Bioremediation System Optimization Support with Mass Flux Site Characterization

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SITE BACKGROUND

Chemical storage and handling was conducted at the former Ashland LLC (Ashland) facility in New York (site) from approximately 1905 to 2001. Various remedial actions were completed from 1987 to 2010, when an enhanced reductive dechlorination (ERD) program began along the downgradient site boundary to address off-site migration of chlorinated volatile organic compounds (CVOCs) in groundwater. Six injection events were completed from 2010 to 2016; the results of these events indicated the following:

- Successful ERD at the property boundary
- Limited downgradient treatment effects
- A potentially unidentified CVOC source or mass flux pathway contributing to off-site migration

Multiple investigations were completed in 2017 to address these remedial system performance deficiencies by supporting a conceptual site model (CSM) and remedial strategy update.

OBJECTIVES

Smart Characterization combines high-resolution data collection technologies, data visualization tools, and an adaptive decision making process to develop flux-based hydrostratigraphic CSMs that can be used to support remedial design. A smart characterization approach was proposed to:

- Evaluate on-site source area mass
- Define mass flux pathways to downgradient receptors

The objectives of this investigation were to:

- Delineate on-site CVOC source mass laterally and vertically
- Determine presence of CVOC mass outside current remedial footprint
- Define primary mass flux pathways
- Evaluate off-site connectivity to source mass
- Provide data to support remedy expansion as needed

METHODS

The investigation consisted of the following:

- A combined membrane interface probe and hydraulic profiling tool (MiHPT)
- Vertical aquifer profiling (VAP) sampling
- A three dimensional (3D) lithologic site model
- Virtual Reality (VR) visualization of site infrastructure

MiHPT borings provided high-resolution, real-time hydrostratigraphic data and a simultaneous qualitative evaluation of CVOC extents. Subsequent VAP borings co-located with likely source areas and mass flux zones provided quantitative soil and groundwater data.

A 3D site model created using Earth Volumetric Studio™ (EVS) enabled mass flux analysis by facilitating a site-wide interpretation of lithology and CVOC impacts. Site infrastructure and other relevant data was loaded into an VR interface and populated on a Microsoft HoloLens™. The 3D and VR models supported the adaptive investigation and communicated results to project stakeholders.

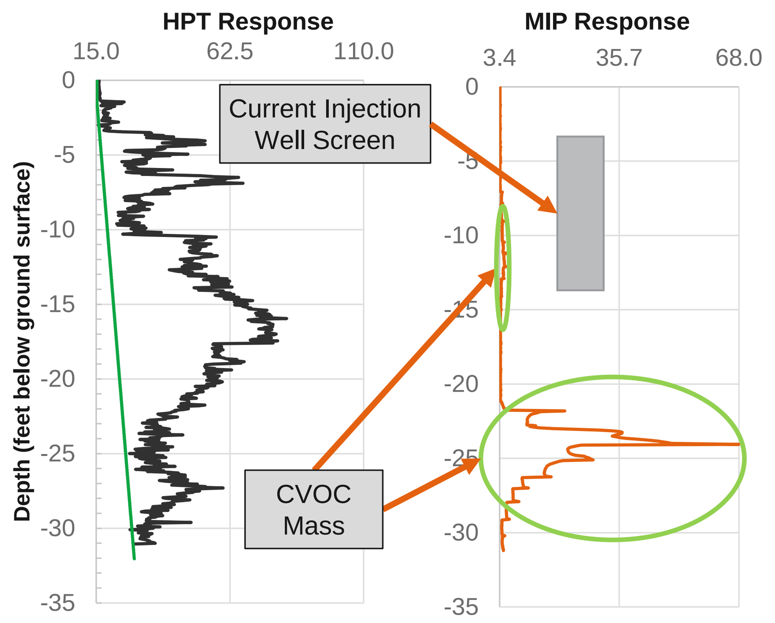


Figure 2: These results from MiHPT-09 (called out on Figure 1 to the right) indicate a deeper zone of relative higher permeability as denoted by lower hydraulic profiling tool (HPT) pressures. This higher permeability zone is co-located with a higher observed halogen specific detector (XSD) response from the MIP. This correlation of CVOC impacts and high permeability are indicative of a mass flux pathway. Note that the exiting site ERD remedy is screened above these newly observed source and mass flux zones.

