

In Situ Thermal Remediation at the SRSNE Superfund Site: Meeting Regulatory Requirements and Removing 225,000 kg of VOCs

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ABSTRACT: The Solvents Recovery Service of New England (SRSNE) Superfund Site (Site) is located in Southington, Connecticut. Disposal to lagoons and other releases produced a multicomponent nonaqueous-phase liquid (NAPL) source zone in glacially derived overburden deposits and fractured bedrock, along with associated aqueous phase plumes. The majority of the volatile organic compound (VOC) mass at the Site was NAPL in the overburden. Accordingly, the Feasibility Study (FS) incorporated NAPL delineation and VOC mass estimates, and evaluated treatment alternatives for the overburden NAPL zone. In situ thermal remediation (ISTR) was selected in the 2005 Record of Decision (ROD) and completed in 2015 as one component of the remedy. ISTR met required soil cleanup levels; in addition, ISTR achieved 99.7% VOC mass removal from treated soils (225,000 kg of VOCs removed), significantly reduced groundwater concentrations, and reduced the risk of further NAPL mobilization into bedrock, which will reduce the duration and cost of long-term groundwater treatment.

INTRODUCTION

Site Description. The SRSNE Site is located in Region 1 of the United States Environmental Protection Agency (USEPA). SRSNE processed more than 100 million gallons of solvents received from more than 2,000 customers between 1955 and 1991 (Figure 1). The variety of solvents and other organic liquids processed resulted in a multicomponent NAPL that contains chlorinated alkenes and alkanes, aromatic and aliphatic hydrocarbons, tetrahydrofuran, ketones, alcohols, 1,4-dioxane, and polychlorinated biphenyls. The particular mixture of organics at a given location results in dense, light, or neutrally buoyant NAPLs, collectively termed “NAPL” in this paper.



FIGURE 1. SRSNE site in 1965.

The Site was added to the National Priorities List (NPL) on September 8, 1983. USEPA conducted two removal actions and three phases of Remedial Investigation (RI) work between 1990 and 1994. The Potentially Responsible Parties (PRPs) Group comprised of former SRSNE customers formed in

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1993, and completed two Non-Time-Critical Removal Actions, the 1998 RI Report, and the 2005 Feasibility Study (FS) Report. The NTCRAs resulted in hydraulic containment and ex situ treatment of the VOC plumes, and were incorporated, along with monitored natural attenuation (MNA), as the long-term groundwater remedy. The PRPs are performing the Remedial Design / Remedial Action (RD/RA) under a 2008 Consent Decree (CD).

Objectives. To perform ISTR, certain issues must be adequately defined, including: appropriate remedial goals, the target area/volume to be treated, the treatment goals (e.g., cleanup levels) and how compliance with those clean up levels will be demonstrated. The estimated mass of VOCs to be removed and the enthalpy of combustion of those VOCs are very important for design of an adequate vapor treatment system. Each of these items must be clearly understood to estimate the costs of ISTR – a necessary part of the evaluation process. Lessons were learned with respect to each of these issues during the installation and operation of the ISTR system.

Remedial Action Objectives. RAOs in the FS relative to ISTR included: “Reduce NAPL mass in this area (as described below in “FS Overburden NAPL Zone Delineation”) to achieve one or more of the following: (1) shorten the time frame that groundwater standards are exceeded, (2) shrink the size of the groundwater plume, (3) reduce groundwater concentrations, and (4) prevent the migration of NAPL.” The NCP sets forth the USEPA’s expectation to use “treatment to address the principal threats posed by a site, wherever practicable” (40 CFR Section 300.430(a)(1)(iii)). NAPLs and highly contaminated soils are examples of principal threat wastes (USEPA, 1991). Additional field studies were implemented to better understand the extent of principal threat wastes, so that treatment could be considered in the FS.

