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35 Years of Conceptual Site Model Evolution at the SRSNE Superfund Site

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ABSTRACT: The Solvents Recovery Service of New England, Inc. (SRSNE) Superfund Site (Site) has been the subject of multiple rounds of investigation, removal actions, and remediation over the past 35 years. The initial focus was delineating volatile organic compound (VOC) groundwater plumes. The Remedial Investigation (RI) process further delineated the VOC plumes and the extent of nonaqueous-phase liquids (NAPLs) in overburden and bedrock, estimating the subsurface VOC mass, and evaluating the potential for natural attenuation of VOCs. During the Feasibility Study (FS), different methods were used to estimate the extent and mass of overburden NAPL. *Dehalococcoides* were confirmed present, adding a line of evidence to the natural attenuation analysis. Remedial Design / Remedial Action (RD/RA) work has included: completing the delineation of the bedrock VOC plume, estimating the extent of the bedrock NAPL zone and refining the estimate of bedrock NAPL mass, continued hydraulic containment and monitoring of the VOC plumes, a quantitative polymerase chain reaction (qPCR) microbial population study, and in situ thermal remediation (ISTR) of overburden NAPL. ISTR was completed in 2015, removing 225,000 kg of VOCs. In 2015, a groundwater conceptual site model (CSM) update was prepared in support of the second five-year review, consistent with EPA's 2014 Groundwater Remedy Completion Strategy.

INTRODUCTION

Site Description. The SRSNE Site is located in Southington, Connecticut. Between 1955 and 1991, SRSNE processed more than 100 million gallons of solvents and other organic liquids taken in from more than 2,000 customers located throughout New England. Still bottom sludge disposal to lagoons and other releases resulted in multi-component NAPLs that contain chlorinated alkenes and alkanes, aromatic and aliphatic hydrocarbons, tetrahydrofuran, ketones, alcohols, 1,4-dioxane, and polychlorinated biphenyls. The particular mixture of VOCs at a given location results in dense, light, or neutrally buoyant NAPLs, collectively termed "NAPL" in this paper. NAPL and associated aqueous phase VOC plumes are present in glacially-derived overburden deposits and fractured bedrock.

VOCs were detected in the late 1970s at two town water supply wells and one private well (see Figure 1). These detections prompted investigations to identify the VOC source(s), and the site was considered one of the likely sources. Further investigations were conducted by the Town Water Department, the U.S. Environmental Protection Agency (EPA) and by SRSNE in the early 1980s.

The site was added to the National Priorities List (NPL) on September 8, 1983. EPA 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 1993, and completed two Non-Time-Critical Removal Actions (NTCRAs), 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). The RD/RA has incorporated additional groundwater studies and NAPL delineation and remediation.

