TRANSMITTAL

SDMS DocID 000209066

Memo

New Bedford

209066

To: Mary Garren, EPA

From: Anna Mayor, DEP

Date: 09/08/99

Re: Transmittal of theTufts Capstone Project Final Report

Mary,

Enclosed is the final Tufts Capstone Project Report on the Central Area, entitled: Evaluation of Remediation Alternatives for the Central Area Groundwater Aquifer at the Wells G & H Superfund Site. The report provides an interesting analysis of the feasibility of cleaning up the Central Area Aquifer. Briefly, their recommendations are the following:

1. Update the groundwater model [specifically, the Ohio State University 1998 groundwater model for the Site].
2. Perform the work specified in the CD.
3. Additional characterization of the bedrock.
4. Determine existence and extent of DNAPLs.
5. Perform additional rounds of groundwater sampling.
6. Use screenings and evaluations of remediation alternatives [included in the report] as basis for further evaluations.

After you take a look at the document, I would like to discuss your thoughts on our plans to distribute this document to the City of Woburn and the Source Area Properties involved in the Central Area investigation. Also, thank you for the help that you gave the Capstone group during their research. They gave an excellent presentation at the end of the project, and I wish you could have seen it. It is unfortunate that they are unable to repeat the presentation for your office.

EVALUATION OF REMEDIATION ALTERNATIVES FOR THE CENTRAL AREA GROUNDWATER AQUIFER AT THE WELLS G & H SUPERFUND SITE, WOBURN, MASSACHUSETTS

A Capstone Project

submitted by

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In partial fulfillment of the requirements
for the degree of

Master of Science

in

Civil and Environmental Engineering

TUFTS UNIVERSITY

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Approved by:
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Larry Cohen

EXECUTIVE SUMMARY

In 1979 the City of Woburn, Massachusetts' water supply wells G and H were shut off when elevated levels of chlorinated volatile organic compounds (cVOCs) were detected in the groundwater from the wells. The primary contaminants detected in groundwater in wells G and H were tricholoroethylene (TCE), which was present at a maximum concentration of 400 ug/L (well G in 1980) and perchloroethylene (PCE), which was present at a maximum concentration of 292 ug/L (well H in 1985).

In 1982, the 330-acre area surrounding wells G and H was designated as a U.S. Environmental Protection Agency (USEPA) Superfund Site (the Site). The Record of Decision (ROD) for the Site specified that groundwater remediation is required at the five upgradient properties designated as Source Areas, and that additional studies are necessary to determine the most effective way to remediate the Central Area (the area where wells G and H are located). The primary remedial objective specified in the ROD for the Site was restoration of the groundwater aquifer to drinking water standards (Maximum Contaminant Levels (MCLs) established under the Safe Drinking Water Act).

In 1991, a Consent Decree (CD) was signed between USEPA, Massachusetts Department of Environmental Protection (MADEP) and four of the Potentially Responsible Parties (the Settling PRPs – W.R. Grace & Company, Unifirst Corporation, Wildwood Conservation Corporation, and New England Plastics). The Settling PRPs agreed to perform investigations and remediation work in the Central Area and in each of the four Source Areas in accordance with the requirements stipulated in the ROD. Groundwater remediation is currently being performed at each of the Settling PRPs' properties. An Initial Characterization of the Central Area was completed by the Settling PRPs in 1994.

The MADEP requested that the Capstone Group identify, screen, and evaluate technologies and alternatives for remediating the cVOCs in the groundwater at the Central Area to drinking water standards. The Capstone Group also determined whether the PRPs have evaluated remedial alternatives for the Central Area as required under the CD, and evaluated the technical and economic feasibility of remediating the Central Area Aquifer using USEPA and MADEP criteria.

Existing Site documents and data were used to develop an understanding of the Site hydrogeology and the extent of contamination. The impacts of the operating Source Areas treatment systems on the Central Area were evaluated. The portion of the Central Area aquifer that is not being captured by Source Area treatment systems but contains cVOCs (mainly PCE and TCE) above MCLs was identified as the remediation area. This area, hereafter referred to as the Central Area Corridor, is 36 acres in area and contains approximately 370 million gallons of groundwater.

By performing a detailed comparison between the Initial Central Area Characterization (Phase 1A Investigation) and the CD requirements, it was determined the Settling PRPs did not meet all the requirements of the CD. Specifically, the Settling PRPs did not identify the potential remedial technologies and alternatives that could be used at the Central Area, nor did they perform the investigations necessary to evaluate the potential technologies.

The Capstone Group screened and evaluated remediation technologies and alternatives consistent with the USEPA's *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA*. Technologies determined to be ineffective for the hydrogeologic conditions and contaminants present at the Central Area were eliminated from further consideration. Remediation technologies and process options were screened for effectiveness, implementability, and cost. A point scoring system was implemented to provide a semi-quantitative means of selecting the technologies from each response action that would be carried into the 'analysis of alternatives' phase of the project. The results of the scoring yielded the following four remediation alternatives that are representative of diverse response actions: (1) no action, (2) monitored natural attenuation, (3) extraction of groundwater followed by treatment using air strippers (a.k.a. pump & treat), and (4) in-well air stripping. Each of these alternatives was evaluated using six of the nine evaluation criteria established under CERCLA.

The results from this evaluation of alternatives indicate that active groundwater remediation at the Central Area would be feasible. The following is a summary of the findings for each alternative:

- <u>No Action</u> – The no action alternative for the Central Area Corridor involves no engineered treatment or containment of groundwater that contains contaminants in excess of cleanup goals. Institutional controls, such as deed restrictions, would be implemented to restrict access to the groundwater. Contaminated groundwater would be allowed to migrate across the Site without treatment. Reduction of the toxicity, mobility, and volume of the contaminants could only occur as a result of natural processes, such as biodegradation and aquifer flushing; however, without groundwater monitoring activities, there would be no method of detecting when cleanup goals are met. The no action alternative is protective of human health but is not protective of the environment. Total present worth cost over 30 years is estimated to be $0.05 million.

- Monitored Natural Attenuation (MNA) – Analysis of MNA was performed by evaluating destructive and non-destructive natural processes. The biological screening to date for MNA indicates inadequate evidence for the biodegradation of cVOCs in the Central Area Corridor groundwater. The duration for the remediation of PCE and TCE in the bedrock was estimated at 200 and 50 years, respectively. Total present worth cost over 30 years is estimated to be $0.7 million. The toxicity of contaminants in groundwater may be reduced via *dilution*, but there would be no reduction in mobility or volume. Because of the variable nature of the fractured bedrock within the Central Area Corridor, it is likely that some groundwater in the bedrock may not flush pockets of residual dense non-aqueous phase liquid (DNAPL).

- Pump & Treat – Assuming a pumping rate of 240 gallons per minute (gpm), 4 bedrock wells and 6 deep unconsolidated wells would remediate groundwater in the Central Area Corridor in about 60 years. The total present worth cost over 30 years is estimated to be $9.1 million. Toxicity, mobility, and volume of the contaminants will be permanently reduced. However, the bedrock may never be fully remediated due to its highly fractured nature and possible pockets of DNAPL. The negative impact to the community and the environment will be minimal.

- In-Well Air Stripping – Assuming an air-water ratio of 75:1, 18 bedrock circulation wells with 18 activated carbon units will remediate cVOCs found in the Central Area Corridor to MCLs in about 15 years at a cost of about $14 million. Toxicity, mobility, and volume of the contaminants would be permanently reduced. However, the bedrock may never be fully remediated due to its highly fractured nature and possible pockets of DNAPL. The negative impact to the community and the environment will be minimal.

Remediation is considered to be economically feasible since the present worth cost to remediate the Central Area Corridor using either pump & treat ($9.1 million) or in-well air stripping ($13.7 million) is less than the cost ($18 million) to continually purchase water from the Massachusetts Water Resources Authority (MWRA) over the next 30 years.

The hydrogeology (an unconfined aquifer over 100 feet deep underlain by highly fractured bedrock) and distribution of contaminants (multiple sources, no defined plume, and other contaminants besides cVOCs present above drinking water standards) in the Central Area aquifer make remediation to drinking water standards a challenging task. However, insufficient information is presently available to conclude that remediation is infeasible or technically impracticable as defined by the USEPA guidance document, *Guidance for Evaluating the Technical Impracticability of Ground-Water Restoration.*

Additional data needs to be collected and more studies need to be performed in order to complete a detailed evaluation of remediation alternatives. This information is also needed to determine the technical feasibility of groundwater remediation and to satisfy the requirements specified in the CD. The additional information and work needed is listed below:

- Perform additional groundwater analyses for cVOCs and natural attenuation parameters in order to obtain current contaminant concentrations (noting that the majority of the existing data set is over six years old), and to assess variations in groundwater concentrations over time.
- Perform additional site investigations to determine the extent of DNAPL present in the Central Area. This information is needed to establish areas where remediation may be technically impracticable.
- Update the existing Site-wide groundwater model developed by Ohio State to incorporate the currently operating Source Area groundwater extraction systems. This model could then be used to evaluate remedial alternatives, such as pump & treat and MNA.
- Conduct pilot tests for in-well stripping and other promising innovative technologies to confirm their effectiveness and to gather data for design purposes.
- Conduct pump tests to design an extraction system that would maximize VOC removal and minimize potential contaminant infiltration from the River.

ACKNOWLEDGEMENTS

The Capstone Group would like to thank all of the people who helped us complete this project on the Wells G & H Superfund Site (the Site). We cannot name all of those who assisted us, for we would inevitably leave some one out by mistake.

First, we would like to thank our client, Massachusetts Department of Environmental Protection (MADEP), for suggesting the project. The MADEP Project Manager, Anna Mayor, spent much of her own time in giving us a tour of the Site, orientating us to the many historical Site documents, making copies of documents, and providing us with feedback and encouragement.

Thanks go to our advisor on this capstone project, Larry Cohen for his direction, support, and good advice throughout the life of the project. We could not have completed the project without his assistance. Willard Murray of Harding Lawson Associates also helped us tremendously by sharing his expertise on groundwater remediation technologies and reviewing early drafts of our report. We greatly appreciate the support of Chris Swan and Joe Stagner for their assistance on the conceptual design of remediation alternatives, and Charles Myette for his historical perspective on the hydrogeology at the Site.

A number of other individuals went out of their way to help us on this project. Thanks go to the representatives of W.R. Grace & Company, Unifirst Corporation, and Wildwood Conservation Corporation, and their consultants from HSI GeoTrans, Environmental Project Control, and RETEC, respectively, who let us tour the treatment facilities and courteously responded to our inquiries. We are also indebted to all of the treatment technology vendors and consultants who were kind enough to provide us the information we needed to evaluate the remediation alternatives.

Lastly, we would like to sincerely thank each of our families and friends for their continued support and encouragement throughout this long and difficult project. Most notably, we would like to acknowledge Dulcey Lacroix, Gary's wife, whose pregnancy unfortunately coincided with the timing of this project. Dulcey was extremely understanding and supportive throughout the life of the project, right up to birth of Gary and Dulcey's son, Benjamin, who was born three weeks before this report was completed.

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LIST OF ACRONYMS AND ABBREVIATIONS

ARARs	Applicable or Relevant and Appropriate Requirements
AS	air sparging
BACT	Best Available Control Technology
bgs	below ground surface
BTEX	benzene, toluene, ethylbenzene, and xylene
BUG	Beatrice, Unifirst, and Grace
CAA	Clean Air Act
CAT/OX	catalytic oxidation
CD	Consent Decree
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CSM	Conceptual Site Model
CWA	Clean Water Act
cVOCs	chlorinated volatile organic compounds
DCA	dichloroethane
DCE	dichloroethene
DEQE	Department of Environmental and Quality Engineering
DNAPL	Dense Non-Aqueous Phase Liquid
DOT	Department of Transportation
EA	Endangerment Assessment
FS	Feasibility Study
GAC	granular activated carbon
gpm	gallons per minute
LS	lump sum
M&E	Metcalf & Eddy
MADEP	Massachusetts Department of Environmental Protection
MADEQE	Massachusetts Department of Environmental and Quality Engineering
MCLs	Maximum Contaminant Limits
MCP	Massachusetts Contingency Plan
Mgal	million gallons
mg/L	milligrams per liter
MIT	Massachusetts Institute of Technology
MNA	Monitored Natural Attenuation
MSDH	Massachusetts State Department of Health
MWRA	Massachusetts Water Resources Authority
NAPL	Non-Aqueous Phase Liquid
NCP	National Contingency Plan
NEP	New England Plastics
NGVD	National Geodetic Vertical Datum of 1929
NIEHS	National Institute of Environmental Health Scientists

NPDES	National Pollutant Discharge Elimination System
NPL	National Priorities List
O & M	operation and maintenance
OHSA	Occupational Health and Safety Association
OSWER	Office of Solid Waste and Emergency Response
OU	Operable Unit
PAHs	polynuclear aromatic hydrocarbons
PCE	tetrachloroethene or perchloroethylene
ppb	parts per billion
PRPs	Potentially Responsible Parties
PV	number of pore volume flushings
PVC	polyvinyl chloride
R	retardation factor
RACT	Reasonably Available Control Technology
RD/RA	Remedial Design/Remedial Action
RETEC	Remediation Technologies, Inc.
RI	Remedial Investigation
SARA	Superfund Amendments and Reauthorization Act
SDWA	Safe Drinking Water Act
sq. ft	square feet
SS	suspended solids
SVE	soil vapor extraction
SVOCs	semi-volatile organic compounds
TBC	to be considered
TCA	trichloroethane
TCE	trichloroethene
TCL	Target Contaminant List
TI	Technical Impracticability
TMV	toxicity, mobility, and volume
ug/L	micrograms per liter
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
UV/OX	ultraviolet oxidation
VC	vinyl chloride
VGAC	vapor-phase granular activated carbon
VOCs	volatile organic compounds

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1. INTRODUCTION

1.1 PURPOSE AND OBJECTIVES

The parties responsible for the contamination in groundwater at the Wells G & H Superfund Site (the Site) in Woburn, Massachusetts have questioned the feasibility and necessity of cleaning the central portion (the Central Area) of the Site, where wells G and H are located, to the applicable drinking water standards. To determine whether it is technically feasible to *remediate* ("clean up") the Central Area, Massachusetts Department of Environmental Protection (MADEP) has requested that our Capstone Group identify and evaluate groundwater technologies and alternatives that could be used to remediate the groundwater in the Central Area to drinking water standards. The feasibility of remediating the Central Area aquifer will be evaluated by applying established MADEP and United States Environmental Protection Agency (USEPA) feasibility assessment criteria. A by-product of the Capstone Group's evaluation will include a data gap assessment that will allow MADEP to plan additional investigations for the Central Area. Factors – such as changes to the aquifer classification or public opinion associated with the Site – that could have a significant impact on restoration objectives and remediation technologies have not been considered in this evaluation unless otherwise noted.

1.2 SITE DESCRIPTION

The Wells G & H Site is located in the eastern portion of Woburn, approximately 10 miles north of Boston. The Site includes the aquifer and land area located within the *zone of contribution*[1] of the two municipal drinking water wells known as wells G and H. The Site is approximately 330

[1] *Zone of contribution* is the portion of the aquifer that supplied groundwater to wells G & H under pumping conditions.

acres and is bounded by Route 128/95 to the north, the Boston and Maine Railroad to the west, and Salem Street, Cedar Street and Route 93 to the south and east (Figure 1-1).

Wells G & H are located in the sand and gravel aquifer of the Aberjona River basin within the Mystic River watershed. The area surrounding the wells within the Site boundary is of mixed use (i.e., light industry, commercial businesses, industrial parks, residences, and recreational property). Industrial and commercial property to the north and residential property to the south dominate the area surrounding the Site (USEPA, 1989)•.

The Aberjona River (the River) flows through the Site from north to south, and eventually reaches the Mystic Lakes in Winchester, Massachusetts. A substantial wetland area associated with the Aberjona River floodplain is located on either side of the river within the Site boundary. A more detailed description of the Site's hydrogeological setting is provided in Section 3. Figure 1-2 is a Site map showing the location of wells G & H, the limits of the Central Area, the Aberjona River, its tributaries and associated wetlands, and the five industrial properties identified by USEPA as sources of contamination (the Source Areas) – W.R. Grace & Company (Grace), Unifirst Corporation (Unifirst), Wildwood Conservation Corporation (Wildwood or Beatrice Foods property), Olympia Nominee Trust (Olympia), and New England Plastics (NEP) (USEPA, 1989). These five companies are collectively referred to as the Potentially Responsible Parties (PRPs).

• See List of References

1.3 METHODS

This Site is listed on USEPA's National Priorities List (NPL) as a "Superfund" site. Therefore, the remediation of the Site must be performed in accordance with the Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA) as amended by the Superfund Amendments and Reauthorization Act of 1986 (SARA) and the requirements of the National Contingency Plan (NCP). These laws and regulations are hereafter referred to as "CERCLA" or "Superfund." Therefore, USEPA and CERCLA guidance and policy documents have been primarily used as the basis for evaluations of remediation feasibility.

A number of tasks are required to meet the objectives described in Section 1.1 above. A description of each task, as well as the methods used to perform the task, is provided below.

- Site Orientation - To effectively evaluate potential methods to remediate the Site, it is necessary to have a thorough understanding of the studies and remediation effort that have been performed and are on-going at the Site. To accomplish this, orientation meetings were held with the MADEP; site visits were made to the Central Area site and the Source Area remediation systems; professionals familiar with the Site were interviewed; scientific conferences were attended in which the Site was discussed; a forum at Tufts University to discuss the Site and groundwater remediation methods was held; and critical Site documents were reviewed. These site documents included:
    - Ebasco's Draft Final Feasibility Study (FS) Report for USEPA, dated January 1989 (Ebasco, 1989)
    - USEPA Record of Decision (ROD), dated September 1989 (USEPA, 1989)

- USEPA "Consent Decree" (CD)[2], dated July 1991 (USEPA, 1991)
- GeoTrans Inc. and Remediation Technology Inc.'s (RETEC's) Central Area Remedial Investigation Phase 1A Report (Phase 1A Report) for Beatrice, Unifirst, and Grace (BUG), dated February 1994 (GeoTrans & RETEC, 1994)
- Documents on the design and/or performance of Source Area remediation systems

(See the LIST OF REFERENCES section for a complete listing of all references used in the preparation of this report.)

- Update the Conceptual Site Model (CSM) - A conceptual site model is a characterization of the physical (i.e., geology and hydrogeology) and chemical (i.e., nature and extent of contamination) aspects of a site. A CSM for this Site was presented in the FS in 1989 and then updated in 1994 as part of the Phase 1A Report. The information collected from the Source Areas and River since 1994 was used to update the CSM for the Central Area. Very little contaminant-related data have been collected in the Central Area since 1994. Therefore, unless otherwise noted, it has been conservatively assumed that the nature and extent of contamination in the Central Area aquifer has not significantly changed since 1994. Because of resource constraints, no new physical or chemical data have been generated for this effort.
- Evaluate the Phase 1A Report - In addition to reviewing BUG's Phase 1A Report for historical Site information, this report was also evaluated to determine whether or not BUG had satisfied the objectives and requirements specified by USEPA and MADEP in the CD. The focus of this evaluation was on those requirements that were related to remedial

2 Consent Decree is a written agreement between at least two parties that has been certified by a judge. In this case, the agreement was between the USEPA, MADEP, and four of the PRPs (Grace, Unifirst, Wildwood, and NEP).

alternatives. BUG's Work Plan for the Remedial Investigation (RI) and Feasibility Study for the Central Area (GeoTrans, et al., 1992) was also reviewed in order to determine whether deviations from CD requirements were identified in the Work Plan before the Phase 1A investigations and report writing took place.

- Determine Remediation Area - Remediation alternatives were only evaluated for application in the Central Area. Within the Central Area, the remediation area was established by eliminating from further consideration those portions of the Central Area that are effectively being captured and treated by Source Area remediation systems (as determined by the respective Source Area PRPs). Similarly, portions of the Central Area where groundwater contaminant levels for primary site contaminants are below, or very close to, target cleanup levels, were also eliminated from further consideration. Additional source areas within the Central Area were also eliminated from consideration in this study if the goals for those areas were inconsistent with those of the rest of the Central Area. Areas close to the River were effectively eliminated from inclusion in the remediation area for those technologies (e.g., pumping) that induce infiltration of surface water from the River and its wetlands into the Central Area aquifer.
- Identify and Screen Technologies - General response actions (e.g., groundwater collection, treatment, and discharge) that are necessary for groundwater remediation were first identified. The potential *technologies* and *process options*[3] that could be used to remediate the groundwater in the Central Area were then identified. Sources used for this identification

[3] *Technologies* refers to general categories of technologies, such as *in-situ* (underground) biological treatment, in-situ physical/chemical treatment, etc. *Process Options* refers to specific processes within each technology type. For example, the in-situ physical/chemical treatment technology includes process options such as air sparging, in-well air stripping, and passive treatment walls.

included remediation databases and information from comparable Superfund sites. Based on the information presented in the CSM, such as site-specific hydrogeology and contaminant characteristics, those technologies and/or process options that would not be technically implementable at this Site were screened out. Technologies and process options that survived the screening were then comparatively evaluated for effectiveness, implementability, and cost in accordance with *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA* (CERCLA RI/FS Guidance) (USEPA, 1988a).

- Evaluate Alternatives - Groundwater remediation alternatives were formed by combining applicable technologies within the categories of general response actions. Alternatives were developed that were consistent with the requirements specified in the CD for the PRPs' screening of groundwater alternatives. Alternatives that were considered included ones that could meet the groundwater cleanup levels within different time frames utilizing different technologies:
    - One alternative using an innovative treatment technology.
    - One aggressive alternative that would, theoretically, require no long-term maintenance.
    - No action alternative.

An evaluation was performed for each of the alternatives by using six of the nine evaluation criteria established in CERCLA RI/FS Guidance. The three criteria that were not used were compliance with (1) ARARs, (2) state acceptance, and (3) community acceptance. Information from comparable Superfund sites, CERCLA guidance documents, treatment technology vendors, remediation databases, and remediation professionals was used to conduct the evaluation.

- Evaluate the Feasibility of Remediation – Established MADEP and USEPA criteria were used to evaluate the feasibility of remediating the Central Area aquifer. MADEP criteria for determining the economic feasibility of remediation (as cited in a MADEP comment letter on the Phase 1A Report) were applied by comparing the estimated costs for remediation developed above for selected technologies against the cost of obtaining water from a regional provider (i.e., the Massachusetts Water Resources Authority [MWRA]). Technical feasibility was assessed by applying USEPA's *Guidance for Evaluating the Technical Impracticability of Groundwater Restoration* (USEPA, 1993a) to this Site.
- Assess Data Gaps – Complete data are needed to fully assess the applicability of a technology or process option to a site. The critical data needed to perform a more detailed evaluation of the applicable technologies and process options has been identified. Data needed to confirm the feasibility of groundwater remediation at the Site were also specified. If these data are not available, or if more recent data are needed, this study has identified it as a data gap. Data gaps were also identified from the "Evaluation of the Phase 1A Report" and the "Evaluation of Technical Feasibility" described above.

1.4 ORGANIZATION OF REPORT

This report has been organized into eleven sections. Most of these sections follow the tasks described above. The following is a short description of the work included in each section.

- **Section 1, Introduction** – Includes the objectives for this report, a Site description, the methods by which this report was prepared, and an outline of how the report has been organized.
- **Section 2, Site History** – Includes (1) background information on how the Site came to be an NPL site, (2) the regulatory history of the Site, (3) a summary of the groundwater cleanup goals for the Site, and (4) an update on the current status of remedial actions at the Site.
- **Section 3, Hydrogeologic Setting** – Includes an updated description of the geology and hydrology in the Central Area to reflect the impact of groundwater remediation being performed at four of the Source Areas.
- **Section 4, Contamination of Groundwater in the Central Area** – Includes (1) a description of historical sources of contamination at the Site, (2) an updated depiction of the nature and extent of groundwater contamination in the Central Area aquifer, (3) a summary of the wells in which contamination exceeded groundwater cleanup levels, and (4) the location and estimates of the areas and volumes of groundwater in the Central Area to which remediation technologies may be applied.
- **Section 5, Evaluation of the Phase 1A Report and Consent Decree Requirements** – Includes an evaluation of the Phase 1A Report that was prepared by Beatrice, Unifirst, and Grace. The purpose for this evaluation was to determine whether the objectives and requirements specified in the CD were met as they relate to remedial alternatives.
- **Section 6, Identification, Screening, and Evaluation of Technologies** – Includes (1) the remedial action objectives for groundwater at the Site, (2) the response actions that will satisfy the remedial action objectives for the Central Area aquifer, the remedial technologies

and process options that could be used, (3) the rationale for, and results of, screening potential remedial technologies and process options, (4) an evaluation of technologies and process options, and (5) a summary of the process options that have been used to develop the Central Area remediation alternatives. This section is generally consistent with Section 2 of the suggested FS report format described in Table 6-5 in the CERCLA RI/FS Guidance.

- **Section 7, Evaluation of Selected Remediation Alternatives** – Includes (1) descriptions of the alternatives developed for the Central Area, (2) summaries of the calculations used to size the alternatives for cost purposes, and (3) an evaluation of each alternative as described in Section 1.3 above. This section is generally consistent with Section 4 of the suggested FS report format described in Table 6-5 in the CERCLA RI/FS Guidance.
- **Section 8, Feasibility of Remediating the Central Area Aquifer** – Includes an evaluation of the feasibility of remediating the Central Area by applying MADEP and USEPA established criteria as described in Section 1.3 above.
- **Section 9, Data Gap Assessment** – Includes a summary of the additional data needed to determine the feasibility of groundwater remediation and to evaluate the applicability of remedial technologies for the Central Area. The data gaps that have been identified resulted from the review of historical information presented in Sections 3 and 4, the evaluations conducted in Sections 5 and 8, and the assessment of the data needed to better evaluate the applicability of technologies and process options identified in Sections 6 and 7.
- **Section 10, Summary of Findings** – Includes (1) summary of the work performed under for this report, (2) a comparative analysis of the remedial alternatives, and (3) a summary of the conclusions from the other sections of the report.

- **Section 11, Recommendations** – Includes the Capstone Group's recommendations for additional work.

2. SITE HISTORY

2.1 REGULATORY HISTORY (1964-1991)

2.1.1 Site Discovery (1964-1981)

The City of Woburn developed wells G and H in 1964 and 1967, respectively. The wells are screened in the Aberjona River aquifer and, when pumped at maximum capacity, were capable of producing two million gallons of water per day. The wells were initially intended to supplement the existing city water supply provided by seven wells located in a separate aquifer near Horn Pond. Local officials have estimated that over 25 percent of the city's water supply was provided by wells G and H when they were operating (USEPA, 1989).

In 1979, MADEP, formerly known as the Massachusetts Department of Environmental Quality Engineering (MADEQE), tested the water supply from wells G and H. Several volatile organic compounds (VOCs), including 1,1,1-trichloroethane (1,1,1-TCA), trans-1,2-dichloroethene (trans-1,2-DCE), tetrachloroethene (PCE), and trichloroethene (TCE), were detected in the water at concentrations ranging from 1 to 400 parts per billion (ppb). The Maximum Contaminant Levels (MCLs) allowed under the Safe Drinking Water Act (SDWA) for these contaminants are 5 ppb for TCE and PCE, 70 ppb for trans-1,2-DCE, and 200 ppb for 1,1,1-TCA. Upon receipt of this information, the City of Woburn immediately shut down the two wells. The City then revived an existing agreement with the MWRA to replace the lost water supply (USEPA, 1989).

In 1981, the USEPA conducted a hydrogeological investigation of a ten-square-mile portion of the east and north sections of Woburn to determine the extent and degree of contamination. As a result of these investigations, five locations – the Grace, Unifirst, Wildwood, Olympia, and NEP properties – were identified as sources of contamination in wells G and H.

2.1.2 Superfund Designation (1982-1989)

The Wells G & H Site, as described in Section 1.2 above, was listed as a Superfund site on the NPL on December 21, 1982.

From 1983 through 1988, a number of investigations and studies were performed by contractors for EPA and the PRPs. Noteworthy studies include:

- A study by the United States Geological Survey (USGS) that was designed to determine the zone of contribution and *area of influence*[4] of wells G and H. Results from a 30-day pump test, performed in 1985, were used in this study (Myette, et al., 1987).
- Remedial Investigations, performed in 1986 by USEPA's contractor, NUS Corporation, that included installation of monitoring wells and collection of groundwater and surface water samples (NUS, 1986).
- Supplemental Remedial Investigations, performed in 1988 by USEPA's contractor, Ebasco Services Inc. (Ebasco), that included collection of soil samples from Source Areas, collection of surface water and sediment samples from the Aberjona River, and additional groundwater sampling from existing monitoring wells (Ebasco, 1988).

[4] *Area of influence* is the area around wells G & H in which water levels are affected by pumping.

- An Endangerment Assessment (EA)[5] for the entire Site, performed in 1988 by USEPA's contractor, Ebasco. The objective of the EA was to estimate the probability and magnitude of potential adverse human health and environmental effects from exposure to contaminants at the Site (USEPA, 1989). The two exposure pathways that presented the greatest potential risks to humans at the Site were future ingestion of contaminated groundwater and inhalation of volatiles while showering. Table 2-1, taken from the ROD, presents the risks by environmental media for the five Source Areas and the Central Area.
- A Feasibility Study, prepared in 1989 by USEPA's contractor, Ebasco, in which technologies and alternatives that could be used to remediate the Site (Source Areas and Central Area) were identified and screened (Ebasco, 1989).

During this period, USEPA also issued several administrative orders to Site property owners requiring cleanup activities (such as removing drums and debris) and limiting site access (USEPA, 1989).

A Record of Decision (ROD), presenting USEPA's strategy for remediating the Site was signed by both USEPA with concurrence by MADEP, in September 1989. Highlights of the strategy selected in the ROD include:

- Establishment, as the first *operable unit*[6] (OU), a remedy for the five Source Area properties (Grace, Unifirst, Wildwood, Olympia, and NEP) that consisted of:

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[5] An Endangerment Assessment is a quantitative evaluation of the risks associated with exposure to chemical contamination in different environmental media.
[6] An Operable Unit is a major component or phase of a comprehensive, Site-wide, remedy. Typically operable units are established when remediation at a site needs to be performed in phases.

Table 2-1 Estimated Risks Associated with Exposure at the Wells G & H Site
(Source: USEPA, 1989, Table 2) Page 1 of 2

SUMMARY TABLE OF ESTIMATED RISKS ASSOCIATED WITH EXPOSURE AT THE WELLS G & H SITE

LOCATION	RISK		HAZARD INDEX	
	AVERAGE	PLAUSIBLE MAXIMUM	AVERAGE	PLAUSIBLE MAXIMUM
W. R. Grace and Company				
Ingestion of Groundwater	2E-03	2E-01	<1 (0.2)	>1 (24)
Inhalation of Volatiles Released while Showering	4E-04	5E-02	<1 (0.2)	>1 (23)
New England Plastics Corporation				
Inhalation of Volatiles Released During Industrial Processes by Industrial Workers	1E-07	1E-06	<1 (0.007)	<1 (0.06)
Dermal Contact and Incidental Ingestion of Surface Soil by Industrial Workers	7E-06	4E-05	<1 (0.005)	<1 (0.7)
Inhalation of Volatiles Released from Soil by Industrial Workers	3E-13	1E-09	<1 (8E-09)	<1 (4E-05)
Future Exposure to Surface Soil	1E-08	8E-04	<1 (0.02)	>1 (4)
Future Inhalation of Volatiles Released from Soil	3E-12	1E-08	<1 (1E-08)	<1 (2E-04)
Future Ingestion of Groundwater	8E-05	5E-04	<1 (0.08)	<1 (0.5)
Future Inhalation of Volatiles Released While Showering	6E-06	3E-05	<1 (0.07)	<1 (0.4)
Olympia Nominee Trust Company				
Dermal Contact and Incidental Ingestion of Soil by Industrial Workers	5E-10	3E-06	<1 (0.002)	<1 (0.3)
Dermal Contact and Incidental Ingestion of Soil by Young Adults	2E-09	3E-06	<1 (0.01)	<1 (0.9)
Inhalation of Dust Generated While Dirtbike Riding	3E-08	5E-06	<1 (2E-05)	<1 (0.001)
Future Exposure to Surface Soil	2E-08	6E-05	<1 (0.009)	<1 (0.8)
Future Ingestion of Groundwater	4E-04	1E-03	<1 (0.2)	<1 (0.7)
Future Inhalation of Volatiles Released While Showering	9E-06	4E-04	<1 (0.02)	<1 (0.06)
Unifirst Corporation				
Future Ingestion of Groundwater	1E-03	4E-02	1	>1 (47)
Future Inhalation of Volatiles Released While Showering	3E-04	1E-02	<1 (0.9)	>1 (41)
Future Exposure to Surface Soil	8E-10	4E-08	<1 (8E-07)	<1 (4E-05)
Wildwood Conservation Corporation				
Dermal Contact and Incidental Ingestion of Soil				
- Surface Soil	7E-08	7E-05	<1 (0.02)	>1 (2)
- Northern Sludges	8E-07	5E-05	<1 (0.4)	>1 (12)
- Southern Sludges	2E-07	2E-05	<1 (0.3)	>1 (18)
Inhalation of Dust Generated While Dirtbike Riding				
- Surface Soil	1E-07	3E-05	<1 (0.002)	1
- Northern Sludges	5E-07	3E-05	<1 (0.004)	<1 (0.5)
- Southern Sludges	7E-08	3E-06	<1 (0.0005)	<1 (0.3)

NOTE: Scientific notation (such as 2E-06) is a shorthand way of indicating decimal places. (i.e., the magnitude of the number). A negative exponent indicates that the decimal should be moved the specified number of places to the left (i.e., 2E-03 = 0.002 = 2×10^{-3})

Table 2-1 Estimated Risks Associated with Exposure at the Wells G & H Site
(Cont.) (Source: USEPA, 1989, Table 2)

SUMMARY TABLE OF ESTIMATED RISKS ASSOCIATED WITH
EXPOSURE AT THE WELLS G & H SITE

LOCATION	RISK		HAZARD INDEX	
	AVERAGE	PLAUSIBLE MAXIMUM	AVERAGE	PLAUSIBLE MAXIMUM
Wildwood Conservation Corporation Continued				
Future Exposure to Surface Soil				
- Surface Soil	7E-07	2E-03	<1 (0.01)	>1 (3)
- Northern Sludges	8E-06	1E-03	<1 (0.3)	>1 (14)
- Southern Sludges	2E-06	4E-04	<1 (0.2)	>1 (20)
Future Inhalation of Volatiles Released from Soil				
- Surface Soil	3E-07	1E-04	<1 (0.0009)	<1 (0.8)
- Northern Sludges	1E-07	2E-04	<1 (0.002)	<1 (0.3)
- Southern Sludges	1E-09	1E-05	<1 (2E-06)	<1 (0.2)
Future Ingestion of Groundwater	8E-04	2E-01	<1 (0.2)	>1 (116)
Future Inhalation of Volatiles Released While Showering	2E-04	7E-02	<1 (0.08)	>1 (96)
Nonsource Area of Wells G&H				
Inhalation of Volatiles Released During Industrial Processes by Industrial Workers	2E-06	3E-05	<1 (0.1)	<1 (0.3)
Dermal Contact and Incidental Ingestion of Soil	2E-09	1E-07	<1 (0.03)	<1 (0.2)
Incidental Ingestion of Surface Water				
- Adults	4E-11	1E-08	<1 (2E-05)	<1 (8E-04)
- Children	2E-09	6E-08	<1 (0.001)	<1 (0.02)
Dermal Contact and Incidental Ingestion of Sediments				
- Adults	3E-07	4E-04	<1 (0.002)	<1 (0.09)
- Children	8E-07	2E-04	<1 (0.003)	<1 (0.02)
Future Ingestion of Groundwater	4E-05	3E-04	<1 (0.1)	1
Future Ingestion of Groundwater Containing Radionuclides				
- Gross Alpha Particles	--	--	>1 (3)	>1 (35)
- Gross Beta Particles				
- Strontium-90	--	--	<1 (0.6)	>1 (4)
- Tritium	--	--	<1 (3E-04)	<1 (0.002)
- Radium	--	--	<1 (0.2)	1
- Uranium	--	--	<1 (0.03)	<1 (0.05)
Future Inhalation of Volatiles Released While Showering	4E-06	3E-05	<1 (0.05)	<1 (0.6)

NOTE: Scientific notation (such as 2E-06) is a shorthand way of indicating decimal places. (i.e.. the magnitude of the number). A negative exponent indicates that the decimal should be moved the specified number of places to the left (i.e.. 2E-03 = 0.002 = 2×10^{-3})

- Remediation of soils and sludges on the Source Area properties by excavation and on-site incineration, and in-situ volatilization with air treatment.
- Remediation of groundwater at each Source Area property by pumping the contaminated groundwater, then treating it on-site. The remediation objective for the groundwater was to achieve SDWA MCLs in the aquifer.

- Determination that the Central Area of the Site and the Aberjona River sediments will be addressed as separate operable units. Further studies would be necessary to determine the most effective way of addressing contamination in the Central Area.

The chemicals of potential concern at each portion of the Site are identified in Table 2-2.

The remediation objectives specified in the ROD (p. 16) for the entire Site at the completion of all operable units are as follows:

1. Restore the aquifer that supplied water to wells G and H to drinking water standards.
2. Stop the introduction of contaminated groundwater from the source areas to the rest of the aquifer.
3. Stop the leaching of soil contaminants to the groundwater.
4. Prevent public contact with contaminated groundwater and soil above the cleanup levels.
5. Protect the natural resources in the area, such as the river and wetlands, from becoming further degraded.
6. Reduce further migration of contaminated groundwater off-site.

(USEPA, 1989, p.16)

Table 2-2 Chemicals of Potential Concern Identified in ROD for Wells G & H Site

	WR GRACE	NEW ENGLAND PLASTICS		OLYMPIA NOMINEE TRUST		UNIFIRST		WILDWOOD			CENTRAL AREA			
	GW	S	GW	S	GW	S	GW	S	SL	GW	S	SD	GW	SW
VOLATILE ORGANICS														
Acetone		●						●				●		
Chloroform									●	●				
1,2-Dichlorobenzene										●				
1,1-Dichloroethane					●		●							
1,2-Dichloroethane	●													
1,1-Dichloroethene	●						●							
trans-1,2-Dichloroethene	●		●		●		●	●	●	●			●	●
Methylene chloride		●						●				●		
Pentachlorophenol									●					
Phenol									●					
Tetrachloroethene	●	●	●		●	●	●	●	●	●			●	●
Toluene							●	●	●					
1,1,1-Trichloroethane		●	●				●		●	●			●	
Trichloroethene	●	●	●		●		●	●	●	●			●	●
Vinyl chloride	●									●				
Xylenes					●				●	●				
SEMI-VOLATILE ORGANICS														
Aldrin													●	
Bis(2-ethylhexyl)phthalate	●	●			●			●	●			●		●
Chlordane								●	●		●			
4,4'-DDT				●				●	●					
Polyaromatic hydrocarbons				●				●	●			●		
Polychlorinated biphenyls								●						
Pyrene											●			
INORGANICS														
Arsenic					●							●		
Barium													●	
Cadmium		●						●	●		●	●		
Chromium				●				●	●			●		
Copper												●		
Iron												●		
Lead		●		●				●	●		●	●		●
Manganese					●					●				
Mercury												●		
Nickel												●		
Zinc												●		
RADIONUCLIDES													●	

S -Soil
SL-Sludge
SD-Sediment
SW-Surface water
GW-Groundwater

DGW: CHEMIC

2.1.3 PRP Settlement (1990-1991)

In July 1991, USEPA, MADEP, and four of the five Source Area PRPs (Grace, Unifirst, Wildwood, and NEP – the Settling PRPs) negotiated and signed a consent decree (CD), under which the Settling PRPs agreed to accept responsibility for much of the Site remediation work required under the ROD. Specifically, the Settling PRPs agreed to:

- Remediate the soil and groundwater on each of their properties. See Section 2.1.4 for the applicable groundwater cleanup goals.
- Evaluate the combined effects of the groundwater extraction systems.
- Conduct a study in the format of an RI/FS for the Central Area. This study is to be performed by Beatrice, Unifirst, and Grace (BUG). This study is not to include the Aberjona River; USEPA agreed to perform the necessary investigations of the River.

An important refinement made in the CD is that the ROD definition of the "Central Area" was changed. The CD effectively established three operable units (OUs).

- OU 1 – The five Source Area properties, as defined in the ROD.
- OU 2 – The Central Area, includes all portions of the soil and groundwater that have not been addressed under OUs 1 and 3. The Central Area specifically now includes three other potential source area properties – Aberjona Auto Parts, Murphy Waste Oil, and Whitney Barrel Corporation – that are located south of the Wildwood Property and west of the River. These three properties are collectively referred to as the Southwest Properties.

- OU 3 – Aberjona River, consists of the River, its tributaries and their sediments, and associated wetlands.

The outer bounds of the Central Area were expanded in the CD (as compared to the Central Area as defined and depicted in the ROD). At the same time, the CD resulted in a significant portion (OU 3 as defined above) of the original ROD-defined Central Area being excluded from the Central Area (GeoTrans, et al., 1992). Figure 1-2 shows the boundaries of each OU.

Four primary objectives for the Central Area RI/FS were identified in the CD.

1. Define the nature and extent of contamination in the Central Area.
2. Refine the present understanding of the interaction of the Aberjona River and the aquifer systems within the Central Area.
3. Evaluate the impact of pumping groundwater within the Central Area on the Aberjona River and associated wetlands by analyzing the USGS pumping test and integrating the results of . . . any additional pumping tests.
4. Identify and evaluate the effectiveness of various established and innovative remedial technologies (e.g., pump & treat and in-situ bioremediation).

(USEPA, 1991, p.26)

Upon completion of the Central Area RI/FS, a second Record of Decision for the Central Area cleanup would be issued by USEPA and MADEP (USEPA, 1991). See Section 2.2.2 for a more detailed discussion of the CD's requirements for the Central Area RI/FS. A summary of the progress made at each operable unit since the CD was signed is presented in Section 2.2.

2.1.4 Cleanup Goals

The remedial objectives presented in the ROD were established to "mitigate existing and future threats to public health and the environment," (USEPA, 1989, p.16). Under CERCLA, remedial objectives must also comply with all Applicable or Relevant and Appropriate Requirements (ARARs), such as state and federal drinking water regulations, and must specify that remediation be carried out to achieve acceptable chemical exposure limits for human and ecological receptors.

To be consistent with these requirements, the ROD (and CD) specified cleanup goals for hazardous substances in the groundwater at the five Source Areas. The groundwater cleanup goals for the Source Area were based on the aquifer's classification by USEPA as a Class IIB – Potential Drinking Water Source, and MADEP's categorical classification of all groundwater in Massachusetts as Class I – Drinking Water Source. In accordance with the remedial objectives listed in Section 2.1.2, the Source Area groundwater cleanup goals must also apply to the Central Area. The groundwater cleanup goals for the Central Area would be based on the MADEP's current classification ~~of~~ the aquifer as a Potentially Productive Aquifer (GW-1), as well as USEPA's Class IIB designation. MADEP also has designated the area around the Site as an Interim Wellhead Protection Area because wells G and H are still considered to be active municipal production wells; the City never formally abandoned the wells. These protected aquifer classifications make the Safe Drinking Water Act (SDWA) an ARAR. Therefore, the MCLs promulgated under the SDWA were identified as the cleanup goals for groundwater within the aquifer. While the SDWA established MCLs for many contaminants, the ROD also identified nine VOCs as the primary site contaminants. The cleanup goals established in the ROD for these nine VOCs are listed in Table 2-3.

There have been some revisions to the SDWA and MCLs since the ROD was written. It is assumed that the cleanup goals for the Central Area would be based on the current MCLs. For those primary site contaminants for which no MCL has been established, the MADEP's GW-1 (drinking water) standards have been used as the cleanup goal. See Table 2-3 for the anticipated cleanup goals for each of the primary site contaminants based on the current MCLs, and the MADEP GW-1 standards. The actual cleanup goals for the Central Area will need to be established in the ROD for OU 2.

Table 2-3 Groundwater Cleanup Goals for Primary Site Contaminants at the Wells G & H Site

Primary Site Contaminants	Cleanup Goals from ROD[a] (ug/L)	Anticipated Cleanup Goals[b] (ug/L)
Chloroform	100[c]	5[g]
1,1-Dichloroethane (1,1 DCA)	5[d]	70[g]
1,2-Dichloroethane (1,2 DCA)	5	5
1,1-Dichloroethene (1,1 DCE)	7	7
trans-1,2-dichloroethene (1,2 DCE)	70[e]	100[h]
Tetrachloroethene (PCE)	5[f]	5
1,1,1-Trichloroethane (1,1,1 TCA)	200	200
Trichloroethene (TCE)	5	5
Vinyl Chloride (VC)	2	2

Notes
[a] All values based on the MCLs established at the time the ROD was written. All of the values and notes presented in this column have been taken from the ROD (USEPA, 1989).
[b] All values represent current drinking water standards (MCLs) per the latest version of the SDWA (http://www.epa.gov/OGWDW) unless otherwise noted.
[c] MCL is for total trihalomethanes; refers to the sum of chloroform, bromodichloromethane, dibromochloromethane, and bromoform.
[d] MCL is for 1,2-dichloroethane. This value was used based on the chemical similarities between the two compounds and their toxicological endpoints.

[e] Proposed.
[f] MCL is for trichloroethene. This value was used based on the chemical similarities between the two compounds and their toxicological endpoints. This value is also the CLP detection limit.
[g] No MCL established. MADEP's GW-1 Standard used instead (MADEP, 1997).
[h] MCL for cis-1,2 DCE is 70 ug/L. When analyses do not differentiate the 'type' of DCE, the more restrictive clean-up goal of 70 ug/L should be used.

USEPA has determined that the use of MCLs as cleanup goals would satisfy the remedial objectives and also be protective based on allowable risk (USEPA, 1989).

2.2 STATUS OF REMEDIAL ACTIONS (1992-1999)

Since the Settling PRPs signed the CD with USEPA and MADEP, much has been accomplished at the Source Areas (OU 1), but little progress has been made on the Central Area and Aberjona River OUs. The following is a summary of the work completed, and the current status, at each OU.

2.2.1 Operable Unit 1 – Source Areas

Remediation of chlorinated volatile organics (cVOCs) in groundwater is underway at four of the Source Areas. Grace and Unifirst have been operating individual pump & treat systems on their respective properties since September 1992. Grace's treatment system utilizes 22 extraction wells to pump groundwater from the unconsolidated deposits (overburden) and shallow bedrock at an average rate of 5 to 8 gallons per minute (gpm) for treatment on-site (Guswa, 1999). Figure 2-1 shows the effects that pumping has on the groundwater table. Unifirst uses a single extraction well, UC22, pumped at approximately 40 gpm, to collect contaminated groundwater for treatment in their facility (Handex, 1998). UC22 is designed to capture groundwater from both the Grace and Unifirst facilities (Figure 2-2). Since April 1998, Beatrice has been operating a treatment system to remediate VOC-contaminated soil and groundwater on the Wildwood property. Remediation consists of in-situ volatilization (air sparging) of the soil and groundwater in both the deep overburden and bedrock. Groundwater beneath the area of influence of the air sparge wells is pumped, at an average of 30 gpm, from five extraction wells to a treatment facility on-site (RETEC, 1998a). Since February 2, 1998, NEP has operated a trailer-mounted soil vapor extraction/air sparge (SVE/AS) system to remediate soil and groundwater contaminated with VOCs (Woodard & Curran, 1999). USEPA and MADEP have not reached an agreement with Olympia for their self-remediation of their property. See Appendix A for a more detailed description of the work that has been performed at each Source Area since 1992.

2.2.2 Operable Unit 2 – Central Area

The CD includes a requirement that BUG conduct an RI/FS for the Central Area. Specific requirements for the individual RI and FS phases were identified in Attachment 2 of the CD – Outline of Work for RI/FS for Wells G & H Superfund Site (RI/FS Outline of Work) (USEPA, 1991).

The objectives specified in the CD for the RI portion were to:

1. Define the source(s), nature, extent, and distribution of contaminants released.
2. Provide sufficient information to evaluate remedial alternatives, conceptually design remedial actions, select a remedy, and issue a Record of Decision that includes the Central Area.

(USEPA, 1991, p. 35 of Attachment 2)

The objectives specified in the CD for the FS portion were to:

1. Review the applicability of various remedial technologies, including innovative technologies, to determine whether they are appropriate remedies for the Central Area.
2. Determine if each alternative developed by combining technologies is effective by evaluating in the short and long term whether it is effective, implementable, and cost effective. Cost shall only to be used to evaluate alternatives of similar effectiveness.
3. Evaluate potential remedial alternative(s) through a detailed and comparative analysis based upon the nine criteria listed in the CERCLA RI/FS Guidance and any more recent CERCLA güidance.
4. Provide direction to the RI such that sufficient data of the appropriate type are gathered to select a remedy based on the factors mentioned in the objectives listed above.

(USEPA, 1991, p. 36 of Attachment 2)

Figure 2-3, taken from the CD, shows the process by which the RI/FS is to be performed, and presents the key deliverables. The first step in the process at the Central Area was for BUG to scope the RI/FS effort and provide a Work Plan for the RI/FS (USEPA, 1991). A schematic timeline of how the investigations at the Central Area relate to the other portions of the Site is shown in Figure 2-4.

An important part of the scoping effort was for BUG to identify, in the Work Plan, a preliminary range of remedial action alternatives and associated technologies. The critical data that were needed to evaluate such technologies were also to be identified in the Work Plan. The data would then be obtained as part of the Phase 1A and Phase 1B Field Investigations (USEPA, 1991). See Section 5.0 for a specific evaluation of the Phase 1A Report and whether it included all of the elements specified in the CD.

In January 1992, BUG submitted a draft RI/FS Work Plan for the Central Area in which they presented their plan for collecting additional RI data. BUG focused their investigations on the Southwest Properties because this area, "has not been subject to as much previous investigation and interpretation" (GeoTrans, et al., 1992, p. 4) as the Central Area aquifer.

In 1992 and 1993, BUG carried out investigations and studies consistent with the approach specified in their Work Plan. The Phase 1A Investigations included installation of 185 new monitoring wells at 114 locations, evaluation of alternative monitoring well installation techniques, collection of 728 groundwater and surface water samples, investigations of the Southwest Properties, review of the USGS groundwater flow model, and collection of a complete round of groundwater and stream level measurements (GeoTrans & RETEC, 1994).

The results from BUG's investigations and studies were presented in the Phase 1A Report, submitted in February 1994. The Phase 1A also included a detailed description of the conceptual model for the Central Area, as well as a comprehensive accounting of potential contamination sources within the Aberjona River watershed. BUG conclude their report by stating that "the ROD objective to restore the Wells G & H Site Central Area Aquifer to drinking water quality is technically impracticable and no additional investigations and evaluations are warranted" (GeoTrans & RETEC, 1994, p. 4-4). Arguments used by BUG to support this conclusion include:

- The widespread contamination within the Central Area from numerous known and unknown sources.

- The ineffectiveness of pumping as a remedial alternative. Pumping will induce infiltration of surface water from the River and the associated wetlands which, themselves, are contaminated with arsenic and chromium.
- The fact that the groundwater naturally discharges from the aquifer to the River, in effect flushing contaminants from the Central Area aquifer.

(GeoTrans & RETEC, 1994)

The MADEP provided their comments on the Phase 1A Report to USEPA on August 29, 1994. A copy of these comments is enclosed (Appendix B). However, the USEPA did not forward the comments to BUG, nor have they formally commented on the Phase 1A Report. It appears that USEPA and MADEP have deferred making a decision on the Central Area until the Source Area remediation systems are implemented and the effects of remediation systems on the Central Area can be evaluated (Garren, 1999).

As part of the agreement documented in the CD, USEPA was to perform an updated risk assessment that was specific to the Central Area. The data used in the risk assessment were to have been collected by BUG during the Phase 1A investigations. USEPA is currently evaluating whether there are sufficient data from potential source areas within the Central Area to complete the risk assessment. Portions of the risk assessment began in 1999 (http://www.epa.gov, 1999).

2.2.3 Operable Unit 3 – Aberjona River

Since the CD was signed, a number of studies have been performed on the Aberjona River and its associated wetlands (the River system), but no determination has yet been made on whether the River and its sediments should be remediated. See Appendix A for additional information on the studies and assessments performed at OU 3 since 1988.

3. HYDROGEOLOGICAL SETTING

3.1 INTRODUCTION

A detailed description of the hydrogeological component for the Central Area is described in this section. The text has been organized to provide a current understanding of the geology and hydrology regarding the Central Area and the Aberjona River watershed. The text also contains information on the effects of pumping within the Central Area by the source areas and by wells G & H. [Note: Some of the information presented herein has been provided by communication with the PRPs or from reports submitted by them and has not necessarily been accepted by USEPA and MADEP. Some of this information has not been reviewed by the Capstone Group for technical merit.]

3.2 GEOLOGY OF THE CENTRAL AREA

The geology of the Central Area consists of two primary layers: the unconsolidated deposits and the bedrock. Unconsolidated deposits are further divided into glacial till, stratified drift deposits/stratified outwash deposits, and swamp deposits. Figure 3-1 illustrates the 2-dimensional cross section of the Central Area (GeoTrans & RETEC, 1994).

3.2.1 Unconsolidated Deposits

3.2.1.1 Glacial Till

The Central Area has two types of glacial till: lodgment till and ablation till. Lodgment till consists of a very dense, poorly sorted, heterogeneous mixture of clay, silt, sand, gravel, cobbles, and boulders. The hydraulic conductivity ranges from 0.01 to 0.60 feet per day. Ablation till is less compact than lodgment till and consists of poorly sorted fine to coarse sand, gravel, cobbles, boulders, and minor amounts of silt and clay. Because ablation till has more sand, the hydraulic conductivity is higher than that of lodgment till. The hydraulic conductivity ranges from 1.1 to 10.3 feet per day. The glacial till lies unevenly on the bedrock throughout most of the Central Area (GeoTrans & RETEC, 1994).

3.2.1.2 Stratified Drift Deposits/Stratified Outwash Deposits

The stratified drift lies above the glacial till and bedrock. It fills the Aberjona River Valley and makes up the Central Area Aquifer. The stratified drift deposits consist of sorted sands, gravel, cobble, and silt. The drift is up to 130 feet thick. The hydraulic conductivity ranges from 0.100 feet per day in the finer-grained deposits to 350 feet per day in the gravelly layers. The stratified drift deposits are shown in Figure 3-1 (GeoTrans & RETEC, 1994).

3.2.1.3 Swamp Deposits

The swamp deposits are located in the wetlands adjacent to the Aberjona River and in isolated areas such as the eastern portion of the Grace property. In the area near the Aberjona River, the swamp deposits overlie the stratified drift. In the upland wetlands, the swamp deposits probably overlie the glacial till as stated by the Phase 1A. The swamp deposits are composed of peat, inter-bedded fine sand, silt, and clay. The thickness of the swamp deposits range from 5 feet to 25 feet. A cross section of swamp deposits can be seen in Figure 3-1 (GeoTrans & RETEC, 1994).

3.2.2 Bedrock Geology

The bedrock consists of Salem Granodiorite, Dedham Granite, and undifferentiated metavolcanics. The bedrock rises from an elevation of 70 feet below the National Geodetic Vertical Datum (NGVD of 1929) to an elevation of approximately 60 feet above the NGVD as seen in Figure 3-1. There is deep bedrock located in the western portion of the Central Area, and shallow bedrock located in the eastern portion of the Central Area. The bedrock has an interconnected fracture network which is not thoroughly fractured, but it contains localized fracture zones capable of yielding water (GeoTrans & RETEC, 1994). Figure 3-2 shows a 3-dimensional view of the underlying bedrock.

The hydraulic conductivity is generally low in the bedrock and would produce low yields; however, there are localized areas in the Site's bedrock that have provided sufficient water yield. The water yields from the bedrock underneath New England Plastics and Grace are generally low. However, the bedrock underneath Unifirst yields a large amount of water. UC22 is a 190-foot deep bedrock well installed at the Unifirst property and can pump at a maximum rate of 45 gallons per minute (gpm) with a drawdown of about 50 feet. A pump test, conducted by Unifirst and Grace, showed variations in drawdown data with response to pumping indicating that an interconnected fracture network existed in the bedrock beneath the eastern portion of the Site. However, it was concluded that there was no systematic pattern to the zone of drawdown and to the fracture orientation within the bedrock (GeoTrans & RETEC, 1994).

3.3 HYDROLOGY OF THE CENTRAL AREA

3.3.1 Surface Water

The Aberjona River is the only surface water body in the Central Area. It generally flows in a north-to-south direction flows through the central portion of a trough-shaped river valley. All surface water runoff within the Site flows towards the Aberjona River through natural and constructed drainage ways. Low permeability till and bedrock underlie the edges of the river valley. The bottom of the river is covered with a coarse-grained glacial outwash. The coarse grained material forms a small but permeable aquifer (GeoTrans & RETEC, 1994). Precipitation directly through runoff and indirectly through groundwater recharge is a source of surface water. The Central Area receives 14 to 28 inches of water per year from precipitation (Metheny, 1998).

The Wells G & H Site is an industrialized and urbanized portion of the Aberjona River watershed within the Mystic Lakes drainage basin. The Aberjona River originates in the town of Reading and flows southward through the city of Woburn towards the Mystic Lakes, as shown in Figure 3-3. Hall's Brook and the East Drainage Ditch are major tributaries upstream of the Site. Snyder Creek is a smaller tributary that is located in the eastern part of the Site, and it flows in a southwesterly direction and joins the River south of the Site (GeoTrans & RETEC, 1994). The wetland is a discharge area and the Aberjona River is normally a gaining river (Metheny, 1998). The Aberjona River becomes a source of water for the underlying aquifer when wells G & H are pumping (GeoTrans & RETEC, 1994). The Central Area is further depicted in Figure 3-4.

3.3.2 Groundwater

3.3.2.1 Non-pumping Conditions

Under non-pumping conditions, the groundwater flows from the sides of the valley towards the center where the Aberjona River lies as seen in Figure 3-5. As groundwater approaches the Aberjona River the flow shifts so that it is more parallel to the river in a southern direction. The vertical flow of the groundwater along the boundaries of the valley also flows downward from the stratified drift deposits into the bedrock. However, as you get closer to the center of the valley, the groundwater flows from the bedrock up into the stratified drift and into the Aberjona River. Figure 3-1 shows a cross section of the groundwater flowing from the stratified drift deposits into the bedrock and then up towards the center of the river valley (GeoTrans & RETEC, 1994).

The sources of groundwater to the Central Area Aquifer are lateral inflow from:

- glacial till, stratified drift deposits, and bedrock from both the eastern and western sides of the Aberjona River
- southerly flow across the northern boundary of the Central Area
- local infiltration of precipitation within the valley

Groundwater discharges from the Central Area Aquifer into the Aberjona River at a rate of about 450 gpm over 3000 linear feet of the River (GeoTrans & RETEC, 1994).

3.3.2.2 Pumping Conditions

The pumping of wells G & H affects the direction of groundwater flow in the Central Area.

Wells G & H were pumped at a combined rate of 1,100 gallons per minute during the 1985/1986 30-day USGS pumping test. The pumping rate represented the peak-pumping rate during the time when wells G & H were in use.

A time-of-travel study was also conducted as part of the USGS pump test report. Metheny (1998), from Ohio State University, has taken the information from the USGS pump test and studies to develop a very extensive groundwater model (MODFLOW) for the Site. Metheny's MODFLOW results showed that it would take seven years for a groundwater particle to flow from Unifirst to well H under pumping conditions. The model also showed that, under pumping conditions, it would take nine years for a particle from Grace to flow into well H, and one-and-a-half years for a particle from Wildwood to flow into well G (Metheny, 1998). A simulation of a particle pathway flow from the Source Areas under natural conditions can be seen in Figure 3-6. Figure 3-7 illustrates particle pathway flow from the source areas under pumping conditions.

The pumping of wells G & H drew water from all directions, lowering the water levels around the wells. However, instead of a circular cone of depression, an elliptical shape occurred. The elliptical shape was because of two reasons: (1) the wells were aligned parallel to the River and (2) there was a limited amount of groundwater available from the till and bedrock in the eastern portion of the Central Area. The cones of depression expanded into areas from where the water was more easily drawn, which in this case was from the sand and gravel outwash that was parallel to the Aberjona River. Figure 3-8 shows the cones of depression caused by the pumping of wells G & H during the USGS pump test (Myette, et al., 1987).

3.3.2.3 *Pumping Effects on the Aberjona River*

The pumping of wells G & H also influenced the flow of the Aberjona River. The effect of the Aberjona River on the Central Area Aquifer is described in the USGS pump test report. The Aberjona River was originally believed to be a natural hydraulic barrier that would prevent contaminants from flowing across the Aberjona River and into wells G & H. The USGS report proved this theory wrong. The test showed that if wells G & H were pumping at 700 gpm and 400 gpm, respectively, the Aberjona River would contribute up to 50 percent of the water being pumped from the aquifer. The pumping caused surface water and groundwater to cross the river into the wells (GeoTrans & RETEC, 1994). Figure 3-9 illustrates the reversal of flow direction in the vicinity of the Aberjona River caused by pumping.

3.3.2.4 *Pumping Effects from Grace's and Unifirst's Recovery Systems*

The Grace recovery system consists of 22 shallow extraction wells that pump water from the unconsolidated deposits and shallow bedrock at a rate of 5 gpm. The Unifirst extraction system consists of one 190-foot-deep bedrock well, UC22, which extracts groundwater at a maximum rate of 45 *gpm*. Under non-pumping conditions, the groundwater would flow from the eastern portion of the Site towards the Central Area. However, when the Grace and Unifirst wells are pumped, the groundwater is captured by the recovery wells, thus preventing further contamination to flow into the Central Area (GeoTrans & RETEC, 1994). The zone of influence created by UC22 reaches a depth of about 400 feet and extends to capture a width of about 1500 feet (See Figure 2-2). The Grace and Unifirst extraction systems combine to create an effective capture zone (The Johnson Company, 1996). However, the extent to which the groundwater is captured in the western portion of the capture zone is still subject to some debate with regulators

(Naparstek, 1999). The effectiveness of the groundwater capture systems that are presented here are those of the PRPs and have not been evaluated by the Capstone Group for this study.

3.3.2.5 Pumping Effects on the Southwest Properties

The Southwest Properties were influenced by wells G & H and the Riley well which was shut down in January 1989 (USEPA, 1989). The Riley well, also numbered S46, was used by Riley Tannery as a source of water for the tannery industry. The Riley well is located west of the Aberjona River, as seen in Figure 3-5. The groundwater from the Riley well naturally flows easterly towards the Aberjona River; however, when the Riley well was pumping, groundwater was diverted towards the well. During the USGS 30-day pump test, the Riley well was not turned off, and because the well was not shut off, the model was more accurate to what would have been observed to the pumping in the 1960's of Wells G & H (Myette, 1999).

Between the Riley well and wells G & H during pumping conditions a line of stagnation (referred as the Downgradient Limit of Zone of Contribution in Figure 3-10) occurs. This line represents a "no flow" pathway that groundwater travels along. The effect that the pumping of wells G & H had on the Southwest Properties was the placement of the line of stagnation. If wells G & H were pumping and not the Riley well, the line of stagnation would move south. If the Riley well was pumping and not wells G & H, the line of stagnation would move north. Wells G & H could not draw groundwater from the Southwest Properties and the Riley well could not draw groundwater from the Central Area Corridor while all the wells were operating. Figure 3-10 illustrates the location of the no flow lines (RETEC, 1997).

3.3.2.6 Pumping Effects from Wildwood Recovery System

The Wildwood groundwater recovery system consists sparge wells and extraction wells. There are five extraction wells pumping at combined rate of 22 gpm. One well is located in the deep bedrock while the other four wells are screened in shallow bedrock. Twenty-four air sparging wells are used to inject air into the subsurface, both above and below the water table. The air is then contained and treated. Figure 3-11 illustrates the radius of influence from both the sparge wells and extraction wells of groundwater on the Wildwood Property under pumping conditions (RETEC, 1997).

4

4. CONTAMINATION OF GROUNDWATER IN THE CENTRAL AREA

Groundwater contamination in the Central Area has been documented ranging from limited analysis to detailed analysis from 1979 to 1998 (GeoTrans & RETEC, 1994; Handex, 1998). These data were used to describe the current Site groundwater contamination presented in this section.

4.1 SOURCES OF CONTAMINATION

Groundwater contamination within the Central Area is from several sources. The sources include historical releases (prior to current Site property owners), and releases from the current Site property owners. However, it is uncertain if each source area has contributed to the contamination in the Central Area and to what extent.

4.1.1 Historical Sources

Degradation of water quality within the Aberjona River basin has occurred in parallel with industrial development in the region. As early as the 1870s, material used by the tanneries was dumped into the river. Direct and indirect discharges from the tanneries appear to have been commonplace. Specific citations of pre-1900 pollution include the discharge of ammonia, tar products, and spent bark liquor into the watershed. During the 1930s the Massachusetts State Department of Health (MSDH) prosecuted five tanneries for industrial pollution (GeoTrans & RETEC, 1994).

From the late 1970s to the present, the major investigations of the Aberjona Watershed have centered on two federal Superfund sites, the Industri-Plex Site and the Wells G & H Site. These studies were conducted by several investigators including a basin-wide chemical fate and transport study conducted by the Massachusetts Institute of Technology (MIT).

4.1.2 Wells G & H Source Areas

The ROD identified the Grace, Unifirst, NEP, Wildwood, and Olympia properties as sources of contamination (see Figure 3-4). The ROD also states that volatile organic compounds are the primary contaminants in the groundwater at the Site (USEPA, 1989). The following is a summary of how each Source Area contributed to the contamination of the Central Area.

Grace

The Cryovac Division of W. R. Grace & Company, Inc., owns the property and buildings located on 12.6 acres of land at 369 Washington Street, east-northeast of wells G & H. Grace manufactured vacuum packaging machines and used TCE during the final processing of the machinery. Prior to 1979, waste TCE was disposed of by pouring it onto the soil. Groundwater contaminated with VOCs exists in both the unconsolidated deposits and bedrock at the property. Groundwater contamination consists primarily of chlorinated solvents and is characterized by a high percentage of TCE and 1,2-DCE. Other contaminants include PCE and vinyl chloride. Maximum contaminant concentrations before remediation began at the site are as follows: TCE (2800 ug/L); vinyl chloride (3600 ug/L); toluene (3600 ug/L); and 1,2-DCE (7300 ug/L) (Ebasco, 1989).

Unifirst

Unifirst is located at 15 Olympia Avenue, northeast of wells G & H. The facility was used for dry-cleaning operations that used and stored PCE. The building is presently used as a truck rental facility and warehouse storage of uniforms.

Groundwater sampling at Unifirst has shown contamination, primarily with PCE, in both the unconsolidated deposits and bedrock aquifers. Secondary constituents are 1,1,1-TCA and smaller amounts of TCE and 1,2-DCE. PCE was present at a maximum concentration of 2600 ug/L in the unconsolidated deposits and a maximum concentration of 20,000 ug/L in the fractured bedrock at a depth of 104 feet prior to remediation (GeoTrans & RETEC, 1994). The contamination extends southwest of the property primarily in the bedrock aquifer.

The PCE contamination has been related to a possible spill in the vicinity of monitoring Well UC-8, as indicated by the presence of PCE in dense non-aqueous phase liquid (DNAPL) (GeoTrans & RETEC, 1994).

Wildwood

The Wildwood Conservation Corporation is the current owner of the undeveloped 15-acre parcel located west of wells G & H on the other side of the river. The Wildwood property was formerly owned by J & J Riley Company and by Beatrice Foods, Incorporated. Wildwood had some of the highest groundwater contaminant levels found at the Wells G & H Site. Prior to remediation, VOC levels in the groundwater were high throughout most of the unconsolidated deposits under this property, with a maximum concentration of TCE of 190,000 ug/L (GeoTrans & RETEC, 1994). Groundwater contaminated with cVOCs is also found in the fractured bedrock with a maximum concentration of TCE of 6700 ug/L (GeoTrans & RETEC, 1994).

New England Plastics

The New England Plastics (NEP) Corporation, located on Cedar Drive north of Salem Street, manufactures vinyl siding and various other plastic extrusions. NEP leased space to a second company, Prospect Tool and Dye Company, that disposed of TCE in the soil on the property (GeoTrans & RETEC, 1994).

Groundwater at this property is contaminated with volatile organics. PCE, TCE, 1,1,1-TCA and DCE were found in both bedrock and unconsolidated deposits wells at NEP. The primary contaminant, PCE, was found in the unconsolidated deposits at concentrations as high as 96 ug/L and in the bedrock wells at concentrations as high a 330 ug/L prior to remediation (GeoTrans & RETEC, 1994).

Olympia

The 21-acre Olympia Nominee Trust facility is located at 60 Olympia Avenue, northeast of well G & H, on the other side of the river. This facility is used for transportation and trucking operations. Diesel and gasoline fuels are stored in underground tanks on the site. Hazardous debris was dumped on the property on the west side of the river (GeoTrans & RETEC, 1994). Groundwater contamination is present in the unconsolidated deposits beneath Olympia. TCE and xylene were detected in the unconsolidated deposits. Elevated concentrations of TCE (3400 ug/L maximum) were observed in a monitoring well on the property (GeoTrans & RETEC, 1994).

4.1.3 Southwest Properties Groundwater Contamination

The 1994 Remedial Investigation presented the analysis of groundwater from the Southwest Properties. The Southwest Properties consist of three areas: Murphy Waste Oil, Whitney Barrel, and Aberjona Auto Parts. Thirteen groundwater samples were analyzed from the Southwest Properties. 1,2 DCE was detected in seven of the thirteen-groundwater samples, TCE was detected in ten samples, and PCE was reported only in the Aberjona Auto Parts property in six of the thirteen samples. Benzene, toluene, ethylbenzene, and xylene (BTEX) were observed in the groundwater at the Murphy Waste Oil property (RETEC, 1994). The specific contaminant distributions for the Southwest Properties are presented below.

Aberjona Auto Parts

Groundwater contamination at the Aberjona Auto Parts property included trans-1-2-DCE, TCE, and PCE. BTEX concentrations were not reported above the MCLs in any of the groundwater samples collected. The concentrations for PCE (22 ug/L), TCE (363 ug/L) and 1-2-DCE were all detected at levels above the MCLs. (RETEC, 1994).

Whitney Barrel

Chlorinated compounds were detected in groundwater samples and include 1,1-dichloroethene (1,1-DCE), 1,2,-DCA, chloroform, 1,1,1-TCA, TCE, and PCE. Contamination in monitoring well MW-4SS, a shallow monitoring well installed along the northern property boundary, contained the greatest number of chlorinated compounds. However, the contaminants were all reported below the MCLs. BTEX contamination was also reported below the MCLs (RETEC, 1994).

Murphy Waste Oil

The chlorinated compounds detected in the Murphy Waste Oil site include 1,1-DCE, 1,2-DCE, 1,1,1-TCA, TCE, and PCE. 1,2-DCE was reported at the highest concentration, (460 ug/L), in monitoring well MR-2SS. TCE in this well was detected at 22 ug/L. All other chlorinated compounds were reported below 5 ug/L. BTEX was reported at a concentration range of 4 to 360 ug/L. The highest concentration was reported in MR-2SS. Total xylene was detected at 320 ug/L and is below the MCLs (RETEC, 1994).

4.2 NATURE AND EXTENT OF CONTAMINATION

Water quality data collected within the Central Area from 1979 to 1998 documents groundwater contamination. The most recent and complete Central Area data was collected from 1991 to 1993 as documented in the Remedial Investigation Phase 1A Report (GeoTrans & RETEC, 1994) and the Draft Remedial Investigation Southwest Properties Report (RETEC, 1994). Water quality data contamination includes VOCs, SVOCs, and inorganic compounds. The maximum concentration of all contaminants historically detected in the Central Area groundwater is presented in Table 4-1.

Table 4-1 Maximum Contaminant Concentration in Groundwater for the Central Area

Compound	Concentration (ug/L)	MCL
Volatile Organic Compounds		
Chloroform	150	5*
1,1 Dichloroethane	15	70*
1,2 Dichloroethane	4	5
1,1 Dichloroethene	9	7
Tetrachloroethene	1,500	5
Trichloroethene	270	5
Vinyl Chloride	0.3J	2
1,2 Dichloroethene total	91	70
1,1,1 Trichloroethane	340	200
Benzene	5,700	5
Ethylbenzene	610	700
Toluene	3,100	1000
Total xylenes	2,700	1000
Inorganic Compounds		
Lead	204	15
Chromium	344	100
Sodium	225,000	-
Arsenic	83	50
Chloride	700,000	-
Sulfate	43,000	-
Nitrate	16,400	-
Iron	8,300	-
Semi-Volatile Organic Compounds		
2-methylnaphthalene	U	10*
Benzo(ghi)perylene	8	300*
Fluorene	U	300*
Phenanthrene	U	300*
Acenaphthylene	U	20*
Acenaphthene	13	20*
Benzo(a)pyrene	U	0.2*
Chrysene	12	2*
Indeno(1,2,3-cd)pyrene	U	0.5*
Pyrene	U	1*
Benzo(b)flouranthene	23	1*
Benzo(a)anthracene	U	1*
Fluoranthene	22	300*
Naphthalene	400	20*

* = MADEP GW-1 standard

Notes:
All values are reported from the Phase 1A Report (GeoTrans & RETEC, 1994).

Abbreviations and Symbols:
MCL = Maximum Contaminant Limits
U = Not detected

4.2.1 Volatile Organic Compounds

Chlorinated VOCs

The main contaminants of concern for the Wells G & H Central Area are organic compounds belonging to the chemical grouping chlorinated (halogenated) VOCs or cVOCs. The following is a summary of the nature and extent of contamination present in the unconsolidated deposits and bedrock aquifers within the Central Area.

- *Unconsolidated Deposits*

From 1979 to 1998, the groundwater within unconsolidated deposits in the Central Area has been sampled and analyzed for contamination. The contamination consists of mainly two constituents PCE (ranging from 5ug/L to 1500 ug/L) and TCE (ranging from 5ug/L to 270 ug/L). Monitoring wells in which cVOCs were detected above the MCLs as of 1993 are listed in Table 4-2. The total cVOCs is a reasonable representation of the data due to the similarities of properties specifically density, Henry's Law constant, and vapor pressure. Total cVOCs within the unconsolidated deposits was calculated by adding the detected values for chloroform, 1,1 DCA, 1,2 DCA, 1,1 DCE, PCE, TCE, VC, 1,2 DCE total, and 1,1,1 TCA using the most recent data from each well. Total cVOC calculations for unconsolidated deposits are illustrated in Figure 4-1. Exceedances of cVOCs were widespread throughout the Site without an identifiable plume or pattern.

Table 4-2 Contaminant Level Measured in Groundwater Monitoring Wells in Unconsolidated Deposits in the Central Area with Detected Exceedances of MCLs

		PRIMARY SITE CONTAMINANTS (ug/l)								
WELL #	**Date**	**Chloroform**	**1,1 DCA**	**1,2 DCA**	**1,1 DCE**	**PCE**	**TCE**	**VC**	**1,2 DCE total**	**1,1,1 TCA**
MCL		*5*[a]	*70*[a]	*5*	*7*	*5*	*5*	*2*	*70*	*200*
AB2	9/19/93	2U	2U	2U	2U	**21.2JD**	**363**	2U	<2U	<500D
BW16	9/19/93	2U	2U	2U	2U	0.6J	**107D**	2U	7.6	12
DP1	12/17/91	5U	5U	5U	5U	**68**	**5**	10U	3J	12
DP6	6/3/92	**11**	10U	10U	10U	**57**	**44**	10U	21	10U
	8/9/93	**150**	0.5U	0.5U	0.5U	**7**	**7**	0.3J	8	0.6
DP7	6/3/92	10U	10U	10U	10U	**89**	**35**	10U	14	14
	4/7/93	0.5U	0.5U	0.5U	0.5U	**6**	2	0.5U	0.5U	0.5U
	8/9/93	0.2J	0.5U	0.5U	0.5U	**7**	3	0.5U	1	0.6
DP24	6/1/92	0.5U	0.5U	0.5U	0.5U	0.7	**40J**	0.5U	6	0.5U
	4/6/93	0.5U	0.5U	0.5U	0.5U	**14**	**7**	0.5U	0.4J	3
K42	7/26/93	4U	2J	4U	4U	**540**	**17**	4U	2J	4U
K50	7/23/93	2	0.6	0.5U	2	0.4J	**8**	0.5U	0.5J	1
K55	9/9/93	1U	1U	1U	1U	**26**	**1**	1U	1U	3
K60	10/19/93	0.3J	0.5U	0.5U	0.5U	**18**	**0.9**	0.5U	0.5U	2
K61	10/20/93	10U	10U	10U	**9J**	**400**	**23**	10U	9J	45
K62	10/19/93	2U	2U	2U	2J	**120**	**11**	2U	4	13
K63	10/18/93	1U	1U	1U	1U	**90**	**13**	1U	1J	10
MR2	9/19/93	2U	2U	2U	2U	<10U	**22.6D**	2U	**461D**	<100D
S39 (H)	5/14/79	1.1	-	-	-	**18.3**	**117.6**	-	-	-
	5/20/80	-	-	-	-	**31**	**102**	-	23	2
	1/25/81	-	-	-	-	**41**	**73**	ND	21	<10
	12/6/85	ND	ND	ND	3.19	**292**	**108**	ND	52.1	47.3
	12/24/85	ND	1.7	ND	2	ND	**65.5**	ND	29.7	16.1
	1/6/86	ND	ND	ND	ND	**91.7**	**57.9**	ND	24.2	23.1
	8/26/91	1U	0.8J	1U	1U	**9**	**10**	5U	2	1U
S40 (G)	5/14/79	**11.8**	-	-	-	**20.8**	**267.4**	-	28	0.6J
	5/20/80	-	-	-	-	**26**	**136**	-	28	-
	1/25/81	ND	ND	ND	ND	**36**	**210**	ND	14	ND
	12/6/85	ND	ND	ND	ND	**43.3**	**87.5**	ND	33.4	9.26
	12/24/85	ND	ND	ND	ND	**43**	**87**	ND	ND	ND
	1/6/86	ND	ND	ND	ND	**48**	**111**	ND	12.5	9.8
	8/21/91	0.5U	0.5U	0.5U	0.5U	**33**	**60**	5U	14	0.6J
S63	4/23/85	ND	ND	ND	ND	**86J**	**72J**	ND	44	ND
	5/21/85	2R	ND	ND	ND	**69**	**64**	ND	41	ND
	12/22/87	ND	ND	ND	ND	**107**	**32**	ND	25.1	ND
	9/20/90	1	1	ND	1	**390**	**79**	ND	31.3	3
	2/26/91	50U	50U	50U	50U	**650**	**89**	100U	31J	50U
	12/22/92	5U	5U	5U	5U	**8.6**	5U	10U	5U	5U
	2/9/93	5U	5U	5U	5U	**20**	5U	10U	5U	5U
	4/28/93	0.5U	0.5U	0.5U	0.5U	**14**	0.6	0.5U	0.5U	0.5U

WELL #	Date	PRIMARY SITE CONTAMINANTS (ug/l)								
		Chloroform	1,1 DCA	1,2 DCA	1,1 DCE	PCE	TCE	VC	1,2 DCE total	1,1,1 TCA
MCL		*5[a]*	*70[a]*	*5*	*7*	*5*	*5*	*2*	*70*	*200*
	5/12/93	ND	ND	ND	ND	17	ND	ND	ND	ND
	8/10/93	0.5U	0.5U	0.5U	0.5U	6	0.5J	0.5U	0.5U	0.5U
	11/9/93	ND	ND	ND	ND	ND	ND	ND	ND	ND
	3/23/94	10U	10U	10U	10U	10U	10U	10U	10U	10U
S64	4/10/85	ND	ND	ND	ND	30J	88J	ND	65J	ND
	9/20/90	130	0.3J	N	N	83	70	ND	33	2
	2/22/91	16	5U	5U	5U	53	38	10U	25	5U
	4/28/93	0.3J	0.5U	0.5U	0.5U	22	9	0.5U	3	0.5
	8/11/93	0.5U	0.5U	0.5U	0.5U	32J	10	0.5U	4	0.9
S65	8/6/93	0.2J	0.5U	0.5U	0.5U	0.5U	17	8	5U	3
S67	4/11/85	ND	ND	ND	2J	ND	17J	ND	ND	15J
	5/22/85	ND	ND	ND	4J	ND	20	ND	ND	18
	6/11/85	ND	ND	ND	3.1J	ND	49	ND	ND	17
	9/19/90	ND	ND	ND	0.5	ND	8	ND	ND	3
	2/19/91	5U	5U	5U	5U	5U	5	5U	10U	5U
	8/6/93	0.5U	0.5U	0.5U	0.7	0.5U	6	0.5U	0.5U	1
	4/23/97	1U	1U	1U	1U	1U	93	1U	1U	1U
S68	4/23/85	ND	ND	ND	ND	52.1	73.1	ND	29.6	7
	11/4/87	ND	ND	ND	ND	47	47	ND	28	5
	8/21/91	2J	2U	2U	2U	50	37	10U	17	1J
S77	9/22/92	5U	5U	5U	5U	2J	16	2U	NA	5U
S81	4/17/85	21R	ND	ND	ND	1000J	180J	ND	19R	120R
	5/14/85	ND	ND	ND	ND	670	30	ND	ND	99
	6/26/85	31J	ND	ND	ND	580	46J	ND	ND	340
	2/20/91	12	5U	5U	5U	50	5U	10U	5U	5U
	5/16/91	6	5U	5U	5U	56	5U	10U	5U	5U
	12/21/92	5U	5U	5U	5U	610	6.2	10U	6.3	13
	2/9/93	5U	5U	5U	5U	420	5.7	10U	5.5	13
	5/13/93	ND	ND	ND	ND	390	ND	ND	ND	ND
	8/11/93	3	0.5U	0.5U	0.4J	200J	1	0.5U	1	4
	11/9/93	ND	ND	ND	ND	98	ND	ND	ND	ND
	5/7/96	10U	10U	10U	10U	29	10U	10U	10U	4J
	4/22/97	2	10U	10U	10U	24	10U	10U	10U	10U
	4/22/98	1U	1U	1U	1U	19	1U	1U	1U	0.8J
S82	4/25/85	ND	ND	ND	ND	39.1	73.9	ND	35.6	ND
	2/22/91	5U	5U	5U	5U	R	38	10U	13	6
	5/29/91	5U	5U	5U	5U	210	26	10U	12	5U
S84	8/20/91	1U	1U	1U	1U	16	16	5U	6	0.3J
S85	4/16/85	ND	ND	ND	ND	56	110	ND	68	7.5
	8/23/91	2	5U	5U	5U	180	41	10U	17	4J
	9/2/93	5	2U	2U	2U	220J	32	2U	2U	2U
S87	8/23/91	5U	5U	5U	5U	150	45	5U	23	11
S89	8/26/91	1U	0.9J	1U	1U	2	15	0.4J	0.7J	2
S90	8/22/91	4J	5U	5U	5U	77	46	10U	24	2J

WELL #	Date	PRIMARY SITE CONTAMINANTS (ug/l)								
		Chloroform	**1,1 DCA**	**1,2 DCA**	**1,1 DCE**	**PCE**	**TCE**	**VC**	**1,2 DCE total**	**1,1,1 TCA**
MCL		*5[a]*	*70[a]*	*5*	*7*	*5*	*5*	*2*	*70*	*200*
S91	8/21/91	0.3J	1U	1U	1U	**91**	**60**	5U	28	7
	9/1/93	1U	1U	1U	1U	**70**	**32**	5U	16	3
S93	8/27/91	1U	0.7J	1U	1U	**2**	**24**	5U	2	1U
S94	8/20/91	1U	1U	1U	1U	**21**	**21**	5U	9	0.6J
UG2	8/26/91	1U	1U	1U	1U	**5**	**9**	5U	13	1
UG4	8/22/91	1U	1U	1U	1U	**22**	**29**	5U	1U	1U
UG5	3/30/93	5U	15	5U	4J	2U	**41**	1J	24	5U

[a] = MADEP GW1 standard

Notes:
- All values are from RI Phase 1A Report (GeoTrans & RETEC, 1994) and the RD/RA Year 6 Annual Report for the Unifirst Site (Handex, 1998).
- Values shown in **Bold** are greater than or equal to MCLs.
- Maximum value taken from wells with multiple screens

Abbreviations and Symbols:
MCL – Maximum Contaminant Limits
1,1-DCA – 1,1 Dichloroethane
1,2 DCA – 1,2 Dichloroethane
1,1 DCE – 1,1 Dichloroethene
1,2 DCE – 1,2 Dichloroethene
PCE – Tetrachloroethene
1,1,1-TCA – 1,1,1 Trichloroethane
TCE – Trichloroethene
VC – Vinyl Chloride
D – Diluted Sample
J – Approximate
NA – Not Analyzed
ND – Not Detected
R – Rejected
U – Not Detected at noted detection limit
< – Less than noted concentration
- – Not Analyzed for

- *Bedrock*

From 1984 to 1998, groundwater within the bedrock aquifer in the Central Area has been sampled and analyzed for contamination. Data from the monitoring wells that have detected concentrations of cVOCs above the MCLs as of 1993 are listed in Table 4-3.

