Cost and Performance Summary Report

In Situ Thermal Treatment at the Groveland Wells Superfund Site, Groveland, Massachusetts

EXECUTIVE SUMMARY

Groveland Wells Nos. 1 & 2 Superfund Site (Site) is located in Groveland, Massachusetts. There have been historical releases of trichloroethene (TCE), a volatile organic compound (VOC), which have impacted the Valley Manufacturing Products Company (VMPC) property. Cis-1,2-dichloroethene (cis-1,2-DCE), a breakdown product of TCE, is also present in groundwater at the site. The VMPC manufactured metal and plastic parts from 1963 through 2001. Cutting oil, lubricants, and degreasers were used in the manufacturing process. A variety of solvents including TCE and methylene chloride were used as part of degreasing activities. Underground storage tanks (USTs) containing cutting oil, solvents, and mineral spirits were located and removed from the southern portion of the Site. When the facility was in operation, an estimated 3,000 gallons of contaminants were reportedly discharged to the environment from accidental releases and via underground injection systems. Site contamination has migrated from the vadose zone to groundwater. In 1979, two of the Town of Groveland's drinking water supply wells were determined to be impacted by TCE. These wells were taken off-line and a new municipal drinking water well was installed in a different aquifer. In 1982, the Site was placed on the National Priorities List.

In September 2007, an Explanation of Significant Differences (ESD) was issued to the Record of Decision for Operable Unit 02 (OU2). OU2 refers to the source area media at the VMPC. This ESD modified the selected remedy to include In Situ Thermal Treatment (ISTT) or enhanced soil vapor extraction (SVE) for subsurface soil and overburden groundwater within the source area. This enhanced remedy was expected to increase the effectiveness of the source control remedy and decrease the amount of time the groundwater pump and treatment system would have to operate in order to accelerate site closure. Also as part of the 2007 ESD, the soil cleanup goals were revised based on updated TCE toxicity values.

Based on environmental investigations conducted in 2006 and 2009 at the Site, the total area of the treatment zone was calculated to be approximately 14,830 square feet with a total volume of 17,450 cubic yards. Four treatment zones were delineated, each with a different treatment depth ranging from zero to 45 feet below ground surface (bgs). Several chemical oxidation pilot studies were also conducted, however the results showed that this technology did not work well at the site.

The ISTT and SVE system was designed, constructed and began operation in August 2010. The ISTT system applied the use of electrical resistance heating Electro-Thermal Dynamic Stripping Process (ET-DSP™) in the vadose and saturated zones. The treatment system included ET-DSP™ electrodes installed in the subsurface, vapor extraction systems, liquid extraction systems, and a vapor cover that prevented surface water infiltration and provided vapor containment. As

part of the ISTT activities, several groundwater extraction wells were located and operated in the source area. Contaminated groundwater was treated at the existing groundwater pump and treatment system. Ancillary equipment necessary for the ET-DSP™ implementation included a transformer to deliver power to the system, power distribution systems, water circulation units to supply water to the ET-DSP™ electrodes, water injection and cable lines for the ET-DSP™ system, and an emergency power source for the vapor extraction system in the event of a power outage.

The ISTT system operated from August 2010 to February 2011 with one 9-day system shut-down of the liquid extraction and ET-DSP™ components in October 2010 due to a non-aqueous phase liquid (NAPL) breakthrough. Testing of the NAPL indicated that it was a weathered hydrocarbon, most likely a mineral spirit. Upgrades were made to the ISTT liquid extraction system and the system was restarted. A steam enhanced heating system was incorporated in December 2010 to supplement the ISTT's heating capability to account for heating difficulties attributed to highly permeable geology and high resistivity areas.

During the course of treatment, subsurface temperature was monitored using subsurface-thermocouples installed at 3-foot intervals (from ground surface to a maximum depth of 45 feet bgs, depending on the treatment depth of the ISTT area). During operation, 85 percent of the thermocouples reached the target temperature performance goal of 90 degrees Celsius within the vadose zone in the ISTT areas, demonstrating sufficient heating throughout the vadose zone.

Soil and groundwater confirmatory sampling results indicated a 97% reduction of TCE in groundwater at the Site. Despite these significant reductions, concentrations of TCE and cis-1,2-DCE remained elevated above cleanup goals in two small areas below a paved portion of the Site. The decision to shut down the ISTT system in February 2011 was made based on an evaluation of diminishing returns for contaminant removal compared to cost of operating the ISTT system. Confirmation soil and groundwater sampling results indicated that the TCE remaining in the vadose zone above cleanup levels was not significantly affecting groundwater. Confirmation sampling results also indicated that no rebound of TCE and cis-1,2-DCE was occurring.

The estimated overall cost of the ISTT Remedial Action was $6,264,000. This cost includes system design, construction, operations and maintenance, demobilization, electricity costs, and subcontractor costs. The unit treatment cost for the ISTT system is $207 per cubic yard taking into account ISTT subcontractor costs for the system design, construction, operations and maintenance, demobilization, and reporting. The unit costs increases to $242 per cubic yard if electricity costs are included. When other subcontractor costs are considered including site preparation activities, waste disposal, soil borings, laboratory analysis, and electrical/automated controls services, the unit treatment cost is approximately $359 per cubic yard.

