Remedial Design and Implementation Technical Guide

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Abstract

The challenges that many environmental professionals face during the remediation of contamination is the varying technologies, approaches, and potential pitfalls that exist based upon site conditions and variability's. As a result of these challenges, environmental professionals can benefit from examples of different remedial approaches in order to evaluate how similar cases may be approached. In this paper, three distinct sites with varying types of groundwater contamination are presented and evaluated. The remedial technologies presented in this paper include soil vapor extraction of a gasoline release, enhanced bioremediation of chlorinated solvents, and in-well air sparging of chlorinated solvent impacted groundwater occurring within bedrock. Overall, each remedial situation showed successes, however, some issues did arise and as a result changes or modifications to some of the approaches are required to complete each.

Objective

The objective of this paper is to present various examples of different cleanup approaches for contamination within groundwater. Each example is intended to provide other environmental professionals knowledge and a literary experience on how each case's contamination was evaluated and eventually approached on a remedial basis. In the end, the objective is to identify both the successes and failures in each approach in order to educate others dealing with similar challenges and decisions.

Introduction

Many forms and types of remedial technologies exist in eth world and each has its benefits and challenges based upon many things including site specifics, contaminant type, and cost. In relative terms, some of the more difficult contaminants to abate in the environment are chlorinated ethenes which exist in many different forms and can be degraded naturally under certain conditions. Other more common contaminants found in the environment are organics related to petroleum products such as gasoline. These compounds are more readily degraded in aerobic environments and as such have a higher tendency to degrade faster. Unlike the lighter density petroleum organics chlorinated ethenes have a density greater than water which allows them to sink within an aquifer. In any event, these challenges have resulted in the development and deployment of many different treatment technologies which in their own right have been successful.

With respect to treatment technologies, they can be broken into two general categories, being *in-situ* and *ex-situ*. *In-situ*, refers to the in-pace treatment/remediation of contaminants in the environment while *ex-situ* refers treatment which involve removal and disposal or some treatment which does not take place within the contaminated area. Some of the most common types of *in-situ* treatments for contaminants discussed in this paper include soil vapor extraction, chemical oxidation, air sparging, and bioremediation. In the case of *ex-situ* cleanup approaches some of the most common methods employed for the contaminants described herein include: excavation and disposal, groundwater pump-and-treat, and stabilization/solidification.

In this paper, I will be discussing different sites where I have conducted the investigation, remediation selection, and remedial implementation. These sites consist of a total of three with groundwater impacts in varying types of aquifers. The respective treatment technologies will be reviewed to identify their effectiveness and in some cases ways they could be improved.

Site1 Gasoline Filling Station Location: Providence, RI Gasoline Contaminated Soil and Groundwater Soil Vapor Extraction Remediation

1.1   Introduction & Background

The subject parcel is located in Providence, Rhode Island and comprises 0.2 of an acre. The rectangular lot, is improved with a one-story gasoline filling station that was built in 1972. The location of the site has been depicted below.
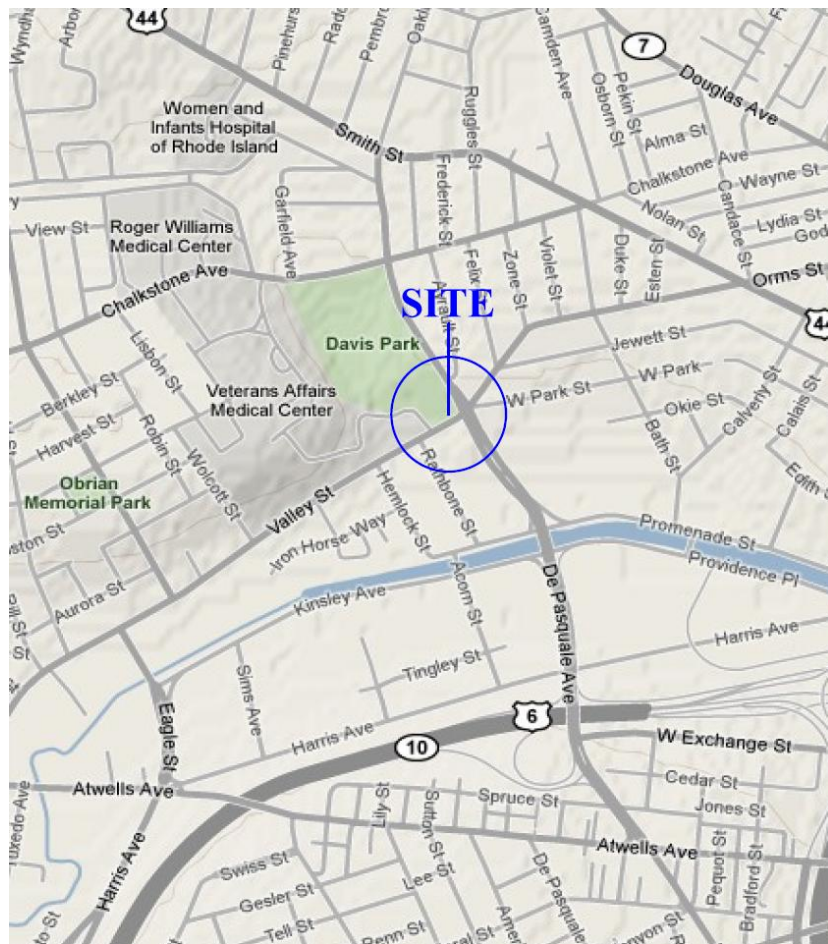
According to records maintained by the Rhode Island Department of Environmental Management (RIDEM), six (6) single wall steel underground storage tanks (USTs) were removed from the site

in 1995 as part as a station upgrade. The products stored and approximate sizes have been

summarized below:

- Tank ID 001, 2,000-gallon gasoline
- Tank ID 002, 1,000-gallon, gasoline
- Tank ID 003, 2,000-gallon, gasoline
- Tank ID 004, 5,000-gallon, gasoline
- Tank ID 005, 500-gallon, waste oil
- Tank ID 006, 500-gallon #2 fuel oil

During the removal of the six (6) USTs, a closure assessment was performed to investigate the

potential release of petroleum products from the USTs to the environment. In an inspection

documented by RIDEM personnel, evidence of petroleum leakage was noted, however, total

volatile organic vapor (TVOV) screenings using a photo-ionization detector (PID) did not exceed

the applicable RIDEM GB Groundwater Screening threshold of 40 parts per million per volume

(ppmv). As a result, no soil samples were submitted for laboratory analysis and no groundwater

samples were collected during the 1995 work.

At the conclusion of the station upgrade, two gasoline steel double walled USTs were installed in

1995 and currently exist at the site.

1 . 2   E n v i r o n m e n t a l   S e t t i n g

Environmental conditions were reviewed at the Rhode Island Geographic Information System

(RIGIS). According to the RIGIS map, there are no sensitive environmental receptors (i.e.

wetlands or wellhead protection areas) at the site or within the surrounding area. The nearest

receptor is the Woonasquatucket River, located approximately 800' to the south.

The groundwater classification for the site, as defined in the RIGIS map is GB, indicating

groundwater that is not suitable for public or private drinking water use without prior treatment.

According to information available from *Soil Survey of Rhode Island[1]*, the overburden geology at

the site is Urban Land. Groundwater is located at approximately 17' below surface grade (BSG).

According to the RIGIS, bedrock at the site is composed of the following characteristics:

Bedrock Characteristics	
Terrane	Avalon
Subterrane	Esmond-Dedham
Geographic	West & East Bay Area
Group	Narragansett Bay
Rock Type	Stratified
Age	Pennsylvanian
Unit	Rhode Island Formation
Label	Pnbr

According to the United States Geological Survey (USGS) bedrock at the site is sandstone, shale,

and conglomerate, with minor coal layers. During subsurface investigation, borings were

advanced as deep as 20' BSG and bedrock was not encountered.

Subsurface Investigation Background

On April 23, 2009, a round of groundwater monitoring was conducted at the site. During this

sampling round, groundwater samples were collected from monitoring wells: AEG-1/MW-6,

AEG-2/MW-4, AEG-3/MW-5, and AEG-4/MW-2.

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[1] *Soil Survey of Rhode Island,* United States Department of Agriculture, Soil Conservation Service in cooperation with Rhode Island Agriculture Experimental Station, July, 1981.

Figure 1-1: Subsurface Evaluation Conditions & Groundwater Elevation Survey

(Butterworth, Combined Release Characterization Report (RCR), Site Investigation Report (SIR), & Corrective Action Plan (CAP), 2009)

Prior to collecting samples, each monitoring well was purged a calculated three well volumes after which a sample was collected from each and submitted to a Rhode Island certified laboratory for analysis of volatile organic compounds (VOCs) by United States Environmental Protection Agency (USEPA) method 8260B. (Butterworth, Combined Release Characterization Report (RCR), Site Investigation Report (SIR), & Corrective Action Plan (CAP), 2009)

In addition to the sampling, the groundwater elevation at each wellhead was surveyed and data incorporated into the modeling program Surfer 7.0 to generate flow contours. According to the survey, groundwater at the Site flows as expected in a southerly direction toward the Woonasquatucket River. The elevation contours are depicted in the figure above.

In addition, information gathered from the groundwater elevation survey including the depths to groundwater gauged at each well can be observed in the table below.

Table 1-1 Groundwater Elevation Survey Notes						
	AEG-1/ MW-6	AEG-2/ MW-4	AEG-3/ MW-5	AEG-4/ MW-2	AEG-5/ MW-3	AEG-6/ MW-1
Groundwater Survey						
Depth to Groundwater (ft.)	16.80	17.19	17.60	17.78	16.50	18.65
Elevation of Well Casing (ft.)	100.00*	100.24	100.62	100.77	100.51	102.58
Groundwater Elevation (ft.)	83.20	83.05	83.02	82.99	84.01	83.93
Notes: * The top of this well casing was used as an assumed benchmark with an elevation of 100.00.						

Analytical results from the testing indicated AEG-1/MW-6 contained toluene and AEG-4/MW-2 contained ethylbenzene exceeding the applicable GB-GWOs. (Butterworth, Combined Release Characterization Report (RCR), Site Investigation Report (SIR), & Corrective Action Plan (CAP), 2009) A summary of the detected analytical results has been provided in the table below.

Table 1-2 Detected Groundwater Analytical Results April 23, 2009				
	AEG-1/ MW-6	AEG-2/ MW-4	AEG-3/ MW-5	AEG-4/ MW-2	**RIDEM GB-GWO**
VOCs					
Benzene	92	17	5.7	12	**140**
Toluene	**2,900**	120	19	1,200	**1,700**
Ethylbenzene	1,300	850	570	**1,800**	**1,600**
Xylenes (total)	12,200	7,500	2,450	5,800	**NS**
Styrene	ND	ND	ND	3.9	**2,200**
Isopropylbenzene	120	60	85	150	**NS**
n-Propylbenzene	200	93	220	270	**NS**
1,3,5-Trimethylbenzene	380	190	350	600	**NS**
1,2,4-Trimethylbenzene	1,700	750	1,400	2,500	**NS**
Sec-Butylbenzene	ND	ND	20	ND	**NS**
p-Isopropyltoluene	9.3	7.5	15	12	**NS**
n-Butylbenzene	22	14	110	59	**NS**
Naphthalene	240	250	250	490	**NS**

Notes:
1. Units: μg/L (ppm)
2. ND: Not Detected above the laboratories method reporting limit
3. GB GWOs as defined in Section 8.03 of the RIDEM *Remediation Regulations* as amended February 2004
4. NS: No Standard Exists within RIDEM *Remediation Regulations* as amended February 2004

Based upon the relatively confined nature of the groundwater plume and limited area of impact several technologies were evaluated. These included, chemical oxidation, exaction and disposal, and soil vapor extraction (SVE). In reviewing these methods, disposal and excavation was eliminated as an option based upon the area size limitations and depth required to reach impact being greater than practical. Chemical oxidation was also evaluated and in some respect would be a viable alternative, however, based upon the volatile nature of the contaminants and worry of possible vapor intrusion, the process of SVE provides an added benefit. As such, SVE was selected as the remedial alterative of choice to both remove gasoline impacts to the subsurface but also control potential vapor intrusion to the site and off-site buildings.

1.3   T h e o r e t i c a l   D e s i g n   F a c t o r s

The theoretic design of the proposed SVE system has been based upon published design standards

presented in the USEPA document EPA 510-R-04-002, dated May 2004. In selecting SVE as a

remedial approach the following key parameters were examined.

Permeability Of Soil	Constituent Volatility
Intrinsic permeability	Vapor pressure
Soil structure and stratification	Product composition and boiling point
Depth to groundwater	Henry's law constant
Moisture content	

(USEPA, Soil Vapor Extraction , 1994)

1.3.1   SOIL FACTORS

1.3.1.1 Intrinsic Permeability

Intrinsic permeability is a measure of how well a specific soil type can transmit fluids and is

considered vital in the selection and design of the SVE system. Based upon field data, site soils

consist of medium sand with gravel. Soils of this type can be expected to have intrinsic

permeability's s ranging between 10^{-6} cm^2 to 10^{-8} cm^2 (USEPA, Soil Vapor Extraction , 1994). For

design purposes, 10^{-7} was used as a theoretical representation for the site. Furthermore, according

to the USEPA, intrinsic permeability greater than 10^{-8} is considered effective.

1.3.1.2 Soil Structure & Stratification

Soil structure and stratification is another important aspect because these elements can affect how

efficiently vapors can flow through the soil formation to the extraction points. All site surfaces are

covered by asphalt and soil observations collected during the advancement of soil borings show

subsurface conditions appear consistent with depth. However, some minor layers of fill (i.e. brick, ash) were noted. These layers are not thought to be restrictive to vapor flow nor prevalent to affect system effectiveness. (Butterworth, Combined Release Characterization Report (RCR), Site Investigation Report (SIR), & Corrective Action Plan (CAP), 2009)

1.3.1.3 Depth to Groundwater

Depth to groundwater is another consideration due to vapor recovery issues associated with shallow water tables such as upwelling or occluding of well screen. In general, depths of 10' BSG and greater are preferable. On average, groundwater at the Site has been gauged at approximately 17' BSG. (Butterworth, Combined Release Characterization Report (RCR), Site Investigation Report (SIR), & Corrective Action Plan (CAP), 2009)

1.3.1.4 Soil Moisture Content

Elevated moisture content within soil can also affect the performance of the SVE system by inhibiting the movement of soil gas through soil pores (USEPA, Soil Vapor Extraction , 1994). Site soils have not been observed to be excessively moist and are not thought to be due to the asphalt cover spanning the Site grade. However, SVE effectiveness is somewhat decreased when approaching the capillary fringe. Due to the coarse nature of site soils, moisture is not believed to be a restrictive factor.

