Intrinsyx Environmental Case Study

Endophyte-Enhanced Phytoremediation of Chlorinated VOCs

Manufacturing Site in Danville, IL

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1. Summary

- Environmental Setting: Former manufacturing site in Danville, IL with soil containing normal pH and conductance and groundwater containing up to 81 mg/L of total chlorinated solvent contaminants.
- Scale of Installation: approximately 15-acre site.
- Contaminants of Concern: Chlorinated volatile organic compounds (cVOC), primarily trichloroethylene (TCE), cis-dichloroethylene (cDCE), vinyl chloride (VC) with limited 1,1,1-trichloroethane (TCA).
- Brief Description of Remedy: Installation of 600+ hybrid poplar and willow trees inoculated with PDN3 endophytes (chlorinated-degrading bacterial endophytes) in 12 separate plots on source areas and groundwater plumes across the entire site.
- Key Successes: Reached regulatory risk-based groundwater targets within four years of planting, resulting in formal site closure 5 years after installation. Established hydrological control and reduced groundwater plume concentrations of TCE and chlorinated solvents to below risk-based levels.

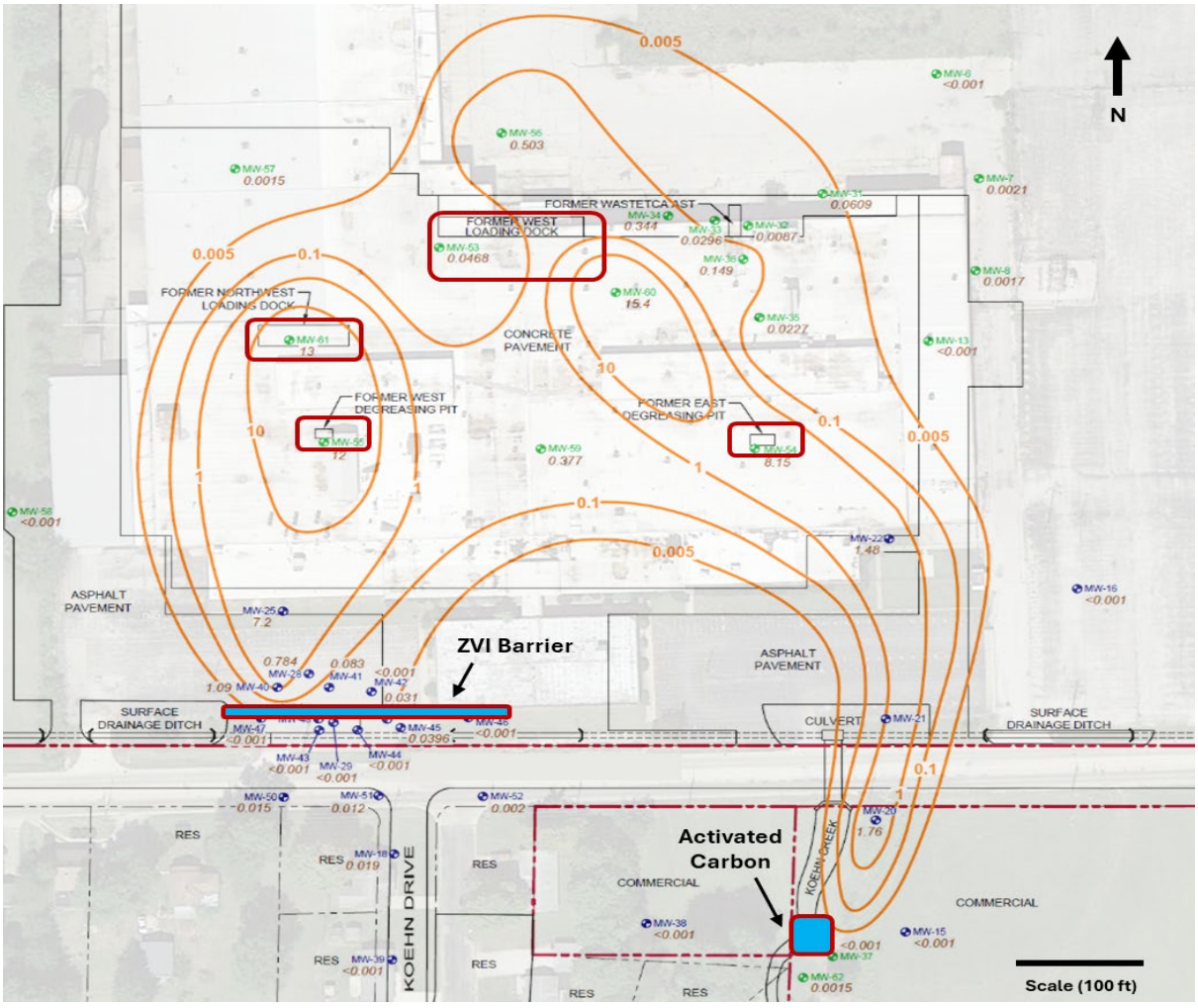
Figure 1: Former manufacturing site in Danville, IL

2. Site Description

Beginning in 1956, the Danville site was formerly used as a manufacturing and heater production facility in eastern Illinois. From 1958 to 1995, chlorinated solvents were used for degreasing during manufacturing operations primarily in two degreasing pits. After the usage of chlorinated solvents was discontinued the pits were backfilled and then paved over in concrete. The solvents, primarily TCE, seeped into the groundwater from these pits and formed two plumes. Chlorinated solvents were also released at two loading docks present in the northwest and west portion of the site. The locations of the source sites are presented below in Figure 2.