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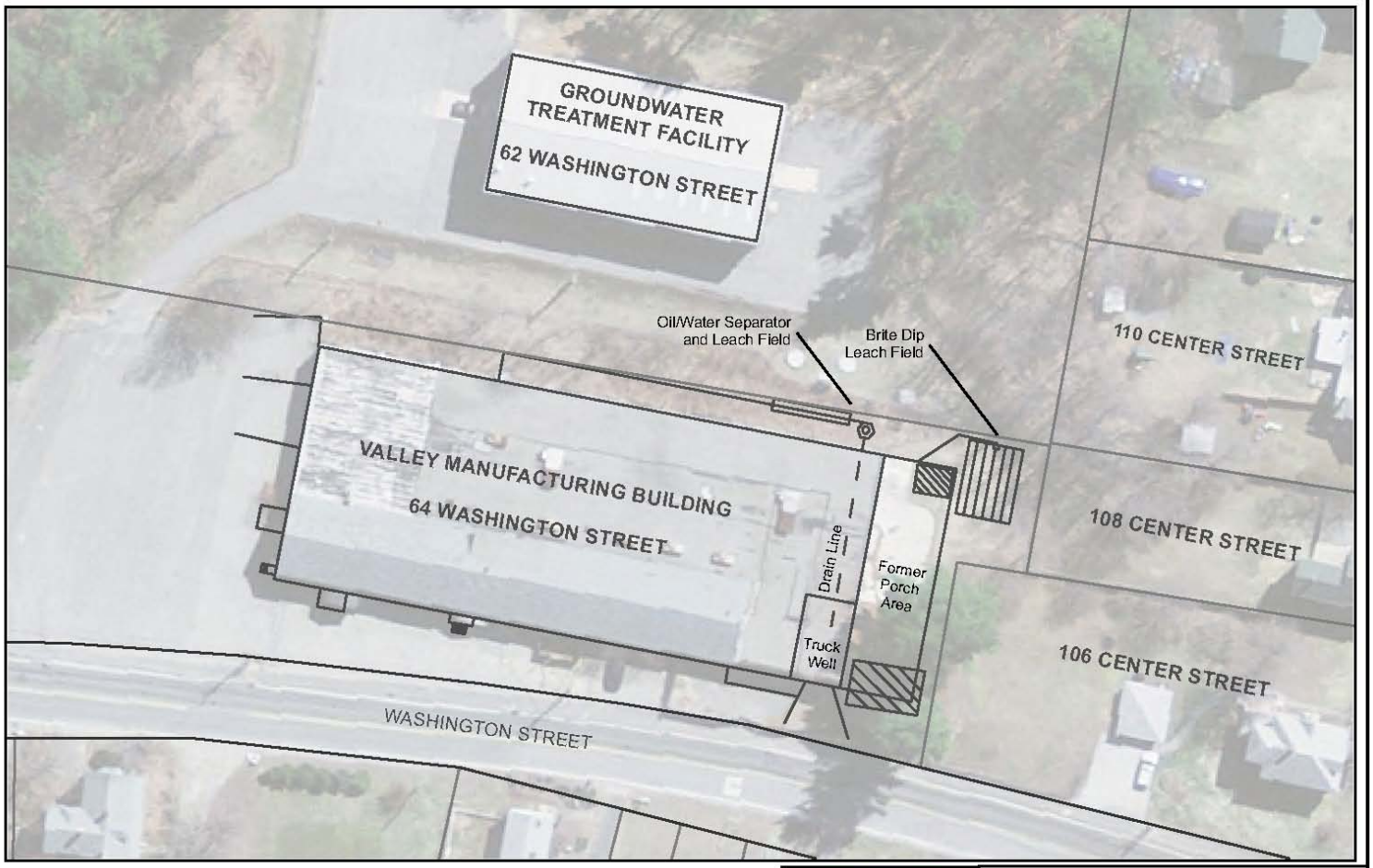
1.0 Background Information [1, 2, 3]

The Groveland Wells Nos. 1 & 2 Superfund Site (Site) is located in Groveland, Massachusetts. The soil and groundwater are contaminated with volatile organic compounds (VOCs), primarily trichloroethene (TCE) and cis-1,2-dichloroethene (cis-1,2-DCE). The Site consists of two Operable Units (OUs), Management of Migration OU1 and Source Control OU2. OU2 is located at the former Valley Manufacturing Products Company/Groveland Resources Corporation property (VMPC) and is the subject of this cost and performance report. The VMPC property was used to manufacture metal and plastic parts from 1963 through 2001. A Site Map is provided as Figure 1.

The manufacturing processes used cutting oils, lubricants, and degreasers. TCE was used in degreasing operations from 1963 to 1979. Methylene chloride was used from 1979 to 1983. After 1984, aqueous detergent degreasers were used. Based on historical records, subsurface disposal systems, including an oil/water separator and a leach field were used for the disposal of wastes associated with the manufacturing processes. Several underground storage tanks (USTs) containing cutting oil, solvents, and mineral spirits were located on the southern portion of the Site. When the facility was in operation, an estimated 3,000 gallons of contaminants were discharged to the environment from several surface and subsurface sources and from routine manufacturing processes. In 1973, 500 gallons of TCE was reportedly discharged to the environment.

Site contamination has migrated from the vadose zone to groundwater. In 1979, two of the Town of Groveland's drinking water supply wells were determined to be impacted by TCE and the wells were taken off-line and a new municipal drinking water well was installed in a different aquifer. In 1982, EPA determined that the groundwater contamination posed a threat to public health and the environment; the Site was placed on the National Priorities List and was assigned CERCLIS identification number MAD980732317.

Figure 1: Site Map [1]



Legend

Approximate Location of Former Underground Storage Tanks

Notes:

1. Aerial photograph provided by MassGIS

N

0 20 40 80

Feet

1 inch = 60 feet

Nobis

Engineering a Sustainable Future

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585 Middlesex Street
Lowell, MA 01851
(978) 683-0891
www.nobisengineering.com

FIGURE 1-2

SITE PLAN
GROVELAND WELLS SUPERFUND SITE
GROVELAND, MASSACHUSETTS

PREPARED BY: JMH	CHECKED BY: LS
PROJECT NO. 80037	DATE: 5/17/2011 Rev 01

Path: R:\80000 Task Orders\80037 Groveland Wells RA\Technical Data - new and previous\GIS\Nobis Maps\Community Involvement Plan\Fig_1-2_Site Plan.mxd

Source: (Nobis, 2011)

In 1991, a Management of Migration Record of Decision (ROD) for OU1 was issued as a means of supplementing the remedy in place at OU2. This ROD selected extraction and treatment of groundwater contaminated outside the source area and in the downgradient plume area.

In 1996, Explanations of Significant Difference (ESDs) were issued to both the OU1 and OU2 RODs. These ESDs removed the requirement that a separate groundwater extraction and treatment system be in place for OU2. Instead, groundwater from the source area was to be extracted and treated in an OU1 groundwater treatment facility that was to be built downgradient of the source area. Because of the potentially responsible party's financial difficulties, the Site became a fund lead site in 2001. The OU1 groundwater extraction and treatment facility was built in 1999 and was operational in 2000. The Massachusetts Department of Environmental Protection (MassDEP) currently funds the operation and maintenance of the groundwater treatment system, which still operates presently.