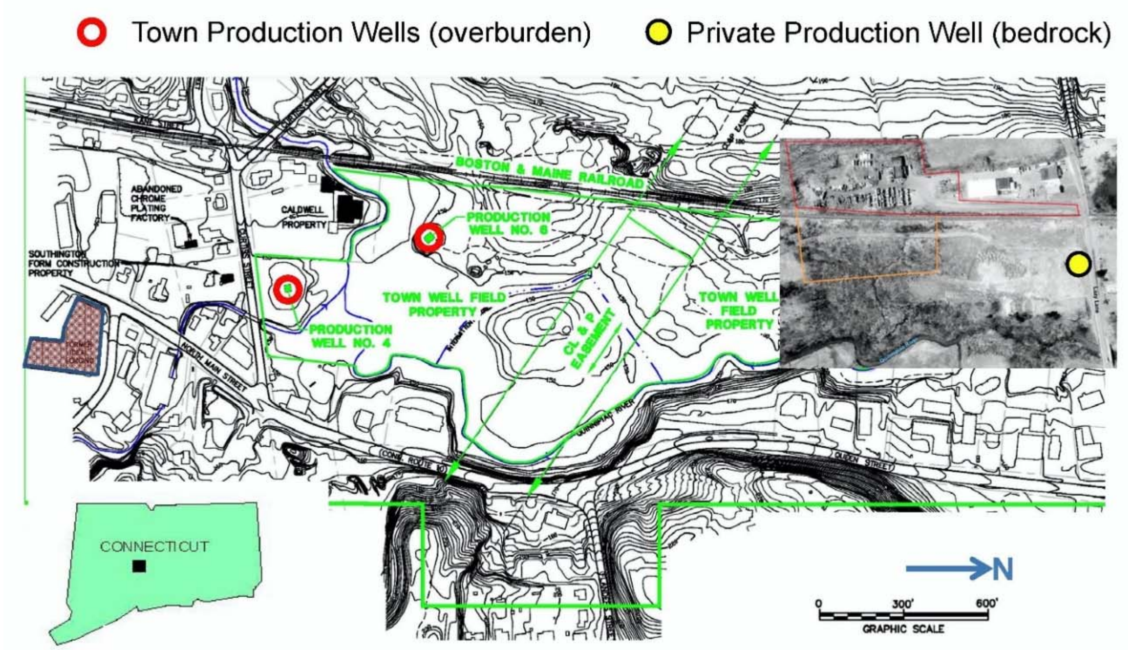

FIGURE 1. Site vicinity.

Objective. The Site has been intensively studied for the past 35 years, during which the conceptual site model (CSM) has significantly evolved, largely due to the detailed analysis of substantial data collected using improved characterization methods.

MATERIALS AND METHODS

Approach/Activities. The groundwater studies in the late 1970s and early 1980s supported the NPL listing process and focused on identifying the perceived sources of VOCs that had resulted in closure of two overburden municipal production wells. Although the monitoring network was limited in extent, it started the delineation process for the aqueous phase VOC plumes in overburden and bedrock. The evolution and expansion of the monitoring networks over time is illustrated in Figures 2 and 3.

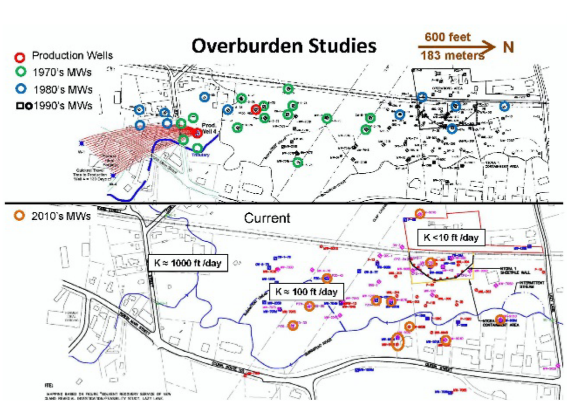

FIGURE 2. Overburden monitoring.

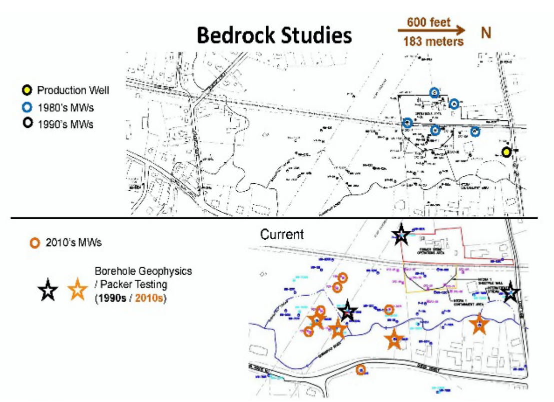

FIGURE 3. Bedrock monitoring.

EPA's RI work in the early 1990s focused on delineating the nature and extent of contamination in soil, sediment, surface water and groundwater. After three phases of field investigation, EPA recognized that significant data gaps still existed in the 1994 draft RI Report.

In conjunction with the second NTCRA conducted to hydraulically contain impacted overburden and bedrock groundwater, the PRPs completed the RI and all subsequent work. The 1995 RI Work Plan presented a Preliminary Conceptual Site Model (CSM) that included both a hydrogeologic and a migration and exposure CSM. These models incorporated the discovery of NAPL at nine locations in 1995 during the first NTCRA, which was conducted to hydraulically contain the most impacted overburden groundwater.