MATERIALS AND METHODS

NAPL Zone Delineation. The RI Work Plan (BBL, 1995) proposed a “front-end” “technical impracticability” (TI) determination of the potential to restore groundwater to drinking water quality within a reasonable time frame (Gefell et al, 1998 and 2000). Accordingly, the overburden and bedrock NAPL zones were defined in the RI Report (BBL, 1998) based on a converging lines-of-evidence approach that included: site use/site history, direct visual observation, ground-water VOC concentrations exceeding 1% and 10% effective solubility, detections of alcohols in ground water, and presence of contamination in hydraulically anomalous locations. For overburden, an additional line of evidence included soil VOC concentrations exceeding the partitioning threshold (Feenstra et al., 1991). This approach defined an overburden “Probable NAPL Zone” of 19,830 m² (4.9 acres), with a total soil volume of 153,000 m³ (200,000 yards³).

FS Overburden NAPL Zone Delineation. Discussions with USEPA during the FS led to a 2003 study that used direct-push methods to collect soil samples, which were assessed using soil-water shake tests and hydrophobic dye (Oil Red O) to enhance visual observation of NAPL (Figures 2 and 3). Prior testing determined that these visual methods were capable of detecting site-specific NAPL saturations as low as 1% of pore space. Direct-push borings were continuously sampled from ground surface to refusal at the top of bedrock, and were advanced using dual-tube methods to allow reliable grouting of boreholes upon completion of sampling. Occurrences of visible NAPL were interpreted as either residual NAPL (pink cross-hatched zones on Figure 3) and or pooled (potentially mobile) NAPL (solid red on Figure 3). The purpose of this delineation

was to identify the portion of the Site where NAPL is unambiguously present, so that remediation could be evaluated. At the request of USEPA, the NAPL zone was defined using only these data in conjunction with the locations of observed NAPL at monitoring and extraction well locations (USEPA Technology News and Trends, 2004 and Appendix C of the FS, 2005). The resulting target area was 6,900 m² (1.7 acres), with a total soil volume of 36,000 m³ (47,000 yards³).

The delineation results were interpreted to evaluate the lateral and vertical distribution of pooled and residual NAPL in this soil volume (Appendix D of the FS, 2005).

