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Groundwater Plume Evolution Following In Situ Thermal Remediation

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Abstract: Solvents Recovery Service of New England, Inc. (SRSNE) processed over 100 million gallons of solvents between 1955 and 1991. Storage in unlined lagoons and other releases produced a nonaqueous-phase liquid (NAPL) source zone in overburden and fractured bedrock. EPA's September 2005 Record of Decision (ROD) selected a remedy that included in situ thermal remediation (ISTR) for NAPL in the overburden. ISTR was successfully implemented from May 2014 to February 2015, removing 225,000 kilograms (kg) of volatile organic compounds (VOCs) from 43,400 cubic meters (m^3) of soil. Data loggers recorded groundwater temperatures daily from February 2009 to present in five of the wells identified by the Remedial Design/Remedial Action (RD/RA) Work Plan. Temperature fluctuations were filtered from the data by subtracting the average pre-ISTR temperature for each calendar date from the daily temperature measured during and after ISTR. Six VOC parameters were chosen as representative compounds of the major classes of VOCs present on site. Approximately one year after the completion of heating, the warm-water "plume" in groundwater has migrated downgradient and appears to have peaked at the shallow overburden wells. Several compounds show a common trend of decreasing and then rebounding. Methane and ethane consistently increased. This may be due to biodegradation of compounds, accelerated by the increased water temperature. Post-ISTR monitoring will continue until equilibrium is established.

INTRODUCTION

The SRSNE Superfund site is located in Southington, Connecticut. Historically, SRSNE performed solvent recovery and processed wastes from multiple fuel based operations, from 1955 to 1991 (ARCADIS 2010). The waste materials (still bottoms) were disposed of in lagoons (through 1967), an open pit incineration (1967–1973), and drums (ARCADIS, 2010). Site operations released complex non-aqueous-phase liquids (NAPL) to the subsurface. Field investigations at the site identified NAPLs in fill materials, glacial overburden deposits and fractured bedrock (ARCADIS 2010).

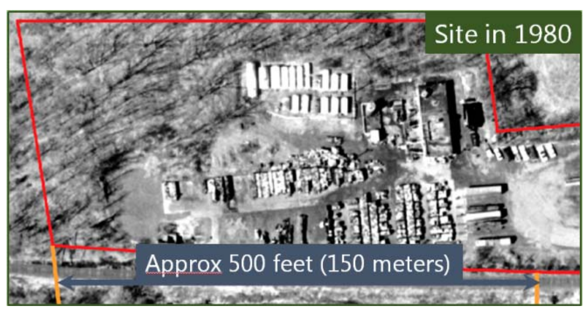

FIGURE 1. Site in 1980.

FIGURE 2. Site in 2014, with ISTR installed.

The Site was placed on the National Priorities List in 1983. USEPA conducted two removal actions and three phases of

Remedial Investigation (RI) work between 1990 and 1994. The Potentially Responsible Parties Group (Group) formed in 1993, and has completed two Non-Time-Critical Removal Actions (NTCRAs), the 1998 RI Report, and the 2005 Feasibility Study (FS) Report.

ISTR was selected in the 2005 Record of Decision (USEPA 2005). The Group has completed design and construction of the ISTR component of the remedy pursuant to a 2008 RD/RA Consent Decree.

ISTR Implementation and Outcome. The remediation implemented for the overburden NAPL area was ISTR (TerraTherm, 2014). ISTR was used to treat 43,400 m^3 of soil, which was estimated to contain 230,000 to 910,000 kg of VOCs (TerraTherm, 2014). The design used 607 heater wells, and vertical and horizontal vapor extraction wells to remove the gaseous mixture which was then processed via thermal oxidation (TerraTherm, 2014). The ISTR treatment area was split into two phases, in an attempt to prevent the overloading of the oxidizer (TerraTherm, 2014). ISTR heating began on May 15, 2014 and was stopped on February 20, 2015; however, for approximately 40 days the heaters were offline in August to September 2014 (TerraTherm, 2014). Approximately 225,000 kg of VOCs were removed, meeting the soil cleanup levels (***de maximis, inc.*** 2015).