The distribution of total cVOCs within the bedrock was calculated by using the most recent data from each well. Total cVOCs was calculated by adding the detected values for Chloroform, 1,1 DCA, 1,2 DCA, 1,1 DCE, PCE, TCE, VC, 1,2 DCE total, and 1,1,1 TCA. The total cVOCs calculations for the bedrock are illustrated in Figure 4-2.

Table 4-3 Contaminant Level Measured in Groundwater Monitoring Wells in Bedrock in the Central Area with Detected Exceedances of MCLs

		PRIMARY SITE CONTAMINANTS (ug/l)								
WELL #	DATE	Chloroform	1,1 DCA	1,2 DCA	1,1 DCE	PCE	TCE	VC	1,2 DCE total	1,1,1 TCA
MCL		*5*[a]	*70*[a]	*5*	*7*	*5*	*5*	*2*	*70*	*200*
AB2	9/1993	2U	2U	2U	2U	20.7D	144D	2U	<20UD	<20UD
BW16	9/1993	2U	2U	2U	2U	10U	41D	2U	<10	<10U
DP6	4/24/93	0.9	0.5U	0.5U	0.2J	18	10	0.5U	6.3	2
	8/9/93	0.3J	0.5U	0.5U	0.5U	11	6	0.5U	4	0.6
DP24	4/28/93	0.5U	0.3J	0.5U	0.5U	0.5U	15	0.5U	5	0.5U
	8/6/93	0.5U	0.3J	0.5U	0.5U	0.2J	11	0.5U	3	0.5U
G01	2/28/91	13U	13U	13U	13U	290	8J	25U	13U	3J
	12/21/92	10U	10U	10U	10U	480	29	10U	6.7	10U
	5/12/93	10U	10U	10U	10U	230	13	10U	10U	10U
	8/10/94	10U	10U	10U	10U	110	6J	10U	10U	10U
	5/9/95	2J	10U	10U	10U	68	4J	10U	10U	10U
	5/7/96	10U	10U	10U	10U	46	3J	10U	10U	10U
	4/22/97	1U	1U	1U	1U	32	2	1U	1U	1U
	4/22/98	1U	1U	1U	1U	30	2	1U	1U	1U
K55	7/26/93	1U	1U	1U	8	260	44	1U	11	37
K56	7/26/93	0.5U	0.5U	0.5U	0.5U	1	5	0.5U	0.5J	0.6
K60	10/19/93	0.5U	1	0.5U	0.5U	26	0.8	0.5U	0.5J	0.9
K61	10/20/93	0.5U	0.6	0.5U	0.3J	32	5	0.5U	5	2
K62	10/19/93	0.5UJ	0.5UJ	0.5UJ	0.5UJ	11J	2J	0.5UJ	3J	0.5J
K63	10/18/93	1UJ	0.5J	1UJ	0.9J	82	14J	1UJ	3J	5J
K64	10/20/93	O.3J	0.5U	0.5U	0.2J	29	6	0.5U	1	1
S22	11/2/81	ND	ND	ND	ND	4	170	ND	ND	ND
	10/11/84	ND	ND	ND	ND	18	88	ND	ND	ND
	8/9/93	0.5U	0.5U	0.5U	0.2J	15	19	0.5U	24.2	2
S63	4/23/85	ND	ND	ND	ND	270	140	ND	91	10
	5/21/85	ND	ND	ND	ND	40	130	ND	84	4J
	6/12/85	ND	ND	ND	ND	170J	150	ND	90	8.4J
	11/19/85	ND	ND	ND	ND	249	68.5	ND	40	8.55
	12/22/87	ND	ND	ND	ND	792	76.8	ND	26.2	ND
	9/20/90	2	3	ND	3	830	120	ND	30.3	7

		PRIMARY SITE CONTAMINANTS (ug/l)								
WELL #	DATE	Chloroform	1,1 DCA	1,2 DCA	1,1 DCE	PCE	TCE	VC	1,2 DCE total	1,1,1 TCA
MCL		*5[a]*	*70[a]*	*5*	*7*	*5*	*5*	*2*	*70*	*200*
	2/26/91	50U	50U	50U	50U	**1100**	**92**	100U	27J	50U
	9/17/92	14U	14U	14U	14U	**490**	**67**	28U	29	14U
	12/22/92	5U	5U	5U	5U	**57**	**7.7**	10U	5U	5U
	2/9/93	5U	5U	5U	5U	**63**	5U	10U	5U	5U
	4/28/93	1U	1U	1U	1U	**33J**	3	1U	1U	1U
	5/12/93	ND	ND	ND	ND	**37**	ND	ND	ND	ND
	8/10/93	0.3J	0.5U	0.5U	0.5U	**18**	0.9	0.5U	0.3J	0.5U
	11/9/93	ND	ND	ND	ND	**6.6**	ND	ND	ND	ND
S64	4/10/85	ND	ND	ND	ND	**44J**	**180J**	ND	**85J**	3J
	11/15/85	ND	ND	ND	ND	**22.5**	**110**	ND	68	2.86
	9/20/90	0.2J	10	ND	4	**1100**	**470**	ND	**71.7**	3
	2/25/91	50U	50U	50U	50U	**880**	**200**	100U	54	50U
	8/11/93	1	2	0.5U	1	**250**	**100**	**2**	53	2
S65	8/11/93	2U	2	2U	2U	**200**	**42**	2U	13	1J
S66	4/16/85	ND	ND	ND	ND	3.2J	**9.8**	ND	5	ND
	9/20/90	ND	ND	ND	ND	**1500**	**100**	ND	21J	ND
	6/5/92	86U	15J	86U	86U	**1300**	**140**	86U	25J	86U
	4/28/93	0.5U	0.5U	0.5U	0.5U	**32**	4	0.5U	0.8	0.5U
	9/20/93	0.5U	0.5U	0.5U	0.5U	**29**	3	0.5U	0.6	0.5U
S67	4/11/85	ND	ND	ND	ND	ND	**33J**	ND	ND	ND
	5/22/85	ND	ND	ND	ND	ND	**37**	ND	ND	ND
	6/11/85	ND	ND	ND	ND	ND	**34**	ND	ND	ND
	2/19/91	5U	5U	5U	5U	5U	**60**	10U	5U	5U
	9/16/92	5U	5U	5U	2J	5U	**30**	10U	5U	5U
	8/6/93	0.5U	0.3J	0.5U	2	0.5U	**23**	0.5U	0.4J	0.9
	4/23/97	1U	1U	1U	1U	0.6J	**22**	2U	2U	0.5J
S77	9/1993	100U	100U	100U	100U	**25DJ**	**403D**	100U	NA	100U
S81	4/9/85	ND	ND	ND	ND	**200J**	**6J**	ND	3J	21J
	5/1/85	ND	ND	ND	ND	**67.4**	3	ND	ND	ND
	5/14/85	ND	ND	ND	ND	**140**	**ND**	ND	ND	ND
	6/28/85	ND	ND	ND	ND	**98J**	3J	ND	1J	16J
	11/19/85	ND	ND	ND	ND	**280**	**13.8**	ND	7.8	84.8
	2/21/91	25U	25U	25U	25U	**320**	**26**	50U	25U	25U
	12/21/92	5U	5U	5U	5U	**210**	**7.8**	10U	5U	5U
	2/9/93	5U	5U	5U	5U	**260**	**8.2**	10U	5U	7.6
	5/13/93	ND	ND	ND	ND	**410**	**10**	ND	ND	5.2
	8/11/93	2U	2U	2U	2U	**190**	**5**	2U	2J	5
	11/9/93	ND	ND	ND	ND	**160**	**ND**	ND	ND	6.4
	8/10/94	2J	10U	10U	10U	**52**	10U	10U	10U	3J
	5/9/95	**15**	10U	10U	10U	**36**	10U	10U	10U	5J
	11/7/95	3J	10U	10U	10U	**98**	10U	10U	1J	8J
	5/7/96	10U	10U	10U	10U	**190**	10U	10U	10U	5J
	4/22/97	1U	1U	1U	1U	**130**	3	2U	2U	1U
	4/21/98	1U	1U	1U	1U	**190**	**5**	2U	1U	1U
S97	11/19/85	ND	ND	ND	ND	3.5	**150**	ND	ND	ND

		PRIMARY SITE CONTAMINANTS (ug/l)								
WELL #	DATE	Chloroform	1,1 DCA	1,2 DCA	1,1 DCE	PCE	TCE	VC	1,2 DCE total	1,1,1 TCA
MCL		*5[a]*	*70[a]*	*5*	*7*	*5*	*5*	*2*	*70*	*200*
	9/2/93	1U	1U	1U	1U	**99J**	**42J**	1U	22	1
UC14	2/18/88	ND	ND	ND	ND	**71**	3.2	ND	ND	ND
	4/13/88	ND	ND	ND	ND	**15**	ND	ND	ND	ND
	2/19/91	5UJ	5UJ	5UJ	5UJ	**140J**	**11J**	10UJ	5UJ	5UJ
	5/15/91	5UJ	5UJ	5UJ	5UJ	**96**	5U	10UJ	5UJ	5U
	2/13/95	5UJ	5UJ	5UJ	5UJ	**5.7**	**96**	5U	11	5U
	5/7/96	100U	100U	100U	100U	100U	**28**	100U	13J	100U
	4/22/97	1U	0.6J	4	1U	4	**26**	2U	1U	1U
	4/22/98	1U	1U	2	1U	1	**11**	2U	1U	1U
	8/18/93	0.2J	1	0.5U	0.5U	**6**	**15**	0.5U	3	5

[a] = MADEP GW1 standard

Notes:
- All values are from RI Phase 1A Report (GeoTrans & RETEC, 1994) and the RD/RA Year 6 Annual Report for the Unifirst Site (Handex, 1998).
- Values shown in **Bold** are greater than or equal to MCLs.
- Maximum value taken from wells with multiple screens
- See Table 4-2 for definition of abbreviations and symbols

Review of the unconsolidated deposits and bedrock areal plots shown in Figures 4-1 and 4-2 indicates that there is a widespread distribution of cVOCs within the eastern and northern portions of the Central Area. Specifically, there are high levels of total cVOCs (5 ug/L to 480 ug/L) in the unconsolidated deposits and bedrock southwest of the Grace property. The areal plots also indicate that there is a localized region of cVOCs contamination (14 ug/L to 274 ug/L) in the unconsolidated deposits southeast of the Olympia property. Individual maps of the distribution of PCE & TCE within the unconsolidated deposits and bedrock (Figures 4-3 and 4-4, respectively) are included (GeoTrans & RETEC, 1994).

Benzene, Toluene, Ethylbenzene, Xylene

BTEX, along with other gasoline-related compounds, has been detected in groundwater above MCLs in isolated locations. Benzene has been detected in groundwater samples from twenty wells in the Central Area, eight of which have concentrations greater than the MCL of 5 ug/L. Benzene is present at concentrations ranging from 18 ug/L to 55 ug/L and is distributed in isolated locations through the Central Area (GeoTrans & RETEC, 1994).

4.2.2 Semi-Volatile Organic Compounds

Polynuclear Aromatic Hydrocarbons (PAHs)

Fifteen PAHs have been detected in groundwater samples from the Wells G & H Site (See Table 4-1). Naphthalene is the PAH that has been detected most often, the most widespread, and has been found at the highest concentrations. The water quality data collected during the Phase 1A investigation indicate several possible naphthalene sources of contamination. The naphthalene contamination ranges from 5 ug/L to 7.7 ug/L with the exception of well S75 that has a concentration of 1,244 ug/L. Samples collected in 1990 indicate the presence of naphthalene on the Olympia property (GeoTrans & RETEC, 1994). In addition, the Phase 1A states that data from well cluster S75 indicate that naphthalene may be flowing into the Site from north of Route 128 where naphthalene contamination has been previously reported (GeoTrans & RETEC, 1994).

Additional Semi-Volatile Organic Compounds

In addition to the PAHs, several other SVOCs were detected in the groundwater at low concentrations. Specifically, phthalate compounds were detected. These compounds are used as plasticizers in the production of polyvinyl chloride (PVC) and other plastics. The concentrations of phthalates were inconsistent between sampling events (GeoTrans & RETEC, 1994).

4.2.3 Inorganic Compounds

Arsenic, Chromium, and Lead

Investigations have shown the ubiquitous presence of arsenic, chromium, and lead in the Central Area groundwater. Arsenic is pervasive in much of the Aberjona River Watershed. Research conducted by MIT has indicated that arsenic and chromium have been transported in surface and groundwater throughout the Aberjona watershed from industrial areas north of the Site. The arsenic, chromium, and lead contamination is present throughout the Central Area but there are no clear patterns to the distribution (GeoTrans & RETEC, 1994).

Nitrate, Sodium, and Chloride

The water quality data collected during the Phase 1A shows that the Central Area groundwater are also contaminated with inorganics, such as nitrate, sodium, and chloride. Historically, nitrate has been a contaminant of concern with respect to the Central Area. Elevated concentrations of nitrate have been detected in the G & H supply wells. Areas of significantly elevated sodium include the northeast portion of the Site and an area between Olympia and Rt. 128. Chloride concentrations are elevated throughout the Central Area (GeoTrans & RETEC, 1994).

4.3 IDENTIFICATION OF AREAS/VOLUMES TO BE REMEDIATED

The primary remedial objective for this Site is to "restore the aquifer that supplied water to Wells G & H to drinking water standards," (USEPA, 1989, p. 16). However, the zone of contribution for wells G & H is quite large and extends beyond the Site boundary (Myette et al., 1987). Figure 4-5 shows the Site boundary as it relates to the entire river watershed upstream of Salem

Street. It is assumed that the limits of the groundwater aquifer are consistent with those of the watershed (Myette, et al., 1987).

Figure 4-5 also shows that there are many MADEP-listed waste sites located within the watershed, with most of them being outside of the Site boundary (GeoTrans & RETEC, 1994). Per MADEP, remedial actions that are consistent with the current groundwater (GW) classification will be required at these other MADEP-listed sites. If these other sites are considered to be within the zone of contribution of wells G & H (i.e., Zone 2 classification) remediation to MCLs and GW-1 standards will be required (Naparstek, 1999).

Since the Site is located at the downgradient portion of the aquifer, it would be best to locate treatment system components so that they collect groundwater at strategic downgradient locations before the groundwater discharges to the surface water (but not so close such that the River water is being drawn into the treatment system). Optimally, these components would be located in areas where contaminant levels exceed the Site's cleanup standards, in order to minimize the drawing of contaminants over "clean" areas.

Based upon this logic, the following approach was used to develop the groundwater remediation area for the Central Area.

- Starting with the Site Boundary shown on Figure 1-2:
    1. Exclude the Source Area Properties (OU 1).
    2. Exclude areas where groundwater is being effectively captured by Source Area remediation systems. From review of the Unifirst Capture Report (The Johnson

Company, 1996), there is some uncertainty as to whether extraction well UC 22 is capturing all of the groundwater within the capture area depicted on Figure 2-2. Specifically, it is questionable whether contaminated groundwater from the deep Aberjona Valley Aquifer[7] is consistently being captured.

3. Exclude areas where the contamination levels in the groundwater are lower than the cleanup levels.
4. Exclude the Southwest Properties. Even though the Southwest Properties are technically within the Central Area, they were not included in the scope of this evaluation because, as noted earlier, groundwater contamination from the Southwest Properties cannot reach wells G and H since there is a line of stagnation between the two areas.

Monitoring wells in which the most recent sampling event contained groundwater exceeding the cleanup standards in the unconsolidated deposits and bedrock are listed on Tables 4-6 and 4-7, respectively. The list of wells has been broken up into five geographic areas: North of Olympia Avenue, the Unifirst Capture Zone, the Southwest Properties, the Aberjona Valley Aquifer (not encompassed within the other geographic areas), and other portions of the Central Area.

Figure 4-6, shows the wells which exceed the cleanup standards and depicts each of the key Site features with the remaining, cross-hatched area representing the Central Area remediation area. The remediation area is the area bounded by the Aberjona Valley to the east, the Site boundary of

[7] Areas with thick and permeable saturated deposits as mapped by Delaney & Gay, 1980, (GeoTrans & RETEC, 1992).

Salem Street to the south, the Southwest Properties and the Wildwood and Olympia properties to the west, and Olympia Avenue to the north. This area comprises an area of approximately 46 acres and is hereafter referred to as the Central Area Corridor. The total volume of groundwater in the Central Area Corridor to be remediated is approximately 370 million gallons: 340 million gallons in the unconfined deposits and 30 million gallons in the shallow bedrock. See Appendix C for remediation area/volume calculations. A cross-section of the Central Area Corridor is presented in Figure 4-7.

From Tables 4-4 and 4-5, one will note that there are three groundwater monitoring wells (UG5 and K42 in the unconsolidated deposits and UC14 in the bedrock) located on the north side of Olympia Avenue within the Central Area where cVOCs exceeded the groundwater cleanup levels. These wells were not included in the remediation area since they are believed to be isolated areas. The groundwater in these isolated areas could be remediated by simply installing extraction wells at each of these locations, and pumping the water to the existing Unifirst treatment system. A simplified approach is considered reasonable for these isolated areas for the following reasons:

1. The volume of contaminated groundwater from these isolated areas is only a fraction (less than 3 percent) of the volume contained within the Central Area Corridor. Therefore, the Capstone Group focused their efforts on the Central Area Corridor.
2. The Unifirst groundwater treatment system has sufficient capacity to accommodate flows from additional extraction wells located downgradient from the Unifirst property.

Table 4-4 Monitoring Wells with cVOCs in the Groundwater above MCLs in the Central Area Unconsolidate Deposits, Broken out by Geographic Area

		PRIMARY SITE CONTAMINANTS (ug/l)									
WELL #	Date	Chloroform	1,1 DCA	1,2 DCA	1,1 DCE	PCE	TCE	VC	1,2 DCE total	1,1,1 TCA	Total Solvents
MCL		*5[a]*	*70[a]*	*5*	*7*	*5*	*5*	*2*	*70*	*200*	
North of Olympia Avenue											
K42	7/26/93	4U	2	4U	4U	**540**	**17**	4U	2	4U	**561**
UG5	3/30/93	5U	15	5U	4	2U	**41**	1	24	5U	**85**
Unifirst Capture Zone											
DP6	8/9/93	**150**	0.5U	0.5U	0.5U	**7**	**7**	0.3	8	0.6	**172.9**
DP7	8/9/93	0.2	0.5U	0.5U	0.5U	**7**	3	0.5U	1	0.6	**11.8**
DP24	4/6/93	0.5U	0.5U	0.5U	0.5U	**14**	**7**	0.5U	0.4	3	**24.4**
K50	7/23/93	2	0.6	0.5U	2	0.4	**8**	0.5U	0.5	1	**14.5**
K55	9/9/93	1U	1U	1U	1U	**26**	**1**	1U	1U	3	**30**
K60	10/19/93	0.3	0.5U	0.5U	0.5U	**18**	**0.9**	0.5U	0.5U	2	**21.2**
K61	10/20/93	10U	10U	10U	**9**	**400**	**23**	10U	9	45	**486**
K62	10/19/93	2U	2U	2U	2	**120**	**11**	2U	4	13	**150**
K63	10/18/93	1U	1U	1U	1U	**90**	**13**	1U	1	10	**114**
S64 *	8/11/93	0.5U	0.5U	0.5U	0.5U	**32**	**10**	0.5U	4	0.9	**46.9**
S67	4/23/97	1U	1U	1U	1U	1U	**93**	1U	1U	1U	**93**
S81 *	4/22/98	1U	1U	1U	1U	**19**	1U	1U	1U	0.8	**19.8**
S82 *	5/29/91	5U	5U	5U	5U	**210**	**26**	10U	12	5U	**248**
Southwest Properties											
AB2	9/1993	2U	2U	2U	2U	**21.2JD**	**363**	2U	<2U	<500D	**384.2**
BW16	9/1993	2U	2U	2U	2U	0.6J	**107D**	2U	7.6	12	**127.2**
MR2	9/1993	2U	2U	2U	2U	<10U	**22.6D**	2U	**461D**	<100D	**484**
S77	9/22/92	5U	5U	5U	5U	**2J**	**16**	2U	NA	5U	**18**
Aberjona Valley Aquifer											
DP1	12/17/91	5U	5U	5U	5U	**68**	**5**	10U	3	12	**88**
S39 (H)	8/26/91	1U	0.8	1U	1U	**9**	**10**	5U	2	1U	**21.8**
S40 (G)	8/21/91	0.5U	0.5U	0.5U	0.5U	**33**	**60**	5U	14	0.6	**107.6**
S68	8/21/91	2	2U	2U	2U	**50**	**37**	10U	17	1	**107**
S84	8/20/91	1U	1U	1U	1U	**16**	**16**	5U	6	0.3	**38.3**
S85	9/2/93	**5**	2U	2U	2U	**220**	**32**	2U	2U	2U	**257**
S87	8/23/91	5U	5U	5U	5U	**150**	**45**	5U	23	11	**229**
S89	8/26/91	1U	0.9	1U	1U	**2**	**15**	0.4	0.7	2	**21**
S90	8/22/91	4	5U	5U	5U	**77**	**46**	10U	24	2	**153**
S91	9/1/93	1U	1U	1U	1U	**70**	**32**	5U	16	3	**121**
S93	8/27/91	1U	0.7	1U	1U	**2**	**24**	5U	2	1U	**28.7**
S94	8/20/91	1U	1U	1U	1U	**21**	**21**	5U	9	0.6	**51.6**
UG2	8/26/91	1U	1U	1U	1U	**5**	**9**	5U	13	1	**28**
UG4	8/22/91	1U	1U	1U	1U	**22**	**29**	5U	1U	1U	**51**
Other Portions of the Central Area											
S65	8/6/93	0.2	0.5U	0.5U	0.5U	**0.5U**	**17**	0.8	5U	3	**21**

[a] = MADEP GW1 standard

* Also within the Aberjona Valley Aquifer

Notes:

- All values are from RI Phase 1A Report (GeoTrans & RETEC, 1994) and the RD/RA Year 6 Annual Report for the Unifirst Site (Handex, 1998).
- Values shown in **Bold** are greater than or equal to MCLs.
- Total solvents calculated using detected values only (including estimated (J) and diluted (D) samples)
- See Table 4-2 for definition of Abbreviations and Symbols.

Table 4-5 Monitoring Wells with cVOCs in the Groundwater above MCLs in the Central Area Bedrock, Broken out by Geographic Area

		PRIMARY SITE CONTAMINANTS (ug/l)									
WELL #	**DATE**	**Chloroform**	**1,1 DCA**	**1,2 DCA**	**1,1 DCE**	**PCE**	**TCE**	**VC**	**1,2 DCE total**	**1,1,1 TCA**	**Total Solvents**
MCL		*5a*	*70a*	*5*	*7*	*5*	*5*	*2*	*70*	*200*	
North of Olympia Avenue											
UC14	4/22/98	1U	1U	2	1U	1	**11**	2U	1U	1U	**14**
Unifirst Capture Zone											
DP6	8/9/93	0.3	0.5U	0.5U	0.5U	**11**	**6**	0.5U	4	0.6	**21.9**
DP24	8/6/93	0.5U	0.3	0.5U	0.5U	0.2	**11**	0.5U	3	0.5U	**14.5**
G01	4/22/98	1U	1U	1U	1U	**30**	2	1U	1U	1U	**32**
K55	7/26/93	1U	1U	1U	**8**	**260**	**44**	1U	11	37	**360**
K56	7/26/93	0.5U	0.5U	0.5U	0.5U	1	**5**	0.5U	0.5J	0.6	**6.6**
K60	10/19/93	0.5U	1	0.5U	**0.5U**	**26**	0.8	0.5U	0.5	0.9	**29.2**
K61	10/20/93	0.5U	0.6	0.5U	0.3	**32**	**5**	0.5U	5	2	**44.9**
K62	10/19/93	0.5U	0.5UJ	0.5UJ	0.5UJ	**11**	2	0.5UJ	3	0.5	**16.5**
K63	10/18/93	1UJ	0.5J	1UJ	0.9	**82**	**14**	1UJ	3	5	**104.9**
K64	10/20/93	1/0/00	0.5U	0.5U	0.2	**29**	**6**	0.5U	1	1	**37.5**
S22	8/9/93	0.5U	0.5U	0.5U	0.2	**15**	**19**	0.5U	24.2	2	**60.4**
S63	11/9/93	ND	ND	ND	ND	**6.6**	ND	ND	ND	ND	**6.6**
S64 *	8/11/93	1	2	0.5U	1	**250**	**100**	**2**	53	2	**411**
S67	4/23/97	1U	1U	1U	1U	0.6	**22**	2U	2U	0.5	**23.1**
S81 *	4/21/98	1U	1U	1U	1U	**190**	**5**	2U	1U	1U	**195**
Southwest Properties											
AB2	9/1993	2U	2U	2U	2U	**20.7D**	**144D**	2U	<20UD	<20UD	**164.7**
BW16	9/1993	2U	2U	2U	2U	10U	**41D**	2U	<10	<10U	**41**
S77	9/1993	100U	100U	100U	100U	**25DJ**	**403D**	100U	NA	100U	**428**
Aberjona Valley Aquifer											
S97	9/2/93	1U	1U	1U	1U	**99**	**42**	1U	22	1	**164**
Other Portions of the Central Area											
S65	8/11/93	2U	2	2U	2U	**200**	**42**	2U	13	1J	**257**
S66	9/20/93	0.5U	0.5U	0.5U	0.5U	**29**	3	0.5U	0.6	0.5U	**32.6**

[a] = MADEP GW1 standard

* Also within the Aberjona Valley Aquifer

Notes:

- All values are from RI Phase 1A Report (GeoTrans & RETEC, 1994) and the RD/RA Year 6 Annual Report for the Unifirst Site (Handex, 1998).
- Values shown in **Bold** are greater than or equal to MCLs.
- Total solvents calculated using detected values only (including estimated (J) and diluted (D) samples)
- See Table 4-2 for definition of Abbreviations and Symbols.

5

5. EVALUATION OF PHASE 1A REPORT AND CONSENT DECREE REQUIREMENTS

5.1 PURPOSE FOR THIS EVALUATION

The Remedial Investigation Phase 1A Report represents the first phase of a multi-phase approach, established in the CD, for the Central Area Characterization (the Central Area RI/FS). The CD identified four primary objectives for the Central Area RI/FS.

1. Define the nature and extent of contamination in the Central Area.
2. Refine the present understanding of the interaction of the Aberjona River and the aquifer systems within the Central Area.
3. Evaluate the impact of pumping groundwater within the Central Area on the Aberjona River and associated wetlands by analyzing the USGS pumping test and integrating the results of . . . any additional pumping tests.
4. Identify and evaluate the effectiveness of various established and innovative remedial technologies (e.g., pump & treat and in-situ bioremediation).

From MADEP's comments on the Phase 1A Report (see Appendix B) it would appear that the fourth objective was not adequately addressed by the PRPs responsible for this report – Beatrice, Unifirst and Grace (BUG).

The Capstone Group has evaluated BUG's RI/FS Work Plan (GeoTrans, et al., 1992) and their Phase 1A Report (GeoTrans & RETEC, 1994) to determine whether the specific objectives and requirements established in the CD for these two documents have been completed. The specific focus of this evaluation is on those requirements related to remedial alternatives.

5.2 RI/FS WORK PLAN

5.2.1 Work Plan Requirements

As part of BUG's scoping effort for the RI/FS, the CD requires that an RI/FS Work Plan be submitted which includes a section on "Data Requirements of Potential Remedial Alternatives and Technologies" (USEPA, 1991, p. 41 of Attachment 2). Specific items that were to be addressed in this section of the Work Plan included:

- Identification of potential remedial action objectives for each contaminated medium and identification of a preliminary range of remedial action alternatives with associated technologies. The range of alternatives to be considered included ones that significantly reduce the toxicity, mobility, or volume of waste as a principal element; one or more alternatives that involve containment with little or no treatment; and a no-action alternative.
- Identification of all potential remedies that may be useful in remediating the affected media.
- Identification of the various technologies, showing the critical data needed to evaluate such technologies and assess the performance of the technologies grouped into alternatives. This information was to be presented using charts, in which the remedial technologies and associated data requirements would be linked to the applicable section of the Work Plan.

(USEPA, 1991, pp. 59-60 of Attachment 2)

It was USEPA's and MADEP's intent that early identification of potential technologies would help ensure that any data needed to evaluate the technologies or alternatives would be collected as part of the RI Phase 1A Field Investigation Phase. Additional data could also be collected during Phases 1B and 2 of the RI as necessary to further support the FS work.

5.2.2 BUG's Work Plan Submittal

BUG's Work Plan does not include a section that meets the CD requirements identified above. BUG deferred development of remedial response objectives and screening of remedial technologies and alternatives until the Phase 1A data collection effort had been completed. Thus, no technology-related data were obtained either.

A general evaluation of remedy types (e.g., *source control* and *management of migration*)[8] was performed for the Southwest Properties. However, the data requirements identified for these remedy types were also very general in nature (e.g., "identify the areal extent of the source," and "confirm the direction of groundwater flow") (GeoTrans, et al., 1992).

For the Central Aquifer portion of the Central Area, no evaluation was performed of potential technologies and associated data requirements. BUG state that, "Within the Central Aquifer, the past data acquisition and current Remedial Design/Remedial Action (RD/RA) investigations and pre-work plan investigations provide an extensive database that obviates the need for additional frequent sampling," (GeoTrans, et al., 1992, p. 80).

Mr. Jeffrey Lawson, a consultant to Unifirst who contributed to both the RI/FS Work Plan and Phase 1A Report, stated that their focus for the Work Plan "was on laying the groundwork for technical impracticability," (Lawson, 1999). In response to a question as to whether sufficient technology-related data had been collected prior to the Phase 1A, Mr. Lawson stated that he felt that there was enough historical data in the Central Aquifer Area to assess the more standard mechanical treatment processes (such as pump & treat), but that other types of technology-

[8] Source control refers to the elimination or significant reduction of contaminants so that they no longer present an unacceptable health risk at their present location or if they migrate. Management of migration refers to the prevention of contaminants from migrating away from a source (GeoTrans, et al., 1992).

related data, such as data to determine the extent of biodegradation occurring at the site, were not available in the historical record (Lawson, 1999).

5.3 RI PHASE 1A

The goal of the RI Phase 1A Field Investigations (also referred to as "Initial Central Area Characterization"), as specified in the CD, was to "collect all data which can reasonably be assumed to be necessary for the RI/FS," (USEPA, 1991, p. 62 of Attachment 2). Furthermore, "the Central Area Characterization shall provide information sufficient to refine the preliminary identification of potentially feasible remedial technologies," (USEPA, 1991, p. 64 of Attachment 2).

A list of the treatment-related items that BUG were required to characterize and/or describe as part of the Phase 1A is presented in Table 5-1. Also in Table 5-1 is the Capstone Group's assessment of whether or not these items were adequately addressed in the Phase 1A Report.

Table 5-1 Evaluation of Phase 1A Work Against the Requirements of the CD

Requirements from the CD for the Phase 1A [page # from Attachment 2 and item # reference]	**Capstone Group's Assessment of BUG's Phase 1A Report with respect to the CD Requirements**
Describe the waste characteristics that affect the type of treatment possible (e.g., BTU values, pH, BOD) [p. 63, item #12].	Not done. A large quantity of data is available on the characteristics of the primary site contaminants as well as on other non-VOC contaminants, such as nitrates, chlorides, and metals which all can impact water quality. However, an evaluation of the waste characteristics as to how they would affect treatment approaches (e.g., a complete list of natural attenuation parameters) was not done.

Requirements from the CD for the Phase 1A [page # from Attachment 2 and item # reference]	**Capstone Group's Assessment of BUG's Phase 1A Report with respect to the CD Requirements**
Describe the general characteristics of the waste(s), including quantities, state, concentration, persistence, and mobility [p. 63, item #15].	Reasonably well done. Most of the information for the types of contaminants and their general characteristics (e.g., volatile organics, inorganics) has been collected in the Phase 1A Report. However, little information has been presented on the mobility of the site contaminants.
Describe other factors that pertain to the characterization of the Central Area or support the analysis of potential remedial action alternatives [p. 64, item #16].	Incomplete. A large quantity of data and much information has been gathered on the presence of other sources of contamination (e.g., identifying MADEP-listed sites) in the Central Area, and the impracticability of groundwater restoration (e.g., multiple contaminants exceeding MCLs). This information has been presented to support an argument that it is technically impracticable to remediate the aquifer (i.e., the 'no action' alternative), but no data has been presented to support analysis of specific technologies or alternatives. (See Section 6 of this Report for examples of the type of data needed for this analysis.)
Perform subsurface and hydrogeological investigations sufficient to quantitatively estimate the number of years necessary to achieve cleanup goals for groundwater extraction and treatment by remedial alternatives [p. 65, item #1].	Not done, not even for the remedial action alternatives discussed in the Phase 1A Report (i.e., no action and pump & treat). Use of groundwater models and/or evaluations comparable to those performed in Section 7 of this Report are needed.
Perform subsurface and hydrogeological investigations sufficient to evaluate appropriate physical and chemical waste characteristics that may affect the possible type of treatment, and organize in a chart the information for each detected compound [p. 66, item #10].	Some data have been compiled that could be used to help evaluate a remedial technology (e.g., pH and temperature values would affect an evaluation of some ex-situ treatment technologies). However, these data are not comprehensive, nor has it been presented in a format (i.e., a chart) consistent with the requirements of the CD.

5.4 FINDINGS – CONTENT OF PHASE 1A VS. CD REQUIREMENTS

The Phase 1A Report does not include an evaluation of potential remedial technologies and alternatives that could be used at the Central Area as required by the CD. Instead, BUG's intent was to defer any such evaluation for a later phase in the RI/FS process (GeoTrans, et al., 1992). BUG's expectation was that the Phase 1A Report would be sufficient to justify no further action at the Central Area. USEPA agreed to defer this work to a later phase in the RI/FS process so that there would be additional time to evaluate the performance of the Source Area treatment systems (Garren, 1999). Now that most of the Source Area treatment systems are operational, the deferred RI/FS Work should be completed, particularly the work and evaluations associated with the remedial technologies. These evaluations are necessary before a 'no action' alternative can be considered as the only practical alternative for the Central Area.

6. IDENTIFICATION, SCREENING, AND EVALUATION OF TECHNOLOGIES

6.1 INTRODUCTION

In this section, remedial action technologies and process options are identified, screened in accordance with the EPA RI/FS guidance, and assembled into alternatives. The screening of remedial technologies is done in two steps.

In the first screening step, the potentially applicable technologies and process options that could be used to remediate the Central Area aquifer at Wells G & H Site are selected. The technology types and process options are examined with respect to their technical implementability at the site, based on the physical and chemical characteristics of the contaminants and site specific conditions. Technology types and process options that are not applicable to the remediation of Site-contaminants are eliminated from further evaluation.

In the second screening step, the technology types and process options remaining after the first screen step are then evaluated for effectiveness, implementability, and cost. The effectiveness, implementability, and cost of each process option is evaluated with regard to the following elements (USEPA, 1988a, p. 4-16):

- Effectiveness - The effectiveness evaluation focuses on (1) the potential effectiveness of process options that would be applied to the estimated areas or volumes of the Central Area aquifer in meeting the remediation goals, (2) potential impacts to human health and the environment during the construction and implementation phase, and

(3) how proven and reliable the process is with respect to contaminants and site condition.

- Implementability - Technical implementability is used as an initial screen of technology types and process options to eliminate those that are clearly ineffective or unworkable at the site. This evaluation is done based on the constructive complexity and technology availability, including the availability of necessary equipment and skilled workers to implement the technology.
- Cost - The cost evaluation in the screening of process options is conducted for comparison reasons; thus, detailed cost estimation is not required. Relative capital and *operational and maintenance costs*[9] (O&M costs) are used rather than detailed estimates. The cost analysis is made on the basis of engineering judgement, and each process is evaluated as to whether costs are high, low, or medium relative to the other process options in the same technology type.

After completing the screening process, the remaining components of the General Response Actions are then recombined into *alternatives*[10]. Detailed analysis of alternatives is conducted in a subsequent evaluation.

[9] *Operational and Maintenance cost* is the cost to keep the system running after it is constructed. For a pump & treat system it would include costs for utilities (heat, electricity, etc.), staffing, supplies, disposal, periodic maintenance and repairs, and replacement parts. O&M costs are typically calculated on an annual basis.
[10] *Alternative* refers to a complehensive combination of remeidal process options selected through the initial screening processes. Alternatives will be evaluated by using 6 criteria of the CERCLA RI/FS guidance, 1989.

6.2 DEVELOPMENT OF GENERAL RESPONSE ACTIONS

The following three steps were taken in order to develop General Response Actions: (1) identifying media to be remediated, (2) developing Remedial Response Objectives, and (3) identifying General Response Actions to remediate identified media.

1) Identifying media to be remediated:

   Only groundwater is targeted as a medium.

2) Developing Remedial Response Objectives:

   In the ROD, EPA established remedial objectives for all portions of the Site. These remedial objectives (listed in Section 2.1.2) were not altered as part of the CD and thus remain in effect. The remedial objectives from the ROD that specifically relate to the groundwater in the Central Area aquifer are:

   - #1 Restore the aquifer that supplied water to Wells G and H to drinking water standards.
   - #4 Prevent public contact with contaminated groundwater and soil above the cleanup levels.
   - #5 Protect the natural resources in the area, such as the river and wetlands, from becoming further degraded.
   - #6 Reduce further migration of contaminated groundwater off-site.

3) Identifying General Response Actions:

   During the screening process, the technologies identified are divided into the six general components of the General Response Actions as follows:

   1. No Action

   No specific action, including groundwater monitoring, will be taken.

2. Limited Action

Natural attenuation is considered a Limited Action. Monitoring of groundwater quality allows for the evaluation of the effects of natural attenuation and biodegradation.

3. Institutional Controls

Institutional Controls is a category of technologies, regulatory, or actions (e.g., land use, water use restrictions) that restrict the use of groundwater. Extension of the existing municipal well system and monitoring of contaminant migration would be subject to Institutional Controls. Drinking water treatment (also known as wellhead treatment) technologies, in which extracted groundwater is treated before distributing to residents, are considered as Institutional Controls (Arthur D. Little, Inc., 1993).

4. Containment

Containment technologies may or may not involve treatment, but reduce the mobility of contaminants and the risk of direct exposure in order to protect human health and the environment. Vertical and horizontal barriers are types of containment technologies.

5. Groundwater Collection

Groundwater collection is a category of technologies that extract groundwater from sites. Construction of several types of wells, including shallow wells, deep wells, and bedrock wells is considered an extraction process option. In addition, interceptor trenches, which are backfilled with permeable material to collect contaminated groundwater, are classified under this category.

6. **Treatment**

In order to reduce the volume and/or toxicity of contaminants in groundwater, four remedial technologies are generally employed: in-situ biological treatment, in-situ physical/chemical treatment, ex-situ biological treatment, and ex-situ physical/chemical treatment. In-situ treatment is a treatment that does not employ groundwater extraction during a remediation process, while ex-situ treatment is a treatment that deals with extracted groundwater. Biological treatment is a treatment that uses microorganisms to degrade inorganic or organic contaminants in groundwater; chemical or physical treatment takes advantage of the chemical or physical properties of contaminants in order to reduce the toxicity and volume of contaminants in groundwater.

7. **Discharge**

Extracted groundwater may be discharged to the Aberjona river either onsite or offsite. Extracted groundwater may also be discharged by injection back into the aquifer. Discharge actions prevent exposure and reduce mobility, yet will not reduce the volume or toxicity of contaminants (GZA, 1991), unless combined with treatment first.

6.3 IDENTIFICATION OF REMEDIATION TECHNOLOGIES AND PROCESS OPTIONS

Available groundwater remedial technologies and their process options are summarized in Table 6-1. In addition, Table 6-2 presents a matrix that shows a brief description of each process option and limitation of each remediation technology.

Table 6-1 General Response Actions, Technology Types and Process Options

General Response Actions	Technology Types	Process Options
No Action	None	Not applicable
Limited Action	Natural attenuation	Natural attenuation
Institutional Control	Access restrictions	Deed restrictions
	Alternative water supply	City water supply
	Drinking water treatment	Wellhead treatment
Containment	Vertical barriers	Sheet barriers
		Slurry wall
		Grout Curtain
		Vibrating beam
	Horizontal barriers	Block displacement
		Pump & Treat
Groundwater Collection	Extraction	Shallow wells
		Deep/bedrock wells
		Well points
		Horizontal wells
	Surface drains	Interceptor trenches
Treatment	In-situ biological treatment	Enhanced aerobic bioremediation
		Anaerobic bioremediation
		Phytoremediation
	In-situ physical/chemical treatment	In well air stripping
		Air sparging
		Bioslurping
		In-situ chemical oxidation
		Dual phase extraction
		Fluid/vapor extraction
		Enhanced flushing
		Hydrofracturing
		Passive/reactive treatment walls
	Ex-situ biological treatment	Bioreactor
	Ex-situ physical/chemical treatment	Adsorption/absorption
		Air stripping
		Granulated activated carbon
		Ion exchange
		Precipitation/coagulation/ flocculation
		Separation/Filtration
		Sprinkler irrigation
		UV oxidation
Discharge	On-site discharge	Local stream or river
		Subsurface recharge
		Groundwater injection
	Off-site discharge	POTW

Table 6-2 Process Options and their Description and Limitation

General Response Actions	Process Options	Description	Limitation	References •
No Action	Not applicable	No action	Required for consideration by the National Contingency Plan.	1, 2
Limited Action	Natural attenuation	Natural subsurface processes are allowed to reduce contaminant concentrations to acceptable levels.	Intermediate degradation products may be more mobile and more toxic than the original contaminant. Contaminants may migrate before they are degraded.	1
Institutional Controls	Deed restrictions	Restrict use of groundwater at the site by imposing deed restrictions on all properties overlying the Site.	Does not reduce toxicity, mobility or volume of contaminants. Effectiveness contingent upon continued future enforcement of the restrictions.	1, 2
	City water supply	Continued use of water from city wells and/or MWRA to replace supply from the Site	Does not reduce toxicity, mobility, and volume of contaminants. Site groundwater not being put to optional beneficial use.	1, 2
	Wellhead treatment	Remediation of contaminants in groundwater to MCLs if groundwater is again used as a drinking water supply.	Defers action at the site. Only portions of the aquifer that are directly influenced by pumping will be remediated.	
Containment	Sheet barriers	Interlocked steel piles assembled and driven directly into the ground to provide a barrier to groundwater flow.	It is not applicable for a site where bedrock is deep and highly fractured or weathered.	1
	Slurry wall	Trench around areas of contamination and fill with soil bentonite slurry.	It is not applicable for a site where bedrock is deep and highly fractured or weathered.	1
	Grout curtain	Grout curtains are functionally similar to slurry walls except that instead of excavating a trench and filling it with a low permeability slurry, grouting materials would be injected into the ground under pressure at regular intervals to form a wall.	It is not applicable for a site where bedrock is deep and highly fractured or weathered.	3

• See a list of references sited at the bottom of Table 6-2.

General Response Actions	Process Options	Description	Limitation	References
Containment (Cont.)	Vibrating beam	Vibrating force to advance beams into ground with injection of slurry as beam is withdrawn.	It is not applicable to a site where bedrock is deep and highly fractured or weathered.	3
	Block displace-ment	In conjunction with vertical barriers, injection of slurry in notched injection holes.	It is not applicable to a site where bedrock is deep and highly fractured or weathered, and/or where DNAPLs exist.	3
	Pump & Treat	Pump & treat	It is not applicable to contaminants with high residual saturation, high sorption capabilities, and homogeneous aquifer with hydraulic conductivity less than 10E-05 cm/sec.	2
Collection	Shallow wells	Series of wells to extract contaminated groundwater	It is not applicable to contaminants with high residual saturation, high sorption capabilities, and homogeneous aquifer with hydraulic conductivity less than 10E-05 cm/sec.	2
	Deep/ bedrock wells	Series of wells to extract contaminated groundwater	It is not applicable to contaminants with high residual saturation, high sorption capabilities, and homogeneous aquifer with hydraulic conductivity less than 10E-05 cm/sec.	2
	Well points	Series of small wells to extract contaminated groundwater at low volume.	It is not applicable to contaminants with high residual saturation, high sorption capabilities, and homogeneous aquifer with hydraulic conductivity less than 10E-05 cm/sec.	2
	Horizontal wells	Drilling technologies are used to position wells horizontally, or at an angle, to reach contaminants not accessible by direct vertical drilling. Usually horizontal wells are installed in shallow groundwater zones.	The potential exists for the wells to collapse. Currently, the technology is limited to depths of less than 50ft.	1, 3

General Response Actions	Process Options	Description	Limitation	References
Collection (Cont.)	Interceptor trenches	Perforated pipe in trenches backfilled with porous media to passively collect contaminated groundwater.	Depth to which technology is effective is limited to vertical limits of trenching equipment. Most effective at sites with shallow bedrock.	1
Treatment	Enhanced aerobic bio remediation	Oxygen and nutrients are injected into the groundwater to enhance biological reaction to reduce toxicity, volume and concentration of contaminants in groundwater.	Where the subsurface is heterogeneous, it is hard to circulate oxygen or hydrogen peroxide throughout every portion of the contaminated zone. PCE and TCA cannot be degraded aerobically. Limited effectiveness for other chlorinated compounds.	3
	Anaerobic bio-remediation	Bioreactors containing microorganisms are used to biodegrade organic contaminants in a groundwater to harmless byproduct under anaerobic conditions.	Difficult to evenly distribute electron acceptors in heterogeneous subsurface. Process by which chlorinated compounds are degraded is slow.	4 .
	Phyto-remediation	Phytoremediation is a set of processes that uses plants to remove, transfer, stabilize and destroy organic/inorganic contamination in groundwater.	It is limited to shallow groundwater. It can transfer contamination across media. Climate may interfere or inhibit plant growth.	1
	In-well air stripping	Creation of groundwater circulation cell through injection of air into a zone of contaminated groundwater through center of double cased stripping well, which is designed with upper and lower double screened intervals. Groundwater is recirculated through the stripping well until remediation goals are met.	Chemical precipitates may form during air stripping and may clog the well screens, which limits groundwater circulation. If air-stripping wells are not properly designed, the plume may be spread beyond the radius of influence of the stripping well.	5
	Air sparging	Air is injected through a contaminated aquifer in order to help to volatilize the contaminants up into the unsaturated zone. A vapor extraction system is usually implemented in conjunction with air sparging to remove the generated vapor phase contamination.	Air flow through the saturated zone may not be uniform. Depth of contaminants and specific site geology, such as vadose zone gas permeability, must be considered.	1, 5

General Response Actions	Process Options	Description	Limitation	References
Treatment (Cont.)	Bioslurping	Combination of the two remedial approaches of bioventing and vacuum-enhanced free-product recovery.	Bioslurping is used for free-product remediation. Bioslurping is applicable at sites with a deep groundwater table (>30ft). Less effective in tight soils. Low temperature slow remediation.	1
	In-situ chemical oxidation	In situ chemical oxidation is based on the delivery of chemical oxidants to contaminated media in order to destroy the contaminants by converting them to innocuous compounds commonly found in nature. Hydrogen peroxide, potassium permanganate, ozone, or dissolved oxygen can be used as oxidants for this technology.	Chemical concentration of oxidants added to groundwater must be in compliance with applicable state and federal standards or captured shortly after introduction into the aquifer. Difficult to evenly distribute oxidants in heterogeneous subsurface.	6, 7, 8
	Dual phase extraction	High vacuum system is applied to simultaneously remove various combinations of contaminated groundwater.	It is not recommended for lower permeability formations due to the potential to leave isolated lenses of undissolved product in the formation. Dual phase extraction is not effective to collect DNAPLs.	1
	Fluid/Vapor extraction	High vacuum system is applied to simultaneously remove various combinations of contaminated groundwater.	Generally used in the vadose zone with hydraulic conductivity range of 10E-08 to 10E-03 cm/sec.	
	Enhanced flushing system	Steam, hot water, or surfactants are forced into an aquifer through injection wells to vaporize volatile and semivolatile contaminants, or increase their solubility	VOCs can be treated but less cost effective than other processes. Soil type, contaminant characteristics and concentration will significantly impact process effectiveness.	1

General Response Actions	Process Options	Description	Limitation	References
Treatment (Cont.)	Hydro-fracturing	Pressurized water is injected through wells and cracks the low permeability and over-consolidated sediments. Cracks are filled with porous media that serve as substrates for bioremediation or to improve pumping efficiency.	The technology should not used in bedrock sensitive to seismic activity. The potential exists to open new pathways leading to the unwanted spread of contaminants. Fractures are anticipated to collapse due to over burden pressure.	1
	Passive/ reactive treatment walls	A permeable reaction wall is installed across the flow path of a contaminant plume, allowing the water portion of the plume to passively move though the wall.	Passive treatment wall permeability may decrease due to precipitation of metal salts. Limited to a subsurface lithology that is within the vertical limits of trenching equipment.	1
	Bioreactor	Contaminants in extracted groundwater are put into contact with microorganisms in attached or suspended growth biological reactors.	Nutrition may need to be added. Air pollution control may need to be applied. Adequate temperature is necessary.	
	Adsorption/ absorption	In liquid adsorption, solutes concentrate at the surface of sorbent, thereby reducing their concentration in the bulk liquid phase.	Water-soluble compounds and small molecules are not adsorbed well. Not applicable to sites having high levels of oily substances. Not practical where the content of the absorbable hazardous substances is high. Limited effectiveness for vinyl chloride.	
	Air stripping/ steam stripping	Volatile organics are partitioned from extracted groundwater by increasing the surface area of the contaminated water exposed to air.	The potential exists for inorganic or biological fouling of the equipment if concentration of iron is greater than 5 ppm and hardness of water is greater than 800 ppm. KH need to be less than 0.01 atm cbm/mol.	1, 2
	Granulated activated carbon	Extracted groundwater is pumped through a series of canisters or columns containing activated carbon to which dissolved organic contaminants adsorb.	Stream with high suspended solids (>50mg/L) and oil and grease (>10 mg/L) may cause fouling of the carbon. Water-soluble compounds (such as vinyl chloride) and small molecules are not adsorbed well.	1, 2

General Response Actions	Process Options	Description	Limitation	References
Treatment (Cont.)	Ion exchange	Ion exchange removes ions from the aqueous phase by exchange with counter ions on the exchange medium.	Oil and grease in the groundwater may clog the exchange resin. Suspended soils content need to be less than 10 ppm. Oxidants in groundwater may damage the ion exchange resin.	1, 2
	Precipitation/ coagulation/ flocculation	This process transforms dissolved contaminants into an insoluble solid, facilitating the contaminant's subsequent removal from the liquid phase by sedimentation or filtration.	The presence of multiple metal species may lead to removal difficulties as a result of amphoteric natures of different compounds. Process may generate toxic sludge. Metals held in solution by complexing agents (e.g., cyanide) are difficult to precipitate.	1, 2
	Separation/ Filtration	Separation/Filtration techniques remove suspended solids and concentrate contaminated wastewater through physical and chemical means.	The presence of oil and grease contaminants may interfere with these processes by decreasing flow rate.	
	Sprinkler irrigation	A process that involves the pressurized distribution of volatile organic compound laden water through a standard sprinkler irrigation system.	Metal contaminated wastewater cannot be treated. Performance may be affected by temperature.	1
	UV/Chemical oxidation	When catalyzed by ultraviolet light, a strong oxidant, such as hydrogen peroxide, or ozone, reforms into hydroxyl radicals (strong oxidizer) which oxidize the organic contaminants in the groundwater to CO_2 and water.	Heavy metal ions need to be less than 10 mg/L. Some volatile compounds, such as TCA may be volatilized, rather than destroyed.	1, 2
Discharge	Local stream or river	Treated groundwater is discharged to local stream or river.	Treated groundwater needs to meet discharge standards for surface water	2
	Groundwater reinjection	Treated groundwater is reinjected to aquifer via upgradient or deep bedrock wells.	Injection will not be used for hazardous waste disposal in any areas where seismic activity could potentially occur.	2, 3

General Response Actions	Process Options	Description	Limitation	References
Discharge (Cont.)	Subsurface Recharge	Treated groundwater is recharged by spraying, trenching or seepage ditches.	Areas required for discharge is proportional to volume of water. Not effective for soils with low permeability.	2, 3
	Publicly Owned Treatment Works (POTW)	Treated groundwater is discharged to local POTW for final treatment.	Some POTWs do not accept wastewater from treatment facilities. Potential adverse impact on area hydrology.	2, 3

List of References for Table 6-2

1. Federal Remediation Technologies Roundtable, Remediation Technologies Screening Matrix and Reference Guide, 3rd Edition, Prepared by the DOD Environmental Technology Transfer Committee, October 1997.
2. EBASCO Service Inc., Draft Final Feasibility Study Report, Wells G & H Site, Woburn Massachusetts, January 1989, Table 2-2.
3. Roy F. Weston, Inc., Draft Final Feasibility Study, Atlas Tack Corporation Superfund Site, Fairhaven, Massachusetts, July 1998.
4. GZA GeoEnvironment Inc., Final Draft Feasibility Study, Silresim Site RI/FS, Lowell, Massachusetts, Vol. 1, June 1991, File No. 4054.19, Table 5-4.
5. GWRTAC, 1999, http://www.gwrtac.org.html/techs.htm
6. EPA 542-R-98-008, http://www.epa.gov/swertio1
7. EPA 542 R-96-001
8. Massachusetts Contingency Plan, Section 40.0046

The technologies and process options presented in Table 6-1 and 6-2 are examined and screened in Section 6.6 with respect to their technical implementability at the site. Furthermore, the technologies and process options remaining after the initial screening are evaluated for effectiveness, implementability, and cost in Section 6.7.

6.4 CRITERIA FOR SCREENING OF TECHNOLOGY TYPES AND PROCESS OPTIONS

6.4.1 Site-Specific Characteristics

In order to select remediation technologies and process options, information about the Site and the characteristics of the contaminants are needed. This information includes, (1) geologic information, (2) hydrogeologic information, and (3) groundwater quality information.

1) Geologic information

Geologic information about soil types, vadose zone gas permeability, and depth to water table is crucial to select remedial options. In addition, it is important to know whether the bedrock is fractured and the degree of heterogeneity of the soil for selecting remedial process options.

2) Hydrogeologic information

Hydrogeologic information, including groundwater velocity, direction of flow, hydraulic conductivity, hydraulic gradient, and effective porosity are key parameters needed to select potential remedial process options.

3) Groundwater quality information

Groundwater quality information includes hardness, metal content (such as iron concentration), grease and oil concentration, and concentration of suspended solids. In addition, temperature of groundwater is an important element because it affects microbial activity in the environment, as well as the solubility of contaminants in groundwater. The pH of groundwater needs to be measured because it may affect contaminant solubility and toxicity and it may increase the risk of poisoning the microorganisms that would be used for biological treatment.

6.4.2 Contaminant Characteristics and Distributions

Contaminant characteristics and distribution in the Central Area aquifer is essential in order to screen groundwater remediation technologies and process options.

1) Contaminant chemical/physical characteristics

The nature and extent of contaminants, especially, halogenated volatile organic compounds, in groundwater are key elements to be considered in an analysis of the technical implementability of remedial process options. In addition, several contaminant characteristics are key to determine the technical implementability of remedial process options. These characteristics include water solubility, vapor pressure, density, and Henry's law constant.

2) Contaminant distribution

Location of major contaminated areas (plumes), vertical and horizontal distribution of contaminants composing plumes, chemical/physical characteristics of these contaminants, and the geological and hydrogeological condition vicinity to plumes should be addressed. These are essential parameters for selecting potentially applicable technologies and process options. For example, process options of remediating PCE distributed in permeable unconsolidated aquifer may not be applicable if PCE exists in the fractured bedrock as DNAPLs.

6.5 PRELIMINARY SCREENING OF TECHNOLOGY TYPES & PROCESS OPTIONS

The preliminary screening has been done based on the geologic and hydraulic information and information of contaminant characteristics and distributions in the Central Area aquifer, which has been discussed in Section 3 and 4. The primary screening has been performed in Figure 6-1.

Technology types and process options that are not potentially applicable based on technical implementability and site-specific condition have been eliminated.

6.6 EVALUATION OF TECHNOLOGIES AND PROCESS OPTIONS

In the second screening step, the technology types and process options remaining after the preliminary screening step are evaluated for effectiveness, implementability, and cost. Effectiveness, implementability, and cost for each process option has been evaluated and summarized in Table 6-3.

Table 6-3 Evaluation of Process Options for Central Area Aquifer Remediation

Response Action/ Technology Types	Process Options	Effectiveness	Implementability	Cost	Reference*
No Action/None	No Action	It provides baseline against which other remedial technologies can be compared. It does not reduce risks or toxicity, mobility, and volume of the contamination. It is required by the National Contingency Plan (NCP).	Not applicable.	- None	1, 2, 3, 4, 5, 6
Limited Action/ Natural Attenuation	Natural Attenuation	Natural attenuation may decrease the toxicity and/or mobility of contamination over time. It does not effectively reduce short-term potential for human exposure with the contamination.	Technical implementation of natural attenuation is feasible. Administrative implementation would require the PRPs to discuss how they could utilize existing monitoring wells, where they should install additional monitoring wells, and which parties would should take responsibility for monitoring the Central Area aquifer.	- Low Capital - Low O&M The most significant costs associated with natural attenuation are groundwater monitoring. The monitoring costs of the groundwater wells could be high depending on how long it has to be monitored.	1, 2, 3, 6
Institutional/ Access restriction	Deed restriction	Does not reduce toxicity, mobility or volume of the primary contaminants in the groundwater. Thus, it is not effective to reduce adverse impact to the environmental receptors. However, risks to human health are eliminated due to restrict usage of the contaminated groundwater	Technical and administrative implementation of deed restriction is feasible. It could be difficult to implement this process option when purchasing drinking water will become economically impracticable than cleaning up the Site groundwater in the future.	- Low Capital - Low O&M	

* See Table of references in the last page of Table 6-3.

Response Action/ Technology Types	Process Options	Effectiveness	Implementability	Cost	Reference*
Institutional/ Alternative water supply	City water supply	Use of city/MWRA water supply eliminates the need to pump the contaminated groundwater, thus effectively eliminating most of the risk to human health. However, this process option does not effectively reduce other long-term risks nor toxicity, mobility, and volume of the contamination at the Site.	Technical and administrative implementation of alternative water supply is feasible. City of Woburn has been using an alternative water supply since 1979. However, the MADEP sees that additional water supply may be necessary in order to solve water shortage occurring every summer.	- Low Capital costs - High O&M costs	2, 3
Institutional/ Drinking water treatment	Wellhead treatment	Would effectively address many of the human health exposure pathways by treating the extracted water prior to distribution and use. However, this process option would likely be deferred until other supply alternatives were depleted. Reduction of long-term risk or toxicity, mobility, and volume of the contamination at the Central Area would be deferred until a later date and then would only be applied to areas directly influenced by pumping.	Technical implementation of wellhead treatment is feasible. Remediation of contaminants using established ex-situ treatment technologies (e.g., granulated activated carbon, air stripping) is common in many communities similar to Woburn. Administrative feasibility would be challenging to determine what portion of the wellhead costs was applicable to contamination originating from Source Areas.	- Moderate Capital * - Moderate O&M * * Assuming only supplemental costs for treatment of site contaminants would be applied here.	2
Containment/ Horizontal Barriers	Pump & treat	Effective alternative for the management of the contaminated groundwater. It would also lower long term risk and toxicity, mobility, and volume of the contamination. Additional source control (i.e., Olympia, leaking sewer pipe) would be necessary to increase the effectiveness.	Pump & treat would be technically feasible. However, to fully cover the remediation area would be a challenge.	- Moderate Capital - Moderate to High O&M Operating costs could be high depending on how long the system is operated.	1, 2, 3, 6, 7
Collection/ Extraction	Shallow wells, Deep wells, and Bedrock wells	Extraction wells are effective in intercepting the plumes. Deep wells and bedrock wells are the only effective methods for collecting groundwater at great depths.	Technical implementation of extraction wells would be easier than an interceptor trench. However, wells are far more likely to draw in water from the river than other extraction process options.	- Low to Moderate Capital - Low O&M	1, 2, 3

Response Action/ Technology Types	Process Options	Effectiveness	Implementability	Cost	Reference*
Collection/ Extraction	Well points	Well points are effective in intercepting the plumes, while minimizing the amount of water extracted from Aberjona River and the wetland (due to their small radius of influence).	Technically, well points would be feasible for this site. However, a large number of well points will be required. Installation of well points and piping in the wetlands would be a challenge.	- Low Capital - Low O&M	1
Collection/ Extraction	Horizontal wells	Horizontal wells are effective in intercepting the plumes. Horizontal wells also could be used with in-situ air sparging or bioremediation systems in order to increase effectiveness in intercepting VOCs.	Technical implementation of horizontal well is feasible; however, currently, the technology is limited to depths of less than 50 feet. Use of horizontal wells below the wetlands would minimize construction impacts in wetlands.	- High Capital - Moderate O&M The capital cost of horizontal wells often would be higher than vertical wells.	6, 7 8
Collection/ Surface drain	Interceptor trenches	Interception trenches would be effective in intercepting the plumes at fairly shallow depths. The effectiveness of this system is similar to using shallow multiple extraction wells.	Technical implementation of interceptor trenches is more difficult than extraction wells. Trenches would require the clearing of large areas for construction of trenches and would be difficult to construct in wetlands.	- Moderate Capital - Moderate O&M	2, 3
Treatment/in-situ Biological	Anaerobic bioremediation	Anaerobic bioremediation is effective for degrading most cVOCs, including TCE and PCE found at the Central Area. However, the Site groundwater may also be contaminated with heavy metals such as arsenic and chromium; high levels of heavy metals are toxic to microorganisms. Therefore, a pilot test will be required to ensure the effectiveness of this technology.	Technical feasibility of the system is uncertain due to the generation of DCE and vinyl chloride as anaerobic degradation compounds. Significant amounts of monitoring would be required.	- Low Capital - Low to High O&M The operating costs could be high depending on how long the system is operated. Costs would increase due to the need for a pilot test.	2, 4, 6

Response Action/ Technology Types	Process Options	Effectiveness	Implementability	Cost	Reference*
Treatment/in-situ Physical/chemical	Air sparging	Most of the Site VOCs can be effectively removed from the groundwater in the unconsolidated deposits (air sparging is not effective on SVOCs). Demonstrated effectiveness at the Wildwood portion of the Site, which has similar characteristics as the Central Area. Vaporized contaminants need to be collected effectively and treated to meet air emission standards. A pilot test would be required to design an air sparging system. Bedrock and deep overburden wells would be required to intercept the deep portions of the plume. Air sparging would have the effect of oxidizing metals. The effect of metals in potentially a higher oxidative state relative to toxicity and mobility would have to be assessed.	Technical and administrative implementation of an air sparging system is feasible as demonstrated at Wildwood. However, groundwater is shallow (< 5'below ground surface (bgs)) in much of the Central Area. Therefore, a surface seal, similar to that constructed at Wildwood, would likely be required to capture the contaminated vapors. Most of the treatment area would need to be cleared resulting in substantial loss of wetlands resource area.	- Moderate Capital - Moderate to High O&M The operating costs could be high depending on how long the system is operated.	2
Treatment/in-situ Physical/chemical	In well air stripping	VOCs and BTEX found at the Central area can be effectively removed from the groundwater. In well vapor stripping can be applied to any soils in the Central area. This technology is not effective on SVOCs. Naturally occurring biodegradation could also be enhanced by injecting additives (nutrients, oxygen, etc.) into the stripping well. A pilot test would be required to design the in-well stripping system. Bedrock and deep overburden wells would be required to intercept the deep portions of the plume.	In well vapor stripping is feasible to remediate primary VOCs contaminants in the Central area. Metals in groundwater may convert to a higher oxidative species. This may cause precipitation of any iron and manganese that could clog this system. This would need to be evaluated further.	- Moderate Capital - Moderate O&M In-well stripping needs lower capital and O&M, due to use of a single well for extraction of vapors and remediation of groundwater and lack of need to pump, handle, and treat groundwater at the surface.	9

Response Action/ Technology Types	Process Options	Effectiveness	Implementability	Cost	Reference*
Treatment/in-situ Physical/chemical	In-situ Chemical oxidation	In-situ chemical oxidation is effective for removal of DCE, TCA, TCE, PCE, SVOCs (including PAHs), PCBs, and BTEX found in the Central Area. The technology can be applied to a variety of soil types consisting in the Central Area aquifer. In addition, the technology can remediate contaminants found in deeper aquifer by using deep/bedrock injection wells. A pilot test would be required to design the in-situ chemical oxidation system.	In-situ chemical oxidation is feasible to remediate VOCs and SVOCs found at the Central area. Given that fractured bedrock exists in the Central Area, designing an oxidant distribution system that gives homogenous levels of oxidant throughout the site may be very difficult. Furthermore, verifying that one has achieved even distribution of oxidant may also be problematic.	- Moderate to High Capital - Moderate O&M The operating costs could vary depending on the cost and quantity of oxidants to be used.	10
Treatment/in-situ Physical/chemical	Hot water or steam Flushing/stripping	Effective for removal of most VOCs at the Site. Most effective for VOCs with boiling point less than 150 °C; DCA, DCE, PCE, TCA, TCE, and vinyl chloride have boiling point less than 150 °C [1].	Technical and administrative implementation of a hot water or steam stripping is feasible.	- Moderate Capital - High O&M The operating costs could be high depending on how long the system is operated.	2, 3
Treatment/in-situ Physical/chemical	Passive/reactive Treatment walls	Passive/reactive treatment walls that may be installed across the flow path of contaminant plumes at the Site are effective in capturing shallow groundwater plumes and preventing further migration of the plumes. Bedrock and deep overburden wells would be required to intercept the deep portions of the plume.	Technical implementation of passive reactive treatment walls is less feasible than other in-situ physical/chemical treatment technologies to capture contaminants in the Central Area. Treatment walls would require the clearing of large areas for construction of trenches and would be difficult to construct in wetlands	Assumed, - High Capital - Moderate O&M Complete cost data are still not available because most sites are scaled for demonstration and may have been over designed for a safety margin.	6, 11

Response Action/ Technology Types	Process Options	Effectiveness	Implementability	Cost	Reference*
Treatment/ex-situ Biological	Bioreactor	Bioreactor would be effective for most of SVOCs and VOCs at the Central Area. However, bioreactor with co-metabolites should be used to remove halogenated VOCs and SVOCs. Treatability studies would be required for determining effectiveness and reliability.	Bioreactor is feasible for treatment of VOCs and SVOCs in site groundwater. High levels of heavy metals, such as arsenic and chromium that may be found at the Site, are most likely toxic to microorganisms and must be removed in a pretreatment process. The treatment train may also require a combination anaerobic followed by aerobic treatment to achieve complete degradation to non-toxic end products. Treatment for volatiles in the off-gas may also be needed.	- Moderate Capital - High O&M Capital cost could escalate depending on whether pretreatment for metals, treatment for volatiles in the off-gas, and/or a second bioreactor (aerobic) is needed. The operating costs could be high depending on how long the system is operated.	1, 2, 3, 6
Treatment/ex-situ Physical/chemical	Granulated activated carbon (GAC)	GAC is highly effective as a polishing step for removal of many of the SVOCs and some VOCs. However, it is expensive for replacement carbon as a stand along treatment. Therefore, GAC could not be used as a stand-alone treatment process option, but it could be effective as a polishing step. GAC has been effectively used to treat for TCA at the Wildwood and Unifirst portions of the Site.	GAC is implementable as a polishing step for treatment of the aqueous phase and treatment of the off-gas from various processes. Could be used in combination with other treatment technologies. Management of the residual carbon would be handled by off-site regeneration or disposal.	- Low to Moderate Capital - Moderate O&M (If used for polishing)	1, 2, 3, 4, 5, 6
Treatment/ex-situ Physical/chemical	Air stripping	Air stripping is very effective for removal of VOCs and SVOCs with a dimensionless Henry's law constant[2] greater than 1.0E-02. Demonstrated effectiveness as a primary treatment unit at the Wildwood portion of the Site.	Air stripping is implementable for treatment of VOCs and some SVOCs in site groundwater as seen at Wildwood. Pretreatment of extracted groundwater may be required if the concentration of iron is greater than 5 ppm and hardness is greater than 800 ppm in order to avoid clogging the columns. Off-gas may require treatment based on mass emission rate.	- Low to Moderate Capital - Low to Moderate O&M The operating costs could be higher depending on how long the system is operated and the air to water ratio, which is fixed based on the percent removal required.	1, 2, 3, 4, 6

Response Action/ Technology Types	Process Options	Effectiveness	Implementability	Cost	Reference*
Treatment/ex-situ Physical/chemical	Ion exchange	Ion exchange is effective for removal of metals; however, it is less effective if groundwater contains high levels of suspended solids (SS) (No SS data in Phase 1A report). Ion exchange is not effective at all for removal of VOCs and SVOCs. The system generates a more concentrated secondary waste (contaminated resins) which must be treated properly.	Ion exchange is implementable for final polishing step of treatment process for metal removal only if required. Technical implementation of the ion exchange is feasible. Extracted groundwater may require pretreatment if the concentration of SS is greater than 10 ppm, which may cause resin blinding.	- Moderate Capital - Moderate O&M	1, 3, 4, 6, 7
Treatment/ex-situ Physical/chemical	Precipitation/ coagulation/ flocculation	Chemical precipitation can effectively remove dissolved toxic metals by converting them into solid-phase particulates, which can be removed from the aqueous phase by coagulation and filtration. In order to remove primary chemicals of concern, VOCs and SVOCs, other treatment systems are required.	The technology is implementable as either a pre-treatment or post-treatment. The technology is well established and is easily implementable. The technology often requires a larger land area than other processes.	- Low to Moderate Capital - Moderate to High O&M Costs depend on the degree of inorganic removal.	3, 4, 6
Treatment/ex-situ Physical/chemical	Separation/ Filtration	Separation can provide an effective pre- or post-treatment step that would remove fine particles and SS. Effectiveness for organic and inorganic removal is high, although dependent on molecular size. Filtration has been used at the Wildwood, Grace and Unifirst treatment systems to effectively treat for metals and suspended solids.	Separation could be implementable as pretreatment for metal and SS removal.	- Moderate Capital - Moderate O&M The costs of separation would be dependent on the flow, the amount of solids in groundwater, and the method of treatment or disposal selected for these solids.	1, 3, 4
Treatment/ex-situ Physical/chemical	Sprinkler irrigation	Sprinkler irrigation could be effective for removal of VOCs, SVOCs, and BTEX at the Site by volatilizing the contaminants and releasing directly to the atmosphere.	Sprinkler irrigation is technically implementable as post-treatment for VOCs and SVOCs, if metals are removed from the site groundwater. However, regulatory approval may be difficult to obtain because of the potential of direct release for contaminants to the atmosphere.	- Low to High Capital - Low to High O&M Costs assumed to be similar to air stripping	6

Response Action/ Technology Types	Process Options	Effectiveness	Implementability	Cost	Reference*
Treatment/ex-situ Physical/chemical	UV oxidation	Effectiveness of the UV/oxidation system has been shown at the Grace and the Unifirst sites where their systems target the removal of VOCs (mainly TCE, 1,2-DCE and PCE) from the groundwater. Remediation for TCA would require an additional treatment step.	UV/oxidation is implementable for treatment of VOCs in site groundwater as shown at Grace and Unifirst. UV lamps can get blocked by deposits and need to be cleaned regularly.	- Moderate to High Capital - High O&M The operating costs could be high depending on how long the system is operated the size of the unit, the type of oxidant, and local electricity costs.	1, 2 Unifirst and Grace Report.
Discharge/on site discharge	Local stream or river	Discharge of the treated groundwater into the Aberjona River would be an effective method for disposal. Discharge could be located to effectively replace the groundwater that had been intercepted by the collection system.	Technical implementation of the discharge of treated groundwater to the Aberjona River is feasible. Would need to meet requirements for NPDES permit and the chemical conditions typical of MA Wetland Protection Act Permit issued by local Conservation Commission. Discharged water would likely need to meet AWQC. This has not been a problem at other treatment systems at the Site. Wildwood, NEP, and Unifirst all discharge (directly and indirectly) their treated effluent to the River.	- Low Capital - Low O&M	2, 4
Discharge/on site discharge	Subsurface recharge	Subsurface recharge of treated groundwater would be an effective means of discharging the water and it could be designed to maintain the water balance in the Central area.	Technical implementation of the recharge of treated groundwater to the subsurface at the Site is feasible. Subsurface recharge would be adversely impacted by the high water table and would require a large recharge area.	- Moderate Capital - Low O&M	2, 4
Discharge/on site discharge	Groundwater injection	Reinjection of treated groundwater would be an effective means of discharging the water. It could also be designed to maintain the water balance in the area and could be used to help flush contaminants in the deeper portions of the aquifer.	Technical implementation for groundwater injection is feasible.	- Low to Moderate Capital - Low O&M	2, 4

Notes:

1. Boiling temperature: 1,2-DCA (83 °C), 1,1-DCE (32 °C), PCE (---), 1,1,1-TCA (74 °C), TCE (87 °C), VC (-14 °C)
2. Henry's constant (dimensionless): 1,1-DCA (2.4E-01); 1,2-DCA (4.1E-02); trans1,2-DCE (7.7E-01), PCE (---), 1,1,1-TCA (1.8E-02), TCE (4.2E-01), VC (99E00): All of these COCs have dimensionless Henry's constant greater than 1.0E-02.

List of References for Table 6-3

1. EBASCO Service Inc., Draft Final Feasibility Study Report, Wells G & H Woburn, Massachusetts, Submitted to US EPA Region 1, January 1989, EPA Contract Number 68-01-7250, Table 2-2 and Table 2-3.
2. Arthur D. Little, Feasibility Study for the Picillo Farm Site, Coventry, RI, Volume 2, Submitted to US EPA Region 1, June 10, 1993, Figure 3.4.2-2 Applicable Remedial Technologies and Process Options for Groundwater.
3. GZA GeoEnvironmental Inc., Final Draft Feasibility Study Silresim Site RI/FS Lowell, Massachusetts, Vol. 1, June 1991, File No. 4054.19
4. Roy F. Weston, Inc., Draft Final Feasibility Study, Atlas Tack Corporation Superfund Site, Fairhaven, Massachusetts, July 1998.
5. Southern Division Naval Facilities Engineering Command, Draft Feasibility Study Operable Unit 8 Naval Sit Station Cecil Field, Jacksonville, Florida, May 1995.
6. Federal Remediation Technologies Roundtable, Remediation Technologies Screening Matrix and Reference Guide, DOD Environmental Technology Transfer Committee, Volume 3.0, October 1997 (http://www.frtr.gov/matrix2/).
7. GeoTrans, Inc., and RETEC, Wells G & H Site Central Area Remediation Investigation Phase 1A Report, February 14, 1994.
8. ISOTEC, The Horizontal Times, Winter 1998 & 1999 and ISOTEC, Case Study 1-10. Contact to ISOTEC: 51A Everett Drive, West Windsor, New Jersey 08550, phone: 609-275-8500.
9. Miller, R. R. and Roote, D. S., "In-well Vapor Stripping, Technology Overview Report," TO-97-01, GWRTAC, February 1997 (www.gwrtac.org/pdf/inwellvp.pdf)
10. EPA, Field Applications of In Situ Remediation Technologies: Chemical Oxidation, EPA 542-R-98-008, September 1998 (www.epa.gov/swertio1).
11. EPA, 1997, Permeable Reactive Subsurface Barriers for the Interception and remediation of Chlorinated Hydrocarbon and Chromium (VI) Plumes in Ground water, EPA/600/F-97/008

6.7 DEVELOPMENT OF ALTERNATIVES

Process options evaluated for effectiveness, implementability, and cost in Table 6-3 have been selected to assemble alternatives for further evaluation. A scoring system shown in Table 6-4 has been developed to select process options from different response actions and technology types.

Table 6-4 Response Actions and Technology Types for the Further Analysis

Response Action	**Technology Type**	**Selection**
No Action	No Action	Must be selected; required by NCP
Limited Action	Natural Attenuation Institutional	One process option has been selected from Limited Action
Collection	Extraction Surface Drain	One process option has been selected from Collection
Treatment	In-situ biological	• One biological technology, either in-situ or ex-situ, has been selected. • One in-situ and one ex-situ physical/chemical treatment has been selected as primary groundwater treatment process option. • One ex-situ physical/chemical technology has been selected as pre-treatment technology
Discharge	On site discharge	• One process option has been selected from Discharge.

In order to select process options in accordance with the criteria in Table 6-4, the following scoring system shown in Table 6-5 was employed.

Table 6-5 Scoring System for Selecting Process Options for Further Analysis

Item	Score	Criteria
Effectiveness	3	Process options that could reduce concentration of majority the primary contaminants (PCE and TCE) in the Site groundwater
	2	May not fully remediate the primary contaminants, but effective for treating other site contaminants (metals).
	1	Not effective at all
Implementability	3	No complex engineering judgement required to implement process options
	2	Some complex engineering judgement required to implement process options
	1	Complex to implement process options
Cost	3	Both Capital and O&M costs are considered low
	2	Between 1 and 3
	1	Both Capital and O&M costs are considered high

Using this scoring system, process options with the highest score under each response action were selected (See Table 6-6).

Table 6-6 Matrix for Selecting Alternatives for Detail Analysis
Page 1 of 7

Response Action/ Technology Types	Process Options	Effectiveness	Points*	Implementability	Points**	Cost	Points***	Total Points
No Action/ None	No Action	It does not reduce risks or mobility and volume of the contamination. It is required by the NCP.	1	Not applicable.	3	- None	3	7 Selected
Limited Action/ Natural Attenuation	Natural Attenuation	Natural attenuation may decrease the toxicity and/or mobility of contamination. Not effectively reduce short-term potential for human exposure with the contamination.	2	Technical implementation of natural attenuation is feasible.	3	- Low Capital - Low O&M	3	8 Selected
Institutional/ Access Restriction	Deed Restriction	Does not effectively reduce long-term risk or toxicity, mobility, and volume of the contamination. However, it reduces short term potential for human exposure.	2	Technical and administrative implementation of deed restriction is not feasible unless maintaining alternative water supply.	2	- Low Capital - Low O&M	3	7
Institutional/ Alternative water supply	City water supply	Does not effectively reduce long-term risk or toxicity, mobility, and volume of the contamination. However, it reduces short term potential for human exposure.	2	Technical and administrative implementation of alternative water supply is feasible.	3	- Low Capital - High O&M	2	7
Institutional/ Drinking water treatment	Wellhead treatment	Does not effectively reduce long-term risk or toxicity, mobility, and volume of the contamination at the Central Area.	2	Technical implementation of wellhead treatment is feasible.	3	- Moderate Capital - Moderate O&M	2	7

Table 6-6 Matrix for Selecting Alternatives for Detail Analysis
(Cont.) Page 2 of 7

Response Action/ Technology Types	Process Options	Effectiveness	Points*	Implementability	Points**	Cost	Points***	Total Points
Containment/ Horizontal Barriers	Pump & treat	Effective alternative for the management of the contaminated groundwater.	3	Technically pump & treat would be feasible. Fully cover the remediation area might be challenge	2	- Moderate Capital - Moderate to High O&M	2	7
Collection/ Extraction	Shallow wells, Deep wells, and Bedrock wells	Extraction wells are effective in intercepting the plumes.	3	Well established technology and used at the Site. Technical implementation of extraction wells would be easier than an interceptor trench.	3	- Low to Moderate Capital - Low O&M	3	9 Selected
Collection/ Extraction	Well points	Well points are effective in intercepting the plumes, without extracting water from Aberjona River and the wetland.	3	Would require extensive number of well points in the wetlands area. Technically, well points would be feasible.	2	- Low Capital - Low O&M	3	8
Collection/ Extraction	Horizontal wells	Horizontal wells are effective in intercepting the plumes.	3	Technical implementation of horizontal well is feasible; however, currently, the technology is limited to depths of less than 50 feet.	2	- High Capital - Moderate O&M The capital cost of horizontal wells often would be higher than vertical wells.	1.5	6.5
Collection/ Surface drain	Interceptor trenches	Interception trenches would be effective in intercepting the plumes. The effectiveness of this system is similar to a multiple extraction well system.	2	Technical implementation of interceptor trenches is more difficult than extraction wells.	1	- Moderate Capital - Moderate O&M	2	5

Table 6-6 Matrix for Selecting Alternatives for Detail Analysis
(Cont.) Page 3 of 7

Response Action/ Technology Types	Process Options	Effectiveness	Points*	Implementability	Points**	Cost	Points***	Total Points
Treatment/ in-situ Biological	Anaerobic bioremediation	Anaerobic bioremediation is effective for primary contaminants, but a long period of time is required.	2	Technical feasibility of the system is uncertain due to the generation of DCE and vinyl chloride as degradation compounds.	2	- Low Capital - Low to High O&M Costs would be increased due to the need for a pilot test.	3	7 Selected
Treatment/ in-situ Physical/ chemical	In well vapor stripping	VOCs and BTEX found at the Central Area can be effectively removed from the groundwater.	3	In well vapor stripping is feasible to remediate primary VOCs contaminants in the Central area.	3	- Moderate Capital - Moderate O&M	2	8 Selected
Treatment/ in-situ Physical/chemical	Air sparging	VOCs and SVOCs can be effectively removed from the groundwater.	3	Technical implementation of an air sparging system is feasible; however, it requires covering the ground at remediation area and may disturb wetland adversely.	1	- Moderate Capital - Moderate to High O&M The operating costs could be high depending on how long the system is operated.	2	6

Table 6-6 Matrix for Selecting Alternatives for Detail Analysis (Cont.)