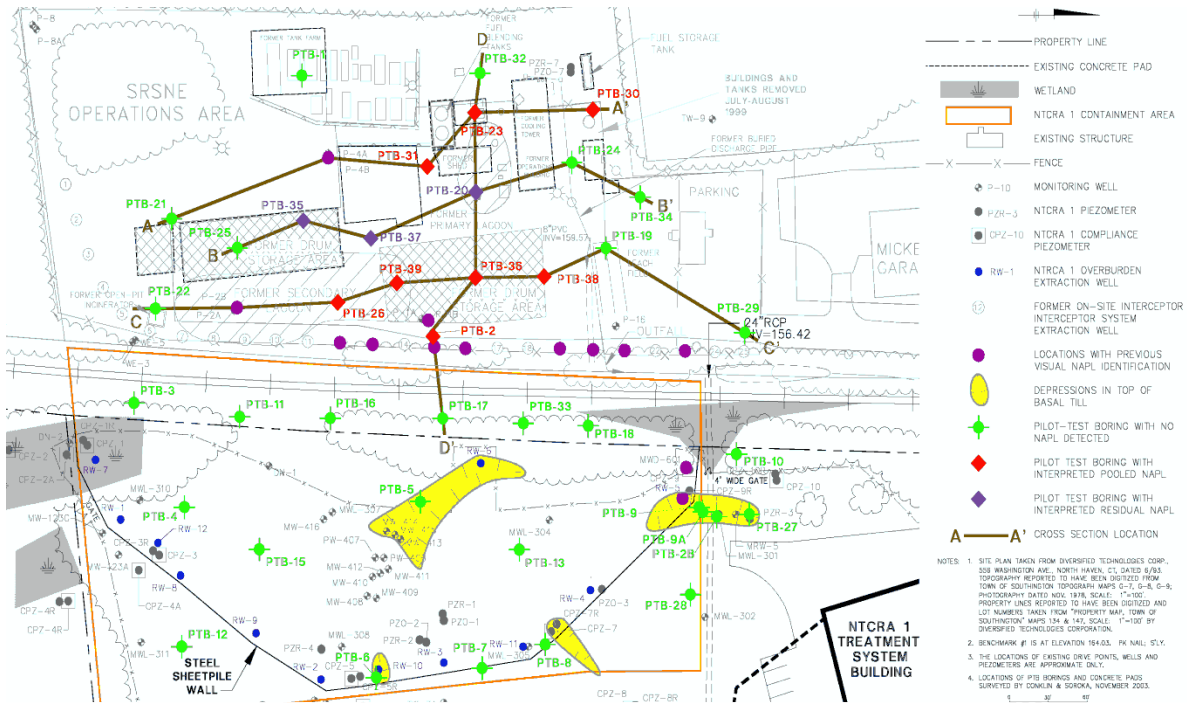


FIGURE 2. Overburden NAPL delineation results.

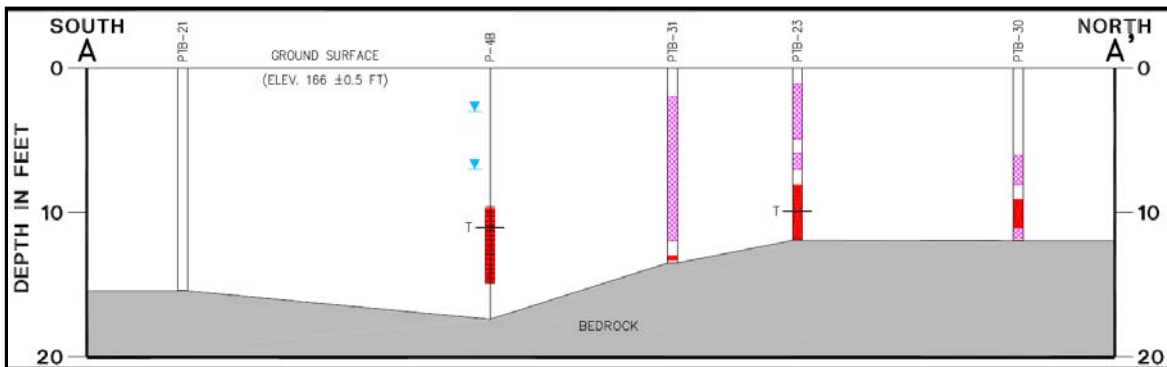


FIGURE 3. A-A' cross section.

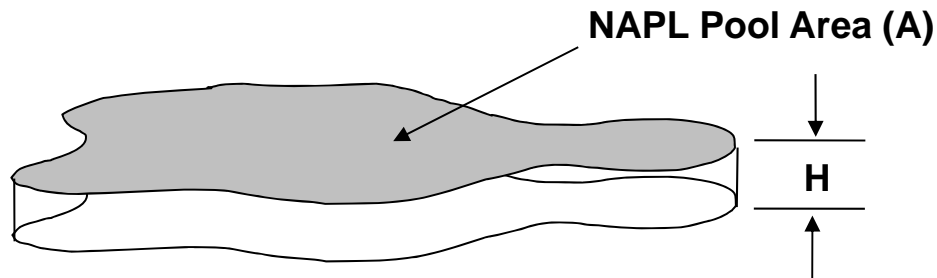


FIGURE 4.

Zones containing residual NAPL were assigned an average NAPL saturation of 10% of pore space. Site-specific parameters were used to calculate NAPL volume per unit volume of soil containing interpreted pooled NAPL using the following equation (Appendix E of the FS, from Longino, B.L. and Kueper, B.H., 1995).

$$V_n = A\phi \left(H - S_r H - \frac{P_d^\lambda (1 - S_r)}{(1 - \lambda)(\Delta\rho g)} \left[(P_d + \Delta\rho g H)^{1-\lambda} - P_d^{1-\lambda} \right] \right)$$

Total overburden NAPL mass was estimated to be in the range of 230,000 to 910,000 kg (507,100 to 2,006,200 pounds). Overburden NAPL was estimated to comprise 84% of the total VOC mass present at the site.