1.3.2   TARGET COMPOUND FACTORS

1.3.2.1 Vapor Pressure

Vapor pressure is considered the most important target compound factor when evaluating SVE. Vapor pressure is a measure of a compounds tendency to evaporate. Target compound vapor pressures greater than 0.5 mm Hg are considered sufficient to support the use of SVE (USEPA, Soil Vapor Extraction , 1994). As discussed earlier, the release is associated with gasoline and the two major compounds of concern are ethylbenzene and toluene which have vapor pressures of 22 mm Hg and 7 mm Hg, respectively.

1.3.2.2 Boiling Point

Boiling point is a measure of products volatility and thus a gauge of response to SVE. According to the USEPA, target compounds with boiling points less than 250°C are sufficiently volatile for removal through SVE (USEPA, Soil Vapor Extraction , 1994). The subject release is associated with gasoline and has a typical boiling point between 40°C and 225°C.

1.3.2.3 Henry's Law Constant

A final screening item to assess the effectives of SVE on a targeted compound is Henry's Law constant. The Henry's Law constant is a partitioning coefficient relating to a compound concentration dissolved in water to its partial pressure in vapor phase. Compounds with Henry's Law constants greater than 100 atmospheres are considered affective for cleanup though SVE (USEPA, Soil Vapor Extraction , 1994). All targeted compounds for cleanup exceed the aforementioned level.

Based upon all the above screening, SVE appears to be an effective approach for remediation. As a result, in the subsequent sections the theoretical remedial design has been provided.

1 . 4   T h e o r e t i c a l   S y s t e m   D e s i g n

For the purposes of system design, three key factors were examined including: vapor extraction flow rate, wellhead vacuum, and radius of influence (ROI).

1.4.1   VAPOR EXTRACTION FLOW

Vapor extraction flow is defined as the volumetric flow rate of soil gas that will be extracted from each extraction well. In calculating this flow, published graphs were utilized based upon flow per unit length of screen and Darcy values for different soil types.

To use these graphs, the theoretically defined intrinsic permeability of 10^{-7} was converted to Darcy through multiplying by $10^{8.}$ The equated Darcy value is 10 (Butterworth, Combined Release Characterization Report (RCR), Site Investigation Report (SIR), & Corrective Action Plan (CAP), 2009). Using the graph below, it was determined that per foot of well screen approximately 8 cfm or 0.0037755796 m^3/s is adequate air flow. The extraction well design, defined later in this report will consist of a 2' section of screen thus resulting in approximately 16 cfm or 0.0075511592 m^3/s per well. This value is consistent with numbers published by USEPA, which range generally between 10 and 100 cfm or 0.0047194745 m^3/s and 0.047194745 m^3/s, respectively per well.

Figure 1-1: CFM per darcy

$R_1 = 23$ m
$R_w = 5.1$ cm
$P_{Atm} = 1.0$ atm

$P_w = 0.60$ atm →

← $P_w = 0.80$ atm

Q^*/H
(scfm/ft)

clayey sands   fine sands   medium sands   coarse sands

k (darcy)
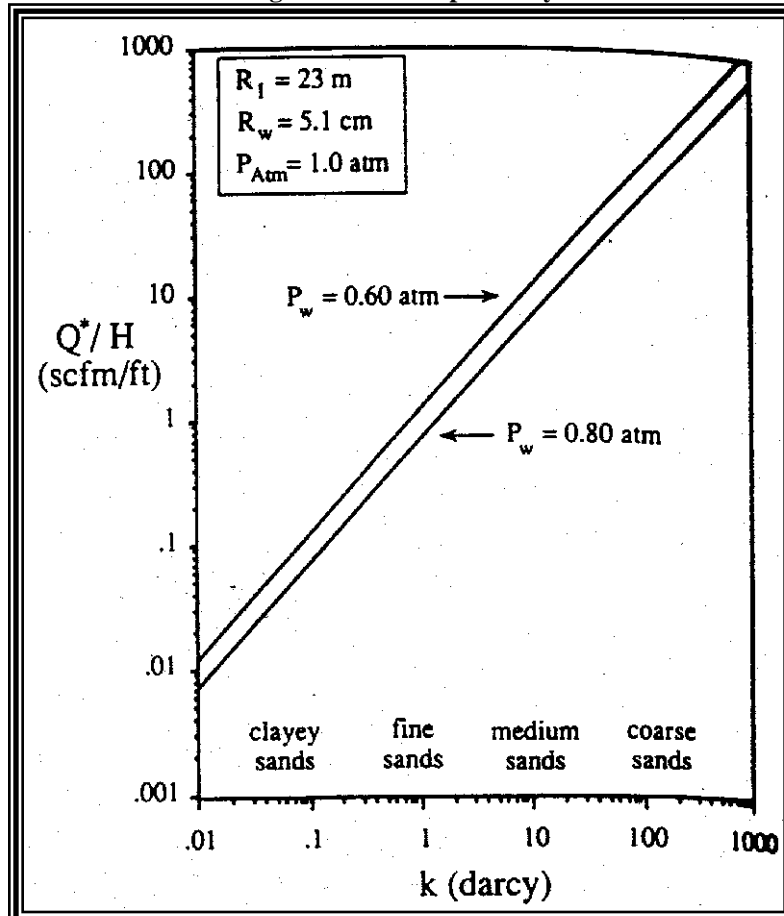
(USEPA, Enhanced Aerobic Bioremediation, 2004)

1.4.2 WELLHEAD VACUUM PRESSURE

Wellhead vacuum pressure is the pressure required at the top of the extraction well to produce the

desired vapor extraction flow rate. To calculate this value, the anticipated blower pump curve

along with the estimated pressure drops over the estimated distance of pipe.

The system will use 3" schedule 40 PVC pipe to construct the SVE system main trunk line

manifold. The lines extending from the manifold to the SVE points will be 2" PVC. Total linear

feet of the system is estimated to be 70 feet and based upon the factory pump curve the selected

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blower supplies, approximately 70 cfm or 0.0330363215 m^3/s at 1.25" Hg. The calculated

pressure drop over the 70' of 3" piping is approximately 0.25"Hg. 3" diameter pipe was chosen

because of the desired 70 cfm flow and restrictions expected from smaller pipe diameters. Based

on this, the expected wellhead vacuum pressure will be no less than -1.25" Hg or approximately

0.95 atmosphere. (Butterworth, Combined Release Characterization Report (RCR), Site

Investigation Report (SIR), & Corrective Action Plan (CAP), 2009)

Figure 1-1: Pressure drop in vacuum pipe lines
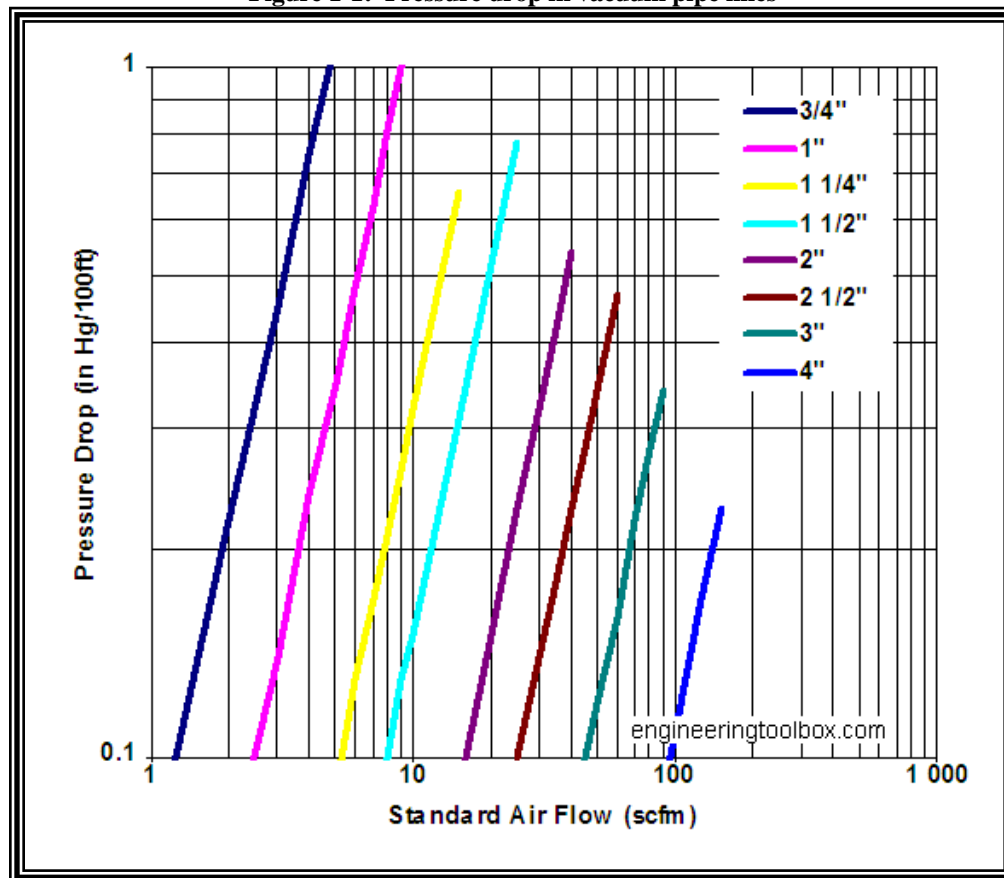
1.4.3 RADIUS OF INFLUENCE

ROI is the radial effect a single extraction well can have over a given area. According to the

USEPA, ROI can range from 5' for fine graded soils (i.e. clay) to 100' for coarse graded soils

(USEPA, Soil Vapor Extraction , 1994). For conservancy purposes, the system was designed the

system for an expected 12' ROI although it will likely be much greater.

1.5 *S V E   S y s t e m   C o m p o n e n t s   &   D e s i g n*

Based upon the above calculations, the developed system was designed and described in detail

within the following sections.

1.5.1 SVE EXTRACTION WELL DESIGN AND LOCATION

The SVE extraction well to be used for the system will consist of 2" schedule 40 PVC. The design

for each well has been depicted in the figure below.

Figure 1-2: SVE Extraction Well Design
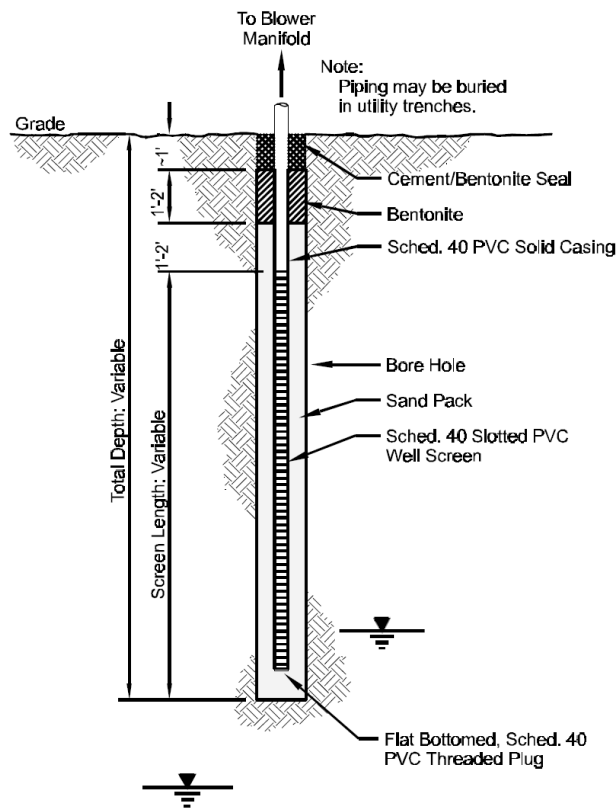
(USEPA, Soil Vapor Extraction , 1994)