Response Action/ Technology Types	Process Options	Effectiveness	Points*	Implementability	Points**	Cost	Points***	Total Points
Treatment/ in-situ Physical/ chemical	In-situ Chemical oxidation	In-situ chemical oxidation is effective for removal of DCE, TCA, TCE, and PCE, SVOCs, including PAHs and PCBs, and *BTEX found in the* Central Area. It can use to remediate contaminants found in deeper aquifer by using deep/bedrock injection wells.	2	In-situ chemical oxidation is feasible to remediate VOCs and SVOCs found at the Central area. *State limits groundwater* injection of some oxidants.	2	- Moderate Capital - Moderate O&M The operating costs could vary depending on oxidants *to be used.*	2	6
Treatment/ in-situ Physical/chemical	Hot water or steam Flushing/stripping	Effective for removal of the primary contaminants at the Site.	2	Technical and administrative implementation of a hot water or steam stripping is feasible.	2	- Moderate Capital - High O&M	2	6
Treatment/ In-situ Physical/ chemical	Passive/ reactive Treatment walls	Effective to capture contaminants in shallow aquifer, but not to capture plume in deep aquifer.	2	It is not implementable to place the wall to capture the contaminants found in bedrock in the Central Area, due to constructability constraints.	1	- High Capital - Moderate O&M Complete cost data are still not available	1.5	4.5
Treatment/ ex-situ Physical/ chemical	Bioreactor	Bioreactor with cometabolites could be used to remove halogenated VOCs and SVOCs. Treatability studies required determining effectiveness and reliability.	2	Bioreactor is feasible for treatment of SVOCs in extracted groundwater, but not *feasible for treatment of* halogenated VOCs without additional treatment processes.	2	- Medium Capital - High O&M The operating costs could be high depending on how long the system is operated.	1.5	5.5

Table 6-6 Matrix for Selecting Alternatives for Detail Analysis
(Cont.)

Response Action/ Technology Types	Process Options	Effectiveness	Points*	Implementability	Points**	Cost	Points***	Total Points
Treatment/ ex-situ Physical/chemical	Granulated activated carbon (GAC)	GAC is highly effective as a polishing step for removal of many of the SVOCs and some VOCs. However, it is less effective to remove halogenated VOCs.	2	GAC is implementable as a polishing step for treatment of the aqueous phase and treatment of the off-gas from various processes. Could be used in combination with other treatment technologies.	2	- Low to Moderate Capital - Moderate O&M (If used for polishing)	2	6 Could be used for post-treatment
Treatment/ ex-situ Physical/chemical	Air stripping	Air stripping is very effective for removal of VOCs and SVOCs with a dimensionless Henry's constant greater than 1.0E-02.	3	Air stripping is implementable for treatment of VOCs and SVOCs in Site groundwater. Extracted groundwater may be required pretreatment if the concentration of iron is greater than 5 ppm and hardness is greater than 800 ppm in order to avoid clogging the columns.	3	- Low to Moderate Capital - Low to Moderate O&M The operating costs could be higher depending on how long the system is operated.	3	9 Selected
Treatment/ ex-situ Physical/chemical	Ion exchange	Ion exchange is effective for removal of metals. Ion exchange is not effective at all for removal of VOCs and SVOCs. The system generate a secondary waste (contaminated resins) which must be treated properly.	1	Ion exchange is implementable for final polishing step of treatment process for metal removal only if required. Due to complexity, not as easy as implement separation.	2	- Moderate Capital - Moderate O&M	2	5

Table 6-6 Matrix for Selecting Alternatives for Detail Analysis
(Cont.)

Response Action/ Technology Types	Process Options	Effectiveness	Points*	Implementability	Points**	Cost	Points***	Total Points
Treatment/ ex-situ Physical/chemical	Pre-cipitation/ coagulation flocculation	In order to remove primary chemicals of concern, VOCs and SVOCs, other treatment systems is required.	1	The technology is implementable as either a pre-treatment or post-treatment. The technology is well established and is easily implementable.	2	- Low to Moderate Capital - Moderate to High O&M Costs depend on the degree of inorganic removal.	2	5
Treatment/ ex-situ Physical/chemical	Separation/ Filtration	Separation can provide an effective pre- or post-treatment step that would remove fine particle. Also, induce some volatilization. Effectiveness for organic and inorganic removal is high, although dependent on molecular size.	2	Separation could be implementable as pretreatment for metal and suspended solids removal.	3	- Moderate Capital - Moderate O&M	2	7 Could used for pre-treatment
Treatment/ ex-situ Physical/chemical	Sprinkler irrigation	Sprinkler irrigation could be effective for removal of VOCs, SVOCs, and BTEX at the Site by volatilizing the contaminants and releasing directly to the atmosphere.	3	Sprinkler irrigation is technically implementable. Regulatory approval may be difficult to obtain because of the potential of direct release for contaminants to the atmosphere.	2	- Low to Moderate Capital - Low to Moderate O&M Assumed	2	7
Treatment/ ex-situ Physical/chemical	UV oxidation	Effectiveness of UV/oxidation system has been proven at the Grace and the Unifirst site.	3	UV/oxidation is implementable for treatment of VOCs in site groundwater. Note: takes longer time to break down TCA in the groundwater.	3	- Moderate to High Capital - High O&M The operating costs could be high depending on how long the system is operated.	1.5	7.5

Table 6-6 Matrix for Selecting Alternatives for Detail Analysis
(Cont.)

Response Action/ Technology Types	Process Options	Effectiveness	Points*	Implementability	Points**	Cost	Points***	Total Points
Discharge/ on site discharge	Local stream or river	Discharge of the treated groundwater into the Aberjona River would be effective.	3	Technical implementation of the discharge of treated groundwater to the Aberjona River is feasible, as long as meeting the discharge standards are achievable.	3	- Low Capital - Low O&M	3	9
Discharge/ on site discharge	Subsurface recharge	Surface recharge of treated groundwater would be an effective means of discharging the water and it could be designed to maintain the water balance in the Central Area.	3	Technical implementation of the recharge of treated groundwater to the subsurface at the Site has limited feasibility. Subsurface recharge would be adversely impacted by the high water table and require large area.	2	- Moderate Capital - Low O&M	2.5	7.5
Discharge/ on site discharge	Ground-water injection	Reinjection of treated groundwater would be an effective means of discharging the water and it could be designed to maintain the water balance in the area.	3	Technical implementation for the groundwater injection is feasible, but strictly regulated.	3	- Low to Moderate Capital - Low O&M	2.5	8.5

* Points for Effectiveness: 3=Process options that could reduce concentration of majority the primary contaminants (PCE and TCE) in the Site groundwater. 2=Not fully remediate the primary contaminants, but effective for treating other site contaminants (metals), 1=Not effective at all.

** Points for Implementability: 3= No complex engineering judgement required to implement process options, 2= Some complex engineering judgement required to implement process options, 1= Complex to implement process options.

*** Points for: 3= both Capital and O&M cost is considered as low, 2= between 1 and 3, 1= both Capital and O&M cost is considered as high.

Figure 6-1 The Preliminary Screening of Technology Types and Process Options

groundwater General Response Actions	Remedial Technologies	Process Options	Description	Screening Comments
No Action	None	Not applicable	No action	Required for consideration by the National Contingency Plan
Limited Action	Natural Attenuation	Natural Attenuation	Natural subsurface processes are allowed to reduce contaminant concentrations to acceptable levels	Required for consideration by the National Contingency Plan
Institutional	Access restrictions	Deed restrictions	Restrict use of groundwater at the site by imposing deed restrictions on all properties overlaying the site	Potentially applicable
	Alternative water supply	City water supply	Continued use of water from city wells and/or MWRA to replace supply from the Site.	Potentially applicable
	Drinking water treatment	Well head treatment	Remediation of contaminants in groundwater to MCLs if groundwater is again used as a drinking water supply.	Potentially applicable

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groundwater General Response Actions	Remedial Technologies	Process Options	Description	Screening Comments
Containment	Vertical Barriers	Sheet barriers	Interlocked piles assembled and driven into the soil	Eliminated due to the presence of weathered, highly fractured, and deep bedrock.
		Slurry wall	Trench around areas of contamination and fill with a soil bentonite slurry	Eliminated due to the presence of weathered, highly fractured, and deep bedrock.
		Grout curtain	Pressure injection of grout in a regular pattern of drilled holes	Eliminated due to the presence of weathered, highly fractured, and deep bedrock.
		Vibrating beam	Vibrating force to advance beams into ground with injection of slurry as beam is withdrawn	Eliminated due to the presence of weathered, highly fractured, and deep bedrock.
	Horizontal Barriers	Block displacement	In conjunction with vertical barriers, injection of slurry in notched injection holes	Eliminated due to the presence of weathered and highly fractured bedrock and DNAPLs[a].
		Pump & Treat	Pump and Treat	Provides an active barriers to contamination migration through the groundwater

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a DNAPLs: Dense Non Aqueous Phase Liquid.

Figure 6-1 The Preliminary Screening of Technology Types and Process Options

groundwater General Response Actions	Remedial Technologies	Process Options	Description	Screening Comments
Collection	Extraction	Shallow wells	Used for extraction of shallow contaminated groundwater	Potentially applicable. Required components of many process options.
		Deep/bedrock wells	Used for extraction of contaminated groundwater from deeper aquifers and/or bedrock	Potentially applicable. Required components of many process options.
		Well points	Series of small wells to extracted contaminated groundwater at low volume.	Potentially applicable. Required components of many process options.
		Horizontal wells	Drilling technologies are used to position wells horizontally, or an angle to reach contaminants	Potentially applicable to a depth is less than 50ft.
	Surface drains	Interceptor trenches	Perforated pipe in trenches backfilled with porous media to collect contaminated groundwater	Potentially applicable

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groundwater General Response Actions	Remedial Technologies	Process Options	Description	Screening Comments
Treatment	In situ biological treatment	Enhanced aerobic bioremediation	Oxygen, hydrogen peroxide, or nutrients are injected into the Site groundwater to enhance biological reaction to reduce toxicity, volume, and concentration of contaminants in the Site groundwater.	The primary contaminants, such as PCE and TCA, in the Site groundwater are not effectively degraded in aerobic condition.
		Anaerobic bioremediation	Anaerobic remediation uses biological reaction under anaerobic conditions. Used for remediation of most halogenated VOCs, including TCA and PCE, which will not be degraded in aerobic conditions.	Potentially applicable to remediate cVOCs found at the Central Area aquifer; however, a series of pilot test may need in order to judge whether halogenated VOCs can be effectively degraded at the Site.
		Phytoremediation	Phytoremediation is a set of processes that uses plants to remove, transfer, stabilize and destroy organic/inorganic compounds in groundwater.	Contaminants at deeper aquifer will not be remediated.
Treatment (cont.)	In situ physical/ chemical treatment	In well vapor stripping	Creation of groundwater circulation cell through injection of air into a zone of contaminated groundwater through center of double cased stripping well, which is designed with upper and lower double screened well until remediation goals are met.	Potentially applicable for treatment of volatile organics in site groundwater.

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groundwater General Response Actions	Remedial Technologies	Process Options	Description	Screening Comments
Treatment (cont.)	In situ physical/ chemical treatment	Air sparging	Air is injected through a contaminated aquifer in order to help to volatilize the contaminants up into the unsaturated zone.	Potentially applicable for treatment of volatile organics in site groundwater.
		Bioslurping	Combination of the two remedial approaches of bioventing and vacuum-enhanced free-product recovery .	Not applicable, since there is no free product at the Site.
		In-situ Chemical Oxidation	In situ chemical oxidation is based on the delivery of chemical oxidants to contaminated media in order to destroy the contaminants by converting them to innocuous compounds commonly found in nature.	Potentially applicable
		Dual phase extraction	A high vacuum system is applied to simultaneously remove various combinations of contaminated groundwater, separated-phase petroleum products, and hydrocarbon vapor from the subsurface	Eliminated: No two phases (layers) present
		Fluid/vapor extraction	A high vacuum system is applied to simultaneously remove liquid and gas from low permeability or heterogeneous formations	Eliminated; need to extract too much groundwater to lower the water table because of the presence of vadose zone with high hydraulic conductivity.

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a Volatile Organic Compounds
b Semi Volatile Organic Compounds

Figure 6-1 The Preliminary Screening of Technology Types and Process Options

groundwater General Response Actions	Remedial Technologies	Process Options	Description	Screening Comments
Treatment (cont.)	In situ physical/ chemical treatment	Enhanced flushing remediation	Steam, hot water, or surfactants is forced into an aquifer through injection wells to vaporize VOCs[a] and SVOCs[b].	Potentially applicable; however, steam is not effectively circulated to vaporize VOCs and SVOCs in the groundwater if the bedrock is fractured
		Hydrofracturing	Injection of pressurized water through wells cracks low permeability and over-consolidated sediments.	Eliminated because of presence of high permeable aquifer; thus, not necessary to be flushed.
		Passive/reactive treatment walls	A permeable reaction wall is installed across the flow path of a contaminant plume, allowing the water portion of the plume to passively move through the wall	Potentially applicable; however, passive/reactive walls is not effective to recover contaminants existing in the deeper aquifer or bedrock.
	Ex situ biological treatment	Bioreactor	Contaminants in extracted ground water are put into contact with microorganisms in attached or suspended growth biological reactors.	Potentially applicable
		Adsorption/Absorption	In liquid adsorption, solutes concentrate at the surface of sorbent, thereby reducing their concentration in the bulk liquid phase.	Potentially applicable
		Air stripping	Volatile organic are partitioned from extracted groundwater by increasing the surface area of the contaminated water exposed to air.	Potentially applicable. Pretreatment may be required to reduce iron concentration in the groundwater.

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groundwater General Response Actions	Remedial Technologies	Process Options	Description	Screening Comments
Treatment (cont.)	Ex situ physical/ chemical treatment	Granulated activated carbon	groundwater is pumped through a series of canisters or columns containing activated carbon to which dissolved organic contaminants adsorb.	Potentially applicable. Pretreatment may be required to reduce iron concentration in the groundwater.
		Ion exchange	Ion exchange removes ions from aqueous phase by exchange with counter ions on the exchange medium.	Potentially applicable. Other treatment systems that reduce concentration and toxicity of organic contaminants, which is the major contaminants, is necessary.
		Precipitation/coagulation/ flocculation	This process transforms dissolved contaminants into an insoluble solid, facilitating the contaminant's subsequent removal from the liquid phase by sedimentation or filtration.	Potentially applicable. Other treatment systems that reduce concentration and toxicity of organic contaminants, which is the major contaminants, is necessary.
		Separation/Filtration	Separation/Filteration techniques concentrate contaminated waste water through physical and chemical means.	Potentially applicable, as a pre- and/or post-treatment system.
		Sprinkler irrigation	A process that involves the pressurized distribution of volatile organic compounds laden water through a standard sprinkler irrigation system.	Potentially applicable Additional treatment systems that deal with metal contaminants is required.
		UV oxidation	When catalyzed by ultraviolet light, a strong oxidant, such as hydrogen peroxide, ozone, reforms into hydroxyl radicals, which oxidize the organic contaminants in the groundwater to CO_2 and water.	Potentially applicable. Pre-treatment is required in order to reduce concentration of suspended solids, iron, and heavy metals.

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Figure 6-1 The Preliminary Screening of Technology Types and Process Options

groundwater General Response Actions	Remedial Technologies	Process Options	Description	Screening Comments
Discharge	Onsite discharge	Local stream or river	Treated groundwater is discharged to local stream or river.	Potentially applicable.
		Subsurface recharge	Treated groundwater is recharged by spraying, trenching, or seepage ditches.	Potentially applicable.
		Groundwater injection	Treated groundwater is reinjected to aquifer via upgradient or deep bedrock wells.	Potentially applicable.
	Offsite discharge	POTW [a]	Extracted water discharged to local POTW for treatment	Not feasible because POTW is not capable of removing volatile organic contaminants in site groundwater. In addition, POWT in the area is not accepting contaminated groundwater directly into the system [b].

[solid box] :Retained [dotted box] :Screened

a Publicly Owned Treatment Works.
b Feasibility Study Report, Ebasco, 1989.

Based on the result from Table 6-6, the following process options have been selected as alternatives to use in the evaluation in Section 7:

Table 6-7 Process Options for Further Analysis

Response Action	**Technology Type**	**Selected Process Option**
No Action	No Action	No Action
Limited Action	Natural Attenuation	Natural Attenuation with anaerobic bioremediation
Collection	Extraction	Shallow, deep, and bedrock well
Treatment	In-situ physical/chemical	In-situ in-well air stripping with GAC for vapor treatment
	Ex-situ physical/chemical	Ex-situ air stripping with filtration for pre-treatment and GAC for vapor treatment
Discharge (treated water)	On-site	Local river

7. EVALUATION OF SELECTED REMEDIATION ALTERNATIVES

7.1 INTRODUCTION

The evaluation of alternatives is the analysis and presentation of the relevant information needed to allow decision-makers to select a Site remedy. As part of this analysis, each alternative is evaluated against evaluation criteria. The results of this assessment are arrayed such that comparisons can be made among alternatives, and the key tradeoffs among alternatives can be identified. This approach to analyzing alternatives is designed to provide decision makers with sufficient information to compare the alternatives adequately, so as to select an appropriate remedy for the remediation of the groundwater at the Wells G & H Central Area.

The analysis of alternatives consists of the following components:

- Further definition of each alternative with respect to the volumes and contamination within the Site groundwater.
- Address the technologies to be used and any performance requirements associated with those technologies.
- An assessment and a summary of each alternative against evaluation criteria.

The aforementioned analysis process is based on the statutory requirements of CERCLA, the NCP, and Feasibility Study Guidance (USEPA, 1988a).

The following six evaluation criteria comprise the technical, cost, institutional, and risk considerations.

- Short-term effectiveness – This evaluation criterion addresses the effects of the alternative during the construction and implementation phases until the remedial response objectives are met. Under this criterion, alternatives are evaluated with respect to their effects on human health and the environment during implementation of the remedial action.
- Long-term effectiveness – The assessment of alternatives against this criterion evaluates the long-term effectiveness of alternatives in protecting human health and the environment after the remedial objectives have been met. It addresses the results of remedial action in terms of the risk remaining at the site after response objectives have been met. The primary focus of the evaluation is the extent and effectiveness of the controls that may be required to manage the risk posed by treatment residuals and/or untreated wastes.
- Reduction of toxicity, mobility, and volume (TMV) of contaminants –The criterion addresses whether the remedial alternative permanently and significantly reduces toxicity, mobility, and volume of the contaminants. This criterion is satisfied when treatment is used to reduce the risks through destruction of contaminants, irreversible reduction of total mass of contaminants, irreversible reduction in contaminant mobility, or reduction of total volume of contaminated media.
- Implementability – This criterion addresses the technical and administrative feasibility of implementing an alternative and the availability of various services and materials required during its implementation. This includes the technical feasibility of the

construction and operation, the reliability of the technology, and the ease of undertaking the remedial action with the alternative.

- Cost – This assessment evaluates the capital, operation and maintenance (O&M), and the total project present worth costs of each alternative. The period of performance for costing purposes will not exceed 30 years for the purpose of this analysis (USEPA, 1988a). The cost estimate will include capital cost, annual operations and maintenance (O&M) costs, and a present worth analysis.
- Overall Protection – The assessment against this criterion provides a final check to assess whether each alternative provides adequate protection of human health and the environment. The overall assessment of protection draws on the assessments conducted under other evaluation criteria, especially long term effectiveness and permanence, and short term effectiveness. Evaluation of the protectiveness of an alternative focuses on whether an alternative achieves adequate protection and how site risks are eliminated, reduced or controlled through treatment, engineering, or institutional controls.

In addition to the above six criteria, the USEPA Feasibility Study Guidance includes compliance with ARARs, state acceptance, and community acceptance criteria. These criteria have not been used for the analysis and fall outside the scope of this report. In Sections 7.2 – 7.8, a detailed description of each of the alternatives is provided, as well as the results of the evaluation of each alternative using the aforementioned criteria.

7.2 DETAILED ANALYSIS OF THE NO ACTION ALTERNATIVE

7.2.1 Description of Alternative

'No action' is not a category of technologies but a group of activities that are used to address groundwater contamination without the use of remediation measures. The no action alternative was included as required under the USEPA's National Contingency Plan (NCP) as a baseline alternative for comparison with other active remedial alternatives. The activities mentioned below will be used to construct a no action alternative.

The no action approach for the Central Area includes the following activities:

- Restrict water use where maximum contamination concentration exceeds an acceptable level.
- Increase public awareness through informing local officials, public meetings, and press releases.

The no action alternative for the Central Area groundwater involves no engineered treatment or containment of groundwater that contains contaminants in excess of cleanup goals. Contaminated groundwater will be allowed to migrate across the Site without treatment. The environmental mechanisms at work in natural attenuation include biodegradation, sorption and desorption of contaminants from soils and sediment to groundwater, and dilution. Reduction of the toxicity, mobility, and volume of the contaminants could only occur as a result of these natural environmental processes; however, without groundwater monitoring activities, there would be no method of detecting when cleanup goals are met. The no action alternative is protective of human health and the environment.

The no action alternative has been evaluated to satisfy the requirement of 40 CFR 300.68(f), which requires consideration of this alternative as a baseline against which other alternatives may be compared (USEPA, 1988a).

7.2.2 Assessment of Alternative

This text and Table 7-1 present an assessment of this alternative against the six evaluation criteria.

Table 7-1 Evaluation Criteria To Be Considered for Remedy Selection Alternative - No Action

Criteria	Assessment
Short Term Effectiveness	
Potential impact on the community, effectiveness of protection measures	There would be no additional impact to the community associated with implementation of this alternative.
Potential impacts on workers, effectiveness of protection measures	None expected because no activities are proposed.
Potential environmental impacts, effectiveness of protection measures	There would be no additional environmental impacts associated with implementation of the alternative because no activities are proposed.
Time until protection is achieved	It is likely to be many decades, if ever, before residual groundwater contamination concentrations are reduced to acceptable levels.
Time until remedial action is complete.	There is no remedial action in this alternative.

Criteria	Assessment
Long Term Effectiveness Magnitude of residual risk from untreated waste and treatment residuals	 There are risks associated with the untreated groundwater. The groundwater will remain contaminated and continue to flow through the aquifer and discharge into the surrounding wetlands and surface water continuing to create some environmental risk. There will not be any treatment residuals created with this alternative. To the extent that human exposure occurs by direct contact (such as the occasional swimmer in the Aberjona River), this will continue.
Adequacy and reliability of engineering and institutional controls used to manage untreated waste and treatment residuals	Groundwater restrictions will be used to prevent residential and commercial use of groundwater. Institutional controls of supplying an alternate water supply to the area residents through the MWRA will continue.
Long Term management and monitoring requirements	Long term groundwater monitoring would not be performed. Monitoring will be needed to ensure restrictions are effective.
Potential for future exposure to human health and environmental receptors	Future exposure of environmental receptors to contaminant in groundwater would continue. Current exposures for human and environmental receptors may be reduced over time, but risks would not necessarily be reduced to acceptable levels. Future recreation, residential and commercial use will be prevented by groundwater restrictions.
Potential need for replacement of alternative	The no action alternative is very likely to need to be "replaced" at this Site, since the contamination would continue to exceed acceptable levels for greater than 30 years.
Reduction of TMV of Contaminants Through Treatment Type and quantity of residuals resulting from treatment process.	 Not applicable
Fate of residuals remaining after treatment	Not applicable
Degree to which treatment is irreversible	Not applicable
Treatment processes employed and type and amount of materials to be treated.	Not applicable
Degree of expected reduction in TMV: is it permanent or significant?	Only reduction in toxicity, mobility, and volume due to natural attenuation processes would be possible.
Implementability Ability to construct technology	 Not applicable
Difficulties and unknowns associated with the technology	The degree to which natural attenuation would reduce contaminant concentrations is unknown.
Ability to monitor effectiveness of remedy	Site conditions would not be monitored.
Reliability of technology	Not applicable
Ability to perform operations and maintenance functions.	Not applicable

Criteria	Assessment
Ability to undertake additional remedial actions, if deemed necessary in the future	No impact on the ability to implement further remedial action.
Availability of necessary equipment, specialists; and treatment, storage and disposal services.	Not applicable.
Ability to obtain approvals from, and need to coordinate with, other agencies.	Approval from federal, state, and local agencies unlikely in areas where chemical and action specific objectives would not be achieved. The groundwater restrictions would need to be coordinated through local, state, and federal agencies.
Cost Capital costs.	Not applicable.
Operation and maintenance costs (30 year present value)	No maintenance is included in this alternative.
Costs of 5-year reviews	Each review is estimated to cost $18,000.
Present Value analysis (30-years)	The present values analysis for 30 years is $53,000
Potential future remedial action costs	Costs of additional remedial action may be incurred.
Protection of Human Health and the Environment	Institutional controls will provide protection of human health. The alternative would not be protective of the environment. Some reduction in the risk to human health and ecological receptors would likely be achieved with time, based on the assumption of some benefit from natural attenuation processes. However this benefit cannot be quantified or even confirmed with this alternative.

7.2.3 Short Term Effectiveness

In the short term, the no action alternative would not reduce the potential for ecological risks posed by the Site groundwater. The alternative would provide only the restrictions of Site access and use. No substantial construction would be involved. There are no short-term threats to neighboring communities and no significant impacts on public health during the implementation activities (Ebasco, 1989). However, wildlife would continue to be exposed to contaminated groundwater due to the continuation of discharge of the aquifer to surface water. Education programs would be undertaken to increase public awareness of the Site. Failure of the alternative to restrict access to the Site could result in the exposure to contaminants by the public (Ebasco, 1989).

7.2.4 Long Term Effectiveness

The no action alternative would not result in immediate attainment of target cleanup levels. The alternative does not estimate the time required for natural attenuation but it is estimated that more than 30 years would be required before the toxicity and concentration of contaminants is significantly reduced (Ebasco, 1989). Since no monitoring would be conducted, it would not be possible to determine if or when cleanup goals are achieved. This alternative is not considered to be effective in achieving the remedial objectives for the Site. The Site access and groundwater use restrictions would minimize human exposure.

7.2.5 Reduction of Toxicity, Mobility, and Volume

This alternative would not include any containment, removal, treatment, or disposal but would leave the contaminated groundwater undisturbed. This alternative would not result in any immediate reduction in the toxicity, mobility, and volume of contaminants. In fact, the volume of contaminated groundwater might increase with time due to the mobility of the contaminants into other areas of the Site, as well as into the deeper fractures in the bedrock aquifer (Ebasco, 1989).

7.2.6 Implementability

- Technical Feasibility - the no action alternative would be implemented without difficulty and in a short period of time. No treatment is employed in this alternative, hence reliability depends mainly on institutional controls. Public awareness would increase the effectiveness of this alternative because the community would be informed of potential hazards on Site.

Regular surveillance would deter access violations.

- Administrative Feasibility – implementation of this alternative would require institutional controls to restrict Site access and use of groundwater. Long-term institutional management would be associated with this alternative since contaminants would remain on-site and review would be necessary every five years (Ebasco, 1989). Annual inspections and public education programs would demand administrative and regulatory attention.

- Availability of Services and Materials – this alternative does not involve any treatment, storage or disposal services.

7.2.7 Cost

The total present value of this alternative is estimated at $53,000. No capital cost is required for this alternative. The costs include five-year reviews, Site and groundwater restrictions, and education programs. Refer to Appendix M for the cost estimate for no action alternative. The five-year reviews, costs for Site and groundwater restrictions, and education programs include an evaluation, reassessment of human health and environmental risks, and addressing public compliance with the institutional controls.

7.2.8 Overall Protection of Human Health and the Environment

The no action alternative would not entail removal or other on-site containment and treatment of the contaminated groundwater. Restricting site access, groundwater use, and public education programs would minimize the human health risk of direct contact with contaminated groundwater. The contaminated groundwater would continue to discharge into the surface water and posses environmental risks. It would not provide adequate protection of the environment since there would not be any immediate reduction in the toxicity, mobility, and volume of the contaminants.

7.2.9 Summary of the No Action Alternative

The no action alternative for the Central Area groundwater involves no engineered treatment or containment of groundwater that contains contaminants in excess of cleanup goals. Contaminated groundwater will be allowed to migrate across the Site without treatment. The environmental mechanisms at work in natural attenuation include biodegradation, sorption and desorption of contaminants from soils and sediment to groundwater, and dilution. Reduction of the toxicity, mobility, and volume of the contaminants could only occur as a result of these natural environmental processes; however, without groundwater monitoring activities, there would be no method of detecting when cleanup goals are met. The no action alternative is protective of human health but not the environment.

7.3 DETAILED ANALYSIS OF THE MONITORED NATURAL ATTENUATION ALTERNATIVE

7.3.1 Overview of Monitored Natural Attenuation

Natural attenuation processes affect the fate and transport of chlorinated solvents in all hydrologic systems. When those processes are shown to be capable of attaining site-specific remediation objectives in a time period that is reasonable compared to other alternatives, they may be selected alone or in combination with other more active remedies as the preferred remedial alternative. Monitored Natural Attenuation (MNA) is a term that refers specifically to the use of natural processes as part of overall site remediation (USEPA, 1998a).

Note: The USEPA defines monitored natural attenuation as "the reliance on natural processes (within the context of a carefully controlled and monitored clean-up approach) to achieve site specific remedial objectives within a time frame that is reasonable compared to other methods. The 'natural attenuation processes' that are at work in such a remediation approach include a variety of physical, chemical, or biological processes that, under favorable conditions, act without human intervention, to reduce the mass, toxicity, mobility, volume, or concentration of contaminants in soil and groundwater. These in-situ processes include, biodegradation, dispersion, dilution, sorption, volatilization, and chemical or biological stabilization, transformation, of destruction of contaminants" (USEPA, 1998a).

Monitored natural attenuation typically will be used in conjunction with active remediation measures (e.g., source control), or as a follow-up to active remediation measures that have already been implemented (USEPA, 1998a).

7.3.2 Natural Attenuation in the Central Area

Natural attenuation of cVOCs in the Central Area could occur via several processes. These processes cause a reduction in the concentration and/or mass of a contaminant dissolved in groundwater. The processes that result only in the reduction of a contaminant concentration but not of the total contaminant mass in the system is termed "non-destructive". Non-destructive processes include advection, hydrodynamic dispersion, sorption, dilution, and volatilization (USEPA, 1999). Destructive processes include biodegradation and abiotic degradation mechanisms. Biodegradation is the dominant destructive attenuation mechanism acting on cVOCs (USEPA, 1999; Hinchee, et al., 1992; Noris, et al., 1994). Abiotic degradation processes are also known to degrade chlorinated solvents, where biodegradation is not occurring.

However, the rates of abiotic processes are generally slow relative to biodegradation rates (USEPA, 1999; Hinchee, et al., 1992; Noris, et al., 1994).

7.3.3 Destructive Attenuation Mechanisms in the Central Area

Abiotic Mechanisms

The cVOCs in the Central Area may be degraded by abiotic mechanisms, although the reactions are typically not complete and often result in the formation of an intermediate that may be at least as toxic as the original (McCarty and Semprini, 1994; Bradley and Chapelle, 1996; Bouwer and McCarty, 1984). The most common reactions are hydrolysis and dehydrohalogenation. Butler and Barker (1996) note that no abiotic oxidation reactions involving typical halogenated solvents have been reported in the literature (USEPA, 1998a).

To substantiate that hydrolysis and dehalogenation are occurring, the presence of non-halogenated breakdown products such as acids and alcohols should be established (USEPA, 1998a; Murray and Richardson, 1993). In general, these products are more easily biodegraded than their parent compounds and can be difficult to detect (USEPA, 1999; Butler and Barker, 1996). Field evidence of this nature has yet to be collected to demonstrate hydrolysis of halogenated solvents (Butler and Barker, 1996).

Given the difficulties of demonstrating abiotic degradation on the field scale, it may not be practical to demonstrate that the processes are occurring during the MNA initial screening. The rate of abiotic degradation is slow relative to biotic mechanisms and therefore will not be quantified in this analysis (USEPA, 1998a).

Biotic Mechanisms

Over the past two decades, numerous laboratory and field studies have demonstrated that subsurface microorganisms can degrade a variety of chlorinated solvents (Bouwer, 1992; Cline and Defino, 1989; Freeman and Gossett, 1989; McCarty, et al.,1994; Vogel, 1994).

During biodegradation, dissolved contaminants are ultimately transformed into byproducts such as carbon dioxide, chloride salt, methane, and water (Hinchee, 1994). In some cases, intermediate products of these transformations may be more hazardous than the original compounds. Biodegradation of organic compounds dissolved in groundwater results in a reduction in contaminant concentration (and mass) and slowing of the contaminant from relative to the average advective groundwater flow velocity (USEPA, 1998a). The most important process for the natural biodegradation of the more highly chlorinated solvents is reductive dechlorination. Refer to Appendix D for a more detailed description of this process.

7.3.4 Biodegradation Screening Process for the Central Area

An accurate assessment of the Central Area's potential for natural biodegradation of chlorinated compounds should be made before investing in a detailed study of natural attenuation (USEPA, 1999). The USEPA has developed a screening process to determine if natural bioattenuation is likely to be a viable remedial alternative before additional time and money are expended.

The first step in the screening process is to use the existing site data for the Central Area and analyze the parameters specific for natural attenuation via biodegradation. The information consists of the most recent analytical data for the Central Area remediation area.

The screening uses information collected from each monitoring well within the remediation area. The second step was to compare the Phase 1A data and score it based on the USEPA established weighted parameters. Table 7-2 lists all the possible parameters for the preliminary screening. The right hand column of the matrix contains scoring values that were used to assess the likelihood that biodegradation is occurring. This method relies on the fact that the biodegradation will cause predictable changes in groundwater chemistry. The guidance provides a specific methodology for assigning the values. For example, if the dissolved oxygen concentration in the area of highest contamination is less than 0.5 milligrams per liter (mg/L), 3 points were awarded. If the dissolved oxygen is greater than 0.5 mg/L then -3 points were awarded. The scoring values for each parameter ranges from -3 to 3 with greater chance biodegradation is occurring the higher the value. The range of total possible scores and interpretations is presented below in Table7-3.

Table 7-2 USEPA Established Analytical Parameters and Weighting Used for the Preliminary Screening of Biodegradation

Analysis	Concentration in Most Contaminated Zone	Interpretation	Scoring Value [a]
Oxygen*	<0.5 mg/L	Tolerated, suppresses the reductive pathway at higher concentrations	3
	>5 mg/L	Not tolerated' however, VC may be oxidized aerobically	-3
Nitrate*	<1 mg/L	At higher concentrations may compete with reductive pathway	2
Iron II*	>1 mg/L	Reductive pathway possible; VC may be oxidized under Fe(III) reducing conditions	3
Sulfate*	<20 mg/L	At higher concentrations may compete with reductive pathway	2
Sulfide*	>1 mg/L	Reductive pathway possible	3
Methane*	<0.5 mg/L	VC oxidizes	0
	>0.5 mg/L	Ultimate reductive daughter product, VC accumulates	3

Analysis	Concentration in Most Contaminated Zone	Interpretation	Scoring Value [a]
Oxidation Reduction Potential	<50 millivolts (mV)	Reductive pathway possible	1
	<-100 mV	Reductive pathway likely	2
pH*	5< pH<9	Optimal range for reductive pathway	0
	5>pH>9	Outside optimal range for reductive pathway	-2
TOC	>20 mg/L	Carbon and energy source; drives dechlorination; can be natural or anthropogenic	2
Temperature*	> 20° C	At T>20°C biochemical process is accelerated	1
Carbon Dioxide	> 2x background	Ultimate oxidative daughter product	1
Alkalinity	>2x background	Results from interaction between CO2 and aquifer minerals	1
Chloride	>2x background	Daughter product of organic chlorine	2
Hydrogen	>1 nM	Reductive pathway possible, VC may accumulate	3
	<1 nM	VC oxidized	0
Volatile Fatty Acids	>0.1 mg/L	Intermediates resulting for biodegradation of more complex compounds, carbon as an energy source	2
BTEX*	> 0.1 mg/L	Carbon and energy source; drives dechlorination	2
PCE*		Material released	0
TCE*		Material released	0
		Daughter product of PCE	2
DCE*		Material released	0
		Daughter product of TCE	2
VC*		Material released	0
		Daughter product of DCE	2
1,1,1-TCA*		Material released	0
DCA*		Daughter product of TCA under reducing conditions	2
Carbon Tetrachloride		Material released	0
Ethene/Ethane	>0.01 mg/L	Daughter product of VC/ethene	2
	>0.1 mg/L	Daughter product of VC/ethene	3
Chloroform		Material released	0
		Daughter product of Carbon Tetrachloride	2
Dichloromethane *		Material released	0
		Daughter product of Chloroform	2

Source: USEPA (U.S. Environmental Protection Agency) September 1998. Technical Protocol for Evaluating Natural Attenuation of Chlorinated Groundwater, Office of Research and Development, Washington D.C.

[a] See Table 7-3 for description of scoring.
* = Analysis required by the USEPA

Table 7-3 Interpretation of Points Awarded During Biodegradation Screening

Score	Interpretation
0 to 5	Inadequate evidence for anaerobic biodegradation of chlorinated organics
6 to 14	Limited evidence for anaerobic biodegradation of chlorinated organics
15 to 20	Adequate evidence for anaerobic biodegradation of chlorinated organics
>20	Strong evidence for anaerobic biodegradation of chlorinated organics

Source: USEPA (U.S. Environmental Protection Agency) September 1998. Technical Protocol for Evaluating Natural Attenuation of Chlorinated Groundwater, Office of Research and Development, Washington D.C.

The chemical and geochemical data presented in Section 4 of this document was used for the screening process. In addition, the following table was created from information contained within the Phase 1A Remedial Investigation document (GeoTrans & RETEC, 1994).

Table 7-4 Chemical and Geochemical Data for the Screening of Biodegradation in the Central Area

Well	Temp °C	pH	Oxygen (ug/L)	Nitrate (ug/L)	Sulfate (ug/L)	BTEX (ug/L)
DP2	18.7	6.91	-	350	16100	0
S39	-	-	-	-	1800	9
S40	11.6	7	-	-	2100	0.7
S64	14.9	6.92	-	-	29600	0
S66	18.1	7.26	-	900	20000	0
S68	11.3	6.25	-	4900	81500	0
S81	11.3	6.54	-	1100	12100	0
S84	13.5	6.03	-	-	31000	0
S85	12.4	6.35	2.9	2900	28000	0
S86	6.6	12	-	-	24000	0
S87	14	6.8	-	-	23000	0
S90	13.3	6.6	-	-	10700	0
S91	15.6	5.5	2.6	4000	35000	0
S93	13.5	6.2	1	-	102000	0
S94	12	5.7	-	-	19200	0
S97	14.6	7	4.6	3100	44000	0
UG2	18.3	6.6	-	-	27000	0
UG4	11.9	7.2	-	-	33000	0
Average	**13.6**	**6.87**	**2.8**	**2464.3**	**30006**	**0.54**

Source: GeoTrans & RETEC (GeoTrans & RETEC), February 14, 1994. Wells G & H Site Central Area Remediation Investigation Phase 1A Report.

If bioattenuation of cVOCs is occurring in the Central Area, the initial biotransformation in the environment is a reductive dechlorination (USEPA, 1999). The initial screening process is designed to recognize geochemical environments where reductive dechlorination is plausible.

Table 7-5 Preliminary Screening for Anaerobic Biodegradation in the Central Area

Analysis	Concentration	Value
Oxygen	2.8 ug/L	3
Nitrate	2464 ug/L	0
Sulfate	30006 ug/L	0
pH	6.87	0
Temperature	13.6 °C	0
BTEX	0.54 ug/L	0
PCE	1500 ug/L	0
TCE	267.4 ug/L	0
1,2 DCE	4 ug/L	0
VC	0.3 ug/L	0
1,1,1-TCA	340 ug/L	0
Chloroform	150 ug/L	0
Total Points Awarded		3

In the preliminary screening (Table 7-5), it is inferred that biodegradation of cVOCs is probably not occurring or is occurring too slowly to contribute to natural attenuation. It should be noted that values for iron II, sulfide, and methane were not included in the preliminary screening due to lack of data. It is recommended that future studies include a sampling analysis for all MNA parameters (including sulfide, methane, and iron II) to determine if natural attenuation is occurring. The next step is to evaluate whether the non-destructive natural attenuation processes can meet the cleanup objectives of the Site.

7.3.5 Non-Destructive Natural Attenuation

Natural attenuation of cVOCs in the Central Area can occur via several processes. These processes cause a reduction in the concentration and/or mass of a contaminant dissolved in groundwater. The processes that result only in the reduction of a contaminant's concentration but not of the total contaminant mass in the system is termed "non-destructive". Non-destructive processes include advection, hydrodynamic dispersion, sorption, dilution, and volatilization

(USEPA, 1999; USEPA, 1998a; Hinchee et al., 1994; Noris et al., 1994). Table 7-6 describes the non-destructive natural attenuation processes:

Table 7-6 Summary of Non-Destructive Processes Affecting Solute Fate and Transport

Process	Description	Dependencies	Effect
Advection	Movement of solute by bulk groundwater movement.	Dependent on aquifer properties, mainly hydraulic conductivity, effective porosity, and hydraulic gradient. Independent of contaminant properties.	Main mechanism driving contaminant movement in the subsurface.
Dispersion	Fluid mixing due to groundwater movement and aquifer heterogenetics.	Dependent on contaminant properties and concentration gradients. Describes by Fick's law.	Diffusion of contaminant from areas of relative high concentrations to areas of relatively low concentrations.
Sorption	Reaction between aquifer matrix and solute whereby relatively hydrophobic organic compounds become sorbed to organic carbon or clay minerals.	Dependent on aquifer matrix properties and contaminant properties.	Tends to reduce apparent solute transport velocity and remove solutes from the groundwater via sorption to the aquifer matrix.
Recharge	Movement of water across the water table into the saturated zone.	Dependent on aquifer matrix properties, depth to groundwater, surface water interactions, and climate.	Causes dilution of the contaminant plume and may replenish electron acceptor concentrations, especially dissolved oxygen.
Volatilization	Volatilization of contaminants dissolved in groundwater into the vapor phase.	Dependent of the chemical's vapor pressure and Henry's Law constant.	Removes contaminants from groundwater and transfers them to soil gas.

Source: USEPA September 1998. Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Groundwater.

7.3.6 Preliminary Screening for Non-Destructive Natural Attenuation Mechanisms

Remediation of the Central Area by MNA results from the integration of all subsurface attenuation mechanisms (both non-destructive and destructive). The preliminary screening for non-destructive processes will provide an estimate for the length of time for the cVOCs to move through the subsurface media in the Central Area.

The preliminary screening uses calculations of advective transport to estimate the cVOCs travel time through the Central Area. Advective transport is the transport of solutes by the bulk movement of groundwater. Advection is the most important process driving dissolved contaminant migration in the subsurface (USEPA, 1998a).

Due to the fact that this analysis is a preliminary screening of non-destructive natural attenuation, it considers only advective transport of cVOCs in the Central Area. It has been shown that the use of advective transport may be a fair approximation for simulating non-destructive solute migration because it is the main force behind contaminant migration (USEPA, 1998a). However, because of dispersion, diffusion, and sorption; additional analysis should be conducted to obtain an accurate mathematical description of non-destructive solute transport.

The advective travel time was calculated using the one dimensional advective transport component of the advection dispersion equation (Refer to Appendix E for calculations). The average linear velocity was taken from the 1998 report, *Numerical Simulation of Groundwater Flow and Advective Transport at Woburn, MA based on a Sedimentological Model of Glacial and Glaciofluvial Deposition* (Metheny, 1998). The calculation was based on modeling of particle travel time (Metheny 1998) from five locations within the Site. The particle path travel times were obtained by using forward particle tracking in transient simulations (Metheny, 1998).

The average advective travel time for cVOCs within the Central Area was calculated to be 6.4 years. The amount of time needed to remediate the groundwater in the Central Area was then calculated. This was done by multiplying the advective travel time by the number of pore volume flushings that are needed specifically for PCE and TCE for the Central Area aquifer. This was calculated for both bedrock and unconsolidated deposits. Both the retardation coefficient and the pore volume values are located in Table 7-7. Refer to Appendix G for the detailed calculations. The calculation assumes source control is completely effective and no other sources exist (i.e., DNAPL).

Table 7-7 Retardation, Pore Volume, Advective Travel Time, and Remediation Time for the Central Area

Contaminant	Retardation coefficient (R)	Number of pore volume flushings (PV)	Advective Travel Time	Remediation Time
Bedrock				
PCE	9.4	32.9	6.4 years	211 years
TCE	3.1	7.9	6.4 years	51 years
Unconsolidated Sediments				
PCE	2.5	6.4	6.4 years	41 years
TCE	1.4	2.4	6.4 years	15 years

7.3.7 Destructive and Non-Destructive Natural Attenuation Results

The initial screening of destructive natural attenuation produced inadequate evidence for the biodegradation of cVOCs in the Central Area groundwater.

The initial screening of non-destructive natural attenuation estimates the time to achieve Site cleanup goals via advective transport of contaminants. The remediation of PCE and TCE in the bedrock was estimated at 211 and 51 years respectively. This calculation is due to the high retardation coefficient and pore volume flushing calculation for the contaminant and aquifer properties. Due to confined spaces and the extent of fractured bedrock within the Central Area, it is possible that some contaminated groundwater in the bedrock may not flush. Due to these hydrogeological characteristics, contamination may never be completely remediated to cleanup standards within the bedrock.

To evaluate the natural attenuation of the site in more detail, additional data need to be collected. Specifically, data including the parameters for biodegradation, which include hydrogen, methane, ferrous iron, nitrate, sulfate, and sulfide.

7.4 TECHNICAL CRITERIA EVALUATION OF THE MONITORED NATURAL ATTENUATION ALTERNATIVE

This text and Table 7-8 present an assessment of this alternative against the six evaluation criteria.

Table 7-8 Evaluation Criteria To Be Considered for Remedy Selection Alternative – Monitored Natural Attenuation

Criteria	Assessment
Short Term Effectiveness Potential impact on the community, effectiveness of protection measures	There would be minimal impact to the community associated with implementation of this alternative.
Potential impacts on workers, effectiveness of protection measures	None anticipated. Workers would be adequately protected with appropriate personal protective equipment if necessary.
Potential environmental impacts, effectiveness of protection measures	There would be minimal environmental impacts associated with implementation of this alternative.
Time until protection is achieved	Protection of people from contact with contaminated groundwater would be achieved once land use restrictions were implemented.
Time until remedial action is complete	Long term monitoring can begin immediately. It is uncertain the exact time until remedial action is complete. Initial calculations estimate over 40 years for the unconsolidated sediment and over 200 years for the bedrock.

Criteria	Assessment
Long Term Effectiveness	
Magnitude of residual risk from untreated waste and treatment residuals	Placement of deed restrictions on groundwater use would lower the potential for human contact with contaminated groundwater. Untreated groundwater could continue to be released to surface water, causing risk to aquatic and terrestrial receptors.
Adequacy and reliability of engineering and institutional controls used to manage untreated waste and treatment residuals	Institutional controls limiting use of the groundwater would be reliable and monitoring would be a reliable means of detecting changes in contaminant concentrations in groundwater.
Long Term management and monitoring requirements	In accordance with CERCLA requirements, it was assumed that long-term (30-year) groundwater monitoring would be conducted.
Potential for future exposure to human health and environmental receptors	Future exposure of environmental receptors to contaminant in groundwater would continue. Current exposures for human and environmental receptors may be reduced over time, but risks would not necessarily be reduced to acceptable levels. Future recreation, residential and commercial use will be prevented by groundwater restrictions.
Potential need for replacement of alternative	The alternative is like to need to be "replaced" at this Site, since risks would continue to exceed acceptable levels in the future. Monitoring wells may require replacement.
Reduction of TMV of Contaminants Through Treatment	
Type and quantity of residuals resulting from treatment process.	Site groundwater contaminants may be left in aquifer pore volumes and not be remediated.
Fate of residuals remaining after treatment	MNA may produce byproducts (i.e., vinyl chloride) that may be more toxic than the parent compounds.
Degree to which treatment is irreversible	*Dilution of contaminants in groundwater is not reversible.*
Treatment process employed and types and amount of materials to be treated.	Contaminated material will be subject to monitored natural attenuation.
Degree of expected reduction in TMV: is it permanent or significant?	Long term reduction in toxicity, mobility, and volume due to natural attenuation is not significant. Since only non-destructive natural attenuation will be occurring the toxicity of the contaminant will not decrease, the mobility of the contaminant will not decrease.
Implementability	
Ability to construct technology	Qualified vendors can easily monitor wells and analyze the samples.
Difficulties and unknowns associated with the technology	The degree to which natural attenuation would reduce contaminate concentration is unknown. The time required to meet acceptance criteria is estimated.
Ability to monitor effectiveness of remedy	The well sampling program would effectively monitor on-site groundwater conditions. However, some parameters (fatty acids, sulfate, hydrogen) of MNA may prove difficult to monitor.

Criteria	Assessment
Reliability of technology	Reliable, but wells may require maintenance.
Ability to perform operations and maintenance functions.	Operation and maintenance and environmental monitoring would be conducted with readily available expertise.
Ability to undertake additional remedial actions, if deemed necessary in the future	No impact on the ability to implement further remedial action.
Availability of necessary equipment, specialists; and treatment, storage and disposal services.	Readily available.
Ability to obtain approvals from, and need to coordinate with, other agencies.	Approval from federal, state, and local agencies unlikely in areas where chemical and action specific objectives would not be achieved. The groundwater restrictions would need to be coordinated through local, state, and federal agencies.
Cost Capital costs.	 None
Operation and maintenance costs (30 year present value)	$600,000
Costs of 5-year reviews (30 year present value)	$53,000
Net Present Value analysis (30-years)	$720,000
Potential future remedial action costs	Costs of additional remedial action may be incurred.
Protection of Human Health and the Environment	Institutional controls will provide protection of human health. The alternative would not be protective of the environment. Some reduction in the risk to human health and ecological receptors would likely be achieved with time, based on the assumption of some benefit from natural attenuation processes. However this benefit cannot be quantified or even confirmed with this alternative.

7.4.1 Short Term Effectiveness

There would be no risk to the community during implementation of this alternative. Workers involved in installation of additional monitoring wells, monitoring activities, and maintenance activities would be protected from any risk resulting from inhalation or direct contact with contaminated groundwater through the use of personal protective equipment.

7.4.2 Long Term Effectiveness

Deed restrictions will minimize the potential for human contact with and ingestion of potentially contaminated groundwater. The long-term effectiveness of this alternative in protecting human health would depend on the ability to enforce institutional controls.

This alternative would not prevent contaminated groundwater from discharging to surface water but will reduce contaminant concentrations in the groundwater through dilution.

7.4.3 Reduction of Toxicity, Mobility, and Volume

MNA will not reduce the toxicity, mobility, and volume of contaminants. Since only non-destructive natural attenuation will be occurring the toxicity of the contaminant will not decrease, the mobility of the contaminant will not decrease, and the volume of the contaminants will not decrease.

7.4.4 Implementability

The monitoring portion of this alternative could be implemented immediately since existing monitoring wells will be utilized. The degree to which natural attenuation attains remedial goals for groundwater has been calculated to be over 40 years for unconsolidated sediments and over 200 years for bedrock. Environmental monitoring to be performed in conjunction with this alternative would track removal rates and would provide additional information concerning the necessity of any contingency remedial actions.

7.4.5 Cost

The estimated capital cost and operation and maintenance costs for this alternative at a 30-year present value is $720,000. The detailed cost estimate is included in Appendix M. The alternative does not contain any capital costs or takes into account the cost of deed restrictions, and installation of new monitoring wells. Operation and maintenance includes 30 years of maintenance of wells, implementation of the long term monitoring program, and the SARA five-year review.

7.4.6 Overall Protection of Human Health and the Environment

The placement of land use restriction on groundwater would minimize possible contact between human receptors and contaminated groundwater. Monitored natural attenuation would slowly reduce contaminant concentrations in groundwater and thereby reducing risks to ecological receptors. This alternative would be protective of human health but not the environment in the long term.

7.4.7 Summary of the Monitored Natural Attenuation Alternative

The USEPA states that natural attenuation processes are typically occurring at all sites, but to varying degrees of effectiveness depending on the types and conditions of contaminants present and the physical, chemical, and biological characteristics of the groundwater (USEPA, 1999).

The detailed analysis of MNA presented in this study has evaluated for the destructive and non-destructive processes of MNA. The biological screening for MNA indicates inadequate evidence for the biodegradation of cVOCs in the Central Area groundwater. The initial screening of non-destructive natural attenuation has estimated the times to achieve Site cleanup goals via advective transport of the contaminants. The duration for the remediation of PCE and TCE in the bedrock was estimated at 211 and 51 years respectively, assuming complete and effective source control and no other sources such as DNAPL are present. This calculation is due to the high retardation coefficient and pore volume flushing values for the contaminant and aquifer properties. Due to confined spaces and the extent of fractured bedrock within the Central Area, it is possible that some contaminated groundwater in the bedrock may not flush. Due to these hydrogeological characteristics contamination may never be completely remediated to cleanup standards within the bedrock.

To properly evaluate the natural attenuation of the Site, additional data need to be collected. Specifically, data including the specific parameters for bioattenuation, which include methane, ferrous iron, and sulfide.

7.5 EVALUATION OF THE PUMP & TREAT ALTERNATIVE (Groundwater Extraction, Air Stripping, and Discharging into the Aberjona River)

7.5.1 Description of Alternative

Pump & Treat is an aggressive method of the groundwater remediation. Once the groundwater has been extracted from the ground, an ex-situ treatment is used to remediate the water. The wells need to be placed in specific areas to be effective in capturing and containing the contaminants. One of the main objectives is to maximize the capture of groundwater without influencing the Aberjona River or destroying the wetlands.

7.5.2 Design of the Installation for Pump & Treat

This alternative consists of hydraulic control of groundwater in the Central Area Corridor through extraction of the contaminated groundwater, treatment with an air stripper, vapor granulated activated carbon (GAC) unit, and discharge of the treated water into the Aberjona River. The groundwater will be extracted from the remediation area and will be treated by passing the groundwater through an air stripper. Air will be forced up through the water and the VOCs will transfer from the water into the air. The air will be treated with a granulated activated carbon (GAC) unit to the Massachusetts air discharge standards, which is 95 percent removal of the influent contaminant concentration. The extracted groundwater will be treated to the Massachusetts surface water discharge standards and discharged into the Aberjona River.

The first criterion needed to install the pump & treat system is to determine the pumping rate. Each well with a specific pumping rate will create a certain drawdown and a width of capture zone. The second criterion is to determine the number of wells needed to maximize the capture of groundwater. Equations for solving the first and second criteria were provided by Willard Murray from Harding Lawson Associates. The location of the wells was determined by placing the wells where they would have the most effect capture area based on their widths of capture zone. The third criterion was to determine the approximate length of time for the wells to capture the groundwater at the desired pumping rate. This value was calculated by dividing the volume of groundwater within the unconsolidated deposits or the bedrock within Central Area Corridor by the pumping rate and adjusting the value with the retardation coefficient and the number of pore volume flushings. Finally, with the pumping rate and number of wells, we contacted vendors to aid in the design of the air stripper and ~~VGAC~~ unit to assess the approximate cost for the treatment system.

7.5.2.1 Determining Pumping Rate

Since the area was not modeled, the number of wells needed was estimated based on the equations provided by Willard Murray from Harding Lawson Associates (HLA). To determine the pumping rate, the drawdown and width of capture zone per well was calculated. Appendix G has the specific equations used for determining these values. Table 7-9 shows the drawdown and the width of the capture zone per well based on the pumping rate.

Table 7-9 Drawdown and Width of Capture Zone per Well Based on Pumping Rate

Pumping Rate per Well (gpm)	Drawdown per Well (ft)	Width of Capture Zone per Well (ft)
Bedrock (T=250 ft^2/day)		
0	0	0
1	1	40
2	2	80
3	3	120
4	4	150
5	5	190
6	6	230
7	8	270
8	9	310
9	10	350
10	11	390
11	12	420
12	13	460
13	14	500
14	15	540
15	16	580
16	17	620
17	18	660
18	19	690
19	20	730
20	21	770

Pumping Rate per Well (gpm)	Drawdown per Well (ft)	Width of Capture Zone per Well (ft)
Unconsolidated Deposits (T=2285ft^2/day)		
0	0	0
1	0.1	4.2
5	0.6	21
10	1.2	42
11	1.3	46
12	1.4	51
13	1.5	55
14	1.6	59
15	1.8	63
16	1.9	67
17	2.0	72
18	2.1	76
19	2.2	80
20	2.3	84
21	2.5	88

Pumping Rate per Well (gpm)	Drawdown per Well (ft)	Width of Capture Zone per Well (ft)
Unconsolidated Deposits (T=2285ft²/day)		
22	2.6	93
23	2.7	97
24	2.8	100
25	2.9	110
26	3.0	110
27	3.2	115
28	3.3	120
29	3.4	120
30	3.5	130

Based on these calculations, a pumping rate of 30 gpm per deep unconsolidated well and 15 gpm per bedrock well was chosen. The widths of the capture zone for the bedrock and unconsolidated wells were based solely on the equations listed in Appendix G. Since the transmissivity of the bedrock is low, the width of the capture zone from the bedrock wells will be larger than the width of capture zone for the unconsolidated wells. However, the bedrock wells will likely remove the water from the unconsolidated deposits as well as the bedrock.

7.5.2.2 Determining Number of Wells and Well Placement

The number of wells needed to capture the maximum groundwater was determined by placement of the widths of the capture zone. By location, the width of the capture zone needed to be large enough to capture the contaminated groundwater in the part of the Central Area corridor with PCE and TCE levels above the MCLs, yet small enough to minimally influence the Aberjona River and wetlands. The well system required for this alternative is a design of 6 deep unconsolidated wells and 4 bedrock wells. As seen in Figure 7-1, the location of the widths of the capture zones have minimal effect on the Aberjona River and the wetlands.

7.5.2.3 Determining Approximate Time of Remediation for Pump & Treat

The amount of time needed to remediate the groundwater in the Central Area Corridor was then calculated based on the volume of water within the Central Area Corridor. These values can be found in Appendix C. Using the volumes of water in either the bedrock or the unconsolidated deposits and the pumping rate, an approximate time of remediation could be determined. However, the time of remediation is affected by the natural flushing and retardation of the contaminants within the aquifer; therefore, an adjusted remediation time needed to be calculated.

To determine the adjusted remediation time, the retardation coefficient and the pore volume values are needed. The Batch Flush Model is representative of how long it would take for the contaminants to flush out of the aquifer under natural flushing and this model is used to adjust for the time value. The equations used to calculate these values can be found in Appendix G. Both the retardation coefficient and the pore volume values for the unconsolidated deposits and the bedrock pertaining to PCE and TCE are found in Table 7-10.

Table 7-10 Retardation Calculation and Pore Volume

Bedrock (29 million gallons of groundwater)			
PCE	Average Concentration (ug/L)	Retardation coefficient (R)	Number of pore volume flushings (PV)
	163.8	9.4	32.9
TCE	Average Concentration (ug/L)	Retardation coefficient (R)	Number of pore volume flushings (PV)
	40.4	3.1	6.5
Unconsolidated Deposits (343 million gallons of groundwater)			
PCE	Average Concentration (ug/L)	Retardation coefficient (R)	Number of pore volume flushings (PV)
	64.5	2.5	6.4

TCE	Average Concentration (ug/L)	Retardation coefficient (R)	Number of pore volume flushings (PV)
	27.1	1.4	2.4

According to Table 7-10, the largest average concentration (163.8 ug/L), the largest retardation coefficient (9.4), and the greatest number of pore volume flushings (32.9) are those values listed under PCE in the bedrock. It was determined that these values represent the worst case scenario that the Central Area Corridor would have. Using the assumed pumping rates for the extraction wells in the unconsolidated deposits and the bedrock, a remediation time was determined.

Using six deep unconsolidated wells and 4 bedrock wells pumping at a combined rate of 240 gpm, Table 7-11 shows that the amount of time needed to remediate the bedrock groundwater will be 30 years and the amount of time to needed to remediate the unconsolidated groundwater will be 23 years. As a safety factor, the time required to remediate the Central Area Corridor should be doubled. A safety factor of 1.5 is a safe assumption, according to Willard Murray from Harding Lawson Associates. However, since this design has not been modeled a larger safety factor of 2 is sufficient. Therefore, for the worst case scenario, which is the remediation time for the bedrock, it should take approximately 60 years to remediate the groundwater. However, according to the *USEPA Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA* (USEPA, 1988a), only remediation up to 30 years will be accounted for.

Table 7-11 Time Needed to Remediate the Central Area Corridor as a Function of Pumping Rate.

Pumping Rate per Well (gpm)	Time to Remediate Area Without Safety Factor (years)
Bedrock ($T=250\ ft^2/day$) using 4 bedrock wells	
0	0
1	454
2	227
3	151
4	113
5	91
6	76
7	65
8	57
9	50
10	45
11	41
12	38
13	35
14	32
15	30
16	28
17	27
18	25
19	24
20	23

Pumping Rate per Well (gpm)	Time to Remediate Area Without Safety Factor (years)
Unconsolidated Deposits ($T=2285ft^2/day$) using 6 extraction wells	
0	0
1	700
5	140
10	70
11	63
12	60
13	54
14	50
15	46
16	44
17	41
18	39
19	37
20	35
21	33
22	32
23	30
24	29
25	28

Pumping Rate per Well (gpm)	Time to Remediate Area Without Safety Factor (years)
Unconsolidated Deposits (T=2285ft^2/day) using 6 extraction wells	
26	27
27	26
28	25
29	24
30	23

7.5.2.4 Air Stripper

An air stripper will be used to remediate the extracted groundwater and a detailed description of an air stripper can be found in Appendix F. To first determine if this type of ex-situ treatment could be used, the dimensionless Henry's constant has to be greater than 0.01.

Dimensionless Henry's constant at 25°C:

- PCE: 0.626
- TCE: 0.372

- Discharge criteria:

Since the effluent water will be discharged directly to surface water, a dilution factor can be taken into account (as allowed in the Operations, Maintenance, and Monitoring Manual provided by RETEC for the Wildwood treatment system) for determining the levels of contaminants that may be present in the effluent. Appendix G shows the dilution factor calculation, which is 1.58.

The discharge criteria will follow the substantive requirements of the Massachusetts Clean Air/Water Act. Discharge limits for monthly average concentrations were calculated using the Ambient Water Quality for Aquatic Life Criteria-Chronic Exposure. In addition, each individual sample must meet the discharge limit based on the Ambient Water Quality for Aquatic Life Criteria-Acute Exposure.

Table 7-12 Criteria for Discharge Limits for PCE and TCE

Contaminant	Aquatic Life Criteria-Chronic Exposure (ug/L)[1]	Aquatic Life Criteria-Acute Exposure (ug/L)[1]	Proposed Discharge Limit Monthly Average Dilution Factor (1.58)	Proposed Discharge Maximum Dilution Factor (1.58)
PCE	8.91	8.91	14	14
TCE	811	811	128	128

[1] No aquatic life criteria available. Value is Human Health Value – Fish only.

From Table 7-13, it can be seen that the influent concentration of TCE (40.4 ug/L) is lower than its discharge limits (128 ug/L) and, in a sense, has already met the Massachusetts discharge criteria once the groundwater has been extracted. Therefore, the PCE discharge limit represents the worst case scenario for remediation. TCE will still be remediated by the air stripper, but the air stripper design is based on the values for PCE. PCE needs to have a 92 percent removal before discharging the groundwater into the Aberjona River.

Table 7-13 Air Stripper Influent and Effluent Concentrations

Contaminant	Stripper influent Untreated Concentration[1] (ug/L)	Stripper Effluent Required (ug/L)	% Removal Required
PCE	163.8	14	92
TCE	40.4	128	Effluent concentration is higher than influent concentration.

[1] The average concentration within the bedrock of the Central Area Corridor – worst case scenario.

Given the available data from the Phase 1A concerning concentration values, the assumed pumping rate, the number of wells and their locations, available vendors (North East Environmental Products (NEEP) and Delta Cooling Towers) were able to design an air stripper system and estimate a cost. The extracted groundwater can then be discharged into the Aberjona River once discharge levels have been met.

- Vapor Granulated Activated Carbon (VGAC)

To clean the air from the air stripper, the contaminated air is sent to a vapor VGAC system. VGAC is a common and effective method of treating low concentrations of VOCs. The contaminated air will pass through a bed of carbon and the VOCs will adsorb onto the carbon. Ultimate destruction of the VOCs occur when the carbon in the VGAC unit is regenerated in place, regenerated at an off-site regeneration facility, or disposed of. A more complete description of VGAC units is described in Appendix H.

- Placement of Equipment

The air stripper and VGAC system will be set up on the Site. The best location is one that is not in the wetlands but above the floodplain level because of electrical safety reasons and compliance with the wetlands regulations to the greatest extent possible. Also, easy access to a public road and utilities is a necessity. As seen in Figure 7-1, a building that is 50 by 100-ft will be constructed on the east side of the access road (Rifle Range Road) before the rifle range. The land is town property, and is therefore not difficult to obtain access to. There are several different industries in the area so utility accommodations should be readily available. Also, the placement of the building is far enough from the wetlands that impact to the resource areas should be minimal. The building is also above the flood level, which means there will be little flood damage to the equipment. For public safety, the area will be fenced off, posted, and access will be authorized.

7.6 TECHNICAL CRITERIA EVALUATION FOR THE PUMP & TREAT ALTERNATIVE

This text and Table 7-14 present an assessment of this alternative against the six evaluation criteria.

Table 7-14 Evaluation Criteria To Be Considered for Remedy Selection Alternative – Pump & Treat

Criteria	Assessment
Short Term Effectiveness	
Potential impact on the community, effectiveness of protection measures	Addition of wells and a building will effect the community. Dust, noise, and congestion of vehicles will effect the community when the equipment is installed. Measures will need to be taken to limit the potential impact on the community such as fences, signs, time of construction limitations, and security.
Potential impacts on workers, effectiveness of protection measures	There will be exposure to workers because the workers will be exposed to the contaminated groundwater when installing the wells. Specific precautions will be taken to prevent injury to workers such as personal protective equipment, training, and decontamination areas.
Potential environmental impacts, effectiveness of protection measures	Because pump & treat is an aggressive treatment, there will be some effect on the environment. The low extraction flow rate should limit the effect on the Aberjona River. Discharging the clean groundwater into the Aberjona River should have a minimal effect on the wetlands and the Aberjona River. Also, the installation of only 10 wells should minimally effect the wetlands.
Time until protection is achieved	Due to the low extraction flow rate, the time of remediation should be approximately 60 years.
Time until remedial action is complete	Due to the low extraction flow rate, the time of remediation should be approximately 60 years.

Criteria	Assessment
Long Term Effectiveness Magnitude of residual risk from untreated waste and treatment residuals	Low concentrations of untreated waste will remain and pose little risk.
Adequacy and reliability of engineering and institutional controls used to manage untreated waste and treatment residuals	The treatment system will remain in place until adequate discharge levels are achieved. The management of contaminated activated carbon is a routine operation that has been done at many facilities.
Long Term management and monitoring requirements	Long term monitoring may be necessary to detect for rebounding contamination.
Potential for future exposure to human health and environmental receptors	After remediation, there will be no potential for future exposure to human health. Individual treatment components may need to be replaced.
Potential need for replacement of alternative	Need for replacement of alternative may be necessary if DNAPL is detected in future studies.
Reduction of TMV of Contaminants Through Treatment Type and quantity of residuals resulting from treatment process.	No residuals will remain after treatment in the discharge stream.
Fate of residuals remaining after treatment	Natural degradation will occur if residuals remain. Natural flushing out of the aquifer will also occur.
Degree to which treatment is irreversible	Treatment is irreversible and permanent.
Treatment processes employed and type and amount of materials to be treated.	Groundwater extraction, with ex-situ air stripping plus a VGAC unit with discharge to Aberjona River. Ten wells and one building containing equipment will be needed.
Degree of expected reduction in TMV: is it permanent or significant?	Total and permanent removal in toxicity, mobility, and volume of contaminant.
Implementability Ability to construct technology	Technology readily constructable. Need to take into consideration potential construction impacts to the wetlands and the Aberjona River.
Difficulties and unknowns associated with the technology	A pilot study needs to be conducted to achieve the proper extraction rate. Fouling of equipment may occur because of iron and manganese buildup. There is a high concentration of chlorides, which should be addressed.
Ability to monitor effectiveness of remedy	Site conditions readily monitored. Samples should be taken regularly from monitoring wells and effluent groundwater. Air monitoring should also occur.
Reliability of technology	Very reliable as long as Henry's constant for contaminants is greater than 0.01. Fouling of equipment may occur because of iron and manganese buildup, necessitating metals removal as a pre-treatment step. There is a high concentration of chlorides, which should be addressed.
Ability to perform operations and maintenance functions.	Easily maintainable. Need to watch for fouling of equipment.
Ability to undertake additional remedial actions, if deemed necessary in the future	If additional remedial actions are deemed necessary, the system is readily adjustable.
Availability of necessary equipment, specialists; and treatment, storage and disposal services.	Air stripping is a well-known technology and there are many suppliers, vendors, and consultants in area.

Criteria	Assessment
Ability to obtain approvals from, and need to coordinate with, other agencies.	Approval from federal, state and local agencies would be likely in areas where chemical and action specific ARARs are achieved. Community may be concerned with the short-term effects.
Cost	
Capital costs.	$1,300,000
Operation and maintenance costs (30 year present value)	$6,300,000
Costs of 5-year reviews	$53,000
Net Present Value analysis (30-years)	$9,100,000
Potential future remedial action costs	Future remedial action costs will not be needed unless rebound occurs.
Protection of Human Health and the Environment	There needs to be protection to human health and the environment because the contaminant of concern is over the MCL. Limited effects on the wetlands will need to be taken into account when installing the wells and the building for the equipment. Once the operation of the equipment has taken place, monitoring of the Aberjona River and the level of the contaminants need to be taken. If the pump & treat alternative is implemented, the contaminants of concern will be captured and removed and human health and the environment will ultimately be protected.

7.6.1 Short Term Effectiveness

By implementing the pump & treat alternative, the migration of groundwater contamination into the Aberjona River and the wetlands would be affected immediately. Contaminated groundwater would be extracted by 10 wells, thereby removing the contaminants from the Central Area Corridor (HLA, 1999). Potential public health threats to the community and workers during construction would exist from direct contact with the contaminated groundwater and soil, and inhalation of fugitive dust and organic vapors resulting from construction and operation of the treatment plant. Air monitoring for particulates and organic vapors would be conducted to monitor exposure of the community and workers to dust and organic vapors. The treatment plant would be fenced and access would be restricted to authorized personnel only. Water spray would be used to during construction to suppress fugitive dust. Vapor phase adsorption of the air emissions using VGAC has been included to control and treat volatile emissions from air strippers (Ebasco, 1989). Because the groundwater is not currently used as drinking water, there is little potential for a public health threat by ingesting the water. In addition, as far as each system is operated properly, the likelihood of exposure to the contaminated groundwater and air is low (inhalation of the contaminated vapor phase may occur if the off-gas treatment system does not operate properly).

The risk to workers from exposure to contaminated soil and water would be minimized by use of adequate preventive measures and personal protection equipment. Health and safety training would be provided to workers to educate them with respect to potential risks and preventive measures. This alternative may require clearance of some trees for treatment plant construction. Construction of discharge lines from this treatment plant would require construction in the wetlands. This construction would have some negative environmental impact on the wetlands temporarily. Measures to minimize wetlands impact would need to be implemented. Discharge of treated water to the Aberjona River would increase the river flow during low flow periods. However, under average flow conditions the impact on the river is expected to be minimal. Under these conditions, the Central Area Corridor would be remediated in approximately 30 years. As a safety factor, the time required to remediate the area should be double to about 60 years.

If spills or incidents that add extra amounts of VOCs in the aquifer occur upgradient of the Site, the GAC unit will be able to handle the extra contamination. There will be minimal exposure of contaminants to workers with the use of proper protection and preventative measures.

7.6.2 Long Term Effectiveness

This alternative is focused on the treatment of VOC contamination within the Central Area Corridor prior to discharging the treated groundwater into the Aberjona River. Groundwater extraction, air stripping, and VGAC are well proven technologies and are readily available. Air stripping with vapor GAC systems has effectively been used to remediate organics in groundwater at hazardous waste sites and at wastewater treatment facilities (HLA, 1999). Final removal of the VOC contaminant will occur when the carbon in the VGAC unit has been disposed of or regenerated providing a long-term remediation method.

Contamination of groundwater would be reduced under this alternative by restoring groundwater to MCL goals throughout the Site except in the areas of fractured bedrock. This alternative would meet the remedial objectives of rapid aquifer restoration since it is anticipated to achieve MCLs in about 30 years assuming no further contamination. There is some uncertainty as to whether the bedrock would be fully remediated due to the fractures in the bedrock and possible DNAPL contamination (Ebasco, 1989). No uncertainties associated with long-term operation of the treatment would be expected (Ebasco, 1989).

7.6.3 Reduction of Toxicity, Mobility, and Volume

This alternative would permanently reduce the toxicity, mobility, and volume of VOCs in extracted groundwater. VOCs would be removed from the extracted groundwater by air stripping to reduce the mobility of the contaminants, and the off-gas from the air stripper would be treated with VGAC (HLA, 1999). Regeneration of spent vapor phase activated carbon or disposal of the spent activated carbon would ultimately destroy the volatile organic contaminants. The treated air will be emitted from the VGAC unit in compliance with the Massachusetts State requirement, which is 95% removal rate. This alternative would use treatment to reduce the toxicity, mobility, and volume of the contaminated groundwater in the unconsolidated deposits throughout the Site. Contaminated groundwater in the bedrock would also be treated but to a lesser extent because of the uncertainty of extracting groundwater from bedrock (Ebasco, 1989). The treated effluent would readily meet the Massachusetts surface water discharge standards for VOCs (HLA, 1999).

7.6.4 Implementability

Construction of the extraction and treatment system is relatively easy to implement and would pose a minimal threat to workers or the community. All unit processes associated with this alternative have been used extensively to treat VOCs in groundwater. The proposed treatment system is expected to have a 92 percent removal efficiency of PCE. If the total volume of groundwater to be treated is higher than anticipated, the time of operation of the treatment plant will be extended to achieve Massachusetts discharge levels. All vapors will be collected and treated by granulated activated carbon. Air quality concerns should be minimal. All contaminated groundwater in the fractured bedrock may not be possible to extract (Ebasco, 1989). Components for the proposed air stripper are readily available, and there are multiple vendors for both wells and air stripping systems with VGAC. The wells and the widths of their capture zone will be placed according to Figure 7-1. The system will be located east of the access road (Rifle Range Road) before the rifle range as seen in Figure 7-1. The required utilities are readily available at the Site. Figure 7-1 also has the schematic layout of the proposed air stripper system, groundwater extraction wells, and effluent discharge into the Aberjona River.

Implementation of this alternative would require establishing administrative and institutional responsibilities for the operation and maintenance of the treatment plant. Since the treatment plant would be on-site, it could be implemented without obtaining federal, state, or local permits although actions must comply with substantive requirements of the permits. Disposal of the treated water to the Aberjona River would likely be considered "on-site" and would not require Massachusetts or NPDES permits (Ebasco, 1988).

7.6.5 Cost

The cost for the pump & treat alternative is $9.1 million. Table 7-15 shows the basic cost analysis of the pump & treat alternative. A more detailed table for the pump & treat alternative is located in Appendix M.

Table 7-15 Cost Analysis of the Pump & Treatment Alternative

Cost Item	Cost
DIRECT COST	
Site Preparation and Mobilization	$320,000
Groundwater Extraction System	$530,000

Cost Item	Cost
Ex-Situ System	$90,000
Total Direct Cost	$940,000
INDIRECT COST	
Health and Safety	$40,000
Administration and Permitting	$30,000
Engineering and Design	$140,000
Construction Support Services	$100,000
Total Indirect Cost	$310,000
Total Capital Cost (Direct + Indirect)	$1,250,000
OPERATION AND MAINTENANCE (O&M) COST	
Wells (30 years)	
Present Worth – System Operation (5%, 30 years)	$6,300,000
5-Year Site Reviews (every 5 years for 30 years)	
Present Worth – 5-Year Site Reviews (5%, 30 years)	$53,000
Total O&M Cost (present worth)	$6,400,000
Total Capital and O&M Cost	$7,600,000
Contingency (20%)	$1,520,000
Total Cost of Pump & Treat Alternative - Groundwater Treated to Drinking Water Standards	**$9,100,000**

7.6.6 Overall Protection of Human Health and the Environment

The VOC-contaminated groundwater poses an unacceptable risk to future residents and the environment that is associated with the drinking water supply and the discharge into the Aberjona River. The pump & treat alternative relies on the extraction of contaminated groundwater from the Central Area Corridor for treatment prior to discharge into the Aberjona River. The ten wells that will be installed will capture the contaminated groundwater and prevent further migration of the groundwater. Groundwater-use restrictions would be required because the area poses a potential risk to future residents during the operation of the treatment system (HLA, 1999).

This alternative would control the migration of contaminated groundwater within and downgradient of the Site. Extraction and treatment by pump & treat would remove contaminants from the unconsolidated deposits throughout the Site and most of the bedrock to MCLs. Toxicity, mobility, and volume of the contaminants in groundwater would be reduced. Volatile organics removed would ultimately be permanently destroyed using the proposed VGAC system. Iron and manganese removed during pretreatment would be disposed at an off-site disposal facility if need be. Treated groundwater would meet discharge requirements and result in the protection of the Aberjona River. This alternative would result in overall protection of human health and environment and the Central Area Corridor would meet the objective of rapid aquifer restoration (Ebasco, 1989).

7.6.7 Summary of Pump & Treat with Air Stripping Alternative

Pump & treat is an aggressive method of treatment. It is easily implemented, effective, and has a comparable cost with other alternatives. The contaminants of concern will be immobilized and removed from the Central Area Corridor. Ultimately, the contaminants will be destroyed. Short-term effects, such as noise, dust, and congestion will have a minor effect on the community. But the long-term effects will be expected to remove the contaminants and prevent further exposure to the community. A major concern is the effect that pumping will have on the wetlands and the Aberjona River. Implementation of pump tests will allow the pumping rate and the location of wells to be adjusted to extract the groundwater without destroying the wetlands.

To further evaluate this option, more tests on the effect of pumping will need to be performed. Data such as manganese concentration, hardness, suspended solids, dissolved solids, total solids, and alkalinity will need to be collected. An updated version of the contamination concentrations would also support the technical design of the air stripper.

Ultimately, the detailed analysis performed on this alternative shows that remediation goals will be met, but it is estimated that it will take close to 60 years. There are other available technologies that are just as effective and will remediate the groundwater in a shorter time period. Pump & treat is proven and effective approach and does comply with the six criteria designated by the CERCLA guidance documents.

7.7 EVALUATION OF THE IN-WELL AIR STRIPPING ALTERNATIVE

7.7.1 Description of Alternative

In-well air stripping is an in-situ, innovative technology that reduces the concentration of organic compounds in groundwater without extraction. Therefore, adverse impacts to the wetland from groundwater extraction can be avoided in the Central Area Corridor.

Figures 7-2a and 7.2b depict typical schematics for an in-well air stripping system. The air stripping well has upper and lower screens within the same aquifer, circulating groundwater around a well. The in-well air stripping system involves groundwater circulation by injecting air into a well, which causes an air-lift, pumping effect; drawing the groundwater into the well through the lower screened interval and discharging the air-stripped groundwater through the upper screened interval. In addition, the system involves simultaneous stripping of VOCs from the groundwater. The well is capped with cement so that contaminated air can be captured through effluent pipe. The contaminated vapor is then treated above ground to adsorb VOCs in a Granulated Activated Carbon (GAC) unit.

7.7.2 Design of In-Well Air Stripping Alternative

7.7.2.1 Design Criteria

This alternative consists of the following treatment systems:

1) The groundwater treatment with multiple in-well stripping systems
2) The contaminated vapor phase treatment with Granulated Activated Carbon (GAC) units

The design objectives for this alternative are the determination of the location, number, and size of the in-well air stripping wells that would be installed to remediate the Site groundwater. The primary contaminants (PCE and TCE) must meet both the MCL standards and the State air discharge standards. Another design objective is to determine the effectiveness of remediating the primary contaminants using this alternative and the impact that key parameters have in determining contaminant removal.

Criteria for designing the system are the following:

In-well air stripping system

- Multiple in-well air stripping systems will be installed, as a "curtain," in the downgradient section of the aquifer where PCE and TCE levels are above the MCLs.
- The MCLs standard should be achieved with a single circulation of the groundwater.

GAC unit

- GAC unit will treat the contaminated air to meet Massachusetts air discharge standards, which is 95 percent removal (State off-gas discharge policy).

7.7.2.2 Location

In-well air stripping technology often works effectively if more than one system is installed downgradient of a plume. Multi-well systems installed in an aquifer provide a "curtain" to remove enough VOCs from the groundwater so that the groundwater on the downgradient of the Site of the curtain meets the MCL standards (Gorelick, 1999).

In order to decide the location of the "curtain," specific sections of the Central Corridor aquifer with PCE and TCE levels above the MCL standards (i.e., plumes) were identified. The radius of influence of each well was then determined in order to estimate the number of the wells necessary to capture and treat the contaminated groundwater.