RESULTS AND DISCUSSION

ISTR Performance Standards. The Record of Decision (ROD) (USEPA, 2005) set an expectation that the remedy would remove 95% to 99% of the NAPL mass, and that the RD would establish the ISTR-specific performance standards. The ROD also determined that restoration of groundwater to drinking water quality is technically practicable, with a restoration timeframe of approximately 225 years. Groundwater restoration will be controlled by reverse diffusion of stored VOC mass from bedrock (FS Appendix F).

The Statement of Work (SOW) attached to the 2008 RD/RA CD states: "VOC contamination shall be reduced to levels that are not indicative of the presence of pooled or residual NAPL". Clean up levels were developed by USEPA and established in the SOW. Sensitivity analysis of aquifer and NAPL characteristics resulted in the following "Interim NAPL Cleanup Levels" being established in the SOW for soil from the ground surface to the top of bedrock:

Trichloroethene (TCE) – 222 mg/kg
 Tetrachloroethene – 46 mg/kg
 1,1,1-Trichloroethane – 221 mg/kg
 Ethylbenzene – 59 mg/kg

Toluene – 48 mg/kg
 p/m Xylene – 70 mg/kg
 o-Xylene – 42 mg/kg.

Quantitative clean up levels were essential to the bidding process used to better define ISTR costs for the PRP's settlement. The SOW provided for a process to continue

ISTR for a period of time after achievement of Interim NAPL Cleanup Levels in areas where “EPA determines that appreciable amounts of NAPL continue to be recovered”. The 100% Design and Remedial Action Work Plan for ISTR (100% Design) established a process to demonstrate compliance that involved collecting soil samples at centroids between ISTR heaters. Fifty sampling locations were identified, and up to three samples were collected from random depths at each location (number of samples depended on depth to bed-rock).

ISTR Wellfield Installation.

The ISTR well field was installed between April and September 2013. ISTR required installing 733 heaters and monitoring points 3 feet into bedrock through an area where NAPL had already been encountered at 20 locations, 13 of which had interpreted or known pooled NAPL, and the total NAPL mass in the overburden was estimated to range from 230,000 to 910,000 kg (507,100 to 2,006,200 pounds). Therefore, well installation was conducted following protective measures to avoid mobilizing further NAPL into bedrock. Protective measures included use of dual-casing roto-sonic drilling, stopping at the top of rock to check for, and remove NAPL (if accumulated), and checking for and removing NAPL prior to installing the well and removing the casing.

Heaters were installed along the periphery of the treatment zone, to offset the influence of inflowing cool groundwater. NAPL was detected at numerous locations during heater installation, including three locations at the periphery of the treatment zone. Additional NAPL delineation was performed using Oil Red O hydrophobic dye testing, and the treatment zone was expanded to incorporate the additional NAPL areas. The FS delineation used a Geoprobe® to define refusal, and heater installation used roto-sonic methods, resulting in an approximately 3 foot deeper wellfield than estimated in the FS. The final volume of 42,050 m³ (55,000 yards³) is a 21% increase over the FS estimate. This resulted in the need, during construction, to lengthen heaters, redesign the circuitry, and increase the power supply to 6300 KVA (Figure 5).

ISTR Vapor Phase Treatment. Based on the assumption of up to 460,000 kg VOCs to be treated with ISTR, at a fuel value of 13,000 BTU/lb (30.28 megajoule/kg), a significant focus of the ISTR design was selection of an adequate treatment train for extracted vapors.