The soil vapor extraction (SVE) system that the responsible party installed pursuant to the OU2 ROD was found to be ineffective based on a review of historical SVE system data from 1992 through 2002. The data indicated that TCE removal had been minimally effective. Findings from a 2004 source area evaluation indicated that source area characterization data gaps existed. In 2006, an extensive source area re-evaluation was conducted and it was determined that the source control remedy for soil and groundwater needed modification to include in-situ thermal treatment (ISTT)/enhanced SVE. The results of the pilot study indicated that chemical oxidation was not a viable treatment alternative.

In September 2007, an ESD was issued for OU2. This ESD modified the selected remedy to include ISTT/enhanced SVE in conjunction with a liquid extraction system for subsurface soil and overburden groundwater. This enhanced remedy was expected to increase the effectiveness of the source control remedy and decrease the amount of time the groundwater pump and treatment system would have to operate in order to accelerate site closure. Also as part of the ESD, soil cleanup goals were revised and are provided in Table 1.

During a 2009 baseline sampling event for the ISTT, the primary contaminant TCE, was detected at a maximum concentration of 20,000 micrograms/kilogram (µg/kg) from a depth of 0 to 11 feet below ground surface (bgs) in the Former Porch Area of the Site (See figure 1 on page 2). Baseline sampling results indicated TCE concentrations as high as 96,000 micrograms/liter (µg/L) in groundwater.

Based on environmental investigations conducted in 2006 and 2009 at the Site, the total area of the treatment zone was determine to be approximately 14,830 square feet with a total volume of 17,450 cubic yards. Four treatment zones were delineated, each with a different treatment depth ranging from zero to 45 feet bgs. Table 2 provides the area, volume, and depth of each of the ISTT areas. The ISTT/enhanced SVE system began operation in August 2010.

Table 1: Soil and Groundwater Cleanup Goals [1]

Chemical of Concern	Vadose Zone Soil (µg/kg)	Overburden Groundwater (µg/L)
Trichloroethene (TCE)	77	5
1,1-Dichloroethene (1,1-DCE)	45	7
trans-1,2-Dichloroethene (tDCE)	626	100
cis-1,2-Dichloroethene (cDCE)	418	70
Methylene chloride (MC)	22	5
Tetrachloroethene (PCE)	56	5
1,1,1-Trichloroethane (111-TCA)	1,388	200
Toluene	22,753	1000
Vinyl chloride	11	2

Notes; µg/kg - microgram/kilogram; µg/L - microgram/liter.

Table 2: In-Situ Thermal Treatment Area and Volume Summary [1]

Zone Description	Area (ft^2)	Depth (ft bgs)	Volume (yd^3)
Area A	8,460	0 to 45 (1)	14,100
Area B	910	0 to 25	850
Area C	2,950	0 to 10 (2)	1,600
Area D	2,510	0 to 10	930
Total	14,830	Varies	17,450

Notes: ft^2 – square feet
ft bgs – feet below ground surface. Ground surface is below concrete slab, where applicable.
yd^3 – cubic yards
(1) Area A extended vertically from the ground surface to bedrock, which was estimated to be approximately 45 ft bgs.
(2) As a result of the baseline groundwater investigation, a portion of Area C below the Valley Building was extended deeper.

2.0 Matrix Characteristics [1, 3]

Table 3 provides the parameters that define the key matrix characteristics affecting ISTT and the values measured for each parameter during the site characterization.

Table 3: Groveland Wells Matrix Characteristics [1, 3]

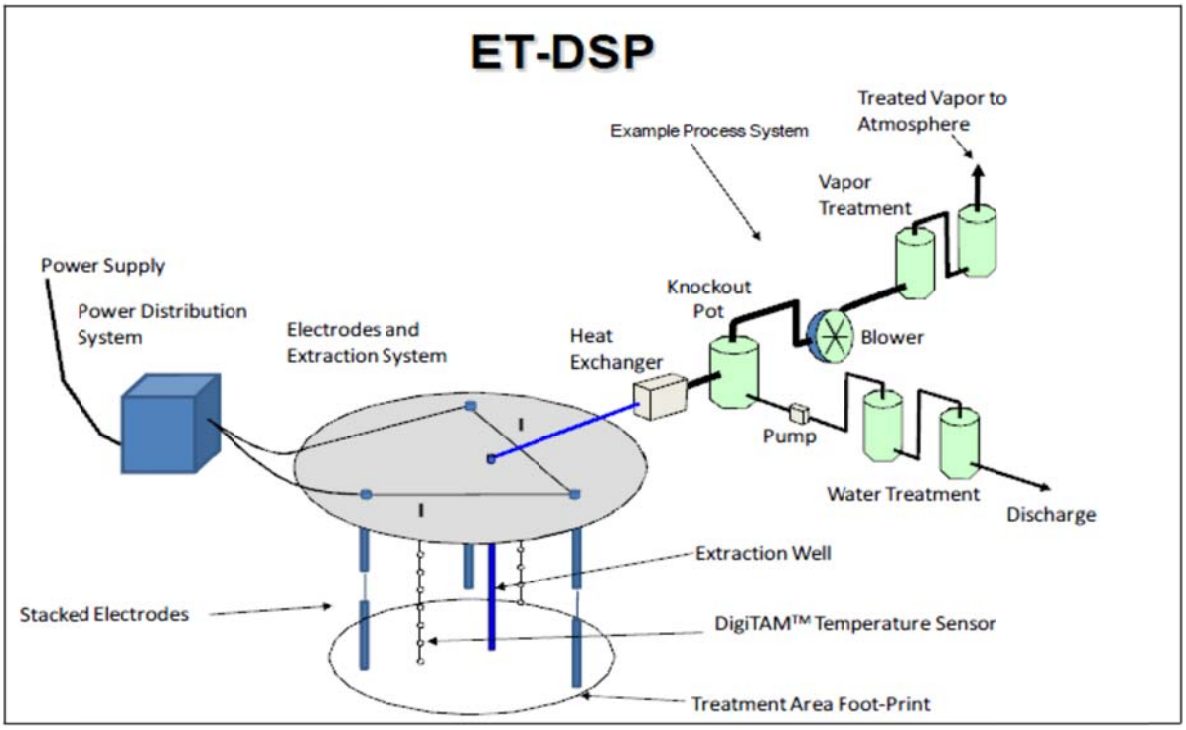
Parameter	Value
Soil classification	Glacially derived unconsolidated sediments that overlie fractured phyllite bedrock
Depth to ground water	35 to 40 feet below ground surface (bgs)
Depth of interest	0 to 45 feet below ground surface (bgs)
Volume of interest	Approximately 17,450 cubic yards (cy)
Primary porosity	0.35
Composition of DNAPL	Trichloroethene (TCE)
Areal extent of DNAPL	Approximately 14,830 square feet (sf)

Notes: DNAPL – dense non-aqueous phase liquid.