Based upon the theoretical ROI and area of impact spanning an area of approximately 850 ft^2, the

total SVE wells required was calculated to be 3. However, for conservancy purposes a fourth well

was added to improve system performance and create overlaps of the SVE ROI's. A plan

depicting the area of groundwater impact, the location of SVE wells and theoretical ROI's has

been provided below.
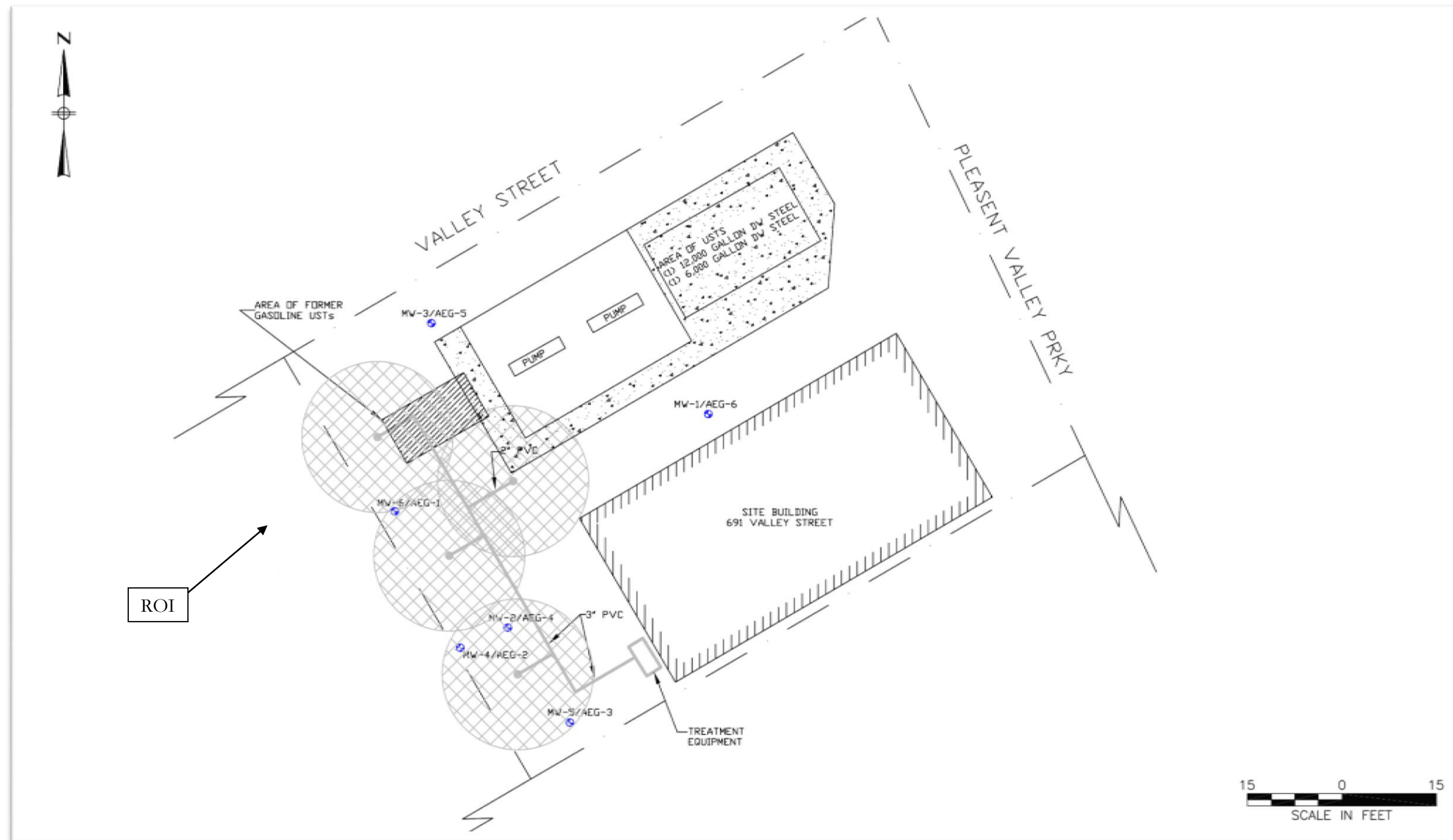
Figure 1-5: SVE System Design and ROI

(Butterworth, Combined Release Characterization Report (RCR), Site Investigation Report (SIR), & Corrective Action Plan (CAP), 2009)

1.5.2 SVE BLOWER

To provide the necessary vacuum for the system, a regenerative blower, Sweetwater model S41 was selected. (Butterworth, Combined Release Characterization Report (RCR), Site Investigation Report (SIR), & Corrective Action Plan (CAP), 2009)

1.5.3 SVE AIR TREATMENT

Gasoline vapors extracted from the system will be passed first through a condensation "knock-out tank" and then through a 55-gallon drum of granular activated carbon (GAC) and eventually to the ambient air. Based upon an assumed average total volatile organic vapor (TVOV) concentration of 100 ppm within the contaminant vapor stream, the known contamination being associated with gasoline, and the approximate molecular weight of gasoline being 100 daltons, an expected waste stream air concentration of 409 mg/m^3 was developed. With an overall expected air flow of 70 cfm and 95% removal rate, it is expected the air phase GAC drum will remove contaminant at a rate of 0.052 lbs/hr. At the assumed rate removal, the GAC drum is expected to last approximately 35 days. (Butterworth, Combined Release Characterization Report (RCR), Site Investigation Report (SIR), & Corrective Action Plan (CAP), 2009)

This calculation is based upon a non diminishing TVOV concentration which is not likely and also a relatively high TVOV concentration.

1.5.4 SVE SYSTEM CONSTRUCTION LAYOUT

As detailed earlier, the system will consist of a main 3" schedule 40 PVC trunk line which will manifold with the 4 SVE wells through 2" schedule 40 PVC. At each SVE point, a flow control

valve, flow indicator, sampling port and pressure indicator will be installed. All aforementioned

equipment and piping will be buried below grade within a protective road box.

The blower for the system will be housed in an enclosure on grade along with the knock out

drum and air phase GAC drum. A construction schematic has been depicted below.

Figure 1-3: SVE System Layout
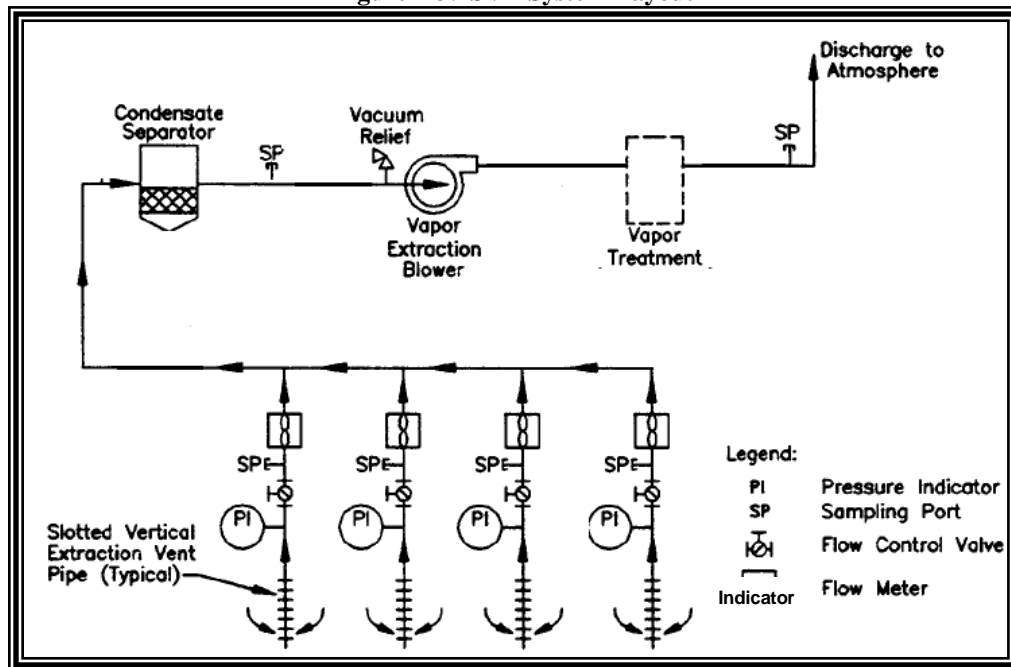
(USEPA, Soil Vapor Extraction , 1994)

1 . 6   P e r f o r m a n c e   E v a l u a t i o n   &   C o m p l i a n c e   M o n i t o r i n g

On July 23, 2009, the system as designed herein was installed and operated at the site. Over both

quarterly and semi-annual sampling rounds groundwater samples were collected and analyzed

for VOCs to track the remedial system effectiveness. Below is a table summarizing the historical

and current groundwater quality levels. (Butterworth, 2009) and (Butterworth, Semi-Annual

Status Report, 2011)

Table 1-4
Historical Groundwater Analytic al Results Summary

	Benzene	Toluene	Ethylbenzene	Xylenes (total)	Isopropylbenzene	n-Propylbenzene	1,3,5-Trimethylbenzene	1,2,4-Trimethylbenzene	Sec-Butylbenzene	p-Isopropyltoluene	n-Butylbenzene	Naphthalene
AEG-1												
4/23/2009	92	**2,900**	1,300	12,200	120	200	380	1,700	ND	9.3	22	240
9/25/2009	120	**3,300**	1,200	10,700	130	190	450	1,700	20	13	37	250
3/26/2010	60	**1,900**	**1,700**	12,000	190	300	650	2,600	17	52	ND	290
9/8/2010	100	**3,700**	1,400	11,000	130	280	680	2,500	24	37	48	170
3/28/2011	16	**3,300**	1,300	8,300	110	220	460	1,700	14	46	75	230
9/30/2011	69	**3,700**	1,300	10,200	120	220	490	1,600	18	52	35	240
AEG-2												
4/23/2009	17	120	850	7,500	60	93	190	750	ND	7.5	14	250
9/25/2009	19	110	530	2,350	41	48	89	330	8.1	8.4	7.7	180
3/26/2010	20	140	870	1,900	70	93	160	570	6.3	24	ND	180
9/8/2010	14	110	400	1,680	37	51	99	230	7.5	14	9	120
3/28/2011	19	150	700	2,650	40	57	100	390	6.1	19	7.4	160
9/30/2011	19	83	470	1,740	41	58	110	290	6.7	20	8.6	130
AEG-3												
4/23/2009	5.7	19	570	2,450	85	220	350	1,400	20	15	110	250
9/25/2009	12	2.4	14	ND	ND	9.7	18	45	4.9	5.5	4	6.5
3/26/2010	11	3.3	51	36	9	16	33	100	3.2	8.2	ND	15
9/8/2010	12	1.8	5.8	16.3	3.4	4.4	14	40	1.7	3.7	2.5	2.7
3/28/2011	11	2.2	7.8	21.8	4.3	8.9	18	44	2.9	2.3	1.6	8.4
9/30/2011	12	1.6	15	36.1	5.4	10	22	54	3.3	6.5	3.7	13
AEG-5												
4/23/2009	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
9/25/2009	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
3/26/2010	ND	7.1	3.1	28	ND	ND	3.4	7.8	ND	ND	ND	ND
9/8/2010	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
3/28/2011	ND	8	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
9/30/2011	ND	ND	ND	6.5	ND	ND	1.3	ND	ND	ND	ND	ND
RIDEM GB-GWO	**140**	**1,700**	**1,600**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

Notes:
1. Units: μg/L (ppb)
2. **BOLD** indicates exceedance of RIDEM GB-GWO.
3. ND: Not Detected above the laboratories method reporting limit
4. GB GWOs as defined in Section 8.03 of the RIDEM *Remediation Regulations* as amended February 2004
5. NS: No Standard Exists within RIDEM *Remediation Regulations* as amended February 2004
6. NA: Monitoring well Not Sampled on this date.

As can be seen above, overall contaminant mass reduction has been achieved at both AEG-2 and AEG-3. Some modulation of levels at AEG-1 has also been observed, although, it is apparent the system is not effectively removing contaminant from this area.

Continued operation of the system at this capacity will likely not result in much compliance achievement at AEG-1 based upon the results seen to date. As a result, a design change could be

considered that could both improve contaminant recovery through the SVE system and also promote the natural degradation of contaminant via bacterial respiration.   The system improvement could be the induction of air sparging, which involves pushing of atmospheric air through a well into the contaminated groundwater plume. The injected air causes a lower vapor pressure upon the contaminants thus forcing them out of solution more readily for capture through the SVE vacuum.   In addition, the induction of air will also cause fairly localized addition of oxygen which will drive aerobic bacterial respiration of the organic gasoline contaminants (USEPA, Enhanced Aerobic Bioremediation, 2004).

Site2 Former Dry-Cleaning Facility Location: Greeneville, RI Bioremediation of Chlorinated Solvent Impacted Groundwater

2.1   Introduction & Background

The subject parcel is located in a rural area of Rhode Island, known as Greenville. The site is developed with a single-story commercial structure half of which is occupied by a law office while the remaining is a dry-cleaning drop off center. A site locus map has been provided below.
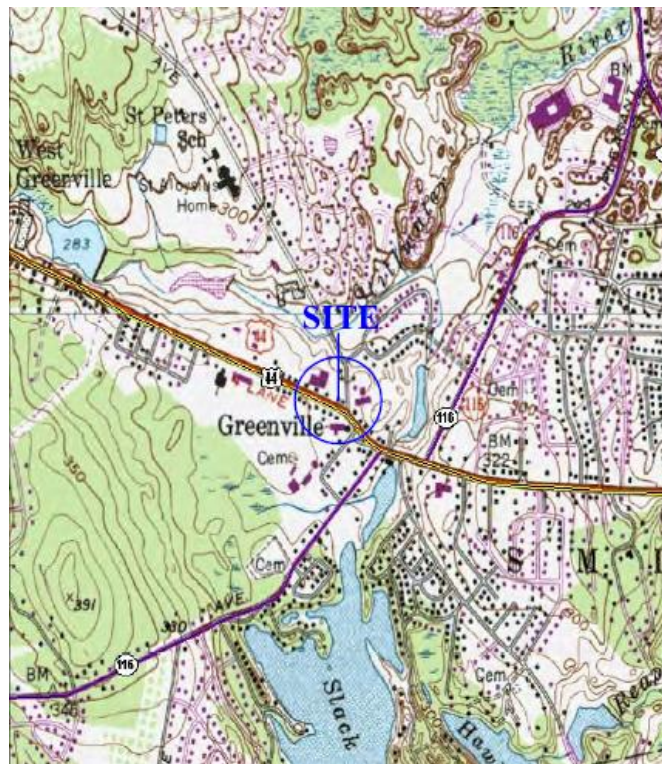
Records reviewed at the Rhode Island Department of Environmental Management (RIDEM) indicate that a property located downgradient of the subject site was investigated previously in 2008 and found to contain elevated levels of chlorinated solvents in groundwater. The contaminants were found in the forms of tetrachloroethene (PCE), trichloroethene (TCE), and

cis-1,2-dichloroethene (cis-1,2-DCE). The investigated parcel had no known historical use of

chlorinated solvent, and all properties immediately surrounding were residential use in nature.

Based upon these findings and the evidence presented with respect to the investigated parcel,

Rhode Island Department of Environmental Management (RIDEM) conducted a survey of

potential upgradient sources and identified the subject site based upon its historical use.

2.2   E n v i r o n m e n t a l   S e t t i n g

Environmental conditions were reviewed at the Rhode Island Geographic Information System

(RIGIS). According to the RIGIS map, there are no sensitive environmental receptors (i.e.

wetlands or wellhead protection areas) at the Site or within the surrounding area. The nearest

receptors are unnamed surface water tributaries which are locate approximately 500-700 feet to

the north and east. These streams eventually feed into the Slack Reservoir.

The groundwater classification for the Site, as defined in the RIGIS map is GA, indicating

groundwater that is suitable for public or private drinking water use without prior treatment.