The selected approach consists of condensation (primarily to remove water vapor), thermal oxidation, and acid gas scrubbing. The key question revolved around the most cost-effective oxidizer sizing. Too small, and the treatment system would not be able to adequately treat the extracted VOCs – running the risk of either exceeding maximum allowable stack criteria and violating the CD, or prolonging the treatment duration. Too large, and significant capital and operations and maintenance costs would be incurred

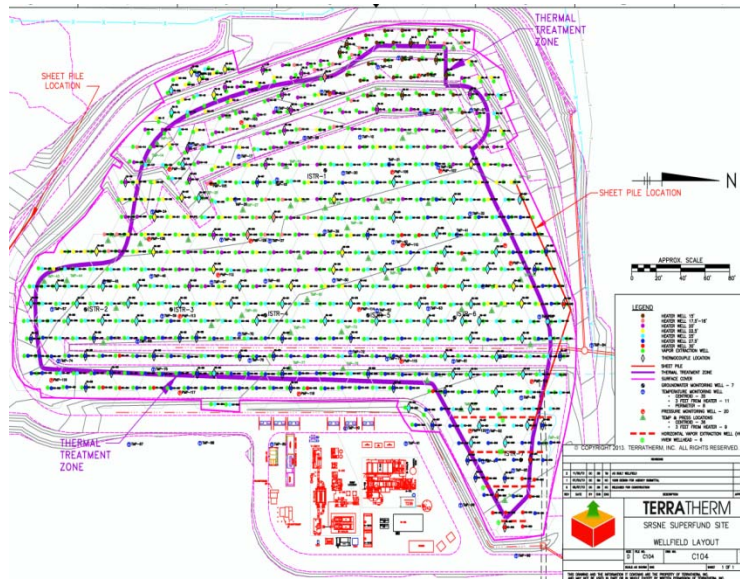


FIGURE 5. Final ISTR wellfield.

for “excess” treatment capacity. Additional analysis during design found a higher than anticipated fuel value in the NAPL, which created concerns that the design VOC throughput of the thermal oxidizer might be exceeded (a given size oxidizer can only handle a certain amount of fuel). Coupled with the wide range in potential mass to be extracted, a revised approach was incorporated into the design.

This approach splits the Site into two phases, with heating of the second half to be initiated after the peak VOC production from the first is completed. This concept is illustrated in Figure 6. The actual mass removal is shown on Figure 7.

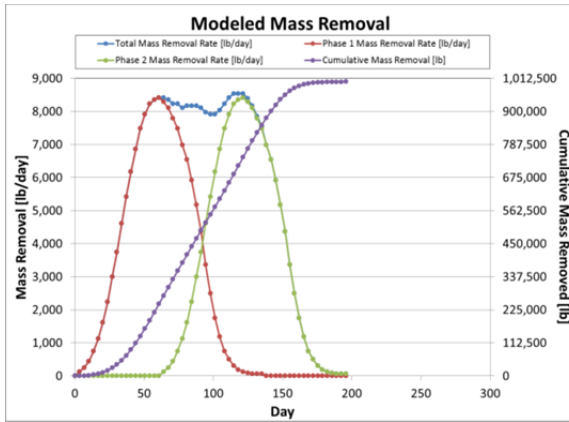


FIGURE 6. Modeled VOC removal.

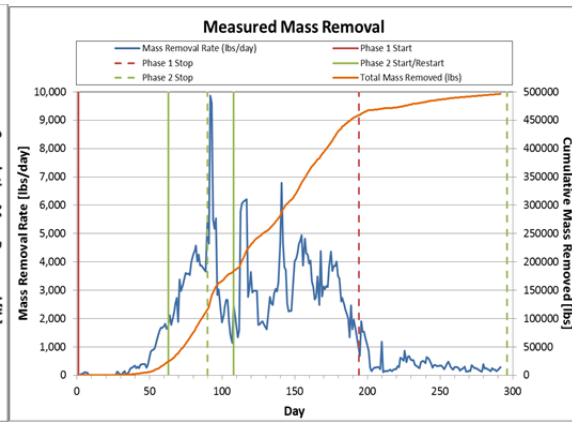


FIGURE 7. Actual VOC removal.