Remediation Areas

Three major contaminated portions have been identified in the Central Area Corridor (See Section 4 and Figure 7-3):

Area 1: Western portion of the Central Area Corridor along the Aberjona River

- S 39 (H), S40 (G), S68, S85, S87, S91, S94, S97, and UG2 are the wells that are contaminated with PCE and TCE above the MCL standards.

- These wells line up with a length approximately 900 feet from north to south, parallel to the River.
- The contaminated groundwater discharges into the Aberjona River.

Area 2: Eastern portion of the Central Area Corridor near New England Plastic

- S64, S65, and S66 are the wells that are located in this area
- These three wells line up with a length approximately 600 feet from northwest to southeast.
- S65 and S66 are located outside of the Corridor, but contaminants found in these wells flow into the Central Area Corridor aquifer.

Area 3: Northern portion of the Central Area Corridor

- Well S81 represents a small area that needs to be remediated.

In order to remediate these contaminated sections with different geographic conditions, three different sets of in-well air stripping systems would be installed.

Radius of Influence

Gvirtzman and Gorelick presented an equation to determine radius of influence, which requires data, such as hydraulic conductivity and pumping rate (caused by injected air), and computer models, such as MODFLOW and MODPATH, to solve the equation (Gvirtzman and Gorelick, 1992). Wasatch Environmental Inc., a vendor of in-well air stripping technology, also uses aquifer thickness, horizontal and vertical hydraulic conductivities, effective porosity, and groundwater velocity to design systems (including radius of influence) (Pennington, 1999).

Although modeling can be used to determine the radius of influence, in most cases, the radius of influence of an in-well air stripping system is determined by conducting a pilot study [rather than by using equations presented in literatures] (Klingel, 1999; Gorelick, 1999; McNeil, 1999; Pennington, 1999; and Stagner, 1999). If a pilot study has not been conducted, the radius of influence is generally assumed approximately 1 to 2 times the distance from the water table to the middle of the lower screened interval (Buermann and Bott-Breuning, 1994; Gorelick, 1999; Stagner, 1999). Therefore, in this report, the distance from the water table to the middle of the lower screened interval is considered as a radius of influence.

The radius of influence (or the distance from the water table to the middle of the lower screened interval) of a well in each of the three contaminated portions (Area 1, 2 and Well S81) has been estimated with data from the Phase 1A reports and boring logs (GeoTrans & RETEC, 1994; boring logs). The results are shown in Table 7-16.

Table 7-16 Radius of Influence of In-Well Air Strippers

	Area 1	**Area 2**	**Well #S81**
Location	Along the Aberjona River	Near the eastern border of the Corridor	Northern portion of the Corridor
Width of the area[1]	900feet	600 feet	N/A
Wells located in the Area	S39 (H), S40 (G), S68, S85, S87, S91, S94, S97, UG2	S64, S65, S66	S81
Depth to the Groundwater table (GW) [2]	5 feet	5 feet	5 feet
Depth of Unconsolidated zone (U) [2]	96 feet bgs	35 feet bgs	62 feet bgs
Length from the bottom of the unconsolidated to the middle of the lower screened interval (L) [3]	5 feet	15 feet	15 feet
Radius of influence [4]	**96 feet**	**45 feet**	**72 feet**

	Area 1	Area 2	Well #S81
Number of wells necessary [5]	7	10	1

Notes:

1 See Figure 7-3

2 Boring Logs (GeoTrans & RETEC, 1994)

3 Wells with 10-foot lower screened interval are proposed to remediate the unconsolidated aquifer and 10 feet (Area 1) and 20 feet (Area 2 and Well S 81) of the upper part of the bedrock. The lower screened interval is located the bottom 10 feet of each well (Gorelick, 1999; Stagner, 1999).

4 Radius of influence = (U) – (GW) + (L)

5 See Appendix K of this paper for detailed calculations.

Figure 7-3 shows the location of these proposed in-well air stripping systems. Based on a radius of influence of 96 feet, it is estimated that 7 in-well air stripping systems would be installed to remediate Area 1. With radius of influence of 45 feet, 10 systems would be necessary to remediate Area 2. In addition to these two "curtains" of systems, one more in-well air stripping system would be necessary to remediate the area near Well S81. See Appendix K for detailed calculations.

Size of Wells

A typical in-well air stripping well, which is also called a "double cased well," consists of an outer casing with upper and lower screened intervals and an inner casing. The outer casing is an 8-inch diameter PVC well. A typical upper-screened interval is 10 feet long, 5 feet of the screen is above the groundwater table and the rest of 5 feet is below the groundwater table. The lower screened interval is 10 feet long, which is located the bottom of a well (Gorelick, 1999; Stagner, 1999).

The inner casing used for an air stripping well typically consists of two parts: an eductor tube and an air injection line. The eductor tube is 2.5 to 3-inch diameter tube, running from the ground surface to 5 feet above the bottom of the well. The air injection line is a ¾-inch line inside the eductor tube, running from the ground surface to 10 feet above the bottom of the well (Stagner, 1999). The size of the proposed in-well air stripping units is summarized in Table 7-17.

Table 7-17 Size of In-Well Air Stripping Units

	Area 1	Area 2	Well #S81
Location	Along the Aberjona River	Near the eastern border of the Corridor	Northern portion of the Corridor
Wells located in the Area	S39 (H), S40 (G), S68, S85, S87, S91, S94, S97, UG2	S64, S65, S66	S81
Depth to the Groundwater table (GW) [1]	5 feet	5 feet	5 feet
Depth of Unconsolidated zone (U) [1]	96 feet bgs	35 feet bgs	62 feet bgs
Thickness of Bedrock needs to be remediated (B) [1]	10 feet	20 feet	20 feet
Aquifer thickness (A) [2]	100 feet below groundwater table	50 feet below groundwater table	77 feet below groundwater table
Outer casing			
Total length (A+ 10 feet) [3]	110 feet	60 feet	87 feet
Upper screened interval	0-10 feet bgs	0-10 feet bgs	0-10 feet bgs
Lower screened interval	96-106 feet bgs	45-55 feet bgs	77-87 feet bgs
Inner casing			
Eductor tube (2.5 to 3-inch ∅)	105 feet	55 feet	82 feet
Air injection line (3/4-inch ∅)	100 feet	50 feet	77 feet

Notes:
1 Boring Logs (GeoTrans & RETEC, 1994)
2 A=U+B-GW
3 Since the Site has the thin vadose zone (< 5ft), vendors recommended that the well should have enough length above the groundwater table (10 feet) for effective air stripping and for allowing air-lift effect (< 10 feet) within the well resulted from air injection (Gorelick, 1999; McNeil, 1999; Pennington, 1999; Stagner, 1999).
∅ Inner diameter

7.7.2.3 Cleanup effectiveness

Groundwater Treatment

One of the main parameters that control cleanup effectiveness of an in-well air stripping system is the air/water ratio. In general, the air/water ratio is between 50 to 100 (Stagner, 1999;

Gorelick, 1999). Using an equation given by Gvirtzman and Gorelick, air/water ratio is determined as 75, which allows the system to cleanup the aquifer with PCE at a maximum concentration of 250 ppb and TCE at a maximum concentration of 100 ppb to meet the MCL standards in a single groundwater circulation step (Gvirtzman and Gorelick, 1992). See Appendix K for detailed calculations.

It is assumed that possible airlift of each of the proposed well is equivalent to 10 gallon per minute (gpm) pumping rate, which results from air injection (Stagner, 1999; Gorelick, 1999). Thus, air needs to be injected into the proposed wells for pumping and air stripping would be 750 gpm, which gives approximately 100 standard cubic feet per minute (scfm). Therefore, each well should have a 100 scfm air compressor to provide air necessary to cleanup the aquifer.

Vapor Phase Treatment

The primary contaminants of PCE and TCE emitted from an in-well air stripping system would be collected and treated through a GAC unit. With 100 scfm of air flow per well for both air lift pumping and in-well aeration, PCE and TCE at maximum concentrations found at the Site groundwater would be removed to the MCL standard and transferred to the vapor phase. With dimensionless Henry's law constants of PCE (0.63) and TCE (0.37), the concentrations of these contaminants in the vapor phase are determined by the calculation in Appendix K:

- Air flow rate (influent) 100 scfm
- PCE concentration (air) 85 ppb
- TCE concentration (air) 41 ppb

Each vapor phase treatment unit (GAC) requires 55 gallon of activated carbon to remediate the contaminants to meet Massachusetts air discharge standards (Joyce, 1999).

7.7.2.4 Remediation Time

Remediation time would be estimated in the following two ways:

- Method 1: Time for remediating contaminants within a capture zone
- Method 2: Time for remediating contaminants outside of the capture zone

(Gvirtzman and Gorelick, 1992; ABB, 1995; and HLA, 1999)

Method 1 is presented by Gvirtzman and Gorelick in 1992 and requires special computer models and data collected through a pilot study to determine travel time of targeted contaminants. This method is usually used to determine the time for remediating a source area plume. For this study, Method 2 may be applicable as the worst case scenario for the Site that does not have a particular plume and may be contaminated outside of the capture area. The remediation time has been estimated with the following equation:

Remediation time = [Distance [1]] x [Retardation factor [2]] / [Groundwater velocity] (HLA, 1999)

Notes:

1 The longest distance that PCE (with the largest retardation factor) may travel cross the Central Area Corridor has been used.

2 The largest retardation factor has been used

Based on the distance between Line A and Line B (600 feet or 183 m), velocity of groundwater (7.08 E-04 cm/s in bedrock @ $n = 0.05$), and retardation factor of PCE (9.4), it is deduced that the remediation time would be approximately 7.5 years. With a safety factor of 2, the time required to remediate the Central Corridor aquifer would be approximately15 years.

See also Appendix K, which contains both Method 1 and Method 2 calculations and results.

7.8 TECHNICAL CRITERIA EVALUATION OF THE IN-WELL AIR STRIPPING ALTERNATIVE

This text and Table 7-18 present an assessment of this alternative against the six evaluation criteria that were introduced in Section 7-1.

Table 7-18 Evaluation Criteria Remedy Selection Alternative – In-well Air Stripping

Criteria	Assessment
Short Term Effectiveness	
Potential impact on the community, effectiveness of protection measures	The impact of well system installation to the community will be minimal; the likelihood of exposure to the contaminants is low because the alternative would not require handling contaminated groundwater above ground. Inhalation of the contaminated vapor phase may occur if the off-gas treatment system does not operate properly. The possibility of increasing run-off or flooding may increase, due to groundwater redischarge at or above the groundwater table, which is located less than 5 feet below ground surface
Potential impacts on workers, effectiveness of protection measures	The construction workers may be exposed to the contaminated groundwater or soil at the Site while installing well system, but the potential of being exposed to the contaminated groundwater is not higher than the pump & treat alternative. Inhalation of the contaminated vapor phase may occur if the off-gas treatment system does not operate properly.
Potential environmental impacts, effectiveness of protection measures	Adverse impact to the wetlands and River will be minimal.
Time until protection is achieved	The time of remediating the contaminated aquifer in the Central Corridor will take approximately 7.5 years; with a safety factor of 2, the remediation time would be approximately 15 years.

Criteria	Assessment
Long Term Effectiveness	
Magnitude of residual risk from untreated waste and treatment residuals	Low concentrations of untreated waste will remain and pose little risk.
Adequacy and reliability of engineering and institutional controls used to manage untreated waste and treatment residuals	Although the technology is considered an innovative one, many case studies have proven that the technology is likely to reduce VOCs sufficiently in the groundwater.
Long Term management and monitoring requirements	Proposed alternative may require approximately 15 years to remediate the Central Corridor aquifer, but to ensure the effectiveness and liability of the alternative, longer term monitoring may be required.
Potential for future exposure to human health and environmental receptors	Since this alternative remediates not only contaminants in the groundwater, but also helps to enhance aerobic bioremediation in the vadose zone, potential for future exposure of groundwater and soil to human health will decrease.
Potential need for replacement of alternative	A pilot study would be required to verify that the system can actually work.
Reduction of TMV of Contaminants Through Treatment	
Type and quantity of residuals resulting from treatment process.	No residuals will remain after treatment. However, the contaminant level remaining in the fractured bedrock is uncertain.
Fate of residuals remaining after treatment	Natural degradation will occur if residuals remain. Natural flushing out of the aquifer will also occur.
Degree to which treatment is irreversible	Treatment is irreversible.
Treatment process employed and type and amount of materials to be treated.	18 in-well air stripping systems; each well system with an air injection blower, a GAC unit, and four monitoring wells.
Degree of expected reduction in TMV: is it permanent or significant?	Total and permanent removal in toxicity, mobility, and volume of contaminant.
Implementability	
Ability to construct technology	Qualified hydrogeological constructor can easily install the system.
Difficulties and unknowns associated with the technology	A pilot study must be conducted to verify the appropriate number of systems, size, locations, and cleaning effectiveness. Chemical precipitation may form during air stripping and may clog the well screens, which limits groundwater circulation. There is a high concentration of chlorides, which should be addressed.
Ability to monitor effectiveness of remedy	Site groundwater conditions readily monitored by installing monitoring wells in downgradient and upgradient edge of the radius of influence of each well. Site air conditions also readily monitored by measuring PCE and TCE in effluent air.

Criteria	Assessment
Reliability of technology	Air stripping portion of the alternative is reliable because both PCE and TCE has Henry's law constant greater than 0.01. Wells may require periodical maintenance to avoid chemical precipitation that may form during air stripping and may clog the well screens, which limits groundwater circulation.
Ability to perform operations and maintenance functions.	Operation and maintenance of in-well air stripping system would be performed readily.
Ability to undertake additional remedial actions, if deemed necessary in the future	If additional remedial actions are deemed necessary, the system is readily adjustable.
Availability of necessary equipment, specialists; and treatment, storage and disposal services.	Compared to traditional pump & treat, the number of specialists and vendors of in-well air stripping technology is limited, as a result, the technology could be difficult on a timely basis.
Ability to obtain approvals from, and need to coordinate with, other agencies.	Approval from federal, state and local agencies would be likely in areas where chemical and action specific ARARs are achieved. Community may be concerned by the short-term effects.
Cost Capital costs.	Approximately $4,400,000
Operation and maintenance costs (15 year present value)	Approximately $7,000,000
Costs of 5-year reviews (15 years present value)	Approximately $45,000
Net Present Value analysis (15-years)	Approximately $13,700,000
Potential future remedial action costs	Future remedial action costs will not be needed unless rebound occurs.
Protection of Human Health and the Environment	There needs to be protection to human health and the environment because the contaminant of concern is over the MCLs. Limited effects on the wetlands will need to be taken into account when installing the wells and the building for the equipment. Once the operation of the equipment has taken place, monitoring of the contaminant level in the groundwater and air need to be taken. If the in-well air stripping alternative is implemented, the contaminants of concern will be destroyed and human health and the environment will ultimately be protected.

7.8.1 Short Term Effectiveness

The remediation goal of the drinking water standard is achieved by using a multiple number of in-well air stripping units. Each system is designed for remediating the primary contaminants, TCE and PCE, in a single groundwater circulation step without extracting the contaminated water above the ground. TCE and PCE in the groundwater are mixed with injected air and transferred to the vapor phase; this contaminated vapor phase is then treated by a GAC unit, which would be placed above ground.

Because the groundwater is not currently used as drinking water, there is little potential for a public health threat by ingesting the water. In addition, as far as each system is operated properly, the likelihood of exposure to the contaminated groundwater and air is low. (Inhalation of the contaminated vapor phase may occur if the off-gas treatment system does not operate properly.)

The potential exposure to workers performing well installation, treatment processes, and groundwater monitoring may result in a threat to human health. However, the risk could be minimized by wearing personal protection equipment and/or by educating workers how to prevent the possible exposure to the contaminants.

The adverse impact to the wetlands and Aberjona River would be minimal, because the groundwater in the Area would not be extracted. However, the possibility of increasing run-off or flooding may increase, because the alternative involves groundwater being discharged at or above the groundwater table, which is located less than 5 feet below ground surface (McNeil , 1999; GWRTAC, 1997).

Under the proposed conditions, the Central Corridor aquifer, both the unconsolidated zone and bedrock, would be remediated in approximately 7.5 years. With a safety factor of 2, the time required to remediate the area would be approximately 15 years (See appendix K).

If spills or incidents that add extra amounts of VOCs in the aquifer occur upgradient of the Site, the GAC unit may not be able to handle the extra contamination and possibly emit contaminated vapor phase into the atmosphere. Therefore, the vapor emission also needs to be monitored for the long term.

7.8.2 Long Term Effectiveness

The proposed design of the in-well air stripping system would remove PCE and TCE at maximum concentrations of 250 ppb and 100 ppb to the MCL standards with a single loop circulation of groundwater flow though each well. This alternative is designed to remediate the unconsolidated aquifer and 10 to 20 feet of the upper bedrock aquifer.

Uncertainties of evaluating long term effectiveness of this alternative are (1) the presence of fractured bedrock, which may be contaminated with PCE and TCE more than expected and (2) the potential for pockets of source material that have not been discovered to date. Therefore, the Central Corridor aquifer would require long-term monitoring.

7.8.3 Reduction of Toxicity, Mobility, and Volume

The in-well air stripping system proposed is expected to reduce toxicity, mobility, and volume of PCE and TCE in the Central Corridor aquifer. More than 95% of PCE and TCE in the aquifer will be removed from the groundwater to the vapor phase in the well system. The contaminated vapor phase will be treated in the GAC unit. Regeneration of spent vapor phase activated carbon or disposal of the spent activated carbon would ultimately destroy the volatile organic contaminants. The treated air will be emitted from the GAC unit in compliance with the Massachusetts State requirement (95 % removal).

The potential may exist for mobilizing or distributing other chemical compounds such as salt, carbon dioxide, and metals or currently immobile free product due to the groundwater circulation (Trizinsky, 1999).

Note: The alternative would not reduce toxicity, mobility, and volume of inorganic compounds, such as iron, chromium, or arsenic.

7.8.4 Implementability

Installation of the in-well air stripping system will require use of specially designed equipment and contractors that are technically trained for construction of the system. A limited number of vendors provide the in-well air stripping technology. Therefore, it may be difficult to implement this alternative in a timely manner.

In addition, the vendors would require a pilot test to ensure the location, size, and design of the in-well air stripping system. Once the system is designed properly, the operation would be readily implemented and would not require many workers.

Implementation of this alternative would require establishing administrative and institutional responsibilities for the operation and maintenance of the treatment system. Since the treatment system would be on-site, it could be implemented without obtaining federal, state, or local permits although actions must comply with substantive requirements of the permits.

7.8.5 Cost

The total present worth of this alternative is estimated to be at $13,700,000, including a capital cost of $4,400,000 and an annual operation and maintenance cost of $668,000 per year for approximately 15 years. A more detailed cost evaluation table for the in-well air stripping alternative is located in Appendix M.

7.8.6 Overall Protection of Human Health and the Environment

The PCE and TCE-contaminated groundwater poses an unacceptable risk to the public and the environment that is associated with the drinking water supply. This alternative relies on physical removal of VOCs in the Central Area aquifer to reduce risk to human health and the environment. Groundwater-use restrictions would be required because the area poses a potential risk to future residents during the operation of the treatment system (HLA, 1999).

Eighteen sets of an in-well air stripping system and a GAC unit would be installed: Eight of them would be designed to capture PCE and TCE; Ten of them would be expected to capture deep groundwater contaminants not being captured by Well UC22, a remediation well installed at Unifirst. This remediation alternative would be designed properly to cleanup the Central Corridor aquifer and protect the wetlands from the further degradation from contaminated groundwater. Therefore, this alternative would be protective of human health and the environment.

7.8.7 Summary of the In-Well Air Stripping Alternative

In-well air stripping is an in-situ, innovative treatment technology. This technology has been developed recently and is a modification of air sparging that increases its reliability and capability.

Analysis of this alternative shows that in-well air stripping technology can be easily implemented and safely operated without extracting contaminated groundwater above the ground. The contaminants of concern will be transferred from the liquid phase to vapor phase within a circulation well. The vapor will be treated to acceptable levels by GAC units. Short-term negative impact to the community adjacent to the Site will be minimal. In addition, because no groundwater extraction will be involved, there may be minimal adverse impact to the wetlands. However, workers may be exposed to contaminated groundwater during the construction period; therefore, the adequate personal protection equipment will be necessary. Long-term effects will be expected to remove the contaminants permanently and prevent further exposure to the community.

Major concern of implementing this alternative is uncertainty of effectiveness of the bedrock remediation, if DNAPL layers exist in the bedrock. In addition, if the groundwater was to be used for drinking water in the future, metal levels, other inorganic, and non-volatiles would have to be removed, possibly with well-head treatment.

The further investigations for implementing this technology would include:

- Pilot test: to determine (1) radius of influence, (2) number of circulation wells, (3) location of systems, (4) air/water ratio that would affect cleanup effectiveness, air-lift effect, and circulation steps, and (5) remediation time for the contaminants both inside and outside of the capture zone while operating the system.
- Additional sampling collecting data for manganese concentration, hardness, suspended solids, dissolved solids, total solids, and alkalinity, which may cause fouling of the well screen. It is also important to know whether and where DNAPL may be present in the bedrock. This would aid in defining the remediation time and effectiveness of this alternative.

The proposed alternative is expected to remediate the Site contaminants in approximately 15 years. Note: accuracy of the determination of the remediation time may be approximate, due to lack of information on the groundwater flow while operating the 18 units of in-well air stripping system.

8

8. FEASIBILITY OF REMEDIATING THE CENTRAL AREA AQUIFER

8.1 PURPOSE OF THIS EVALUATION

In the Phase 1A Report, BUG state that restoration of the Central Area Aquifer to drinking water standards is technically impracticable and not warranted. This conclusion is based on hydrogeologic and contaminant-related conditions, such as the interaction between the River and the Central Area Aquifer, and the variable nature and widespread extent of contamination in the groundwater in the Central Area that exceeds drinking water standards (GeoTrans & RETEC, 1994).

In an attempt to answer the question, "Can the Central Area be remediated?", the Capstone Group has presented and evaluated four groundwater remediation approaches (including 'no action'). The conclusion from this evaluation is that groundwater remediation at the Central Area would appear to be feasible (subject to confirmation by more detailed evaluations and site investigations using models and pilot tests). Two focused evaluations of the feasibility of remediating the Central Aquifer to drinking water standards are presented in this Section. The evaluations were performed by (1) evaluating the economic feasibility of groundwater remediation using MADEP criteria, and (2) evaluating the technical impracticability of groundwater restoration using USEPA guidance documents.

8.2 ECONOMIC FEASIBILITY

In the MADEP's comments on the Phase 1A Report (Appendix B), they indicate that an evaluation of the *economic feasibility* (a measure of the remedial treatment costs versus the regional municipal water supply cost per 1000 gallons of water) could result in a change in the Site's Potentially Productive Aquifer status. Such a change could make it easier to remediate the Site since the groundwater cleanup goals would likely be less ambitious. In this section of the report, the remediation costs for the two active groundwater treatment alternatives evaluated in the previous section are compared against the cost for the City of Woburn's continuing to purchase water from the Massachusetts Water Resources Authority (MWRA). If the costs to remediate the Central Area are less than, or equal to, the MWRA's costs, remediation is economically feasible.

In order to determine the cost of replacing the water from wells G & H with MWRA water, it is necessary to calculate how much water was lost when the wells were shut down. Then, the per gallon rate at which the MWRA charges the City of Woburn for water needs to be determined. Rate increases are then projected over a 30-year period and present worth costs are determined for comparison to the present worth cost of remedial alternatives over the same period.

Wells G & H were capable of supplying two million gallons (Mgal) of water per day (730 Mgal/year), but they were not pumped continuously. Metheny (1998) used historical pumping records to determine the frequency and rates at which wells G and H were pumped. Metheny calculated an average monthly pumping rate of 684 gpm and 389 gpm, respectively, for wells G and H. Pumping records over the five years prior to the wells being shut down show that wells G & H were pumped, on average, 7.4 months/year and 4.2 months/year, respectively. Allowing for a 50 percent increase in the demand over the last 20 years, it was determined that 440 million gallons of water supply are lost per year by the wells being shut down. This is within the pumping capacity (730 Mgal/year) of the wells. See Appendix N for calculations.

For Fiscal Year 2000, which began on July 1, 1999, the City of Woburn is paying $1,264,573 for water to supplement their existing Horn Pond water supply. This charge is based upon the city's 1997 (calendar year) usage of 1177 Mgal of water, and a charge of $1,074 per Mgal (Kuklinski, 1999).

Projecting continued increases in the rates that the MWRA charges and inflation over a 30-year period, it is estimated that the cumulative present worth cost to purchase water from the MWRA is approximately $18.1 million (See Appendix N). This cost is likely to be low since it does not include any additional increase in demand over the next 30 years and does not include any large (greater than 5 percent) MWRA rate increases after the year 2005.

Remediation of the groundwater in the Central Area would appear to be economically feasible since the costs for the in-well stripping ($13.7 million) and pump & treat ($9.1 million) alternatives are both less than the costs to continue to purchase the water from the MWRA. Table 8-1 shows the differences in costs.

Table 8-1 Comparison of Cost to Purchase Water from the MWRA vs. the Cost to Remediate the Groundwater in the Central Area

Present Worth (PW) Costs[1]	Purchase Water from MWRA ($ million)	Remediation Using Pump & Treat[2] ($ million)	Remediation using In-Well Air Stripping[3] ($ million)
Capital Costs	0	1.5	5.3
O&M Costs	18.1	7.6	8.4
Total PW Costs	18.1	9.1	13.7

[1] Present Worth Costs applied over 30 years using a 5 % discount rate.
[2] Present Worth Costs for Pump & Treat applied over 30 years with a 20 % contingency.
[3] Present Worth Costs for In-well Air Stripping applied over 15 years with a 20 % contingency.

8.3 TECHNICAL IMPRACTICABILITY

A determination of technical impracticability (TI) could be the basis for granting a waiver of a site's ARARs. For the Wells G & H Site, where the Safe Drinking Water Act is an ARAR, this would mean that a waiver could be granted so that the MCLs were not the cleanup goals for the Site. To ensure consistent implementation of technical impracticability (TI) determinations and to establish alternative protective strategies where restoration is technically impracticable, USEPA developed the *Guidance for Evaluating the Technical Impracticability of Ground-Water Restoration.* ("the guidance document") (USEPA, 1993a). This guidance document is directly relevant to this Site since BUG cited this guidance to support their claim that remediation of groundwater in the Central Area was technically impracticable.

A summary of the guidance document (1993a) and the two USEPA memorandums which transmitted and clarified the guidance (1993b and 1995, respectively) are provided in this Section. Also provided herein is an assessment of whether BUG's Phase 1A Report was sufficient in determining technical impracticability in accordance with the guidance, and a summary of the types of data that would be needed to support a TI determination. This Section concludes with a short discussion on whether it is reasonable and justified, based upon the available data, to conclude that remediation of the groundwater to MCLs is technically impracticable.

8.3.1 Summary of Technical Impracticability Guidance Document

8.3.1.1 Factors Affecting Technical Impracticability

Restoration of a groundwater supply to drinking water quality may not always be achievable. Per the guidance document, there are two primary factors that can inhibit groundwater restoration (1) hydrogeological factors and (2) contaminant-related factors.

Hydrogeological limitations to aquifer remediation include conditions such as complex sedimentary deposits, aquifers of very low permeability, certain types of fractured bedrock, and other conditions that make extraction or in-situ treatment of contaminated groundwater extremely difficult.

Contaminant-related factors are related to contaminant properties that may limit the success of an extraction or in-situ treatment process. Noteworthy examples of contaminants that may pose such technical limitations to aquifer restoration are NAPLs, especially DNAPLs. The ability of DNAPLs to sink through the water table and penetrate deeper portions of the aquifers is one of the properties that make them so difficult to remediate. See Figure 8-1 taken from the guidance document presents some of the types of hydrogeological and contaminant-related factors affecting groundwater restoration (USEPA, 1993a).

8.3.1.2 Approach for Evaluating Technical Impracticability

The guidance document promotes the use of a phased approach to site remediation, particularly where a moderate to high level of uncertainty exists regarding the potential outcome of restoration efforts. Early or "Interim" actions to control plume migration and remove contaminant sources are encouraged. These actions not only help reduce risks posed by contaminated groundwater, but also provide information useful in evaluating the restoration potential of the Site (USEPA, 1993b).

TI determinations are typically made when a final site decision document (such as a ROD) is being developed. Pre-decision or "front end" TI determinations may be made if supported by detailed site characterization and data analysis that focus on that information which is most critical in determining the limitations to groundwater restoration (USEPA, 1993a).

8.3.1.3 DNAPLs

Sites where DNAPLs are present are more likely to require TI evaluations than sites with other types of contaminants. Three areas that should be delineated at DNAPL sites are (1) the *DNAPL entry location* – areas where DNAPL was released, (2) the *DNAPL zone* – that portion of the subsurface containing free-phase or residual DNAPL, and (3) the *aqueous contaminant plume* – the portion of the site which contains organic chemicals in the dissolved phase (See Figure 8-2) (USEPA, 1993a). Characterization and delineation of the DNAPL zone is critical for design of the remedy and for evaluation of the restoration potential of the site. This may be difficult at sites with complex geology or waste disposal practices.

USEPA strongly recommends a phased approach for DNAPL sites. Short term goals would include containment of the aqueous contaminated plume and removal of DNAPL sources if possible. Long term objectives for a DNAPL zone would be to remove the free-phase, residual and vadose phase DNAPL to the extent practicable, and to contain the DNAPL sources that cannot be removed. USEPA expects the aqueous contaminant plume outside the DNAPL zone to be restored to the required cleanup levels (USEPA, 1993a).

8.3.1.4 Components of a Technical Impracticability Evaluation

A TI evaluation should include the following components, based on site specific information and analyses:

1. The specific ARARs or media-specific cleanup standards (i.e., the specific contaminants) for which TI determinations are sought. Such contaminants should include only those for which attainment of the required cleanup levels is technically impracticable.
2. The spatial area (i.e., the horizontal and vertical extent) over which TI decisions will apply (referred to as the *TI zone*). The potential to spatially restrict the TI zone will depend on the ability to delineate and contain the non-removable subsurface contamination sources and restore those portions of the aqueous plume outside of the source containment area.
3. A conceptual site model that describes the site geology, hydrogeology, and groundwater contamination sources, transport, and fate. Information should be presented that specifically defines the contamination problem to facilitate analysis of site restoration potential.
4. An evaluation of the restoration potential of the site, including data and analyses that support an assertion of TI from an engineering perspective. At a minimum, this should generally include:
   a. A demonstration that contamination sources (including subsurface NAPLs) have been identified and have been or will be removed and contained to the extent practicable.

USEPA expects that all reasonable efforts will be made to identify the location of source areas, understanding that locating some sources, like DNAPLs, may be impracticable. Where complete source removal or treatment is impracticable, use of migration controls or containment measures should be considered to at least enable restoration of those portions of the aquifer outside of the containment zone.

b. An analysis of the performance of any ongoing or completed remedial actions. See Figure 8-3 for examples of remedy performance data that should be provided.

c. Predictive analyses of the timeframes necessary to attain required cleanup levels using available technologies. No single timeframe can be specified during which restoration must be achieved to be considered technically practicable. However, very long timeframes (e.g., greater than 100 years) may be indicative of hydrogeologic or contaminant-related constraints to remediation.

d. A demonstration that no other remedial technologies could feasibly attain the cleanup levels at the site within a reasonable timeframe. These demonstrations should include: a review of technology literature; a screening of candidate technologies to identify those that are potentially applicable; and a site-specific analysis of the capabilities of any of the applicable technologies to achieve the required cleanup standards. This last step can be performed using *paper studies*[11], site-specific models, treatability studies, or pilot tests.

5. Cost estimates for existing or proposed remedial options including construction, operation and maintenance costs. A remedial alternative may be determined to be technically

[11] Use of technical literature and published screening matrices applied to site-specific conditions.

impracticable if the cost of attaining the ARAR-required cleanup standards were inordinately high.

(USEPA, 1993a)

8.3.1.5 Alternative Remedial Strategies

Lastly, the guidance document specifies that an alternate remedial strategy needs to be established where complete restoration is technically impracticable. Alternate remedial strategies need to address the following types of problems at contaminated groundwater sites:

1) Prevention of exposure to contaminated groundwater using institutional controls
2) Remediation or at least containment of contamination sources
3) Remediation of aqueous contaminant plumes outside of the containment areas

The inability to contain the sources or other technical constraints may make plume restoration technically impracticable. In such cases, options for alternative remedial strategies include (1) hydraulic containment of the leading edge of the plume, (2) establishment of less-stringent cleanup levels that would be actively sought throughout the plume, and (3) natural attenuation or natural gradient flushing of the plume. The guidance document states, however, that natural attenuation or flushing is most likely to be appropriate "where the affected groundwater is not a current or reasonably expected future source of drinking water, and groundwater discharge does not significantly impact surface water or ecological resources," (USEPA, 1993a, p. 21).

8.3.2 Application of Guidance to Central Area

A matrix is presented in Table 8-2 in which the work presented in BUG's Phase 1A Report is compared against the TI evaluation components described in the guidance document. A summary of the additional data that is needed to complete the TI evaluation is also included in Table 8-2.

Table 8-2 Application of Technical Impracticability Guidance to Central Area Aquifer

Technical Impracticability (TI) Evaluation Components	**Assessment of BUG's Phase 1A Report against TI Components**	**Additional Work Required to Complete TI Evaluation**
1. Identify specific contaminants for which TI determination are sought	Not done i/a/w[12] TI guidance. BUG identified a number of contaminants that exceeded the cleanup standards, but did not identify the specific contaminants that would make remediation technically impracticable.	- Evaluate a number of potential remedial technologies using site-specific models to identify those contaminants (if any) which could not be remediated to cleanup standards. Contaminants which could not be remediated would likely be dependent on DNAPLs being present.
2. Identify spatial area over which TI determinations will apply	Not done i/a/w TI guidance. BUG identified the entire Central Area as the TI zone. BUG stated that the Site's data indicate the presence of DNAPL, but they do not identify a DNAPL zone or specific areas where attainment of cleanup standards is technically impracticable.	- Perform additional site investigations to identify locations where residual or free-phase DNAPL is present. If DNAPLs are found, try to define the extent of their presence laterally and at depth (i.e., DNAPL zone). - Potentially identify the fractured bedrock as a TI zone.
3. Present conceptual site model	Partially meets the requirements of the TI guidance. The conceptual site model presented in the Phase 1A thoroughly depicts the geology, hydrogeology, and nature and extent of contamination in the Central Area. BUG also present their evaluation of the potential for restoration of the Central Area, but this evaluation is incomplete as required by the TI guidance.	- Perform another round of groundwater sampling in the Central Area to get an up-to-date picture of the nature and extent of contamination in the Central Area. - Update the conceptual site model to include the results from any additional investigations. Include any other information that could be used to evaluate the restoration potential of the Central Area.

12 i/a/w - in accordance with

Technical Impracticability (TI) Evaluation Components	Assessment of BUG's Phase 1A Report against TI Components	Additional Work Required to Complete TI Evaluation
4. Evaluation of the Restoration Potential for the Site including:		
a. Demonstrate that sources have been identified	Meets most of the requirements of the TI guidance. The five Source Areas have been identified in the ROD and other Site documents. In the Phase 1A Report, other sources for primary site contaminants (cVOCs) within the Aberjona River watershed (but outside the Site boundary) are identified. Sources for other contaminants (non-cVOCs such as benzene, naphthalene and sulfates) within the Site boundary are also identified. However, no other sources for cVOCs nor DNAPL areas are defined in the Central Area.	- Update the database of potential sources which could impact the groundwater in the Central Area. Specifically look for DNAPL and sources of cVOCs within the Site boundary.
b. Present analysis of performance of ongoing remedial actions	Meets most of the requirements of the TI guidance. When the Phase 1A was written, remediation systems at the Grace and Unifirst properties had been operational for 1 year. An evaluation of the two treatment systems' impacts on portions of the Central Area was included in the Phase 1A. This evaluation would need to be updated once remediation is performed at all five Source Areas. Note - only Olympia is not performing any groundwater remediation.	- Evaluate the performance of on-going and completed remedial actions. - Determine the impact of remedial actions on the hydrogeology and extent of contamination in the groundwater in the Central Area.
c. Predict timeframe to achieve cleanup levels	Not done.	- Evaluate a number of potential remedial technologies using site-specific models, pilot tests, and/or treatability studies to identify the time required to achieve cleanup levels for each of the primary site contaminants. - For specific technologies, identify those contaminants which would take significantly longer than other contaminants to be remediated to cleanup levels.

Technical Impracticability (TI) Evaluation Components	Assessment of BUG's Phase 1A Report against TI Components	Additional Work Required to Complete TI Evaluation
d. Demonstrate that no other remedial technologies would be effective	Incomplete. The Phase 1A Report only indicates that pumping from the Central Area aquifer would be ineffective due to the effect pumping would have in infiltrating surface water from the River and wetlands. No other technologies were evaluated.	- Evaluate potential remedial technologies by doing a study comparable to a Feasibility Study. - Use site-specific models, pilot tests, and/or treatability studies to determine whether any remedial technologies or strategies would be capable of achieving groundwater restoration in the Central Area.
5. Present cost estimates	Not done.	- Develop present worth cost estimates that include construction and O&M costs for potential remedial technologies as would be required as part of a Feasibility Study. - Specifically identify costs for technologies that would be inordinately high, thus making use of that technology technically impracticable.
Present Alternative Remedial Strategies	BUG propose continued natural flushing of the Central Area aquifer, but present limited evidence as to its effectiveness. BUG do not present any specific evaluation of other remedial or containment technologies that could be used at the Central Area, nor do they propose less-stringent cleanup levels.	- Should it be determined that it is technically impracticable to remediate the primary site contaminants in the groundwater at the Central Area to drinking water standards, propose an approach for actively remediating the Central Area consistent with the TI guidance for Alternative Remedial Strategies.

8.3.3 Conclusions on Technical Impracticability

Results from the Capstone Group's evaluation of remediation alternatives indicate that remediation could be performed at the Central Area within a reasonable timeframe (i.e., less than 20 years for in-well air stripping), and at a cost ($9 to $14 million) that is comparable to other Superfund groundwater remediation projects (See Section 7). Based upon our findings, there is a strong potential for groundwater restoration in the Central Area, thus a determination of technical impracticability would not be justified.

However, additional investigations could produce data that support a finding of technical impracticability, at least for a portion (e.g., the bedrock) of the Central Area aquifer. A key component affecting technical impracticability is the presence of DNAPL. While there have been instances where DNAPL and very high concentrations of Site contaminants were found at the Source Areas, the contaminant concentrations in the Central Area are more indicative of an aqueous (dissolved) contaminant plume. Since most of the sites where USEPA has determined that groundwater restoration is technically impracticable have DNAPLs present (USEPA, 1993a), the extent of DNAPL (if any) in the Central Area needs to be assessed before a final determination of technical impracticability can be made.

Even in the presence of contaminant-related factors (e.g., DNAPLs), or hydrogeological factors (complex and dense geology) making remediation for a portion of the site (the TI zone) technically impracticable, some groundwater remediation to MCLs would likely be warranted for the areas outside of the TI zone. Alternatively, less stringent, site-specific cleanup levels can be considered for the TI zone, the aqueous contaminant plume, or both. In order to support a determination of technical impracticability, one would need to address each of the evaluation components cited in the TI guidance and identified in Section 8.3.1.4. There is insufficient information presently available to support BUG's determination of technical impracticability.

9

9. DATA GAP ASSESSMENT

In conjunction with the assessments, screening, and evaluations that were presented in Section 3 through 8, a number of data gaps were identified that need to be filled in order to complete the site characterization and evaluation of remedial alternatives. In this section of the report, the key data gaps for the Central Area are presented by the section of the report where the data gaps were identified.

At the end of this section, a table (Table 9-1) is provided in which the data gaps are grouped into three general types, (1) data to better characterize the hydrogeology and geology, (2) data to better characterize the nature and extent of contamination, and (3) data needed to characterize treatment technologies and alternatives. Grouping of data gaps into 'types' was performed to facilitate presentation of this information; however, data gaps could be placed under more than one type.

Table 9-1 also includes suggestions on how the data should be used and when the data should be collected. Note that data gaps identified herein specifically do not relate to the Southwest Properties.

Hydrogeological Setting

The groundwater model developed for the Site by USGS in 1989 was recently updated by Ms. Maura Metheny (1998) of Ohio State University. Soil borings and monitoring wells installed through 1997 were used to create a groundwater model that more accurately maps and defines the Site as compared to the USGS model. The Ohio State Model has been used to simulate the effects of pumping wells G & H under a number of conditions, and the effect when there is no pumping at the Site. However, the model has not been updated to reflect current Site conditions where groundwater extraction is on-going at three of the Source Areas. This is a data gap. An updated groundwater model would be an effective tool to help evaluate the effect of Source Area pumping, especially Unifirst well UC22, on groundwater movement in the Central Area.

Contamination of Groundwater in the Central Area

The most recent complete data set for groundwater contaminants in the Central Area is from sampling performed in 1993. More recent data should be used to depict the extent of contamination that is currently present in the Central Area. This information could then be used to refine the target remediation area and adjust the concept designs for evaluation of the in-well air stripping and pump & treat alternatives (see below).

While identifying the remediation area and assessing those wells that contained cVOCs in groundwater above MCLs, it was noted that there were very few bedrock monitoring wells in the Central Area. Only three bedrock monitoring wells are located within the deep Aberjona Valley Aquifer as mapped on Figure 4-8 (compared to 17 wells in the unconsolidated deposits). Additional monitoring wells are needed to assess the extent of contamination in the bedrock of the Central Area – especially in the portion of the Aberjona Valley Aquifer between well H and Salem Street (where there are no bedrock monitoring wells).

Evaluation of Phase 1A Report and Consent Decree Requirements

By reviewing the Phase 1A Report against the requirements of the CD, it was noted that most of the data associated with remedial technologies that was specified in the CD were not collected during the Phase 1A Investigations. Additional data that are needed includes evaluations of the physical and chemical waste characteristics (e.g., biological activity and methane) that could support an analysis of potential remediation technologies, and evaluation of waste mixtures and partitioning of contaminants in groundwater (e.g., presence of DNAPL), to help determine the persistence and mobility of contaminants.

Identification, Screening, and Evaluation of Technologies

The severity of bedrock fractures and extent of the hydraulic connection between unconsolidated aquifer and the bedrock need to be thoroughly investigated to complete the screening of potential technologies and process options. An accurate understanding of the bedrock condition (i.e., extent and depth of fractures) is a major factor in the screening of technologies. Without knowing the condition of the bedrock, the technical implementability and effectiveness of process options that involve injection of water, oxidants, and nutrients (e.g., in-situ chemical oxidation, enhanced bioremediation and flushing, and containment technologies) cannot be accurately evaluated.

Additional data need to be collected for hardness, iron concentration, and concentration of grease and oil in the groundwater. These parameters affect the technical implementability and effectiveness of in-situ and ex-situ physical/chemical treatment technologies such as in-well air stripping, ex-situ air stripping, ion exchange, and filtration.

Evaluation of Selected Remediation Alternatives

Four remediation alternatives that have been evaluated are No Action, Monitored Natural Attenuation, Pump & Treat, and In-Well Air Stripping. Site specific data used to evaluate these alternatives were collected more than six years ago. Therefore, to better evaluate the effectiveness of these alternatives, data on the nature and extent of the contaminants in the groundwater should be updated. Specific data that should be updated includes the following:

- Extent of the primary contaminants (PCE and TCE). The extent of PCE and TCE contamination present in the groundwater has a major impact on the design (size and performance) of ex-situ air stripping, in-well air stripping, and off-gas treatment units. Adjustments to the designs of these alternatives would similarly affect the capital and O&M cost of these alternatives.

- Assessment of natural attenuation parameters. A groundwater monitoring program needs to be performed to assess the presence of natural attenuation parameters in groundwater (e.g., hydrogen, methane, ferrous iron, and sulfide). An evaluation of destructive natural attenuation mechanisms cannot be done adequately without having these parameters. Samples for natural attenuation parameters should be collected twice a year for two years.

- Extent of iron and hardness and suspended solids. High concentrations of iron and hardness in groundwater may cause fouling of ex-situ and in-well air strippers. For example, if the concentration of iron is greater than 5 ppm and hardness of groundwater is greater than 800 ppm, ex-situ air stripping will not work effectively without using some kind of pretreatment system. If the groundwater contains high levels of iron, hardness, and suspended solids, periodic flushing for in-well air stripping and groundwater pretreatment for ex-situ air stripping will be necessary. Additional monitoring for iron, hardness, and suspended solids in the remediation area is necessary.

In addition to updating nature and extent of the contaminants in bedrock, investigation of the bedrock itself should be conducted. The information previously mentioned for screening could be combined with this investigation to support the detailed evaluation of remediation alternatives. The investigation should be focused on determining the (1) existence and extent of DNAPLs, and (2) hydraulic connection between the fractured bedrock and the unconsolidated aquifer. The existence of DNAPLs in fractured bedrock affects the evaluation of effectiveness and reduction of toxicity, mobility, and volume criteria for the monitored natural attenuation, pump & treat, and in-well air stripping alternatives. More information on the hydraulic connection between the unconsolidated aquifer and the bedrock is needed to assess the performance of the pump & treat and in-well air stripping alternatives.

To ultimately evaluate the effectiveness of the pump & treat and in-well air stripping alternatives, the technologies must be physically applied to the Site. The effectiveness of pump

& treat can be assessed using the updated groundwater model, but the most accurate method of determining the hydrogeological impact of pumping is to perform a pump test. A pilot test using a single in-well stripper operating at the design capacity is needed to determine how well this alternative will work at the Site.

Feasibility of Remediating the Central Area Aquifer

To support a waiver of the ARARs (such as MCLs) based on technical impracticability, a technical impracticability (TI) evaluation consistent with the, *Guidance for Evaluating the Technical Impracticability of Ground-Water Restoration* (USEPA, 1993a) should be conducted. Since a key component in a TI evaluation is to determine the effectiveness of potential remedial technologies, the data gaps presented above would also apply to this evaluation. An additional data gap specific to the TI evaluation is data regarding the performance of on-going remedial actions in the Source Areas. The effectiveness of Source Area treatment systems (e.g., air sparging at Wildwood) and their impacts on the Central Area (e.g., demonstrating Unifirst's capture of groundwater in the Central Area) should be assessed. Additional data may be needed to do these assessments.

Table 9-1 Summary of Data Gaps for the Central Area

Data Gap	**Rationale**	**Reference**[1]	**Suggestions on Implementation and Use**
Hydrogeology/Geology-Related:			
Update Ohio State University Groundwater Model (Metheny, 1998).	Obtain Metheny's comprehensive groundwater model for the Site and update it by inputting characteristics (e.g., extraction wells) from each of the Source Area treatment systems. Once re-calibrated, this tool could be used to assess the impact of Source Area extraction systems on the Central Area and to simulate the performance of remedial alternatives.	3.0; 7.0; 8.3.2; CD (p. 28 of Attachment 2); Phase 1A Report (p.2-21)	Once remedial design has been completed at each of the Source Areas, suggest that the model be used to facilitate preparation of the Combined Effects Reports. The model could then be used to help scope the RI Phase 1B field program
Conduct a pump test.	Provide information that can be used to design an extraction system that would maximize VOC removal and minimize potential contaminant infiltration from the River.	7.5 & 7.6; CD (p. 28 of Attachment 2)	Should be addressed in the RI Phase 2 field program.
Related to Nature & Extent of Contamination:			
Perform another complete round of groundwater sampling.	Data would be used to get an updated picture of the contaminant concentrations in the groundwater (last full sampling round was in 1993).	4.0; 8.3.2	This should be the top priority for data collection since the sampling results would likely impact further scoping of the RI/FS. Suggest that this be done prior to the full RI Phase 1B field program.

Data Gap	Rationale	Reference[1]	Suggestions on Implementation and Use
Perform periodic (e.g., quarterly) groundwater monitoring over a one- to two-year period.	Assuming contaminants are still present in the groundwater above cleanup levels, periodic sampling could be used to determine the changes in the groundwater due to seasonal variability, evaluate impacts from Source Area treatment systems, help calibrate the groundwater model, and assess the viability of natural attenuation and flushing.	7.3 & 7.4; 8.3.3; CD (p. 67 of Attachment 2)	Suggest that this be done as part of the RI Phase 1B field program.
Evaluate waste mixtures and partitioning of contaminants between groundwater and unconsolidated deposits.	Will help determine the persistence and mobility of contaminants at the Site. Information could also be used to quantitatively estimate the time required to achieve cleanup goals using different remediate technologies.	5.3; CD (p. 63 of Attachment 2)	Suggest that this be done as part of the RI Phase 1B field program.
Determine extent of DNAPL or other sources.	Will be used to define the DNAPL Zone (if any) and to determine the contaminants and areas to which Technical Impracticability status could be applied.	7.0; 8.2.2	Suggest that this be done as part of the RI Phase 1B field program.
Install additional bedrock monitoring wells	Will be used to better assess the nature and extent of contamination in the bedrock, to help in the DNAPL zone evaluation, and to assess the hydraulic connection between the unconsolidated deposits and the bedrock. Specifically, the southern portion of the Aberjona Valley Aquifer (between well G and Salem Street) should be further characterized to better define the remediation area.	4.3; 6.0; 8.2.2	Suggest that this be done as part of the RI Phase 1B field program.

Data Gap	Rationale	Reference[1]	Suggestions on Implementation and Use
Related to Treatment Technologies or Alternatives:			
Evaluate appropriate physical and chemical waste characteristics.	Specifically evaluate those characteristics (e.g., hardness, methane, biological activity) that support the analysis of potential remediation technologies and alternatives.	5.3; CD (p. 63 & 66 of Attachment 2)	Suggest that this be done as part of the RI Phase 1B field program.
Gather data regarding the performance of on-going remedial actions in the Source Areas.	Evaluate Source Area treatment systems (e.g., Wildwood's air sparging system) as to their applicability to the Central Area and their impacts on the Central Area (e.g., Unifirst's capture of groundwater).	8.2.2	Include this requirement in the reporting requirements for Source Area treatment systems. Collect any supplemental data as part of the RI Phase 1B field program.
Collect and analyze data for additional groundwater parameters including: iron, manganese, and calcium concentrations, hardness, suspended solids, dissolved solids, total solids, alkalinity.	Vendors require these parameters for the design of pump & treat and in-well air stripping systems. High concentrations of these contaminants may cause fouling of equipment, therefore leading to inefficient remediation.	7.5, 7.6, 7.7 & 7.8	This data gap should be addressed in the RI Phase 1B field program.
Collect data to evaluate the potential for natural attenuation. Specific groundwater parameters that need to be analyzed for include: hydrogen, methane, ferrous iron, and sulfide.	The parameters listed on the left are needed in order to complete an evaluation of whether natural attenuation is taking place in accordance with USEPA natural attenuation guidance.	7.3 & 7.4	This data gap should be addressed in the RI Phase 1B field program.

Data Gap	Rationale	Reference[1]	Suggestions on Implementation and Use
A pilot test must be conducted if in-well air stripping is implemented to determine the effect of this technology on the groundwater.	Vendors require conducting a pilot study to determine actual radius of influence and air/water ratio, which controls effectiveness. In addition, circulation flow rate and vertical/horizontal groundwater flow should be monitored during the operation of a pilot study in order to more accurately predict the duration of the remedy.	7.7 & 7.8	This data gap should be addressed in the RI Phase 2 field program.

[1] All references are to sections of this report unless otherwise noted.

10

10. SUMMARY OF FINDINGS

Presented in this Section is a summary of the findings from Sections 5 – Evaluation of Phase 1A Report and Consent Decree Requirements, Section 6 – Identification, Screening, and Evaluation of Technologies, Section 7 – Evaluation of Selected Remediation Alternatives, and Section 8 – Feasibility of Remediating the Central Aquifer.

Evaluation of Phase 1A Report and Consent Decree Requirements

The RI/FS Work Plan and Phase 1A Report – as prepared by Beatrice, Unifirst, and Grace (BUG) – was evaluated to determine whether the specific objectives and recommendations established in the CD for these two documents have been met. The focus of this evaluation was on those requirements related to remedial alternatives. The two documents were reviewed and compared to the CD's requirements. Interviews were also conducted with EPA and MADEP personnel and a consultant for Unifirst. From this evaluation, it is clear that BUG's focus for the Phase 1A Investigations was to collect data on the nature and extent of contamination in the Southwest Properties and to lay the groundwork for demonstrating the technical impracticability of remediating the Central Area Aquifer. Therefore, most of the CD requirements for studies related to remedial technologies and alternatives (e.g., identify potential remedies and technologies that could be applied at the Site and identify the critical data needed to evaluate such technologies) were deferred to a later phase in the RI/FS process. BUG did this with the hope that the Phase 1A Report would be sufficient to justify no groundwater remediation in the Central Area. A summary of the specific requirements from the CD that were evaluated against BUG's documents is provided in Table 5-1.

Identification, Screening, and Evaluation of Technologies

Fifteen technology-types (chemical, physical, thermal, and biological processes) and forty-one specific process options within these technology types were initially identified for the remediation of Central Area groundwater. Fourteen process options were eliminated by screening against technical implementability (not suitable for the type of volatile contaminants or for the Central Area). Table 6-3 presents the twenty-seven process options that could potentially be applied to the Central Area.

These process options consisted of in-situ and ex-situ chemical processes, physical and biological processes, and innovative and traditional processes. A quantitative scoring system was used to facilitate the selection of technologies. Technologies were selected that represented diverse response actions. Finally, process options with the highest score within the same category of response action were combined in order to develop four alternatives: no action, monitored natural attenuation, pump & treat with air stripping, and in-well air stripping (See also Table 6-7).

Evaluation of Selected Remediation Alternatives

The Capstone Group evaluated the four groundwater remediation alternatives: no action, monitored natural attenuation, pump & treat with air stripping, and in-well air stripping. This evaluation was performed by applying a concept design of the four alternatives to this specific Site. Following is a brief summary of the technical criteria evaluation that was done for the selected alternatives:

- Short-Term and Long-Term Effectiveness: In-well air stripping and pump & treat with an air stripping process effectively removes volatile organics from groundwater media and transfers the contaminants to an air stream where the volatile organics are removed by an activated carbon filter. These remedial alternatives effectively and permanently treat groundwater while causing minimal impacts of the community and the environment adjacent to the Site. For monitored natural attenuation, the Capstone Group could not find adequate evidence (e.g., no breakdown products of TCE and PCE or sufficient other indicators) in the existing data that natural biodegradation processes were occurring at a rate to effectively remediate the Central Area aquifer.
- Reduction of Toxicity, Mobility, and Volume of Contaminants: The pump & treat and in-well air stripping alternatives will produce a reduction in toxicity, mobility, and volume of contaminants. The no action and monitored natural attenuation alternatives may reduce the toxicity of the contamination via dilution, but the reduction in mobility and volume is not significant. However, no monitoring data would be available to substantiate the impacts of the no action alternative.
- Implementability: All four alternatives can be implemented in the Central Area to remediate groundwater. For no action, monitored natural attenuation, and pump & treat, no significant obstacles (e.g., lack of vendors or materials) were found that would preclude remediation of the Central Area. However, in-well air stripping has a limited number of qualified vendors, which will make the logistics of implementation more difficult from both an equipment availability and a human resources point of view.

- Cost: Total present value cost (using a five percent discount rate) for a the length of time to reach remedial goals (maximum time 30 year) for each alternative is $ 0.05 million for 30 years of no action, $ 0.7 million for 30 years of monitored natural attenuation, $ 9.1 million for 30 years of pump & treat, and $13.7 million for 15 years of in-well air stripping.
- Protection of Human Health and the Environment: In-well air stripping and pump & treat with an air stripping process are protective of human health and the environment. The alternatives achieved adequate protection and eliminate site risks through treatment and engineering. The monitored natural attenuation and no action alternatives are protective of human health because institutional controls will address the primary exposure pathway (i.e., groundwater ingestion and contact). However, no action and monitored natural attenuation are not protective of the environment because contaminated groundwater will continue to discharge into the river.

A comparative analysis of each of the four alternatives is presented in Table 10-1.

The conclusion from this evaluation is that groundwater remediation at the Central Area is technically feasible (subject to confirmation by more detailed evaluations and site investigations using models and pilot tests).

Table 10-1 Comparative Analysis of Selected Remedial Alternatives

Criteria	No Action	Monitored Natural Attenuation Assessment	Pump & Treat with Air Stripping Assessment	In Well Air Stripping Assessment
Short Term Effectiveness	No additional impact to community and environment. Remediation is expected to be over 30 yr., if ever, to reach cleanup levels. Institutional controls will be implemented.	Minimal impact to community, workers, and environment. Remediation time is high with > 40 yr. for unconsolidated deposits and > 200 yr. for bedrock. Institutional controls will be implemented.	Some impact on the community from construction. Possible exposure to workers during construction. Possible impact on environment and wetlands but this should be limited due to low extraction rate and discharge of treated water to the River/wetlands. Remediation is estimated to take about 60 years.	Some impact on the community from construction. Possible exposure to workers during construction. Adverse impact to the wetlands and River will be minimal. Remediation is estimated to be 15 years.
Long Term Effectiveness	Minimal human contact via institutional controls. Risks to the environment would not be reduced to acceptable levels. Alternative likely to be replaced.	Minimal human contact via institutional controls. Monitoring of alternative should be conducted and is reliable. Alternative likely to be replaced.	Alternative is well documented and a proven technology. Potential for future exposure of groundwater to the community and environment will be minimal due to reduced concentrations of PCE and TCE. Individual treatment components may need to be replaced.	Alternative is innovative but has been implemented successfully to remediate cVOCs. Monitoring of alternative should be conducted and is reliable. Potential for future exposure of groundwater to the community and environment will be minimal due to reduced concentrations of PCE and TCE.

Criteria	No Action	Monitored Natural Attenuation Assessment	Pump & Treat with Air Stripping Assessment	In Well Air Stripping Assessment
Reduction of TMV of Contaminants Through Treatment	Reduction in toxicity, mobility, and volume due to natural attenuation is not significant. Only non-destructive natural attenuation will be occurring; the toxicity, mobility, and volume of the contaminant will not decrease.	Reduction in toxicity, mobility, and volume due to natural attenuation is not significant. Only non-destructive natural attenuation will be occurring; the toxicity, mobility, and volume of the contaminant will not decrease.	Total and permanent removal in toxicity, mobility, and volume of contaminants.	Total and permanent removal in toxicity, mobility, or volume of contaminants.
Implementability	- The alternative can be implemented easily. - Degree of contaminant reduction to meet acceptance criteria is unknown and estimated. - Federal, State approval unlikely because remedial objective would not be met.	- Qualified vendors can easily monitor wells and analyze the samples. - Degree of contaminant reduction to meet acceptance criteria is unknown and estimated. - Equipment and resources readily available. - Federal, State approval unlikely because remedial objective would not be met.	- A pump test needs to be conducted to achieve the proper extraction rate. - Fouling of equipment may occur because of inorganics and high chlorides. - Equipment and resources readily available. - Approval from Federal, State, and local agencies would be likely.	- A pilot test needs to be conducted to achieve the proper extraction rate. - Fouling of equipment may occur because of inorganics and high chlorides. - Numbers of vendors are limited. - Approval from Federal, State, and local agencies would be likely.

Criteria	No Action	Monitored Natural Attenuation Assessment	Pump & Treat with Air Stripping Assessment	In Well Air Stripping Assessment
Cost	Capital Costs - None O & M Costs – None Review Costs - $53,000 Total PV Cost 30 yr. - $53,000 Future costs may be incurred.	Capital Costs - None O & M Costs - $600,000 Review Costs - $53,000 Total PV Cost 30 yr. - $720,000* Future costs may be incurred.	Capital Costs - $1,300,000 O & M Costs - $6,300,000 Review Costs - $53,000 Total PV Cost 30 yr. - $9,100,000* No future costs	Capital Costs - $4,400,000 O & M Costs - $7,000,000 Review Costs - $45,000 Total PV Cost 15 yr. - $13,700,000* No future costs
Protection of Human Health and the Environment	Protective of human health but not of the environment.	Protective of human health but not of the environment.	Alternative is protective of human health and the environment.	Alternative is protective of human health and the environment.

* Present Value cost which includes a 20% contingency

Abbreviations and Symbols
cVOCs – Chlorinated Volatile Organic Compounds
O&M – Operation and Maintenance
PV – Present Value
TMV – Toxicity, Mobility, and Volume

Feasibility of Remediating the Central Area Aquifer

The Capstone Group performed two focused evaluations of the feasibility of remediating the groundwater in the Central Area. The evaluations were performed by (1) evaluating the economic feasibility using MADEP criteria as defined in the MADEP comment's on the Phase 1A Report (Appendix B), and (2) evaluating the technical impracticability of groundwater restoration using the protocol established in the USEPA guidance document, *Guidance for Evaluating the Technical Impracticability of Ground-Water Restoration* (USEPA, 1993a).

Economic feasibility was determined by comparing the cost of groundwater remediation against the cost of obtaining water from a regional municipal water supply on a per 1000 gallon basis. Remediation of the groundwater in the Central Area would appear to be economically feasible since the costs for the in-well stripping ($13.7 million) and pump & treat ($9.1 million) alternatives are both less than the costs to continue to purchase the water from the MWRA over the next 30 years ($18.1 million).

The USEPA guidance document requires that an evaluation of technical impracticability (TI) address five components. These components include (1) identifying specific contaminants for which attainment of required cleanup levels is technically impracticable, (2) identifying areas over which TI decisions will apply, (3) developing a conceptual site model for the Site, (4) evaluating the restoration potential for the Site by mapping sources and evaluating potential remedial technologies, and (5) evaluating the cost to remediate the groundwater. The technical impracticability of groundwater restoration in the Central Area was evaluated by applying the information contained in the Phase 1A Report against the TI evaluation components. The results of this evaluation showed that only one (developing a conceptual site model) of the five TI evaluation components were satisfactorily addressed in the Phase 1A Report. See Table 8-2 for a detailed evaluation of the Phase 1A Report using the TI Guidance. Insufficient information is presently available to conclude that remediation is infeasible or technically impracticable as defined by the USEPA TI guidance.

Data Gap Assessment

Additional data and studies are needed to (1) better characterize the contamination in the Central Area, (2) complete the detailed analysis of alternatives, (3) make a final determination on the technical impracticability of remediating groundwater, and (4) meet the requirements specified in the CD. The Capstone Group identified three categories of data gaps – data related to the Site's hydrogeology and geology, the nature and extent of contamination at the Site, and selection of treatment technologies and alternatives. Additional hydrogeological data are needed to simulate and assess the current groundwater flow conditions in the aquifer and to determine optimal groundwater remedial system configurations. Additional data on the nature and extent of contamination are needed because the existing contaminant data set is over six years old and needs to be updated and because there is a lack of data in the bedrock. Information on treatment technologies and alternatives is needed because additional analytical parameters are needed to better evaluate remediation technologies, and because site-specific information (e.g., pilot tests) must be collected to complete the detailed evaluation of alternatives. See Section 9 and Table 9-1 for more detailed information.

11. RECOMMENDATIONS

The Capstone Group recommends the following additional work in the Central Area. Recommendations are presented in the general order in which they should be implemented.

1. Update the groundwater model. It is recommended that the Ohio State University 1998 groundwater model for the Site be updated by inputting characteristics (e.g., extraction wells) from each of the treatment systems currently in use at the Source Areas. After the model is re-calibrated, this tool could be used to evaluate the effectiveness of the Source Area remediation systems and simulate the performance of remedial alternatives in the Central Area.

2. Perform the work specified in the CD. The Capstone Group believes that the investigations and studies that were specified in the CD but were not completed as part of the RI Phase 1A investigation are critical to determining the best approach for remediating the groundwater in the Central Area. It is recommended that the investigations and studies outlined in the CD be completed. Any additional work to be performed at the Central Area should be included in the scope of the RI Phase 1B Investigations. The RI Phase 1B work should be performed after groundwater remediation systems at each of the five Source Areas (including Olympia) has been designed and after each of the Combined Effects Reports[13] have been completed.

[13] Combined Effects Reports are required submittals under the CD. The PRPs are to submit a report for each side of the River that assesses the combined effects and interactions of the full-scale groundwater extraction and treatment systems proposed or operating at each of the Source Area properties (USEPA, 1991).

3. Additional characterization of the bedrock. It is recommended that additional monitoring wells be installed in the bedrock. Additional bedrock wells are needed to complete the assessment of the nature and extent of contamination in the bedrock, and to help evaluate the extent of the DNAPL zone. Specifically, the southern portion of the Aberjona Valley Aquifer (between well G and Salem Street) should be further characterized to refine the area where remediation is required. The extent and depth of fractures in the bedrock and the hydraulic connection between the unconsolidated deposits and the bedrock needs to be assessed in more detail. This information is needed to determine the effectiveness of the pump & treat and in-well air stripping alternatives.

4. Determine existence and extent of DNAPLs. It is recommended that investigations to determine the presence, nature, and extent of DNAPL present in the Central Area be performed. The existence of DNAPL (as either a separate layer or residual DNAPL) is integral to a potential finding of technical impracticability of groundwater restoration. In addition, the presence of DNAPLs to any great extent could dramatically affect the performance and effectiveness of the monitored natural attenuation, pump & treat, and in-well air stripping alternatives evaluated by the Capstone Group.

5. Perform additional rounds of groundwater sampling. It is recommended that groundwater monitoring be performed in both the unconsolidated deposits and the bedrock because current data should be used for further evaluations of remediation alternatives. Additional groundwater analysis of PCE, TCE, and other primary contaminant identified in the ROD (cVOCs) is needed because the data set is six years old. In addition, monitoring for natural

attenuation parameters (e.g., hydrogen, sulfide, and methane) and treatment performance parameters (e.g., hardness, iron, and suspended solids) should also be included. As specified in the CD, sampling should be conducted quarterly for a period of one to two years.

6. Use screenings and evaluations of remediation alternatives as basis for further evaluations. It is recommended that the work performed by the Capstone Group be used as a starting point when performing additional RI/FS work in the Central Area. A thorough screening of the technologies and process options that are applicable to the Central Area has been performed. The information presented in Section 6 – Identification, Screening, and Evaluation of Technologies – should be used in the Phase 1 FS required under the CD. Each of the four alternatives evaluated for this project should be included in the detailed evaluation to be performed as part of the Phase 2 FS work. To fully evaluate the effectiveness of the pump & treat and in-well air stripping alternatives, a pump test and pilot test, respectively, would need to be performed as part of the RI Phase 2 field program.

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FIGURES

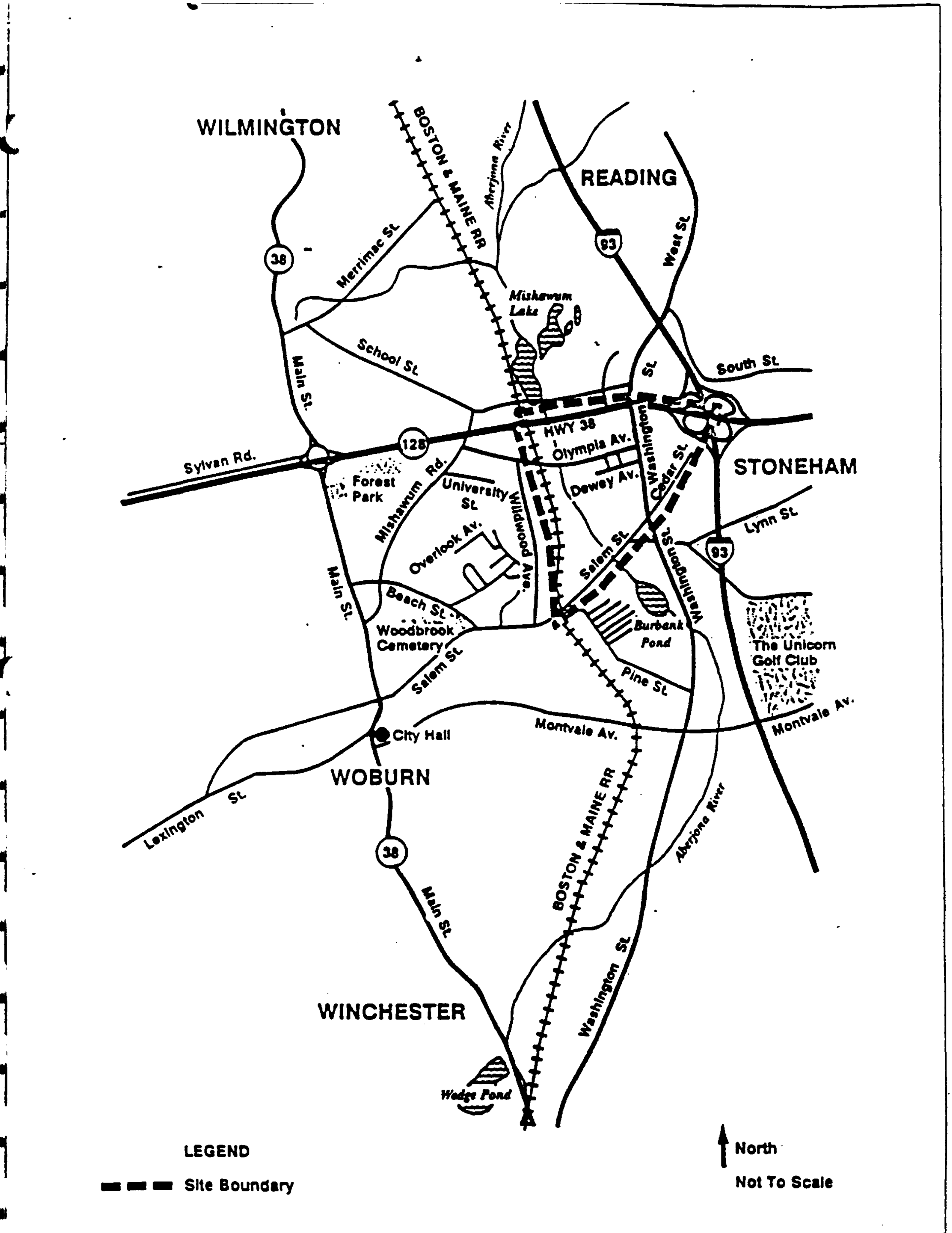


Figure 1-1 Site Location Map of the Wells G & H Site, Woburn, Massachusetts (Source: USEPA 1989, Figure 1)

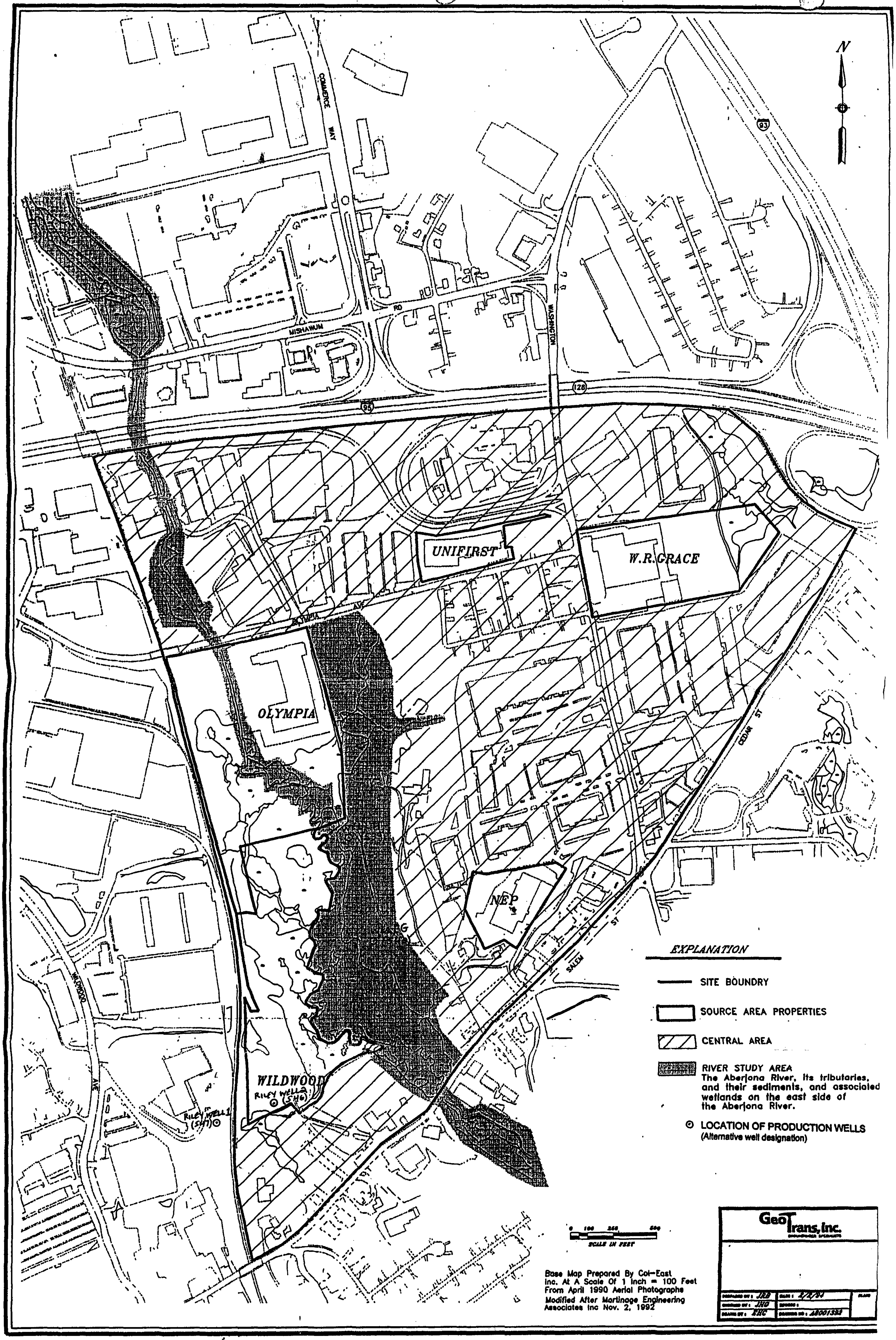


Figure 1-2 Location of Source Area Properties, Central Area, and River Study Area on Wells G & H Site (Source: GeoTrans & RETEC, 1994, Figure 1-1)

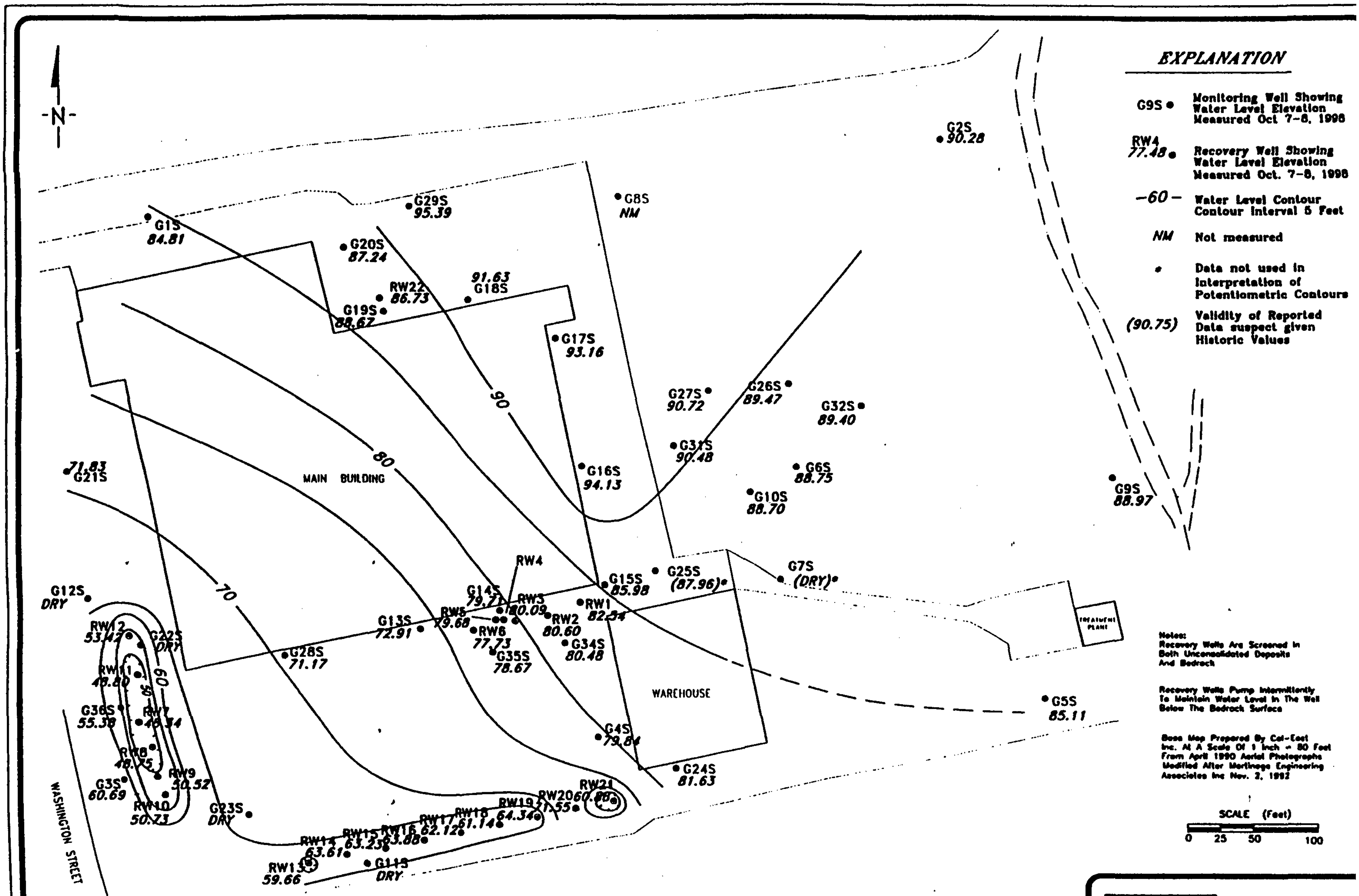


Figure 2-1 Groundwater Elevations and Well Locations on the Grace Property, Wells G & H Site
(Source: HSI GeoTrans, 1998, Figure 2-1)

HSI GEOTRANS
A TETRA TECH COMPANY
oct98.DWG

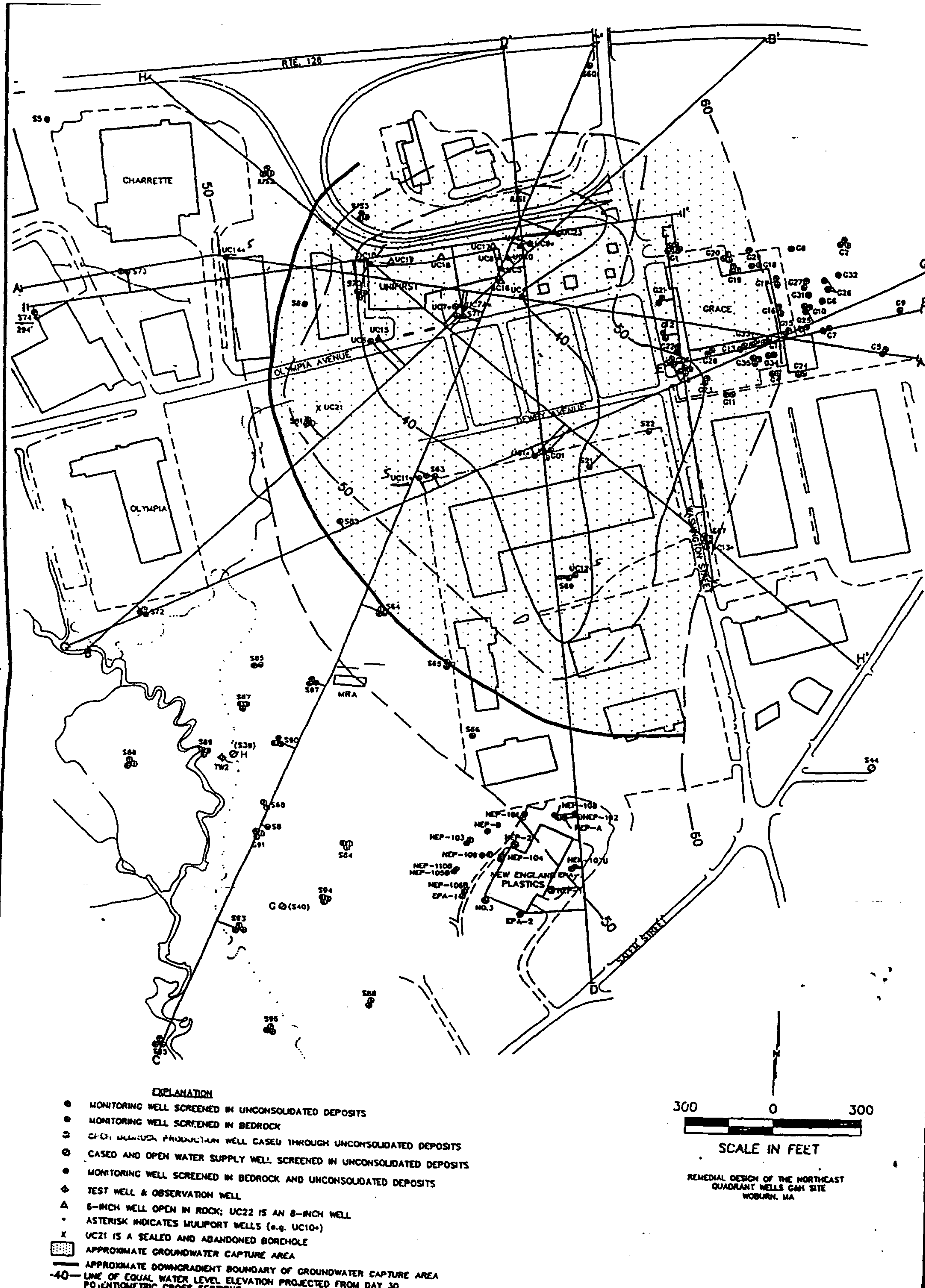


Figure 2-2 Estimated Capture Area of Well UC22, Wells G & H Site (Source: The Johnson Company, 1996, Figure 1)

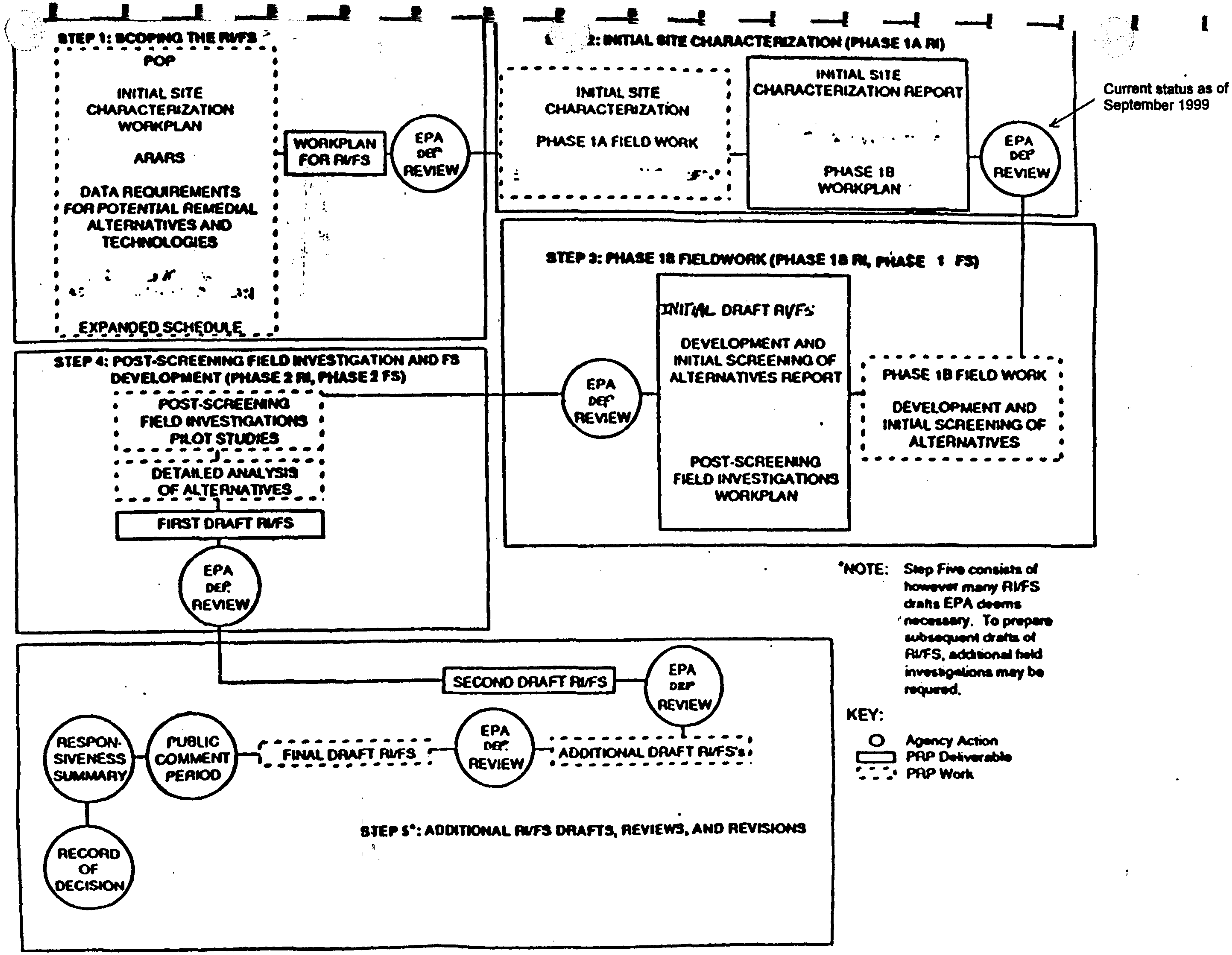
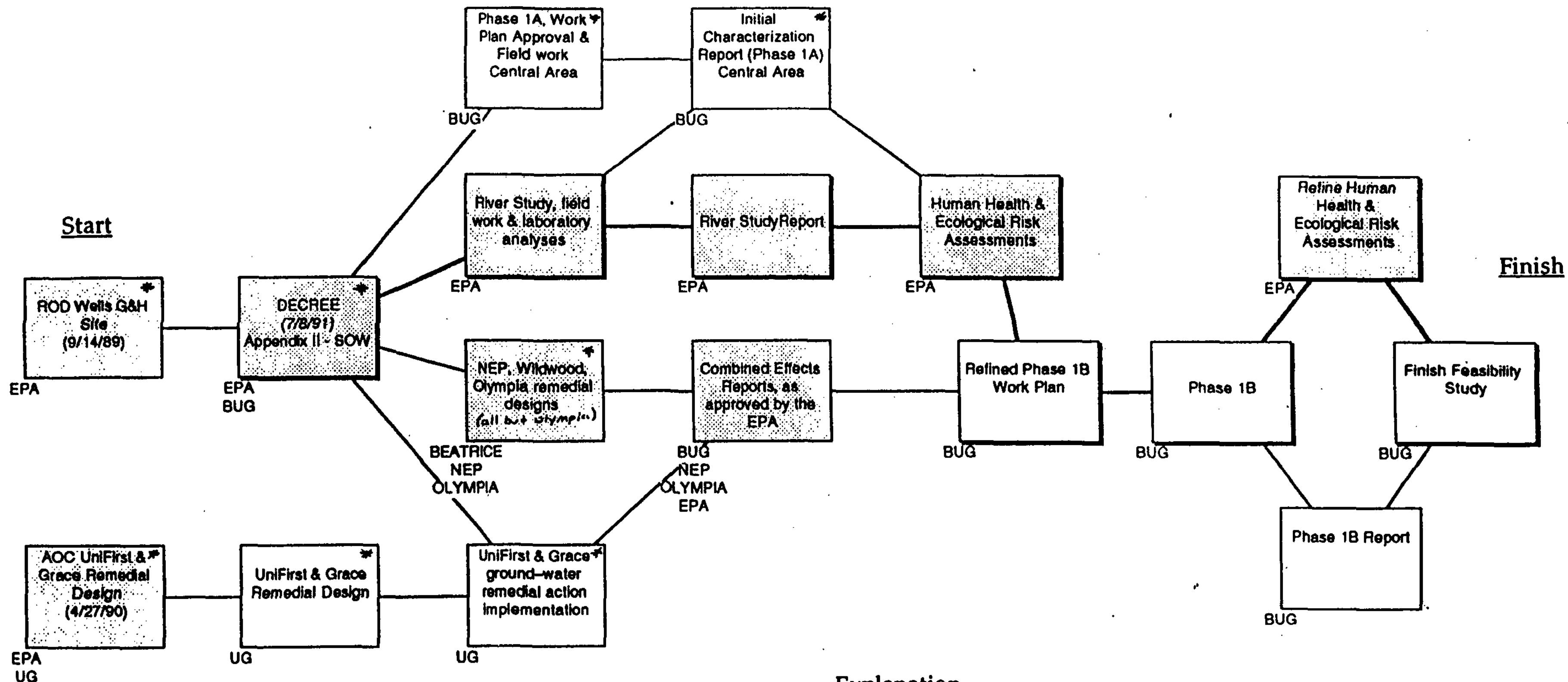


Figure 2-3 Flow Diagram of RI/FS Process to be Followed by PRPs Under the Consent Decree
(Source: USEPA, 1991, Figure 1)



Explanation

Abbreviations:

AOC: Administrative Order on Consent
BUG: Beatrice, UniFirst and Grace
NEP: New England Plastics
ROD: Record of Decision
UG: UniFirst and Grace

* Indicates tasks that have been completed as of September 1999

Note:

General tasks and dependencies for completion of the RI/FS are based on the December 4, 1991 meeting with the EPA, wherein Beatrice, UniFirst, & Grace and the EPA scheduled refinement of the Phase 1B Work Plan based on the findings of the Human Health and Ecological Risk Assessments and the Combined Effects Reports, as approved by the EPA.