According to information available from *Soil Survey of Rhode Island*[2], the overburden geology at

the Site is Urban Land. Groundwater is located at approximately 17' below surface grade

(BSG). According to the RIGIS, bedrock at the Site is granite.

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[2] *Soil Survey of Rhode Island,* United States Department of Agriculture, Soil Conservation Service in cooperation with Rhode Island Agriculture Experimental Station, July, 1981.

According to the United States Geological Survey (USGS) bedrock at the Site is sandstone,

shale, and conglomerate, with minor coal layers. During subsurface investigation, borings were

advanced as deep as 40' BSG and bedrock was encountered.

Subsurface Investigation Background

In May of 2006, during site investigation, 3 shallow groundwater monitoring wells were installed

and testing of groundwater samples from these wells found volatile organic compounds (VOCs)

at levels above exceeding the applicable RIDEM GA Groundwater Objectives. (Butterworth,

RAWP Status Report, 2009)

Table 2-1 Groundwater Analytical Results 2006				
Target Analyte	MW-1	MW-2	MW-3	**GA Groundwater Objectives**
Trans-1,2 dichloroethylene	8.0	ND	ND	**100.0**
Cis-1,2 dichloroethylene	**1,020.0**	ND	ND	**70.0**
Tetrachloroethylene	**431.0**	**33.2**	**10.3**	**5.0**
Trichloroethylene	**378.0**	ND	ND	**5.0**
All results reported in ug/l Numbers in **Bold** indicate levels above the GA Groundwater objective				

Each of the three (3) shallow wells were advanced to a depth of approximately 8 feet below the

water table (~18' +/-) with the well screen placed to intersect the water table (8'-18').

Based upon the specific gravity of the detected compounds (chlorinated solvents) being heavier

than water, over time they tend to sink within the aquifer. Consequently, to determine the impact

of these compounds at greater depths, 4 additional groundwater monitoring wells were installed.

On March 6, 2008, 4 groundwater monitoring wells were installed at the site. The intent of the

wells was to assess groundwater conditions at greater depths toward bedrock. All 4 borings

encountered refusal (bedrock) at varying shallower depths (Butterworth, RAWP Status Report,

2009):

Table 2-2 Monitoring Well Total Depths				
Monitoring Well	B-1/MW-101	B-2/MW-102	B-3/MW-103	B-4/MW-104
Depth of Refusal	27'	27'	40'	24'

- Boring B-1/MW-101 was located to determine the groundwater conditions near the eastern property line along Austin Avenue.

- Boring B-2/MW-102 was located in the central portion of the Site near MW-2. B-3/MW-103 was placed close to the property line at the rear of Specialty Cleaners.

- B-4/MW-4 was placed at the northern end of the Site to evaluate the groundwater conditions at depth near the abutting residential property.

The well locations are depicted on the figure below.

Figure 2-1 – Monitoring Well Locations
(Butterworth, RAWP Status Report, 2009)

In each new well, only the bottom 10 feet was screened to insure the samples were collected at

deeper depths in the water column than from the shallow wells.

On March 9, 2008, a round of groundwater sampling was conducted at the site. Each well was

gauged using a Solinist® Interface Probe to identify the depth to groundwater. Then samples

were collected using a peristaltic pump with tubing extending from the pump to the bottom of the

well. The groundwater samples were sent to a Rhode Island certified laboratory for VOC

analysis by United States Environmental Protection Agency (USEPA) Method 8260

(Butterworth, RAWP Status Report, 2009). The results of the testing are summarized in the

below table.

Table 2-3 Groundwater Analytical Results 2008					
Target Anlayte	MW-101	MW-102	MW-103	MW-104	GA Groundwater Objectives
Cis-1,2 dichloroethene	ND	0.0029	ND	ND	**0.07**
Naphthalene	ND	0.0011	ND	ND	**0.02**
Tetrachloroethene	**0.0954**	**0.0377**	ND	**0.0191**	**0.005**
Tetrahydrofuran	0.0053	ND	ND	ND	**NS**
Trichloroethene	ND	0.0032	ND	0.0010	**0.005**
1. All results reported in mg/l 2. Numbers in **Bold** indicate levels above the GA Groundwater Objective 3. ND = compound not detected 4. NS = no standard					

The analytical results of the samples from the 4 deep wells show that tetrachloroethene exceeds

GA Groundwater Objectives at MW-101, MW-102, and MW-104.

The following table summarizes the results of all groundwater testing conducted to date:

Table 2-4 Groundwater Analytical Results Summary 2006 & 2008								
Compound	MW-1	MW-101	MW-2	MW-102	MW-3	MW-103	MW-104	GA Groundwater Objectives
Cis-1,2 dichloroethene	**1020.0**	ND	ND	0.0029	ND	ND	ND	**0.07**
Trans-1,2 dichloroethene	**8.0**	ND	ND	ND	ND	ND	ND	**0.1**
Naphthalene	ND	ND	ND	0.0011	ND	ND	ND	**0.02**
Tetrachloroethene	**0.431**	**0.0954**	**0.033**	**0.0377**	**0.010**	ND	**0.0191**	**0.005**
Tetrahydrofuran	ND	0.0053	ND	ND	ND	ND	ND	**NS**
Trichloroethene	**0.378**	ND	ND	0.0032	ND	ND	0.0010	**0.005**
1. All results reported in mg/l 2. Numbers in **Bold** indicate levels above the GA Groundwater Objective 3. ND = compound not detected 4. NS = no standard								

On September 18, 2009, two (2) new monitoring wells were installed to further investigate

downgradient water quality. Monitoring well MW-105 was installed at the northeast corner of

the site and was installed down to refusal encountered at approximately 21 feet below surface

grade (BSG). MW-105 was screened from 6 feet BSG down to the bottom of the well.

Groundwater was measured at 12 feet BSG. (Butterworth, RAWP Status Report, 2009)

Well MW-106 was installed off-site near Austin Avenue. This well was installed down to

refusal at a depth of approximately 29 feet BSG, and screened from 6 feet BSG down to the

bottom of the well. Groundwater was measured at 12 feet BSG.
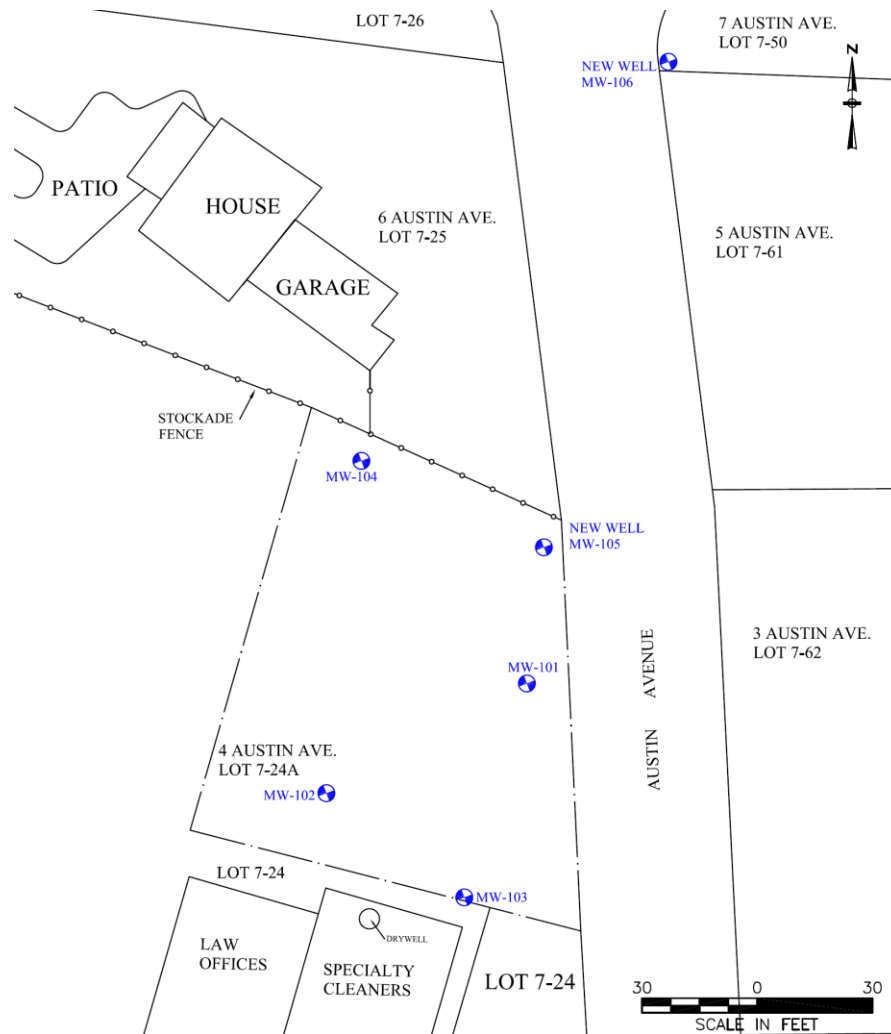
Figure 2-2 – Monitoring Well Locations Continued
(Butterworth, RAWP Status Report, 2009)

On September 21, 2009, a round of groundwater testing was performed and samples collected

from MW-101, MW-102, MW-104, MW-105, and MW-106. Prior to the collection of a

sample, each well was purged of 3-well volumes using a low-flow peristaltic pump. After

which, a sample was collected for laboratory analysis of VOCs USEPA method 8260B.

(Butterworth, 2009) A summary of the laboratory results has been provided in the table below.

Table 2-5 Detected Groundwater Analytical Results September 21, 2009					
Location	Acetone	2-Butanone	cis-1,2-Dichloroethene	Trichloroethene	Tetrachloroethene
MW-101					
9/21/2009	ND	ND	ND	ND	**160**
MW-102					
9/21/2009	ND	ND	6.8	4.2	**96**
MW-104					
9/21/2009	30	29	ND	ND	3.1
MW-105					
9/21/2009	ND	ND	**74**	5.0	3.9
MW-106					
9/21/2009	ND	ND	26	**7.3**	**10**
RIDEM GA-GWO	**NS**	**NS**	**70**	**5.0**	**5.0**
Notes: 1. Units: μg/L (ppb) 2. **BOLD** indicates exceedence of RIDEM GA-GWO. 3. ND: Not Detected above the laboratories method reporting limit 4. GA-GWOs as defined in Section 8.03 of the RIDEM *Remediation Regulations* as amended February 2004 5. NS: No Standard Exists within RIDEM *Remediation Regulations* as amended February 2004					

Based upon the results of site investigation, two remedial options were evaluated for the site

contamination. Both were in-situ in application and included chemical oxidation and

bioremediation in the form of biostimulation. Based upon potential groundwater quality

impairment concerns and environmental risks associated with chemical oxidation such as metal

impurities in injected oxidants, and residential downgradient receptors, bioremediation was

selected. In this case, bioremediation in the form of biostimulation in which an organic food

source is applied to the aquifer to create a highly anaerobic environment, conducive to proper

bacterial growth was selected.

2.3   T h e o r e t i c a l   D e s i g n   F a c t o r s

Based upon a review of potential response actions, it was determined that the most appropriate

for the site was to abate chlorinated solvent impacts via creating an anaerobic environment. This

process is also referred to as biostimulation. Under anaerobic conditions, chlorinated solvents

are degraded via the process of reductive dechloianation by bacteria collectively known as

Dehalococcoides. To create an anaerobic environment, a carbon source is typically supplied to

aquifer which in turn creates a high biological oxygen demand (BOD) that removes competing

electron acceptors, such as oxygen ((ITRC) I. T., 2008). This drives the environment to an

anaerobic state in which the aforementioned *Dehalococcoides* can thrive.

In this case, the *Dehalococcoides* use the chlorinated solvent in their metabolic pathway as an

electron acceptor, thus continuing to cleave chlorine atoms.
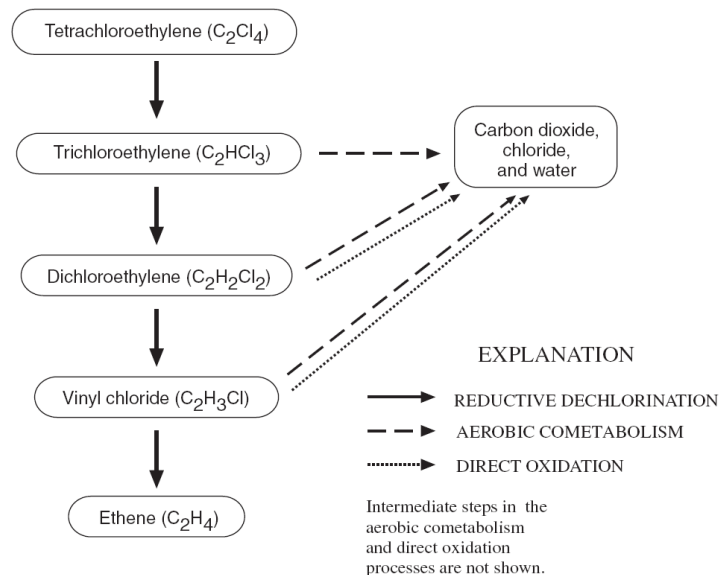
Figure 2-3 – Chlorinated Solvent Biodegradation Pathway
((ITRC) T. I., 2008)

To create the anaerobic emulsified vegetable oil was injected. Because the dechlorination reaction is acidifying, a phosphate based buffer was also injected to control pH.