The regional water-table at the site is shallow and ranges from 2-6 feet below the ground surface; the soil is primarily silty clay till and with sandy stringers and tight glacial till aquitard. Shallow groundwater and permeable sediment allowed both plumes to begin migrating south of their sources, visible in Figure 2 by the arrows. In 2005 a permeable reactive barrier containing Zero-Valent Iron (ZVI) was installed, along the facility property southern boundary, to serve as an interim measure to stop the spread of the west plume. Additionally, in 2017 there was a focused injection of liquid activated carbon, to serve as an interim permeable reactive barrier at the leading edge of the eastern plume (see Figure 2).

Figure 2: The gradient of groundwater plume concentrations represented by orange with east and west primary sources represented by the red boxes. The arrows represent the groundwater flow towards the south of the site.



3. Remedial Objectives

The remedial objective of the Danville site were to decrease the concentrations of contaminants in the groundwater to acceptable risk-based levels based on the State of Illinois and Federal EPA Regulations.

3.1 Remedial Site Goals

1. The groundwater concentrations of the following compounds were identified for risk-based closure following Illinois State and Federal EPA guidelines: Acetone, Ethylbenzene, 1,1 DCA, 1,2 DCA, 1,1 DCE, cis-1,2- DCE, trans-1,2-DCE, MIBK, PCE, 1,1,1-TCA, 1,1,2-TCA, TCE, VC, and Xylene.

3.2 Phytoremediation Goals

1. Establish healthy poplar and willow tree remediation plot
2. Establish a cone of depression in local groundwater to mitigate plume migration
3. Protect trees from contaminants phytotoxicity with PDN3 endophyte
4. Enhance rhizosphere breakdown of source zone contaminants with tree roots and microbial amendments

4. Remedial Approach

Final selected remedy: Endophyte-assisted phytoremediation using PDN3, a TCE-degrading endophyte to inoculate hybrid poplar and willow trees.