3.0 Treatment Technology Description [1]

The electrical resistance heating system installed at the Site is an ISST system. Electrical resistance heating applies electricity to electrodes installed in the subsurface soil. As the electrical current passes through the soil from electrode to electrode, it heats the soil and groundwater. Contaminants present in the soil become more mobile or volatized, creating soil vapors and steam that can be extracted by vapor recovery wells. A soil vapor and liquid extraction system then treats the extracted soil vapor and liquids. Figure 2 shows a typical layout of this remediation process.

Figure 2: Typical Layout of the ET-DSP™ Remediation Process [1]



For each electrode well, 1 to 3 electrodes were installed. The number of electrodes was dependent on the depth of the treatment zone. Greater treatment zone depths require a larger number of electrodes. ISTT Area A which had the greatest treatment depth of 45 feet contained three electrodes in each boring. ISTT Area B which had a treatment depth of 25 feet contained two electrodes per boring. ISTT Areas C and D which had a treatment depth of 10 feet generally contained only one electrode per boring. Figure 3 shows the ISTT treatment zones.

The treatment system at the Site included a subsurface network of 64 electrode wells; 143 electrodes; 29 shallow SVE wells; 15 multi-phase extraction (MPE) wells; 16 temperature sensor wells; 12 temperature, pressure, and vacuum sensor wells; a concrete vapor cover; extraction conveyance lines and manifolds; SVE, MPE and sensor well heads; and a SVE and liquid extraction system for control and treatment of vapors and liquids.

The forty electrode well locations installed outside the Site building were comprised of standard, 8-inch diameter electrode wells. The electrode wells were spaced in an array approximately 19.7 feet on center.

Twenty-four electrode wells with 6-inch diameters were installed within the former VMPC building. These electrode wells were spaced in an array approximately 16.4 feet on center. A smaller diameter well was needed due to the height restraint for a drill rig inside the building.

Temperature sensor wells were installed between electrode pairs or in the center of electrode well triangles in 16 locations. Each temperature sensor well was equipped with a digiTAM™ digital temperature sensor that included a series of individual temperature sensors vertically spaced at 3 foot intervals from treatment depth to approximately ground surface.

Pressure/vacuum sensor wells were installed at 12 locations in ISTT Areas A, C, and D and on the perimeter of the entire treatment area. These sensors measured pressure changes due to water level changes and were also equipped with a temperature sensor well. Each pressure/vacuum sensor well was equipped with a digiPAM™ pressure sensor.

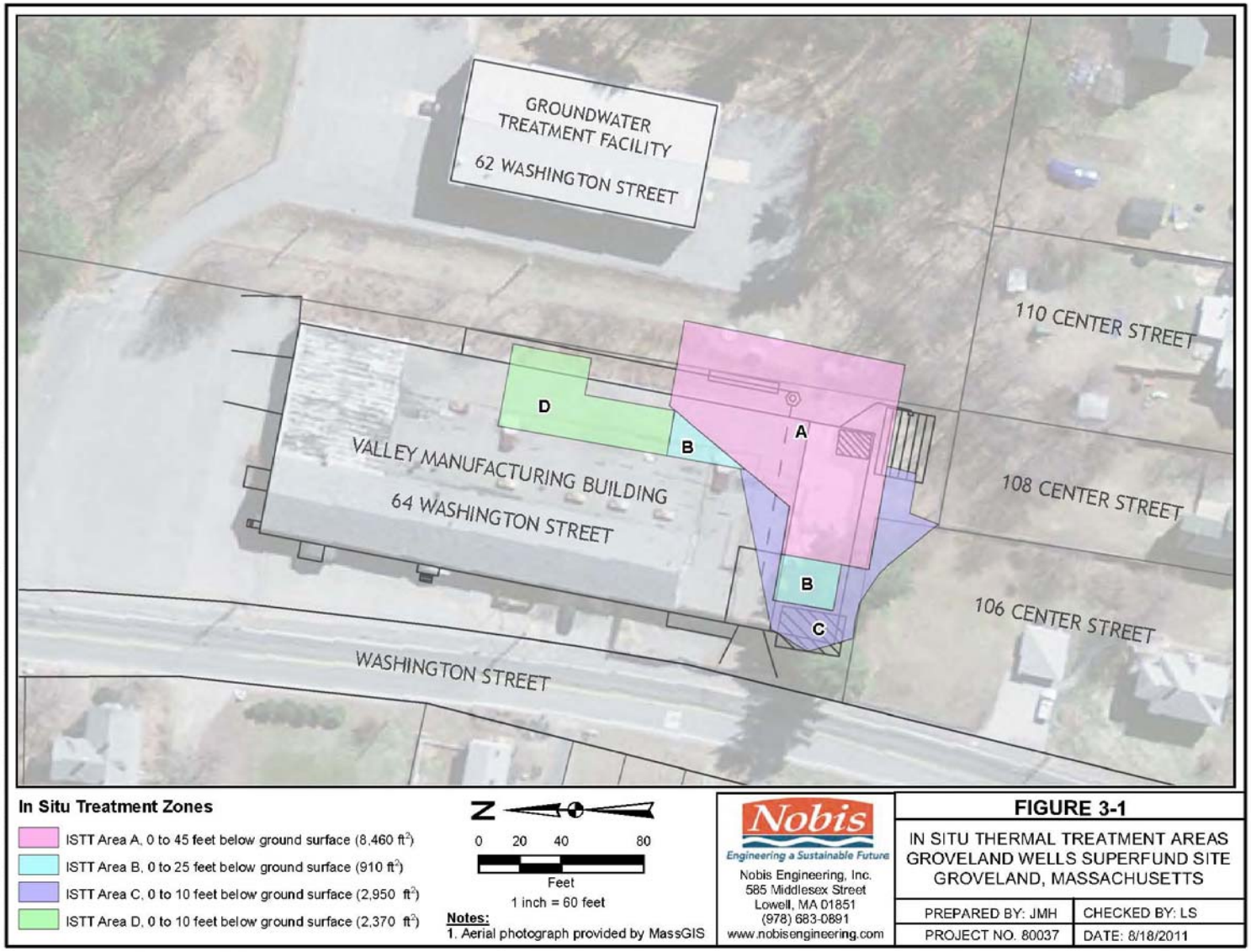
As part of the system's extraction and treatment components, a vapor recovery network and a liquid extraction and treatment system were installed. Details regarding these components are described below:

The vapor recovery network included the following:

- heat exchangers
- cooling tower
- moisture knockout tanks
- two rotary lobe positive displacement 40 horsepower vacuum blower system
- process equipment skids
- granular activated carbon units

Vapors extracted from the ISTT areas were first directed to heat exchangers that reduced the moisture content. These heat exchangers were cooled with water from a cooling tower. After the heat exchanger, the vapor was introduced to a moisture knockout tank that removed condensate and liquid. Two rotary lobe positive displacement vacuum blowers provided vacuum to draw the vapors from the wellfield and subsequently through a second heat exchanger, a chiller, and a

Figure 3: In Situ Thermal Treatment Areas, Groveland, Massachusetts [1]



Source: (Nobis, 2011)

second moisture knockout tank to further reduce temperature and condensate. The vapor was then heated and dried to a relative humidity of less than 50 percent; it was sent through two granular activated carbon (GAC) vessels, and then released to the ambient air. To ensure the continued protection of local residents and site workers, air monitoring was conducted using summa canisters. The results of this sampling indicated that there were no unacceptable risks from vapors.

The liquid extraction system equipment included the following:

- pair of bag filters
- heat exchanger
- oil/water separator
- pneumatic groundwater extraction pumps

The purpose of the liquid extraction system was to reduce groundwater temperatures, remove NAPL, and remove particulates prior to discharge to the OU1 groundwater treatment facility (GWTF) for complete and proper treatment of dissolved contaminants. Groundwater extracted from the ISTT area was first filtered through a pair of bag filters to remove particulates and then was directed through a heat exchanger that reduced the water temperature. The water and condensate from the vapor system's moisture knockout tanks was then directed into an oil/water separator to allow for NAPL separation and collection. After the oil/water separator, the process water was then discharged to the influent equalization tank of the OU1 GWTF.

During system operation in October 2010, a NAPL breakthrough of the liquid treatment system was identified at the Site when NAPL was detected at the OU1 GWTF located on a neighboring property. There were no exceedances of the effluent discharge limits for the GWTF. The ISTT system was immediately shut-down on October 12, 2010. This breakthrough was attributed to the NAPL exhibiting an unanticipated specific gravity close to that of water. The ISTT system was upgraded to account for these properties and was restarted on October 20, 2010. Upgrades to the system included:

- the installation of cooling plates and a cooling loop to increase cooling capacity of the liquid heat exchanger
- the installation of an 800-gallon weir tank before the oil-water separator to increase greater NAPL separation
- the installation of a second bag filter skid after the oil water separator to capture NAPL that may have not been removed by the oil water separator
- the installation of a 500-pound organoclay media vessel to remove any remaining NAPL
- the installation of a 5,000-gallon settling tank as the last step of the liquid treatment prior to discharge to the OU1 GWTF.

Additional system enhancements were made to optimize heating conditions at the Site in December 2010. Due to the existence of highly permeable geologic units and areas of high resistivity within the treatment area, the subsurface electrical conductivity and moisture content requirements were not being met. Therefore, a steam-enhanced heating component was added to

the ISTT system to resolve these issues. This steam-enhanced heating component was composed of a steam generator that provided steam to 14 steam spears and select shallow SVE wells. To allow for increased shallow vadose zone heating, vapor extraction was reduced in the ISTT areas.

A vapor cover insulation cap was installed in December 2010 to account for cold winter conditions at the Site. Two layers of 2-inch thick polystyrene insulating boards with R-values of 20 were placed on the concrete vapor cover and were secured by sand bags. This insulation cap reportedly reduced heat loss from the subsurface by 98 percent.

3.1 Operating Parameters [1]

Table 4 lists the key operating parameters for the ISTT system which included an electrical resistance heating system and a soil vapor and liquid extraction system.

Table 4: ISTT System Operating Parameters [1]

Parameter	Value
Electrical Resistance Heating	
Target temperature for vadose zone located 0 to 25 feet bgs	90 degrees Celsius
Target temperature for saturated zone located 25 to 45 feet bgs	100 degrees Celsius
Power input	18,896 kilowatt-hour (kWh) per day average
Soil Vapor and Liquid Extraction System	
Vapor flow rate	450 standard cubic feet/minute (scfm)
Steam flow rate	200 to 500 scfm
Average steam extraction rate	2 gallons per minute (gpm)
Average liquid extraction rate	6.9 gpm

3.2 Timeline [1]

Table 5 provides a summary of key ISTT dates.

Table 5: Summary of ISTT Key Dates [1]

Date	Activity
August 2010	In Situ Thermal Treatment (ISTT) system activated
October 2010	ISTT system shut down for liquid extraction system upgrades and is restarted
December 2010	Steam-enhanced heating system is activated
February 2011	ISTT system shutdown

4.0 Performance Information [1]

The overall ISTT system performance objective for the Site was to reduce contaminant concentrations in the source area soils to meet site cleanup levels as specified in the 2007 ESD and to also reduce the amount of time that the groundwater treatment system would need to operate. For this application of ISTT, a performance objectives metrics system was developed to evaluate system performance and determine when a point of diminishing returns was reached. A summary of the performance objectives is provided below:

- The target temperature for the vadose zone was 90 degrees Celsius, where the vadose zone is assumed to be 0 to 25 feet bgs.

- The target temperature for the saturated zone was the boiling point of water where the saturated zone is assumed to be 25 to 45 feet bgs.

Metrics developed in order to meet target temperatures were defined by the consultant as:

- 85 percent of the temperature sensors within the vadose zone reach 90 degrees Celsius
- 85 percent of the temperature sensors within the saturated zone reach the boiling point of water
- 100 percent of the temperature sensors within both the vadose and saturated zones reach a minimum of 60 degrees Celsius.