Using a direct-push Geoprobe, between September 23 and 24, 2009, subsurface injections began at the site. A total of nine (9) injection points spread throughout the site were selected. The Geoprobe drill rig was used to advance each injection point. At each point, a 7% by weight mixture totaling 180 gallons of emulsified vegetable oil and water was injected (Butterworth, RAWP Status Report, 2009). Each injection was done at four intervals from 15 feet BSG down to refusal and then the borehole was sealed with bentonite.
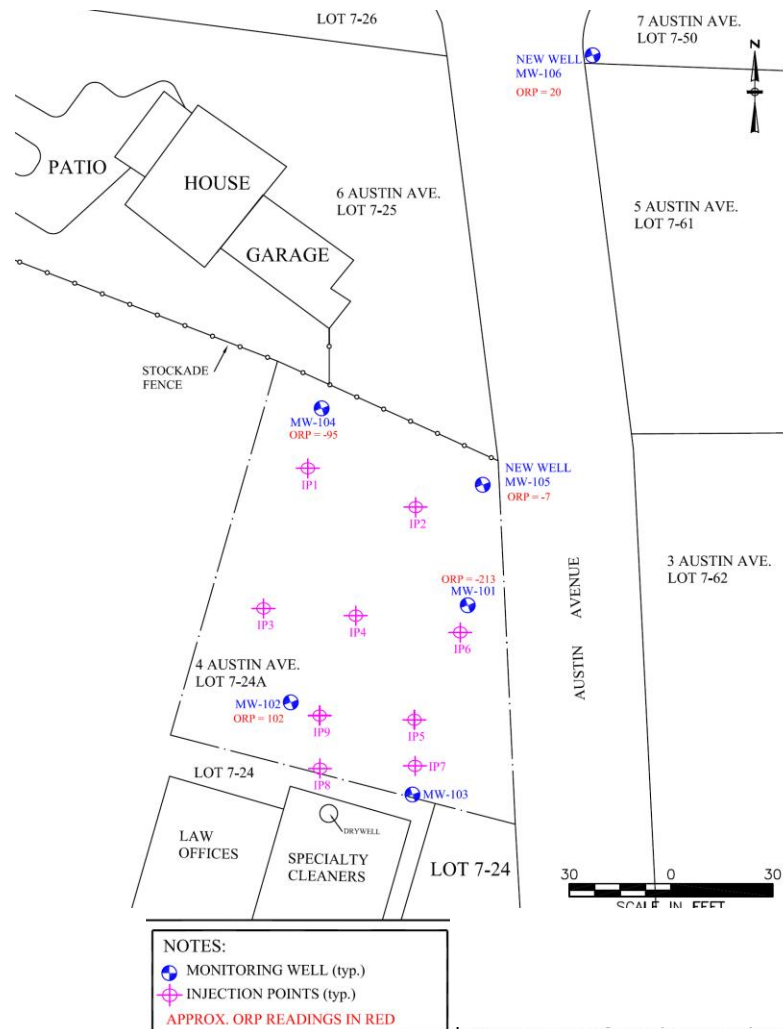
Figure 2-4 – Injection Locations
(Butterworth, 4th Quarter 2011 Groundwater Monitoring Report, 2012)

2.4   Performance Evaluation & Compliance Monitoring

To track the progress of contaminant degradation, quarterly rounds of groundwater testing was

performed at select monitoring wells. To date, monitoring results along with oxidation-reduction

potential (ORP) values has been provided in the tables below (Butterworth, Semi-Annual Status

Report, 2011).

Table 2-6
Historical Groundwater Analytical Results

Detected Contaminants of Concern	MW-101											MW-105										MW-106											RIDEM GA-GWO
	9-Mar-08	9-Sep-09	9-Dec-09	24-Mar-10	23-Jun-10	17-Sept-10	22-Dec-10	30-Mar-11	28-Jun-11	12-Oct-11	21-Dec-11	9-Sep-09	9-Dec-09	24-Mar-10	23-Jun-10	17-Sept-10	22-Dec-10	30-Mar-11	28-Jun-11	12-Oct-11	21-Dec-11	4-Oct-04	9-Sep-09	9-Dec-09	24-Mar-10	23-Jun-10	17-Sept-10	22-Dec-10	30-Mar-11	28-Jun-11	12-Oct-11	21-Dec-11	
Cis-1,2-Dichloroethene	ND	ND	ND	**160**	40	57	**350**	95	**600**	**350**	**540**	**74**	**110**	70	**120**	6.2	**110**	**500**	86	85	**920**	8.7	26	34	4.6	5.7	4.8	25	14	9.3	9.7	ND	**70**
Trichloroethene	0.5	0.5	4.8	**9.9**	4.5	**5.5**	**15**	2.1	**28**	**26**	3.7	5	**63**	ND	4.3	2.6	3	**8.4**	ND	1.4	1.9	**6.4**	**7.3**	**5.3**	ND	2.8	2.6	2.5	2.7	ND	ND	ND	**5**
Tetrachloroethene	**95**	**160**	**130**	ND	30	25	9.5	2.2	**45**	**80**	15	3.9	**31**	4.6	2.9	3.3	2.3	**6.1**	ND	ND	ND	1.2	**10**	**7.6**	4.2	4.9	3.3	2.3	3	2.4	2.5	ND	**5**

Notes:
1. Units: µg/L (ppb)
2. **BOLD** indicates exceedance of RIDEM GA-GWO.
3. ND: Not Detected above the laboratory method detection limit.
4. GA-GWOs as defined in Section 8.03 of the RIDEM *Remediation Regulations* as amended February 2004
5. NS: No Standard Exists within RIDEM *Remediation Regulations* as amended February 2004
6. Well MW-104 groundwater monitoring stopped in December, 2010 with RIDEM approval because results consistently below applicable GA-GWOs

Table 2-7
Pre and Post-injection ORP Levels

Date	MW-101	MW-102	MW-104	MW-105	MW-106
9-Sep-09	131	43	55	-134	-185
28-Dec-09	-213	102	-95	-7	20
24-Mar-10	-233	5	120	-100	61
23-Jun-10	-258	-134	-70	-247	-93
17-Sept-10	-44	127	155	79	121
22-Dec-10	-260	118	NA	-135	29
30-Mar-11	-263	45	NA	-185	46
28-June-11	-120	39	NA	-100	135
12-Oct-11	-113	NA	NA	-122	67
21-Dec-11	-136	NA	NA	-135	42

Notes:
1. ORP Levels recorded with YSI Flow through cell Model 556 MPS.
2. NA: ORP levels not analyzed for this well.

As can be seen in the above tables, the process of reductive dechlorination is and has occurred with great effect. In fact, the parent compound PCE and associated daughter compound TCE in many wells has been reduced significantly in concentration and in some cases below the applicable standard. However, concentrations of one of the final degradation compounds (cis-1,2-DCE) appears to be increasing in concentration. Under the normal degradation pathway, the reduction of the parent compound and concentration increases in the successive daughter compounds is expected based upon the dechlorination process. However, some species of *Dehalococcoides* do not have the gene expression to create the necessary enzyme to further degrade cis-1,2-DCE which will result in a buildup of the daughter compound ((ITRC) I. T., 2008).

In this case, this is a possible explanation for the current condition as ORP levels as depicted in Table 2-6, suggest an anaerobic environment although levels are not excessively reductive. The addition or more electron donor in the form of emulsified vegetable oil may prove to be a success however, it may be beneficial to perform a gene expression laboratory test to identify if the bacterial population is capable of metabolizing the remaining contaminant. In the event the gene test I negative, addition of cultured bacterial populations should be performed also known as bioaugmentation ((ITRC) T. I., 2008).

Site3 Municipal Airport/Former Navy Airport Location: Beverly, MA   In-well Air Sparge Chlorinated Solvent Impacted Groundwater Remediation in Bedrock

3.1   Introduction & Background

The Site consists of approximately 4.5 acres, which is occupied by an aviation hangar building and an adjacent one-story commercial building. A figure depicting the site location has been provided below.

The City of Beverly currently leases the commercial building to several businesses including a restaurant and a swimming pool maintenance company. The Vitale Company used the hangar, built in 1939 and originally occupied by Revere Aviation, as a vehicle maintenance garage. Aircraft from the adjacent Beverly Airport were maintained and parked in the areas north and east of these buildings where it was reported that chlorinated solvents were commonly used to degrease engine parts. The U.S. Navy constructed the commercial building in 1942 to serve as barracks. When the Navy vacated the Site in 1950, the commercial building was leased to

Gurnard Manufacturing, Beswick Manufacturing and, later, Comdel Manufacturing, a

manufacturer of electronic power supplies and communication equipment. During the

commercial building's occupancy, chlorinated solvents were reportedly used. (Butterworth,

Phase II, Phase III and Phase IV Report; and RAO Statement - Former Revere Aviation/ Beverly,

MA, 2006)

3.2   Environmental Setting

Environmental conditions were reviewed at the Massachusetts Geographic Information System

(MAGIS). According to MAGIS, the site bedrock is granite and groundwater immediately at the

site is not used for drinking water. However, downgradeint of the site to the east is the Wenham

Lake, and unnamed stream network which is zoned as a drinking water source.

Subsurface Investigation Background

From 1986 to date, several investigators have analyzed groundwater, soils (both subsurface and

surface), sediment and soil gas. Reviews of these investigations indicate that a release of

chlorinated volatile organic compounds (VOCs) has impacted soil and groundwater at the Site.

The primary impacted medium is groundwater, with the primary contaminants being

trichloroethene (TCE), cis-1,2-dichloroethene (cis-1,2-DCE), 1,1-dichloroethene (1,1-DCE) and

vinyl chloride (VC). The highest concentrations of contaminants of concern (COC) found in

groundwater to date prior to remedial activities are 19,000 parts per billion (ppb) of TCE, 11,000

ppb of cis-1,2-DCE, 150 ppb of 1,1-DCE, and 380 ppb of VC. (Butterworth, Phase II, Phase III

and Phase IV Report; and RAO Statement - Former Revere Aviation/ Beverly, MA, 2006)

Chlorinated VOCs found in groundwater are believed to be due to the degreasing activities of former occupants. Specific "point source" discharges of wastes have not been identified. In addition, there is no indication that dense non-aqueous phase liquid (DNAPL) is present in the groundwater under the site. This is supported by the fact that the maximum concentrations of contaminants detected were well below 10% of their solubilities in water (e.g. the solubility of TCE at 20°C is 1,000 mg/l or 1,000,000 ppb). (Butterworth, Phase II, Phase III and Phase IV Report; and RAO Statement - Former Revere Aviation/ Beverly, MA, 2006)

In February and June of 2006, further assessment of subsurface conditions was performed. In February, five soil borings were advanced to various depths throughout the site and the property adjoining the site to the east. Borings were advanced using a hollow stem auger, upon encountering bedrock, a rotary air hammer was used for further advancement.

- AEG-101 was advanced to the west of the General Aviation building to a depth of 41' below surface grade (BSG).

- AEG-102 and AEG-103 were advanced at locations approximately 393 and 281 feet east, respectively, from the easterly border of the Site to depths of 83' and 82' BSG, respectively.

- AEG-104 was drilled to the east of the former Revere General Aviation building, in the area of former groundwater monitoring wells MW-306 and MW-306B, to a depth of 82' BSG.

- In June of 2006, monitoring well AEG-107 was drilled north and east of AEG-104, towards the easterly border of the Site to a depth of 119' BSG.

Upon completion, all borings were converted into groundwater monitoring wells. AEG-104 and -107 were screened at multiple intervals.

As described above, five (5) deep bedrock-monitoring wells were installed on the site between February to June 2006. AEG-101 was constructed outside of the west side of the commercial building to determine whether there is an up gradient (westerly) source of TCE and/or its anaerobic decomposition products (VC, cis-1,2-DCE and 1,1-DCE). AEG-104 was constructed as a replacement for MW-306B, which could not be located and was presumed destroyed. AEG-107 was constructed in the northeastern-most (downgradient-most) part of the site. In addition, two deep-bedrock wells, AEG-102 and AEG-103, were constructed on the site due east on the property adjacent to the site. (Butterworth, Phase II, Phase III and Phase IV Report; and RAO Statement - Former Revere Aviation/ Beverly, MA, 2006)

These locations were chosen since it has been determined that groundwater flow is in a northeasterly direction. Monitoring wells AEG-102 and AEG-103 are located approximately 393 and 281 feet, respectively, due northeasterly, in a downgradient direction from the Site's boundary. Monitoring wells AEG-107, AEG-102 and AEG-103, along with MW-305B, a deep-bedrock well, already located on this easterly adjacent property, were used to delineate contaminant migration. Between March and June 2006, groundwater samples were collected from monitoring wells AEG-101 (at one depth), AEG-104 (at three depths), AEG-107 (at four depths), existing Site wells MW-102 and OW-1 (each at one depth), and off-Site wells AEG-102 (at three depths), AEG-103 (at four depths) and MW-305B (at one depth) (Butterworth, Phase II, Phase III and Phase IV Report; and RAO Statement - Former Revere Aviation/ Beverly, MA, 2006). All wells were purged using

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a low-flow peristaltic pump and groundwater was field screened using an YSI 556 multi-parameter probe with a flow-through cell. A sample was collected from each well following the United States Environmental Protection Agency (USEPA) protocol "Low Stress (low flow) Purging and Sampling Procedure for the Collection of Ground Water Samples From Monitoring Wells". All groundwater samples collected for the analysis of VOCs using USEPA Method 8260B.

Specifically, in groundwater from monitoring well MW208, where the maximum concentration of TCE was measured, a decrease in the concentration of TCE (from 19,000 ppb measured in 1999 to 455 ppb measured in 2005) was observed. In addition subsequent increases in both cis-1,2-DCE (from 750 ppb to 1,340 ppb) and VC (from 55 ppb to 200 ppb) occurred. This increase in cis-1,2-DCE and VC is due to the anaerobic decomposition of TCE.   Also, in groundwater from well MW307B, the concentrations of TCE also decreased over time (11,000 ppb measured in 2001, to 3,020 ppb measured in 2005). However, cis-1,2-DCE shows significant reductions from when last sampled in 2001. In this same well, over the same timeframe, the concentration of cis-1,2-DCE decreased (from 11,000 ppb to 3,310 ppb) while the concentration of VC increased (from below method reporting levels to 380 ppb). (Butterworth, Phase II, Phase III and Phase IV Report; and RAO Statement - Former Revere Aviation/ Beverly, MA, 2006)

 The concentrations of contaminants in groundwater from the additional monitoring well AEG-101 were all below appropriately low detection limits. These results indicate that contamination is not migrating onto the site from the west. Contaminant levels in groundwater from OW-1 were also below appropriately low detection limits. In groundwater from MW-102, sampled in June of 2006, the concentrations of VC and cis-1,2-DCE were above their respective

groundwater standards. Groundwater from the second newly constructed monitoring well AEG-104, from which groundwater samples were collected at three depths, was found to contain TCE, cis-1,2-DCE and VC at concentrations that exceed applicable groundwater standards. In the third deep-bedrock monitoring well, AEG-107, both applicable groundwater standards were exceeded for the same contaminants as those found in groundwater from monitoring well AEG-104. Analytical results are summarized in Table 3-7, herein.

