%

= data from Elisabeth Martin, ENSR

= assumed reduction goal

Other parameters are calculated from provided data and/or assumed goals.

From Pilot Study:

total tons of Site 3 drill cuttings	131	tons
24 borings @ 60 ft per boring =	1440	linear feet

Full-Scale

rotosonic borings	196	borings
average depth	34.4	feet
linear feet of rotosonic drilling	6742.4	linear feet
estimated drill cuttings	613.4	tons

transportation and disposal

Assume 15% of cuttings hazardous			
521 tons non-hazardous @	$109.50	per ton	57,049.50
92 tons hazardous @	$198.00	per ton	18,216.00
			75,265.50
roll-off rental			
Assume 12 tons per roll-off			
51 roll-offs required			
set-up fee @	$225	per roll-off	11,475.00
Assume average time roll-off on site	4	weeks	
roll-off rental per week:	$65.50		13,362.00
roll-off liners	$40		2,040.00
		SUBTOTAL	**102,142.50**

solidification

1 bag of polymer	$175		
Assume 2 bags of polymer per roll-off			
102 @	$175		17,850.00
labor			
5 roll-offs solidified/day = 11 days @	$2200/day		24,200.00
		SUBTOTAL	**42,050.00**

Frac Tanks for wastewater

1 frac tank for 1 day	$26		
Assume 3 frac tanks for 6 months			14,040.00
set-up fee @ 3 @	$225		675.00
frac tank cleaning 3 @	$2,770		8,310.00
421000 non-haz gallons	$0.08		33,680.00
		SUBTOTAL	**56,705.00**
		TOTAL	***200,897.50***

On 11/8/04 Elisabeth Martin told Greg Beyke to assume that the VOC mass had to be reduced by 95%.

Greg-

See forwarded message below regarding your 1st question.

Regarding your second question, bedrock was not included in these calculations.

On #3, I still do not have confirmation of the 95% reduction number, but expect to before the end of the week.

-----Original Message-----
From: Herberich, Jim
To: Martin, Elizabeth
Sent: 11/2/2004 10:29 AM
Subject: RE: Bedford Geometry

Sorry, but it looks like the original volume and mass we had sent for the 218 isolevel were not correct. They should be:

Isovolume above 218 ug/l
soil vol 2.61700e+05 cu yd
chem mass 7.75080E+01 kg
average conc 1.54955E+03 ug/l

All other values reported yesterday are correct. So, the "average concentration" between the 218 and 1,000 isolevels is 515 ppb, by the formula below. (Couldn't be 1,784 now could it? It was after 5, what do you expect?!?)

Jim.

Elisabeth,

Thank you for making these calculations. However, we must be misunderstanding the calculation or there is a typo:

I tried to solve for the average contamination level in the region between the 218 ug/l and the 1000 ug/l contours by using a volume-weighted average. I figured that by definition the "answer" had to lie in the range 218 to 1000 ug/l. The formula and result for that calculation are:

average concentration (between 218 and 1000 contours) = (2.00375e+05 cu yd * 1.67756E+03 ug/l - 1.03655E+05 cu yd * 3.12639E+03 ug/l) / (2.00375e+05 cu yd - 1.03655E+05 cu yd) = 125 ppb.

This answer does not make any sense. On a related issue, Jim reported that the average concentration in the 218 ug/l contour was 1,678 ug/l. Based on previously supplied information, the average concentration appeared to be 2,267 ug/l (see below).

Two other questions:

2) Does any of the above discussion include bedrock contamination?

3) Do you know what final VOC mass we need to achieve yet? For example, if we have 64.25 kg of VOCs, do we need to reduce the contamination to 5% of that level, or 3.21 kg?

Greg Beyke

-----Original Message-----
From: Martin, Elizabeth [mailto:EMartin@ensr.com]
Sent: Monday, November 01, 2004 10:10 AM
To: Myse, Todd; Greg Beyke
Subject: FW: Bedford Geometry

See below for volume calculations computed using EVS. Calculations are similar to TRS "guesstimate".

From: Herberich, Jim
Sent: Monday, November 01, 2004 10:52 AM
To: Martin, Elizabeth
Subject: RE: Bedford Geometry

Isovolume above 218 ug/l
soil vol 2.00375e+05 cu yd (erroneous)
chem mass 6.42497E+01 kg (erroneous)
average conc 1.67756E+03 ug/l(erroneous)
plan view area 2.05212E+05 sq ft

Isovolume above 1,000 ug/l
soil vol 1.03655E+05 cu yd
chem mass 6.19419E+01 kg
average conc 3.12639E+03 ug/l
plan view area 1.06897E+05 sq ft

Jim.