Temperature sensors were located in ISTT Areas A, C and D. The sensor locations were spatially distributed to adequately monitor the entire treatment zone. Since Area B was the smallest of the treatment zones and was surrounded by the other zones, sensors were not situated within Area B. Several sensors in close proximity to Area B were used to provide representative temperature measurements of Area B vadose zone soils.

In Area A, 80 percent of the temperature sensors in the vadose zone achieved the metrics goal of reaching 90 degrees Celsius and 50 percent of temperature sensors in the saturated zone achieved the metrics goal of reaching the boiling point of water. For Areas C and D, 80 percent of the sensors achieved the target temperature in the vadose zone and 100 percent achieved the target temperature in the saturated zone. Figure 4 is a graphical representation of average temperatures achieved by the ISTT system in each treatment area. All temperature sensors exceeded the minimum temperature metric of 60 degrees Celsius.

As part of performance monitoring, baseline and confirmatory soil and groundwater samples were collected to assess the success of the treatment system in removing TCE and cis-1,2-DCE.

The Former Porch Area average TCE and cis-1,2-DCE concentrations in vadose zone soil exhibited a significant decrease between the baseline and confirmation soil sampling events and are shown in the Table 6 [1]:

Figure 4: Average Temperatures of ISTT Areas [1]

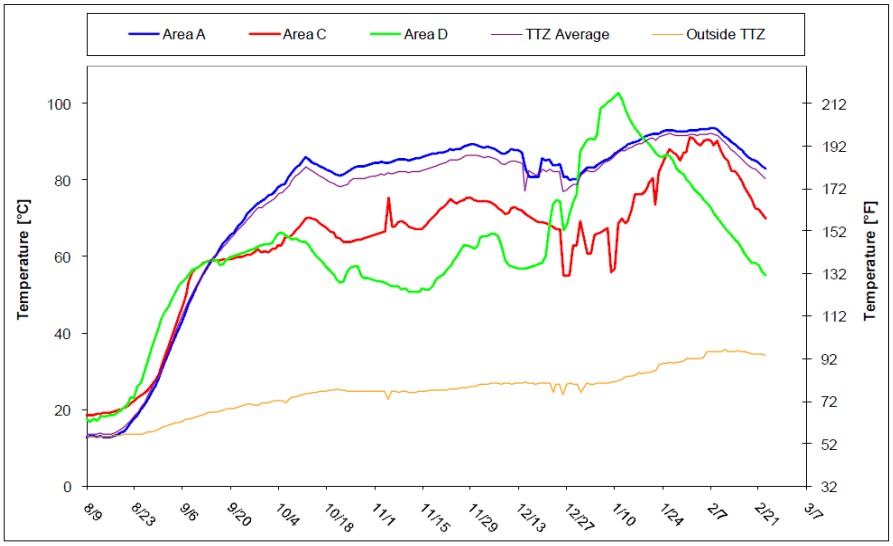


Table 6: Former Porch Area TCE and Cis-1,2-DCE Vadose Zone Soil Concentrations by Sampling Event [1]

Sampling Event	TCE concentrations (µg/kg)	Cis-1,2-DCE concentration (µg/kg)
Baseline	3,700	304.5
Confirmation	1,029	205
Desired Cleanup Level	**77**	**418**

Notes; ug/kg - microgram/kilogram

Average TCE and cis-1,2-DCE concentrations in soil for the Former Porch Area were calculated from samples collected from eight baseline soil borings and four confirmation soil borings.

In general, TCE mass reduction in groundwater was observed after ISTT remediation in most wells. Significant TCE mass reduction, ranging from 86 to 100 percent was observed in 11 of the 16 wells sampled as part of the remedial action. Groundwater from two of the 16 wells monitored was non-detect for TCE throughout the remedial action. Finally, at three of the 16 wells, TCE concentrations increased to concentrations as high as 38 µg/L. The spatial variability of removal rates closer to electrodes or at different depths was not evaluated from the groundwater confirmation sampling results because depth variability was not expected to be a significant factor. It is assumed however, that TCE would volatize more readily in areas that are in close proximity to the heating electrodes. Table 7 provides a baseline and confirmation groundwater data comparison for TCE.

Table 7: Baseline & Confirmation Groundwater Data Comparison – TCE and Cis-1,2-DCE [1]

Location	Baseline Event	Confirmation Event No. 1 after 6 weeks following ISTT completion	Confirmation Event No. 2 after 12 weeks following ISTT completion	Confirmation Event No. 3 after 24 weeks following ISTT completion	Percent Reduction in Concentration[(1)]
	June, July, & August 2009	March 2011	May 2011	August 2011	
	Result Qualifier	Result Qualifier	Result Qualifier	Result Qualifier	
TCE					
EW-S3	**28**	**36**	**15**	**38**	-36%
RW-01	5U	5 U	5 U	5 U	-
RW-02	**15**	**1 J**	5 U	5 U	100%
RW-03	**11000 D**	**5.9**	**17**	**17**	100%
RW-04	**290 D**	**24**	**25**	**20**	93%
RW-05	**11000 D**	**37**	**15**	**78**	99%
RW-06	5U	**1.2 J**	5 U	**8.9**	-
RW-07*	**83**	**28**	**9.6**	**11**	87%
RW-07B	**52**	**4.6 J**	**5.8**	**7.2**	86%
RW-08	**4 J**	**1.2 J**	5 U	5 U	100%
RW-09	**10**	**12**	5 U	5 U	100%
RW-10	**390 D**	**3.3 J**	**10**	**1.9 J**	100%
RW-10B	**1.4 J**	5 U	5 U	5 U	100%
TW-31	**8.7 B**	**130**	**83**	**38**	-337%
TW-40	5 U	5 U	5 U	5 U	-
TW-47	**8.3 B**	**2.3 J**	**1.3 J**	5 U	100%
cis-1,2-DCE					
EW-S3	**6.6**	**17**	**6.1**	**17**	-158%
RW-01	5 U	5 U	5 U	5 U	-
RW-02	**3.1 J**	**2 J**	5 U	5 U	100%
RW-03	**260 DJ**	**2.8 J**	**7.8**	**11**	96%
RW-04	**57**	**8.6**	**9.6**	**14**	75%
RW-05	**325 DJ**	**19**	**13**	**78**	76%
RW-06	5 U	5 U	5 U	**4.7 J**	-
RW-07*	**37**	**13**	**5.2**	**9.2**	75%
RW-07B	**4.5 J**	5 U	**1.1 J**	5 U	100%
RW-08	5 U	**1.2 J**	5 U	5 U	-
RW-09	**2.8 J**	**8.9**	5 U	5 U	100%
RW-10	**180 D**	5 U	**5.9**	**1.9 J**	99%
RW-10B	5 U	5 U	5 U	5 U	-
TW-31	5 U	5 J	**4.6 J**	**4.1 J**	-
TW-40	5 U	5 U	5 U	5 U	-
TW-47	**1.3 J**	5 U	5 U	5 U	100%