Stippling indicates that Beatrice, UniFirst, & Grace do not control the schedule for execution of the task or only partially control it. Therefore, the schedule for completion of the RI/FS will be determined, in great part, by other Source Area Defendants and the EPA.

Figure 2-4 Schematic Timeline of Major Remedial Tasks for the Wells G & H Site (Source: GeoTrans, et al., 1992, Figure 1-2)

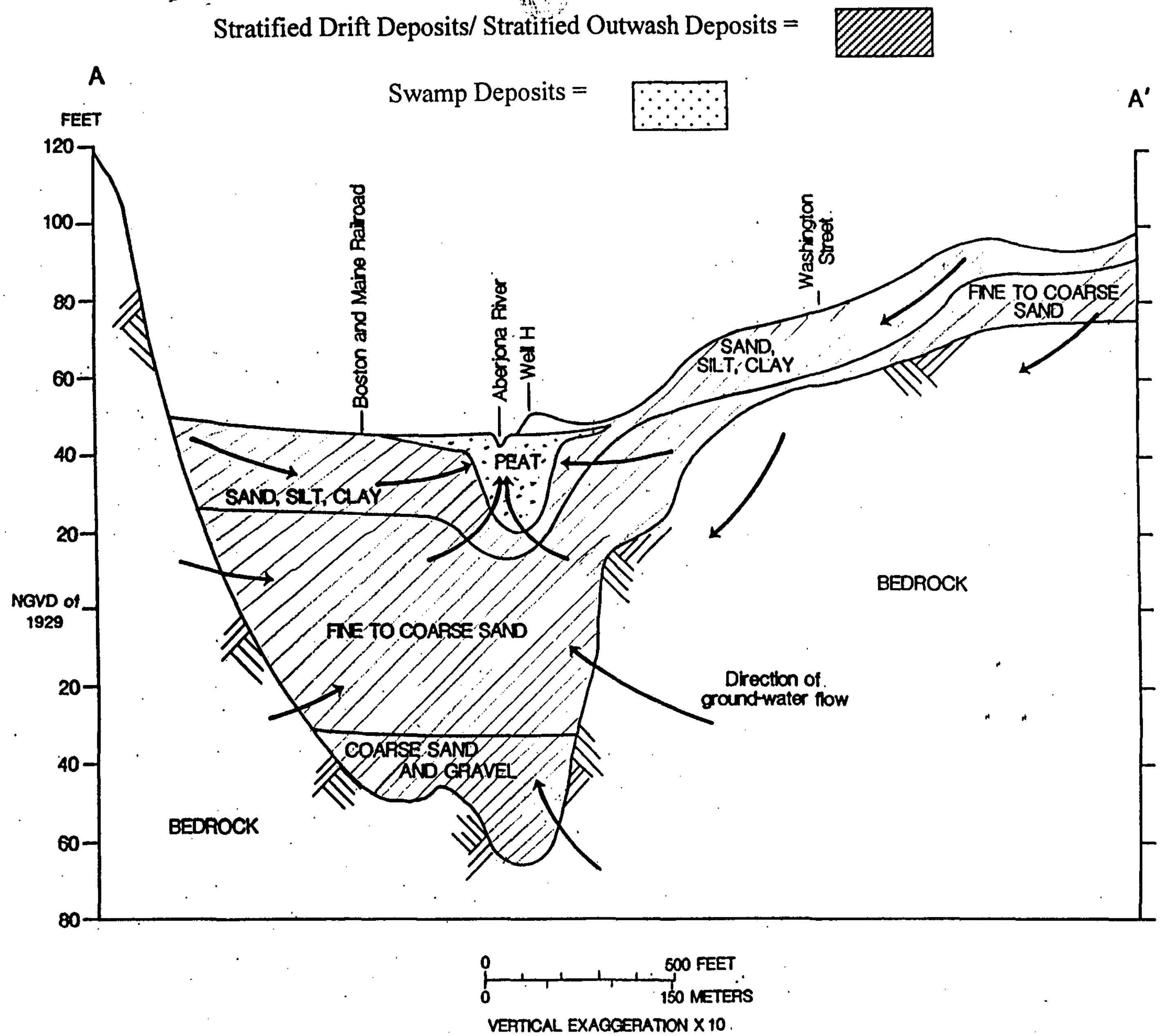


Figure 3-1 Depth of Geological Layers in the Central Area, Woburn, Massachusetts
(Source: Myette et al., 1987, Figure 4)

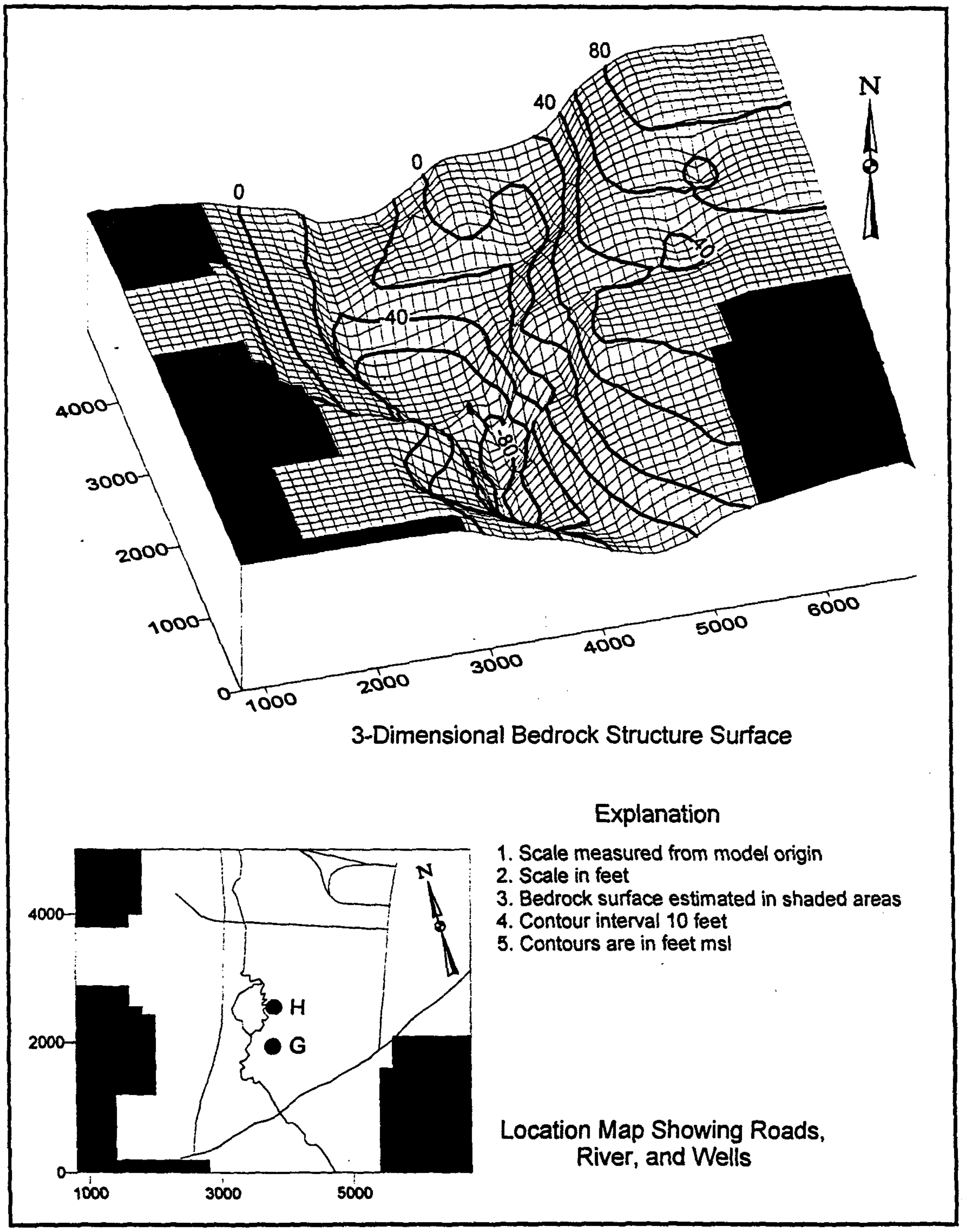


Figure 3-2 Structure Map of Bedrock Surface in the Central Area, Woburn, Massachusetts (Source: Metheny, 1998, Figure 4.5)

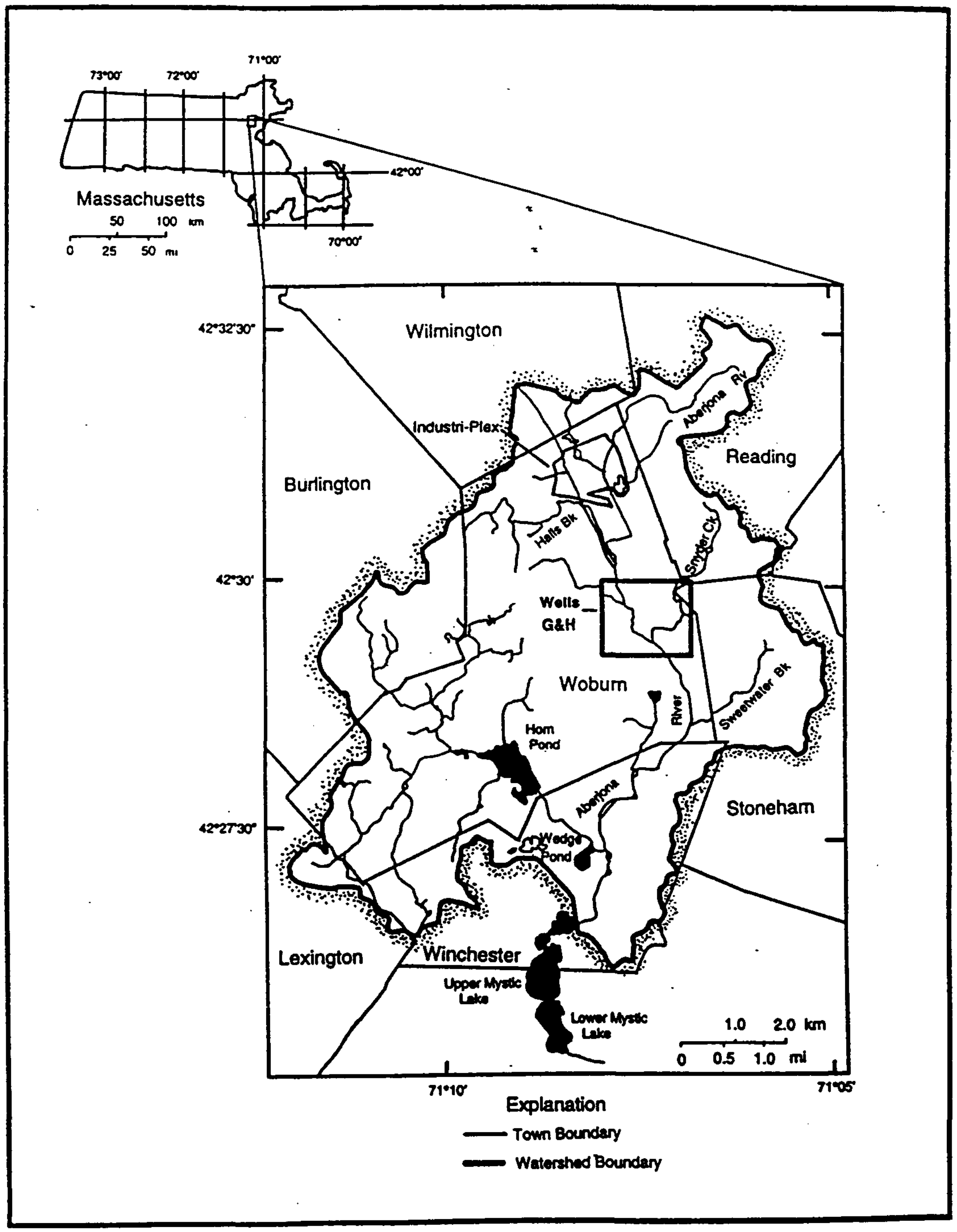


Figure 3-3 Wells G & H and Aberjona River Location Map, Woburn, Massachusetts (Source: Metheny, 1998, Figure 1-1)

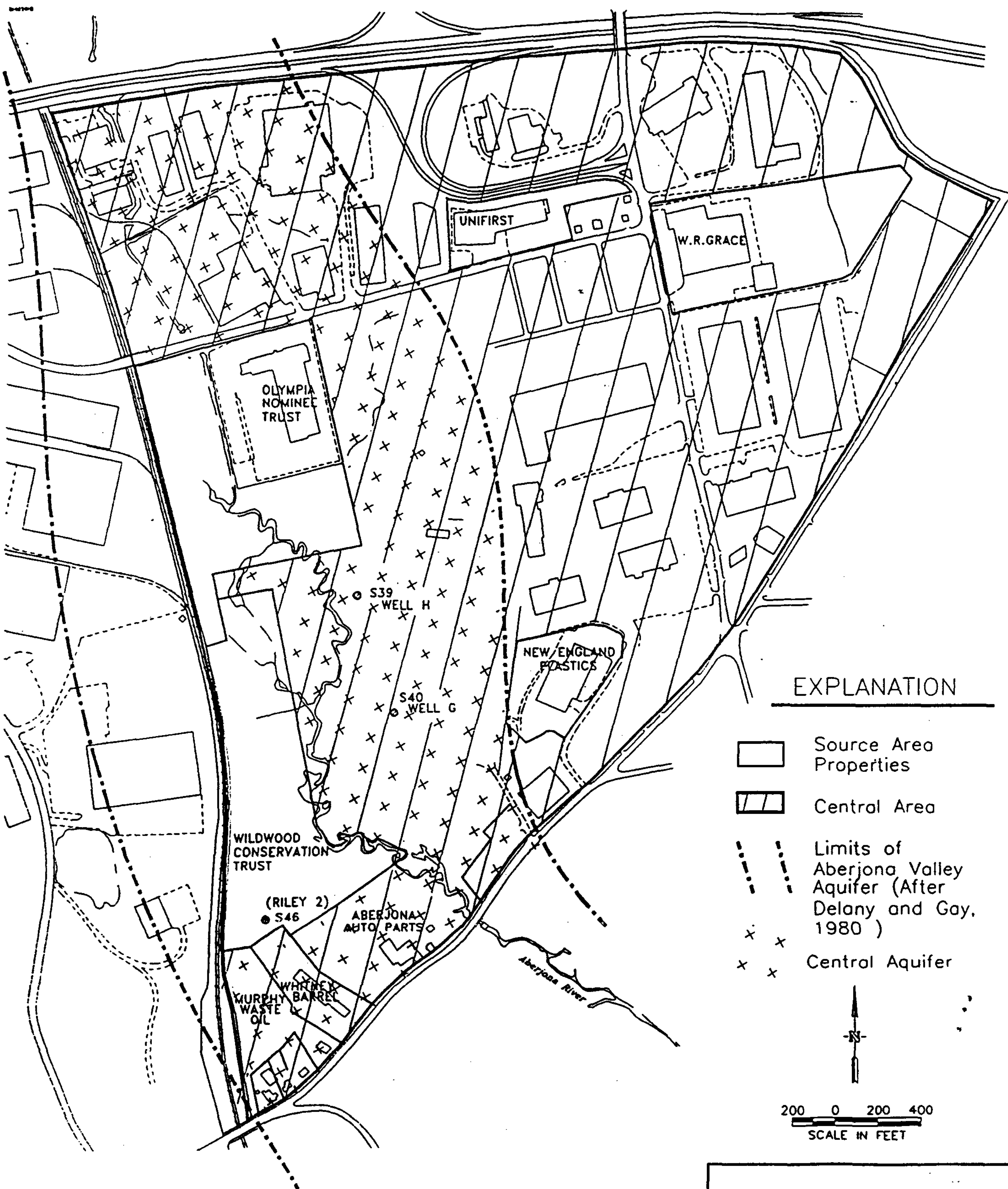


Figure 3-4 Map Showing Central Area, Southwest Properties, and Central Aquifer of Wells G & H Site, Woburn, Massachusetts (Source: GeoTrans, et al., 1992, Figure 2-1)

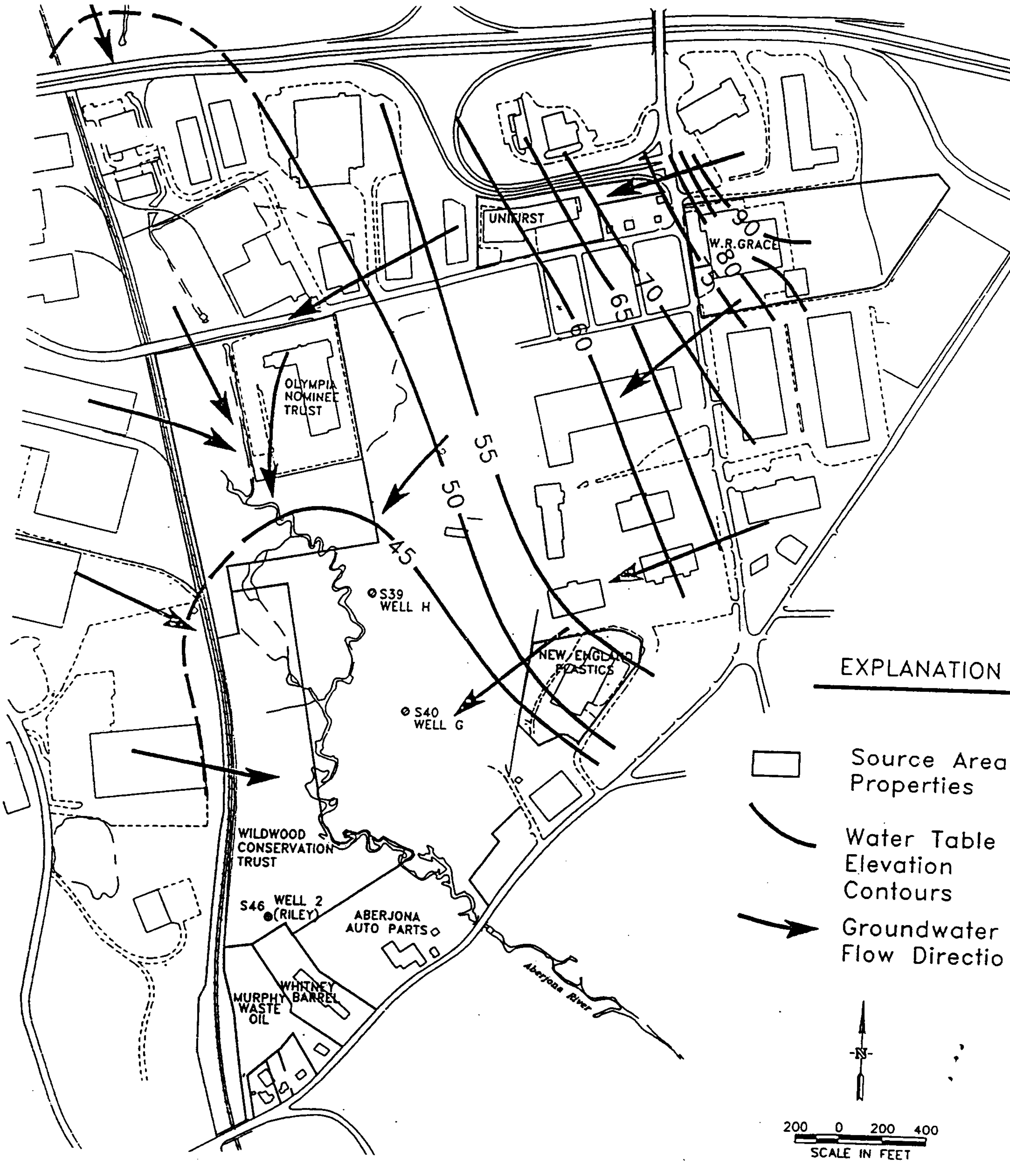


Figure 3-5 Direction of Water Flow Under Non-Pumping Conditions of Central Area, Woburn, Massachusetts (Source: GeoTrans, et al., 1992, Figure 2-5)

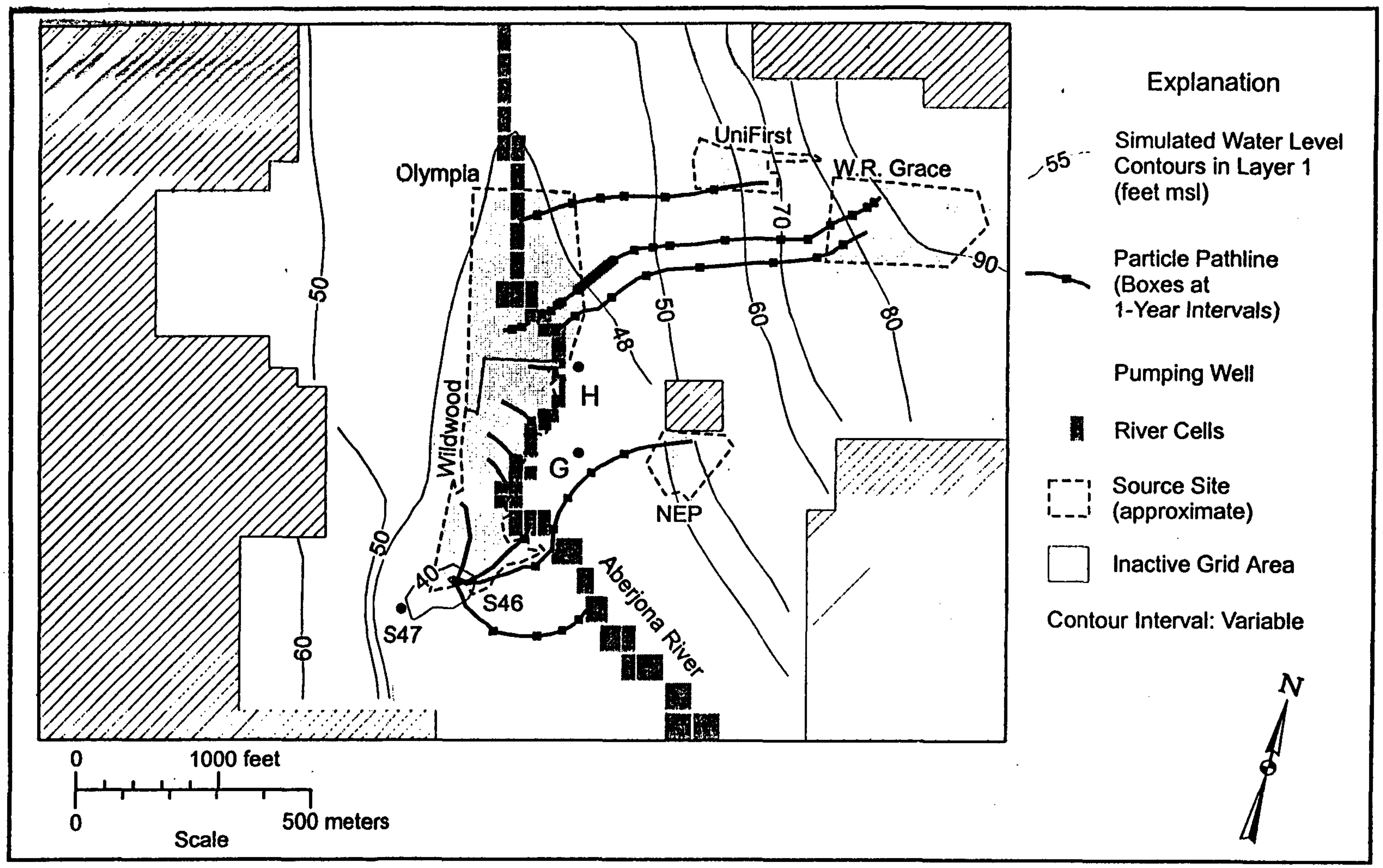


Figure 3-6 Particle Pathlines from Source Areas During Steady-State Simulation With No Pumping at Wells G & H Site, Woburn, Massachusetts (Source: Metheny, 1998, Figure 9.39)

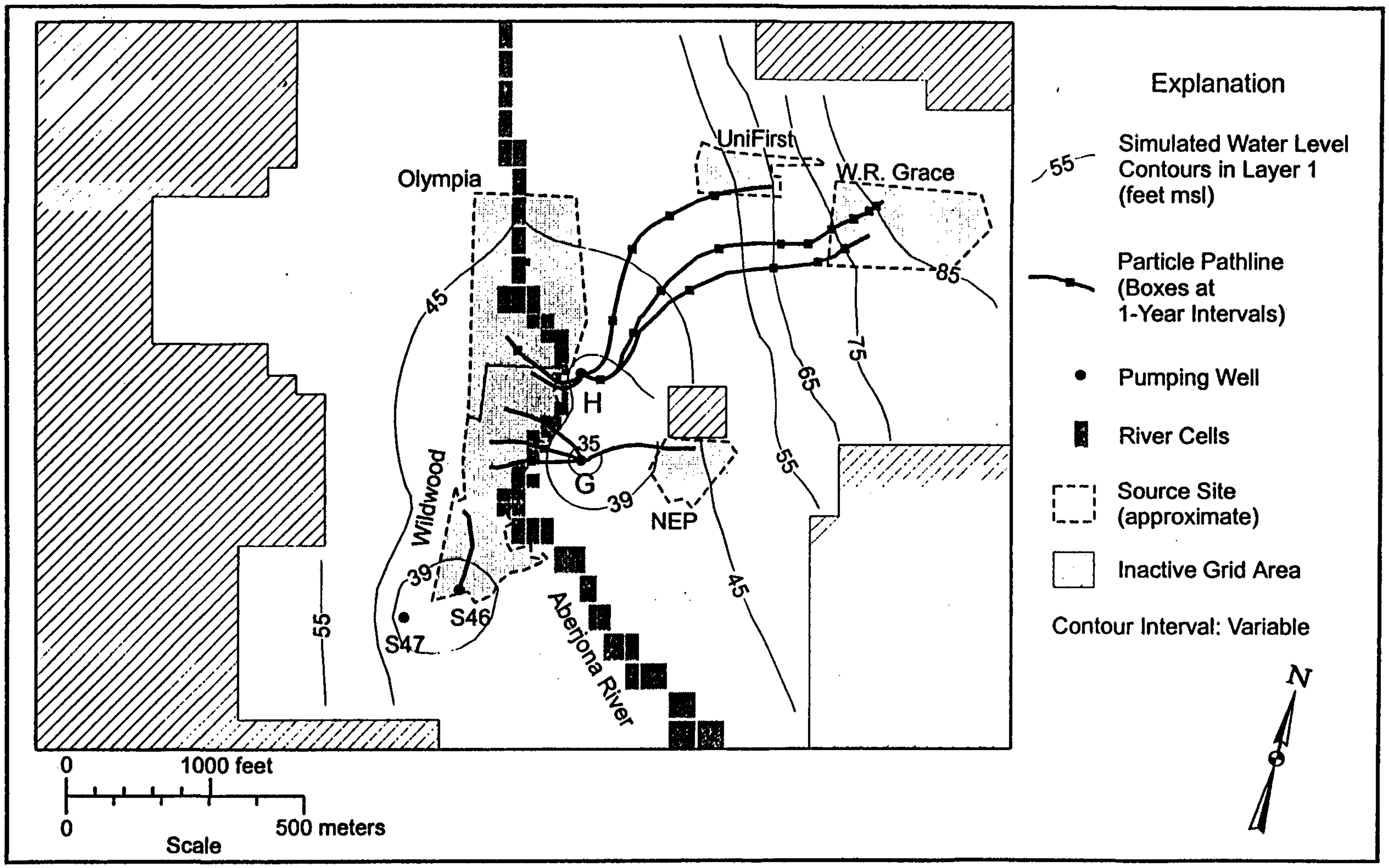


Figure 3-7 Particle Pathlines from Source Areas During Steady-State Simulation With Pumping at Wells G & H Site, Woburn, Massachusetts (Source: Metheny, 1998, Figure 9.36)

Figure 3-8 Water Table Drawdown at End of USGS Pump Test of Wells G & H Site, Woburn, Massachusetts (Source: Myette et al., 1987, Plate 3)

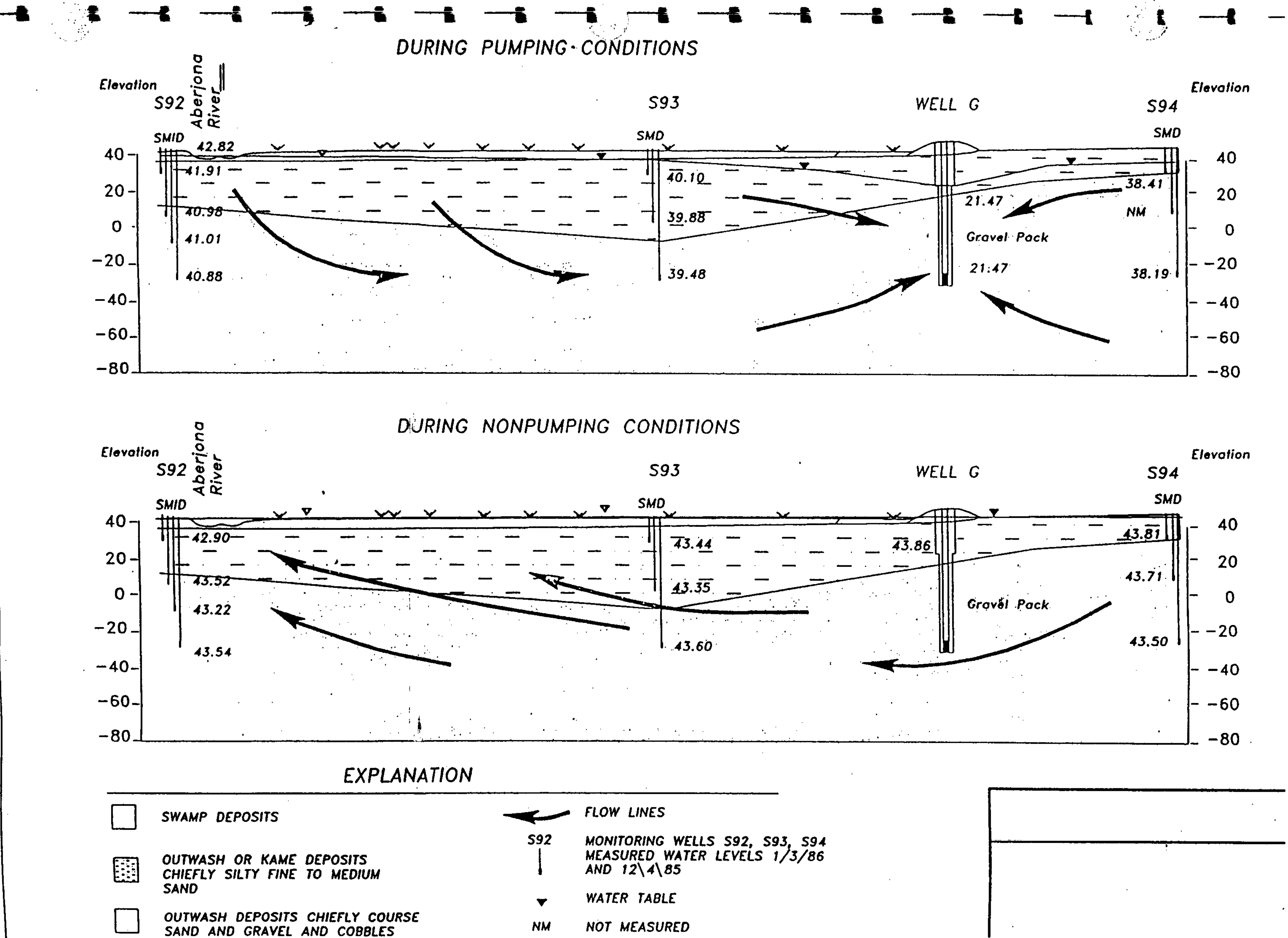


Figure 3-9 Central Aquifer Cross-Section Showing Vertical Groundwater Flow Pattern Under Pumping and Non-Pumping Conditions of Wells G & H Site, Woburn, Massachusetts (Source: GeoTrans, et al., 1992, Figure 2-7)

Figure 3-10 Line of Stagnation (referred to as the Downgradient Limit of Zone of Contribution) Under Pumping Conditions at Central Area of Wells G & H, Woburn, Massachusetts (Source: Myette et al., 1987, Plate 5)

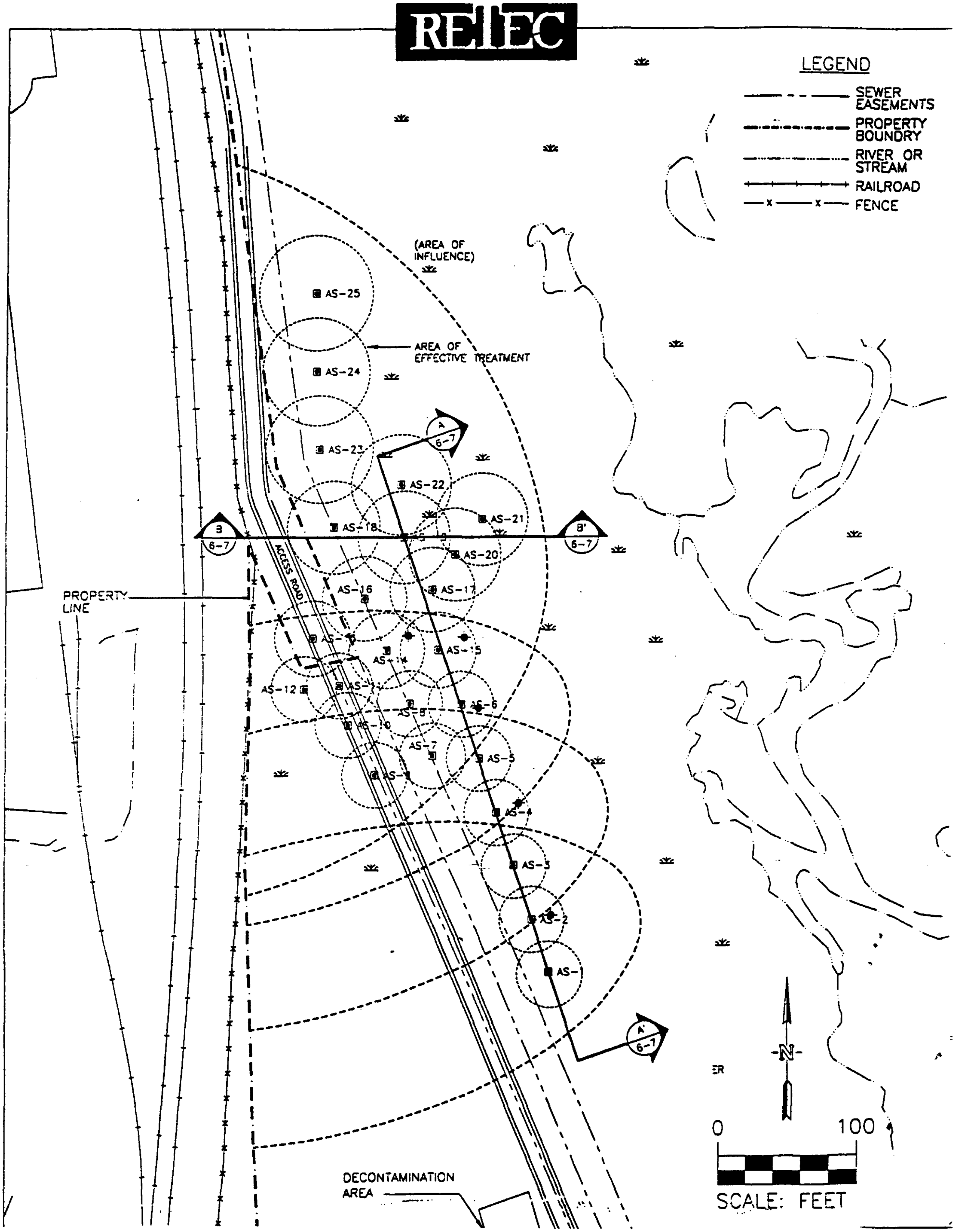


Figure 3-11 Radius of Influence from Extraction Wells and Air Sparge Wells at Wildwood Property in the Central Area, Woburn, Massachusetts (Source: RETEC, 1997, Figure 6-6)

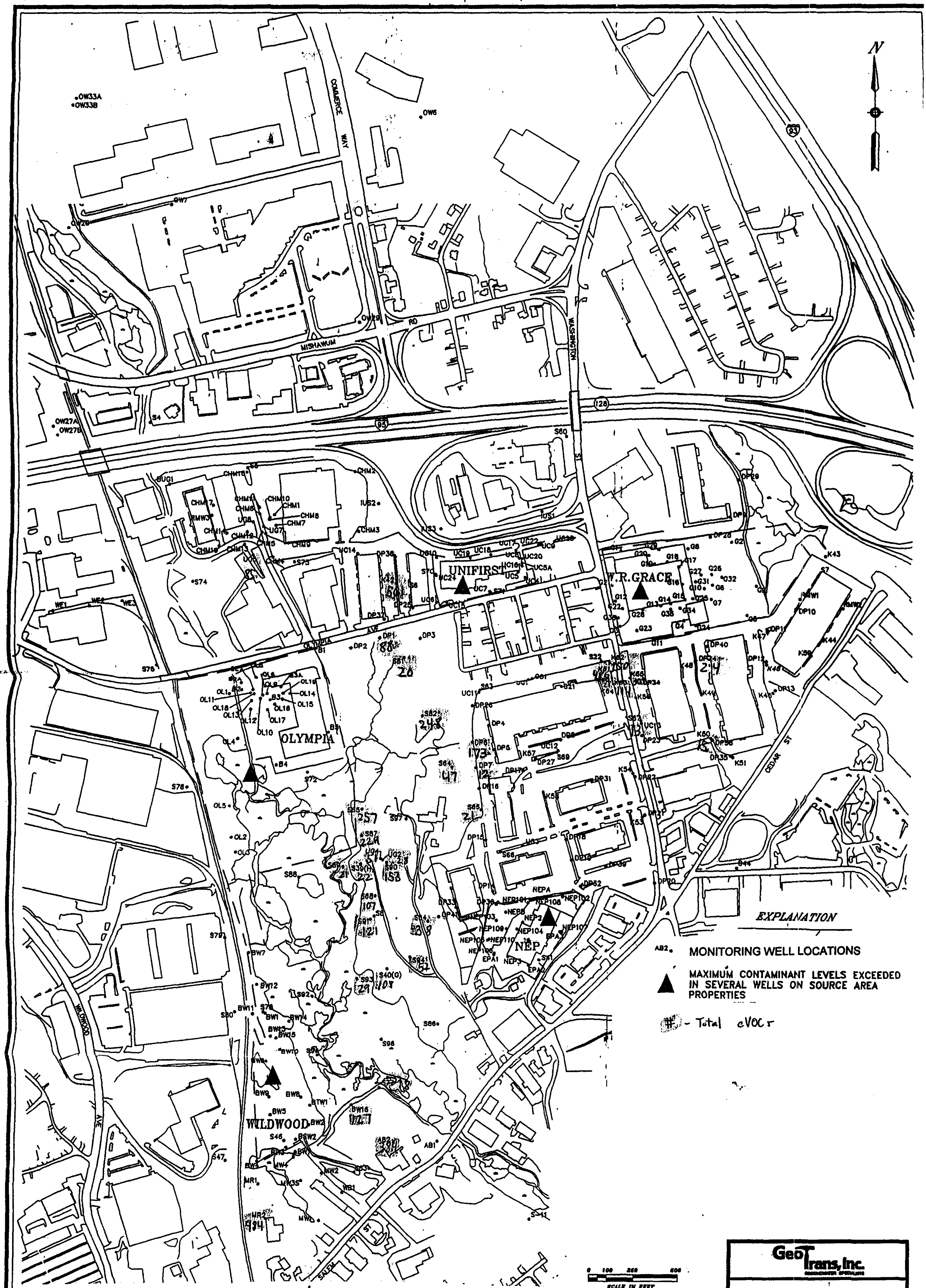


Figure 4-1 Areal Distribution of Total Solvents in Unconsolidated Deposits of Central Area, Woburn, Massachusetts

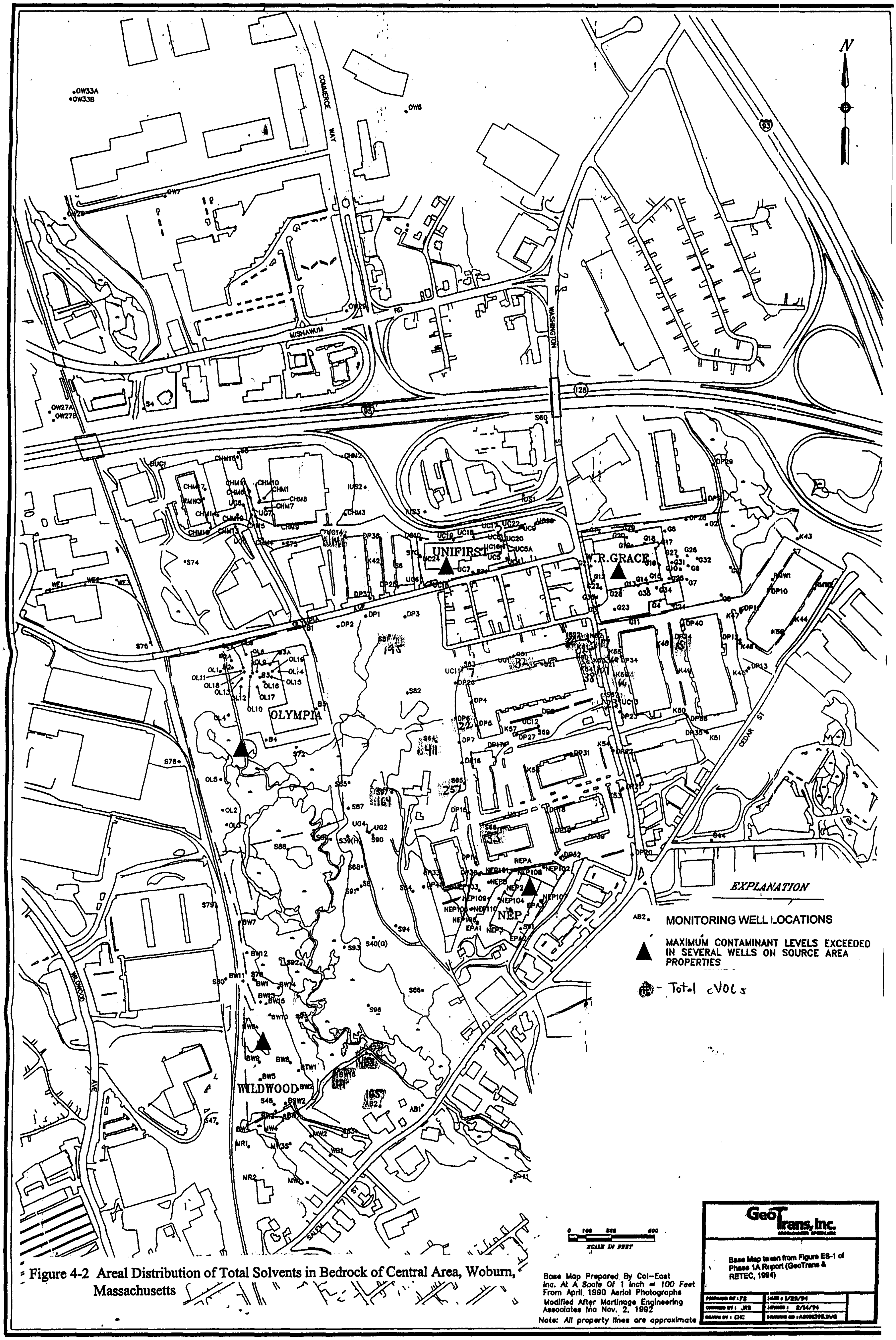


Figure 4-2 Areal Distribution of Total Solvents in Bedrock of Central Area, Woburn, Massachusetts

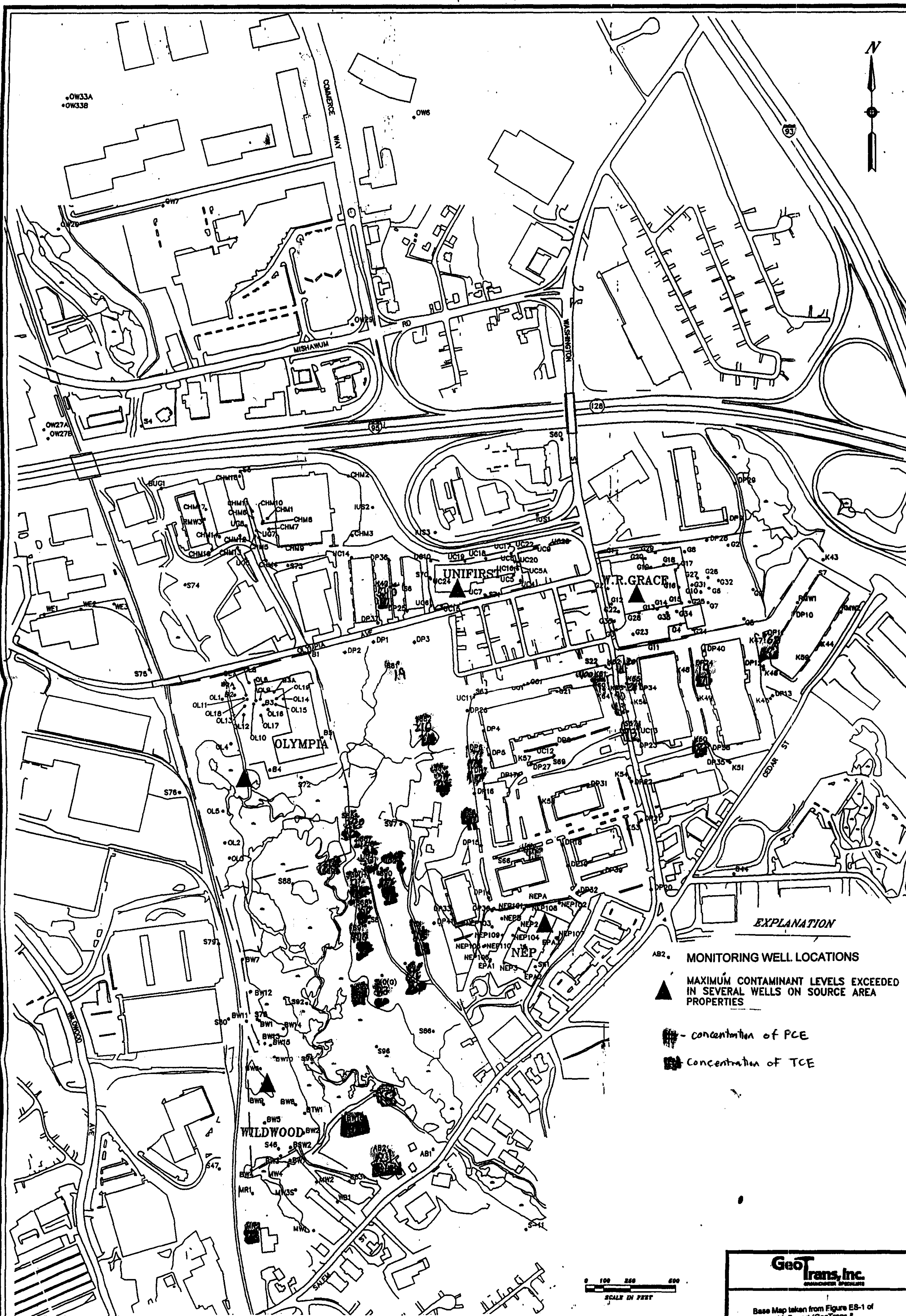


Figure 4-3 Areal Distribution of Tetrachloroethene and Trichloroethene in Unconsolidated Deposits of Central Area, Woburn, Massachusetts

Base Map Prepared By Col-East Inc. At A Scale Of 1 Inch = 100 Feet From April, 1990 Aerial Photographs
Modified After Martinage Engineering Associates Inc Nov. 2, 1992
Note: All property lines are approximate

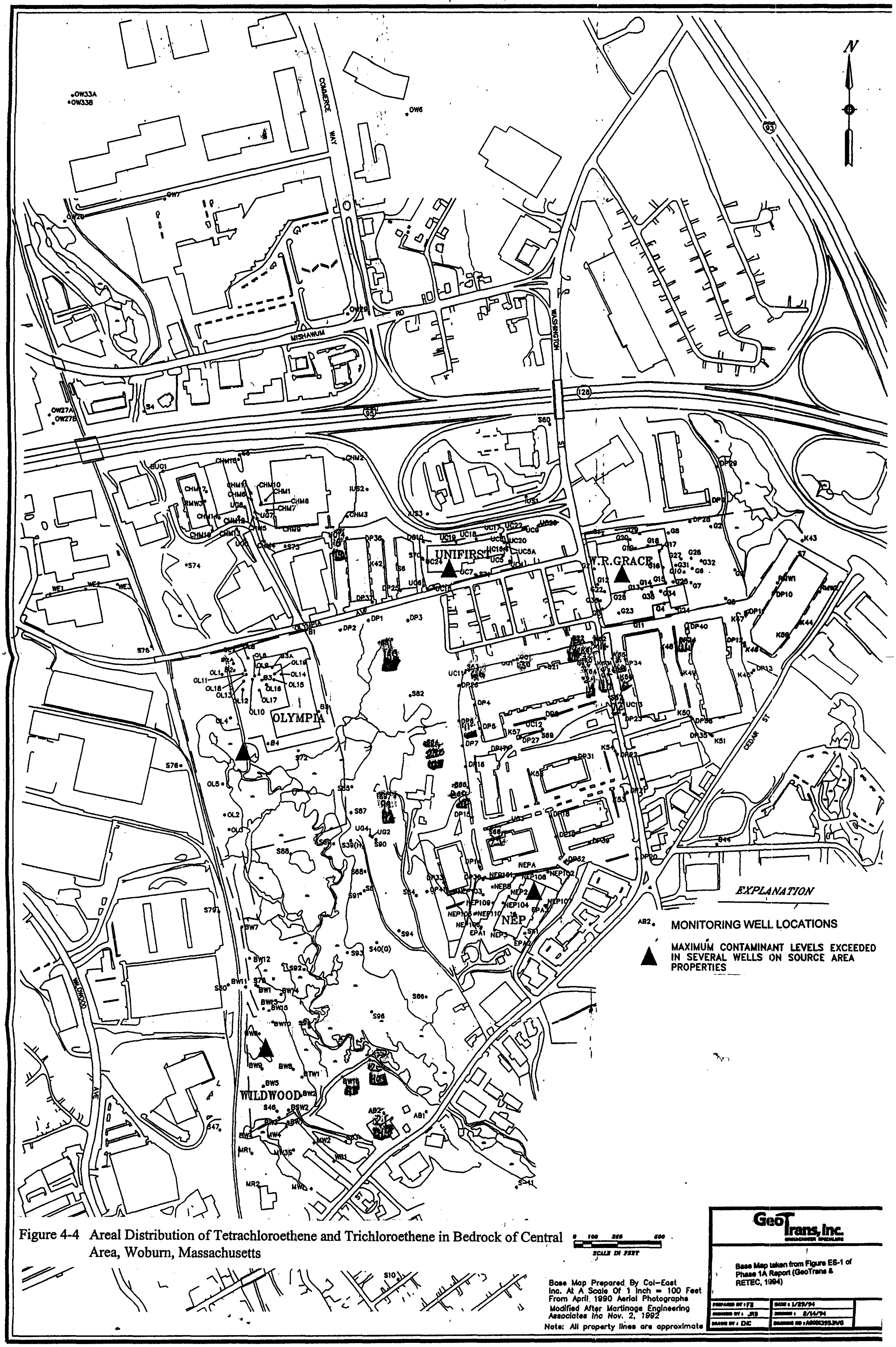


Figure 4-4 Areal Distribution of Tetrachloroethene and Trichloroethene in Bedrock of Central Area, Woburn, Massachusetts

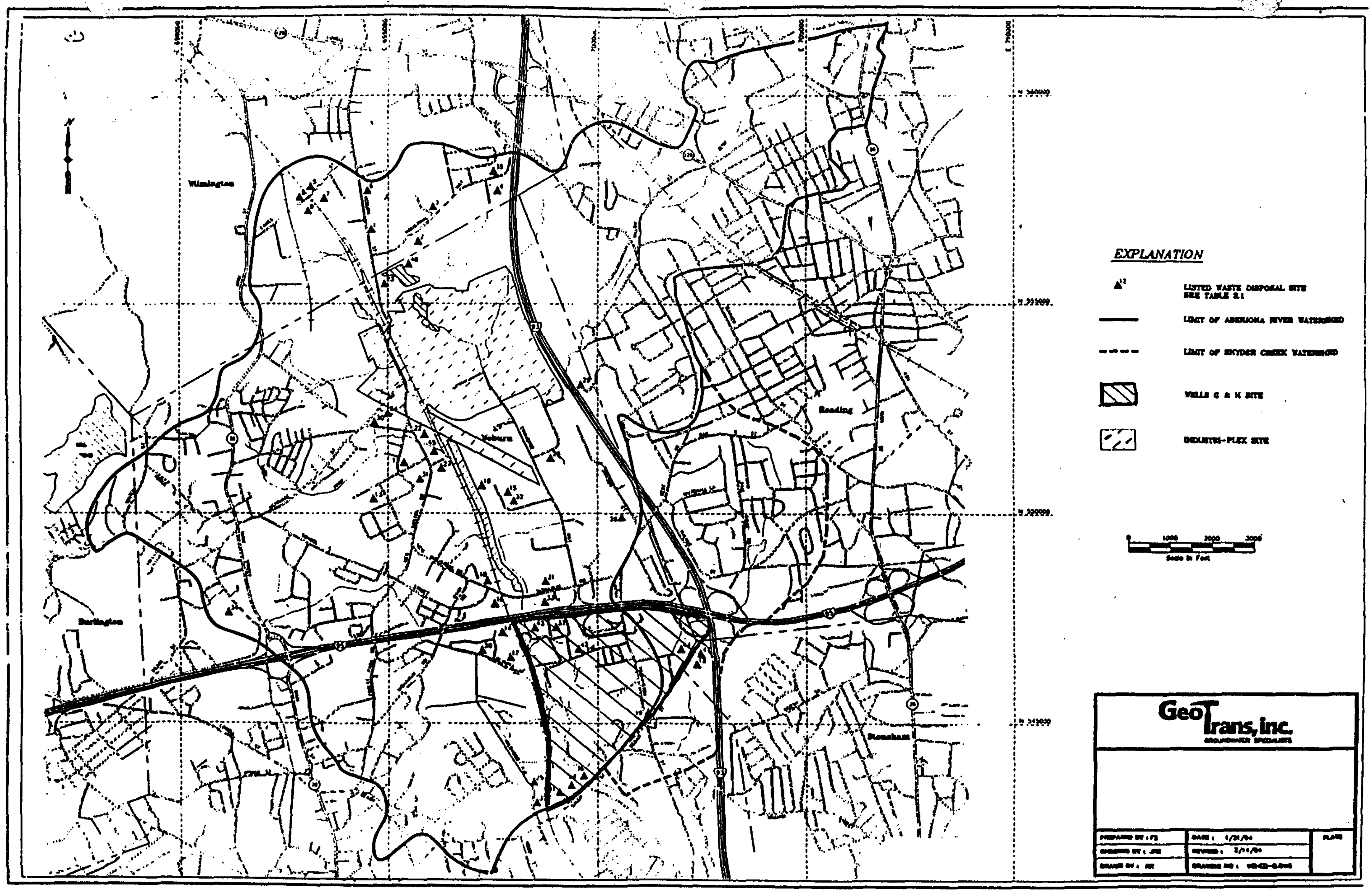


Figure 4-5 Aberjona River Watershed Boundary Upstream of Salem Street
(Source: GeoTrans and RETEC, 1994, Figure 2-1)

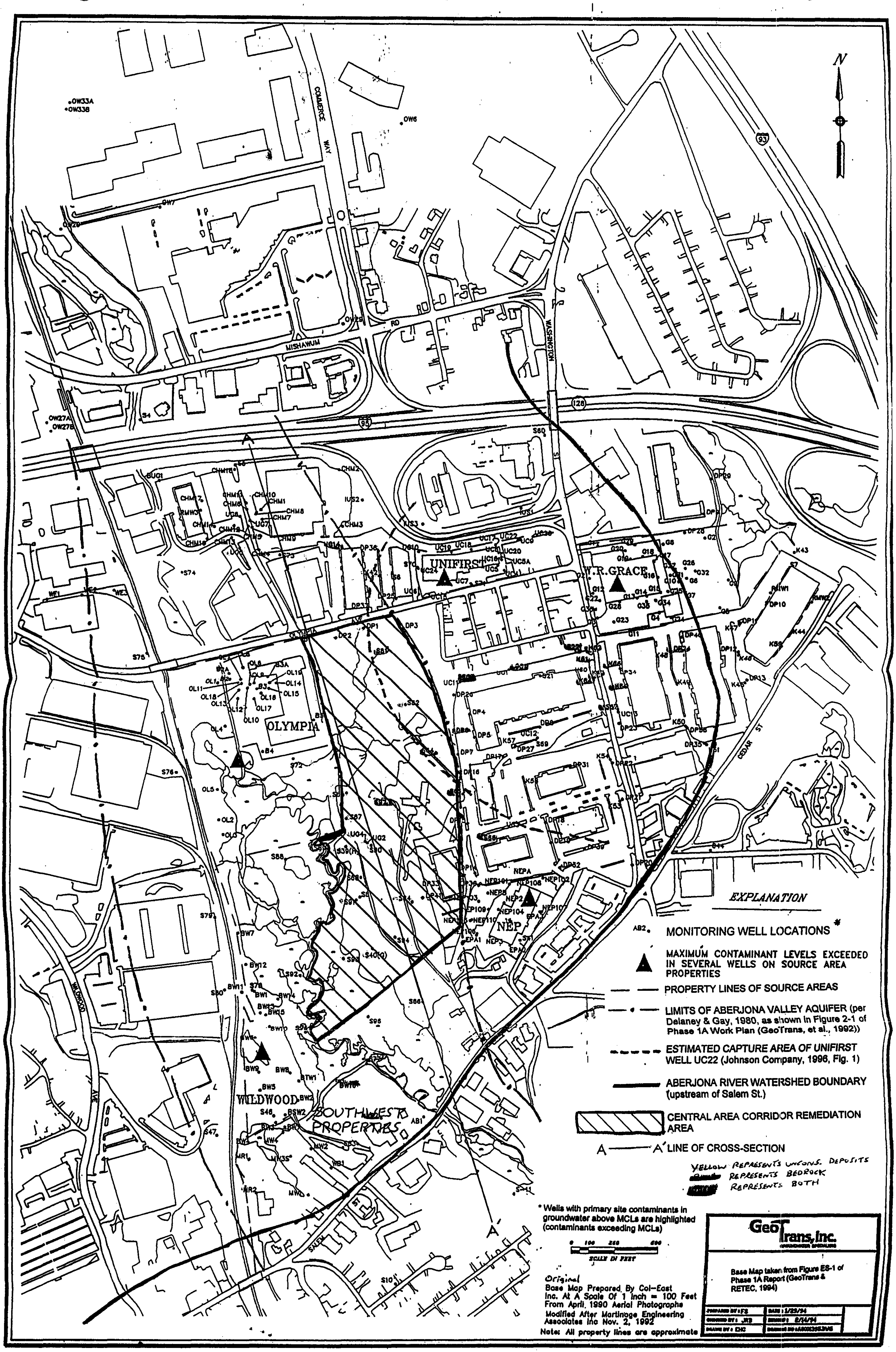


Figure 4-6 Target Remediation Area for the Central Area, Wells G & H Site

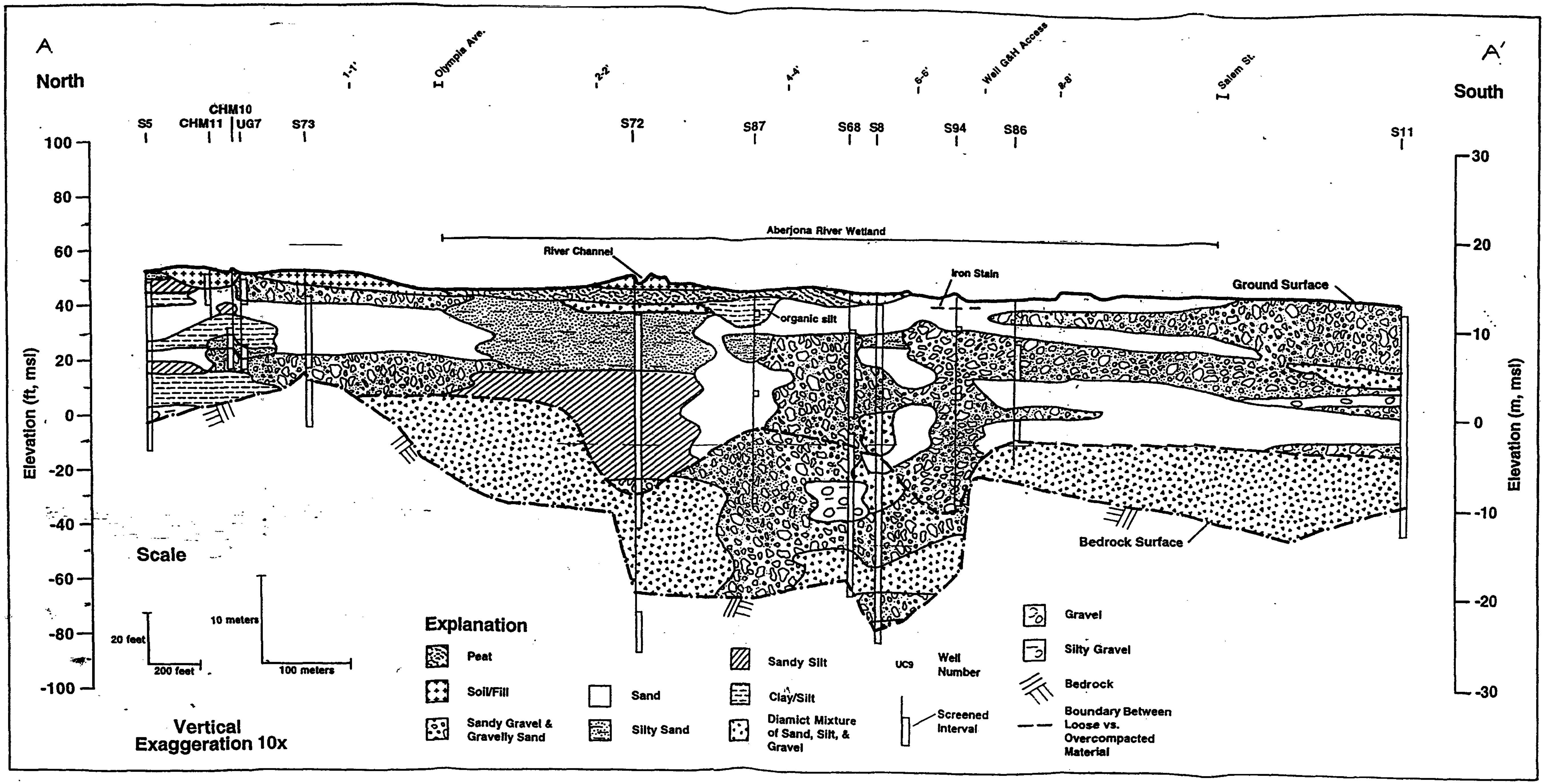


Figure 4-7 Representative Cross-section of the Central Area Corridor
(Source: Metheny, 1998, Figure 8-3, Cross-section 5-5')

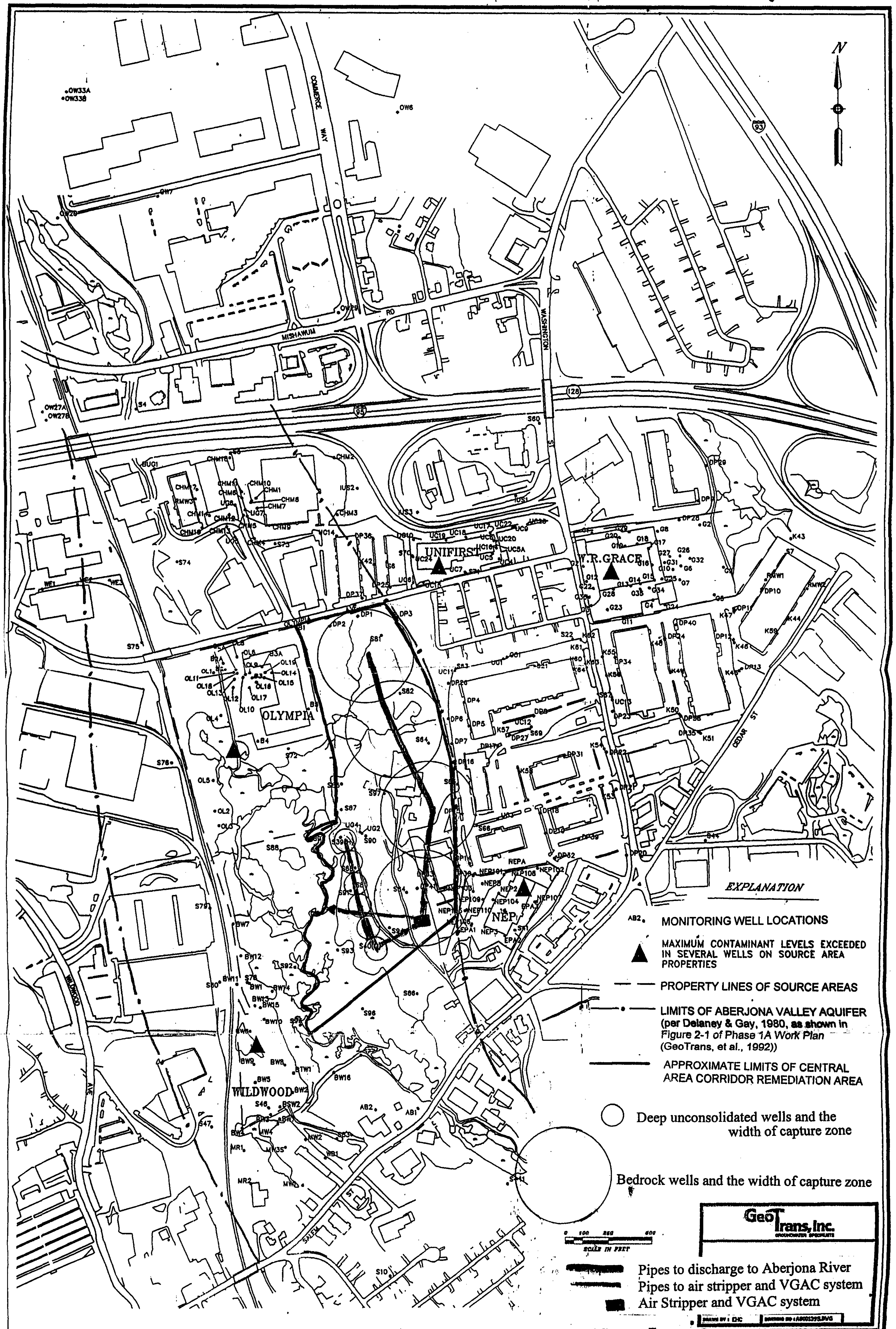


Figure 7-1 Location of Wells for Pump and Treat Alternative with the Width of Capture Zone; Location of Building with Air Stripper and VGAC System.

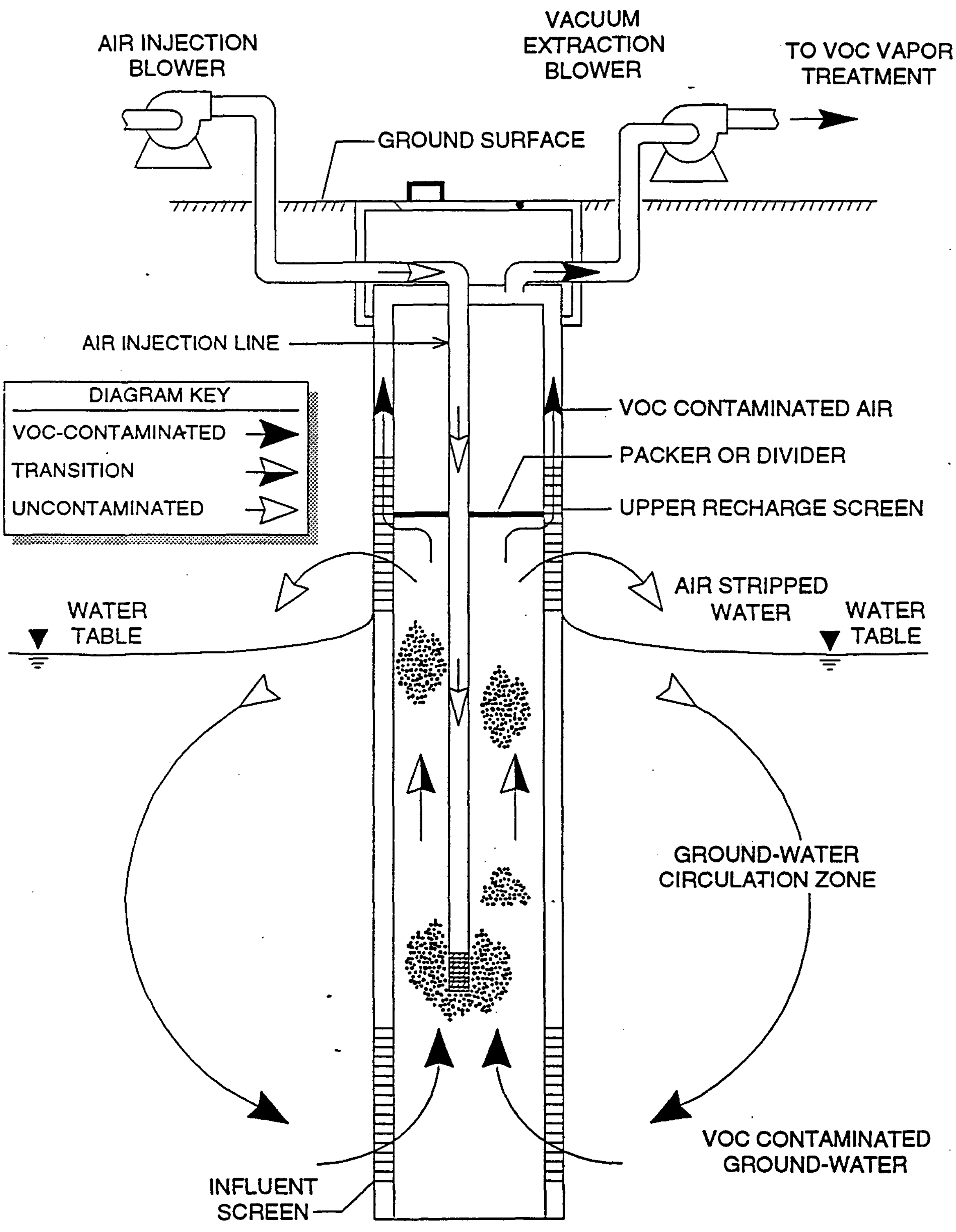


Figure 7-2a In-well Air Stripping System

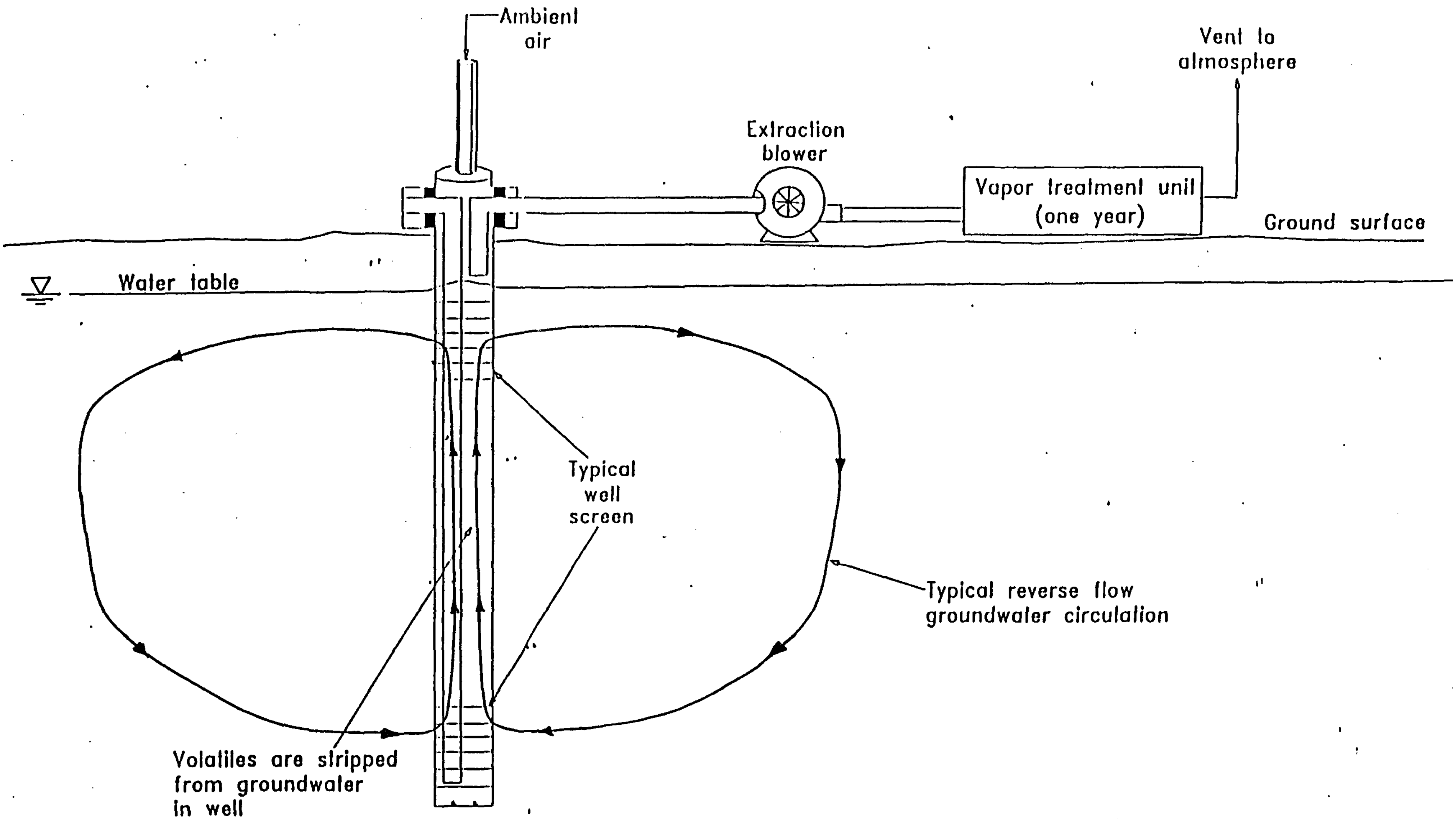


Figure 7-2b Treatment Process: In-well Air Stripping Alternative

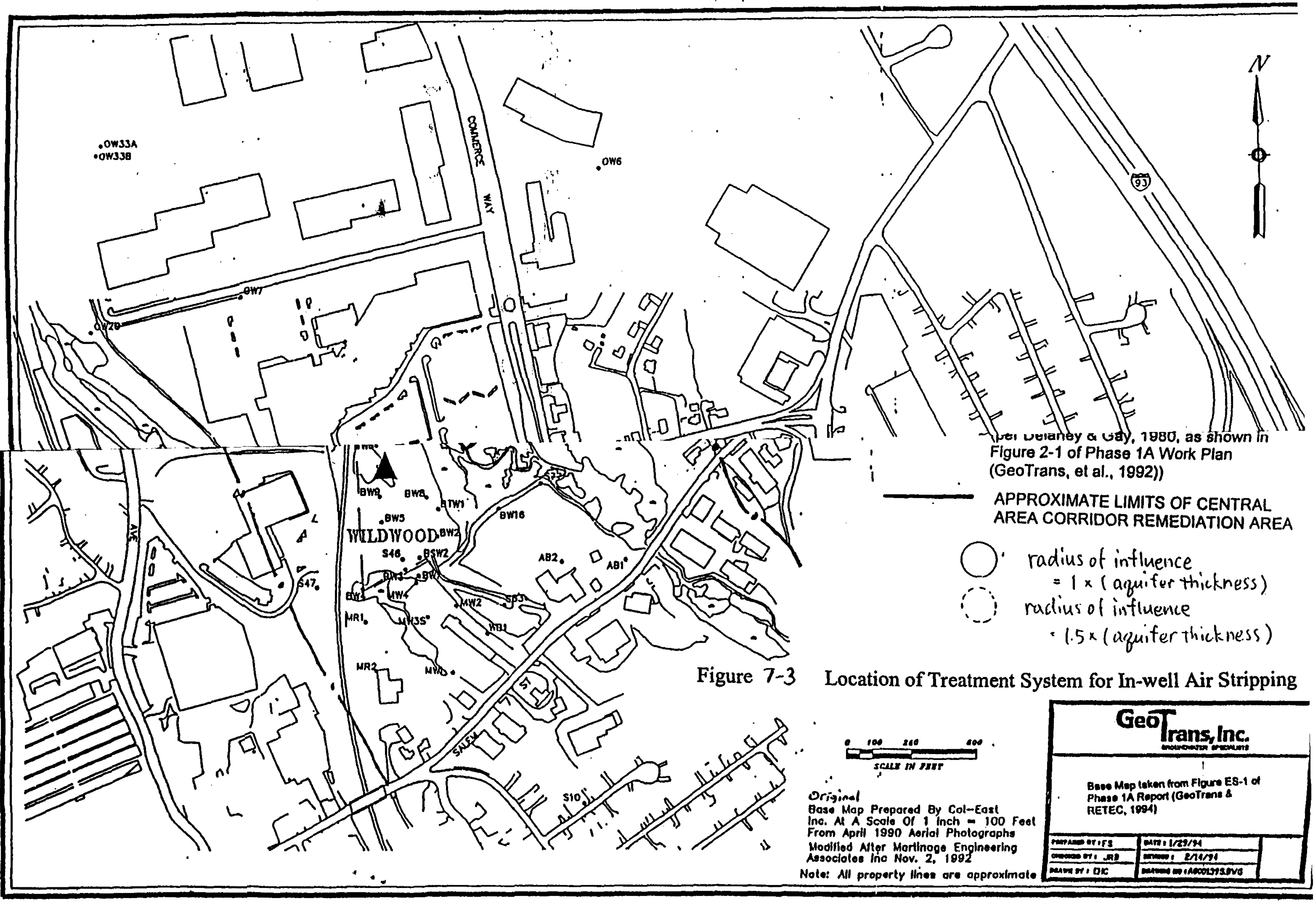


Figure 7-3 Location of Treatment System for In-well Air Stripping

Certain site characteristics may limit the effectiveness of subsurface remediation. The examples listed below are highly generalized. The particular factor or combination of factors that may critically limit restoration potential will be site specific.