Smart Characterization

32 MiHPT and 7 VAP borings completed throughout the property and near the west-adjacent property (see Figure 1 below) resulted in the following:

- Lateral and vertical delineation of CVOC impacts via qualitative assessment of membrane interface probe (MIP) results (see Figure 1 below).
- Validation of qualitative CVOC impacts determination with VAP.
- Determination of CVOC parent and daughter compound distribution with VAP.
- Confirmation of deeper source and mass flux zones (see Figure 2 below).

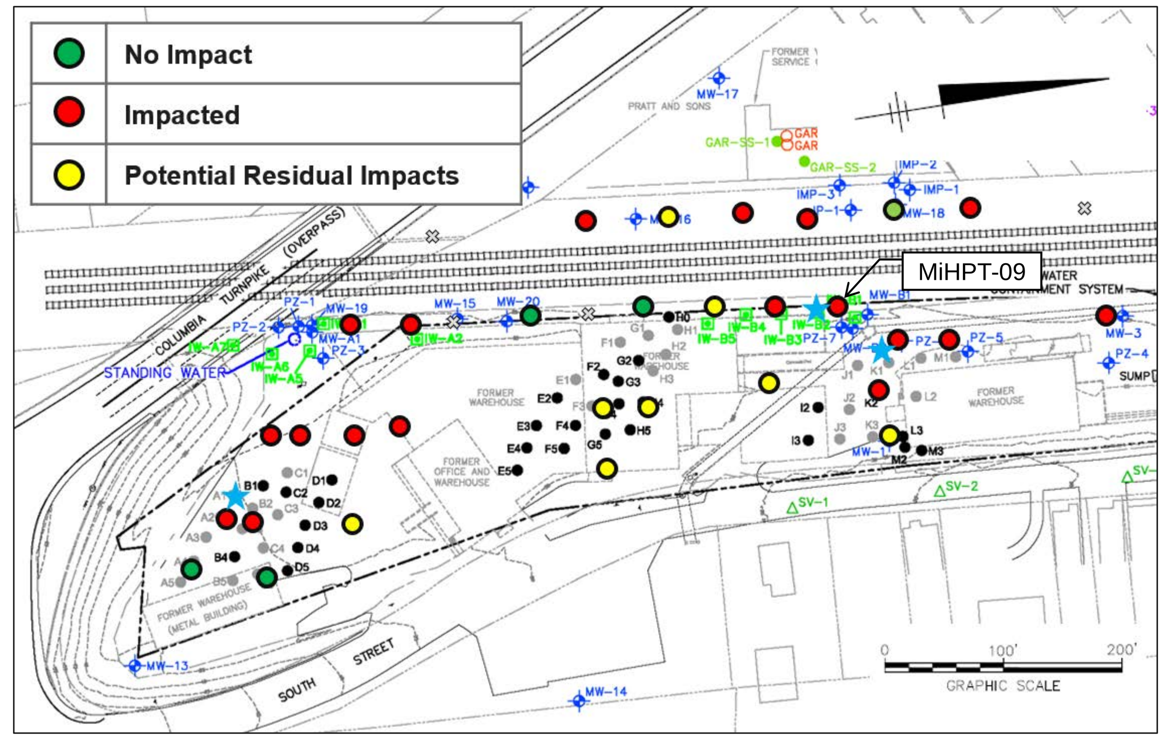


Figure 1: Membrane interface probe results were utilized to categorize locations according to their relative qualitative CVOC impacts. The results indicated distinct north and south impacted zones. Note that a third, centrally located, potential source area was determined to be limited and of insignificant mass.

CSM Update

The CSM was updated to incorporate the following new conclusions:

- Mass flux pathways are located below the current treatment transect interval as shown on Figure 3 below.
  - Potential transport pathway off site to the west.
- Site stratigraphy is complex (see Figure 4 below).
- Two deeper CVOC source areas are located upgradient of current ERD injection transects as shown on Figure 5a.
  - Northern source area
  - Southern source area
- Natural attenuation is occurring.