During ISTR operation, damage occurred to the “daisy wheel” — the combustion chamber flow distributor as a result of temperatures in the oxidizer pre-heat heat exchanger exceeding lower flammability limits (LFL). Heating was suspended, and the vapor control system switched to back up vapor phase GAC while a root cause analysis and repairs were conducted. The issue was carry over of NAPL from the condensation step into the air stripper and lack of a dilution air sensor upstream of the process vapor inlet to the oxidizer pre-heat heat exchanger. As a result, an organoclay filter was added between the oil-water separator and air stripper, a redundant LFL sensor was installed, an additional temperature sensor was installed at the oxidizer inlet, and reinforcements were incorporated into the replacement daisy wheel. Heating was restarted in Phase 1, and slowly ramped up for Phase 2.



Compliance Soil Sampling. The 100% design contemplated a “weight of evidence” approach to trigger soil sampling to demonstrate compliance with clean up requirements. These included: achieving soil temperatures above DNAPL/water azeotrope temperature (75°C to 80°C), preferably closer to 100°C, demonstrating decreasing trends in vapor phase VOC mass removal rates (e.g., <100 lbs/day [45.4 kg/day]), results from interim soil sampling that indicated soil clean up levels were already met, a lack of “hot spots” indicated by vapor extraction well and manifold piping vapor phase sampling,

diminishing groundwater VOC concentrations, and a review that indicated the energy balance and temperature data were consistent.

In Figure 8, every orange dot and red circle represents a compliance or interim sampling location, where up to three soil samples were collected at depths determined by random number generator. Sampling locations were at “centroids” between heaters, so as not to negatively bias the results. Three shallow compliance soil samples did not meet cleanup criteria on first sampling, resulting in continued operation, adding surface insulation, and raising heaters within the wells to better treat shallow soil. Subsequent re-sampling met cleanup requirements.