Generalized Remediation Difficulty Scale

Increasing difficulty →

	Contaminant Characteristics	Lower difficulty		Higher difficulty
Site Use	Nature of Release	Small Volume Short Duration Slug Release	→	Large Volume Long Duration Continual Release
Chemical Properties	Biotic/Abiotic Decay Potential	High	→	Low
	Volatility	High	→	Low
	Contaminant Retardation (Sorption) Potential	Low	→	High
Contaminant Distribution	Contaminant Phase	Aqueous, Gaseous → Sorbed → LNAPLs	→	DNAPLs
	Volume of Contaminated Media	Small	→	Large
	Contaminant Depth	Shallow	→	Deep
	Hydrogeologic Characteristics			
Geology	Stratigraphy	Simple Geology, e.g., Planar Bedding	→	Complex Geology, e.g., Interbedded and Discontinuous Strata
	Texture of Unconsolidated Deposits	Sand	→	Clay
	Degree of Heterogeneity	Homogeneous (e.g., well-sorted sand)	→	Heterogeneous (e.g., interbedded sand and silts, clays, fractured media, karst)
Hydraulics/Flow	Hydraulic conductivity	High (>10^{4} cm/sec)	→	Low (< 10^{4} cm/sec)
	Temporal Variation	Little/None	→	High
	Vertical Flow	Little	→	Large Downward Flow Component

Figure 8-1 Factors Affecting Groundwater Restoration (Source: USEPA, 1993a, Figure 1)

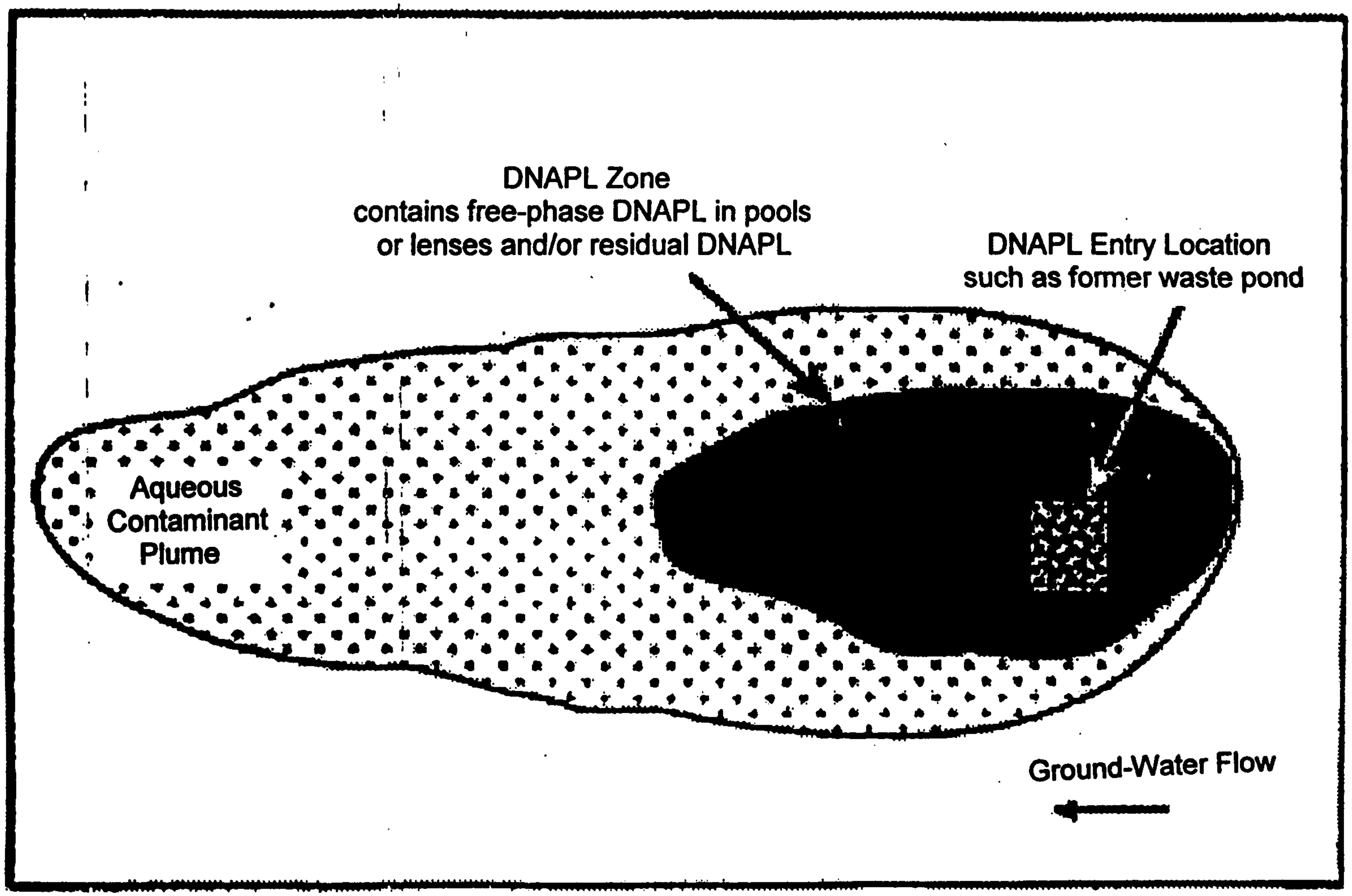


Figure 8-2 Components of DNAPL Sites (Source: USEPA, 1993a, Figure 3)

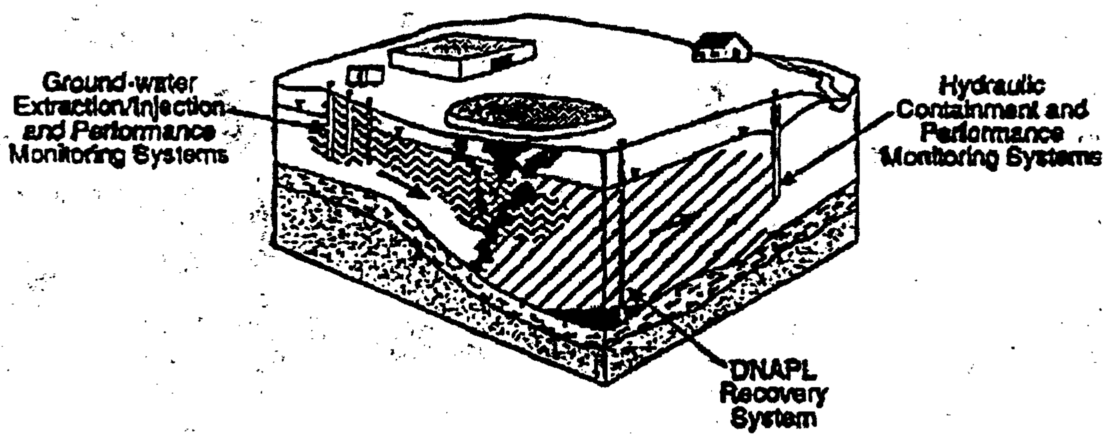
Remedy design and performance data requirements should be specific to technologies employed and site conditions. The categories of required information normally necessary to evaluate performance are provided below with some examples of specific data elements. These data should be reported to EPA in formats conducive to analysis and interpretation. Simple data compilations are insufficient for this purpose.

Remedy Design and Operational Information

- Design and as-built construction information, including locations of extraction or *in situ* treatment points with respect to the contamination.
- Supporting design calculations (e.g., calculation of well spacing).
- Operating information pertinent to remedy (e.g., records of the quantity and quality of extracted or injected fluids).
- Percent downtime and other maintenance problems.

Enhancements to Original Remedial Design

- Information concerning operational modifications, such as variations in pumping, injection rates, or locations.
- Rationale, design, and as-built construction information for system enhancements.
- Monitoring data and analyses that illustrate the effect these modifications have had on system performance.



Source Removal or Control

- Source removal information (e.g., results of soil excavations, removal of lagoon sediments, NAPL removal activities).
- Source control information (e.g., results of NAPL containment, capping of former waste management units).

Performance Monitoring Information

- Design and as-built construction information for performance monitoring systems.
- Hydraulic gradients and other information demonstrating plume containment or changes in areal extent or volume.
- Trends in subsurface contaminant concentrations determined at several/many appropriate locations in the subsurface. Trends should be displayed as a function of time, a function of pore volumes of flushed fluids, or other appropriate measures.
- Information on types and quantities of contaminant mass removed and removal rates.

Figure 8-3 Factors to Consider in the Analysis of Remedy Performance (USEPA, 1993a, Figure 5)

APPENDICES

APPENDIX A

Summary of the Work Performed at Operable Units 1 and 3 since 1992

The following is a summary of the work completed, and the current status, at Operable Unit (OU) 1 – Source Areas, and OU 3 – Aberjona River. For information on contaminants detected at each OU, see Section 4 of the Report - Contamination of Groundwater in the Central Area.

Operable Unit 1 – Source Areas

- Grace – Since September 1992, Grace has been operating a treatment facility to remediate chlorinated volatile organic compounds (cVOCs) in the groundwater. Grace utilizes a network of 22 extraction wells that is designed to recover groundwater from unconsolidated deposits (overburden) and shallow bedrock on the Grace property. Figure 2-1 shows the effects that pumping has on the groundwater table. Contaminated groundwater in the deep bedrock is captured by a deep bedrock recovery well on the Unifirst property. Groundwater from Grace's extraction system is pumped at an average rate of 5 to 8 gallons per minute (gpm) to their on-site treatment plant (Guswa, 1999). The groundwater is treated using particulate filters and ultraviolet/oxidation (UV/OX) and is then discharged into Snyder Creek, approximately 40 feet east of the treatment plant building. Through six years of operation (1992-1998), Grace calculates that they have removed a total of 53.3 pounds of VOCs from the groundwater beneath their property (HSI GeoTrans, 1998).

- Unifirst – Since September 1992, Unifirst has been operating a treatment facility to remediate cVOCs, primarily PCE, in the groundwater. Unifirst uses a single extraction well, UC22, pumped at approximately 40 gpm to collect contaminated groundwater. UC22 is installed to a depth of 190 feet below ground surface (bgs) with an open interval of 175 feet in the bedrock (Handex, 1998). As noted above, the well is designed to capture groundwater from both the Grace and Unifirst facilities (Figure 2-2). See Section 3 for a discussion on the impact of the Unifirst extraction system on groundwater flow in the Central Area. Groundwater is treated using a multimedia pressure filter, a UV/OX system, and liquid-phase granular activated carbon (GAC) filters. After treatment, the groundwater is pumped into a City of Woburn storm drain that eventually discharges into the Aberjona River. Through six years of operation (1992-1998), Unifirst estimates that 1300 pounds of PCE, 62 pounds of TCE, and small amounts of other cVOCs have been removed from the groundwater (Handex, 1998).

- Wildwood – From 1992 through 1994, Beatrice removed 67 tons of hazardous sludge, 354 tons of non-hazardous sludge, 255 tons of soil mixed with debris, 45 drum carcasses, and 987 tons of soil with a mix of contaminants from the Wildwood property (http://www.epa.gov, 1999). A treatment system to remediate the remaining VOC-contaminated soil and groundwater began operating in April 1998. Remediation consists of in-situ volatilization of the soil and groundwater in both the deep overburden and bedrock. Twenty-four air sparging wells are used to inject air into the subsurface, both above and below the water table. After coming into contact with the contaminated media, the air is collected, under negative pressure, beneath a low permeability membrane cap. Groundwater beneath the area of influence of the air sparge wells is collected from five extraction wells pumping at an average of 30 gpm. The vapor and liquid waste streams are directed to a single treatment facility. The groundwater is treated using a particulate filter, air stripper, and liquid-phase GAC unit, and is then discharged to the Aberjona River. The vapors from the collection system and the air stripper are treated using a catalytic oxidation (CAT/OX) unit prior to discharge to the atmosphere (RETEC, 1998a).

- NEP – Since February 2, 1998, NEP has operated a trailer-mounted soil vapor extraction/air sparge (SVE/AS) system to remediate soil and groundwater contaminated with VOCs. Air is injected below the water table via a network of seven air sparge wells. The air is then collected from six SVE wells. The contaminated vapors and (liquid) condensate are treated using vapor-phase and liquid-phase GAC, respectively, prior to discharging to the environment. Soil samples were collected in November 1998 to determine whether the SVE/AS system has been successful in remediating the soil above the water table to the ROD cleanup standards. The system continued to operate through May 1999 in an attempt to remediate the groundwater as well. After additional groundwater samples are collected in August 1999, a decision will be made as to whether continued operation of the treatment facility is necessary. Through the first year of operation, NEP estimates that 75 pounds of VOCs have been removed from the soil and groundwater beneath their property (Woodard & Curran, 1999).

- Olympia – USEPA and MADEP have not reached an agreement with Olympia for their self-remediation of their property. In September 1997, USEPA collected groundwater and surface soil samples in anticipation of their use in designing a pump & treat system to treat contaminated groundwater beneath the Olympia property (http://www.epa.gov, 1999). Olympia is currently (1999) in negotiations with USEPA to discuss an arrangement under which Olympia would remediate their property (Mayor, 1999).

Operable Unit 3 – Aberjona River

Since the CD was signed, a number of studies have been performed on the Aberjona River and its associated wetlands (the River system), but no determination has yet been made on whether the River and its sediments should be remediated.

Since 1988, students and faculty from the Massachusetts Institute of Technology (MIT) have conducted a number of studies to evaluate the migration of contaminants through the Aberjona River watershed. Their studies have been funded by grants from the USEPA-sponsored National Institute of Environmental Health Scientists (NIEHS). The focus of these studies has been primarily on the contaminants *arsenic* and *chromium* because of their past use in the watershed, their widespread presence in sediments and surface water, and their chemical characteristic of being fairly stable (i.e., they do not break down) in the environment. The MIT studies found that a major source of the arsenic and chromium is the Industri-Plex Site located north of the Site, north of Route 128 (GeoTrans & RETEC, 1994).

In 1995 and 1997, USEPA collected sediment, surface water, and biota samples to determine the nature and extent of contamination in the River system from Route 128 in Woburn to Upper Mystic Lake in Winchester. Sampling results indicated that the sediments and surface water are primarily contaminated with polycyclic aromatic hydrocarbons (PAHs) and metals. Low levels of VOCs were also detected in the sediment and surface water. A draft baseline risk assessment for the River system was developed in 1998 for USEPA using the 1995 and 1997 data (M&E, 1998). The risk assessment is currently (1999) being reviewed by USEPA and MADEP.

Additional sampling may be necessary to complete the risk assessment (Lemay, 1999). Based upon the results of the risk assessment, USEPA and MADEP will determine whether remediation of the River system is warranted.

APPENDIX B

MADEP letter to USEPA, dated August 29, 1994
Re: MADEP's comments on the
Wells G & H Site Central Area RI Phase 1A Report,
And the Draft RI, Southwest Properties

SITE: 3-0479.2
5.2
36

Commonwealth of Massachusetts
Executive Office of Environmental Affairs

Department of Environmental Protection

DEP

William F. Weld
Governor
Trudy Coxe
Secretary, EOEA
Thomas B. Powers
Acting Commissioner

August 29, 1994

Paula Fitzsimmons
USEPA, Region 1
HRR-CAN3
J.F.K Federal Building
Boston, MA 02203

RE: The Department's Comments on the Wells G + H Site Central Area Remedial Investigation Phase 1A Report--Vol. I-III (Dated February 14, 1994) by Geotrans, Inc., and the Draft Remedial Investigation, Southwest Properties, Wells G & H Superfund Site (Dated January, 1994).

Dear Paula:

The Department has received and has completed its review of the documents cited above, submitted for the Wells G and H Site in Woburn, Massachusetts.

The Department has few questions on the data presented in the report. These comments instead will focus on the major points that are emphasized throughout the report: 1) That aquifer restoration is impracticable, and 2) That the aquifer should not be cleaned up to drinking water standards. As an attachment to this letter, the Department is also recommending a list of additional state ARARs applicable to a groundwater remedy.

To place the comments in context, it is essential first to establish the present status of the Central Area aquifer. Wells G + H continue to be officially designated as Inactive according to our Division of Water Supply. They have not been officially abandoned. Therefore; at present, the entire Central Area is encompassed within the two wells' Interim Wellhead Protection Area (IWPA). In addition, the Aberjona River aquifer underlying the study area is designated as a Potentially Productive Aquifer under the Massachusetts Contingency Plan (MCP) because of its medium and high yield characteristics (Woburn's population density is below that required to trigger the exemption criteria). The status of the aquifer under the regulations of either division require that it be remediated as a drinking water supply. However, in view of the arguments presented in the Phase IA Report, the Bureau of Waste Site Cleanup will again discuss the appropriateness of these designations and requirements with our Division of Water Supply. Assessment of regional demand for the water supply, and the question of the economic feasibility (as a measure of remedial treatment cost versus regional municipal water supply cost per 1,000 gallons of water) will be discussed as considerations which may change aquifer status.

One of the arguments presented in the report as justification for clean-up below drinking water standards, is that the DEP has accepted Waivers for sites located within the Aberjona River Watershed. The Department, after investigating this information, has decided that this incidence does not have the significance given in the report. There are a variety of factors that sway regional decisions to waiver sites. Even though these sites are waivered, they still must be remediated in compliance with applicable regulations, including regulatory groundwater standards. Out of the three waivered sites closest to Wells G + H (one named "Property at 5 Wheeling Ave", site #3-2079; another named Charrette's, site # 3-3377; and one named Woburn Mall, site #3-3794), Charrette is the only one that falls within the IWPA of the wellheads. Our office is investigating the process that led to the waiver decision at this site; however, decisions made at any of the waivered sites do not alter the status of the Central Area aquifer.

Another major argument presented to support the impracticality of cleaning up the aquifer is the presence of multiple, persistent, and off-site contaminant sources. The industrial characteristic of the area promotes roadway runoff and possible future spills as contaminant sources; but, unfortunately that is increasingly the situation and the environment in which town water supplies must be located. The State waste site cleanup program is set up to address spills and releases, and all the sources (with the exception of the roadway runoff) will eventually be monitored and remediated according to appropriate standards. The Department agrees that it is unreasonable for the PRPs to conduct site investigations for all the potential waste-sites proximal to the Central Area. The RI/FS for the source area properties; however, did establish that the majority of the chlorinated organics mixed plume present in the central area aquifer originated from the 5 source areas cited in the ROD. If the Department and the EPA demand that remediation remain consistent with the ROD, it would not expect the PRPs to reduce all contaminants present in the aquifer (i.e., sulfates, nitrates, sodium, etc.) to drinking water levels, but only those contaminants for which the source areas are responsible.

The PRPs appear to assume that the Agencies will accept a no further action alternative, and therefore do not explore alternative remedial options sufficiently in the report.
According to the Wells G + H Consent Decree (Appendix II, pg. 64),

at a minimum, the report should provide a preliminary identification of potentially feasible remedial technologies. Organized in chart form, there needs to be an evaluation of appropriate physical and chemical waste characteristics that may affect the possible type of treatment (Appendix II, pg. 66). The discussion of the one option of a pump and treat system in the Phase 1A report is cursory and is narrowly limited to a system that would operate similarly (having the same impact on the water flow in the aquifer and the river) to the pumping of the original Wells G + H. Alternative pumping techniques (e.i., lower pumping rates, varied distances from the river) and in-situ options (e.g., bioremediation techniques that would not require water withdrawal) need to be discussed as to their practicality and to their respective technical and physical requirements.

The Department rejects the notion of using the Aberjona River system as a flushing mechanism for all the contaminants in the aquifer, but it is open to the option of using limited flushing action in combination with other treatment, as necessary to prevent infiltration of river contaminants deeper into the aquifer.

In view of the potentially major repercussions that a decision of no further action for the Central Area would represent to the Department, the Department plans to hold further discussions with your Agency. The Department will also investigate further the regional decisions made for the 21E Waiver sites cited in the report, and to the status of the Aberjona River aquifer.

Please address any questions concerning the enclosed comments to Anna Mayor, Project Manager for the Wells G & H Superfund Site (Tel: 617-556-1112). Thank you.

Sincerely,

Jay Naparstek

Jay Naparstek
Section Chief, BWSC RR

AHM/bwsc

cc. Mary Garren, USEPA RPM
Anna Mayor, DEP BWSC

APPENDIX C

Remediation Area and Volume Calculations

Total Solvent Calculation of Groundwater Monitoring Wells in Unconsolidated Deposits in the Central Area

		PRIMARY SITE CONTAMINANTS (ug/l)									
WELL #	Date	Chloroform	1,1 DCA	1,2 DCA	1,1 DCE	PCE	TCE	VC	1,2 DCE total	1,1,1 TCA	Total Solvents
MCL		*5[a]*	*70[a]*	*5*	*7*	*5*	*5*	*2*	*70*	*200*	
AB2	9/1993	2U	2U	2U	2U	21.2JD	363	2U	<2U	<500D	384.2
BW16	9/1993	2U	2U	2U	2U	0.6J	107D	2U	7.6	12	127.2
DP1	12/17/91	5U	5U	5U	5U	68	5	10U	3	12	88
DP24	4/6/93	0.5U	0.5U	0.5U	0.5U	14	7	0.5U	0.4	3	24.4
DP6	8/9/93	150	0.5U	0.5U	0.5U	7	7	0.3	8	0.6	172.9
DP7	8/9/93	0.2	0.5U	0.5U	0.5U	7	3	0.5U	1	0.6	11.8
K42	7/26/93	4U	2	4U	4U	540	17	4U	2	4U	561
K50	7/23/93	2	0.6	0.5U	2	0.4	8	0.5U	0.5	1	14.5
K55	9/9/93	1U	1U	1U	1U	26	1	1U	1U	3	30
K60	10/19/93	0.3	0.5U	0.5U	0.5U	18	0.9	0.5U	0.5U	2	21.2
K61	10/20/93	10U	10U	10U	9	400	23	10U	9	45	486
K62	10/19/93	2U	2U	2U	2	120	11	2U	4	13	150
K63	10/18/93	1U	1U	1U	1U	90	13	1U	1	10	114
MR2	9/1993	2U	2U	2U	2U	<10U	22.6D	2U	461D	<100D	484
S39 (H)	8/26/91	1U	0.8	1U	1U	9	10	5UV	2	1U	21.8
S40 (G)	8/21/91	0.5U	0.5U	0.5U	0.5U	33	60	5UV	14	0.6	107.6
S63	3/23/94	10U	10U	10U	10U	10U	10U	10U	10U	10U	0
S64	8/11/93	0.5U	0.5U	0.5U	0.5U	32	10	0.5U	4	0.9	46.9
S65	8/6/93	0.2	0.5U	0.5U	0.5U	0.5U	17	0.8	5U	3	21
S67	4/23/97	1U	1U	1U	1U	1U	93	1U	1U	1U	93
S68	8/21/91	2	2U	2U	2U	50	37	10U	17	1	107
S77	9/22/92	5U	5U	5U	5U	2J	16	2U	NA	5U	18
S81	4/22/98	1U	1U	1U	1U	19	1U	1U	1U	0.8	19.8
S82	5/29/91	5U	5U	5U	5U	210	26	10U	12	5U	248
S84	8/20/91	1U	1U	1U	1U	16	16	5U	6	0.3	38.3
S85	9/2/93	5	2U	2U	2U	220	32	2U	2U	2U	257
S87	8/23/91	5U	5U	5U	5U	150	45	5U	23	11	229
S89	8/26/91	1U	0.9	1U	1U	2	15	0.4	0.7	2	21
S90	8/22/91	4	5U	5U	5U	77	46	10U	24	2	153
S91	9/1/93	1U	1U	1U	1U	70	32	5U	16	3	121
S93	8/27/91	1U	0.7	1U	1U	2	24	5U	2	1U	28.7
S94	8/20/91	1U	1U	1U	1U	21	21	5U	9	0.6	51.6
UG2	8/26/91	1U	1U	1U	1U	5	9	5U	13	1	28
UG4	8/22/91	1U	1U	1U	1U	22	29	5U	1U	1U	51
UG5	3/30/93	5U	15	5U	4	2U	41	1	24	5U	85

[a] = MADEP GW1 standard

Notes:

- All values are from RI Phase 1A Report (GeoTrans & RETEC, 1994) and the RD/RA Year 6 Annual Report for the Unifirst Site (Handex, et al., 1998).
- Values shown in **Bold** are greater than or equal to MCLs.
- Maximum value taken from wells with multiple screens

Abbreviations and Symbols:
MCL – Maximum Contaminant Limits
1,1-DCA – 1,1 Dichloroethane
1,2 DCA – 1,2 Dichloroethane
1,1 DCE – 1,1 Dichloroethene
1,2 DCE – 1,2 Dichloroethene
PCE – Tetrachloroethene
1,1,1,-TCA – 1,1,1 Trichloroethane
TCE – Trichloroethene
VC – Vinyl Chloride
D – Diluted Sample
J – Approximate
NA – Not Analyzed
ND – Not Detected
R – Rejected
U – Not Detected at noted detection limit
< - Less than noted concentration
-- - Not Analyzed for

Total Solvent Calculations of Groundwater Monitoring Wells in Bedrock in the Central Area

		PRIMARY SITE CONTAMINANTS (ug/l)									
WELL #	DATE	Chloroform	1,1 DCA	1,2 DCA	1,1 DCE	PCE	TCE	VC	1,2 DCE total	1,1,1 TCA	Total Solvents
MCL		*5[a]*	*70[a]*	*5*	*7*	*5*	*5*	*2*	*70*	*200*	
AB2	9/1993	2U	2U	2U	2U	**20.7D**	**144D**	2U	<20UD	<20UD	**164.7**
BW16	9/1993	2U	2U	2U	2U	10U	**41D**	2U	<10	<10U	**41**
DP6	8/9/93	0.3	0.5U	0.5U	0.5U	11	6	0.5U	4	0.6	**21.9**
DP24	8/6/93	0.5U	0.3	0.5U	0.5U	0.2	**11**	0.5U	3	0.5U	**14.5**
G01	4/22/98	1U	1U	1U	1U	**30**	2	1U	1U	1U	**32**
K55	7/26/93	1U	1U	1U	**8**	**260**	**44**	1U	11	37	**360**
K56	7/26/93	0.5U	0.5U	0.5U	0.5U	1	**5**	0.5U	0.5J	0.6	**6.6**
K60	10/19/93	0.5U	1	0.5U	0.5U	**26**	0.8	0.5U	0.5	0.9	**29.2**
K61	10/20/93	0.5U	0.6	0.5U	0.3	**32**	**5**	0.5U	5	2	**44.9**
K62	10/19/93	0.5U	0.5UJ	0.5UJ	0.5UJ	**11**	2	0.5UJ	3	0.5	**16.5**
K63	10/18/93	1UJ	0.5J	1UJ	0.9	**82**	**14**	1UJ	3	5	**104.9**
K64	10/20/93	1/0/00	0.5U	0.5U	0.2	**29**	**6**	0.5U	1	1	**37.5**
S22	8/9/93	0.5U	0.5U	0.5U	0.2	**15**	**19**	0.5U	24.2	2	**60.4**
S63	11/9/93	ND	ND	ND	ND	**6.6**	ND	ND	ND	ND	**6.6**
S64	8/11/93	1	2	0.5U	1	**250**	**100**	**2**	53	2	**411**
S65	8/11/93	2U	2	2U	2U	**200**	**42**	2U	13	1J	**257**
S66	9/20/93	0.5U	0.5U	0.5U	0.5U	**29**	3	0.5U	0.6	0.5U	**32.6**
S67	4/23/97	1U	1U	1U	1U	0.6	**22**	2U	2U	0.5	**23.1**
S77	9/1993	100U	100U	100U	100U	**25DJ**	**403D**	100U	NA	100U	**428**
S81	4/21/98	1U	1U	1U	1U	**190**	**5**	2U	1U	1U	**195**
S97	9/2/93	1U	1U	1U	1U	**99**	**42**	1U	22	1	**164**
UC14	4/22/98	1U	1U	2	1U	1	**11**	2U	1U	1U	**14**

[a] = MADEP GW1 standard

Notes:

- All values are from RI Phase 1A Report (GeoTrans & RETEC, 1994) and the RD/RA Year 6 Annual Report for the Unifirst Site (Handex, et al., 1998).
- Values shown in **Bold** are greater than or equal to MCLs.
- Maximum value taken from wells with multiple screens

Abbreviations and Symbols:

MCL – Maximum Contaminant Limits
1,1-DCA – 1,1 Dichloroethane
1,2 DCA – 1,2 Dichloroethane
1,1 DCE – 1,1 Dichloroethene
1,2 DCE – 1,2 Dichloroethene
PCE – Tetrachloroethene
1,1,1,-TCA – 1,1,1 Trichloroethane
TCE – Trichloroethene
VC – Vinyl Chloride
D – Dilutes Sample
J – Approximate
NA – Not Analyzed
ND – Not Detected
R – Rejected
U – Not Detected at noted detection limit
< - Less than noted concentration
- - Not Analyzed for

CENTRAL AREA CORRIDOR (SEE FIGURE 1)

AREA [A] = $\frac{1}{2}(550' + 700') \times 1200'$ = 750,000 s.f. (= 17.2 acres)

AREA [B] = $850' \times 700'$ = 595,000 s.f. (= 13.7 acres)

AREA [C] = $\frac{1}{2}(1100' \times 380')$ = 209,000 s.f. (= 4.8 acres)

1,554,000 s.f. (= 35.7 acres)
or 1.55×10^6 s.f
= REMEDIATION AREA OF CENTRAL AREA CORRIDOR

VOLUME DETERMINATION

ASSUMING THE AREA IS REPRESENTED BY CROSS-SECTION 5-5' (METHENY, 1998) (FIGURE 2 ATTACHED)

- UNCONSOLIDATED DEPOSITS:
  AVERAGE DEPTH OF WATER TABLE = 102'

  FOR POROSITY:
  MOST OF THE MATERIALS SHOWN IN THE CROSS-SECTION ARE SANDS + GRAVEL, WHICH HAS A POROSITY OF 0.25-0.26 ACCORDING TO METHENY (1998) - TABLE 9.3

  TO ACCOUNT FOR LESS PERMEABLE MATERIALS (CLAY, PEAT + SILT) ASSUME = 25% OF THESE SOILS - USE n of 0.40 for

  $n_{avg} = .75(0.255) + .25(0.40) = 0.29125$ say 0.29

  VOLUME OF WATER = n_{avg} × depth × Area

  $= 0.29 \times 102' \times (1.55 \times 10^6 \text{ s.f.}) \times 7.48$ gallon/cu.ft

  $= 343 \times 10^6$ gallons ◄

- BEDROCK
  USING A RECOVERY DEPTH OF 50'* and n = 0.05 (METHENY, 1998)

  ASSUME ALSO SAME CONTAMINATION AREA

  VOLUME = $0.05 \times 50' \times (1.55 \times 10^6 \text{ s.f}) \times 7.48$ gal/c.ft

  $= 29.0 \times 10^6$ gallons ◄

* DEPTH WITHIN BEDROCK USED BY GEOTRANS AND RETEC (1994) TO REPORT CONTAMINANT LEVELS IN BEDROCK.

AREAS NORTH OF OLYMPIA AVENUE

- UNCONSOLIDATED DEPOSITS (WELLS K42 + UG5)

  - ASSUME 100' RADIUS AROUND EACH WELL
    AREA = $\pi (100')^2$ = 31,400 s.f.

  @ WELL K42 → DEPTH TO BEDROCK ≈ 70' bgs
  DEPTH TO W.T. ≈ 5 bgs   > 65'

  FROM METHENY, 1998 CROSS-SECTION 1-1' + TABLE 9-3
  USE A POROSITY OF 0.25   FIGURE 3 ATTACHED

  VOLUME @ K42 = 0.25 × 65' × 31,400 sf × 7.48 gal/c.ft

  = 3.82 × 10^6 gallons ◄

  @ WELL UG5 → DEPTH TO BEDROCK ≈ 50' bgs
  DEPTH TO W.T ≈ 5' bgs

  FROM METHENY, 1998 CROSS-SECTION 1-1' + TABLE 9-3
  USE A POROSITY OF 0.27

  VOLUME @ UG5 = 0.27 × 45' × 31,400 sf × 7.48 gal/c.ft

  = 2.85 × 10^6 gallons ◄

- BEDROCK (WELL UC14)

  - ASSUME 200' RADIUS AND A FRACTURED DEPTH OF 50'

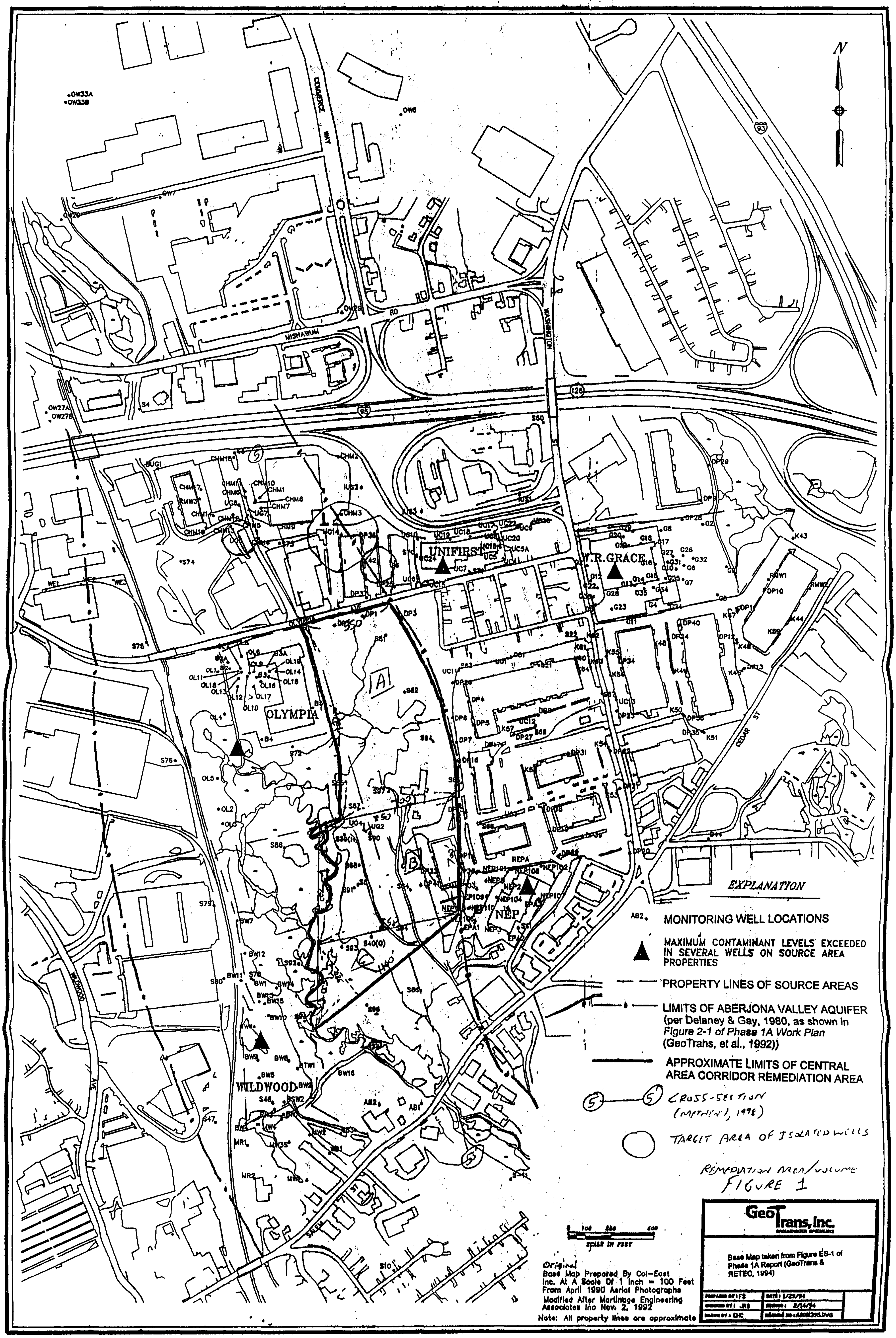
  FROM METHENY, 1998 – TABLE 9.3, USE A POROSITY OF 0.05 FOR BEDROCK

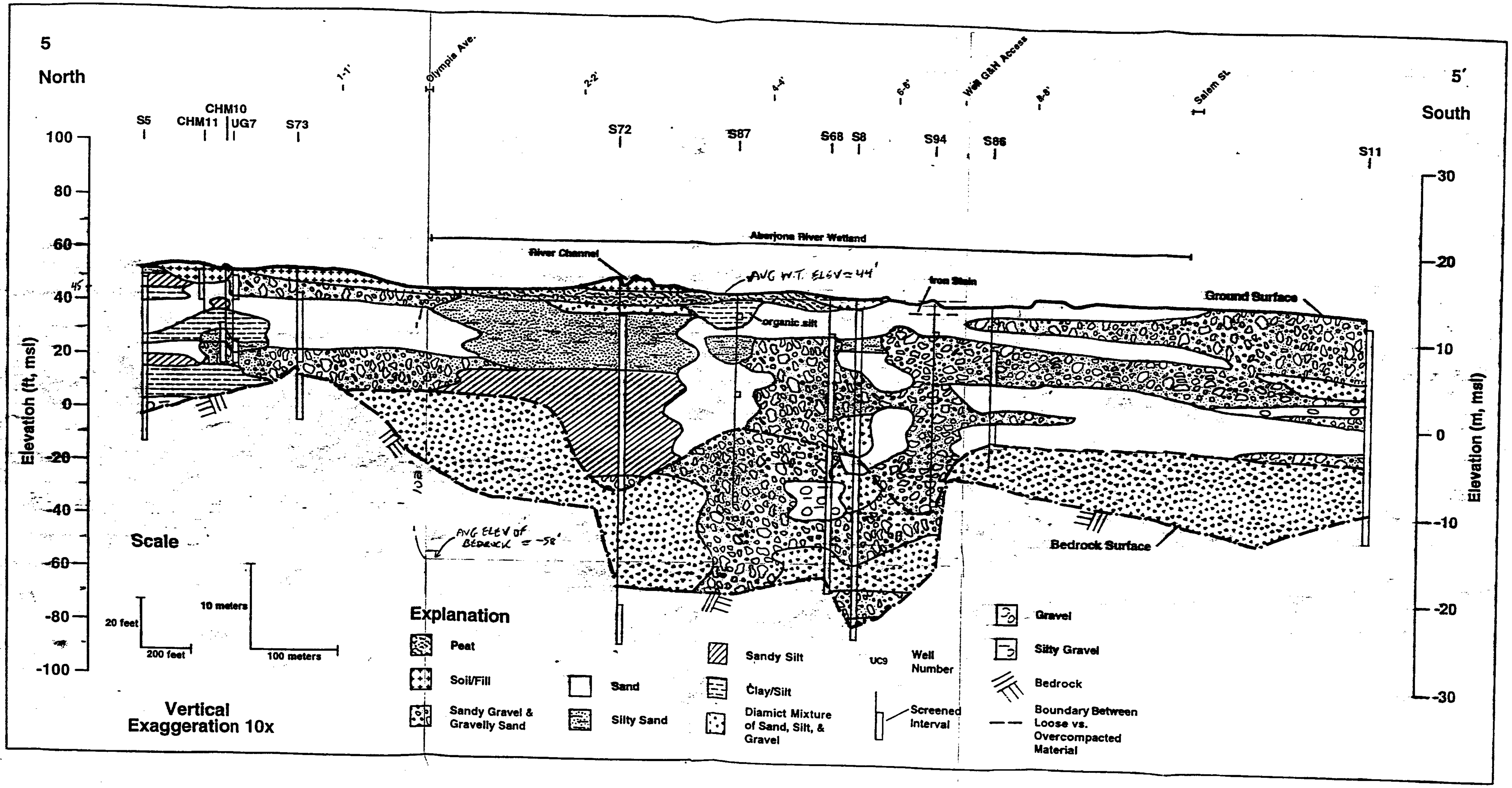
  AREA = $\pi (200')^2$ = 126,000 s.f.

  VOLUME @ UC14 = 0.05 × 50' × 126,000 sf × 7.48 gal/c.ft

  = 2.36 × 10^6 gallons ◄

TOTAL VOLUME NORTH OF OLYMPIA AVENUE = 9.03 × 10^6 gallons


UNIFIRST
W.R.GRACE
OLYMPIA
NEP
WILDWOOD
MISHAWUM RD
COMMERCE WAY
WASHINGTON ST
CEDAR ST
WILDWOOD AVE
SALEM ST
EXPLANATION
MONITORING WELL LOCATIONS
MAXIMUM CONTAMINANT LEVELS EXCEEDED IN SEVERAL WELLS ON SOURCE AREA PROPERTIES
PROPERTY LINES OF SOURCE AREAS
LIMITS OF ABERJONA VALLEY AQUIFER (per Delaney & Gay, 1980, as shown in Figure 2-1 of Phase 1A Work Plan (GeoTrans, et al., 1992))
APPROXIMATE LIMITS OF CENTRAL AREA CORRIDOR REMEDIATION AREA
CROSS-SECTION (METCALF, 1998)
TARGET AREA OF ISOLATED WELLS
REMEDIATION AREA/VOLUME
FIGURE 1
GeoTrans, Inc.
Base Map taken from Figure ES-1 of Phase 1A Report (GeoTrans & RETEC, 1994)
SCALE IN FEET
Original
Base Map Prepared By Col-East Inc. At A Scale Of 1 Inch = 100 Feet From April 1990 Aerial Photographs
Modified After Martinage Engineering Associates Inc Nov. 2, 1992
Note: All property lines are approximate



HORIZ
0.48" = 200'
1" = 417'

VERTICAL
0.48" = 20'
1" = 42'

Figure 8.3 continued...

REMEDIATION AREA / VOLUME
FIGURE 2.

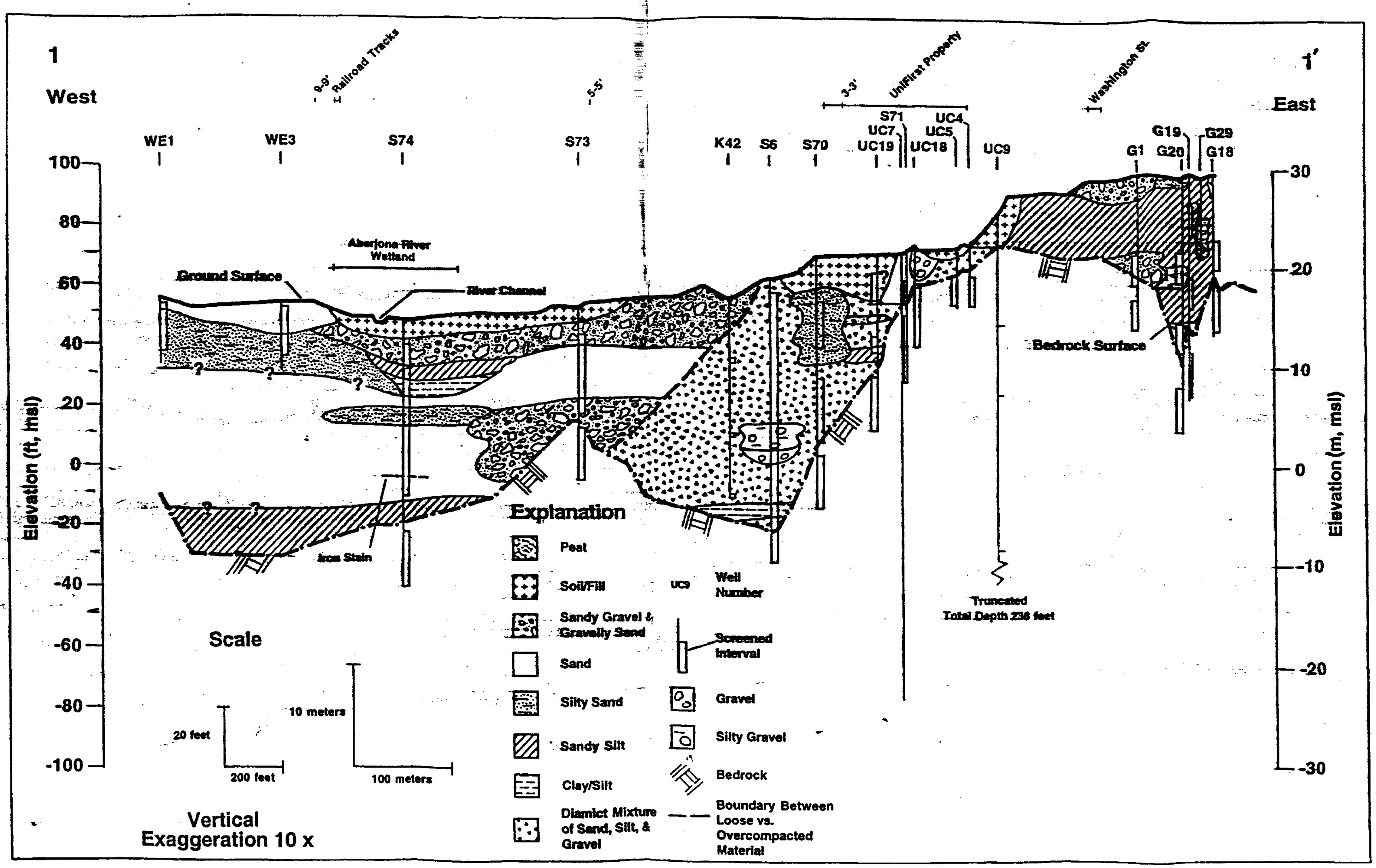


Figure 8.2 East-West Geologic Cross Sections 1-1', 2-2', 4-4', 6-6', and 8-8'

REMEDIATION AREA / VOLUME
FIGURE 3

APPENDIX D

Background on Natural Attenuation Alternative

Aliphatic Hydrocarbon Biodegradation

Over the past two decades, numerous laboratory and field studies have demonstrated that subsurface microorganisms can degrade a variety of chlorinated solvents (Bouwer and Wright,, 1988; Miller and Guengerich, 1982; Cline and Defino, 1989; Freeman and Gossett, 1989' Hartmans and de Bont, 1992' McCarty and Semprini, 1994, Vogel, 1994).

In an uncontaminated aquifer, native organic carbon is used as an electron donor, and dissolved oxygen (DO), is used first as the prime electron acceptor. Where anthropogenic carbon (e.g., as fuel hydrocarbons) is present, it also will be used as an electron donor. After the DO is consumed, anaerobic microorganisms typically use additional electron acceptors in the following order of preference: nitrate, ferric iron oxyhydroxide, sulfate, and finally carbon dioxide. Evaluations of the distribution of these electron acceptors provide evidence of where and how chlorinated aliphatic hydrocarbon biodegradation is occurring. In addition, because chlorinated aliphatic hydrocarbons may be used as electron acceptors or electron donors. As with BTEX, the driving force behind oxidation-reduction reaction results in degradation. Although thermodynamically favorable, most of the reactions involved in chlorinated hydrocarbons reduction and oxidation do not proceed abiotically. Microorganisms are capable of carrying out the reactions, but they will facilitate only those oxidation-reduction reactions that have a net yield of energy (USEPA, 1998).

Mechanisms of Chlorinated Aliphatic Hydrocarbon Biodegradation

Electron Acceptor Reactions (Reductive Dehalogenation)

The most important process for the natural biodegradation of the more highly chlorinated solvents is reductive dechlorination. During this process, the chlorinated hydrocarbon is used as an electron acceptor, not as a source of carbon, and a chlorine atom is removed and replaced with a hydrogen atom. In general, reductive dechlorination occurs by sequential dechlorination from PCE, to TCE to DCE to VC to ethene. Depending upon environmental conditions, this sequence may be interrupted, with other processes then actions up the products. During reductive dechlorination, all three isomers of DCE can theoretically be produced. However, Bouwer (1994) reports that under the influence of biodegradation, ciis-1,2-DCE is a more common intermediate than trans-1,2-DCE, and that 1,1-DCE is the least prevalent of the three DCE isomers when they are present as daughter products. Reductive dechlorination of chlorinated solvent compounds is associated with accumulation of daughter products and an increase in the concentration of chloride ions. Reductive dechlorination affects each of the chlorinated ethenes differently. Of these compounds, PCE is the most susceptible to reduction dechlorination because it is the most oxidized. Conversely, VC is the least susceptible to reductive dechlorinated because it is the least oxidized of these compounds. As a result, the rate of reductive dechlorination decreases as the degree of dechlorination decreases (Vogel and McCarthy, 1985, Bouwer, 1994).

Murray and Richardous (1993) estimated that the reductive dechlorination rate decrease might explain the accumulation of VC in PCE and TCE plumes that are undergoing reducing conditions. Reductive dechlorination has been demonstrated under nitrate and iron reducing conditions, but the most rapid biodegradation rates, affecting the widest range of chlorinated aliphatic hydrocarbons, occur under sulfate reducing and methanogenic conditions (Bower, 1994). Because chlorinated aliphatic hydrocarbons are used as electron acceptors during reductive dechlorination, there must be an appropriate source of carbon for microbial growth in order for this process to occur (Bouwer, 1994). Potential carbon sources include natural organic matter, fuel hydrocarbons, or other anthropogenic organic compounds such as landfill leachate.(USEAP, 1998)

Electron Donor Reactions

Microorganisms are generally believed to be incapable of growth using PCE and TCE as a primary substrate (Murray et al., 1993). However under aerobic and some anaerobic conditions, the less oxidized CAHs can be used as the primary substrate in biological mediated oxidation-reduction reactions (McCarthy and Semprini, 1994). In this type of reaction, the facilitating microorganism obtains energy and organic carbon from the degraded CAH. IN contrast to reactions in which the CAH is used as electron donors in biological mediated oxidation-reduction reaction. McCarthy and Semprini (1994) describe investigation in which VC and 1,2 DCA were shown to serve as primary substrates under aerobic conditions. The authors also document that DCS has the potential to function as a primary substrate. In addition, Klier et al. (1988) and Bradley and Chapelle (1997) show mineralization of DCE to carbon dioxide under aerobic Fe(IOII) reducing and methanogenic conditions (USEPA 1998).

Cometabolism

When a CAH is biodegraded via cometabolism, an enzyme or cofactor that is fortuitously produced by the organisms for other purposes catalyzes the degradation. The organism receives no known benefit from the degradation of the CAH. Rather, the cometabolic degradation of the CAH may in fact be harmful to the microorganism responsible for the production of the enzyme or cofactor (McCarthy and Semprini, 1994). Cometabolism is best documented in aerobic environments, although it potentially could occur under anaerobic conditions (USEPAS, 1998)

Behavior of Chlorinated Solvents

Chlorinated solvent plumes can exhibit three types of behavior depending on the amount of solvent, the amount of biological available organic carbon in the aquifer, the distribution and concentration of natural electron acceptors, and the types of electron acceptors being used. Individual plumes may exhibit behavior are summarized below.

Type I Behavior

Type I behavior occurs where the primary substrate is anthropogenic carbon (e.g. BTEX or landfill leachate), and microbial degradation of this carbon drives reductive dechlorination. The following questions must be address for Type I:

- Is the electron donor supply adequate to allow microbial reduction of the chlorinated organic compounds? In other words, will the microorganisms run out of CAH used as electron acceptor before they run out of carbon?
- What is the role of competing electron acceptors?
- Is VC oxidized or reduced?

Type II Behavior

This behavior dominates in areas that are characterized by relatively high concentrations of biologically available native organic carbon. Microbial utilization of this natural carbon source drives reductive dechlorination. When evaluating type II the same questions as those posed in Type I must be answered. Type II generally results in slower biodegradation of the highly chlorinated solvents than Type I (USEPA, 1999).

Type III Behavior

Type III behavior dominates areas that are characterized by inadequate concentrations of native and or anthropogenic carbon, and concentrations of dissolved oxygen that are greater than 1.0 mg/L. Under these aerobic conditions, reductive dechlorination will not occur. The most significant natural attenuation mechanisms for PCE, TCE, and DCE will be advection, dispersion, and sorption. Type III behavior also occurs in groundwater that does not contain microbes capable of biodegradation of chlorinated solvents (USEPA, 1999).

Type IV Behavior

A chlorinated solvent plume can exhibit all three types of behavior in different portions of the plume. This can be beneficial for natural biodegradation of CAHs. The following sequence of reactions occur in a plume that exhibits mixed behavior (USEPA, 1999).

$$\text{PCE} \rightarrow \text{TCE} \rightarrow \text{DCE} \rightarrow \text{VC} \rightarrow \text{Carbon Dioxide}$$

In general TCE, DCE, and VC may attenuate at approximately the same rate. Note that not ethene is produced during this reaction.

When CAHs are reductively dechlorinated via type I or type II behavior, vinyl chloride is reduced to ethene, which may further be reduced to ethane or methane. The following sequence of reactions occurs in the type of plume (USEPA, 1999).

$$\text{PCE} \rightarrow \text{TCE} \rightarrow \text{DCE} \rightarrow \text{VC} \rightarrow \text{Ethene} \rightarrow \text{Ethane}$$

In this type of plume, VC degrades more slowly than TCE, and thus tends to accumulate.

APPENDIX E

Calculations for the Natural Attenuation Alternative

1. One Dimensional Advective Dispersion Equation

The one dimensional advective transport component of the advection dispersion equation is

$$t = C/(v * \frac{C}{x})$$

given by:

Where:

- t = time
- v = average linear velocity
- C = contaminant concentration
- x = distance along flow path

2. Pore Volume Calculation for the Central Area

$PV = -R \ln(C_s/C_i)$

Where

- PV = the number of pore volumes of flushing required to reduce the concentration from C_i to C_s
- R = retardation coefficient
- C_s = final concentration (5 μg/L – drinking water standard)
- C_i = initial concentration

  (PCE: 168.3 μg/L; TCE: 40.4 μg/L – worst case scenerio average)

3. Retardation Equation

The retardation coefficient was determined by this equation:

$R = 1 + K_d \bullet \rho_b/n$

where

- R = retardation coefficient
- K_d = partitioning coefficient = $f_{oc} \bullet k_{oc}$
- f_{oc} = 0.001 (RETEC, 1997)
- k_{oc} = 263 for PCE (Suthersan, 1997)
- k_{oc} = 66 for TCE (Suthersan, 1997)
- ρ_b = 1.6gm/mL (RETEC, 1997)
- n = porosity (0.28 for unconsolidated deposits and 0.05 for bedrock, both values from Capstone calculations)

4. Calculation of Advection Transport Time

Location	pathline time (years)	pathline distance (meters)	Average linear velocity meters/year	contaminant conc. Ug/m³	distance (meters)	Advection Transport time (years)
1	33.6	1150	34	263,000	450	13.1
2	8.5	1250	147	263,000	450	3.1
3	2.8	300	107	263,000	450	4.2
4	5.5	250	45	263,000	450	9.9
5	0.7	200	286	263,000	450	1.6
Average	**10.2**	**630.0**	**123.9**	**263000**	**450**	**6.4**

Notes:
Source: Metheny, Maura Agnew. 1998. Numerical Simulation of Groundwater Flow and Advective Transport at Worburn, MA, Based on Sedimentological Model of Glacial and Glaciofluvial Deposition. The Ohio State University. Columbus, OH.

Locations:
1 = W.R. Grace Property (Northern) to the Aberjona River
2 = W.R. Grace Property (Southern) to the Aberjona River
3 = Olympia Property to the River
4 = NEP Property to Well S46
5 = Wildwood Property to the Aberjona River

COLUMBIA ANALYTICAL SERVICES

Quote From:

_X_ 1 Mustard St. ▪ Suite 250 ▪ Rochester, NY 14609 ▪ 716/288-5380 ▪ (FAX) 716/288-8475

___ 69 South Main St. ▪ Lambertville, NJ 08530 ▪ 609/397-5326 ▪ (FAX) 609/397-5327

Quotation

| 2985 |

Quote Date : 07/23/99
Valid Until: 12/31/00
Client ID : MAL-BOSTON

Attn: Mr. Peter Carvalho
Company: Malcolm Pirnie
Address: 2 Faneuil Hall
Boston, MA 02109

Phone No. (617) 624-6867
FAX No. (617) 742-3666

PROJECT REFERENCE:
EPA PROJECT

ANALYSIS OF 18 WATER SAMPLES PLUS 1 MS/MSD QUARTERLY FOR THE PARAMETERS LISTED BELOW. A STANDARD HARD COPY REPORT WILL BE MAILED WITHIN 3 WEEKS OF SAMPLE RECEIPT. ALL MS/MSD'S AND FIELD QC ARE BILLABLE AT THE UNIT COSTS. SHIPPING VESSLES AND SAMPLE CINTAINERS ARE AVAILABLE AT NO ADDITIONAL COST PROVIDED A 3 BUSINESS DAY NOTICE IS GIVEN.

HYDROGEN WILL BE SUBCONTRACTED TO MICROSEEPS. THE METHANE METHOD QUOTED ACHIEVES A DETECTION LIMIT OF 1-2 PPB. IF A LOWER DETECTION LIMITS IS REQUIRED, IT WOULD HAVE TO BE SUBCONTRACTED TO MICROSEEPS AT A COST OF $85.00.

Profile/ Test #	Sample Matrix	Method/Analyte		No. of Samples	Unit Price	Extended Price
344	AQUEOUS	TCLP ORGANICS 8260/8270A/8081/8151		20	670.00	13400.00
1318	AQUEOUS	HYDROGEN (SUBCONTRACTED)		20	85.00	1700.00
411	AQUEOUS	TCLP VOLATILES BY 1311/8260B		20	110.00	2200.00
VOLATILE ORGANICS						
2935	AQUEOUS	8015B	METHANE ONLY BY 8015	20	70.00	1400.00
WET CHEMISTRY						
3003	AQUEOUS	FE+2.	FERROUS IRON BY METHOD 3500	20	35.00	700.00
3119	AQUEOUS	300.0	NITRATE NITROGEN (NO3) AS N BY ION CHROM	20	15.00	300.00
3120	AQUEOUS	300.0	SULFATE BY ION CHROMATOGRAPHY	20	15.00	300.00
2652	AQUEOUS	9030B	SULFIDE, TOTAL	20	40.00	800.00
						==========
			Analytical Total :			20800.00
			Quotation Total:			20800.00

DELIVERABLES: I [X] II [ ] III [ ] IV [ ] V [ ]

* N.Y. State Certification Fee is not applicable to subcontracted analytical work or to field services.

Follow up Call: ________ ________

Project Chemist: Janice Jaeger
Sales Person : UN-ASSIGNED

FAX ACKNOWLEDGMENT TO (716) 288-8475

Date Sample Bottles Needed: ________

Estimated Sample Deliver Date: 8/99
Estimated Results Due Date : 8/99
TAT in Business Days : 10
P.O. # ____________ (If Available)

____________________ ________
Quotation Accepted By Date

APPENDIX F

Background on Air Stripping

Air Stripping

Air stripping is an ex-situ treatment technology where volatile organic compounds are stripped from the groundwater and partitioned into the air. The air is then treated and the volatile organic compounds are removed or destroyed. There are four types of aeration methods:

- Packed towers
- Diffused aeration
- Tray aeration
- Spray aeration (http://www.frt.gov/matrix2/section4/4_50.html#cost, 1999)

Air stripping is used to separate VOCs from water and is ineffective for inorganic contaminants. Some compounds that have been successfully separated from water using air stripping include BTEX, chloroethane, TCE, DCE, and PCE (www.frt.gov/matrix2/section4/4_50.html#cost, 1999). The following factors may limit the applicability and effectiveness of the air stripping process:

- The potential exists for inorganic (e.g., iron greater than 5ppm, hardness greater than 800ppm) or biological fouling of the equipment, requiring pretreatment or periodic column cleaning.
- Effective only for contaminated water with VOC or semivolatile concentrations with a dimensionless Henry's constant greater than 0.01.
- Consideration should be given to the type and amount of packing used in the tower.
- Process energy costs are high.
- Compounds with low volatility at ambient temperatures may require treatment based on mass emission rate (http://www.frt.gov/matrix2/section4/4_50.html#cost, 1999).
- Contaminant concentration.
- Water temperature.
- Air-to-water ratio (McFarland, 1990).

Air stripping is usually carried out in towers where water is pumped to the top of a system and the water is distributed over slats, rings, or corrugated surfaces. Air is usually blown counter-current or cross-current to the water. The internal components of an air stripper are selected to ensure that mass transfer takes place under the most effective and economical conditions. The packing material is one of the most important factors in stripper design. It provides surface area for the air and water to interact and creates turbulence in the water stream to expose the water surfaces to the air (Watts, 1997).

Treated effluent from the air stripper is discharged directly to surface water, groundwater, storm drains, or municipal sanitary sewers. A single pass through an air stripper will not usually remove all the contaminants and it may be necessary to provide additional treatment with further air stripping or activated carbon adsorption prior to discharge depending on effluent discharge standards. The process is fairly easy to install and operate and can result in effective removal of nearly all VOCs from solution. Removal efficiencies for BTEX can exceed 99% for a single pass system. Removal of PCE, TCE and MEK can be 95 to 99% under good conditions (McFarland, 1990).

APPENDIX G

Calculations for the Pump & Treat Alternative

Wells used to Determine PCE and TCE Concentrations in the Centrals Area Cooridor for the Pump and Treat Alternative

Unconsolidated Deposits

Well	TCE	PCE
DP1	5	ND
S39 (H)	10	9
S40 (G)	60	33
S64	33	92
S65	7	17
S68	37	50
S81	5	200J
S82	26	210
S84	16	16
S85	32	220J
S87	45	150
S89	21	97
S90	46	77
S91	32J	70J
S93	30	17
S94	21	21
UG2	9	5
UG4	29	22

J – Approximate
ND – Not Detected

Bedrock

Well	TCE	PCE
S64	100	250
S65	42	250
S66	3	30
S81	5	180
S97	42J	99J

J – Approximate

Equations for Determining Drawdown and Width of Capture Zone

The drawdown was determined by using the following equations (Murray, 1999).

$Q/S = T/2000$ (for a confined aquifer)

where

- Q = flow rate from a well in gpm
- S = drawdown at the well in feet
- T = transmissivity in gpd/ft

The calculations for transmissivity were determined from the average hydraulic conductivity data given in the Phase 1A. The depth of the bedrock used was 50 ft and the depth of the unconsolidated deposits used was 93 ft. Another equation (Murray, 1999) was to determine the width of the capture zone:

$W = Q/(Ti)$

where

- W = width of capture zone
- Q = discharge rate
- T = transmissivity
- i = hydraulic gradient (0.02 from USGS (Myette, 1987))

Equations for drawdown:

$\frac{Q}{S} = T/2000$ (for a confined aquifer)

where Q = flow rate from a well in gpm
S = drawdown @ the well in feet
T = transmissivity in gpd/ft

Bedrock

$T = 250 \frac{ft^2}{day} \Big| \frac{7.48 \text{ gal}}{1 ft^3} = 1870 \frac{gal}{ft \cdot day}$

Unconsolidated

$T = 2285 \frac{ft^2}{day} \Big| \frac{7.48 \text{ gal}}{1 ft^3} = 17091.8 \frac{gal}{ft \cdot day}$

• see Table 7-9 for drawdown results

Bedrock

$\frac{10 \text{ gpm}}{S} = \frac{1870 \frac{gal}{ft \cdot day}}{2000}$

∴ S = 10.7 @ 10 gpm in bedrock

Equation for Width of Capture Zone

$W = \frac{Q}{Ti}$ where Q = discharge rate

T = transmissivity

i = hydraulic gradient [illegible]

[illegible] 7-9 for Width of Capture Zone [illegible]

T = 350 ft²/day in bedrock

[illegible] ft²/day in unconsolidated deposits

[illegible]

$W = \frac{10\ gpm}{([illegible]\ \frac{ft^2}{day})([illegible])} \left| \frac{1\ ft^3}{7.48\ gal} \right| \frac{60\ min}{1\ hr} \left| \frac{24\ hr}{day} \right.$

W = 385 ft. @ 10 gpm

Equations for Determining Number of Pore Volume Flushing and Retardation

The EPA Batch Flush Model equation (USEPA, 1988b) was needed to determine the time needed to remediate the Central Area Corridor:

$$PV = - R \ln(C_s/C_i)$$

where

- PV = the number of pore volumes of flushing required to reduce the concentration from C_i to C_s
- R = retardation coefficient
- C_s = final concentration (5 µg/L – drinking water standard)
- C_i = initial concentration (PCE: 168.3 µg/L; TCE: 40.4 µg/L – worst case scenerio average)

The retardation coefficient was determined by this equation:

$$R = 1 + K_d \bullet \rho_b/n$$

where

- R = retardation coefficient
- K_d = partitioning coefficient = $f_{oc} \bullet k_{oc}$
- f_{oc} = 0.001 (RETEC, 1997)
- k_{oc} = 263 for PCE (Suthersan, 1997)
- k_{oc} = 66 for TCE (Suthersan, 1997)
- ρ_b = 1.6gm/mL (RETEC, 1997)
- n = porosity (0.28 for unconsolidated deposits and 0.05 for bedrock, both values from Capstone calculations)

c. Time for Number of Pore Volume Flushings

$PV = -R \ln\left(\frac{C_f}{C_i}\right)$ where PV = # of pore volume [illegible]

R = retardation coefficient

C_f = final concentration = (4)

C_i = initial concentration

PCE = 163.8 mg/L

TCE = 40.4 mg/L

see Table 7-10 for results

a) PCE in bedrock

$PV = -9.4 \ln\left(\frac{5\ mg/L}{163.8\ mg/L}\right)$

= 32.9 for PCE in bedrock

Equation for Retardation Coefficient

$R = 1 + K_d \cdot \frac{\rho_b}{n}$ where K_d = partitioning coefficient

$= f_{oc} \cdot K_{oc}$

$f_{oc} = 0.001$

$K_{oc} = 263$ for PCE

$= 66$ for TCE

$\rho_b = 1.6$ gm/mL

$n = 0.28$ for unconsolidated

$= 0.05$ for bedrock

See Table 7-10 for results

ex. PCE in bedrock

$R = 1 + K_d \cdot \frac{\rho_b}{n}$

$K_d = f_{oc} \cdot K_{oc}$

$= 0.001 \cdot 263 \Rightarrow K_d = 0.263$

$\therefore R = 1 + 0.263 \cdot \frac{1.6}{0.05}$

R = 9.4 for PCE in bedrock

Equation to Determine Dilution Factor

The dilution factor is dependent on the pumping rate:

$$\text{Dilution Factor} = \frac{(Qd + 7Q10)}{Qd}$$

where

- Qd = maximum discharge flow (240 gpm)
- 7Q10 = the lowest flow over seven consecutive days on the average once in ten years (139 gpm) (RETEC, 1999)

Equation for Dilution Factor:

Dilution Factor = $\frac{Qd + 7Q10}{Qd}$

$Qd = 240$ gpm

$7Q10 = 139$ gpm

Dilution Factor = $\frac{240 + 139}{240}$

$= 1.58$

Equations to Determine Remediation Time

To get the approximated remediation time, the volume of groundwater of either the unconsolidated deposits or the bedrock is divided by a given pumping rate. This value is then multiplied by the number of pore volumes (PCE is the worst case scenerio and is therefore a conservative value) and divided by the number of wells pumping at that rate.

- Approximate remediation time = (volume of groundwater)/(pumping rate)
- Adjusted remediation time = $\dfrac{\text{(pore volume number) x (Remediation time)}}{\text{number of wells pumping at that rate}}$

Equations for Remediation Time

Incomplete remediation time (IRT) $= \frac{\text{vol. of GW}}{\text{pumping rate}}$

Remediation time $= \frac{PV \times IRT}{\#\text{ wells pumping @ that rate}}$

* see table 7-11 for remediation time

PCE in bedrock

Incomplete remediation time $= \frac{29 \times 10^6 \text{ gal}}{10 \text{ gpm} \cdot \frac{60 \text{ min}}{1 \text{ hr}} \cdot \frac{24 \text{ hr}}{\text{day}} \cdot \frac{365 \text{ d}}{\text{yr}}}$

$= 5.5$ yr

Remediation time $= \frac{32.9 \times 5.5 \text{ yr}}{4 \text{ wells}}$

Remediation time = 45 yrs to remediate bedrock w/ 4 wells @ 10 gpm each

APPENDIX H

Background on Vapor Granulated Activated Carbon

Vapor Granulated Activated Carbon

Vapor-phase carbon adsorption is a remediation technology in which pollutants are removed by physical adsorption onto activated carbon grains. Carbon is "activated" for this purpose is processing the carbon to create porous particles with a large surface area that attracts and adsorbs organic molecules as well as certain metal and inorganic molecules. The adsorption of VOCs on the surfaces of carbon is mainly a physical process involving van der Waals type forces. The VOCs are mostly retained in the carbon pore structure (Suthersan, 1997).

Vapor-phase carbon adsorption is not recommended for high contaminant levels from effluent air streams (http://www.frtr.gov/matrix2/section4/4_64.html, 1999). GAC systems are generally fixed beds, and the contaminated air is passed through the adsorbent bed. The adsorption of VOCs from the air by a carbon bed is a continuous process. Factors that may limit the effectiveness of this process include:

- Spent carbon transport may require hazardous waste handling.
- Spent carbon must be disposed of and the absorbed contaminants must be destroyed, often by thermal treatment.
- Relative humidity greater than 50% can reduce carbon capacity.
- Elevated temperatures from SVE pumps (greater than 38°C or 100°F) inhibit adsorption capacity.
- Biological growth on carbon or high particulate loadings can reduce flow through the bed.
- Some compounds, such as ketones, may cause carbon bed fires because of their high heat release upon adsorption (http://www.frtr.gov/matrix2/section4/4_64.html, 1999).
- Chlorinated organics compounds may produce HCl during steam regeneration and cause the beds and container to corrode, requiring periodic replacement (Suthersan, 1997).

Desorption of the carbon refers to the process or regenerating the carbon to restore its adsorbing capacities and preserve its useful life (usually 2 to 5 years). The desorption process normally lasts 1 to 2 hours and consists of the following three steps:

1. Regeneration of the carbon
2. Bed drying
3. Returning the bed to its operating temperature

Carbon regeneration is accomplished by volatilizing the adsorbed compounds either by raising the temperature of the carbon bed by steam or lowering the temperature of the carbon bed to vacuum conditions to increase the vapor pressure of the adsorbed VOCs (Suthersan, 1997). The carbon can be regenerated in place, regenerated at an off-site regeneration facility, or disposed of.

APPENDIX I

Vendor Pricing for the Air Stripper and Vapor Granulated Activated Carbon System

"CLEANING THE WORLD WITH ACTIVATED CARBON"

GC Corp
GENERAL CARBON CORP.

Facsimile Transmission

To: Ms. Piyaluck Rattanaront

From: Tim Joyce

Date: July 12, 1999

Number of Pages (including cover page): 3

Please Call (973)523-2223 If You Do Not Receive the Correct Number of Pages

33 Paterson Street Paterson New Jersey 07501 Tel: 973 523 2223 Fax: 973 523 1494

"CLEANING THE WORLD WITH ACTIVATED CARBON"

GENERAL CARBON CORP.

July 12, 1999

Ms. Piyaluck Rattananont
Massachusetts DEP
87 Cambridge Park Drive
Cambridge, MA 02140

Fax: (617)85-8878

Dear Piyaluck:

I would like to express my gratitude for your inquiry concerning a vapor phase activated carbon adsorber. The adsorber you are looking for should be able to handle a minimum of 1800 cfm. Systems of this size are usually custom designed, however our ES-84 does fit your airflow requirements.

We are a full service activated carbon company in Paterson NJ. Our inventory consists of several million pounds of activated carbon. This carbon is used for the treatment of both both air and water. Our catalog features a complete line of carbon adsorption equipment for sale or lease, however if an application is not covered by our featured equipment, our engineering staff can design a system to fit your needs. General Carbon has the ability to service carbon filters on-site. This includes the physical changeout of carbon beds utilizing our own trucks and vacuum equipment. All spent carbon is sent to our own state of the art reactivation facility in Dover Plains, NY.

To assist you in preparing a budgetary outline please accept for consideration the followig pricing:

ES-84 Activated Carbon System $ 17,000.00 - include carbon

I hope this is of interest to you. If you should have any other questions, or if we can ever assist you in any way, please feel free to contact us.

Sincerely,

Tim Joyce

TJ/mjk

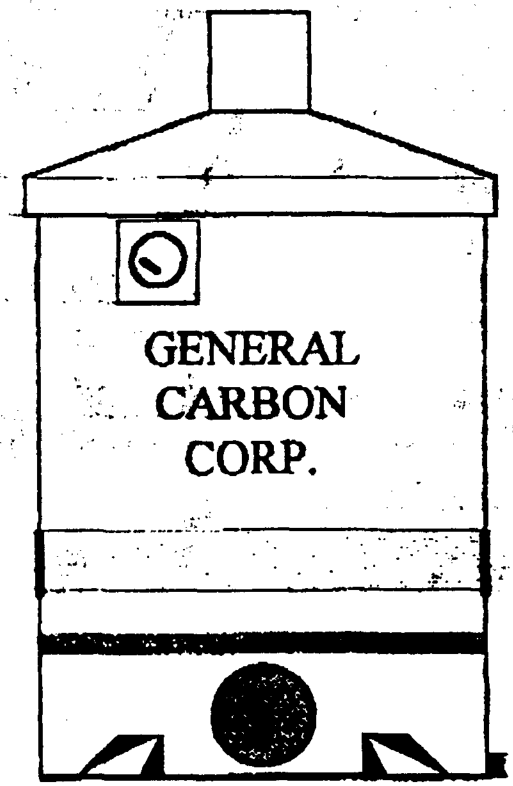
$ 550 + transport

"CLEANING THE WORLD WITH ACTIVATED CARBON"

GENERAL CARBON CORP.

ES - SERIES
ACTIVATED CARBON
Odor Control Systems

GENERAL CARBON ES Systems provide a simple, cost effective solution for odor control problems and air treatment applications. The adsorber is constructed from linear polyethylene for corrosion and weather resistance as well as durability. All fittings are welded to the tank and the top is removable for easy carbon service.



Other features are:

* High quality virgin or impregnated carbons
* Magnehelic gauge and condensate drain
* Belt driven fan with locking damper
* Standard TEFC motor at your voltage
* System mounted on structural steel skid
* Stainless Steel carbon bed ground rod
* Motor, fan and power combinations to match your project requirements
* Optional operating and instrumentation packages available upon request

MODEL	Dia.	Carbon (lbs)[1]	Recommended Flow: CFM	I/O	System Dimensions Length	Width	Height
ES-36	36"	740	285-430	8"/8"	72"	36"	72"
ES-42	42"	1010	390-610	8"/8"	84"	42"	78"
ES-48	48"	1320	510-760	8"/8"	98"	48"	84"
ES-60	60"	2100	800-1180	8"/8"	110"	60"	86"
ES-73	73"	3100	1170-1760	10"/10"	122"	73"	88"
ES-84	84"	4050	1560-2340	12"/12"	146"	84"	94"
ES-95	95"	5200	2000-3000	14"/14"	160"	95"	110"

[1] Pounds of GC-IPH Impregnated carbon. Regular Carbon will be 20% less by weight.

[illegible]

FAX TRANSMITTAL

FROM Jeffrey Barbour
Tetrasolv Filtration, Inc.
36 Taylor Ave.
Plymouth, MA 02360
508-224-1784
FAX 508-224-5997

TO Piyaluch Rattananont

FAX NUMBER : 617-665-8878
DATE : 1999/07/15

No. of Pages (Including Cover Sheet) 1

COMMENT:

Dear Kari,

Attached is the GAC calculation that we discussed today.

The vapor phase vessels I would recommend would be our VF-3000 vessels for a cost of $7,480.00 ea. plus freight from Anderson IN. Please visit our web site www.tetrasolv.com for our complete catalog and some photographs of our vessels.

If you need any more help in the future please don't hesitate to call.

Flow (CFM)	1,800.00
System Temperature (C)	20.00
System Pressure (mm Hg)	760

Compound	Mol wt	Mass Flow (lb/hr)	ppm (v/v)	Sorption (% w/w)	Carbon Saturated (lb/hr)
Tetrachloroethene	165.83	1.96E-02	3.92E-01	2.56E+01	0.076

GZA

GZA Drilling, Inc.
1215 W. Chestnut St., Brockton, MA 02301
(A Division of GZA Geo Environmental, Inc.)
Phone: 508-583-8522
Fax: 508-586-3965

Fax Cover Sheet

To: Kaori Sakaguchi
From: John Forde
Attn:
Date: 7-16-99
Fax #:
RE: Woburn, MA Proposed Wells

Total number of pages including this cover sheet: 2

Kaori,

I have some questions that I will need information on. The questions are on the attached sheet. Please fill in the information and fax back to me. I am still waiting on quotes for PVC costs. I will try to get costs to you today if possible. If not then I should have cost estimate completed by Monday 7-19-99.

John

If there are any problems with this transmission call: 508-583-8522

QUESTIONS

→ WELL POINTS

1. HOW MUCH SCREEN PER WELL ??
2. WHAT SIZE SCREEN SLOT ?
3. WHAT TYPE OF WELL PROTECTION
4. SCH. 40 OR 80 PVC ?
5. WHAT SIZE DRILL HOLE ?
6. Previous boring logs showing types of soil/rock?
7. CONTAMINATION - P.P.E. LEVEL ??
8. DRUM CUTTINGS/WASH WATER ??
9. WELL BACKFILL SPECIFICATION ?

→ CIRCULATION WELLS (IN-WELL AIR STRIPPING)

1. WHAT SIZE PVC WELL 8" OR 12" ?
2. WHAT SIZE SCREEN SLOT
3. WHAT TYPE OF WELL PROTECTION ?
4. SCH. 40 OR 80 PVC ?
5. What size Drill hole ?

EARTH EXPLORATION, INC.

Earth Exploration, Inc.

86 Elm Street, Hopkinton, MA 01748

Tel: (508) 435-7888 FAX: (508) 435-5512

PROPOSAL

via Facsimile

File Name: F:\EEI\99PROPOS\DEP9900C

Date: July 14, 1999

Subject: Wells G&H Site Woburn, MA

To: Kaori Sakaguchi
MDEP

Tel: 617-627-5118
Fax: 617-627-3401

Scope of Work:

ITEM	DESCRIPTION	UNIT $	ESTIMATED QUANTITY	TOTAL $
1)	Mobilization/Demobilization - Air Rotary Rig	$8,500.00 /ls	1 ls	$8,500.00
2)	Day Rate Air Rotary Rig & Crew 4" Wells	2,200.00 /day	25 days	55,000.00
3)	Day Rate Air Rotary Rig & Crew 8" Wells	2,400.00 /day	62 days	148,800.00
4)	4" PVC Wells Installed	17.50 /lf	740 lf	12,950.00
5)	8" PVC Wells Installed	27.50 /lf	1374 lf	37,785.00
			ESTIMATED TOTAL:	$263,035.00

Quantities listed are considered estimates not to be exceeded without notification of the Client. Price quotations will be held firm for a period of ninety days unless otherwise specified. Changes in project quantities or requirements may be cause for revision of prices as listed.

Assumptions:
The site and boring locations are truck accessible. DIGSAFE will be provided by others.

Thank you for the opportunity to submit this proposal. Feel free to call with any questions or comments.