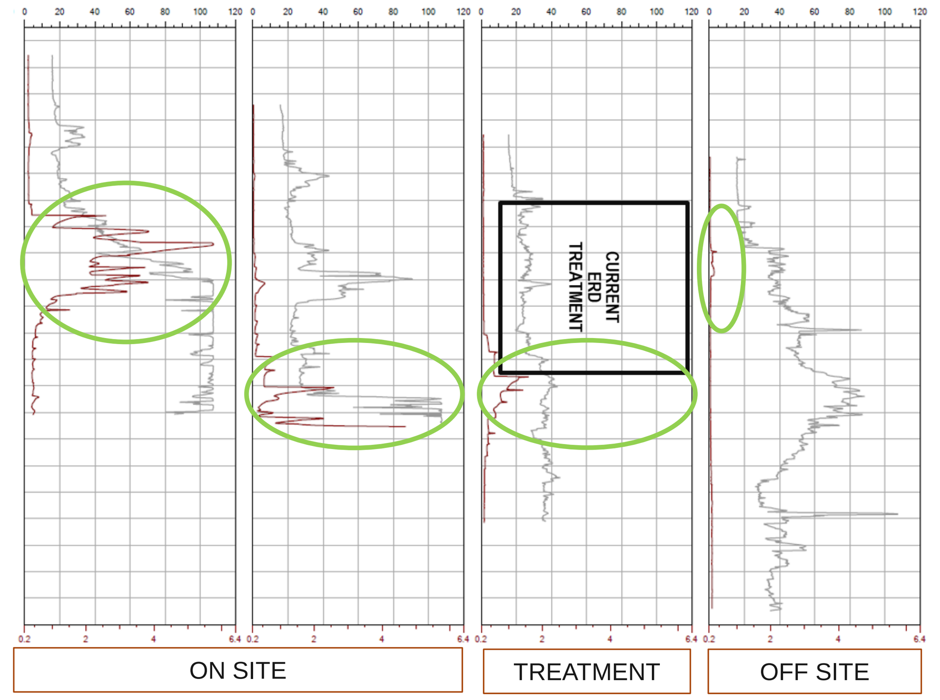


Figure 3: This cross section shows MIP response versus depth from east to west in the direction of groundwater flow. The black box in the treatment section shows the depth of the existing remedy along the property boundary, and the green circles highlight elevated MIP responses. Impacts appear to travel under the existing remedy through a mass flux pathway before upwelling off site.

3D Modeling

The site EVS model was created shortly after the investigation and used to guide the CSM update and remedial optimization. Site infrastructure was uploaded to a VR interface and shared with stakeholders to facilitate decision making.

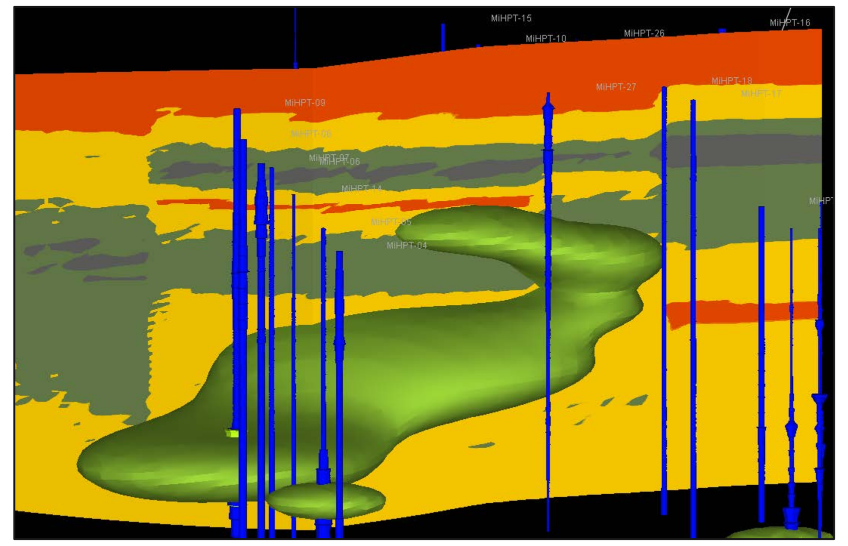


Figure 2: MiHPT data was Kriged to interpolate lithology and impacts between completed borings. The result is a "plume" of MIP responses from 100,000 to 200,000 microvolts (µV) displayed alongside lithologic intervals. Note that the "plume" is confined in the orange/yellow higher permeability lithology. This is consistent with the theory of deeper mass flux pathways at the site.