Notes:

All values are in micrograms per liter (µg/L)
Bold - Detected Concentration
Shaded - Detected Concentrations Exceeds the CUG
TCE – Trichloroethene
cis-1,2-DCE - cis-1,2-Dichloroethene
CUG - Interim Cleanup Goal - based on current Federal & State Maximum Contaminant Levels, per the RODs (1991).
CUG of cis-1,2-dichloroethene is 70 µg/L.
CUG of trichloroethene is 5 µg/L

(1) Mass reduction was calculated using baseline event & confirmation event No. 3. Zero was used for non-detect values.
* Well MPE-06 was used as a substitute for RW-07 during Confirmation Sampling Event No. 2 only because of a problem with well RW-07.
J – Quantitation is estimated as it is below the Sample-Specific Detection Limit (SSDL)
U – Not detected above the SSDL
B – Analyte detected in laboratory blanks
D – Concentration is reported from a dilution of the sample

The magnitude of the mass reduction appeared to correlate largely with the relative magnitude of baseline concentrations and location relative to the heart of the contaminant plume. The largest reductions in contaminant concentrations were observed at locations with the highest baseline concentrations; in general, these wells were located along the center line of the contaminant source plume. The three wells where TCE concentrations increased were along the edge of (EW-S3) or outside the treatment zone (TW-31 and RW-06). These increases can be attributed to changes in contaminant migration patterns when the source area extraction wells were shut off in preparation for ISTT and following treatment.

Baseline and confirmation sampling data were compared for cis-1,2-DCE. Cis-1,2-DCE mass reductions of 75 to 100 percent were observed in nine monitoring wells. Six of the 16 monitoring locations sampled exhibited concentrations below the laboratory detection limit during both baseline and confirmation sampling. One monitoring location was observed to have a concentration increase from 6.6 µg/L to 17 µg/L. Table 7 provides groundwater sampling results for cis-1,2-DCE from baseline through confirmation sampling..

The ISTT heating system was shut down in February 2011 and vapor extraction ceased three weeks later. The ISTT system's rate of contaminant mass removal had decreased to a level where it was no longer cost effective to continue operation, i.e., a point of diminishing returns. Confirmation soil and groundwater sampling results indicated that the TCE remaining in the vadose zone above cleanup levels was not significantly affecting groundwater. Since the areas of elevated concentrations were located beneath a paved portion of the Site, surface water infiltration was expected to be minimal. Confirmation sampling concentrations also indicated that no rebound of TCE and cis-1,2-DCE occurred in the 6-month period between system shutdown and the most recent round of groundwater sampling(August 2011). Although contamination was significantly reduced in the source area, TCE and cis-1,2-DCE concentrations remained above cleanup goals in two soil sampling locations. The project team recommended that the source area groundwater extraction wells located downgradient of the Former Porch Area be restored to their original functioning condition.

4.1 Performance Data Quality [1]

No exceptions to established quality assurance/quality control (QA/QC) procedures were noted in the available references.

5.0 Factors That Affected Technology Cost or Performance [1]

Several system modifications and optimizations were implemented over the course of the ISTT system operation to improve system performance and to address issues related to neighborhood complaints. These modifications and optimizations are discussed below.

To improve the performance of the ISTT system, saline was injected into the ISTT wellfields and into certain electrodes. These injections enhanced the electrical conductivity of the soil within the vadose zone and were performed throughout the course of the ISTT system operation.

Extracted groundwater and condensate conveyed to the GWTF were routinely monitored to ensure that chloride concentrations were acceptable for discharge to surface water. The chloride levels observed ranged from 75 to 115 parts per million (ppm) which is below the freshwater ambient water quality criteria.

Upgrades to the liquid extraction component of the system were made after an unexpected NAPL breakthrough was detected at the OU1 GWTF on October 12, 2010. There were no exceedances of the effluent discharge limits. The liquid extraction system and ET-DSP™ system were shut down and an investigation into the breakthrough revealed that the physical and chemical properties of the NAPL were significantly different than expected because the NAPL was most likely a mineral spirit, and not TCE. The NAPL's specific gravity was identified as very close to that of water. Upgrades to the liquid extraction system were implemented to address the additional time and cooling needed to effectively achieve NAPL separation. These upgrades included the (1) installation of several cooling plates and a cooling loop that utilized water from a cooling tower to increase the cooling capacity of the liquid heat exchanger, (2) installation of an 800-gallon weir tank before the oil water separator to facilitate settling and separation of NAPL, (3) the installation of a second bag filter skid after the oil water separator to collect additional product that may have not been captured by the oil water separator, (4) installation of a 500-pound organoclay media vessel to increase petroleum capture, and (5) the use of a 5,000-gallon weir tank as the last component to provide for additional settling prior to discharge to the OU1 GWTF. The liquid extraction system was restarted on October 20, 2010 and the ET-DSP™ system was restarted on October 21, 2010.

Due to the increased groundwater extraction from the source area attributable to the operation of the ISTT system, increased iron biofouling was observed at the OU1 GWTF. As a result, more frequent backwashing and maintenance of the multi-media and peroxide destruction unit filters were required. In an effort to manage the biofouling, the project team re-routed the influent to the GWTF. Process water from the ISTT was first directed to a plate clarifier, while influent water from downgradient extraction wells was routed to bypass the plate clarifier. This encouraged additional ISTT process water retention and eased the maintenance issues encountered with the iron-bacteria biofouling.

A steam-enhancing component was installed in December 2010 to address difficulties encountered due to high permeability geologic units within the ISTT treatment areas. These geologic units were located mostly in the shallow vadose zone and caused issues in maintaining optimal moisture content and subsurface electrical conductivity. Additionally, several areas of high resistivity were identified at locations of low electrode power. Enhancements made to the steam-enhancing component included the installation of a steam generator, the installation of 14 steam spears to a depth of 10 feet bgs in the vadose zone, injection of steam into the steam spears and into certain vapor extraction wells, and a reduction of the ISTT vapor extraction to allow for more efficient heating of the shallow vadose zone. This steam component operated until the system shutdown in February 2011.