Prepared by: ____________________
Christopher C. DeVillers
Operations Manager

This work can be scheduled by authorizing this proposal below:

Authorized by: ____________________ Date: ____________

NEEP™ Systems
environmental technologies
North East Environmental Products, Inc.
17 Technology Drive West Lebanon, NH 03784. 603-298-7061
Fax: 603-298-7063 e-mail: sales@neepsystems.com www.neepsystems.com

Thursday, 8 July 1999

Piyaluck Rattananont
MA DEP % Genetics Institute Incorporated
87 Cambridge Park Drive
Cambridge, Massachusetts 02140

Phone: 617-665-7116
Fax: 617-665-8878

RE: Proposal # 799902-1
Site ID: Wells G & H, Woburn, MA

Dear Piyaluck,

To follow-up your request, North East Environmental Products Incorporated (NEEP) is pleased to submit the following revised proposal for our ShallowTray® air stripper to remove Tetrachloroethylene (PCE) from the groundwater treatment stream on the project for the Wells G & H Superfund site in Woburn, Massachusetts. The revision being the increase of water flow to 240 gpm.

Performance:

To provide the required stripping performance at a design flowrate of up to 240 gpm and a minimum influent water temperature of 49°F, we offer our skid-mounted two-tray 316L stainless steel **Model 31221** ShallowTray low profile air stripper (hydraulic flow range 6-425 gpm, fresh air inlet flowrate 1800 cfm). Removals will follow the attached System Performance Estimate for the **Model 31221**.

It is also important that foam causing surfactants (soaps, detergents, oils, and greases) be prevented from entering the influent stream since they can inhibit the stripping operation if not properly treated. Additionally, high levels of bacteria, iron, manganese, calcium, and magnesium may affect the long term operation of the stripper and therefore require sequestration or maintenance consideration.

Pricing: The selling price for the ShallowTray **Model 31221** air stripper is as follows:

Basic System Model 31221	
Sump tank & cover, ~~304L~~ 316 stainless steel fabrication	
Two (2) Series 31200 stripper trays, 304L SS fabrication; each with gasket, latches, weirs, downcomer, & sealpot	
Forced Draft Blower, 2 tray, 25 hp, 1800 cfm @ 26wc, 3 Ø, 230V, 60Hz, TEFC, with inlet screen & damper	
Basic system accessories: spray nozzles, sight tube, drain valve, Schedule 80 PVC piping, 304L SS mist eliminator, and tray cleanout & inspection port caps	
Basic System Price Model 31221	~~$28,740~~ 37,362

Options		
Skid Mounting: Fabricated Frame with Control & Instrument Stanchion	1	$1,834
Air pressure gauge, pneumatic, in. H2O	1	$74
Discharge pump, 350 gpm, 50 tdh, 7.5 hp, 3 Ø, 230V, TEFC	1	$1,390
NEMA 4 Control Panel, w/main disconnect switch, alarm interlocks & light, and blower & discharge pump motor starters, fuses, O/Ls, H-O-A switches, & run lights; UL listed	1	$2,604
Panel Option: Intermittent operation circuitry	1	$336
Low Air pressure alarm/shutdown switch, pneumatic, EXP	1	$171
High water level alarm/shutdown float switch (N.C.)	1	$70
Discharge Pump level control float switch(es) (N.O.)	1	$70
Digital water flowmeter/totalizer (60 - 400 gpm & gal)	1	$3,218
Air flow meter, insertion pitot tube w/pressure gauge, pneumatic, in. H2O	1	$144
Viewport Set complete, (2) 4 inch & (1) 8 inch Lexan viewport	1	$62
Air blower silencer, fan inlet	1	$548
Washer wand, duplex, with (2) high pressure spray nozzles, on rollers	1	$195
Options Subtotal		$10,716
Total Model 31221 System Price, Including Options, US$ Each:		**$39,455**

Design Details:

Additional design and dimension information is included in the attached Model 31221 drawing. This design and dimension data is for preliminary information only, and is not intended for finished engineering.

Electrical Requirements:

Please note that the ShallowTray system quoted above requires the supply of 230 volt, three phase, three-wire plus ground, 60 Hertz electrical power. If your onsite electrical provisions are different, please contact North East Environmental Products. Please confirm this vital electrical information in writing on your formal purchase order.

Blower Selection:

The blower selected for the stripper above was sized to provide an additional 12" w.c. for downstream pressure losses in an offgas treatment process. As indicated in the drawing, the blower is arranged to provide forced draft to the ShallowTray, and forced draft to subsequent equipment. This arrangement exploits the temperature rise typical of centrifugal blowers by absorbing the heat energy in the vapor stream, thus lowering the vapor's Relative Humidity (RH).

Vapor stream flowrate and pressure drop are essential to the dynamics of the low-profile air stripping mechanism. ShallowTray vapor inlet and outlet duct diameters must be maintained at a minimum equal to or larger than those indicated in the drawing schedule. Additional vapor treatment equipment including dampers, filters, adsorbers, heaters, as well as unusually long or complex duct configurations require prudent engineering design to minimizing additional pressure drop and consequent additional blower duty.

Terms & Shipment:

Each ShallowTray system is shipped pre-assembled and factory tested, and an O&M manual and system start-up video are included with each unit. Normal shipment is 4-6 weeks after receipt of authorized purchase order, submittal approval, or Notice-To-Proceed (NTP).

Standard payment terms are 30% with order, 70% net 30 days from shipment, with approved credit, unless prior arrangements are made. Prices are quoted in US$, F.O.B. West Lebanon, New Hampshire, excluding freight, duty, taxes, and brokerage, and are valid for 90 days. Sales tax is neither levied nor collected in the state of New Hampshire.

Start-up Supervision:

North East Environmental Products can provide a factory-trained technician for installation inspection, start-up supervision, and operation and maintenance training provided scheduling notification is made five business days prior to onsite arrival. The cost for the technician is $720.00 per 8-hour straight-time weekday for onsite and travel time, plus food, lodging, and travel expenses.

General Conditions:

Shop Tests - ShallowTray systems are operationally tested to insure that the mechanical and electrical systems function properly. Stripping performance testing is not provided.

Codes - NEEP is *not responsible for local code or special regulatory compliance.* This quotation is based on the information provided prior to the indicated proposal date. Additional specifications included by reference (and not explicitly detailed in the documentation given to NEEP) are not covered by this proposal. Specifications provided after the date of this proposal may void this proposal, and may require significant revisions.

Site Tests - NEEP does not supply or subcontract site testing. This proposal is based solely on the operating conditions provided, and NEEP will not be responsible for verification of actual site conditions.

Engineering Services - NEEP will provide engineering services only as detailed in this proposal. Any additional engineering services requested and authorized by the customer will be billed on a time and materials basis.

Shipment Schedule - Anticipated shipment schedule is based on NEEP standard engineering and shop work loads. Actual schedule may vary at time of purchase. Equipment ship date estimates are projected from receipt of final approval of all design aspects of the project, (i.e. the Notice-To-Proceed).

Notice-To-Proceed - Receipt of a signed purchase order assumes approval of all design aspects of the project and constitutes a Notice-To-Proceed (NTP), unless otherwise stated in writing on the purchase order, or if specific requirement for submittals are noted.

Change Orders - Any changes made to a project following receipt of a Notice-To-Proceed will constitute a change to the project. Additional engineering, purchasing, equipment, and testing costs for these changes will be billed in addition to the original purchase price. The customer will be responsible for any restocking or cancellation charges associated with changes, as well as associated disposal fees and return freight charges.

Project Planning - Project planning meetings are not typically included in NEEP proposals. Complicated integrated systems or complex projects may necessitate project planning meetings and are strongly encouraged. They can take place in the following forms:

1. Telephone or face-to-face conference with NEEP engineers at the factory. (No Charge)
2. Video Conference. (POA)
3. Jobsite or client office meeting. (POA)

Submittals - Submittal documents are provided for approval only when specified. If required, NEEP will prepare submittal packages (two copies only) on the major equipment items in the project. The submittal will include a process and instrumentation diagram, an equipment layout drawing, a ladder logic diagram for the control panel, and vendor cut sheets. One set of revisions will also be prepared if required.

All additional submittal work will be billed at $135.00 per hour. Submittal drawings will be NEEP's manufacturing drawings when available. Production of custom drawings in lieu of standard drawings will be at an additional charge.

Operation and Maintenance Manuals - An as-built Operations & Maintenance (O & M) manual is shipped complete with each system. Additional copies of O & M manuals may be purchased prior to equipment shipment for $25.00 each. Additional copies of O & M manuals may be purchased after shipment of the system at a cost of $75.00 each.

Substitutions - Unless a cited product vendor or brand name is specified as "No Equal", NEEP reserves the right to substitute a selection of equal or better quality for efficiency of process, cost, or schedule.

Warranties - Equipment purchased as a result of this proposal shall be guaranteed in accordance with NEEP's "Limited Equipment and Performance Warranty".

I invite you to phone or fax me immediately if we can answer any additional questions, comments, or concerns you may have. I look forward to working with you on this project as it develops, and to providing you and your client the most cost effective stripper available. Once again, thank you for your interest in our products.

Sincerely,

[signature]

Gordon Clarke
Customer Service
gordon_clarke@neepsystems.com

File: Massachusetts Department of Environmental Protection

Visit our website at www.neepsystems.com

cc: Don Shearouse

ShallowTray™
low profile air strippers

System Performance Estimate

Client & Proposal Information:

Massachusetts: Piyaluck Rattananont
Wells G7H S/F, Woburn, MA
#799902-1

Model chosen: 31200
Water Flow Rate: 240.0 gpm
Air Flow Rate: 1800 cfm
Water Temp: 49.0 °F
Air temp: 33.0 °F
A/W Ratio: 56.1
Safety Factor None

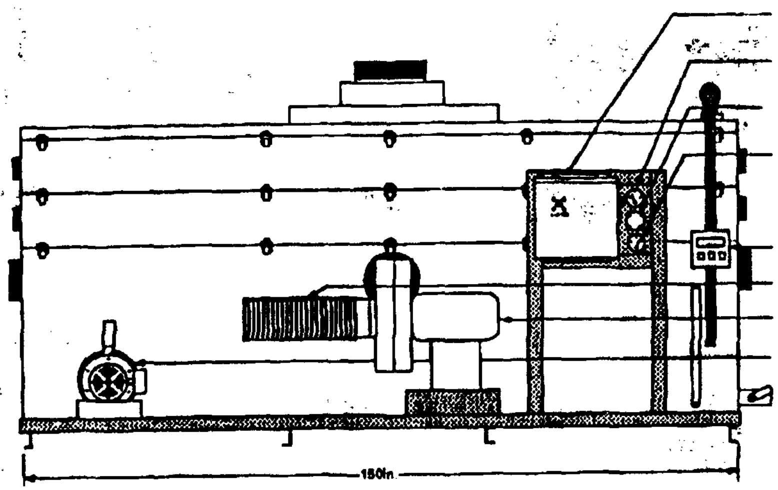
Contaminant	Untreated Influent Effluent Target	Model 31211 Effluent Water Air(lbs/hr) % removal	Model 31221 Effluent Water Air(lbs/hr) % removal	Model 31231 Effluent Water Air(lbs/hr) % removal
Tetrachloroethylene	164 ppb 14 ppb	29 ppb 0.016207 82.7486%	5 ppb 0.019088 97.0239%	1 ppb 0.019569 99.4866%

This report has been generated by ShallowTray Modeler software version 2.1N. This software is designed to assist a skilled operator in predicting the performance of a ShallowTray air stripping system. North East Environmental Products, Inc. is not responsible for incidental or consequential damages resulting from the improper operation of either the software or the air stripping equipment. Report generated: 7/8/99

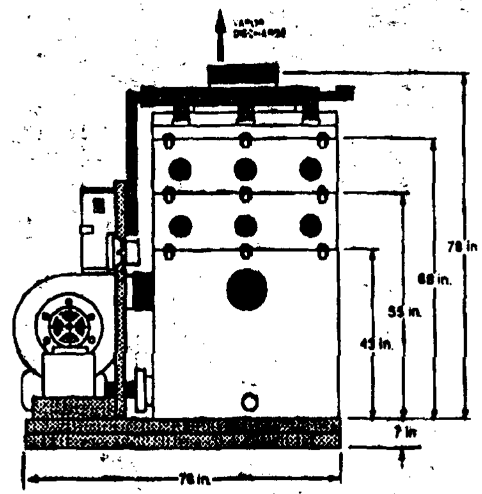
MINIMUM CLEARANCE

FRONT	1.5 ft
TOP	14 ft
REAR	1 ft
LEFT	8.5 ft
RIGHT	[illegible]

FRONT



RIGHT SIDE



BASIC SYSTEM

- ✓ SUMP TANK
- ✓ STRIPPER TRAYS
- ✓ BLOWER
- ✓ MIST ELIMINATOR
- ✓ PIPING
- ✓ SPRAY NOZZLE
- ✓ WATER LEVEL SIGHT TUBE
- ✓ GASKETS
- ✓ LATCHES

OPTIONAL ITEMS

- ✓ FRAME
- ✓ AIR PRESSURE GAUGE
- DISCHARGE PIPING
- ✓ DISCHARGE PUMP
- FEED PUMP
- ADDITIONAL BLOWER
- EXPLOSION-PROOF MOTORS
- BLOWER START/STOP PANEL
- ✓ CONTROL PANEL
- ✓ MAIN DISCONNECT SWITCH
- I.S. COMPONENTS/REMOTE MOUNT
- INTERMITTENT OPERATION
- ✓ STROBE LIGHT
- ALARM HORN
- POWER LAPSE INDICATOR
- LOW AIR PRESSURE ALARM SWITCH
- ✓ HIGH WATER LEVEL ALARM SWITCH
- ✓ DISCHARGE PUMP LEVEL SWITCH
- ✓ WATER PRESSURE GAUGE(S)
- DIGITAL WATER FLOW INDICATOR
- ✓ AIR FLOW METER
- ✓ TEMPERATURE GAUGE(S)
- LINE SAMPLING PORTS
- ✓ AIR BLOWER SILENCER
- ✓ WASHER WAND
- ✓ AUTO DIALER

NOTE:

1.) THIS DRAWING IS REPRESENTATIVE OF A TYPICAL CONFIGURATION SIMILAR TO THE UNIT REQUIRED, AND IS NOT INTENDED FOR ENGINEERING DESIGN OR LAYOUT. PLEASE CONTACT YOUR NEEP REPRESENTATIVE FOR DETAILED DESIGN INFORMATION

CONNECTION INFORMATION

ITEM	SIZE
GRAVITY DISCHARGE	6 in Ø SOCKET, PVC80
DISCHARGE PUMP	3 in. Ø FNPT
WATER INLET	4 in. Ø FNPT
AIR EXHAUST NOZZLE	16 in Ø STUB w/16 in. CPLG

POWER: 3Ø, 230 volt, 3 WIRE + GROUND

*CONSULT N.E.E.P. FOR AMPACITIES AND OTHER VOLTAGE OPTIONS

NORTH EAST ENVIRONMENTAL PRODUCTS, INC.
17 TECHNOLOGY DRIVE
WEST LEBANON, NEW HAMPSHIRE 03784
PHONE: 603-298-7061 FAX: 603-298-7063

TOLERANCES UNLESS OTHERWISE SPECIFIED ± 1 INCH	DRAWING NAME: ShallowTray® Model 31221		
	DRAWING #: Proposal #799902-1		
DRAWN: GWC	CUSTOMER: MA DEPc/o GII		
DATE: 7/8/99	SCALE: NTS	SIZE: A	SHEET: 1 OF: 1

Delta Cooling Towers, Inc.
134 Clinton Road
P.O. Box 952
Fairfield, New Jersey 07004
Telephone 973/227-0300
Fax 973/227-0458
Email: deltacooling@worldnet.att.net
URL: http://www.deltacooling.com

Delta Cooling Towers

Fax 617-665-8878

July 13, 1999

Mr. Pat Rattananowt
MA DEP c/o Genetics Institute
87 Cambridge Park Drive
Cambridge, MA 02140

Subject: Vanguard® Packed Column Air Stripper
Delta Quotation #

Dear Mr. Rattanaowt,

Thank you for your subject RFQ fax dated 7/10/99, and for the opportunity to submit our budget proposal for your consideration.

Delta's Model AS4-150F Vanguard® air stripper is recommended for this application to remove 92% of PCE at the design influent flow specified of 240 gpm of water @ 50° F.

This air stripper will be skid mounted and will consist of a 4' diameter FRP column with 15' of Delta-Pak® structured packing, a ladder/safety cage assembly, a differential pressure gage, an air flow switch, a vibration cut out switch, and an anti-freeze drain valve actuator. This air stripper will be approximately 24' high.

The budget materials price for this air stripper system as described above is $30,000.00 F.O.B. Fairfield, N.J.

Terms of payment are net 30 days after shipment and date of invoice. Shipment of the strippers specified can be made within 6-8 weeks after receipt of your formal order, or after the return of approved submittal's, if required.

This proposal does not include -
Influent or effluent pumps.
Stripper sump liquid level controls.
Influent of effluent piping.
Strainers, valves or other components not referenced.
Pre-wiring, or other instrumentation or controls for components not be provided by Delta.

Anchor bolts and anchorage devices shall be provided by others.
Field performance testing and reports.
Delta will supply its standard IOM manuals

Enclosed is our standard sales literature for reference.

If you are considering liquid phase carbon systems in lieu of using packed column air strippers the carbon systems should be supplied by others.

I trust this information satisfies your request, however, if we can be of further assistance in any way please feel free to contract me.

Thank you for your interest in Delta and its products.

Sincerely,
John T. Halligan
John T. Halligan
Vice President

Delta Cooling Towers Inc.
134 Clinton Road
P.O. Box 952
Fairfield, New Jersey 07004-2970
Telephone 973/227-0300
Fax 973/227-0458

Delta Cooling Towers

Delta Cooling Towers, Inc. was founded to manufacture and market the initial concept of a maintenance free seamless one-piece non-corrosive Polyethylene cooling tower, and sold its first units in June, 1971.

In 1981 Delta entered the air stripper market and currently markets a standard line of **VANGUARD®** air strippers from 1' through 5' diameter.. Larger custom system designs can been provided up to 15' diameter.

Delta prides itself in its ability to provide the technical expertise necessary to meet the requirements of any application with respect to stripper design, materials of construction, type of packing and total system capability. Some of our recent systems, for both easy and difficult stripping applications, are discussed in our general literature.

Delta's **PIONEER®** forced draft cooling tower line is factory assembled in single modules from 10 through 100 tons of cooling capacity.

Delta's **PARAGON®** induced draft cooling towers are also factory assembled in single modules, from 100 to 250 tons in single modules.

Delta's **PREMIER™** induced draft cooling towers are provided "factory complete", no field assembly required, designed for ease of installation to span existing cooling tower structural supports, from 250 to 500 tons where larger capacity is required.

For more information about Delta and its products call (973) 227-0300, or fax your request to (973) 227-0458.

You may also visit our Web Site: http://www.deltacooling.com, or reach us by E-mail: deltacooling@worldnet.att.net.

Thank you for your interest in Delta and its products.

Delta Cooling Towers Inc.
134 Clinton Road
P.O. Box 952
Fairfield, New Jersey 07004-2970
Telephone 973/227-0300
Fax 973/227-0458

Delta Cooling Towers

DELTA AIR STRIPPERS-BENEFITS

*VANGUARD®-standard models-proven design, economics, short delivery.

*CUSTOM strippers-up to 10 ft. diameter, 2000 gpm water flow.

*Basic MATERIALS OF CONSTRUCTION:
-high performance structured modular packing.
-film type, PVC.

*STATIC PRESSURE LOSSES of DELTA-PAK®:
-about 4 to 30 times lower than dumped packings, depending on type and conditions.
-fan horsepower requirements are typically lower than those of competing systems (lower operating costs).

*FLOODING CHARACTERISTICS of DELTA-PAK®:
-superior to dumped packings.
-water loadings in excess of 20 gpm/sq. ft. can be handled at air flow rates 600 to 700 cfm/sq. ft. (about 3000 lb/hr. sq. ft.) and higher.

*HIGH MASS TRANSFER coefficients.

*REMOVAL RATES-correspondingly high:
-99.9% and higher in a single stripper (1) at only 20 to 25 foot overall height.
-1,000,000 to 1 or higher contaminant reduction in two stripping stages is possible (1).

*Stripping of "HARD-TO-STRIP" compounds (4):
-often very efficient with DELTA VANGUARD® air strippers, without preheating, with low blower HP. Consult others.

*MODULAR construction (2): utilizing prepacked, preassembled standardized sections.

*FUTURE UPGRADING is possible on most models.

*ERECTION TIME-normally hours (3). LIGHT WEIGHT.

*ACCESSORIES, CONTROLS are available. SYSTEMS can be supplied.
*ASSISTANCE, SERVICE, SUPPORT

1) Removal of TCE, PCE, benzene and many other compounds, subject to water flow treated.
2) Delta VANGUARD® standard air strippers.
3) Particularly in skid mounted stripper installations.
4) Compounds with low Henry's law constant, generally.

Delta Cooling Towers Inc.
134 Clinton Road
P.O. Box 952
Fairfield, New Jersey 07004-2970
Telephone 973/227-0300
Fax 973/227-0458

Delta Cooling Towers

July 1992

TECHNICAL SPECIFICATIONS
DELTA VANGUARD AIR STRIPPERS (FORCED DRAFT TYPE)

Delta Air Strippers are designed to remove volatile organic chemicals and certain other substances from water.

A blower, ducted into the sump plenum provides air at a slight positive pressure and forces it to flow upward against the downward trickling water. This is a countercurrent forced draft design.

As the air passes over the water, spread over the packing surface as a thin film, the molecules of contaminant cross the air/water interface and enter the air stream. The air then exits the column either to atmosphere or to some means of vapor phase remediation process.

Delta VANGUARD® Air Strippers possess known, predetermined stripping performance and operational characteristics based upon field test data obtained from independent sources.

Stripper shell. The shell material is a hand lay-up FRP isophthalic polyester resin of sufficient thickness to withstand the specified operating conditions, as well as external loads imposed from earthquake Zone 4 and 120 mile/hour wind loading. Guy wiring is standard; free-standing design is available as an option. The shells are designed using the ASME/ANSI RTP-1-1989 Rev. 1991 Standards as a guide.

Treated water collection sump is integral with lower part of the shell, forming a one piece, seamless component. The sump is provided with outlet and other required connections, and incorporates a blower duct for air supply to the stripper. Access and inspection port is provided in the sump plenum.

Connections (outlet, inlet and others) are constructed of FRP and are fully gasketed with neoprene gaskets. 3" and larger connection sizes are flanged (150# flanges), smaller than 3" size connections are NPTF. All flanges up to and including 4" are gussetted.

Water distribution system is constructed of Type 1 PVC. Uniform water distribution is effected (on ASS Series Air Strippers and smaller) by a single full cone, non-clog PVC spray nozzle which provides uniform water loading to the entire packing surface. The typical nozzle flow turn - down ratio is 2/1. For flows up to 350 GPM the nozzle is threaded into the inlet header via an NPTM thread and can be readily removed and replaced. Nozzles for flows greater than 350 GPM are 6" 150# flange connections.

Packing. Delta Pak®, used in all standard stripper models, is a high performance structured packing constructed of Type 1 PVC material protected against UV degradation.

Applicable data below is for air - water atmospheric system:

Surface area:	90 sq. ft./cu.ft.
Void space:	Higher than 98%
Open cross-section:	Higher than 98%
Maximum air flow before flooding, at 20 gpm/sq.ft.:	750 scfm/sq. ft. or higher
Static pressure loss at 20 gpm/sq.ft. and 500 scfm/sq. ft. air flow:	0.10 in. W.C./ft. or lower
Orientation of corrugation:	Vertical ("see - through")
Nominal corrugation size:	Approx. 3/4 in.
"Channelling" characteristics:	No channeling occurs. Packing construction prevents any radial transfer of mass, due to its spirally wound configuration. Transfer in tangential direction is negligible.
"Clogging" and "fouling" characteristics:	The absence of any horizontally oriented surfaces reduces accumulation of precipitates and deposition of suspended solids. Most solids including precipitates pass freely through packing along vertical corrugations.

Standard packing layer heights: 12.6 in. and 6.3 in.

Mist eliminator is Delta AB mist eliminator, constructed of Type I PVC material, compounded with carbon black for UV resistance. The eliminator is designed to minimize drift loss to lower than 0.02% of the water flow.

Depth: 12 in.
Type: Crimped plate, impingement type

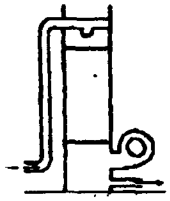
Blower ΔS1 and ΔS1.5 use a cast aluminum/bronze radial bladed wheel. The unit is arrangement 4 and is directly driven by a 3450 RPM motor. ΔS2 uses a backwardly inclined centrifugal blower wheel. The unit is arrangement 10 and is belt driven by a 3450 RPM TEFC motor. ΔS3 through ΔS5 uses an airfoil blade design for most efficient and quiet operation. The unit is arrangement 10 and is belt driven with an 1800 RPM TEFC motor.

Skid used with skid-mounted strippers (an option) is a welded steel frame with 10 ga. plate decking, coated with black air dried phenolic paint.

Fasteners and other hardware: Type 304 SS

Standard features:

- Motors are TEFC design with a minimum 1.15 SF.
- Provided with a motor/drive weather enclosure or guard (ΔS5)
- Belt drive units are provided with vibration isolation and blower to duct neoprene bellows.
- Designed based upon tests made in accordance with ASHRAE Standard 51 and AMCA Standard 210-74, and are licensed to carry the AMCA SEAL.
- Factory dynamically balanced and checked against the acceptable levels on the Rathbone Chart.
- Standard coating is an industrial baked enamel. Other coatings are available and provided based upon AMCA Recommended Practice NO. 2601-66



Delta Vanguard®
Air Strippers

Delta Delivers Clean Clear Water

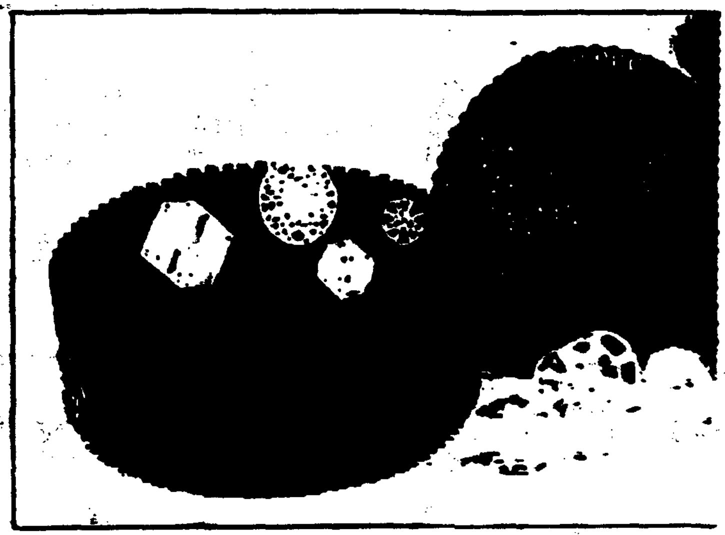
Recent recognition of the massive scale of groundwater contamination has given rise to the development of specific treatment technologies. Adapting the proven mass transfer process of air stripping to remediation of contaminated groundwater has proven to be the most economical. Early on, Delta applied its strong design expertise to this problem and now has a decade of practical experience with field installations throughout the United States.

Delta Experience

Since Delta received its first groundwater remediation air stripper order in 1981 it has provided hundreds of innovative and economical solutions for stripping applications. Air stripping has become the preferred water remediation technology for removal of organic solvents, chlorinated hydrocarbons, fuel/gasoline hydrocarbons, degreasers, and certain other volatile organic chemicals (VOCs), because it is the most cost effective with respect to initial, operating and maintenance costs. Delta's broad knowledge and experience enabled the company to design and develop the Delta Vanguard® line of standard air strippers, which are suitable for most applications. Delta's Vanguard® air stripper systems are preferred for routine as well as for many applications with difficult to strip compounds. The equipment selection process is simpler and often less costly.

Air Stripping — The Packing

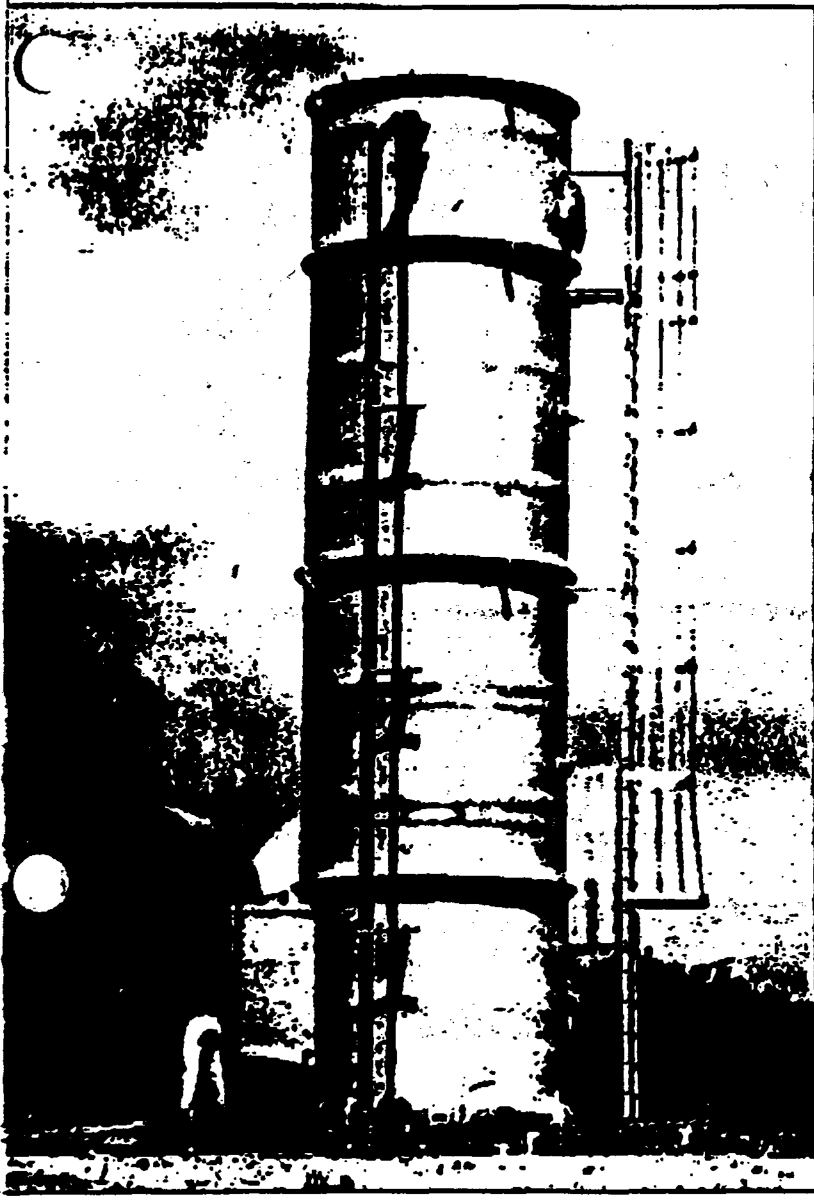
The heart of any air stripper is the packing. Operational parameters, such as a compound's ease of removal, the mineral content of the water which can induce fouling, and air flow requirements as related to the necessity for vapor phase treatment, often dictate a preferred packing media. Delta designs and supplies strippers utilizing all packing types and will recommend the most suitable for your specific situation. Delta can provide any type and size of commercially available random packing, in addition to Delta-Pak®. This proprietary structured packing manufactured by Delta is often the preferred mass transfer media.



Delta-Pak® — Major Advantages

Delta-Pak® is a specially formed PVC, spirally wound structured packing media, which, when installed in an air stripper, becomes a series of long, parallel tubes the length and diameter of the column. This design permits a large volume of uncontaminated airflow, which in turn facilitates efficient stripping. This unique Delta-Pak® media has proven very successful removing compounds that have low Henry's Law Constants, (a relative measure of volatility), such as ammonia and pesticides, which are considered difficult to strip.

Front Cover:
ΔSS - 210 air stripper. 5' Dia. x 31' - 9 1/2" high.
350 GPM - Benzene 99.4% removal,
MTBE 97.5% removal. Napthalene 91.4% removal.



ΔS9-190 Ammonia air stripper, 9' Dia. x 33'-10" high, 70 GPM-250,000 ppb influent. 50,000 ppb effluent. 80% removal.

Another significant advantage of Delta-Pak® is its resistance to fouling. Mineral buildup restricts airflow which reduces efficiency. Since Delta-Pak® is designed to operate at much higher air flows than random packing, contaminant removal efficiency remains high by comparison, and the problems of flooding, bridging, etc. are significantly reduced. Delta-Pak® has become the packing of choice when groundwater contains high mineral content. Actual experience with applications containing high levels of dissolved iron has demonstrated that Delta-Pak® structured packing operates efficiently several times longer than random packing.

Delta Provides a Wide Range of Custom Solutions

Over the years, Delta has developed a wide range of standard options and accessories to meet the demanding requirements of air stripper systems. Delta's experience and technical expertise guarantees the design and manufacture of custom components that will meet environmental compliance requirements.

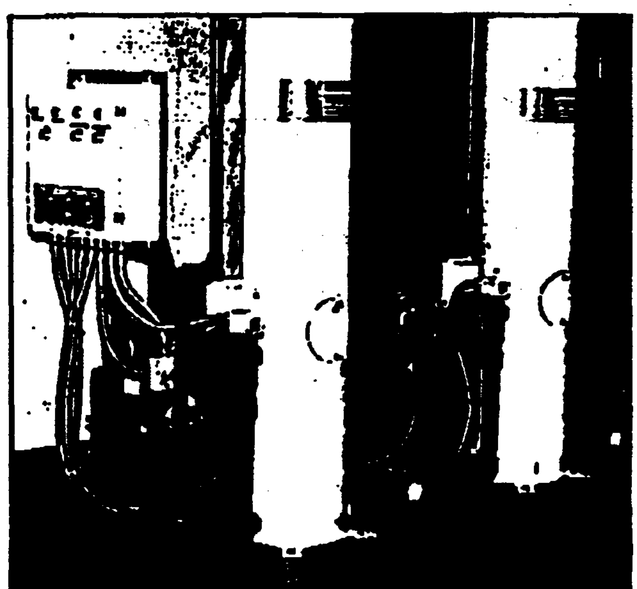
Air Emission Controls— Delta offers appropriate vapor recovery systems including carbon adsorbers.

Chemical Cleaning Systems — Delta developed this option to ensure long term operation, at maximum efficiency, and to minimize or eliminate packing replacement.

Instrumentation, Controls and Telemetry— Delta provides systems to integrate pressure, flow, overflow, fail-safe and transfer control systems for remote monitoring and data collection.

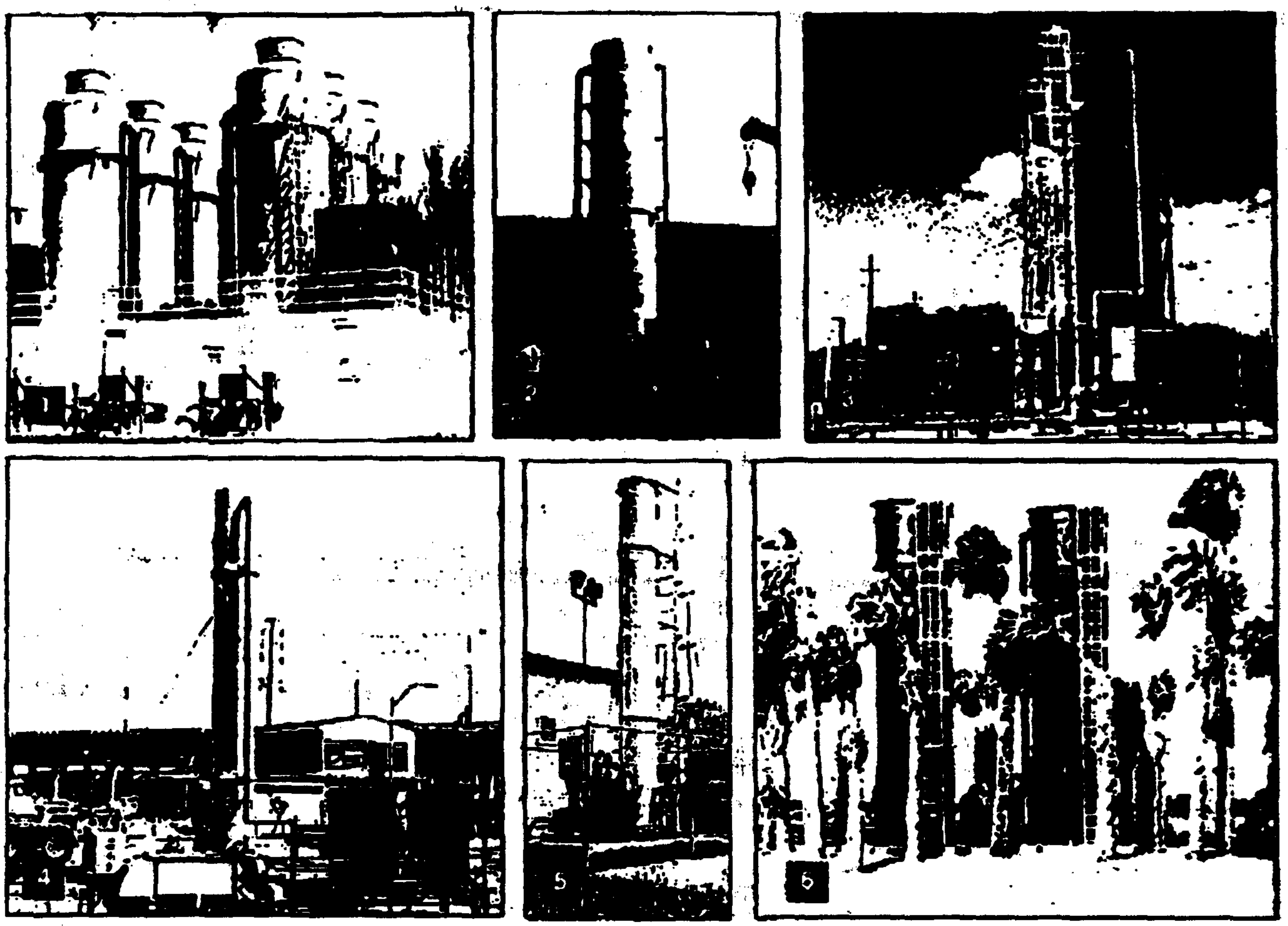
Corrosive Environments — Delta designs major components in Fiberglass (FRP), Stainless Steel or Aluminum.

Extreme Winter Conditions — Delta has the experience necessary for successful cold weather applications, which are a particular challenge to air strippers.



A dual Vanguard model ΔS1-163 air stripping system skid mounted pre-piped and pre-wired. 5 GPM-Methylene Chloride and 1,1,1,TCA 99.99% removal. Benzene 96.2% removal. Toluene 88.9% removal.

DELTA, PROVIDING PRODUCTS FOR A SAFE ENVIRONMENT



(1) (6)ΔS9-100 Hydrogen Sulfide Strippers, 8' Dia. x 24' High, 1500 GPM each unit - 8,000 ppb influent, 400 ppb effluent. 95% removal. (2) ΔS7-235 with dual blowers. 1000 GPM -TCE 99.7% removal. 1,1,1, TCA 97.1% removal. 1,1,2, DCE, Chloroform. Xylenes 90% removal. (3) (2) ΔS4-185T. 210 GPM-1,1,1.TCA. 1.1.DCE. 1.1. Dichloroethane. PCE 99.95% removal. (4) ΔS2-145 Ammonia Air Stripper, 12 GPM-90% removal of NH_3. (5) ΔS2-145, 60 GPM-1,1,2,DCE,TCE. 1.1.1.TCA. 1.1.DCE. 1.1.DCA 95.7% removal. (6)(2)ΔS6-150. 6' Dia. x 25'-9' High, 625 GPM-Total Xylenes 97.6% removal, Chlorobenzene 96.6% removal. Benzene 94.6% removal, Napthalene 92.3% removal.

Delta Experience

Delta Air Strippers have been provided

- As custom designed systems tailored to specific needs
- As integrated equipment systems with automatic process controls, completely pre-assembled, skid mounted, pre-piped, pre-wired and hydrostatically/electrically factory tested
- With vapor phase air emission control devices
- With chemical cleaning, and other system packages
- For pilot test systems

Major Benefits

Delta air strippers

- Are constructed of Fiberglass, Stainless Steel or Aluminum
- Are available with skid mounted options
- Can be provided free standing or guy wired
- Are provided with proven packing design, usually pre-packed in column prior to shipment
- Are modular, pre-assembled and lightweight for simple, fast, economical installation
- Apply modular design concepts for easy upgrade
- Have demonstrated effective removal of contaminants considered difficult, and in some circles, impossible to strip
- Are usually the most economical treatment option

For Further Information:

Delta Cooling Towers, Inc.
134 Clinton Road
P.O. Box 952
Fairfield, New Jersey 07004-2970
Telephone 201/227-0300
Fax 201/227-0458

Delta Cooling Towers

APPENDIX J

Background on In-Well Air Stripping and Vapor Granulated Activated Carbon System

Technology Overview Report

TO-97-01

GWRTAC O SERIES

In-well Vapor Stripping

Prepared By:

Ralinda R. Miller, P.G.

and

Diane S. Roote, P.G.

Ground-Water Remediation
Technologies Analysis Center

February 1997

Prepared For:

GWRTAC Ground-Water Remediation Technologies Analysis Center

615 William Pitt Way • Pittsburgh, PA 15238 • (412) 826-5511 • (800) 373-1973
Homepage: http://www.gwrtac.org • E-mail: gwrtac@netac.org

FOREWORD

About GWRTAC

The Ground-Water Remediation Technologies Analysis Center (GWRTAC) is a national environmental technology transfer center that provides information on the use of innovative technologies to clean-up contaminated ground-water.

Established in 1995, GWRTAC is operated by the National Environmental Technology Applications Center (NETAC) in association with the University of Pittsburgh's Environmental Engineering Program through a Cooperative Agreement with the U.S. Environmental Protection Agency's (EPA) Technology Innovation Office (TIO). NETAC is an operating unit of the Center for Hazardous Materials Research and focuses on accelerating the development and commercial use of new environmental technologies.

GWRTAC wishes to acknowledge the support and encouragement received for the completion of this report from the EPA TIO.

About "O" Series Reports

This report is one of the GWRTAC "O" Series of reports developed by GWRTAC to provide a general overview and introduction to a ground-water-related remediation technology. These overview reports are intended to provide a basic orientation to the technology. They contain information gathered from a range of currently available sources, including project documents, reports, periodicals, Internet searches, and personal communication with involved parties. No attempts are made to independently confirm or peer review the resources used.

Disclaimer

GWRTAC makes no warranties, express or implied, including without limitation, warranty for completeness, accuracy, or usefulness of the information, warranties as to the merchantability, or fitness for a particular purpose. Moreover, the listing of any technology, corporation, company, person, or facility in this report does not constitute endorsement, approval, or recommendation by GWRTAC, NETAC, or the EPA.

ABSTRACT

This technology summary report is an overview of information collected by the Ground-Water Remediation Technologies Analysis Center (GWRTAC) on in-well vapor stripping (also known as vacuum vapor extraction and in-well air stripping) as an *in situ* ground-water remediation technology. Information provided includes an introduction to the general principles and techniques, a discussion of the general applicability of the technology, available data relating to its utilization, and reported advantages and limitations of the technology. Also provided are a list of references cited, and related references compiled during preparation of this report.

In-well vapor stripping technology involves the creation of a ground-water circulation pattern and simultaneous aeration within the stripping well to volatilize VOCs from the circulating ground-water. Air-lift pumping is used to lift ground-water and strip it of contaminants. Contaminated vapors may be drawn off for aboveground treatment or released to the vadose zone for biodegradation. Partially treated ground-water is forced out of the well into the vadose zone where it reinfiltrates to the water table. Untreated ground-water enters the well at its base, replacing the water lifted through pumping. Eventually, the partially treated water is cycled back through the well through this process until contaminant concentration goals are met.

Modifications of the basic process involve combinations with soil vapor extraction and aboveground treatment of extracted vapors and/or injection of nutrients and other amendments to enhance natural biodegradation of contaminants. Applications of in-well stripping have generally involved chlorinated organic solvents (e.g., TCE) and petroleum product contamination (e.g., BTEX, TPH). Proposed application of this technology, based on system modifications, may address non-halogenated VOC, SVOC, pesticide, and inorganic contamination. In-well stripping has been used in a variety of soil types from silty clay to sandy gravel.

Reported advantages of in-well stripping include lower capital and operating costs due to use of a single well for extraction of vapors and remediation of ground-water and lack of need to pump, handle, and treat ground-water at the surface. Additional advantages cited involve its easy integration with other remediation techniques such as bioremediation and soil vapor extraction and its simple design with limited maintenance requirements. Limitations reported for this technology include limited effectiveness in shallow aquifers, possible clogging of the well due to precipitation, and the potential to spread the contaminant plume if the system is not properly designed or constructed.

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1.0 INTRODUCTION

1.1 GENERAL

In-well vapor stripping, also known as *in situ* vapor or *in situ* air stripping, is a pilot scale technology for the *in situ* remediation of ground-water contaminated by volatile organic compounds (VOCs) (and possibly other types of contaminants, see Section 2.1). The in-well stripping process, an extension of air sparging technology, involves the creation of a ground-water circulation cell around a well through which contaminated ground-water is cycled. The air stripping well (See Figure 1) is a double-cased well ("well-within-a-well") with hydraulically separated upper and lower screened intervals within the same saturated zone (aquifer). The lower screen, through which ground-water enters, is placed at or near the bottom of the contaminated aquifer and the upper screen, through which ground-water is discharged, is installed across or above the water table.

Air is injected into the inner casing, decreasing the density of the ground-water and allowing it to rise within the inner casing. This constitutes a type of ***air-lift pumping system***, similar to that found in an aquarium filter system. Through this air-lift pumping, volatile contaminants in the ground-water are transferred from the dissolved phase to the vapor phase by the rising air bubbles through an ***air stripping*** process. Contaminated vapors can be drawn off and treated above ground (similar to a soil vapor extraction system) or discharged into the vadose zone, through the upper screened interval, to be degraded via *in situ* bioremediation.

The ground-water, which has been partially stripped of volatile contaminants, continues to move upward within the inner casing and is eventually discharged into the outer casing, moving through the upper screened interval into the vadose zone or the upper portion of the aquifer. Once returned to the subsurface, ground-water flows vertically downward, eventually reaching the lower portion of the aquifer where it is cycled back through the well into the lower screened interval, replacing the water that rose due to the density gradient.

This cycling of water in the area around the well creates a hydraulic circulation pattern or cell that allows continuous cycling of ground-water *in situ* through the air stripping process. Ground-water is repeatedly circulated through the system until sufficient contaminant removal has taken place.

In the in-well vapor stripping process, contaminants that are dissolved in ground-water are transferred to the vapor phase, which is generally easier and less expensive than ground-water to treat. Ground-water is not removed from the subsurface, but is circulated back into the well to facilitate further vapor removal. The vapors can be removed using the same stripping well, or, if applicable, can be discharged into the vadose zone for *in situ* bioremediation (See Figure 1).

1.2 MODIFICATIONS

Modifications to the basic in-well stripping process may involve additives injected into the stripping well to enhance biodegradation (e.g., nutrients, electron acceptors, etc.). In addition, the area around the well affected by the circulation cell (radius of influence) can be modified through the addition of certain chemicals to allow *in situ* stabilization of metals originally dissolved in ground-water. (4, 5, 7, 9, 11 14,15).

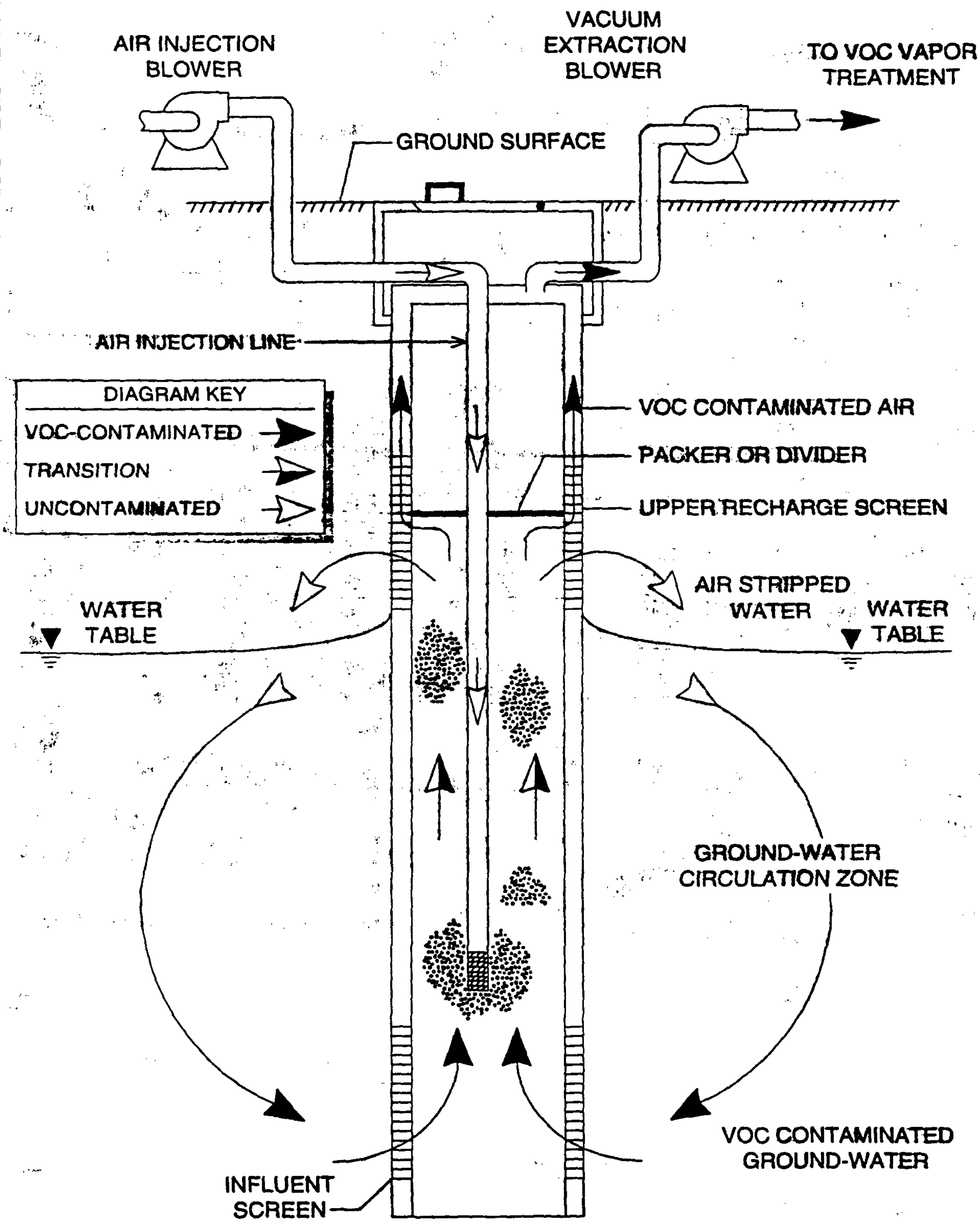

FIGURE 1. IN-WELL VAPOR STRIPPING PROCESS

2.0 APPLICABILITY

2.1 CONTAMINANTS

Most of the field applications of this technology have involved halogenated volatile organic compounds (VOCs), such as trichloroethylene (TCE), and petroleum products/constituents such as benzene, toluene, ethylbenzene, and xylene (BTEX). Applications of in-well stripping to non-halogenated VOCs, semi-VOCs (SVOCs), pesticides and inorganics have been proposed based on modifications of the basic remedial process. In addition, the technology has been applied to ground-water contaminated with both radionuclides and VOCs. (2, 5, 7, 11, 15).

2.2 SITE CONDITIONS

Site soil conditions seem to be less of a limitation for in-well stripping than air sparging, since air movement through aquifer material is not required for contaminant removal. In-well vapor stripping has been applied to a wide range of soil types ranging from silty clay to sandy gravel (8, 9, 10).

3.0 METHODOLOGY

3.1 GENERAL

Several commercial variations of the basic in-well stripping process have been developed. The following is a synthesis of information from all information reviewed about the operations of these current systems. Modifications of standard methods will be explored following the general discussion.

As described in Section 1.0, the in-well stripping well consists of an inner and outer casing hydraulically separated from one another (See Figure 1). This separation, generally accomplished by a packer assembly, metal plate, or grout seal, ensures one-directional flow of water into the well at its base (through the lower screen in the inner well) and out of the well above the water table (through the upper screens in both casings). The outer well may also be screened above the water table if the well is to be used for soil vapor extraction (7, 14, 15).

The following outlines the general steps in the in-well stripping process (See Figure 1):

- ***Air*** (or an inert gas) is ***injected into the inner well*** through a gas injection line using a vacuum blower, compressor, diffuser plate or other means, releasing bubbles into the contaminated ground-water. The ***resulting bubbles aerate the water,*** forming an air-lift pumping system and causing ground-water to flow upward in the well.

- The ***gas bubbles rise through the water in the well and also lift the water*** due to a density gradient (ground-water containing air bubbles is less dense than ground-water without bubbles outside of well).

- As the bubbles rise through the VOC-contaminated ground-water, these ***compounds are naturally transferred from the dissolved to the vapor phase*** through an air stripping process (In the UVB process, this occurs in a stripper reactor.).

- The ***air/water mixture rises until it encounters the dividing device*** within the inner well, above the contaminated zone. The dividing device is designed and located to maximize volatilization.

- The water/air mixture is forced out of the upper screen below this divider.

- The outer casing is under a vacuum, and ***vapors are drawn upward*** through the annular space and are collected at the surface for treatment, or may be released to the unsaturated zone for *in situ* bioremediation.

- The ***ground-water***, from which some VOCs have been removed, ***re-enters the contaminated zone.***

- As a result of rising ground-water lifting at the bottom of the well, ***additional water enters the well at its base.*** This water is then lifted via aeration.

- The partially treated water re-entering the aquifer is eventually cycled back through the process as ground-water enters the base of the well. This pattern of ground-water movement forms a ***circulation cell*** around the well, ***allowing ground-water to undergo sequential treatment cycles*** until remedial goals have been met. The area affected by this circulation cell, and within which ground-water is being treated, is called the radius of influence of the stripping well. (11, 14)

In-well vapor stripping systems can utilize soil vapor extraction techniques simultaneously with other modifications. In addition, in-well stripping technologies can be modified through the use of bioremediation principles and other physical and chemical treatment technologies as described below (7).

3.2 TYPES OF SYSTEMS

NOTE: Information provided in this report about technologies from a specific company are presented for informational purposes only.

GWRTAC (EPA TIO, NETAC, and the University of Pittsburgh) neither endorses nor in any way recommends the companies discussed. No effort has been made, nor will be made, to verify the accuracy of the information provided, or to assess the validity of any claims about the companies or their products. GWRTAC makes no warranties, expressed or otherwise, without limitation or liability, for the completeness, accuracy, or usefulness on the information provided.

The three main types of in-well vapor stripping systems examined for inclusion in this report include:

- **NoVOCs™** system patented by Stanford University and purchased in 1994 by EG&G Environmental;
- **Unterdruck-Verdampfer-Brunnen** (UVB) or "vacuum vaporizer well" system, developed in Germany by IEG Technologies Corporation and being demonstrated by Roy F. Weston, Inc.;
- **Density Driven Convection** (DDC) system, developed and patented by Wasatch Environmental, Inc.

3.2.1 NoVOCs™

The basic *NoVOCs™* system (See Figure 2) is largely similar to the generic description provided in Section 3.1. The NoVOCS™ system uses a compressor to deliver the air to the contaminated water column. The bubble-water mixture rises to a point where optimum volatilization has occurred, where it encounters a deflection plate. At this point the air bubbles combine. The water flows out of the well through the upper screen and the coalesced bubbles are drawn off by vacuum for above ground treatment for VOCs. In addition, one modified NoVOCs™ system is purported to allow ***removal of metals from ground-water through* in situ *fixation*** using common water treatment chemicals. Chemicals appropriate for treatment (adsorption and/or precipitation) of the target contaminants are emplaced around the NoVOCs™ well. The ground-water circulation pattern created by the process described above (air-lift pumping of ground-water to the vadose zone where it is released and allowed to reinfiltrate into the aquifer) brings metal-contaminated ground-water into contact with chemicals in the unsaturated zone that are designed to immobilize them. The *in situ* treatment/ infiltration gallery contains the chemicals and other additives necessary to provide

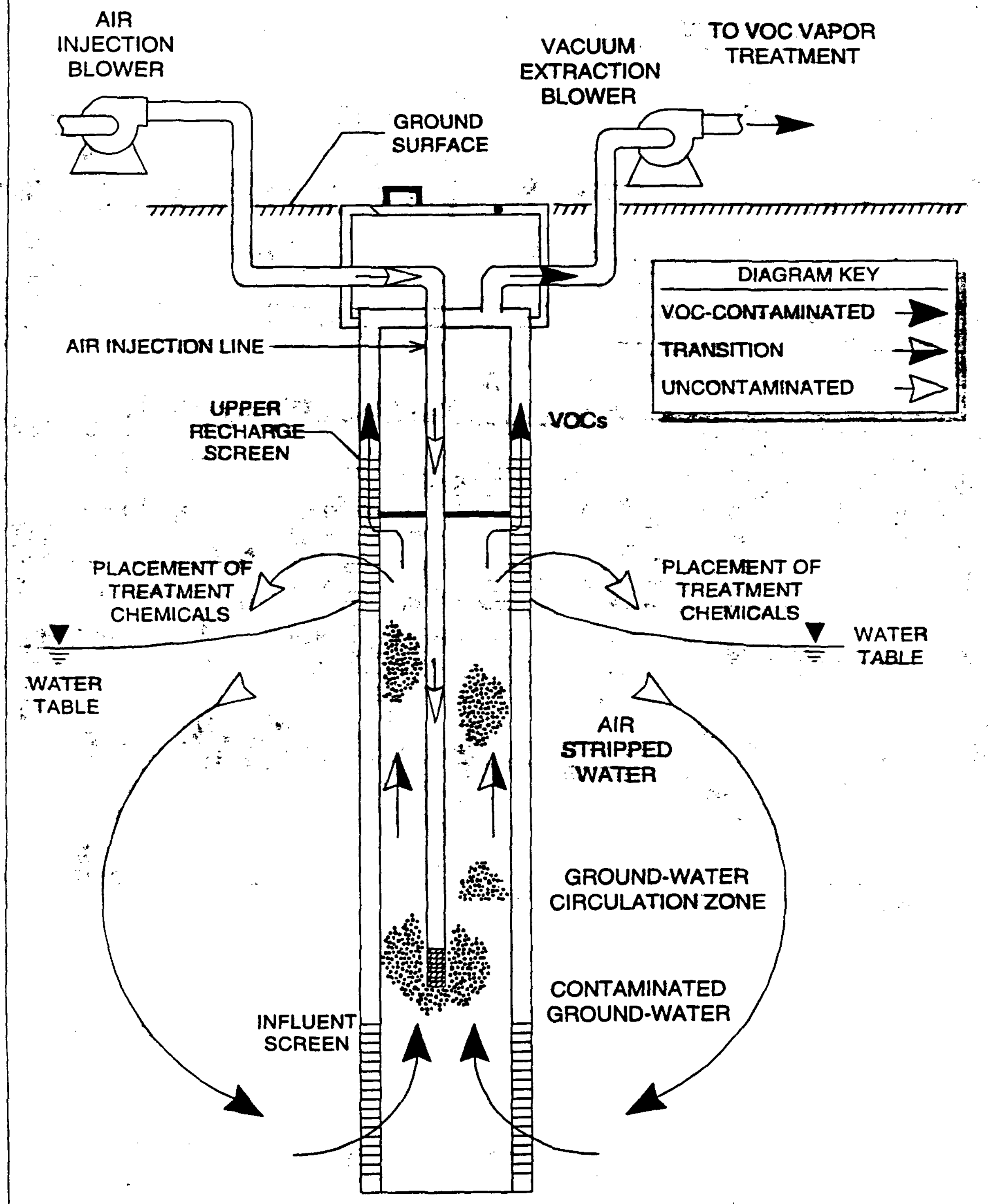

FIGURE 2. NoVOCs ™ IN-WELL VAPOR STRIPPING PROCESS

the proper pH and redox conditions for fixation of metals contained in the ground-water. Following the treatment process, the treatment gallery can be covered in place, excavated and replaced with backfill, or the gallery can be designed as a "retrievable cartridge" that can be "replaced when exhausted" (2).

3.2.2 UVB

The ***UVB*** system (See Figure 3) supplements air-lift pumping via a ***submersible pump*** to maintain flow at a standard rate. In addition, the UVB system employs a ***stripper reactor*** to facilitate transfer of volatiles from aqueous to gas phase before the water is returned to the aquifer. This device, located just below the air diffuser, "consists of fluted and channelized column that facilitates transfer of volatile compounds to gas phase by increasing contact time between two phases and by minimizing coalescence of air bubbles" (11).

3.2.3 DDC

The ***DDC*** system (See Figure 4) emphasizes the enhancement of bioremediation and involves the discharge of extracted vapors into the vadose zone for degradation by naturally-occurring microorganisms. Nutrient solutions may be added to the DDC well as a concentrated slug. Oxygen is supplied to both the saturated subsurface and the vadose zone promoting natural aerobic processes (8).

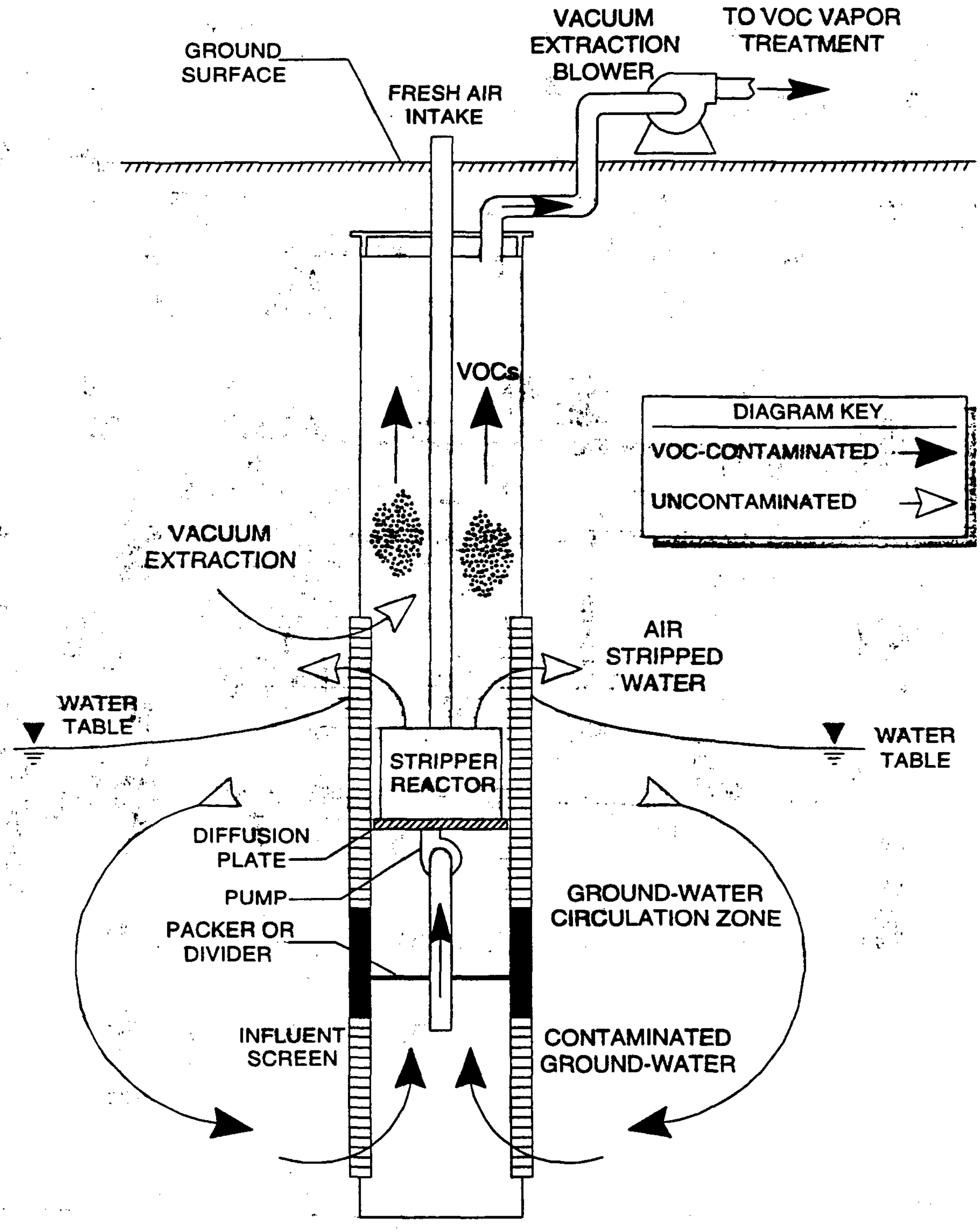

FIGURE 3. UVB IN-WELL VAPOR STRIPPING PROCESS

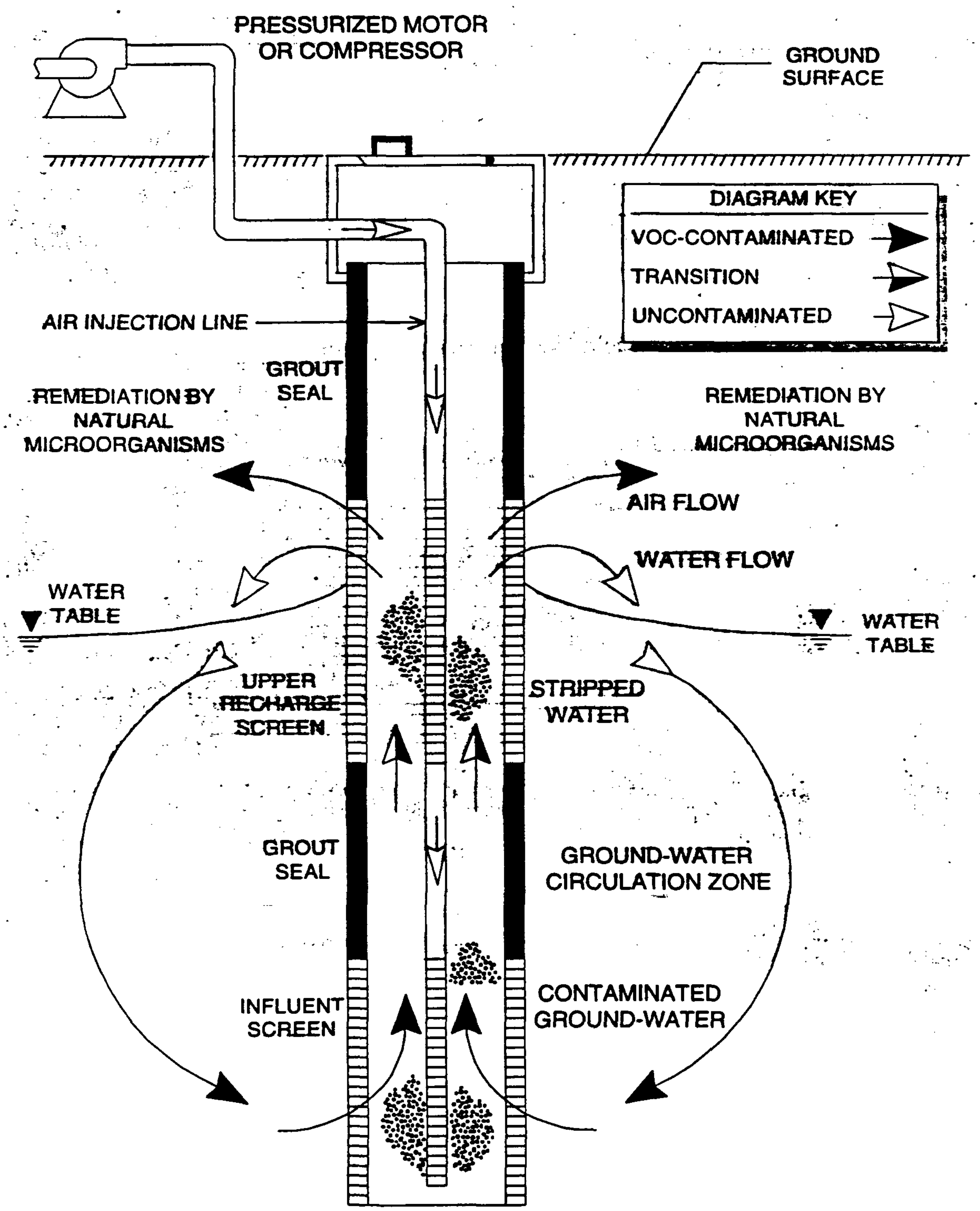

FIGURE 4. DDC IN-WELL VAPOR STRIPPING PROCESS

TABLE 1. IN-WELL VAPOR STRIPPING--SELECTED PERFORMANCE INFORMATION

Type of System	Soil Type	Plume Area	Operating Period (in Months)	Initial Contaminant Concentration(s)	Final Contaminant Concentration(s)	Percent Reduction
NoVOCS™	Silty sand with clay	--	2	TPH: 10,200 µg/L	TPH: 3,000 µg/L	71%
	Sandy silt/ silty sand	--	4	TCE: 50-310 µg/L	TCE: 4-251 µg/L	Average: 63% Maximum: 93%
	Fine to medium sand	--	18	TCE: 2,140-3,650 µg/L	TCE: 80-385 µg/L	Average: 91% Maximum: 98%
UVB	Silt, sand and minor clay	--	18	TCE: 940 µg/L	TCE: 150 µg/L	84%
	Silt, sand and minor clay	--	18	TCE: 1,000 µg/L	TCE: 270 µg/L	73%
	Silt and silty fine sand	--	18	TCE: 400 µg/L	TCE: 45 µg/L	89%
DDC	Sand and gravel	9,000 ft^2	20	TPH: 30 mg/L Benzene: 0.049 mg/L	TPH: 15 mg/L Benzene: 0.008 mg/L	TPH: 50% Benzene: 84%
	Sand and silt	2,400 ft^2	6	TPH: 0.56 mg/L Benzene: 0.34 mg/L	TPH: <0.02 mg/L Benzene: <0.002 mg/L	TPH: >96% Benzene: >99%
	Clay	1,000 ft^2	22	TPH: 110 mg/L Benzene: 0.055 mg/L	TPH: <0.02 mg/L Benzene: <0.002 mg/L	TPH: >99% Benzene: > 96%

4.0 TECHNOLOGY PERFORMANCE

4.1 GENERAL DESIGN CONSIDERATIONS

- Packer and well configurations must be designed to maximize volatilization of VOCs and adequately direct ground-water flow into the unsaturated zone;
- Chemical changes in ground-water and soil (chemical precipitation or oxidation) due to use of system must be addressed (7);

Performance data for selected applications of the three in-well vapor stripping processes described are presented in Table 1 on the previous page.

4.2 NoVOCs™

Table 2 presents cost comparisons prepared by EG&G Environmental for the NoVOCs™ system and other technologies. This information is provided as normalized costs to account for site-specific variations, including capital and operation and maintenance (O&M) expenses, over an estimated project duration of two years for NoVOCs™, air sparging, and biodegradation and five years for pump and treat. All costs are site specific and actual costs will vary depending on site specific parameters (2).

TABLE 2. NoVOCs™ COST INFORMATION

Technology	Normalized Cost	
	TCE	BTEX
NoVOCs™ with Biocube™	NA	1
NoVOCs™ with activated carbon	1	1.5
Air sparging with SVE and activated carbon	2.5	1.9
In situ biodegradation	NA	2.2
Pump and treat with air stripping and activated carbon*	3	2.5

* Pump and treat costs vary greatly depending on water disposal costs. For these examples, mid-range disposal costs were assumed when computing site costs.

4.3 UVB

Cost information for application of the UVB system for an approximate 65 week period, is presented in Table 3, and provides equivalent U.S. dollars. The costs presented may not be directly applicable to current applications of this system in Germany or other countries due to the "price structure" in West Germany at the time of remediation (1989) and the increased amount of testing/monitoring necessary for what was a relatively unknown technology. This demonstration site contained one UVB well, six ground-water monitoring wells, and four soil air monitoring wells installed at depths generally less than 35 feet. Electricity costs are not included since energy was supplied by the owner, however approximately 35,000 kW-hrs were used during the 11,000 hour run time (3).

TABLE 3. UVB COST INFORMATION

Type of Expense	% of Total	Equivalent $ U.S.*
Planning, organization, project management, remediation equipment	25.3	64,000
Field work	17.4	44,000
Laboratory analytical work	29.2	74,000
Drilling costs	11.5	29,000
Activated carbon and regeneration	16.6	42,000
Total:	100.0	253,000

* Original cost information was provided in German Marks (DM) and converted at a conversion rate of 1 U.S. dollar = 1.70 DM.

4.4 DDC

Representative cost information for installation, operatic... and maintenance of a DDC system is presented in Table 4. In addition, an analysis by the developer of the DDC system comparing system costs to areal size of the ground-water plume for numerous applications yielded total costs of $8.82 per square foot of plume, with installation costs comprising $5.80 per square foot and O&M costs of $3.02 per square foot (13).

TABLE 4. DDC COST INFORMATION

Type of Expense	Cost	% of Total
Capital Costs		
Drill and install wells (3 extraction, 13 sparging, 6 monitoring)	$16,000	10.5
Install ground-water and vapor extraction system	$40,300	26.4
Install ground-water sparging system	$25,750	16.9
Electrical connections	$4,050	2.7
Trenching, soil disposal, backfilling, asphalting	$26,800	17.5
Air compressor and control trailer	$26,800	17.5
Initial system startup and de-bugging	$3,000	2.0
Project management, constructions oversight, regulatory reporting and coordination	$10,000	6.5
Total Capital Costs:	**$152,700**	**100**
Annual Operating Costs		
Maintenance labor and parts	$30,000	47.8
System monitoring and reporting	$30,000	47.8
Electricity (@$0.07/kw-hr)	$2,750	4.4
Total Annual Operating Costs:	**$62,750**	**100**

5.0 TECHNOLOGY ADVANTAGES

<u>Cost-effectiveness</u>:

- Does not require injection wells, discharge lines, discharge fees, etc. to recirculate/discharge ground-water (2, 15);
- Single well can be used for extraction of vapors and ground-water remediation (14);
- Can continuously remove VOCs from ground-water without pumping water to surface, avoiding the need to handle contaminated water above ground and/or to dispose of or store partially-treated water (7, 15);
- Contaminated vapors are more easily and inexpensively removed and treated aboveground than contaminated water (2);
- Contaminants not typically displaced due to lower air injection pressures and flowrates relative to air sparging (8);
- Low operation and maintenance costs (10).

<u>Integration</u>:

- Enables recirculation of chemical aids to ground-water remediation (surfactant, catalysts, etc.) (14);
- Enhances bioremediation of hydrocarbons as a result of aeration/ recirculation of treated water (2);
- Wells can be used to distribute nutrients amendments for bioremediation (10);
- Facilitates coupling with soil vapor extraction systems (2).

<u>Simplicity</u>:

- Involves no moving parts beneath ground surface;
- Designed to run continuously with only routine maintenance;
- Does not involve complicated components (7, 15).

<u>Effectiveness</u>:

- Accelerates restoration due to disruption of free-phase product in capillary fringe (2);
- Creates both vertical and horizontal ground-water flow allowing penetration of low permeability horizontal layers (10).

6.0 TECHNOLOGY LIMITATIONS

- Chemical precipitates may form during air stripping and may clog the well screens, limiting ground-water circulation (5, 9);
- Shallow aquifers may limit system effectiveness due to limited space for reinfiltration/circulation (5);
- If air stripping wells are not properly designed or constructed, the plume may be spread beyond the radius of influence of the stripping well (7, 14);
- Ground-water discharges to unsaturated soils may mobilize pockets of contamination, adding to total mass of contaminants in aquifer. *(These contaminants can be removed using the in-well stripping system minimizing the impact of this potential problem.)* (7, 14).

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APPENDIX K

Calculations for the In-Well Stripping Alternative

1 CALCULATION FOR DESIGNING IN-WELL AIR STRIPPING ALTERNATIVE

The goal of this section is to identify location, radius of influence, numbers of in-well air stripping systems that will capture and remediate the primary contaminants found in the aquifer of the Central Corridor.
First, site specific data is summarized and then designing factors are discussed. Second, the designing components are determined (e.g., location, number, and size of the system). Third, effectiveness of this alternative is explored, including air/water ration, duration, and factors for vapor phase treatment system.

1.1 Site specific data

Table K-1 shows the summary of site specific hydrogeological data and Table K-2 shows the summary of site specific contaminants data.

Table K-1

Site Specific data – Hydrogeology

	Symbol	Unconsolidated	Bedrock
Depth to the groundwater table	NA	5ft 1.5m	NA
Thickness of the aquifer (Below the ground surface)	H	96ft 29m	146ft 45m
Groundwater discharge rate[a]	Q	450 gpm 2.8E+04 cm^3/s	450 gpm 2.8E+04cm^3/s
Hydraulic conductivity[a]	K	24.6 ft/d 8.7E-03 cm/s	5 ft/d 1.8E-03 cm/s
Hydraulic gradient[a]	dh/dx	0.02	0.02
Specific discharge rate[b]	q	1.7E-04 cm/s	3.54E-05 cm/s
Porosity[a]	n	0.28	0.05
Seepage velocity[c]	Vs	6.2E-04 cm/s	7.1E-04 cm/s
Wells need to be remediated		S39, S40, S 64, S68, S85, S87, S91, S94, and UG2	S64, S66, S81, and S97

[a] Data are given in the text (Section 3) and Phase 1A report
[b] $q = (-K) \times (dh/dx)$
[c] $Vs = q / n$

Abbreviation

NA	Not applicable	gpm	gallon per minute
cm^3/s	cubic centimeter per second	ft/d	feet per day
cm/s	centimeter per second		

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Table K-2

Groundwater Monitoring Wells in the Central Corridor Area

With detected Exceedances of MCLS for Primary Site Contaminants

			PRIMARY SITE CONTAMINANTS [a] (ug/l or ppb)		
			PCE	TCE	VC
MCLs			5	5	2
Wells #		Sampling location (ft)[b]			
S39 (H)	Un	78-88	9	10	5UV
S40 (G)	Un	69-79	33	60	5UV
S64	Un	10-15	32J	10V	0.5U
	Un	27-32	92V	33V	0.8U
	B	40-55	250V	100V	2V
S65	Un	4-24	0.7V	0.5UV	0.5UV
	Un	27-37	17V	8V	0.5UV
	B	41-56	250V	42V	2UV
S66	B	Deep	29V	3V	0.5U
S68	Un	14.5-45	48	30	10U
	Un	105	50	37	5U
S85	Un	20-30	220J	32	2U
	Un	64-71	190J	15	2U
S81	Un	10-20	98	ND	ND
	Un	35-50	120	ND	ND
	B	82	160	ND	ND
S87	Un	Shallow	150	45	10U
	Un	Middle	7	1	5U
	B	Deep	130	19	10U
S91	Un	Shallow	57J	29J	1U
	Un	Middle	67J	28J	1U
	Un	Deep	70J	32J	1U
S94	Un	Shallow	7	9	5U
	Un	Middle	21	21	5U
	Un	Deep	6	11	0.4
S97	Un	Shallow	18	70	ND
	B	Deep	99JV	42JV	1UV
UG2	Un	---	5	9	5U

Notes:
[a] See also tables in Section 4
[b] See boring logs (Phase 1A)

Abbreviations:
Un Unconsolidated aquifer
B Bedrock
ND Not detected

1.2 Designing In-well air stripping System

In order to capture and cleanup the primary contaminants detected in the wells summarized in Table K-2, location of in-well air stripping systems, radius of influence of each system, and number of the system should be determined.

1.2.1 Location

In-well air stripping often works effectively if more than one system is installed downgradient of a plume. If multi-well systems are installed in groundwater, they provide a "curtain" to remove enough VOCs from the water so that the water on the downgradient side of the curtain meets the MCL standards (Gorelick, 1999a). Therefore, first, the location of contaminated wells that line up cross the groundwater flow needs to be found, and then the location of the "curtains" need to be determined.

- Location of well lines

As seen in Figure 7-3 (in the text), well lines can be drawn in the following locations:

1st Line — Wells that are located in line adjacent to Aberjona River (Line 1)
North: S85 – S87 – S39 (H) – S68 – S91 – S40 (G): South
- Distance between S85 and S40 is approximately 900ft

2nd Line — Wells that are located upgradient of Line 1 (Line 2)
North: S97 – UG2 – S94: South
- Distance between S97 and S94 is approximately 800ft
- Distance between Line 1 and Line 2 is approximately 150-250ft.

3rd Line — Wells that are located in line away from the River (Line 3)
Northwest: S64 – S65 – S66: Southeast
- Distance between S64 and S66 is approximately 600 ft

Others — Wells that do not belong to any other groups
S81

- Locations of multi-well systems

1. Line A (length is approximately 900ft)
A series of in-well air stripping system will be installed to be parallel and downgradient of the Line 1. These in-well air stripping systems will remediate the primary contaminants found between the River and wells of the 1st and eventually, the 2nd group.

2. Line B (length is approximately 600ft)

The second multi-well systems will be installed on the downgradient side of the Line 3.

3. Well C
   One in-well air stripping system will installed in downgradient of the well S81.

1.2.2 *Radius of influence*

Equations and models for estimating the radius of influence of an in-well air stripping system have been discussed in several literatures (Gvirtzman and Gorelick, 1992). Yet, since the technology is still in development process, in often cases, the radius of influence needs to be estimated by conducting a pilot test (Pennington, 1999a & Klingel, 1999a). In general, radius of influence is about 1 to 2 times the distance from the water table to the middle of the lower screened interval (Gorelick, 1999a; Buermann & Bott-Breuning, 1994, p. 98). Therefore, the approximate radius of influence of a well can be determined if 1) the thickness of aquifer, 2) depth to the groundwater table, and 3) the distance from the bottom of the aquifer to the middle of the lower screened interval are identified. Radius of influence of each well system is summarized in Table K-3.