The RD/RA Statement of Work (SOW) requires groundwater monitoring at locations immediately downgradient of the ISTR zone prior to, during, and after ISTR. Monitoring parameters have included temperature, VOC concentrations and MNA parameters. The purpose of the monitoring is to determine when post-ISTR “equilibrium” temperatures are restored.

MATERIALS AND METHODS

Temperature Data Analysis. In-Situ™ Troll data loggers were installed in five wells (two shallow overburden wells, one middle overburden well, one deep overburden well, and one shallow bedrock well) in 2009 and programmed to record data twice daily. Pre-ISTR temperatures fluctuated seasonally by up to 15^{o}C (Figure 3). To create a seasonally adjusted baseline dataset and help identify groundwater warming due to ISTR, pre-ISTR data were averaged for every calendar date. Data collected during and after ISTR were averaged on a daily basis, and the daily baseline data were subtracted to identify temperature increases relative to baseline conditions.

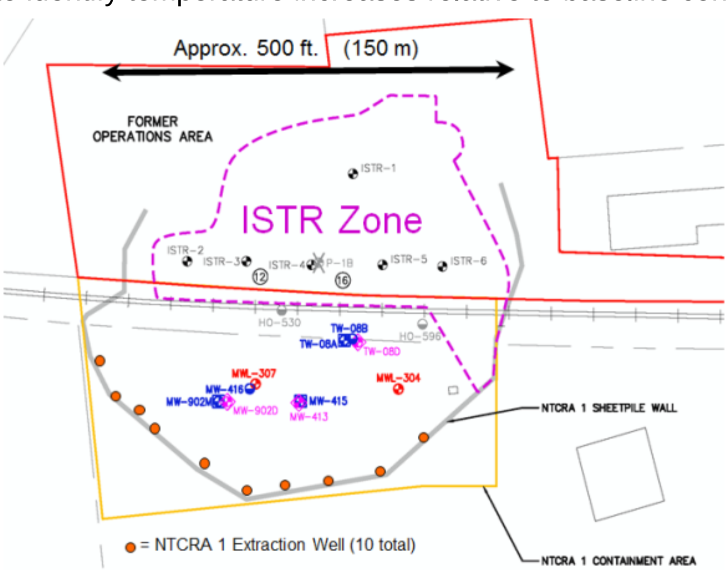

FIGURE 3. Site layout with ISTR zone, selected monitoring wells, and NTCRA 1 overburden groundwater extraction wells.

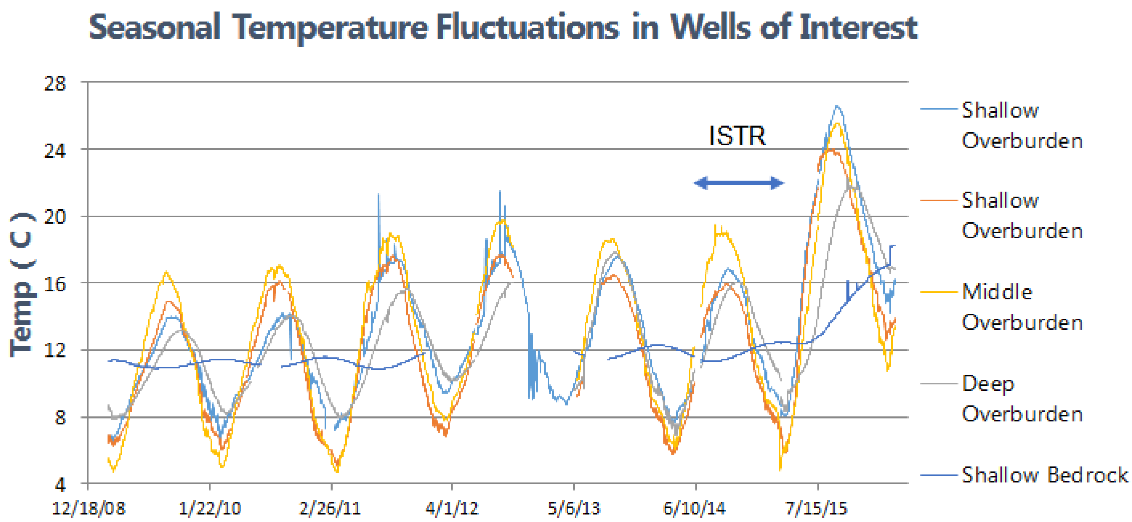

FIGURE 4.Temperature fluctuations at monitoring wells approximately 25 meters downgradient of thermal treatment zone. Blue "ISTR" arrow indicates when thermal treatment occurred.