The RI field work incorporated robust bedrock characterization, with borehole geophysics and packer testing to quantify bedrock apertures and hydraulic conductivity. Bedrock sampling and analysis demonstrated the presence of VOCs within the sandstone matrix. The RI field work also included analysis for methane, ethane, ethene and phospholipid fatty acids, which supported the first assessment of natural attenuation processes at the site, and concluded that there was "strong evidence for biodegradation of chlorinated organics."

One important aspect of the second NTCRA in 1998 was development of a MODFLOW model for use in hydraulic containment evaluation and capture zone analysis. The long axis of the VOC plume deviates significantly from the hydraulic gradient direction, as shown in Figure 4 (depicting shallow bedrock).

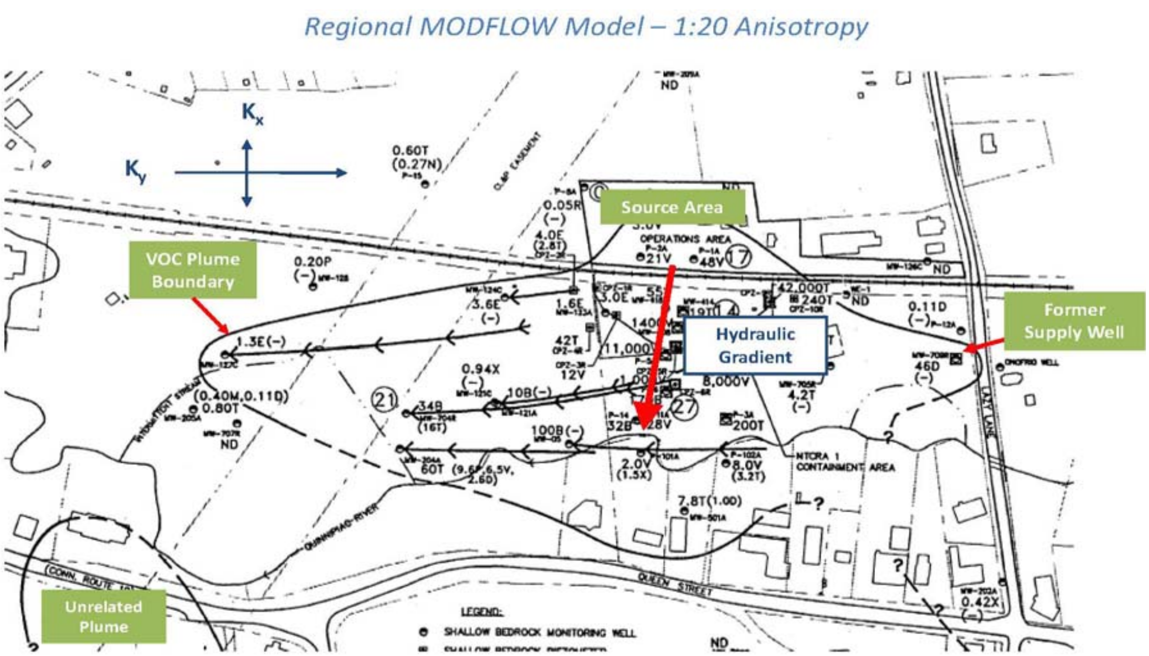

FIGURE 4. Calibration of anisotropy by reverse particle tracking.

The plume extends mainly southward at a significant angle to the hydraulic gradient direction. This strong anisotropy in the horizontal plane is attributed to the presence of a single predominant fracture set oriented approximately north-south. At first, the modelers could not match the flow directions to the plume axis, even when the modeled water levels closely matched those measured at the wells. Based on the fracture data, however, the theoretical ratio was calculated between the higher permeability in the north-south direction, approximately parallel to the predominant fracture strike, versus the lower permeability in the east-west direction, approximately perpendicular to the strike. By changing the horizontal permeability ratio to match the calculated bedrock anisotropy of 20 to 1, a reasonable match was produced between the simulated flow lines (shown with black arrows), and the overall shape of the bedrock VOC plume.