REMEDY OPTIMIZATION

ERD expansion was selected as the optimal remedial adjustment following review of the updated CSM. The optimization was accomplished by:

- A limited-scale injection
- Modification of the ERD injection well network in the following areas:
  - Deeper upgradient source areas
  - Deeper mass flux zones along the site boundary

Limited-Scale Injection

Wells MW-22, MW-23, and MW-24 (see Figure 5b) were installed to:

- Inject carbon substrate
- Assess natural attenuation
- Evaluate the hydraulics of future full-scale injections
- Confirm mass flux pathways

A limited-scale injection was conducted with a 2% molasses and 40 micrograms per liter [µg/L] rhodamine dye (tracer) solution and resulted in the following conclusions:

- Deeper mass flux pathways are confirmed by off-site tracer observation.
- Deeper source and mass flux zones are conducive to reagent injection.
- ERD is successful as indicated by elevated ethene and ethane shown on Figure 6 below.

ERD Expansion

17 injection wells were installed in the newly identified source and mass flux areas. Approximately 67,000 gallons of a 2% emulsified vegetable oil (EVO) and conservative tracer solution (62 µg/L rhodamine WT and 27 µg/L fluorescein split between the northern and southern source zones) was injected into the new wells and one well from the limited scale injection to:

- Promote ERD for CVOC remediation in source and mass flux zones
- Confirm suspected flow pathways
- Evaluate groundwater flow paths and velocity
- Evaluate organic carbon consumption rates

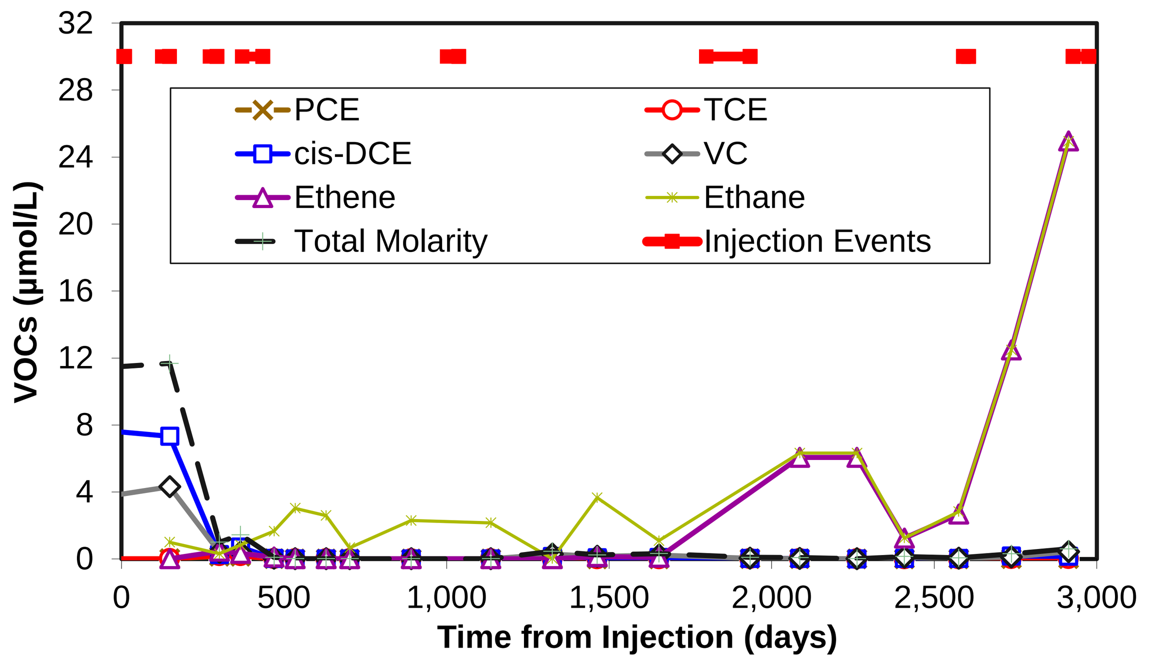
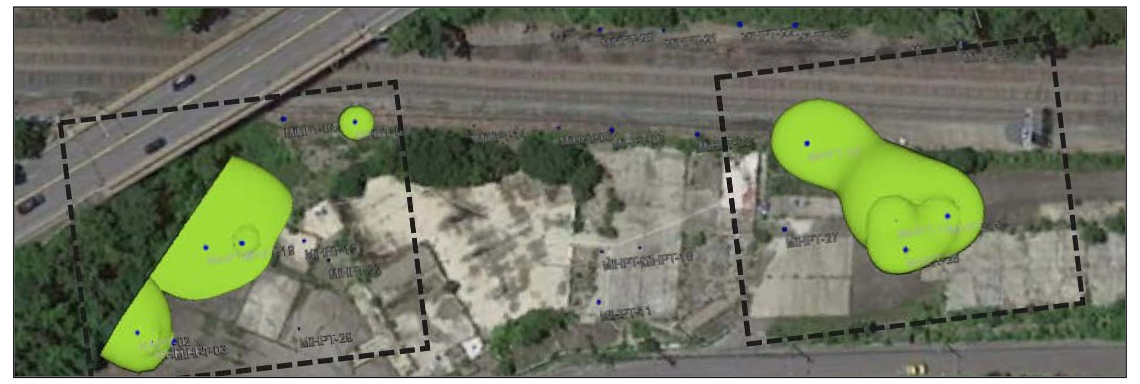