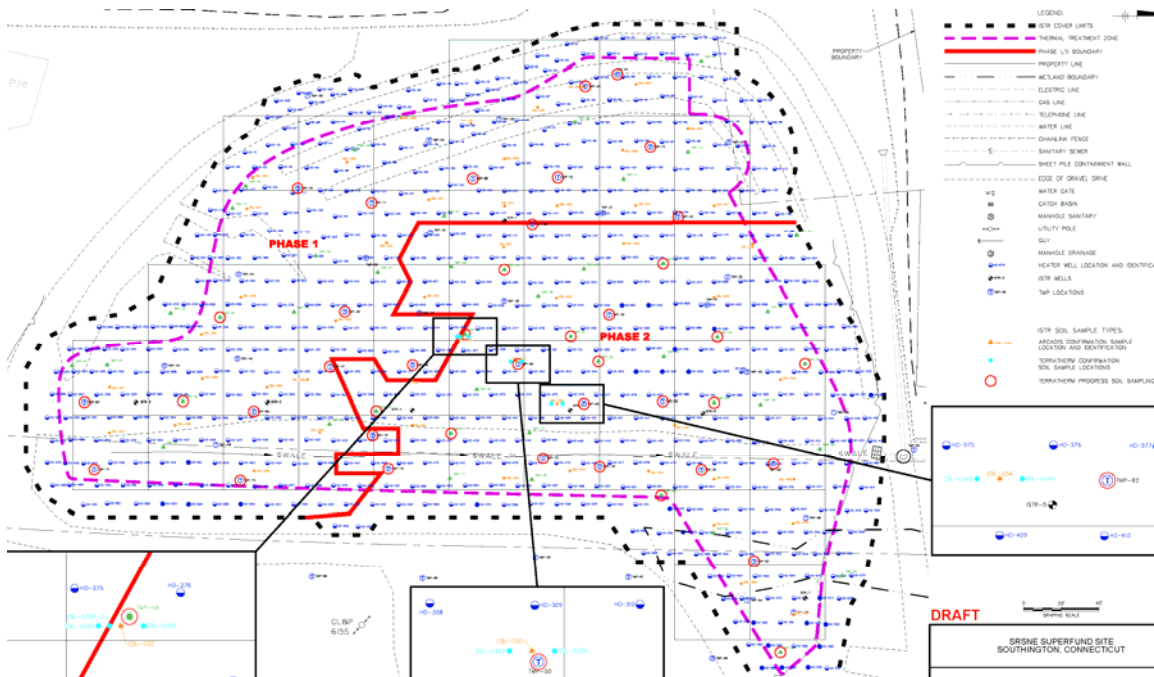


FIGURE 8. Confirmatory sampling locations.

Agency Communications. Successful projects require routine, detailed and collaborative communications and sharing of data with all stakeholders. During construction and operation, weekly reports and team conference calls were held with USEPA and CTDEEP representatives, along with Web-based access to real-time soil temperatures. Summary reports presented key data to support Agency decisions to shut down portions or all of a treatment phase. At an operational cost of approximately \$20,000 per day, it is worthwhile to effectively communicate with the regulatory team.

Groundwater Sampling Results. Groundwater was sampled at wells within and immediately downgradient of the ISTR zone prior to, during and after ISTR treatment. Monitoring locations are show in Figure 9. An example result for a well located in a former lagoon within the ISTR Zone is in Figure 10, showing > 2 orders of magnitude decrease in total VOCs. Of note are the rapid decline to non-detect of 1,1,1-trichlorethane after the initiation of heating, and that cis-1,2-dichloroethene, a breakdown product of trichloroethene degradation is the dominant residual VOC after treatment.

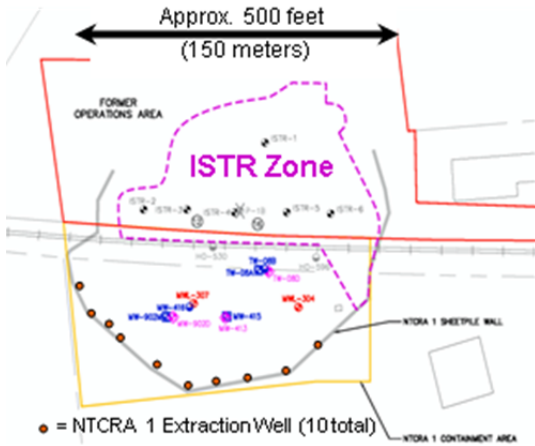


FIGURE 9. Monitoring locations.

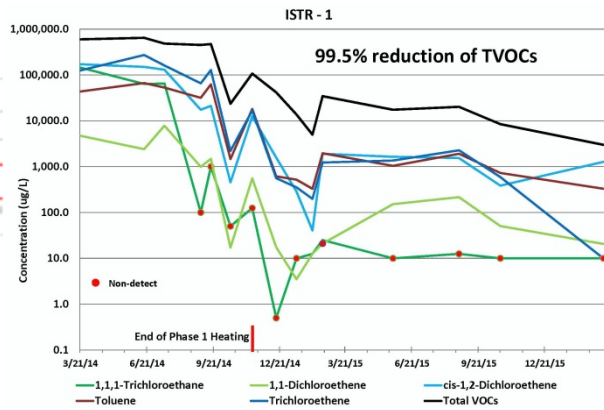


FIGURE 10. ISTR Groundwater VOCs.

Figure 11 illustrates the effects of ISTR observed at extraction wells downgradient of the ISTR treatment zone. At a point in time reasonably consistent with the groundwater travel time from the ISTR treatment zone to the point of extraction, decreases in total VOCs in the pumped flow are observed simultaneously with an eight-fold increase in the chloride levels. Background chloride is ~8 mg/L, and pre-ISTR influent was ~34 mg/L (associated with ongoing biodegradation of chlorinateds prior to ISTR). Post-ISTR, chloride increased to ~267 mg/L, indicative of further degradation of chlorinated contaminants.