The 1998 RI Report updated the CSM, incorporating the following: estimates of the extent and mass of NAPL and aqueous VOCs in overburden and bedrock; the likely effects on of bedrock matrix diffusion on the timeframe to restore groundwater quality; and evaluation of MNA processes and extent.

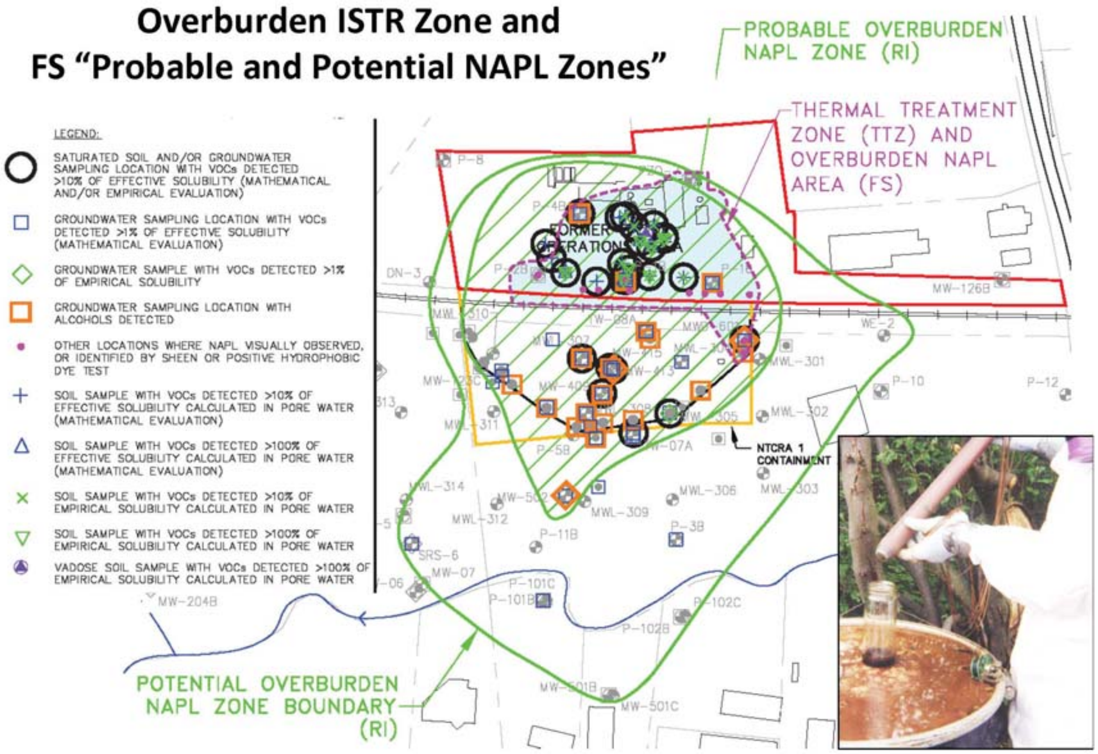

FIGURE 5. Overburden NAPL delineation.

As shown in Figure 5, for the RI, the "probable" overburden NAPL zone was defined using a weight of evidence approach using groundwater and soil data and other indirect indicators. A larger "potential" NAPL zone served as a "safety factor" around the "probable" zone. In the RI, a similar weight of evidence approach was used to define probable and potential bedrock NAPL Zones as shown in Figure 6.

CSM refinements in the 2005 FS included re-evaluating the overburden NAPL zone extent and NAPL mass. A series of continuously sampled boreholes were drilled and the distributions of residual or pooled NAPL were interpreted using direct observations of NAPL, including reactions with Oil Red "O" hydrophobic dye. These observations produced a smaller interpreted overburden NAPL zone area and volume, and a smaller estimate of the overburden NAPL mass. Additional CSM changes during the FS included estimating the timeframe for reverse diffusion of VOCs from bedrock, documenting the presence of *dehalococcoides* and estimating biodegradation rates. Based on the reverse diffusion modeling, the 2005 Record of Decision (ROD) states that groundwater is expected to be restored to federal drinking water standards or risk based levels within approximately 225 years.