Groundwater samples from the newly constructed off-site deep-bedrock monitoring wells AEG-102 and AEG-103, along with deep-bedrock monitoring well MW-305B constructed in 2001, were found to contain either non-detectable or trace amounts of TCE, cis-1,2-DCE and VC, with all other COCs present at levels below applicable groundwater standards. A summary of all groundwater analytical results for these off-site wells appears Table 3-7, herein.

Both of the following site maps were taken from (Butterworth, Phase II, Phase III and Phase IV Report; and RAO Statement - Former Revere Aviation/ Beverly, MA, 2006).

**General Aviation
Services Site**

N

OW-2
(NOT FOUND)

MW-307B

MW-208/
B-211

CONCRETE SEPTIC TANK

MW-207/
B-210

MW-205/
B-208

MW-101/
B-101

Pipe 1

MW-102/
B-102

AEG-107

Pipe 2

MW-206/
B-209

SS-1

General Aviation
Hangar

SS-3

AEG-101

MW-306

SS-3

SS-2

MW-306B

SS-220

AEG-104

SS-219

SS-222

SS-217

Commercial
Building

SS-2

OW-3
(DESTROYED)

SS-221

**Approximate
Extent of Marsh**

OW-1

Pipe 3

SOIL GAS SAMPLING LOCATION

INDOOR AIR SAMPLING LOCATION

APPROXIMATE SCALE:

75   0   75

SCALE IN FEET
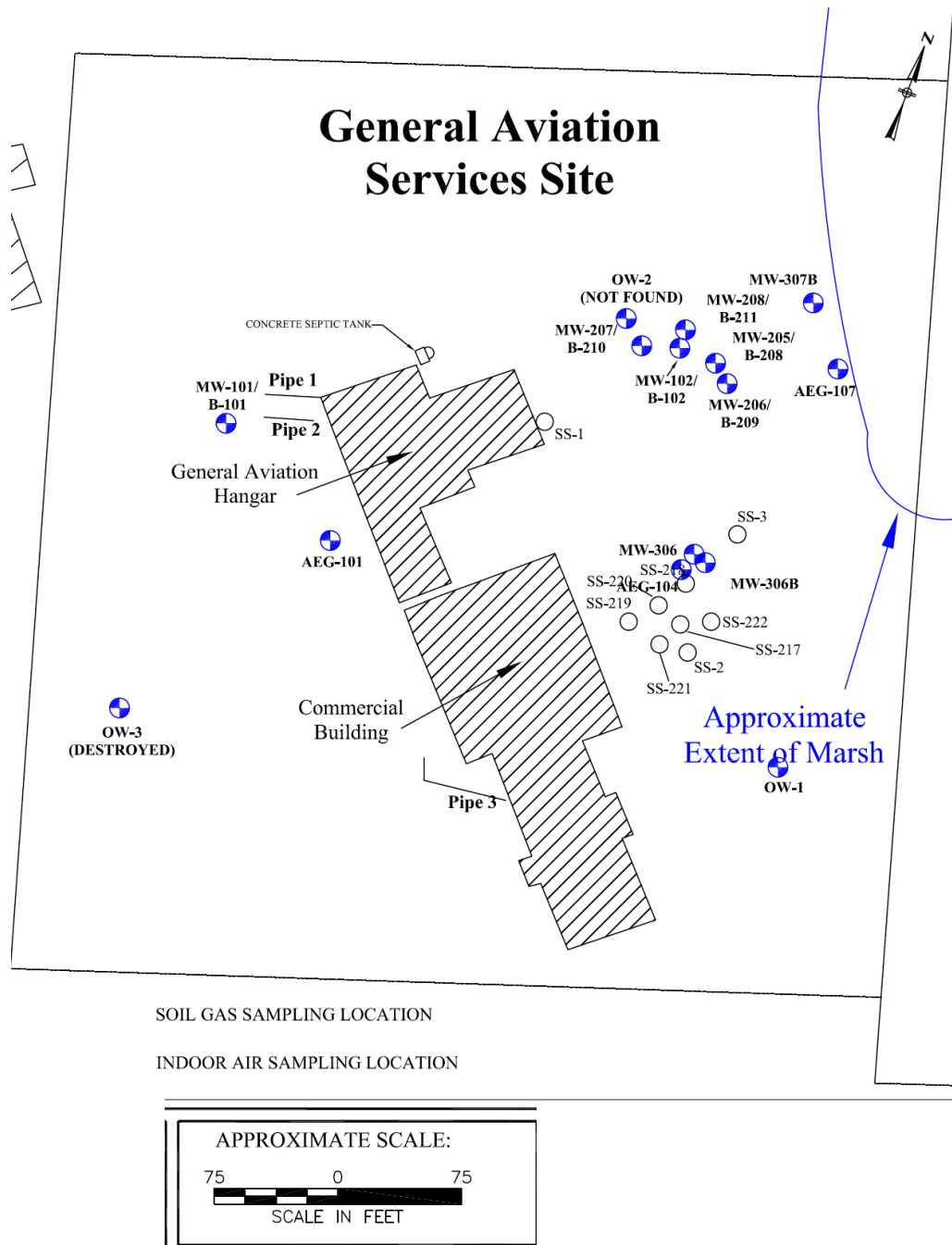
Figure 3-1 – Sample Locations
(Butterworth, Phase II, Phase III and Phase IV Report; and RAO Statement - Former Revere
Aviation/ Beverly, MA, 2006)

40
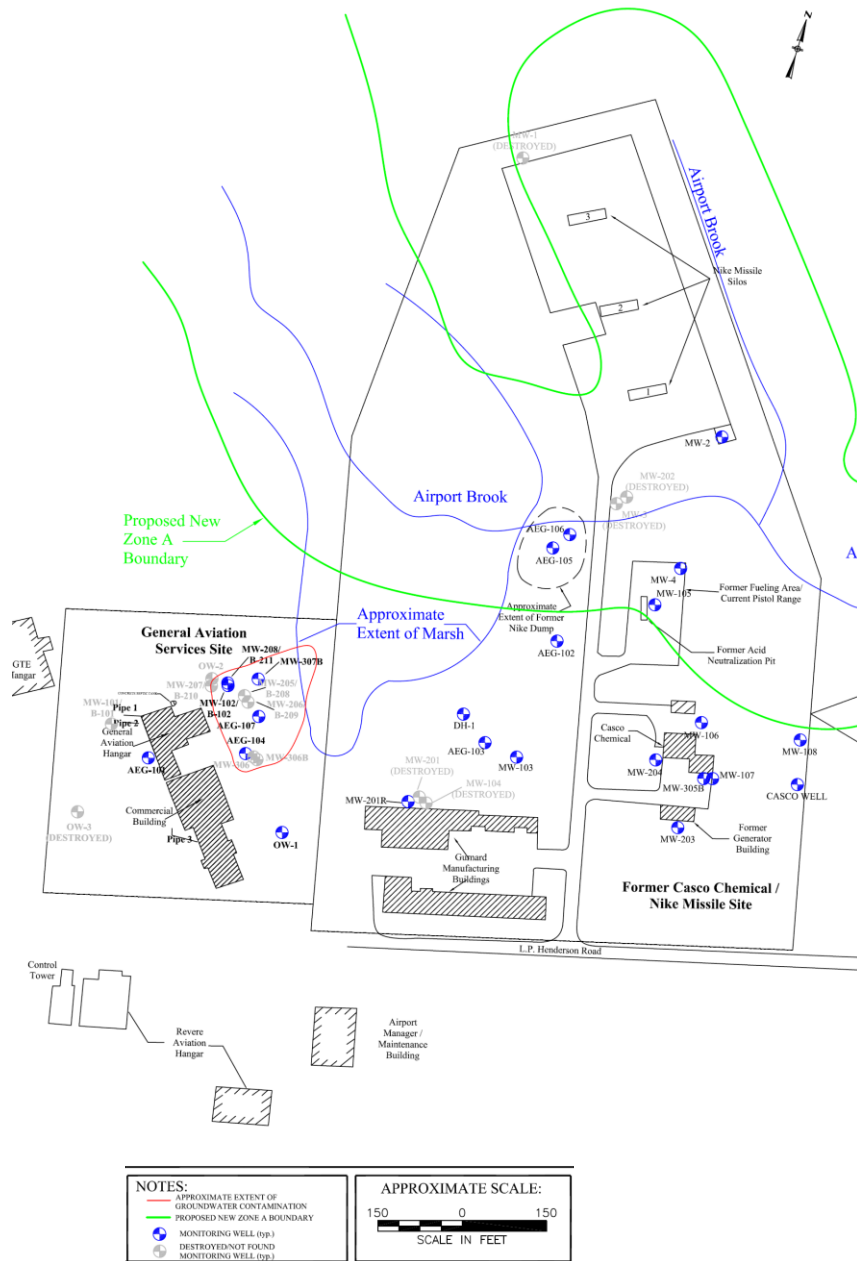
Figure 3-2 – Sample Locations Continued
(Butterworth, Phase II, Phase III and Phase IV Report; and RAO Statement -
Former Revere Aviation/ Beverly, MA, 2006)

In evaluating remedial alternatives, several were discussed. These included: bioremediation

strictly via monitored natural attenuation (MNA), chemical oxidation, and in-well air sparging.

Past remedial progress was attributed to MNA and based upon the unsuccessful nature and

migration of the plume, MNA was not selected.   Furthermore, due to the difficulties in applying

a bioremedial promoter into bedrock such as was completed in the Site 2 above, MNA was not

selected. Chemical oxidation was also not selected because due to a lack in confidence sufficient

oxidant could be delivered into bedrock. As a result, in-well air sparging was the selected

remedial alternative.

3.3   Theoretical Design Factors

The selected response action for the identified impact was the installation of a combined

groundwater air sparge system that will is designed to remove dissolved VOCs by injecting air,

causing the contaminants to volatilize out of the water table. In summary, the overall approach

of this technology s depicted in the diagram below and also spoke about in further detail below.

Figure 3-3: Summary of Air Sparge Procedure

| **A.** Well Under Normal Pressure | **B.**   Induction of air causes rise in groundwater and solvent off gassing | **C.**   Treated water falls through the saturated zone from the upper screen, causing a cyclic effect |

The injection of air draws groundwater into the lower screen of the sparge well. Due to the injection of air, the groundwater table rises. The rising water is allowed to discharge through a screened section of the treatment well located immediately above the static water table. The exit of the treated water enhances the flow of water into the bottom-screened depth.

When designing a system of this nature, three main parameters must be determined. First, the (1) hydraulic conductivity must be measured and evaluated; (2) second, the efficiency of the system to remove contaminants from groundwater must be determined; and the three (3) expected emissions generated from the full-scale system must be measured.

3.3.1 HYDRAULIC CONDUCTIVITY

Typically, remediation systems of this type are used to treat contamination located in overburden groundwater where circulation cells will develop. However, these types of systems are also effective in removing contaminants dissolved in groundwater occurring within bedrock. As part of the system design, an evaluation of the communication between the lower well screen interval with bedrock seams needs to be conducted. In this case, a rising head tests was performed to calculate hydraulic conductivities (*K*) at AEG-104B and AEG-107A.   These wells were selected since they are within or proximal to the area requiring treatment.

3.3.1.1 Rising Head Test

On June 29, 2006, a rising head test on monitoring wells AEG-104B and AEG-107A was conducted to calculate *K*. This test was done to gather information used to determine each well's hydraulic conductivity. Each test involved the evacuation of water from each well and measuring the groundwater recharge rate using an In-Situ MiniTroll™ pressure transducer. K

values were calculated using the Hvroslev Method (1951). The following is a summary of the

formula and variables:

Equation 3.1

$$K = \frac{r^2 \ln(L_e/R)}{2L_e T_0}$$

where: r = Well Casing Radius (0.5"/12) = **0.0416 feet or 1.267968 cm**
L_e = Length of Screen in Groundwater (feet or cm)
L_e (AEG-104B) = **20' or 609.6**
L_e (AEG-107A) = **10' or 304.8**
R = Radius of Boring Annulus (3"/12)' = **0.5 feet or 15.24**
T_0 = Time for Water Level to Rise 37 % of Initial Height
T_0 (AEG-104B)= **43.2 minutes or 2592 seconds**
T_0 (AEG-107A)= **20.15 minutes or 1209 seconds**

The resulting information results in a *K* value of **0.0064 ft/day or 0.00000226 cm/s** for

monitoring well AEG-104B and **0.023 ft/day** or **0.00000812 cm/s** for well AEG-107A. Both

values are consistent with those expected for fractured bedrock. Moreover, the conductivity in

well AEG-107A, and to a lesser degree in AEG-104B, suggests that there is good connectivity

with fractures in the bedrock under the Site. (Butterworth, Phase II, Phase III and Phase IV

Report; and RAO Statement - Former Revere Aviation/ Beverly, MA, 2006)

3.3.2 SYSTEM EFFICIENCY AND PILOT TESTING

In addition to collecting data used to calculate a *K* value for each well, pilot testing at AEG-107C

was also conducted to evaluate the potential removal efficiency of the system as well as the

potential emissions generated from the VOC volatilization from groundwater. The pilot test was

performed to model conditions under which the remediation system will operate. This test

consisted of sampling groundwater and air emissions at monitoring well AEG-107C during a 24-

hour air sparge period. Over this time period air was injected into the well using an air pump

located at surface grade. The pump supplied approximately 0.5 standard cubic feet per minute

(SCFM) of air through a diffusser located 47 feet below the static water surface. The subsequent

sections describe in detail tests that were used to determine the VOC removal efficiency from

groundwater, and the emissions generated. (Butterworth, Phase II, Phase III and Phase IV

Report; and RAO Statement - Former Revere Aviation/ Beverly, MA, 2006)

3.3.2.1 Pilot Test Groundwater Sampling

Prior to air injection, a groundwater sample was collected to represent initial groundwater quality

conditions. Next, air was injected into the well after which four groundwater samples were

collected, one after 10 minutes, 30 minutes, 2 hours and 24 hours.