Table K-3 Radius of Influence

	Area 1	Area 2	Well #S81
Location	Along the Aberjona River	Near the eastern border of the Corridor	Northern portion of the Corridor
Width of the area[1]	900feet	600 feet	N/A
Wells located in the Area	S39 (H), S40 (G), S68, S85, S87, S91, S94, S97, UG2	S64, S65, S66	S81
Depth to the Groundwater table (GW)[2]	5 feet	5 feet	5 feet
Depth of Unconsolidated zone (U)[2]	96 feet bgs	35 feet bgs	62 feet bgs
Length from the bottom of the unconsolidated to the middle of the lower screened interval (L)[3]	5 feet	15 feet	15 feet
Radius of influence[4]	**96 feet**	**45 feet**	**72 feet**
Number of wells necessary[5]	**7**	**10**	**1**

Notes:
1. See Figure 7-3
2. Boring Logs (GeoTrans & RETEC, 1994)
3. Wells with 10-foot lower screened interval are proposed to remediate the unconsolidated aquifer and 10 feet (Area 1) and 20 feet (Area 2 and Well S 81) of the upper part of the bedrock. The lower screened interval is located the bottom 10 feet of each well (Gorelick, 1999; Stagner, 1999).
4. Radius of influence = (U) – (GW) + (L)
5. See Appendix K of this paper for detailed calculations.

1.2.3 Number of systems

Number of system can be estimated if the radius of influence and the spacing is identified. The following steps are taken to estimate the number of well systems in the Central Area Corridor:

1) Identify the length of Line A and B, each of which is located perpendicular to groundwater flow.
2) Identify the radius of influence of in-well air stripping systems that will be installed to remediate Line A, Line B, and Well C.
3) Identify the diameter of influence.
4) Calculate 70% of the diameter of influence of the in-well air stripping systems.
5) Number of systems that will be determined by the equation below:
   Number of systems = (Length of Line) ÷ (70% of the diameter)
   30% of diameter of wells next each other will be overlapped to increase security.

The results are summarized in Table K-4

Table K-4 Size of In-Well Air Stripping Units

	Area 1	Area 2	Well #S81
Location	Along the Aberjona River	Near the eastern border of the Corridor	Northern portion of the Corridor
Wells located in the Area	S39 (H), S40 (G), S68, S85, S87, S91, S94, S97, UG2	S64, S65, S66	S81
Depth to the Groundwater table (GW)[1]	5 feet	5 feet	5 feet
Depth of Unconsolidated zone (U)[1]	96 feet bgs	35 feet bgs	62 feet bgs
Thickness of Bedrock needs to be remediated (B)[1]	10 feet	20 feet	20 feet
Aquifer thickness (A)[2]	100 feet below groundwater table	50 feet below groundwater table	77 feet below groundwater table
Outer casing			
Total length (A+ 10 feet)[3]	110 feet	60 feet	87 feet
Upper screened interval	0-10 feet bgs	0-10 feet bgs	0-10 feet bgs
Lower screened interval	96-106 feet bgs	45-55 feet bgs	77-87 feet bgs
Inner casing			
Eductor tube (2.5 to 3-inch ∅)	105 feet	55 feet	82 feet
Air injection line (3/4-inch ∅)	100 feet	50 feet	77 feet

Notes:
1 Boring Logs (GeoTrans & RETEC, 1994)
2 A=U+B-GW
3 Since the Site has the thin vadose zone (< 5ft), vendors recommended that the well should have enough length above the groundwater table (10 feet) for effective air stripping and for

allowing air-lift effect (< 10 feet) within the well resulted from air injection (Gorelick, 1999; McNeil, 1999; Pennington, 1999; Stagner, 1999).

1.3 Effectiveness

The groundwater flowing toward the in-well air stripping system may pass the system several times, due to the continual circulation flow. However, a portion of the water would flow through the system only once (Buermann and Bott-Breuning, 1994, p. 98). Therefore, first, the air stripping effectiveness will be discussed by considering the case of single circulation of the groundwater in order to determine whether the MCLs would be achievable in single groundwater circulation:

#1 Single Groundwater Circulation

Concentration of contaminants in groundwater after flowing through an in-well air stripping system is determined by the following formula presented by Gvirtzman and Gorelick:

$$Cw^1 = \{1/(1+GH)\} \times Cw^0 \qquad (1)$$

Cw^1: Concentration of contaminant in water after 1st circulation
Cw^0: Initial concentration of contaminant in water
G: air/water ratio
H: dimensionless Henry's law constant

In general, air/water ratio is 50 to 100 (use 75 for this FS).
By using the equation (1), Cw^1 of the primary contaminants need to be cleanup in the aquifer of the Central Corridor can be determined. The result is shown in Table K-5.

Table K-5 Site Specific data – Contaminants

	PCE	TCE	VC
Henry's low constant (dimensionless, @25 C)	0.63	0.37	99
Air/water ratio	75	75	75
Maximum Concentration Limit (MCL)[a]	5 ppb	5 ppb	2ppb
Maximum concentration in the unconsolidated aquifer[a]	220 ppb @ S85	60 ppb @ S40	10 U ppb @ S68 & 87
Maximum concentration in the bedrock[a]	250 ppb @ S64 & S65	100 ppb @ S64	10 U ppb @ S64, S68 & S87
Concentration of contaminant in water after first circulation (unconsolidated)	4.6 ppb	2.1 ppb	2.1E-03 ppb
Concentration of contaminant in water after first circulation (bedrock)	5.2 ppb	3.4 ppb	2.1E-03 ppb

[a] *Data was given in the text.*

As seen in Table K-4, PCE in the bedrock might not be reduced to the MCL standard 5ppb. One of the ways to improve the reduction rate of PCE would be using larger diameter of circulation well. With use of 12-inch wells, instead of 8-inch wells, the amount of air flow needed could be reduced substantially, because the residence time of the water flow through the aeration is about 7 times longer in a 12-inch well than in a 8-inch well, in proportion to the greater cross sectional flow area (Stagner, 1999f).

#2 Determine circulation steps need to be taken

How many circulation would be required to remediate PCE in the bedrock to the MCL standard? Gvirtzman and Gorelick presented another equation with which one can calculate the number of circulation steps needed to reduce the concentration of contaminants to achieve a particular goal.

$$P = (-\log R) / \log(1+GH)$$

- P: number of circulation step
- R: (Reduction rate = Final concentration in water) / (Initial concentration in water)
- G air/water ratio (75)
- H dimensionless Henry's law constant.

Number of circulation steps necessary for PCE in bedrock can be determined where:

$R = 5/250 = 0.02$ (Bedrock)
$G = 75$
$H = 0.63$
$P = 1.009$ steps

Thus, PCE at the bedrock could be reduced to the MCL standard with 1.009 circulation step.

Overall, it is practical to say PCE found in the bedrock could be reduced to the MCL standard in single groundwater circulation.

1.4 Remediation time

Remediation time would be estimated in the following two ways:

- Method 1: Time for remediating contaminants within a capture zone
- Method 2: Time for remediating contaminants outside of the capture zone

(Gvirtzman and Gorelick, 1992; ABB, 1995; and HLA, 1999)

Method 1 is presented by Gvirtzman and Gorelick in 1992 and requires special computer models and data collected through a pilot study to determine travel time of targeted contaminants.
This method is usually used to determine the time for remediating a source area plume. For this Feasibility Study, **Method 2 may be applicable as the worst case scenario for the Site that does not have a particular plume and may be contaminated outside of the capture area.**

1.4.1 Method 1: Remediation time within a radius of influence

Given a recirculation flow rate of about 6 gpm (0.375 L/sec), it is expected that 95% of the flow circulates within a radius of about 60 feet of the well (120 diameter). According to an article presented by Gvirtzman and Gorelick, it is deduced that the time for a single circulation step is about 70 days (Gvirtzman and Gorelick, 1992).

> Note: In order to estimate the time for each contaminant being recirculated within a radius of influence, the groundwater circulation pattern that the in-well air stripping system would be produced needs to be estimated. Gvirtzmann and Gorelick present an equation with which one could estimate the likely groundwater patter (1992, equation (13)). To solve the equation given by Gvirtzaman and Gorelick, special computer models need to be used.

To calculate remediation time within the groundwater circulation flow, the largest retardation factor among the primary contaminants needs to be identified, and multiply the number to 70 days identified above.

Retardation factor

Retardation factor (R) equation:

$$R = 1 + K_d \bullet \rho_b / n$$

$$K_d = K_{oc} \bullet f_{oc}$$

K_d	Distribution coefficient
ρ_b	Bulk density
n	Porosity
K_{oc}	Organic carbon/water partition coefficient
f_{oc}	Fraction of organic carbon/soil

In Table K-6, factors and results of calculation of retardation factor are summarized.

Table K-6

Summary of Factors for Determining Retardation Factor

		PCE	TCE	VC
	ρ_b	1.6	1.6	1.6
K_d	K_{oc}	263	66	
	f_{oc}	0.001	0.001	
	K_d	0.263	0.066	
Unconsolidated	n	0.28	0.28	0.28
	R	2.5	1.4	
Bedrock	n	0.05	0.05	0.05
	R	9.4	3.1	

According to Table K-6, the retardation factor of the PCE is the largest; therefore, retardation factor need to be used to determined the remediation time.

Table K-7

Remediation time of remediating contaminants within a radius of influence

Aquifer	Retardation factor of PCE	Remediation time
Unconsolidated	2.5	25 weeks (6 month)
Bedrock	9.4	94 weeks (1.8 years)

1.4.2 Method 2: Remediation time to cleanup the Central Corridor

The remediation time has been estimated with the following equation:

Remediation time = [Distance [1]] x [Retardation factor [2]] / [Groundwater velocity] (HLA, 1999)

Notes:
1 The longest distance that PCE (with the largest retardation factor) may travel cross the Central Area Corridor has been used.
2 The largest retardation factor has been used

Based on the distance between Line A and Line B (600 feet or 183 m), velocity of groundwater (7.08 E-04 cm/s in bedrock @ n = 0.05), *and Retardation factor of* PCE (9.4), it is deduced that the remediation time would be approximately 7.5 years. With a safety factor of 2, the time required to remediate the Central Corridor aquifer would be 15 years. The result is summarized in Table K-8.

Table K-8

Duration time of remediating contaminants outside of the radius of influence

Distance between Line A and the eastern boundary of the Site	600 ft 183 m
Unconsolidated	
Vs	6.2E-04 cm/s
R	2.5
Travel time	2.3 yrs
Bedrock	
Vs	7.08E-04 cm/s
R	9.4
Travel time	7.7 yrrs

1.5. Vapor phase treatment and air monitoring

The primary contaminants of PCE and TCE emission resulting from in-well ari stripping system would be collected and treated though GAC unit.
The air flow rate to GAC is as same as the air injection rate, which will be 100 gpm where the pumping rate is 10 gpm with use of 8-inch diameter.

The effluent of the well system, namely, the influent of GAC unit is determined with Henry's low dimensionless and the contaminant's concentration in the aquifer:

$$C_{air} = C_{water} \times H$$

Therefore, the concentration of PCE in the air would be 158 ppb and TCE would be 37 ppb.

List of References

Buermann, W. and Bott-Breuning, G., "Bioremediation by Groundwater Circulation Using Vacuum-Vaporizer Well (UVB) Technology: Basic and Case Study," in R. E. Hinchee (ed.), Air Sparging for Site Remediation, pp. 97-107, Lewis Publishers, Ann Arbor, 1994.

Gvirtzman, H. and Gorelick, S. M., 1992, "The Concept of In-Situ Vapor stripping for Removing VOCs from Groundwater," *Transport in Porous Media*, vol. 8, pp. 71-92.

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Herrling, et al., "In Situ Bioremediatoin of Groundwater Containing Hydrocarbon, Pesticides, or Nitrate Using the Vertical Circulation Flows (UVB/GZB) Technique," in R. E. Hinchee (ed.), Air Sparging for Site Remediation, pp. 56-80, Lewis Publishers, Ann Arbor, 1994.

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McNail, P., July 1999, multiple interview via phone and electric mails by Kaori Sakaguchi Hall.

Pennington, L., July 1999, multiple interview via phone and electric mails by Kaori Sakaguchi Hall

Pinto, M. J., Gvirtzman, H., and Gorelick, S. M., 1997, "Laboratory-scale analysis of aquifer remediation by in-well vapor stripping 2. Modeling results," *Contaminant Hydrology*, vol. 29, pp. 41-58.

(SITE), Superfund Innovative Technology Evaluation Program, "Technology Profiles 8th edition," National Risk Management Research Laboratory, Office of Research and Development, US EPA, 1995, p. 165

Stagner, J., July 1999, multipie interview via phone and electric mails by Kaori Sakaguchi Hall

Stamm, Juergen, "Vertical Circulation Flows for Vadose and Groundwater Zone In Situ (Bio-) Remediation," in R. E. Hinchee, et al., In Situ Aeration: Air Sparging Bioventing, and Related Remediation Processes, pp. 4483-493, Battelle Press, Columbus, 1995.

APPENDIX L

Vendor Pricing for In-Well Air Stripping and Vapor Granulated Activated Carbon System

"CLEANING THE WORLD WITH ACTIVATED CARBON"

GENERAL CARBON CORP.

Facsimile Transmission

To: Ms Kaori Sakaguchi

From: Tim Joyce

Date: July 14, 1999

Number of Pages (including cover page): 2

Please Call (973)523-2223 If You Do Not Receive the Correct Number of Pages

33 Paterson Street Paterson New Jersey 07501 Tel: 973 523 2223 Fax: 973 523 1494

"CLEANING THE WORLD WITH ACTIVATED CARBON"

GENERAL CARBON CORP.

July 14, 1999

Mr. Kaori Sakaguchi
Massachusetts Dept. of Enviro. Protection

Dear Kaori,

Thank you for the call concerning your air stripping application. The application as I unden it includes 18 wells which are to be air stripped. Each air stripper will generate 100 CFM a the combinations will be in groups of 7, 10, and a single air stripper. The concentrations a PPB of PCE and 37 PPB of TCE.

To assist you in preparing a budgetary outline please accept for consideration the followin pricing:

For One Well To Be Airstripped at 100 CFM	Pr /unit
"The General" Air Pollution Control Barrel	$ 450.00
For Seven Wells To Be Airstripped At 100 CFM Each	
TV - 2200 Vapor Phase Adsorber	$ 7,961.00
For Ten Wells To Be Airstripped At 100 CFM Each Or A Total of 1000 CFM	
ES - 60 Activated Carbon System	$ 8,032.00
Total	$ 16,443.00

Another alternative would be to use one "The General" 55 gallon Air Pollution Control Ba airstripper.

I hope this is of interest to you. If I can be of further assistance please do not hesitate to

Sincerely

Tim Joyce

TJ/mjk

33 Paterson Street Paterson New Jersey 07501 Tel: 973 523 2223 Fax: 973 523 3494

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CC: davisenv@softcom.net, ksakaguc@tufts.edu, ksakaguc@hotmail.com
Subject: In well air stripping
Date: Tue, 06 Jul 1999 14:35:52 PDT

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Prof. Stanger,

Willard A. Murry at Harding Lawson Associate gave your name.

I am a graduate student of Hazardous Material Management program at Tufts University and currently working on a group thesis. We are working on "pre-feasibility study" of the aquifer of Wells G&H, Woburn, MA. We are working for Massachusetts Department of Environmental Protection (MA DEP).

I am in charge of evaluating feasibility of "in-well air stripping" technology at the Site. Currently, I am gathering the information of the technology in order to evaluate it for effectiveness, implementability, and cost.

I have several things that I would like learn from you:

- difference between your technology and other in-well air stripping technologies, such as UVB and DDC

- Factors (parameters) and equations in order to figure out 1) radius of influence, 2) number of wells necessary, and 3) cleaning effect.

- key factors that I need to have in order to calculate cost of the system.

- references that you recommend me to read.

I would like to talk to you tomorrow and ask you the questions above.
I hope that this message will help us to have a nice conversation when I call you tomorrow.

Sincerely,
Kaori Sakaguchi

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To: "'kaori sakaguchi'" <ksakaguc@hotmail.com>
Subject: RE: In well air stripping
Date: Tue, 6 Jul 1999 15:45:29 -0700

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Kaori,

I will be off campus most of the day tomorrow but will be in my office most of Thursday and Friday if you would like to call then. For now, here are some responses to your query.

1. Enclosed is some more information about the Multi-Stage In-Well Aerator (MSIWA) in a MS Word file.

2. Some of the differences between the MSIWA and NoVOCs, UVB, and DDC are as follows. You might also review the enclosed info and compare it to these other in-well technologies by reviewing them at www.gwrtac.org. Note that the MSIWA is not on GRWTAC because it was patented after that publication went to press, however it is listed in the EPA VISITT 6 publication (now called EPA REACHIT).

The MSIWA does not require in-situ recirculation to remove VOCs to Non-Detectable levels- it can do it in a single pumping pass and therefore affords more subsurface hydraulic control and discharge options. It can be used with conventional pump and treat hydraulic containment designs or in-situ recirculation designs. NoVOCs, UVB, and DDC all use in-well recirculation, however there are many sites where in-situ recirculaiton may not be feasible due to the hydrogeology of the site, such as a thin water bearing zone with low permeability overlay or areas with fast groundwater velocity which requires more conventional hydraulic control through extraction wells.

The MSIWA does not require a conventional pump or reactor like UVB- it uses only air lift pumping and in-well aeration through a fixed piping arrangement- no moving parts or mechanical devices.

The MSIWA removes more VOCs than NOVOCs because it adds two additional serial in-well aeration columns to supplement the air lift pumping process to achieve higher VOC removal rates.

VOC vapors from MSIWA are directed out the well at the surface and are not injected into the vadose zone of the ground like in DDC.

The radius of influence and number of wells required for a remediation system using MSIWA depends upon the hydrogeology of the site, remediation goals, and discharge options desired. Usually, a pumping test would be performed to determine the hydrogeologic characteristics of a site and then this data would be input into a groundwater modelling software and various extraction well arrangements would be run to develop a well layout that provides for hydralic containment of the contaminant plume. Once this is done one of the extraction wells would be installed and a pilot test of the MSIWA apparatus in the well would be conducted to establish the relationships between water pumping rate, air flow rate, and amount of VOC removal for that particular site. It would be very difficult to try and calculate these relationships in lieu of an empirical test because of a number of difficult to quantify variables, however educated guesses can be made based on MSIWA performance at other sites. Because the time and cost of a pilot test is small we recommend one at each different site to empirically determine the device efficiency for various water and air flow rates.

Some references include the GWRTAC site referenced above for a discussion on in-well technologies (although it doesn't incude MSIWA because of its more recent development), the enclosed info on MSIWA including a copy of the patent, and a trip to the EPA REACHIT site on the internet for more innovative technologies.

I look forward to talking with you when you call.

Joseph Stagner

P.S.- Thanks for the honorary title, but I am an engineer and manager of the campus utilities department here at UC Davis and not a professor.

-----Original Message-----
From: kaori sakaguchi [mailto:ksakaguc@hotmail.com]
Sent: Tuesday, July 06, 1999 2:36 PM
To: jcstagner@ucdavis.edu
Cc: davisenv@softcom.net; ksakaguc@tufts.edu; ksakaguc@hotmail.com
Subject: In well air stripping

Prof. Stanger,

Willard A. Murry at Harding Lawson Associate gave your name.

I am a graduate student of Hazardous Material Management program at Tufts University and currently working on a group thesis. We are working on "pre-feasibility study" of the aquifer of Wells G&H, Woburn, MA. We are working for Massachusetts Department of Environmental Protection (MA DEP).

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- difference between your technology and other in-well air stripping technologies, such as UVB and DDC

- Factors (parameters) and equations in order to figure out 1) radius of influence, 2) number of wells necessary, and 3)cleaning effect.

- key factors that I need to have in order to calculate cost of the system.

- references that you recommend me to read.

I would like to talk to you tomorrow and ask you the questions above.
I hope that this message will help us to have a nice conversation when I call you tomorrow.

Sincerely,
Kaori Sakaguchi

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Multi-Stage In-Well Aerator

July 7, 1999

Kaori Sakaguchi

Subject: Multi-Stage In-Well Aerator

Thanks for your inquiry about the Aerator. Below is some information about the system, which we will have up on a web page soon.

The Multi-Stage In-Well Aerator is a new technology for in-situ air stripping of VOCs from groundwater. It has no moving parts and is constructed almost entirely of PVC pipe parts for durability and low cost. The system uses only compressed air- no electrical power to the wells is required.

The system has been proven in a full scale commercial application with the four well 160 gpm West Campus Groundwater Cleanup System at UC Davis which has been operational for 3.5 years and which has shown significant containment and cleanup of the VOC contaminant plume. In addition the system has been successfully pilot tested at two other US and one European site within the last 12 months, and deployment of it in a full scale 11 well groundwater treatment system at the Savannah River Site is underway with the design phase having just been completed.

Based on our experience capital cost for the system should be from ¼ to ½ that of a conventional stacked tray or packed tower system.. O&M cost and effort should be much less as well since there are no moving parts in the well, now transfer tanks, level switches, etc and the air compressor does not require descaling or disinfection like stacked trays and packed towers. At UC Davis our O&M cost has been limited to electrical consumption of about $10,000 per year, plus $2,400 per year for contracted quarterly preventative maintenance on the air compressor, and 40 to 80 hours per year of staff time to check up on the system.

Case Histories

Following are Aerator system case histories, plus sketches of some of the configurations used. Also enclosed is a copy of the first page of the Aerator patent. The full patent may be viewed at http://patent.womplex.ibm.com by searching on patent number 5620593, or I can fax/email the rest to you if you need it.

The technology has been peer reviewed and included in the EPA VISITT innovative technologies database, EPA TECHKNOW database, and several other industry innovative technologies databases. It also has been approved for use by the Navy, Army, Air Force, and DOE under a Broad Agency Announcement from the US Navy NELP command.

Davis Environmental 2305 Inverness Place, El Dorado Hills, CA 95762 • (916) 939-7132 (ph/fax) • jstagner@aerator.com

UC Davis
The Aerator was developed at UC Davis for a full scale groundwater containment and cleanup system here on campus. The prime contaminant here is chloroform up to abut 700 ug/l, which has a fairly low volatility and is more difficult than most VOCs to air strip our of water. We've had a four well, 40 gpm per well aerator based system running continuously here since October 1995 in 8" diameter wells, with good results in plume shrinkage returned as documented in our quarterly reports to our Regional Water Quality Control Board. We have also had very high system reliability with very little O&M cost and effort. System installation cost was about $150,000 versus RIFS estimates of $680,000 and actual bids for conventional systems of around $500,000 to $900,000.

Portland Air National Guard Base (March 1998)
A pilot test of the Aerator in a 12" diameter by 25 foot deep well was conducted by Davis Environmental under contract to ERM West for the Air National Guard. In the pilot test the aerator removed all VOCs to non-detect in a single pumping pass with about 60 scfm of air flow. Maximum sustainable water pumping rate from this extremely shallow aquifer was 4 gpm, and the prime contaminant was cis 1,2 DCE at 350 ug/l, which like chloroform is fairly low in volatility.

Savannah River Site- A/M Southern Sector Plume (September 1998)
A pilot test of the Aerator in an 8" diameter in-situ recirculation type well, 170 feet deep, was conducted by Davis Environmental for the Westinghouse Savannah River Company. In the pilot test the aerator improved air stripping efficiency in the 36 gpm recirculation well from about 40% per pumping pass with the previous air lift pumping only arrangement to 92% per pass for TCE and 95% per pass for PCE. This test was conducted with only one stage of the aerator and additional testing with both stages is expected to increase these rates to 100% removal per pass.

Ulstrup. Hvorslev Kommune. Denmark (November 1998)
A pilot test of the Aerator in a 315mm (12 inch) diameter by 7 meter (23 feet) deep well was conducted by Adept Technologies (under license from Davis Environmental) for the Danish EPA in November 1998. Background concentrations of 100 – 200 ug/l of TCE were removed to < .5 ug/l in a single pumping pass through the well.

Savannah River Site- Miscellaneous Chemical Basin Plume (January 1999)
Based upon the pilot test results at Portland and SRS, and the operating performance at UC Davis, Westinghouse Savannah River Company has contracted with Davis Environmental for purchase of the Aerator technology plus design, fabrication and technical support for full scale installation of an Aerator based system in 11 each 200 foot deep in-situ recirculation wells at the MCB site.

Conceptual Pilot Study Plan

A pilot study to establish performance data and prove the effectiveness of the Aerator at any particular site can typically be accomplished in as little as one week at a cost of about $15,000 (not including the test well installation or lab fees). Following is a typical conceptual plan for a pilot study:

1. Design and manufacture Aerator (2 to 4 weeks lead time required);
2. Shipment to the site (one week time required),
3. Installation in a client provided well (one to two days on-site installation time)
4. Perform operational testing (2 to 4 days on-site)
5. Remove Aerator (optional)(one day on-site time)
6. Analyze data, produce report (two weeks after lab data received);
7. (Optional) Repetition of performance testing by Davis Environmental or others;
8. (Optional) Longer term continuous operational testing by DE or others to prove reliability and ease of operation of system.

The figures shown with the case histories below represent some of the Aerator configurations used thus far. Please note that many other configurations of the Aerator system are possible, including placing the whole apparatus below ground, or raising the head structure higher above the ground to establish more gravity head for transporting the water to the discharge point, or reinjecting the cleaned ground water instead of surface discharge, etc.

Full Scale System Cost

The cost for purchase of the technology, including site specific design, fabrication, and assembly drawings, plus testing, operation and maintenance manuals, can range from as little as $10,000 for very small sites with few wells to about $50,000 for larger sites with six or more wells. Cost for fabrication of Aerators ranges from $1,000 to $4,000 per well depending upon well diameter and depth. Total system cost depends upon the number, diameter, depth, and pumping rate of wells needed to achieve plume capture at the site, plus the concentration, and type of VOCs to be removed. We believe that an Aerator based system can typically be constructed for about half the cost of a conventional pump and treat system using stacked tray or packed tower air strippers, and that O&M cost is much less as well.

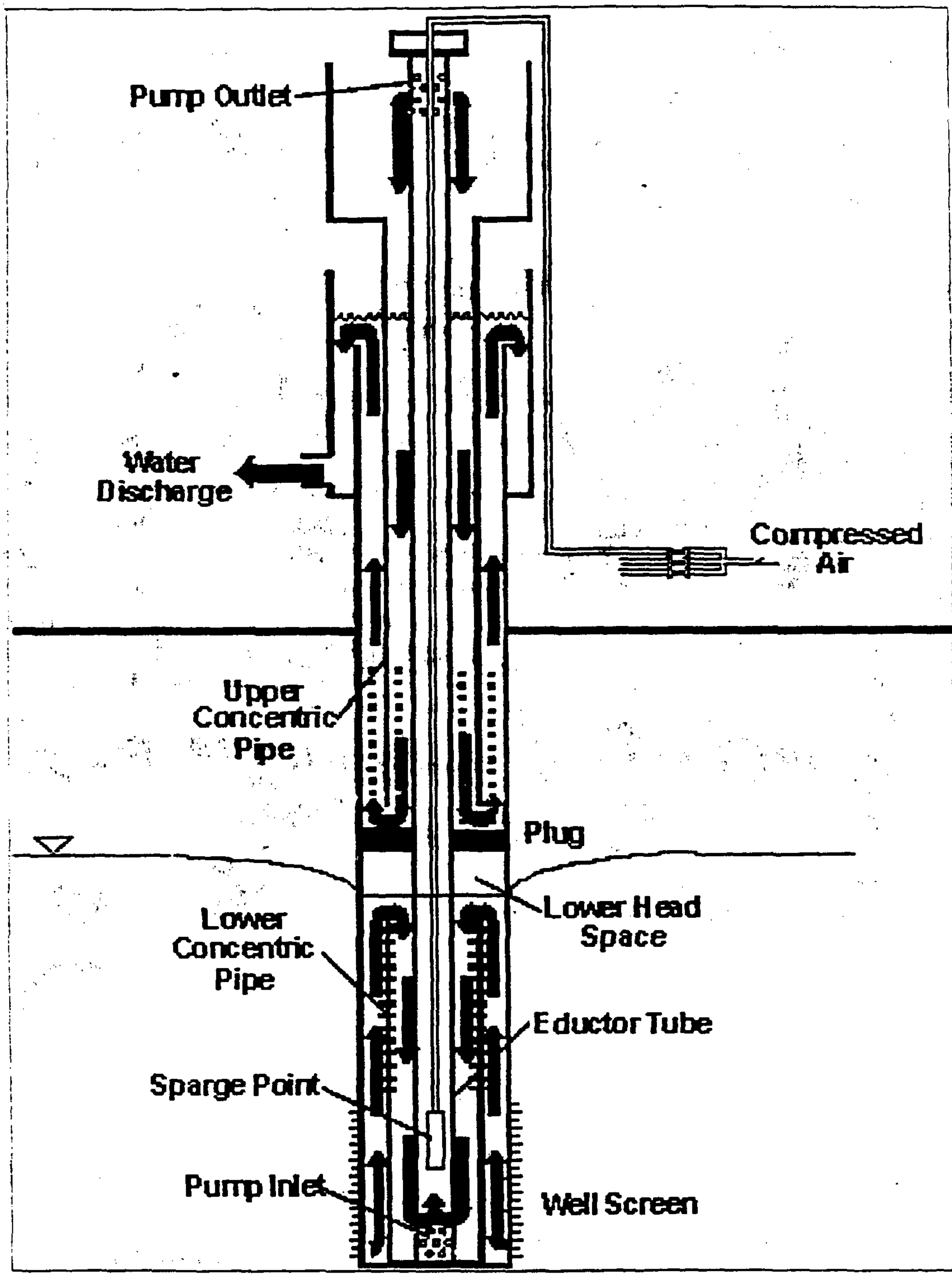
Please contact me again if you would like more information.

Sincerely,

Joseph Stagner, P.E.

Davis Environmental 2305 Inverness Place, El Dorado Hills, CA 95762 • (916) 939-7132 (ph/fax) • jstagner@aerator.com

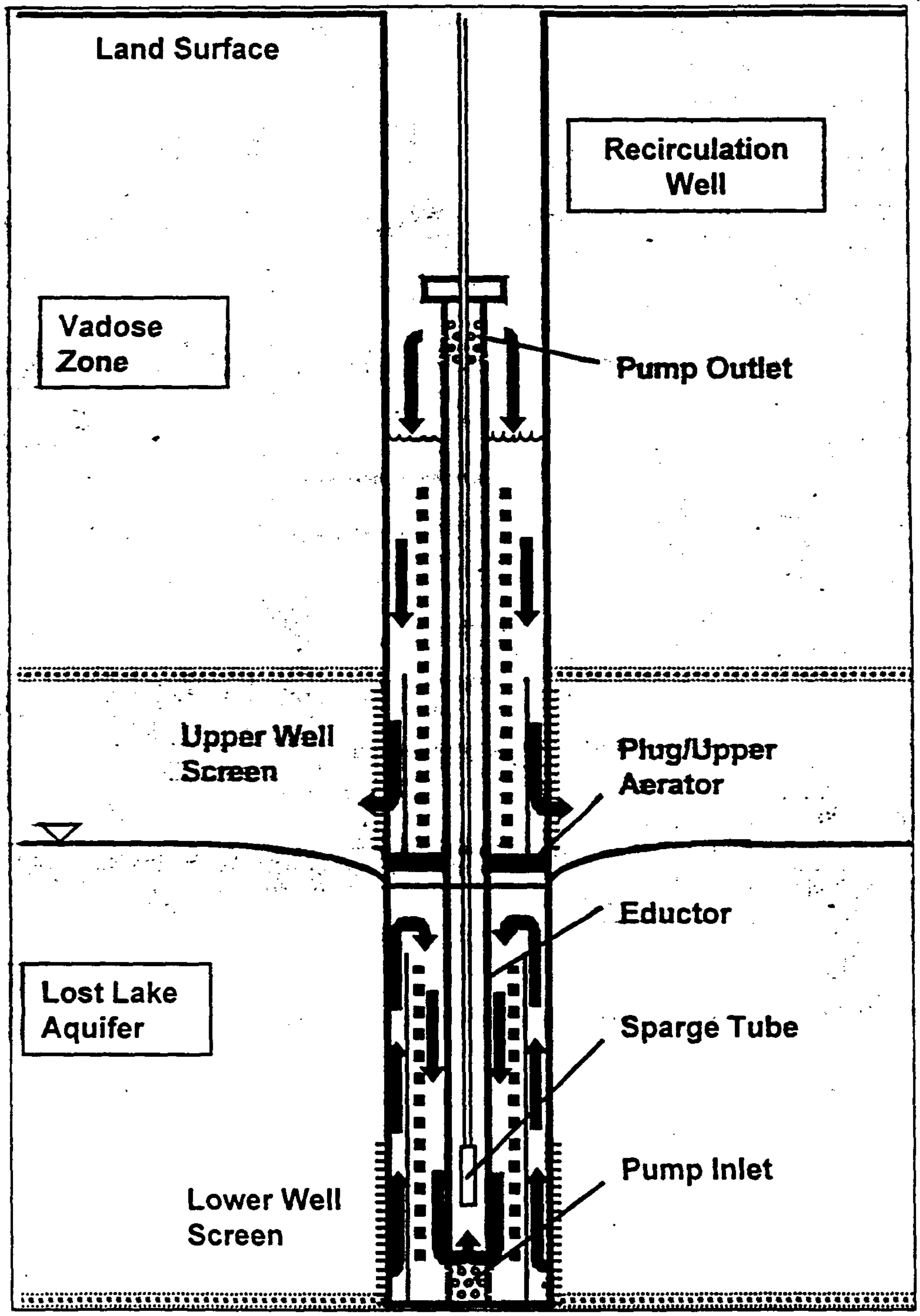
Multi-Stage In-Well Aerator



UC Davis Installation

Davis Environmental
2305 Inverness Place, El Dorado Hills, CA 95762 • (916) 939-7132 (ph/fax) • jstagner@aerator.com

Multi-Stage In-Well Aerator



Savannah River Site Installation

Davis Environmental 2305 Inverness Place, El Dorado Hills, CA 95762 • (916) 939-7132 (ph/fax) • jstagner@aerator.com

US005620593A

United States Patent [19]

Stagner

[11] **Patent Number: 5,620,593**

[45] **Date of Patent: Apr. 15, 1997**

[54] MULTI-STAGE IN-WELL AERATOR

[76] Inventor: Joseph C. Stagner, 2305 Inverness Pl., El Dorado Hills, Calif. 95762

[21] Appl. No.: 662,979

[22] Filed: Jun. 12, 1996

[51] Int. Cl.⁶ C02F 1/20

[52] U.S. Cl. 210/90; 210/170; 210/199; 210/218; 261/21; 261/122.1

[58] Field of Search 210/90, 170, 198.1, 210/199, 205, 209, 218, 220, 747, 908; 261/21, 122.1

[56] References Cited

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4,263,143	4/1981	Ebner et al.	210/218
4,265,753	5/1981	Manuel	210/218
4,278,546	7/1981	Roesler	210/199
4,478,765	10/1984	Tubbs	210/170
5,147,561	9/1992	Burge et al.	210/747
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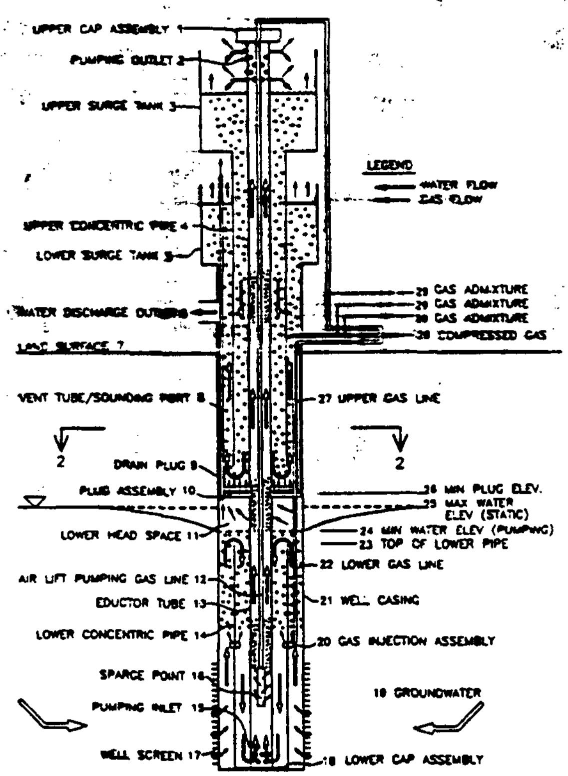
Primary Examiner—Neil McCarthy
Assistant Examiner—Theodore M. Green

[57] ABSTRACT

An in-well system for simultaneously treating and extracting groundwater by injecting compressed gas through the groundwater in multiple successive stages as it is pumped out of a well. The process is usable for in-well aeration stripping of Volatile Organic Compounds from groundwater or for other applications in which it is desirable to pass compressed gas through groundwater to alter the physical, chemical, or radiological properties of the groundwater prior to its discharge from the well.

5 Claims, 2 Drawing Sheets



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RELATED: Dictionary Thesaurus

From: kaori sakaguchi <ksakaguc@hotmail.com> Save Address Block Sender
To: jcstagner@ucdavis.edu
CC: ksakaguc@hotmail.com, ksakaguc@emerald.tufts.edu
Subject: RE: In well air stripping
Date: Wed, 07 Jul 1999 11:32:47 PDT

Reply | Reply All | Forward | Delete | Previous | Next | Close

Dear Joe,

Thank you for your prompt reply.
I really apprecite it.

I am not sure whether you have time to help me designing the in-well air stripping system, but since I have little knowledge of this technology, if an expert like you give me suggestions, that would help me a lot.

Currently, I am trying to find the locations and sizes of the system at our site. Tell the truth, I need to estimate a cost (rough one) by next Tuesday...

Just in case, if you have time for me to help this task, I would like to explain the site briefly.

Attached MS excel file is the summary of the wells contaminated by TCE and PCE, and summary of hydrogeological information.
Attache MS words is the brief summary of the Site.

Questions:

1)Groundwater table
My biggest concern is the shallow groundwater table, which is located within 5ft below the ground surface. How does it affect the system? Do you think that it is feasible to apply the inwell air stripping system in our Site? (the wells are located in vacant area, not residential area, though)

2) Effeciveness
- With the groundwater flow rate 450 gpm, could be the resident time long enough to remediate the groundwater?
- The shallow wells are contaminated by PCE (5-220 ppb) and by TCE (9-60 ppb). The bedrock wells' contamination level is: PCE (29-250 ppb) and TCE (45-100 ppb). Both TCE and PCE should be remediated by less than 5 ppb. Do you think that the remediation would be technically feasible?

3) Depth of the wells
The three bedrock wells that are contaminated in 150 ft below ground surface. Can the system remediate contaminants in this deep aquifer?

4) Location
The wells should be installed down gradient? or up gradient?

5) Cost
Could you estimate rough cost of eight 96 ft length of system and three 150 ft length of the system? What is your best guess of the total cost of these systems with air blowera and GACs and other necessary equipment?

6) Data needs
What information is lacking in terms of estimate cost and effeciveness?

*****
If I were live closer to your office, I would have visited you and asked the questions above for about an hour....
In addition, since I could write better that I could speak in English, I need to send you this long e-mail before I call, in order to explain the condition of the site.

If you give me any answers of my questions, that would help me a lot.
I will call you tomorrow.

Sincerely,

Kaori Sakaguchi
617-776-3473 (home)
617-627-5118 (office)
617-627-3401 (fax)

From: "Joe Stagner" <szcators@ucdavis.edu>
Reply-To: <jestagner@ucdavis.edu>
To: "'kaori sakaguchi'" <ksakaguc@hotmail.com>
Subject: RE: In well air stripping
Date: Tue, 6 Jul 1999 15:45:29 -0700

Kaori,

I will be off campus most of the day tomorrow but will be in my office most of Thursday and Friday if you would like to call then. For now, here are some responses to your query.

1. Enclosed is some more information about the Multi-Stage In-Well Aerator (MSIWA) in a MS Word file.

2. Some of the differences between the MSIWA and NoVOCs, UVB, and DDC are as follows. You might also review the enclosed info and compare it to these other in-well technologies by reviewing them at www.gwrtac.org. Note that the MSIWA is not on GRWTAC because it was patented after that publication went to press, however it is listed in the EPA VISITT 6 publication (now called EPA REACHIT).

The MSIWA does not require in-situ recirculation to remove VOCs to Non-Detectable levels- it can do it in a single pumping pass and therefore affords more subsurface hydraulic control and discharge options. It can be used with conventional pump and treat hydraulic containment designs or in-situ recirculation designs. NoVOCs, UVB, and DDC all use in-well recirculation, however there are many sites where in-situ recirculaiton may not be feasible due to the hydrogeology ot the site, such as a thin water bearing zone with low permeability overlay or areas with fast groundwater velocity which requires more conventional hydraulic control through extraction wells.

The MSIWA does not require a conventional pump or reactor like UVB- it uses only air lift pumping and in-well aeration through a fixed piping arrangement- no moving parts or mechanical devices.

The MSIWA removes more VOCs than NOVOCs because it adds two additional serial in-well aeration columns to supplement the air lift pumping process to achieve higher VOC removal rates.

VOC vapors from MSIWA are directed out the well at the surface and are not injected into the vadose zone of the ground like in DDC.

The radius of influence and number of wells required for a remediation system using MSIWA depends upon the hydrogeology of the site, remediation goals, and discharge options desired. Usually, a pumping test would be performed to determine the hydrogeologic characteristics of a site and then this data would be input into a groundwater modelling software and various extraction well arrangements would be run to develop a well layout that provides for hydralic containment of the contaminant plume. Once this is done one of the extraction wells would be installed and a pilot test of the MSIWA apparatus in the well would be conducted to establish the relationships between water pumping rate, air flow rate, and amount of VOC removal for that particular site. It would be very difficult to try and calculate these relationships in lieu of an empirical test because of a number of difficult to quantify variables, however educated guesses can be made based on MSIWA performance at other sites. Because the time and cost of a pilot test is small we recommend one at each different site to empirically determine the device efficiency for various water and air flow rates.

Some references include the GWRTAC site referenced above for a discussion on in-well technologies (although it doesn't incude MSIWA because of its more recent development), the enclosed info on MSIWA including a copy of the patent, and a trip to the EPA REACHIT site on the internet for more innovative technologies.

I look forward to talking with you when you call.

Joseph Stagner

P.S.- Thanks for the honorary title, but I am an engineer and manager of the campus utilities department here at UC Davis and not a professor.

-----Original Message-----
From: kaori sakaguchi [mailto:ksakaguc@hotmail.com]
Sent: Tuesday, July 06, 1999 2:36 PM
To: jcstagner@ucdavis.edu
Cc: davisenv@softcom.net; ksakaguc@tufts.edu; ksakaguc@hotmail.com
Subject: In well air stripping

Prof. Stanger,

Willard A. Murry at Harding Lawson Associate gave your name.

I am a graduate student of Hazardous Material Management program at Tufts University and currently working on a group thesis. We are working on "pre-feasibility study" of the aquifer of Wells G&H, Woburn, MA. We are working for Massachusetts Department of Environmental Protection (MA DEP).

I am in charge of evaluating feasibility of "in-well air stripping" technology at the Site. Currently, I am gathering the information of the technology in order to evaluate it for effectiveness, implementability, and cost.

I have several things that I would like learn from you:

- difference between your technology and other in-well air stripping technologies, such as UVB and DDC

- Factors (parameters) and equations in order to figure out 1) radius of influence, 2) number of wells necessary, and 3) cleaning effect.

- key factors that I need to have in order to calculate cost of the system.

- references that you recommend me to read.

I would like to talk to you tomorrow and ask you the questions above.
I hope that this message will help us to have a nice conversation when I call you tomorrow.

Sincerely,
Kaori Sakaguchi

<< aerator_info.doc >>

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RELATED: Dictionary Thesaurus

From: "Joe Stagner" <szgators@ucdavis.edu> Save Address Block Sender
Reply-To: <jcstagner@ucdavis.edu>
To: "'kaori sakaguchi'" <ksakaguc@hotmail.com>
Subject: RE: In well air stripping
Date: Wed, 7 Jul 1999 17:53:15 -0700

Hello again Kaori,

Based on the information you provided here are my best guesses:

1. Yes the in-well aerator can work with water tables as high as 5 feet below the ground. We pilot tested the Aerator at the Portland, Oregon Air National Guard Base with a water table 6 feet below the ground and achieved 100% removal of cis 1,2 DCE at 350 ug/l in a single pumping pass at their maximum sustainable extraction rate of 4 gpm per well.

2. PCE and TCE are both fairly volatile and the Aerator should be able to remove them to less than 5 ug/l at concentrations of <300 ug/l and pumping rates of 10 to 20 gpm per well. At the Savannah River Site we removed 96% of PCE (@50 ug/l) and 92% of TCE (@2500 ug/l) in a single pumping pass at 36 gpm in an 8" diameter well with only half the Aerator running and I'm confident that at 10 to 20 gpm in 8" or 12" diameter wells we can get to <5 ug/l fairly easily.

3. Depth of the well is not an issue. The Aerator can be configured for wells as shallow as 30 feet deep or as deep as 250 feet. The test well in Portland was 30 feet deep with water table at 5 feet below ground and the wells at Savannah are as deep as 220 feet. At UC Davis our four well treatment system uses wells at about 105 feet deep.

4. The location of any treatment wells depends upon the hydrogeologic characteristics of the site and the objectives you have for the site. The location points for extraction from the contaminated aquifer will have to be selected through a hydraulic model of the site so as to meet whatever objectives you have for containing the pollution or to simply prevent it from reaching certain receptors or etc.

5. To help you get a rough estimate of costs I can share with you what the costs are that we have observed thus far on our projects. To calibrate this to your location you should call a few local well drillers and ask what the cost for wells of the size and depth (and in the soil types) you anticipate is there:

UC Davis

thick PVC pipe

Engineering, aquifer testing & modelling, well layout = $30,000

Four 105' deep 8" schedule 80 PVC casing wells @ $10,000 each = $40,000
One 50 hp rotary screw air compressor with shed and pad = $25,000

3000 LF 6" SDR 35 water discharge pipe, with trenching = $10,000
1200 LF 2" compressed air supply line to wells = $ 5,000
Four In-Well Aerators, including instrumentation/controls = $20,000

Total installation cost $100,000

Total project cost $130,000

This was for a four well @ 40 gpm per well system. Note that our consultant's feasibility study cost estimate for a conventional packed tower air stripper pump and treat system was $630,000 but we got the job done much cheaper because of the Aerator and we did the project management ourselves. To hire a consultant to install the same system today would probably cost around $250,000 I would guess.

To get a better handle on your project you need somehow to guess how many wells you would need and call local drillers to get an estimate of the cost for installing the wells. Add to that:

- the cost of performing an aquifer pumping test to get the aquifer characteristics (unless you already have that info which it appears you may) and the cost of 2D modelling the aquifer and potential treatment well layouts ($10,000 or so)

- about $5,000 per well for the design, manufacture and installation of In-Well Aerators

- About $25,000 to $50,000 for an air compressor, depending upon what type you want (oil-less or not, rotary or piston, etc) and what the total air flow needed is (to be determined once we know how many treatment wells are needed from your modelling). Note that you can get the air compressor much cheaper by buying used, or leasing, renting, etc if up front installation cost is an issue.

- About $5 per LF for water discharge pipeline to wherever you want to discharge the clean water from the Aerators (unless you use in-well reinjection or recirculaiton). This assumes you use 6" SDR 35 bell and gask et sewer pipe like we did and gravity flow the water somewhere. If you use pressurized line and have to pump it somewhere the cost will be more.

- About $5 per foot for compressed air pipeline from the compressor to the wells.

Please note that these are very rough estimating guesses only and you should determine these factors for your site- labor and material costs will be different between here and there I'm sure.

Hope this starts to help you-

-Joe Stagner

-----Original Message-----
From: kaori sakaguchi [mailto:ksakaguc@hotmail.com]
Sent: Wednesday, July 07, 1999 11:42 AM
To: jcstagner@ucdavis.edu
Subject: In well air stripping

Dear Joe,

Thank you for your prompt reply.
I really apprecite it.

I am not sure whether you have time to help me designing the in-well air stripping system, but since I have little knowledge of this technology, if an expert like you give me suggestions, that would help me a lot.

Currently, I am trying to find the locations and sizes of the system at our site.
Tell the truth, I need to estimate a cost (rough one) by next Tuesday...

Just in case, if you have time for me to help this task, I would like to explain the site briefly.

Attached MS excel file is the summary of the wells contaminated by TCE and PCE, and summary of hydrogeological information.
Attache MS words is the brief summary of the Site.

Questions:

1)Groundwater table
My biggest concern is the shallow groundwater table, which is located within 5ft below the ground surface. How does it affect the system? Do you think that it is feasible to apply the inwell air stripping system in our Site? (the wells are located in vacant area, not residential area, though)

2) Effeciveness
- With the groundwater flow rate 450 gpm, could be the resident time long enough to remediate the groundwater?
- The shallow wells are contaminated by PCE (5-220 ppb) and by TCE (9-60 ppb). The bedrock wells' contamination level is: PCE (29-250 ppb) and TCE (45-100 ppb). Both TCE and PCE should be remediated by less than 5 ppb. Do you think that the remediation would be technically feasible?

3) Depth of the wells
The three bedrock wells that are contaminated in 150 ft below ground surface. Can the system remediate contaminants in this deep aquifer?

4) Location
The wells should be installed down gradient? or up gradient?

5) Cost
Could you estimate rough cost of eight 96 ft length of system and three 110 ft length of the system? What is your best guess of the total cost of these systems with air blowera and GACs and other necessary equipment?

6) Data needs
What information is lacking in terms of estimate cost and effeciveness?

*****
If I were live closer to your office, I would have visited you and asked the questions above for about an hour....
In addition, since I could write better that I could speak in English, I need to send you this long e-mail before I call, in order to explain the condition of the site.

If you give me any answers of my questions, that would help me a lot.
I will call you tomorrow.

Sincerely,

Kaori Sakaguchi
617-776-3473 (home)

617-627-5118 (office)
617-627-3401 (fax)

From: "kaori sakaguchi" <ksakaguc@hotmail.com> Save Address Block Sender
To: szgators@ucdavis.edu
CC: ksakaguc@hotmail.com
Subject: How to calculate air flow?
Date: Sun, 11 Jul 1999 14:16:12 PDT

Dear Joe,

I am trying to design the circulation well system for our site.
Our well design will be:

100ft below groundwater table, 5ft in the vedos zone, and 10ft above the ground, with 8 inch diameter.

We will inject air with air/water ratio of 75, and remediate 100ppb TCE and 250ppb PCE to MCL standard (5ppb).

By using Henry's dimensionless and concentraion is water, concentration of air is estimated 1)41 ppb-TCE and 2) 85 ppb-PCE.

The problem I am facing now is:
1) Air injection: what the compressor capacity should be?
2) Air injection: what the length and size of the injection pipe should be?

3) Air flow rate: what the air flow rate (influence and effluence) should be? - I need to know effluent flow rate and concentration, in order to estimate the size and capacity of GAC system that would treat contaminated air.

May I ask you to give me any idea how to solve these issue?

Sincerely,
Kaori Sakaguchi

Folder: **Inbox**

From: "Joe Stagner" <szgators@ucdavis.edu> Save Address Block Sender
Reply-To: <jcstagner@ucdavis.edu>
To: "kaori sakaguchi" <ksakaguc@hotmail.com>
Subject: RE: How to calculate air flow?
Date: Mon, 12 Jul 1999 09:05:18 -0700

Kaori,

Here are my best guesses, based primarily on empirical data taken from our several years of operation here at UC Davis in 8" wells, plus our performance testing of the Aerator at other sites:

1. Using 8" diameter wells, with TCE @ 100 ug/l and PCE @ 250 ug/l, I estimate that you should allow 100 scfm (standard cubic feet per minute) of air flow per well for both air lift pumping and in-well aeration. With this air flow we achieved 96% PCE and 92% TCE removal at the Savannah River Site at a pumping rates between 28 and 36 gpm in 8" wells, so with pumping rates of 10 to 20 gpm in an 8" well and your lower concentrations of VOCs this same air flow allowance should be adequate.

Please note that with use of 12" wells instead of 8" (extra cost is usually very modest $1,000 to $3,000 per well) the amount of air flow you need could be reduced substantially, perhaps by 25% to 50%, because the residence time of the water flow through the aerator is about 7 times longer in a 12" well than in an 8" well in proportion to the greater cross sectional flow area. Our cost/benefit analyses thus far have shown the modest extra cost of going with 12" wells to be very cost effective to minimize the size of the air compressor and energy use.

2. I would recommend a 2.5" or 3" eductor tube running from the surface to 5' above the bottom of the well, with a 3/4" air injection line inside the eductor tube running from the surface to 10' above the bottom of the well (5' above the bottom of the eductor tube). Any small eductor tube and air lift pumping the volume of water flow you want could get difficult, and any larger eductor would waste cross sectional flow area in the Aerator.

3. A 50 hp rotary screw air compressor, sheaved down for max air flow at lower pressure (220 scfm output @ 90 psi), should be able to run 3 or 4 wells at your pumping rates and desired VOC removal rates. Again, use of 12" wells should allow a smaller air compressor, perhaps in the 25 to 40 hp range for the same amount of wells.

4. You might want to double check the air emission requirements in your rea and the need for GAC treatment of the off-gas. For the VOC oncentrations and pumping rates you are looking at many air districts won't require treatment of the off gas from the well. Here in a tight air

district in central California the local emission limit for permitting requirements is 2 lbs/day and your system would fall below that and not even require a permit, much less treatment with GAC. This is the same as at Savannah River Site, where off gas treatment is not required for TCE removal at 2500 ug/l...

-Joe Stagner

-----Original Message-----
From: kaori sakaguchi [mailto:ksakaguc@hotmail.com]
Sent: Sunday, July 11, 1999 2:16 PM
To: szgators@ucdavis.edu
Cc: ksakaguc@hotmail.com
Subject: How to calculate air flow?

Dear Joe,

I am trying to design the circulation well system for our site.
Our well design will be:

100ft below groundwater table, 5ft in the vedos zone, and 10ft above the ground, with 8 inch diameter.

We will inject air with air/water ratio of 75, and remediate 100ppb TCE and 250ppb PCE to MCL standard (5ppb).

By using Henry's dimensionless and concentraion is water, concentration of air is estimated 1) 41 ppb-TCE and 2) 85 ppb-PCE.

The problem I am facing now is:
1) Air injection: what the compressor capacity should be?
2) Air injection: what the length and size of the injection pipe should be?

3) Air flow rate: what the air flow rate (influence and effluence) should be? - I need to know effluent flow rate and concentration, in order to estimate the size and capacity of GAC system that would treat contaminated air.

May I ask you to give me any idea how to solve these issue?

Sincerely,
Kaori Sakaguchi

EARTH EXPLORATION, INC.

Earth Exploration, Inc.

86 Elm Street, Hopkinton, MA 01748
Tel: (508) 435-7888 FAX: (508) 435-5512

P

File Name: F:\EEI\99P

Date: July 14, 1999

Subject: Wells G&H Site Woburn

To: Kaori Sakaguchi
MDEP

Tel: 617-627-5118
Fax: 617-627-3401

Scope of Work:

ITEM	DESCRIPTION	UNIT $	ESTIMATED QUANTITY
1)	Mobilization/Demobilization - Air Rotary Rig	$8,500.00 /ls	1 ls
2)	Day Rate Air Rotary Rig & Crew 4" Wells	2,200.00 /day	25 day
3)	Day Rate Air Rotary Rig & Crew 8" Wells	2,400.00 /day	62 day
4)	4" PVC Wells Installed	17.50 /lf	740 lf
5)	8" PVC Wells Installed	27.50 /lf	1374 lf

ESTIMATED TOT

Quantities listed are considered estimates not to be exceeded without notification of the Client. Price quotations will be held fo days unless otherwise specified. Changes in project quantities or requirements may be cause for revision of prices as listed.

Assumptions:
The site and boring locations are truck accessible. DIGSAFE will be provided by others.

Thank you for the opportunity to submit this proposal. Feel free to call with any questions or commen

Prepared by: ______________________

Christopher C. DeVillers
Operations Manager

This work can be scheduled by authorizing this proposal below:

Authorized by : ______________________ Date: __________

APPENDIX M

Cost Estimate Tables for the Alternatives

Cost Estimate for No Action Alternative

The total present worth of the No Action alternative was calculated using the following information.

	Unit	Unit Cost	Total Cost
TOTAL CAPITAL COSTS			$0.00

OPERATION AND MAINTENANCE (O&M) COSTS (annual)	Unit	Unit Cost	Total Cost
Five-year Site Reviews (every 5 years for 30 years)			
Meetings (attendance only)			
Senior Scientist	8 hours	$125.00	$1000
Mid-level Scientist	8 hours	$100.00	$800
ODCs	1 LS	$150.00	$150
Five-year Report			
Senior Scientist	40 hours	$125.00	$5000
Mid-level Scientist	60 hours	$100.00	$6000
Associate Scientist	40 hours	$80.00	$3200
ODCs (including photocopying, etc)	1 LS	$1500.00	$1500
Sub-total			**$17,650**
Present Worth 5 Year Site Review @ I=5%, n=5, 10,..., 30			**$48,400**
TOTAL O&M COSTS			**$48,400**
TOTAL CAPITAL COSTS AND O&M COSTS			**$48,400**
CONTINGENCY @ 10 PERCENT			**$4,840**
TOTAL COST OF NO ACTION ALTERNATIVE			**$53,240**

Cost Estimate for Monitored Natural Attenuation

The total present worth of the Monitored Natural Attenuation alternative was calculated using the following information.

DIRECT COSTS	Unit	Unit Cost	Total Cost
TOTAL DIRECT COSTS			$0.00

INDIRECT COSTS	Unit	Unit Cost	Total Cost
TOTAL INDIRECT COSTS			$0.00
TOTAL CAPITAL COSTS			$0.00

OPERATION AND MAINTENANCE (O&M) COSTS (annual)	Unit	Unit Cost	Total Cost
GW Monitoring O&M (annual costs)			
GW Sampling & Monitoring within Central Area during MNA (years 1-30):			
18 Wells + 2QA/QC = 20 samples			
Associate Scientist	50 hours	$80.00	$4000
Technician	50 hours	$60.00	$3000
ODCs (PPE, sampling equipment, expendables)	1 LS	$1500.00	$1500
Analysis – TCL organics (VOCs only),	20 samples	$110.00(1)	$16,000
Analysis - Hydrogen	20 samples	$85.00	$1700
Analysis - Methane	20 samples	$70.00	$1400
Analysis – Ferrous Iron	20 samples	$35.00	$700
Nitrate	20 samples	$15.00	$300
Sulfate	20 samples	$15.00	$300
Sulfide	20 samples	$40.00	$800
Summary Data Report			
Mid-level Engineer	20 hours	$100.00	$2000
Senior Scientist	10 hours	$120.00	$1200
Associate Scientist	20 hours	$80.00	$1600
ODCs	1 LS	$1300.00	$1300
Sub-total Annual Costs			$35,800

Present Worth GW Monitoring @ I=5%, n=(1-30)			$550,333
Five-year Site Reviews (every 5 years for 30 years)			
Meetings (attendance only)			
Senior Scientist	8 hours	$125.00	$1000
Mid-level Scientist	8 hours	$100.00	$800
ODCs	1 LS	$150.00	$150
Evaluate Data/Current Situation			
Senior Scientist	20 hours	$125.00	$500
Mid-level Scientist	40 hours	$100.00	$400
ODCs (including photocopying, etc)	1 LS	$680.00	$680
Five-year Report			
Senior Scientist	40 hours	$125.00	$5000
Mid-level Scientist	60 hours	$100.00	$6000
Associate Scientist	40 hours	$80.00	$3200
ODCs (including photocopying, etc)	1 LS	$1500.00	$1500
Sub-total			**$19,230**
Present Worth 5 Year Site Review @ I=5%, n=5, 10,..., 30			**$52,800**
TOTAL O&M COSTS			**$603,133**
TOTAL CAPITAL COSTS AND O&M COSTS			**$603,133**
CONTINGENCY @ 20 PERCENT			**$120,627**
TOTAL COST OF MONITORED NATURAL ATTENUATION ALTERNATIVE			**$723,760**

Notes:

(1) = Source : Target Environmental Services, Inc. Columbia, Maryland, July 1999.

Cost for the Pump and Treat Alternative

DIRECT COSTS	Unit	Unit Cost	Total Cost
Site Preparation and Mobilization			
Storage Trailer	6 months	$200.00	$1200
Office Trailer	6 months	$340.00	$2040
Trailer Delivery, Setup, Removal	2 trailers	$1360.00	$2720
Treatment System Concrete Pad (60' x 110')	6600 sq. ft	$3.00	$19800
Treatment Building (50' x 100')	5000 sq. ft	$13.00	$65000
Fencing:			
Treatment Area for equipment/controls (60' x 110')	6600 ft	$12.00	$79200
Trailer Area (40' x 80')	1200 ft	$12.00	$14400
Gates	2 gates	$160.00	$320
Office Equipment Rental	6 months	$2710.00	$16260
Utility Connections for trailer, system equipment, controls	5000 sq. ft	$11.00	$55000
Toilet/water cooler service	26 weeks	$75.00	$1950
Miscellaneous Equipment	1 LS	$3400.00	$3400
Decon Equipment and Pad:			
Pressure Washer with Water Tank	3 months	$680.00	$2040
Plastic Sheeting, Drums, Pumps, Hoses, Supplies	1 LS	$4100.00	$4100
Labor (Site Preparation)			
Laborers (6 persons @ 15 days @ 10 hrs/day)	90 days	$440.00	$39600
Foreman/Superintendent (1 person @ 15 days @ 10 hrs/day)	15 days	$810.00	$12150
Sub-total Site Preparation/Mobilization			**$319,180**
Groundwater Extraction System			
Groundwater Extraction Wells			
Mob/Demob (driller and equipment)	1 LS	$8600.00	$8600
Day Rate Rotary Rig & Crew 4" Wells	25 days	$2200.00	$55000
Well Installation			
6 deep unconsolidated wells @ 4" ID, PVC, 90' bgs	540 ft	$17.50	$9450
4 bedrock wells @ 4" ID, PVC, 50' bgs	200 ft	$17.50	$3500
Extraction Well Vault	10 units	$3400.00	$34000
Extraction Pumps			
30 gpm	6 pumps	$6420.00	$38520
15 gpm	4 pumps	$6420.00	$25680
Per Diem/Lodging (9 persons @ 25 days)	225 days	$170.00	$38250
Decontamination	10 hours	$140.00	$1400
Investigation Derived Waste (soil and dev. Water)	1 LS	$14000.00	$14000
Miscellaneous Equipment and Supplies	1 LS	$3000.00	$3000
Electric Power Supply and Water Supply for H&S			
Utility Pole	5 poles	$700.00	$3500
Power Cable	1000 ft	$14.00	$14000
Transformer	1 unit	$1800.00	$1800
Telephone line for Telemetry	100 ft	$14.00	$1400
Service Connection	1 unit	$1600.00	$1600
Gauge, curb box, equipment	1 unit	$1600.00	$1600
Piping and Equipment			
RWs *to treatment system* (2" ID, PVC)	3500 ft	$27.00	$94500
Discharge to Aberjona River (2" ID, PVC)	700 ft	$27.00	$18900
Flow Meters	10 units	$250.00	$2500
Pressure Gauges	10 units	$22.00	$220

Telemetry	1 LS	$14000.00	$14000
Temperature Gauges	10 units	$110.00	$1100
Instrumentation Controls	1 LS	$9700.00	$9700
Discharge pump	1 pump	$4070.00	$4070
Labor			
9 persons @ 5 weeks @ 50 hrs/week	2250 hours	$50.00	$112500
1 Engineer/Foreman @ 5 weeks @ 50 hrs/week	150 hours	$100.00	$15000
Sub-total Groundwater Extraction System			**$527,790**
Ex-Situ Air Stripper System Air Stripper with Options Air Stripper Installation GAC Unit with Carbon and Transportation GAC Installation	 1 unit 10 days 1 unit 10 days	 $50000.00 $1000.00 $20000.00 $1000.00	 $50000 $10000 $20000 $10000
Sub-total Air Stripper and GAC System			**$90,000**
TOTAL DIRECT COSTS			**$936,970**

INDIRECT COSTS	**Unit**	**Unit Cost**	**Total Cost**
Health and Safety (4%)			$37500
Administrative Fees (3%)			$28100
Engineering and Design (15%)			$140500
Construction Support Services (10%)			$93700
TOTAL INDIRECT COSTS			**$299,800**
TOTAL CAPITAL COSTS			**$1,236,770**

OPERATION AND MAINTENANCE (O&M) COSTS (annual) **Treatment of Groundwater to Site-Specific Remedial Goals**	**Unit**	**Unit Cost**	**Total Cost**
Extraction Wells O&M (30 years) 6 deep unconsolidated wells and 4 bedrock wells ($300,000 annual cost for 30 years)	1 LS	$300000.00	$300000
Sub-total Extraction Wells O&M			**$300,000**
Present Worth @ I=5%, n=30 years			**$4,611,735**
Treatment System O&M (annual for 30 years)			
Utilities			
Groundwater Extraction Pumps	12 months	$200.00	$2400
Treatment System	12 months	$300.00	$3600
System Maintenance			
Labor (1 operator @ 8 hrs/week, 52 weeks/year)	416 hours	$100.00	$41600
Aeration System Components	12 months	$1000.00	$12000
Sub-total Treatment System O&M			**$59,600**
Sampling and Monitoring			
Extraction Well Influent Grab Samples (10 wells, 1 per month): TCL Organics (VOCs only)	120 samples	$110.00	$13200

Effluent Grab Sample (1 per month): Full Suite Discharge Requirements	12 hours	$1600.00	$19200
Sub-total GW Sampling and Monitoring			**$32,400**
Present Worth System O&M @ I=5%, n=30 years			**$1,414,266**
GW Monitoring O&M (annual costs)			
GW Sampling & Monitoring within Central Area Corridor during pump and treat (years 1-30):			
10 Wells + 2QA/QC = 20 samples Associate Scientist Technician ODCs (PPE, sampling equipment, expendibles)	 50 hours 50 hours 1 LS	 $80.00 $60.00 $1500.00	 $4000 $3000 $1500
Analysis – TCL organics (VOCs only)	20 samples	$110.00	$2200
Summary Data Report Mid-level Engineer Senior Scientist Associate Scientist ODCs	 20 hours 10 hours 20 hours 1 LS	 $100.00 $120.00 $80.00 $1300.00	 $2000 $1200 $1600 $1300
Sub-total Annual Costs			**$16,800**
Present Worth GW Monitoring @ I=5%, n=(30)			**$258,257**
Five-year Site Reviews (every 5 years for 30 years)			
Meetings (attendance only) Senior Scientist Mid-level Scientist ODCs	 8 hours 8 hours 1 LS	 $125.00 $100.00 $150.00	 $1000 $800 $150
Evaluate Data/Current Situation Senior Scientist Mid-level Scientist ODCs (including photocopying, etc)	 20 hours 40 hours 1 LS	 $125.00 $100.00 $680.00	 $500 $400 $680
Five-year Report Senior Scientist Mid-level Scientist Associate Scientist ODCs (including photocopying, etc)	 40 hours 60 hours 40 hours 1 LS	 $125.00 $100.00 $80.00 $1500.00	 $5000 $6000 $3200 $1500
Sub-total			**$19,230**
Present Worth 5 Year Site Review @ I=5%, n=5, 10,..., 30			**$52,800**
TOTAL O&M COSTS			**$6,337,058**
TOTAL CAPITAL COSTS AND O&M COSTS			**$7,573,828**
CONTINGENCY @ 20 PERCENT			**$1,514,766**
TOTAL COST OF PUMP AND TREAT ALTERNATIVE			**$9,088,594**

Notes:

LS lump sum

Cost Estimate for In-well Air Stripping Alternative

DIRECT COSTS	Unit	Unit Cost	Total Cost
Site Preparation and Mobilization			
Storage Trailer	2 months	$200.00	$400
Trailer Delivery, Setup, Removal	2 trailers	$1360.00	$2720
Treatment System Concrete Pad (10 x 10) x 18	1800 sq. ft	$3.00	$5400
Shed (8' x 8') x 18	1152 sq. ft	$91.00	$104256
Fencing:			
Treatment Area for equipment/controls (10 x 10) x 18	720 ft	$12.00	$8640
Gates	18 gates	$160.00	$2880
Office Equipment Rental	2 months	$2710.00	$5420
Utility Connections for trailer, system equipment, controls	1 lump sum	$136000.00	$136000
Toilet/water cooler service	8 weeks	$75.00	$600
Miscellaneous Equipment	1 LS	$3400.00	$3400
Decon Equipment and Pad:			
Pressure Washer with Water Tank	2 months	$680.00	$1360
Plastic Sheeting, Drums, Pumps, Hoses, Supplies	1 LS	$4100.00	$4100
Labor (Site Preparation)			
Laborers (2 persons @ 15 days @ 10 hrs/day)	30 days	$440.00	$25800
Foreman/Superintendent (1 person @ 15 days @ 10 hrs/day)	15 days	$810.00	$30000
Sub-total Site Preparation/Mobilization			**$ 300,526**
In Well Air Stripping System			
Groundwater Extraction Wells			
Mob/Demob (driller and equipment)	1 LS	$8500.00	$8500
Day Rate Rotary Rig & Crew 4" Wells	62 days	$2400.00	$148800
Well Installation			
18 deep bedrock wells @ 8" ID, PVC, 90' bgs	1374 ft	$18	$24045
Per Diem/Lodging	days	$170.00	$38250
Well development (recirculation well)	18 each	$4300.00	$77400
Decontamination	10 hours	$140.00	$1400
Investigation Derived Waste (soil and dev. Water)	1 LS	$41000.00	$41000
Miscellaneous Equipment and Supplies	1 LS	$2700.00	$2700
Electric Power Supply and Water Supply for H&S			
Utility Pole	1 poles	$700.00	$700
Power Cable	200 ft	$14.00	$2800
Transformer	1 unit	$1800.00	$1800
Telephone line for Telemetry	200 ft	$14.00	$2800
Service Connection	1 unit	$1600.00	$1600
Gauge, curb box, equipment	18 unit	$1600.00	$28800
Piping and Equipment			
Recirculation wells internals	18	$70500.00	$1269000
Recirculation well vault	18	$19870.00	$357660
Instrumentation Control	18 units	$13600.00	$244800
Labor			
2 persons @ 6 weeks @ 50 hrs/week	600 hours	$43.00	$ 25,800
1 Engineer/Foreman @ 6 weeks @ 50 hrs/week	300 hours	$100.00	$ 30,000
Sub-total In Well Air Stripping System			**$ 2,490,325**

Cost Estimate for In-well Air Stripping Alternative

Off-gas Treatment System			
GAC Unit with Option	18 unit	$5440.00	$97920
Spent carbon disposal			
GAC Installation	3 days	$800	$2400
Profile fee	1 LS	$1630.00	$1630
Transportation fee	1 LS	$1360.00	$1360
Sub-total GAC System			**$103,310**
TOTAL DIRECT COSTS			**$2,894,161**

INDIRECT COSTS	Unit	Unit Cost	Total Cost
Health and Safety			$115766
Administrative Fees			$86825
Engineering and Design			$434124
Direct cost contingency (excluding Pilot test)			$578832
Construction Support Services			$289416
TOTAL INDIRECT COSTS			**$1,504,964**
TOTAL CAPITAL COSTS			**$4,399,125**

OPERATION AND MAINTENANCE (O&M) COSTS (annual) Treatment of Groundwater to Site-Specific Remedial Goals	Unit	Unit Cost	Total Cost
In-well Air Stripping O&M (15 years)			
Utilities (@540/m. per circ.well)	12 month	$9720.00	$116640
System Maintenance (25 K per well x 18)	1 LS	$430000	$430000
Sub-total In-Well Air Stripping O&M			**$546,640**
Present Worth @ I=5%, n=15 years			**$5,673,936**
Sampling and Monitoring			
Recirc Well Influent Grab Samples (18 wells, 1 per month): TCL Organics (VOCs only)	72 samples	$110.00	$7920
Effluent Grab Sample (18 wells, per month): Full Suite Discharge Requirements	216 samples	$110.00	$23760
GW Monitoring O&M (annual costs)			
GW Sampling & Monitoring within Central Area Corridor during pump and treat (years 1-15):			
18 Wells x 4 + 2QA/QC = 74 samples			
Associate Scientist	480 hours	$80.00	$38400
Technician	480 hours	$60.00	$28800
ODCs (PPE, sampling equipment, expendibles)	1 LS	$1000.00	$1000
Analysis – TCL organics (VOCs only)	144 samples	$110.00	$15840

Cost Estimate for In-well Air Stripping Alternative

Summary Data Report			
Mid-level Engineer	20 hours	$100.00	$2000
Senior Scientist	10 hours	$120.00	$1200
Associate Scientist	20 hours	$80.00	$1600
ODCs	1 LS	$1300.00	$1300
Sub-total Annual Costs			**$121,820**
Present Worth GW Monitoring @ I=5%, n= 15 yrs)			**$1,264,450**
Five-year Site Reviews (every 5 years for 30 years)			
Meetings (attendance only)			
Senior Scientist	8 hours	$120.00	$960
Mid-level Scientist	8 hours	$100.00	$800
ODCs	1 LS	$135.00	$135
Evaluate Data/Current Situation			
Senior Scientist	20 hours	$120.00	$2400
Mid-level Scientist	40 hours	$100.00	$4000
ODCs (including photocopying, etc)	1 LS	$680.00	$680
Five-year Report			
Senior Scientist	40 hours	$120.00	$4800
Mid-level Scientist	60 hours	$100.00	$6000
Associate Scientist	40 hours	$80.00	$3200
ODCs (including photocopying, etc)	1 LS	$1355.00	$1355
Sub-total			**$24,330**
Present Worth 5 Year Site Review @ I=5%, n=5, 10,..., 30			**$45,422**
TOTAL O&M COSTS			**$6,983,808**
TOTAL CAPITAL COSTS AND O&M COSTS			**$11,382,933**
CONTINGENCY @ 20 PERCENT			**$2,276,587**
TOTAL COST OF PUMP AND TREAT ALTERNATIVE			**$13,659,520**

Notes:

LS lump sum

APPENDIX N

Calculations and Notes for Economic Feasibility Determination

Table 1

Pumping Frequency at Wells G & H

Year[a]	# months pumping/year Well G	Well H
1965	1	-
1966	12	-
1967	7	4[b]
1968	8	0
1969	9	0
1970	9	0
1971	6	0
1972	4	0
1973	0	0
1974	5	3
1975	8	3
1976	0	4
1977	12	1
1978	12	10
Average # months pumping/year	6.6	1.9
Average # months pumping/ year over the last 5 years	7.4	4.2

[a] Only the years when wells were operational the entire year are listed
[b] Well H was turned on part way through 1967. This value was not used in the calculation of the average.

(Source: Metheny, 1998, p. 130)

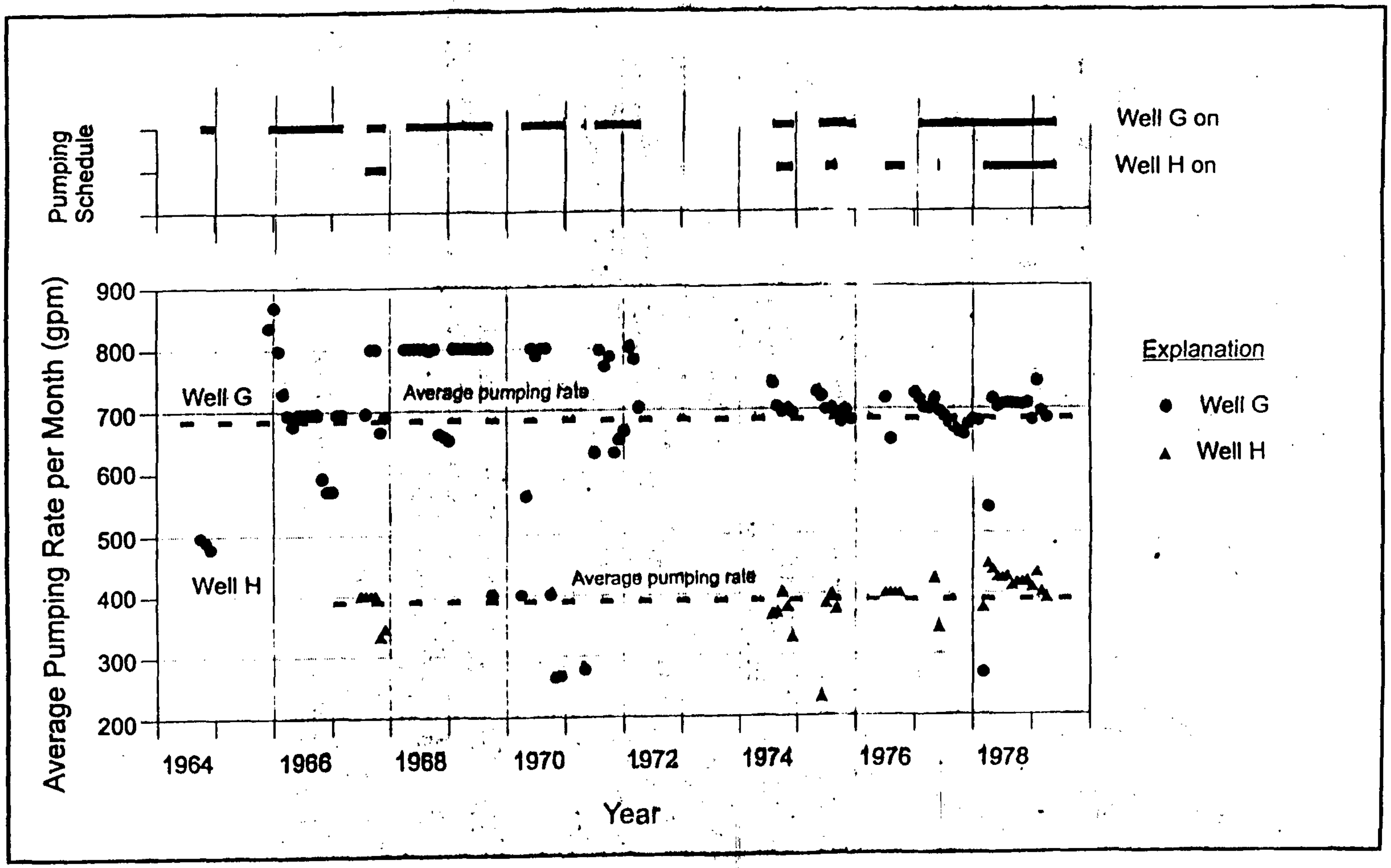

Figure 9.34 Pumping Rates and Schedules of Wells G and H from 1964 to 1979

Calculation of water supplied by Wells G&H for use in determining replacement costs

From City of Woburn historical pumping records, Metheny (1998) calculated an average monthly pumping rate of 684 gpm from Well G and 389 gpm from Well H.

The frequency by which the wells were pumped is shown on Table 1.

For the sake of this calculation, the frequency of pumping over the last five years was used to reflect the City of Woburn's use of the water from Wells G&H at the time they were shut down.

Water provided from well G on a yearly basis:

684 gpm x 60 min/hr x 24 hr/day x 365 day/year x (7.4 mon./12 mon.) = 221,698,080 gals.

Water provided from well H on a yearly basis:

389 gpm x 60 min/hr x 24 hr/day x 365 day/year x (4.2 mon./12 mon.) = 71,560,440 gals.

Total from both wells = 293,258,520 gals.

Allow for increases in the water supply demand over the last 20 years (+50%) 146,629,260 gals.

GRAND TOTAL = 439,887,780 gals.

say 440 million gallons/yr

Calculation of the cost to obtain water from MWRA to replace Wells G&H supply

Using a yearly demand of 440 million gallons (mgal) per year.

Year #	Year	Yearly Rate Increase	Yearly Rate ($/mgal)	Cost	Annual Present Worth Cost	Cumulative Present Worth Cost
1	2000	-	$1,074	$472,560	$450,057	$450,057
2	2001	17.7%	$1,264	$556,203	$504,493	$954,550
3	2002	16.6%	$1,474	$648,533	$560,227	$1,514,777
4	2003	9.5%	$1,614	$710,143	$584,237	$2,099,014
5	2004	13.4%	$1,830	$805,303	$630,976	$2,729,989
6	2005	20.9%	$2,213	$973,611	$726,523	$3,456,513
7	2006	5.0%	$2,323	$1,022,291	$726,523	$4,183,036
8	2007	5.0%	$2,440	$1,073,406	$726,523	$4,909,560
9	2008	5.0%	$2,562	$1,127,076	$726,523	$5,636,083
10	2009	5.0%	$2,690	$1,183,430	$726,523	$6,362,607
11	2010	5.0%	$2,824	$1,242,602	$726,523	$7,089,130
12	2011	2.6%	$2,898	$1,274,909	$709,917	$7,799,047
13	2012	2.6%	$2,973	$1,308,057	$693,691	$8,492,738
14	2013	2.6%	$3,050	$1,342,066	$677,835	$9,170,573
15	2014	2.6%	$3,129	$1,376,960	$662,341	$9,832,914
16	2015	2.6%	$3,211	$1,412,761	$647,202	$10,480,116
17	2016	2.6%	$3,294	$1,449,493	$632,409	$11,112,525
18	2017	2.6%	$3,380	$1,487,180	$617,954	$11,730,479
19	2018	2.6%	$3,468	$1,525,846	$603,829	$12,334,308
20	2019	2.6%	$3,558	$1,565,518	$590,027	$12,924,336
21	2020	2.6%	$3,651	$1,606,222	$576,541	$13,500,877
22	2021	2.6%	$3,745	$1,647,984	$563,363	$14,064,240
23	2022	2.6%	$3,843	$1,690,831	$550,486	$14,614,726
24	2023	2.6%	$3,943	$1,734,793	$537,904	$15,152,630
25	2024	2.6%	$4,045	$1,779,897	$525,609	$15,678,238
26	2025	2.6%	$4,150	$1,826,175	$513,595	$16,191,833
27	2026	2.6%	$4,258	$1,873,655	$501,855	$16,693,689
28	2027	2.6%	$4,369	$1,922,370	$490,384	$17,184,073
29	2028	2.6%	$4,483	$1,972,352	$479,176	$17,663,249
30	2029	2.6%	$4,599	$2,023,633	$468,223	$18,131,472

Notes:
1. The rate of $1,074/mgal for the City of Woburn was established on 30 Jun 1999 by the MWRA (Kuklinski, 1999)
2. Yearly rate increases for years 2 though 6 are projected estimates per MWRA.
   Yearly rates vary depending upon interest payments and bonds due on major infrastructure projects (Kuklinski, 1999)
3. Yearly rate increases for years 7 though 11 were not available from MWRA. Estimated rate increase are assumed to reflect a reduction in interest payments, but continuing costs above inflation.
4. Yearly rate increases of 2.6% over the long term have been used to reflect continued maintenance of water supply system The rate of 2.6% was taken from the U.S. Army Corps of Engineers Civil Workls Construction Cost Index System to reflect yearly cost growth under the Permanent Operating Equipment Category. (USACE, 1998)

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