VOC Data Analysis. Thirty-five VOC parameters have been measured routinely at the site since 1996. This analysis compares data immediately prior to ISTR implementation (2014) to the present at select monitoring wells at different depths within the overburden and shallow bedrock. As there are different classes of compounds present on site, specific chemicals were selected for detailed analysis as representative compounds.

The NTCRA 1 system includes 10 overburden groundwater extraction wells and a steel sheet-pile wall that extends from the ground surface to the top of bedrock, and has contained the highest dissolved VOC concentrations since 1995. The combined discharge from these wells is also being evaluated for changes that may relate to ISTR affects. Locations of the NTCRA 1 extraction wells are shown as orange dots on Figure 3.

RESULTS AND DISCUSSION

Groundwater temperatures have increased following ISTR startup. Approximately one year post-ISTR, temperatures continue to increase in some of the wells, while others may have reached and passed peak temperature (Figures 5, 6, and 7). The shallow overburden wells have peaked at a time reasonably consistent with thermal dissipation model predictions; however, peak temperature increases at these wells are approximately half of those predicted by the model. The deeper wells show consistently slower warming with increasing depth; the bedrock well has still not reached peak temperature.

Multiple wells show two temperature "peaks"; the period between the peaks may relate to an approximately one-month period when the ISTR heater wells were not operating (see temperature in Figures 5 and 6 as examples).

VOC Data Results. VOC data changes are not consistent across all monitoring wells. However, degradation products such as methane, ethane and ethane and consistently increased – some by over two orders of magnitude. Vinyl chloride has decreased over two orders of magnitude at select overburden monitoring wells, indicating enhanced degradation, which is attributed in part to the increase in groundwater temperatures.

Complete chlorinated VOC degraders such as *Dehalococcoides* have been confirmed in site groundwater (ARCADIS 2014).

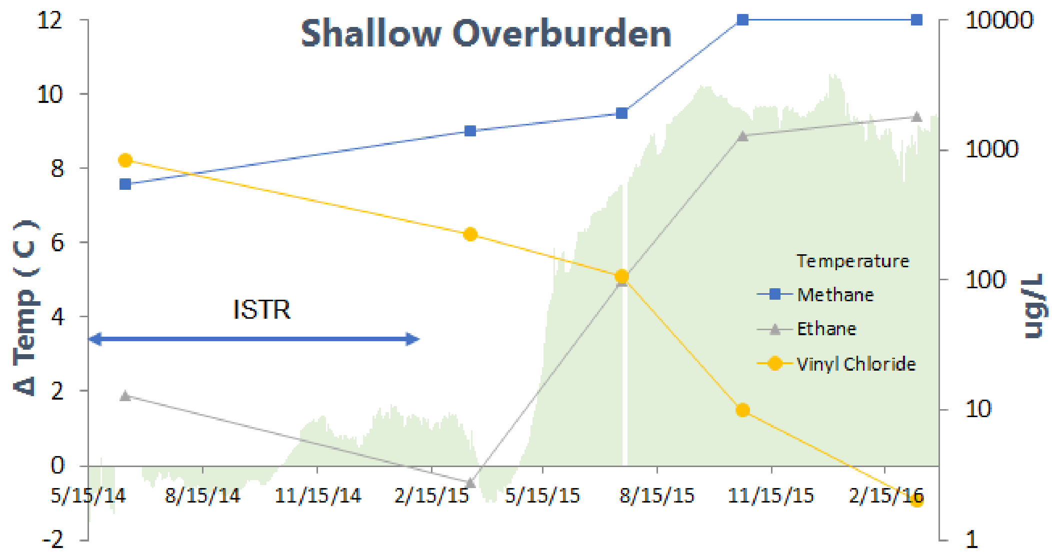

FIGURE 5. Temperature changes and chemical concentrations at shallow overburden monitoring well MWL-307. Note the simultaneous decrease in vinyl chloride with the increase of methane and ethane. Blue "ISTR" arrow indicates when thermal treatment occurred.