Figure 6: Volatile Organic Compounds (VOCs) concentration versus time at performance indicator well MW-B1 (called out on Figure 5b). Note the significant increase of CVOC daughter products ethene and ethane following the limited-scale injection event at approximately 2,600 days from injection.

Updated Injection Infrastructure



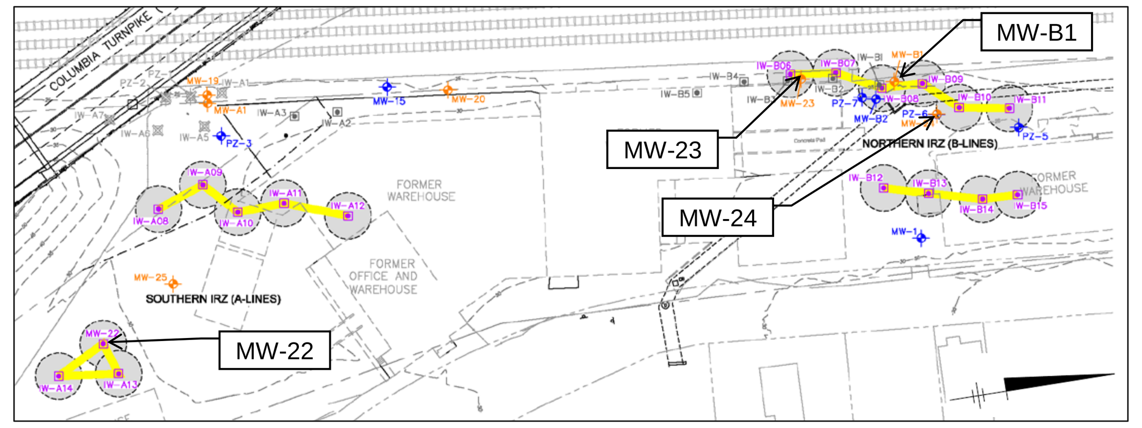


Figure 5a (top) and 5b (bottom): Figure 5a shows the aerial view of MIP "plumes" which delineate the lateral and vertical extents of impacts in the northern and southern source areas (delineated with dashed grey boxes) identified during Smart Characterization. Figure 5b shows the 17 newly installed wells and their respective in situ reactive zones (IRZ) shown by yellow lines. Note that the wells are installed in upgradient areas serving as source zones as well as in transects perpendicular to groundwater flow along mass flux pathways at the property boundaries. In all instances, wells are installed in deeper zones that have not been affected by historical remedial activities.

RESULTS

Smart Characterization

The Smart Characterization approach resulted in:

- Delineation of CVOCs.
- Identification of mass flux pathways not targeted by the current ERD remedy.
- Data necessary to support remedy expansion.
- 3D model and VR interface with lithology and impact distribution.

Digital

- The process supported real-time data analysis.
- 3D modelling facilitated communication of the revised CSM to project stakeholders and resulted in regulatory approval for remedy expansion to target source mass and deeper mass flux pathways.

Remedial Optimization

- Limited-scale injection event indicated successful small-scale ERD in the deeper source zones.
- Preliminary results from the full-scale remedy optimization injection indicate up to 99% removal of parent compounds.
  - However, performance monitoring is currently underway and requires further data analysis before definitive conclusions are drawn.