RD/RA work resulted in completing the delineation of the bedrock VOC plume, estimating the extent of the bedrock NAPL zone and refining the estimate of bedrock NAPL mass, continued hydraulic containment and monitoring of the VOC plumes, a qPCR microbial population study, and in situ thermal remediation (ISTR) of overburden NAPL. In 2015, a Groundwater CSM Update was prepared in support of the second five-year review, consistent with EPA's 2014 Groundwater Remedy Completion Strategy.

RESULTS AND DISCUSSION

Results/lessons learned: The 1980s studies were limited by the extent and vertical coverage of monitoring wells, resulting in a failure to identify a key additional source of VOCs directly in the capture zone of the primary production well. A lack of knowledge of how NAPL migrates in fractured rock and the potential influence of anisotropy within the bedrock, understandable for that point in time, led to an erroneous conclusion that there was "no direct relationship between SRSNE contamination and that found in Cianci's well" (the bedrock production well).

The 1994 RI applied the "1% solubility rule" from EPA's 1992 guidance, but mistakenly concluded that "NAPL was not likely extensive", interpreting that co-solvency effects in a multi-component NAPL result in higher dissolved concentrations for individual compounds (not lower). Since then, NAPL and/or sheens have been observed at 33 locations in overburden and 30 times in bedrock.

In Figure 6, the "Cianci Well" defines the northern edge of the probable bedrock NAPL zone. Detailed understanding of the bedrock characteristics resulted in the conclusion that pumping of the Cianci bedrock production well likely dragged NAPL along the strike of the predominant bedrock fractures, explaining the VOCs detected in that bedrock well. That induced NAPL migration also explains why NAPL was found in PZ-906DR, a bedrock well installed during the RD on the edge of the "potential' NAPL zone defined during the RI. 14 gallons of NAPL was recovered from 100 feet into bedrock during packer testing at this well. The probable and potential NAPL zones were redefined based on this result.

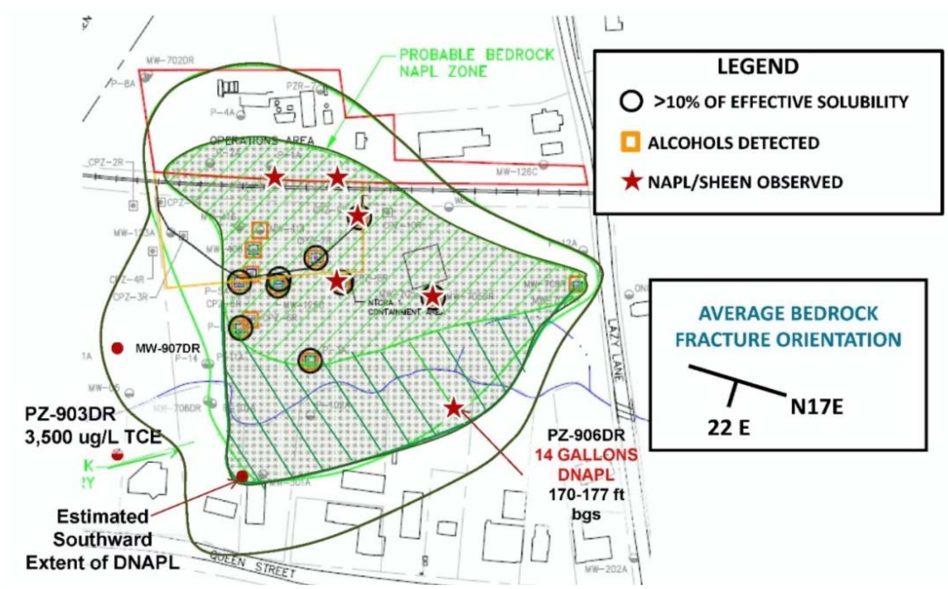

FIGURE 6. Bedrock NAPL delineation.