The collected samples were then submitted to a Massachusetts certified laboratory for the

analysis of VOCs by USEPA Method 8260B. The table below summarizes the groundwater

analytical results. .

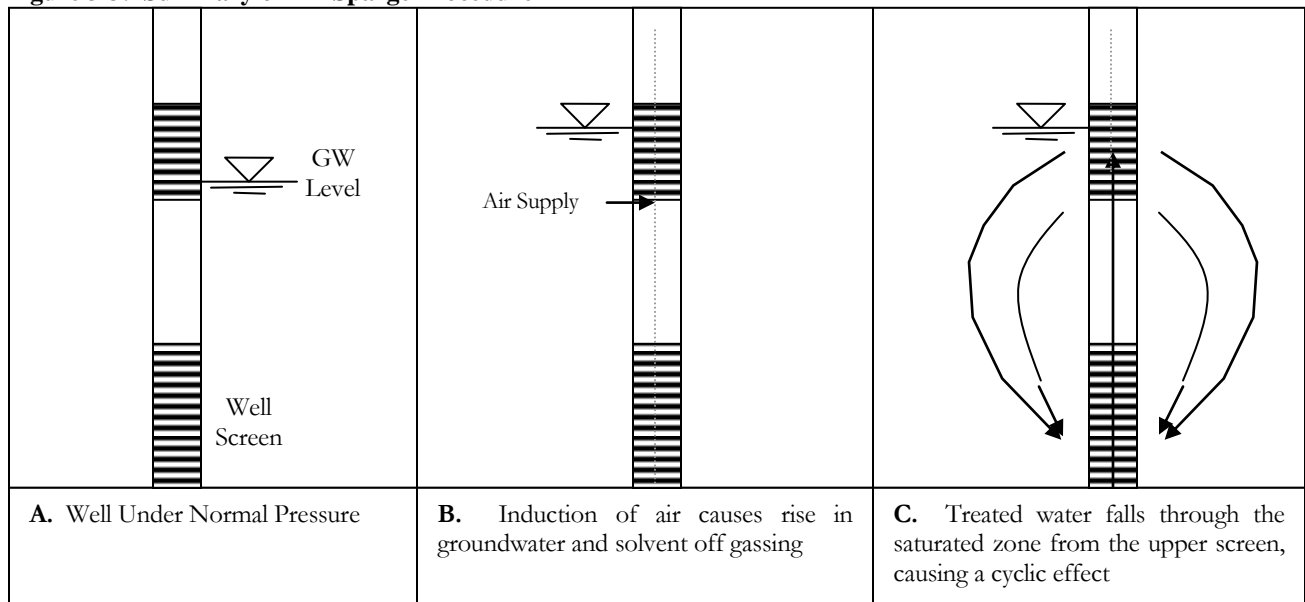| Table 3.1 Pilot Test Groundwater Analytical AEG-107C					
Target Analyte	Initial Conc.	@ 10 Minutes	@ 30 Minutes	@ 2 Hours	@ 24 Hours	MCP Method 1 GW-2/3 Groundwater Standards
1,1-Dichloroethane	5.2	3.7	1.2	ND	ND	**1,000/20,000**
1,1-Dichlorethene	30.9	12.9	2.5	ND	ND	**80/30,000**
2-Butanone	244	248	331	5,530	581	**NS**
Chlorobenzene	4.6	1.4	2.8	ND	ND	**200/1,000**
cis-1,2-Dichloroethene	**672**	**713**	**384**	ND	6.3	**100/50,000**
Methyl tert-Butyl Ether	2.7	3.7	8.9	ND	ND	**50,000/50,000**
Tetrahydrofuran	837	386	614	9,910	1,210	**NS**
Toluene	20.9	7.1	9.7	ND	ND	**8,000/4,000**
Trans-1,2-Dichloroethene	20.3	10.0	4.2	ND	ND	**NS**
Trichloroethylene	**1,010**	**669**	**615**	ND	14.8	**30/5,000**
Vinyl Chloride	**55.4**	**26.1**	**2.2**	ND	ND	**2/50,000**

Notes:
1. Units in μg/L
2. ND: Analyte not detected above laboratory method reporting limit
3. MCP Method 1 GW-2/3 Groundwater Standards as defined in 310 CMR 40.0974(2), Table 1
4. NS: No standard defined in Method 1 GW-2/3 Groundwater Standards
5. **Bold**: Concentration above MCP Method 1 GW-2 Groundwater Standard

In summary, target analytes, including cis-1.2-DCE, TCE, and VC, were initially observed to be at concentrations exceeding applicable standards. However, these concentrations were lowered to non-detectable levels after 2 hours of air sparging (note: the minimum detection limits for the 2 hour sample were higher than for the other samples). Detections observed in the sample collected after 24 hours are likely due to infiltration of additional contaminated water.

<u>3.3.2.2 System Removal Efficiency Estimations</u>

The removal efficiency (RE), (fraction of contaminant removed through the air sparge process), was calculated to illustrate the effectiveness of the sparging technique. RE is expressed by the following equation:

<u>Equation 3.2</u>

$$RE = \frac{\text{Contaminant Concentration }_{initial} - \text{Contaminant Concentration }_{time (n)}}{\text{Contaminant Concentration }_{initial}}$$

Based upon the initial measured concentrations of cis-,1,2-DCE, TCE, and VC, REs for each compound was calculated using the above equation and are summarized in the Table 3.2 below.

Table 3-2 Pilot Test Removal Efficiencies (REs) AEG-107C				
Target Analyte	@ 10 Minute	@ 30 Minutes	@ 2 Hours	@ 24 Hours
cis-1,2-Dichloroethene	*	0.43	0.92	0.99
Trichloroethylene	0.34	0.39	0.95	0.98
Vinyl Chloride	0.53	0.96	*1.00*	0.99
Notes: 1. *Italics*: RE estimated using half detection limit. 2. *: RE not observed, concentration increased slightly				

In summary, the pilot test shows that over a 24-hour period of air sparging, nearly 100 percent of the contaminants were removed from groundwater. (Butterworth, Phase II, Phase III and Phase IV Report; and RAO Statement - Former Revere Aviation/ Beverly, MA, 2006)

3.3.2.3 Pilot Test Air Sampling

Air emissions were sampled during the air sparging period in order to estimate the quantity of air

contamination that would potentially be generated during the operation of the full-scale system.

In addition, air emission results could also be used to calculate the flow of groundwater captured

during the pilot test.

During the pilot test, an air sample over a 30-minute period was collected after 60 minutes of air

sparging. The sample was collected via a Summa® Canister fitted with an airtight polyethylene

tube which was inserted slightly below the top of the well. The collected sample was then

submitted to a Massachusetts certified laboratory for the analysis of VOCs by Method TO-14A.

A summary of the laboratory results has been provided in table below.

Table 3-3 Pilot Test Air Emission Analytical AEG-107C	
Target Analyte	Pounds/M^3 @ 60 Minutes
1,1-Dichloroethene	2.3×10^{-7}
Trans-1,2-Dichloroethene	1.4×10^{-7}
cis-1,2-Dichloroethene	3.5×10^{-6}
Methylene Chloride	1.5×10^{-6}
Trichloroethylene	2.8×10^{-6}
Vinyl Chloride	3.5×10^{-7}

3.3.2.3 Rate of Contaminant Removal

To determine the potential air emissions over a given time period, a rate of contaminant removal

must be calculated. In order to calculate the rate of contaminant removal, the flow of air exiting

the well is needed using the Ideal Gas Law (IGL).

Equation 3.3

$$PV = nRT$$

Normally, the IGL incorporates temperature (T), gas constant (R) and number of moles (n).

However, due to these parameters remaining constant during the test, the IGL can be modified

to:

Equation 3.4

$$\textbf{(PV)}_{\textbf{in-well}} = \textbf{(PV)}_{\textbf{exiting-well}}$$

The in-well pressure was calculated using the sum of hydrostatic pressure exerted at the diffuser

located 47' below the surface of water, atmospheric pressure, and pressure losses in the tubing

and air diffuser. The pressure losses in the tubing and air diffuser were measured and found to be

negligible (less than 0.1 atm).

$$\textbf{P}_{\textbf{in-well}} = [1{,}433 \text{ cm (height of water column)} * 1 \text{ g/cm}^3 \text{ (density of water)}] + 1 \text{ atm (atmospheric pressure)}$$

$$\textbf{P}_{\textbf{in-well}} = 2.38 \text{ atm}$$

The in-well volume flow rate was measured as the flow indicated on the rotometer during the
test.

$$\textbf{V}_{\textbf{in-well}} = 0.93 \text{ standard cubic meter/hour (SCMH)}$$

The exiting-well pressure was determined to be the pressure of air leaving the well. This

pressure was defined as atmospheric pressure.

$$\textbf{P}_{\textbf{exiting-well}} = 1 \text{ atm}$$

With the above values in place, the volumetric rate of air leaving the well was determined via the

calculation below:

$$\textbf{V}_{\textbf{exiting-well}} = \textbf{(PV)}_{\textbf{in-well}} / \textbf{P}_{\textbf{exiting well}}$$

$$\textbf{V}_{\textbf{exiting-well}} = 2.21 \text{ m}^3/\text{hour}$$

Air concentrations reported in the previous table were multiplied by this rate to determine the

rate of contaminant removal. The calculated rates are displayed in Table 8.2.2.4, below.

Table 3-4 Estimated Rate of Contaminant Removal AEG-107C @ 60 Minutes		
Target Analyte	Pounds / hr	mg/hour
1,1-Dichloroethene	5.1×10^{-7}	0.23
Trans-1,2-Dichloroethene	3.1×10^{-7}	0.14
cis-1,2-Dichloroethene	7.7×10^{-6}	3.49
Methylene Chloride	3.3×10^{-6}	1.50
Trichloroethylene	6.2×10^{-6}	2.81
Vinyl Chloride	7.7×10^{-7}	0.35

3.3.2.4 Estimated Groundwater Flow (Q) Through Air Sparge Well

To calculate Q, the flow of contaminated groundwater into the bottom screen, a mass balance of

contaminant removal was performed. This calculation is based upon the mass of contaminant

volatilized into the air being equal to the mass of contaminant entering the well multiplied by the

removal efficiency. Since the initial concentration in the well is the mass of contaminant per

volume of water in the bedrock fractures, the following equation expresses Q:

Equation 3.5

$$Q = \frac{Mass_{air}}{C_i \, (RE)}$$

$Mass_{air}$ = Mass of Contaminant in Air per time (mg/min) from Table 3.4
C_i = Initial Contaminant Groundwater concentration (mg/L) from Table 3.1
RE = Removal Efficiency of System from Table 3.2

Again using the contaminants detected above MCP Method 1 GW-2 Groundwater Standards, Q

values were estimated and summarized in Table 3.5, below. Note that because a mass-balance

approach is being used to estimate Q, each contaminant can be used to estimate Q. By averaging

the three determinations, we improve the reliability of the estimated value of Q. (Butterworth,

Phase II, Phase III and Phase IV Report; and RAO Statement - Former Revere Aviation/ Beverly,

MA, 2006)

Table 3-5 Estimated Groundwater Flow During Pilot Test	
Contaminant	**Q** **L/hour**
cis-1,2-DCE	0.08
TCE	0.05
VC	0.11
Average=	**0.08**

3.3.2.5 Full Scale Air Emissions Determination

To estimate the potential emission from the full-scale implementation of the system, AEG

utilized the maximum Q value reported in Table 3.5 and the highest groundwater concentrations

detected over previous AEG sampling rounds.

In Table 3.5, it is estimated that the maximum volume of water traveling through AEG-107C is

0.11 liters per hour based upon conditions calculated for VC. Although individual Q values were

not calculated for each of the proposed sparging wells, it is expected conditions observed at

AEG-107C to be representative of other treatment wells and, therefore, this is a reasonable

approach to calculating full-scale air emissions. This conclusion is considered conservative,

since removal efficiencies are close to 100 %. (Butterworth, Phase II, Phase III and Phase IV

Report; and RAO Statement - Former Revere Aviation/ Beverly, MA, 2006)

Consequently, by multiplying groundwater concentration by a Q value of 0.11 L/hour, an

estimation of contaminant emissions can be made. This calculation also assumes 100 % removal

efficiency. Groundwater concentrations should fall over time and therefore produce lower

emissions. Air emissions were calculated for those compounds detected in excess of applicable

standards during the pilot test. The highest groundwater concentrations observed over past

sampling rounds were used in the calculations, which have been summarized in Table 3.6,

below.

Table 3-6 Ambient Air Emission Calculations			
Location	**cis-1,2-DCE**	**TCE**	**VC**
AEG-104C (3/22/2006)	35.2	198.0	1.4
AEG-107B (6/15/2006)	153.0	751.3	8.9
AEG-107C (6/15/2006)	154.0	716.1	8.0
MW-307B (11/22/2005)	364.1	332.2	42.0
Total (µg/hour)	706.3	1,997.6	60.3
Total (µg/second)	0.20	0.55	0.02
Acceptable Rate (µg/second)*	10,000	1,000	100

* Acceptable rate without air treatment; taken from MADEP Policy #WSC-94-150 as
the lowest from graphs in the policy based on distance of each well from the appropriate
site structure as described below.

3.4   Performance Evaluation & Compliance Monitoring

On July 28, 2006, following the pilot testing and system design, the full-scale system was

initiated and operated at AEG-104C, AEG-107B, AEG-107C, and MW-307B. Over the

subsequent months, compliance groundwater sampling was constructed at several locations and a

summary of pre-remedial and post-remedial levels compared to applicable standards has been

summarized in the table below.