Due to difficulties in attaining and maintaining acceptable heating rates, the period of operation

of the system was extended past its estimated completion date of late November 2010 into the winter months. To address colder ambient temperatures, a vapor cover insulation cap was installed in December 2010. This cap included two layers of 2-inch thick, R-20 polystyrene foam, and 4-foot by 8-foot insulation sheets laid on the surface of the ISTT treatment areas and anchored by sand bags. The boards succeeded in reducing heat loss through the surface by 98 percent and decreased heat loss from the shallow vadose zone.

As part of site preparation activities, 23 polyvinyl chloride (PVC) groundwater monitoring wells and 6 PVC vapor extraction wells were decommissioned within the ISTT area. The wells were decommissioned because PVC well materials cannot withstand the high temperatures required as part of the ISTT system. A high temperature bentonite cement grout mixture was injected into the bottom of the wells and the wells were filled upwards. The protective casings and top portion of the well risers were removed and cement grout was used to fill in the remaining voids. Ten overburden monitoring wells and two bedrock monitoring wells constructed of type 316, stainless steel were then installed within the ISTT area.

The ISTT's ET-DSP™ Power Distribution System (PDS) warning light needed to have a shield placed on it due to complaints from the neighboring property owner from the flashing strobe light at night. Because it was an important safety feature that indicated that the PDS units were energized, the light was shrouded to direct light only onto the Site and not toward the neighboring property.

Additional costs were incurred due to the fact the ISTT system was modified after a complaint was received from a neighboring resident regarding the high frequency hum that was emitted by the vapor extraction blowers and chiller units, which operated mostly 24 hours/day 7 days/week. Results from a sound survey indicated that the noise levels at the Site met local noise ordinance requirements for a suburban neighborhood setting. However in order to address the complaint, a sound absorbing curtain consisting of three panels was designed and installed. This curtain reduced the high frequency sound outside the Site and addressed the neighbor's concern.

6.0 Cost Information [1]

The estimated overall cost of the ISTT Remedial Action is $6,264,000. This cost includes system design, construction, operations and maintenance, demobilization, electricity costs, and subcontractor costs. The unit treatment cost for the ISTT system is estimated as $207 per cubic yard (including ISTT subcontractor costs for the system design, construction, operations and maintenance, demobilization, and reporting). The unit cost increases to $242 per cubic yard if electricity costs are included. When other subcontractor costs are considered (including site preparation activities, waste disposal, soil borings, laboratory analysis, and electrical/automated controls services), the unit treatment cost is approximately $359 per cubic yard. An EPA mobile laboratory provided real-time TCE data analysis once a month during the active heating period. Use of this mobile laboratory reduced direct analytical costs and provided real time data which helped the team make timely decisions. Table 8 provides a breakdown of the ISTT project costs.

Table 8: Summary of ISTT Project Costs [1]

Cost Element	Cost
ISTT Subcontract Cost – • ISTT design • construction • operation and maintenance • demobilization • reporting	$3,617,610
Other Subcontractor Costs – Services provided by subcontractors for activities including: • clearing & grubbing • utility survey • structural engineering assessment • mold assessment • monitoring well abandonment • well replacement • waste disposal • fence removal & installation • land surveying • soil borings • laboratory analysis • electrical/automated controls services	$284,452
ISTT Electricity Cost - Direct cost of electricity to operate ISTT heating and extraction systems The average cost per kilowatt hour was $0.17. However it should be noted that the actual cost included a cost related to energy demand and a discount for prompt payment. Therefore, the actual electricity cost after all fees and discounts averaged to a monthly cost that ranged from $0.15 to $0.22 per kilowatt hour.	$603,963
Other Costs – • Contractor labor costs (project management, community involvement activities • project plan preparation & specifications • subcontractor procurement • field oversight of subcontractor activities • ISTT O&M • planning & execution of baseline and confirmatory soil & groundwater investigations, • collection of ambient air samples • data management & evaluation • report preparation • costs for sampling equipment & supplies, consumable materials, & transportation	$1,757,975
Overall Project Cost	$6,264,000
Unit Cost per cubic yard when all project costs are considered	$359 per cubic yard

7.0 Observations and Lessons Learned [1]

At the time of ISTT shutdown in February 2011 and after 192 days of operation, the system had removed approximately 1,300 pounds of VOCs from the ISTT areas. In addition to VOCs removal, two-million gallons of water and condensate, 311 million cubic feet of non-condensable vapors, and 18 gallons of NAPL were removed.

Soil and groundwater confirmatory sampling results indicated a significant reduction in TCE and cis-1,2-DCE concentrations at the Site. Despite these significant reductions, concentrations of TCE and cis-1,2-DCE remained above cleanup goals in two small areas below a paved portion of the Site. The decision to shut down the ISTT system in February 2011 was made based on decreasing cost effectiveness and a point of diminishing returns. Confirmation soil and groundwater sampling results indicated that the TCE remaining in the vadose zone above cleanup levels was not significantly affecting groundwater because the areas where elevated concentrations remain are located beneath a paved portion of the Site; therefore, surface water infiltration was expected to be minimal. Post-remedial sampling concentrations also indicated that no rebound of TCE and cis-1,2-DCE had occurred in the 6-months since system shutdown. Although contamination was significantly reduced in the source area, TCE and cis-1,2-DCE concentrations remained above cleanup goals in two confirmatory samples. The project team recommended that the source area groundwater extraction wells downgradient of the Former Porch Area be restored to their original functioning condition.

Aspects that could improve the efficiency of the technology include:

1) Take more samples to better determine the baseline electrical resistivities of the various types of soil present to get a more accurate design;
2) Considering the use of combined thermal treatment technologies (ISTT, Thermal Conduction Heating, and Steam Enhanced Extraction) at sites with varying geologic units;
3) Planning and designing for operation in cold weather conditions by using a thermal insulation vapor cover to control heat losses in soil. Ensure that above ground piping is adequately winterized for cold weather operation;
4) Preventing voltage potential incidents associated with integrating ISTT extraction systems with treatment systems already in operation.

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9.0 References

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