The red stars on Figure 6 illustrate the locations where NAPL and/or sheens were observed in bedrock wells. Those same stars are shown in the EVS depiction in Figure 7, which illustrates that bedrock NAPL occurs in a relatively thin section, with entry points coincident with the most significant overburden NAPL.

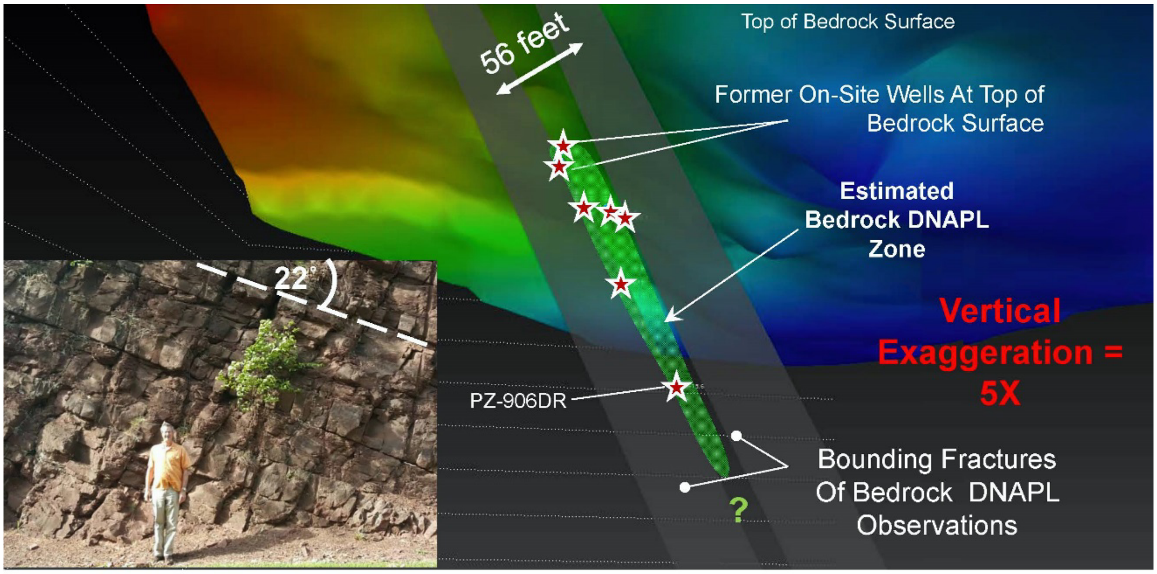

FIGURE 7. EVS bedrock NAPL observations down dip.

These new bedrock data were used to refine the bedrock NAPL mass estimate in a Groundwater CSM Update prepared in 2015. Specifically, the 1998 RI assumed a probable NAPL zone of 6.0 acres by 100 feet thickness, that all fractures were contacted by NAPL, and 60% NAPL retention in each fracture for a total mass estimate of 33,000 kg. The refined estimate assumes 11.5 acres by 60 feet thickness, and that only 20% of the fractures were contacted by NAPL. Longino and Kueper's 1999 study was used as the basis to assume 12% NAPL retention in each NAPL contacted fracture (specific to a 20º dip angle). This resulted in a revised estimated bedrock NAPL mass of 1,500 kg.

The natural attenuation analysis at the site has also improved over time through application of new techniques. In 2014, a baseline microbiology survey was conducted using qPCR analysis. An array of wells was surveyed using Quantarray-Chlor and Quantarray-Petro to enumerate degrading populations. Quantarray-Chlor results indicate robust communities capable of both full reductive dechlorination to innocuous end products, and also aerobic cometabolism of chlorinated compounds at 11 of the 12 monitoring locations sampled (Figure 8). Based on the results of this study, conditions at monitoring well MW-906DR may not currently be conducive to biodegradation, potentially due to the relatively new presence of NAPL and VOCs at this location. Quantarray-Petro results indicate that microbial communities capable of both aerobic and anaerobic degradation of petroleum hydrocarbons are present in Site groundwater. Coupled with long-term monitoring (since 1996) of generally declining VOC concentrations and geochemistry, these data provide a comprehensive basis to conclude that the natural attenuation processes at the site are robust and continuing.