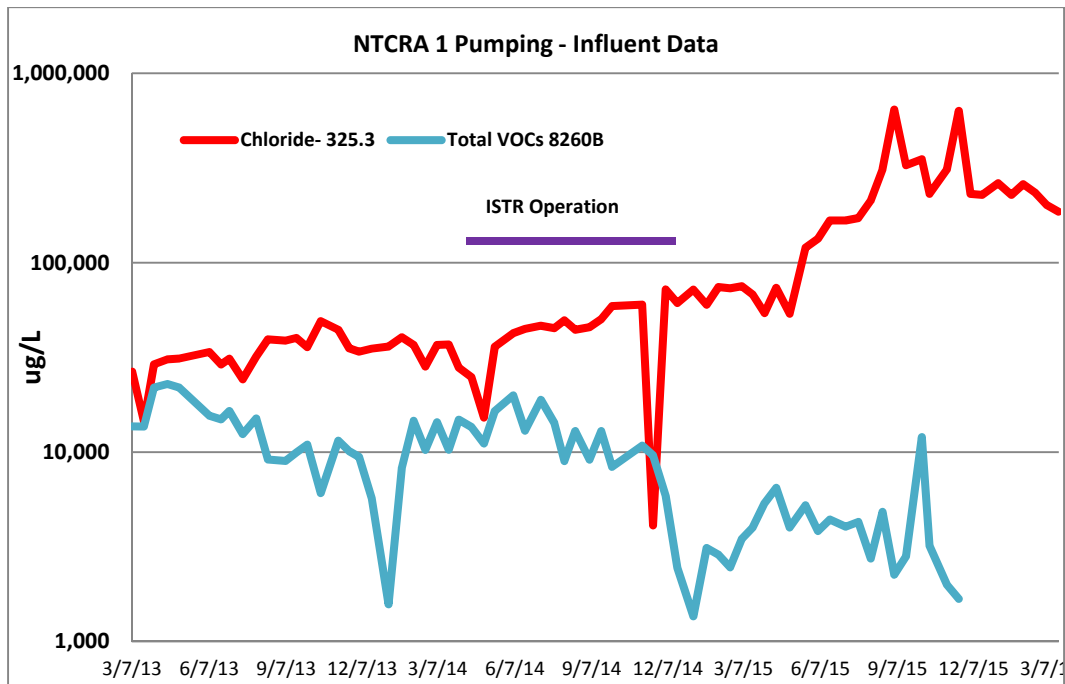


FIGURE 11. VOCs and chloride levels at downgradient extraction wells.

CONCLUSIONS

As documented in USEPA's September 2015 "Remedial Action Report Approval" and its associated ISTR Construction Completion Report, the ISTR system operated May 2014 to February 2015, resulting in removal of 496,400 pounds (225,000 kg) of VOC contamination, which equates to 99.7% VOC mass removal from soils. The soil cleanup levels were met at all locations. Average soil concentrations dropped from 2,795 mg/kg to 5.62 mg/kg total VOCs (TVOCs), approximately two orders of magnitude below requirements. Within the ISTR zone, a 95% reduction in average groundwater TVOC concentrations was achieved, with no "rebound" to date. A 99%+ Destructive Removal Efficiency was achieved for treatment of recovered vapors. No evidence of downward migration of NAPL due to drilling has been observed utilizing a significant number of downgradient monitoring wells.

ISTR achieved a key RAO, preventing future migration of NAPL, which effectively reduces the overall risk of the site. Preventing additional NAPL migration into bedrock and removing a significant mass of VOCs is expected to help meet another aspect of the RAO, which is to shorten the timeframe that groundwater standards are exceeded. In addition, groundwater concentrations have continued to decline at the extraction system immediately downgradient of the ISTR area, which will result in more cost-effective treatment options over time. Based on the Second Five-Year Review Report issued by USEPA in 2015, VOC concentrations in groundwater are generally declining or constant, and the size of the VOC plumes has decreased, indicating that the final component of the RAO has been met.

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