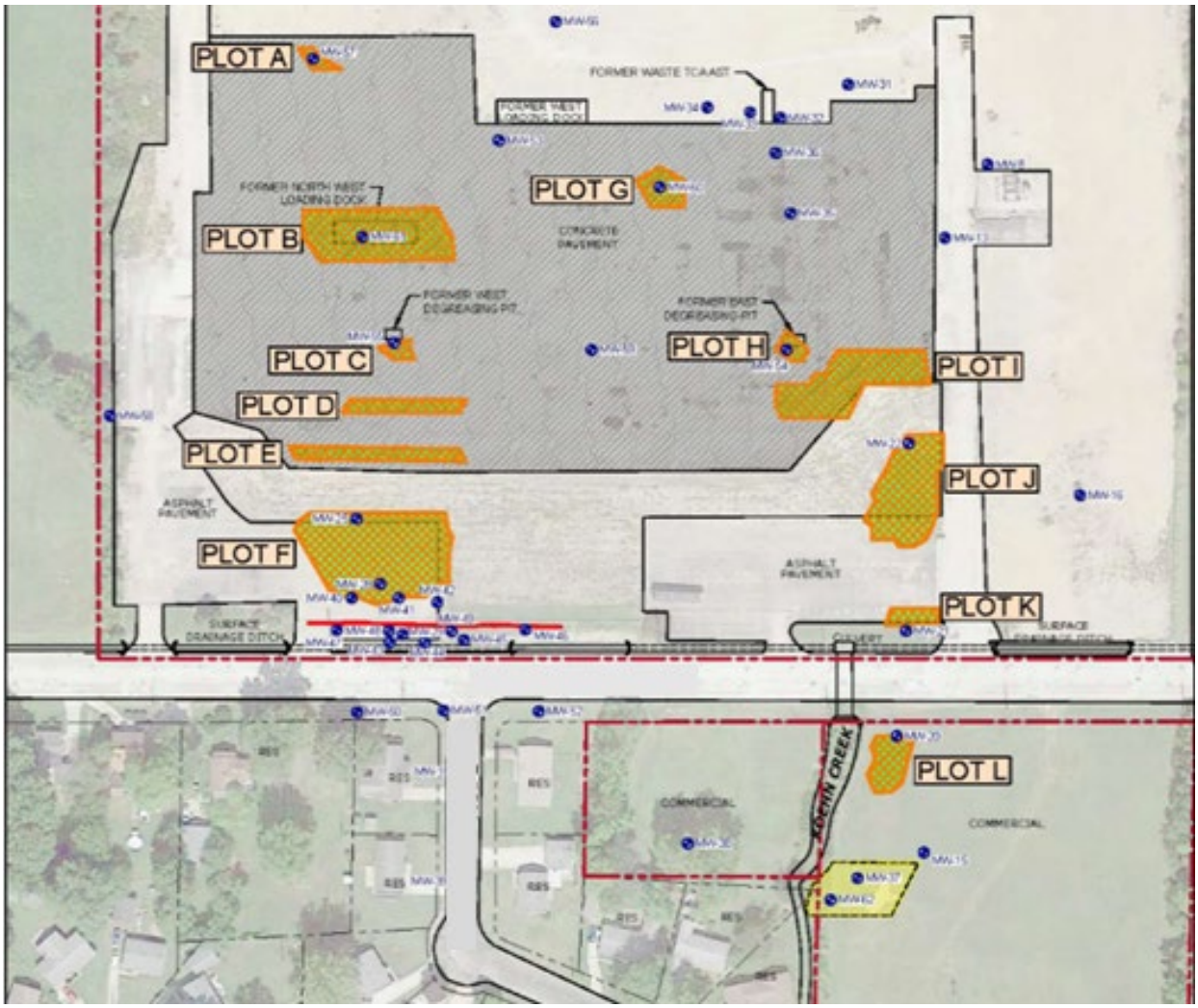
4.1 Remedy Description

Intrinsyx Environmental was consulted to assist in design and installation of phytoremediation plots of hybrid poplar and willow trees that were inoculated with PDN3 bacterial tree endophyte. The trees were planted across 12 individual plots represented in Figure 3. In total over 600 trees were planted in conditions containing cVOCs of approximately 7-15 mg/L, with point source concentrations up to 81 mg/L. The trees were planted in holes bored through pavement and concrete foundations to depths up to 5 feet below ground surface.

4.2 Approach Benefits

Utilizing hybrid poplar and willow trees inoculated with PDN3 bacterial tree endophytes allowed for both hydrological control and treatment of the contaminated groundwater. Poplar and willow trees have very high transpiration, thereby creating a depression cone in the water table and treating the contaminants via rhizodegradation, phytodegradation and biodegradation. PDN3 bacterial tree endophytes use chlorinated compounds, specifically TCE, as a preferred food source (Kang, Khan, & Doty, 2012) which allows for effective remediation of the contaminated groundwater in the root-zone and in the tree tissue. The combined system of poplar trees and PDN3 endophytes provides an effective and regenerative approach to remediation that sequesters carbon and revitalizes the soil ecosystem.

Figure 3: Design layout of hybrid poplar and willow installation plots represented in dark yellow and orange and labeled Plot A-through L.



5. Monitoring and Results

The installation of hybrid poplar trees inoculated with PDN3 bacterial tree endophyte resulted in a successful phytoremediation system. The trees were able to exert hydrological control over the migration of the groundwater plumes and point sources. Pairing the trees with PDN3 endophyte allowed for enhanced degradation of the chlorinated cVOCs in the groundwater. The placement of 600 trees, across 12 plots, allowed for broad control and degradation of contaminants over the site. As present in Table 1, the trees were able to decrease the concentration of cVOCs significantly at both of the primary sources (Plots C & H) and downgradient (Plots F & J).

Table 1: The concentrations of cVOCs shown in mg/L tested at Plots (C, H, F, J) before hybrid inoculated poplar trees were planted and after 2022. Across the four tested plots the average percent decrease was 94%.

Planted Plot	Pre-Planting cVOC conc.	Post 2022 conc.	Percent Decrease
Plot C	81 mg/L	4.4 mg/L	- 95 %
Plot H	11.6 mg/L	0.45 mg/L	- 96 %
Plot F	21.9 mg/L	0.74 mg/L	- 97 %
Plot J	22 mg/L	2.5 mg/L	- 89%

Enhanced phytoremediation was effective at fully bio-degrading cVOC contaminants in groundwater and establishing hydrologic control. Injection of ZVI and activated carbon worked as temporary measures to halt plume migration, giving the poplar and willow trees time to establish. As time passes, the trees will continue to grow, increasing both the rate of groundwater uptake and contaminant degradation.

6. Project Outcomes

Five years after initial plantings, the Danville site received a focused No Further Remediation by Illinois EPA. This action was based on long-term monitoring data including the 2022 data, showing that the system reached risk-based regulatory targets only four years after initial planting of phytoremediation plots installation. The use of hybrid poplar and willow trees paired with PDN3 endophytes was successful in establishing control over the site to prevent the migration of contamination along with enhanced degradation of the contaminants present. The finalization of this project was met with broad acceptance from the community and government officials.

Figure 4: Initial image of the trees following planting in 2018.

Figure 5: Image of trees following more than three years of growth.

7. References

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2. Illinois EPA. (2023). Environmental No Further Remediation Letter. Springfield: Illinois Environmental Protection Agency.
3. Kang, J. W., Khan, Z., & Doty, S. L. (2012). Biodegradation of Trichloroethylene by an Endophyte of Hybrid Poplar. Applied and Environmental Microbiology, 3504-3507.