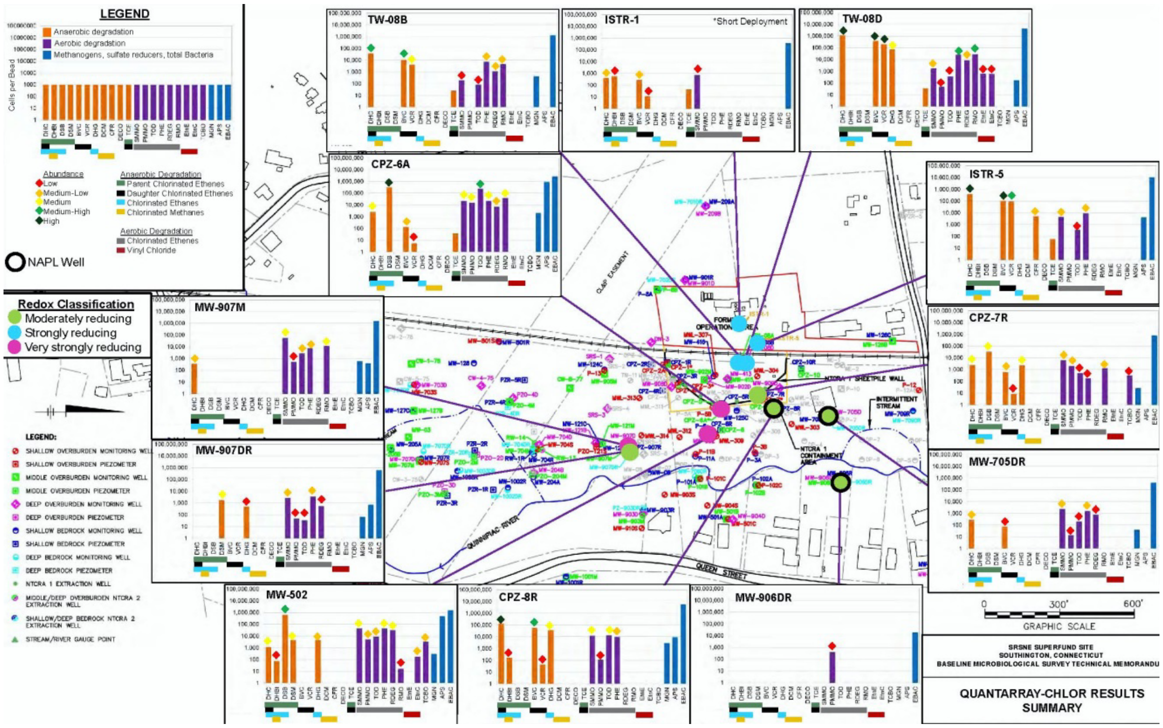

FIGURE 8. Quantarray-Chlor results.

The 2015 CSM Update found that that 97% of the VOC mass estimated present in the 1998 RI has been removed through ISTR (225,000 kg), MNA (300,000 kg), and containment pumping (7,0000 kg). The CSM update details decreasing VOC plume concentrations and extent, shifts in composition from parent to daughter compounds, and decreasing VOC concentration trends in pumped groundwater. These and other data support the CSM's conclusion that the MNA component of the remedy will remain effective, based on the presence of appropriate geochemistry, electron donor supply, and robust microbial communities capable of full reductive dechlorination. The CSM also concludes that the overall remedy is proceeding as expected by the 2005 ROD and is expected to remain protective over time. The CSM Update was referenced in the Second Five-Year Review Report issued by EPA in 2015.

CONCLUSIONS

CSMs are essential to understanding the processes governing a particular site, and to optimize remedial approaches. They should be tailored to the complexity of the geology and contaminants, and updated at key points in the remedial process, as new data are collected and remediation is implemented. New analytical tools should be utilized as necessary and appropriate to refine and support the CSM.

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