Table 3-7
Site-Wide Analytical Summary

Well ID	MW102										MW208								AEG-104B						AEG-104C			AEG-107B			AEG-107C			MW307B				MCP Method 1 Risk Based Standards
Total Depth /Depth to Water (feet)	21/8										41/6								82/37						82/77			119/57			119/80			71/8				
Location	NE of Hangar										NE of Hangar																							NE of Hangar				
VOCs (ppb)	1/14/98	5/12/98	8/19/99	1/12/01	6/15/06	11/2/06	2/21/07	5/4/07	8/28/07	1/17/08	8/19/99	1/15/01	11/22/05	11/2/06	2/21/07	5/4/07	8/28/07	1/17/08	3/22/06	11/2/06	2/21/07	5/4/07	8/28/07	1/17/08	3/22/06	8/28/07	1/17/08	6/15/06	8/28/07	1/17/08	6/15/06	8/28/07	1/17/08	MW307B	11/22/05	8/28/07	1/17/08	GW-3 (ppb)
Vinyl Chloride	58	98	46	brl(1)	60.6	62.8	65.9	36.5	176	16.0	55	brl(1)	200	88.4	86.4	180	172	84	brl(25)*1	2.1	1.8	2.7	2.4	brl(10)	brl(25)*1	45.2	brl(1.0)	80.7	26.8	53.0	72.4	61.4	56.0	brl(1)	380	347	35	50,000
t-1,2-Dichloroethene	2	6	2	10	2	1.6	3.0	1.9	2.1	0.75	5	26	8.2	6.0	7.3	18.6	3.6	brl(7.5)	brl(25)	brl(1)	brl(1)	brl(1)	brl(1)	brl(7.5)	brl(25)	37.5	1.1	47.9	2.2	4.0	39.8	7.4	brl(15)	170	51.7	28.4	3.8	50,000
cis-1,2-Dichloroethene	190	500	240	970	296	183	419	331	155	100	750	5,500	1,340	741	1,120	1,890	503	530	40	21.8	25.4	29.8	22.9	16.0	320	1740	38.0	1,390	94.0	120.0	1,400	95.4	42.0	11,000	3,310	3,750	320	50,000
Chloroform	brl(1)	brl	5	brl(1)	brl(1)	brl(1)	brl(1)	brl(1)	brl(1)	brl(0.75)	4		bdl(1)	bdl(1)	bdl(1)	bdl(1)	bdl(1)	brl(7.5)	brl(25)	brl(1)	brl(1)	brl(1)	1.4	brl(0.75)	brl(25)	brl(1)	brl(0.75)	brl(1)	2.1	brl(1)	brl(1)		brl(15)	brl(1)	bdl(1)		brl(0.75)	10,000
Trichloroethylene	49	110	250	78	24.9	15.4	46.9	43.4	6.0	6.2	19,000	4,700	455	9670	1250	776	332	290	1,100	986	904	1,080	1,160	580	1,800	4,470	74	6,830	2.1	1.4	6,510	1.0	brl(10)	11,000	3,020	46.2	11.0	5,000
Chlorobenzene	2	6	3	brl(1)	brl(1)	2.4	2.8	1.8	3.7	0.68	64	26	9.4	16.9	9.6	14.4	5.8	brl(5.0)	brl(25)	2.8	1.9	2.0	2.6	brl(0.5)	brl(25)	20.4	brl(0.5)	25.3	brl(1.0)	brl(1.0)	20.6	1.4	brl(10)	brl(1)	37.3	23.8	4.2	1,000
Tetrachloroethylene	brl(1)	brl(1)	brl(1)	brl(1)	brl(1)	brl(1)	brl(1)	brl(1)	brl(1)	brl(0.5)	120	13	1.2	10.6	3.6	1.3	1.2	brl(5.0)	brl(25)	16.8	12.2	14.2	14.8	10.0	brl(25)	brl(1)	brl(0.5)	1.9	brl(1.0)	brl(1.0)	1.7	brl(1)	brl(10)	1	bdl(1)		brl(0.5)	30,000
1,1-Dichloroethene	brl(1)	3	brl(1)	2	brl(1)		1.1	1.0	brl(1)	brl(0.5)	1	7	5.4	2.7	3.1	15.6	1.4	brl(5.0)	brl(25)	1.0	brl(1)	1.2	brl(1)	brl(5.0)	brl(25)	40.5	0.58	71.2	brl(1.0)	brl(1.0)	63.6	brl(1)	brl(10)	150	84.2	19.2	3.2	30,000
Methyl t-Butyl Ether (MTBE)	brl(1)	brl(1)	NA	2	4.2	2.0	2.8	2.4	4.9	brl(1)	NA	6	5.4	2.9	4.1	6.9	brl(10)	brl(10)	11.3	9.6	brl(1)	11.3	8.3	brl(7.5)	1.3	3.5	brl(1.0)	2.4	1.6	brl(2.0)	brl(1)	brl(1)	brl(20)	1.4	6.4	brl(1)	brl(1)	50,000
4-Methyl-2-Pentanone (MIBK)	brl(10)	brl(10)	NA	brl(10)	brl(1)	brl(1)	brl(1)	brl(25)	brl(25)	brl(5.0)	NA	brl(25)	brl(25)	brl(1)	brl(25)	brl(25)	brl(50)	brl(50)	brl(250)	brl(25)	brl(25)	brl(25)	brl(25)	brl(50)	brl(250)	brl(25)	brl(5.0)	brl(25)	brl(25)	brl(10)	brl(25)	brl(25)	brl(100)	brl(25)	brl(25)	brl(25)	brl(5.0)	50,000
Benzene	brl(1)	1	NA	brl(1)	brl(1)	brl(1)	brl(1)	brl(1)	brl(1)	brl(0.5)	NA	2	bdl(1)	brl(1)	brl(1)	1.2	brl(5)	brl(5.0)	brl(25)	brl(1)	brl(1)	brl(1)	brl(1)	brl(5.0)	brl(25)	1.3	brl(0.5)	brl(1)	brl(1)	brl(1.0)	brl(1)	brl(1)	brl(10)	brl(1)	bdl(1)	bdl(1)	brl(0.5)	10,000
Ethylbenzene	brl(1)	brl(1)	NA	brl(1)	brl(1)	brl(1)	brl(1)	brl(1)	brl(1)	brl(0.5)	NA	3	bdl(1)	1.8	brl(1)	1.3	brl(5)	brl(5.0)	brl(25)	brl(1)	brl(1)	brl(1)	brl(1)	brl(5.0)	brl(25)	1.0	brl(0.5)	6.9	brl(1)	brl(1.0)	5.9	6.1	brl(10)	18	9.5	1.0	brl(0.5)	4,000
Toluene	brl(1)	brl(1)	NA	brl(1)	brl(1)	brl(1)	brl(1)	brl(1)	brl(1)	brl(0.75)	NA	290	20.4	1080	122	74.3	11.7	brl(7.5)	brl(25)	brl(1)	brl(1)	brl(1)	brl(1)	brl(7.5)	brl(25)	1.4	brl(0.75)	97.9	9.8	13.0	82.3	1480	760	62	17.4	11.7	brl(0.75)	4,000
1,1,1-Trichloroethane	brl(1)	brl(1)	brl(1)	brl(1)	brl(1)	brl(1)	brl(1)	brl(1)	brl(1)	brl(0.5)	brl(1)	brl(1)	bdl(1)	2.2	bdl(1)	bdl(1)	bdl(1)	brl(5.0)	brl(25)	5.4	5.4	5.8	5.5	brl(5.0)	brl(25)	brl(1.0)	brl(0.5)	brl(1)	brl(1)	brl(1.0)	brl(1)	brl(1)	brl(10)	brl(1)	bdl(1)	bdl(1)	brl(0.5)	20,000
Xylenes	brl(1)	brl(1)	NA	brl(1)	brl(3)	brl(3)	brl(3)	brl(3)	brl(3)	brl(1)	NA	7	bdl(1)	5.6	brl(3)	2.2	brl(3)	brl(10)	brl(25)	brl(3)	brl(3)	brl(3)	brl(3)	brl(5.0)	brl(25)	brl(3)	brl(1.0)	11.0	1.0	brl(2.0)	12.4	33.8	brl(20)	12	4.7	1.3	brl(1)	500
Naphthalene	brl(1)	brl(1)	NA	brl(1)	brl(1)	brl(1)	brl(1)	brl(1)	brl(1)	brl(2.5)	NA		brl(1)	bdl(1)	bdl(1)	brl(1)	brl(1)	brl(25)	brl(25)	brl(1)	brl(1)	brl(1)	brl(1)	brl(25)	brl(25)	brl(1)	brl(2.5)	brl(1)	1.2	brl(5.0)	brl(1)	brl(1)	brl(50)	brl(1)	bdl(1)	bdl(1)	brl(2.5)	20,000
1,1 dichloroethane	brl(1)	brl(1)	brl(1)	brl(1)	brl(1)	brl(1)	1.9	brl(1)	brl(1)	brl(0.75)	brl(1)	brl(1)	bdl(1)	bdl(1)	bdl(1)	bdl(1)	bdl(1)	brl(7.5)	brl(25)	2.0	1.9	2.1	1.9	brl(5.0)	brl(25)	5.5	brl(0.75)	7.0	brl(1)	brl(1.5)	6.9	brl(1)	brl(15)	brl(1)	6.2	1.2	brl(0.75)	20,000
Isopropylbenzene	brl(1)	brl(1)	NA	brl(1)	brl(1)	brl(1)	brl(1)	brl(1)	brl(1)	brl(0.5)	NA	brl(1)	bdl(1)	bdl(1)	brl(1)	brl(1)	brl(1)	brl(5.0)	brl(25)	brl(1)	brl(1)	brl(1)	brl(1)	brl(5.0)	brl(25)	brl(1)	brl(0.5)	brl(1)	brl(1)	brl(0.5)	brl(1)	brl(1)	brl(10)	brl(1)	brl(1)	brl(1)	brl(0.5)	NS
sec-Butylbenzene	brl(1)	brl(1)	NA	brl(1)	brl(1)	brl(1)	brl(1)	brl(1)	brl(1)	brl(0.5)	NA	1	bdl(1)	bdl(1)	brl(1)	brl(1)	brl(1)	brl(5.0)	brl(25)	brl(1)	brl(1)	brl(1)	brl(1)	brl(5.0)	brl(25)	brl(1)	brl(0.5)	brl(1)	brl(1)	brl(0.5)	brl(1)	brl(1)	brl(10)	brl(1)	brl(1)	brl(1)	brl(0.5)	NS
1,2,4-Trimethylbenzene	brl(1)	brl(1)	NA	brl(1)	brl(1)	brl(1)	brl(1)	brl(1)	brl(1)	brl(2.5)	NA	brl(1)	bdl(1)	bdl(1)	brl(1)	brl(1)	brl(1)	brl(25)	brl(25)	brl(1)	brl(1)	brl(1)	brl(1)	brl(25)	brl(25)	brl(1)	brl(2.5)	brl(1)	brl(1)	brl(2.5)	brl(1)	brl(1)	brl(50)	brl(1)	brl(1)	brl(1)	brl(2.5)	NS
1,3,5-Trimethylbenzene	brl(1)	brl(1)	NA	brl(1)	brl(1)	brl(1)	brl(1)	brl(1)	brl(1)	brl(2.5)	NA	brl(1)	bdl(1)	bdl(1)	brl(1)	brl(1)	brl(1)	brl(25)	brl(25)	brl(1)	brl(1)	brl(1)	brl(1)	brl(25)	brl(25)	brl(1)	brl(2.5)	brl(1)	brl(1)	brl(2.5)	brl(1)	brl(1)	brl(50)	brl(1)	brl(1)	brl(1)	brl(2.5)	NS
Tetrahydrofuran				brl(5)	brl(5)	brl(5)	brl(5)	brl(5)	brl(10)						brl(5)	brl(5)	brl(5)	brl(100)	brl(250)	5.2	brl(5)	brl(5)	brl(5)	brl(100)	brl(250)	brl(5)	brl(10)	brl(5)	36.0	52.0	brl(5)	94.9	brl(200)			brl(5)	brl(10)	NS

1. brl (xxx) = below reporting limit (reporting limit value)
2. NA = not analyzed for
3. NS = no standard
4. *1 = detection limit too high to compare to GW-2 standard
5. *2 = Sample collected during investigation of anomolies. This is not a well. Sample collected at 4'
6.
7. xxx = concentration xxx meets or exceeds GW-3 std
8. = Monitoring Well
9. = Treatment Well

*3 = Results not noteworthy in past reports; AEG assumes all levels are below GW-2 stds.

As can be seen above, levels of VOCs were reduced at all locations to levels well below

applicable regulatory limits. This design and approach proved to be very successful in this

case. The in-well circulation cells created by the system resulted in a flushing of

contaminated bedrock fractions. In addition based upon the theoretical RE, it was shown that

further operation of the system could have abated the groundwater quality further.

Conclusion

In conclusion, three different contamination situations requiring remediation were discussed and results evaluated. All showed some level of success, although in the case of the air sparge approach for groundwater within bedrock, groundwater quality was restored to applicable standards. The remaining two sites also showed some level of success, however, modifications to the existing approaches is likely required to progress remediation.

In the case of the gasoline impacted groundwater, the contamination is being recovered by the system, but some areas near the original plume source area have shown little to know effect. This can be the result of many factors including soil moisture and soil porosity variability which can limit the vapor recovery. Consequently, a modification to the existing system could like aide in avoiding the current difficulties. This approach would include the injection of atmospheric air into the contaminated groundwater plume via a process called air sparging. This approach can lower the vapor pressure of dissolved contaminants thus increasing their tendency to volatilize and it can also increase locally dissolved oxygen concentrations which can promote biodegradation.

The final site involved the biostimulation of indigenous bacteria using an emulsified vegetable oil as an electron donor. These injections create an anaerobic environment where certain bacteria can thrive and bioremediate chlorinated compounds by the process of reductive dechlorination. In this process bacteria use the chlorinated compound as an electron acceptor in their metabolic pathway. Although results have been favorable, the reduction of

the parent compound, tetrachloroethene into daughter compounds has manifested in a buildup

of cis-1,2-dichloroethene. It appears further degradation has stalled and this could be the

result of a lack in a specific bacterial gene needed to metabolize further. As a result, testing

should be conducted to assess for the need to add or promote a change in the bacterial

community prior to adding additional electron donor. This addition is referred to as

bioaugmentation.

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