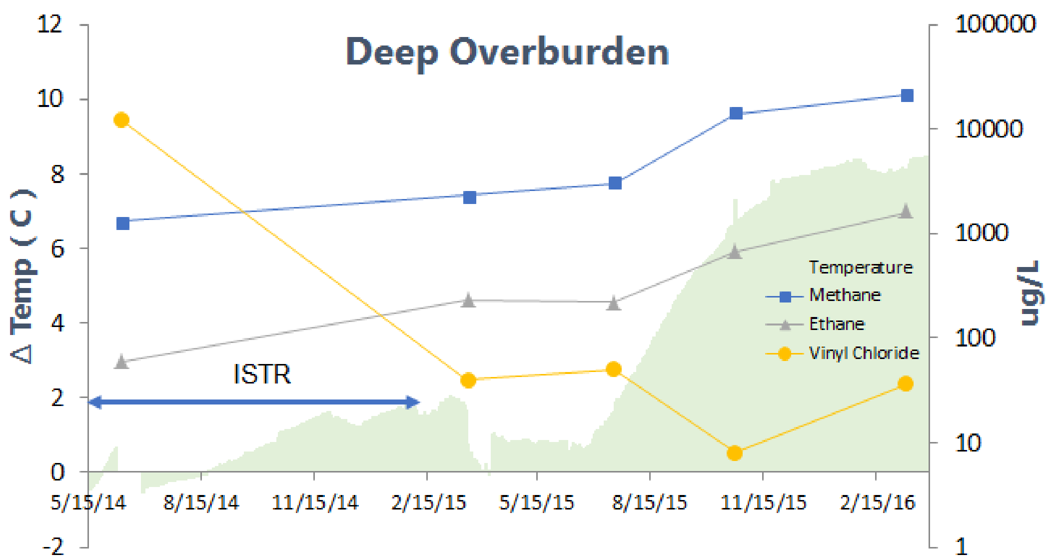

FIGURE 6. Temperature changes and chemical concentrations at deep overburden monitoring well MW-415. Note the decrease in vinyl chloride with the increase of methane and ethane. However, temperature and chemical data is slower than the shallow overburden. Blue "ISTR" arrow indicates when thermal treatment occurred.

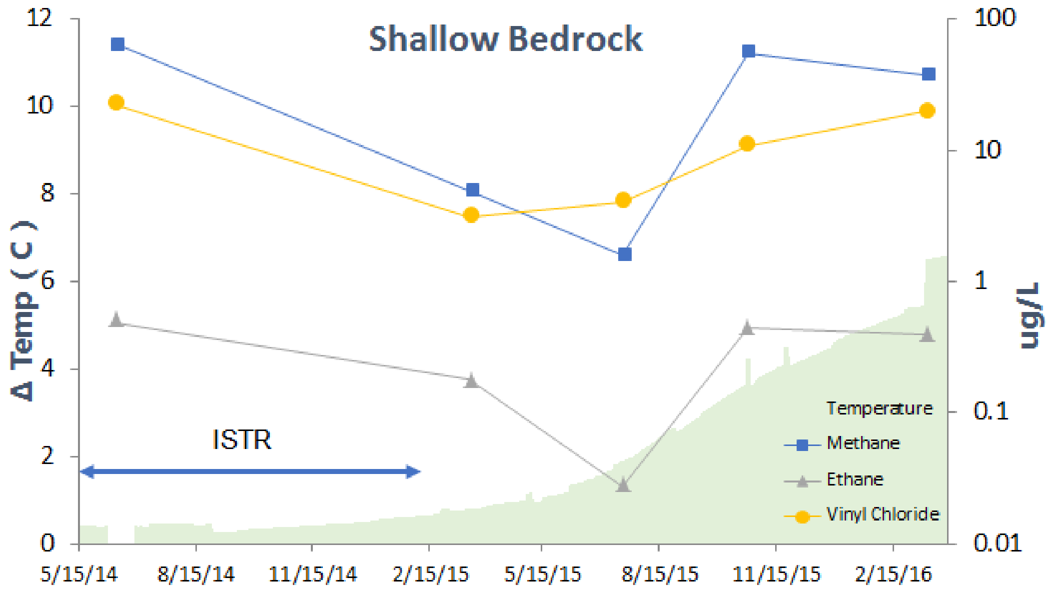

FIGURE 7. Temperature changes and chemical concentrations at shallow bedrock monitoring well MW-416. The lack of consistent concentration changes and the slower temperature change are attributed to the fact that this well is within the bedrock, which is approximately one order of magnitude less permeable than the overburden. Blue "ISTR" arrow indicates when thermal treatment occurred.

NTCRA Chloride Results. Chloride concentrations in the combined water pumped from the 10 NTCRA 1 extraction wells increased by approximately a factor of 8 following ISTR implementation (Figure 8). The timing of the chloride increase is consistent with the calculated average groundwater travel time from the ISTR area to the NTCRA 1 groundwater extraction wells, following the beginning of heating. Total VOC concentrations have decreased. These changes are attributed to enhanced degradation due to the rise in temperature (Fletcher, Kelly E., et al., 2011).

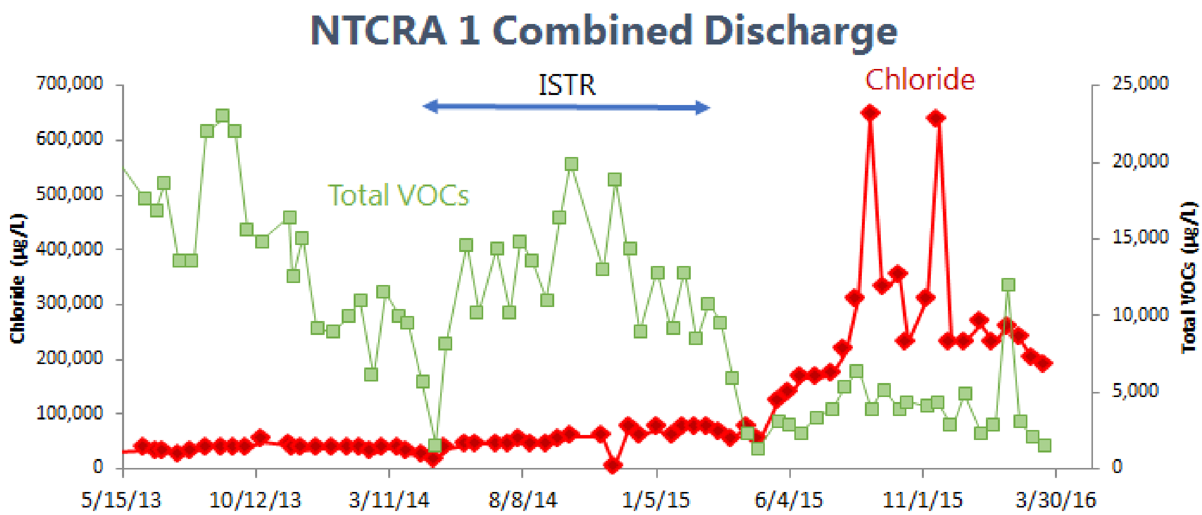

FIGURE 8. Chloride (red) and total VOC concentrations (green) in NTCRA discharge (untreated). Blue "ISTR" arrow indicates when thermal treatment occurred.

CONCLUSIONS

The temperature data indicate that the heat "plume" in the overburden has moved at approximately the rate predicted by pre-ISTR modeling, but has reached a peak temperature increase approximately half of that predicted by pre-ISTR modeling. In general, the shallower wells have been affected more than deeper wells; this has also been seen in the VOC data. VOC data trends in the area downgradient of the ISTR zone vary from compound to compound and well to well since the beginning of heating. Several compounds show a common trend of decreasing and then rebounding in the subject wells. Vinyl chloride has inconsistent changes, with shallower wells generally showing significant decreases. Methane and ethane consistently increased; ethene also increased but less consistently between the various wells. Degradation of chlorinated compounds appears to have accelerated due to the increased water temperature – a chloride "spike" was observed in NTCRA influent data. This chloride "spike" arrival time matches estimated groundwater velocity. Post-ISTR monitoring will continue until equilibrium is established.

ACKNOWLEDGMENTS

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