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A Review of Intrinsic Bioremediation of TCE in Groundwater at Picatinny Arsenal, New Jersey and St. Joseph, Michigan

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Reductive dechlorination occurs frequently in large trichloroethylene (TCE) plumes. TCE is transformed largely to cis-dichloroethylene (cis-DCE), then to vinyl chloride, and finally to compounds that do not contain organic chlorine. This abstract evaluates the rate and extent of natural reductive dechlorination of TCE in two large plumes with similar properties.

Description of the plumes

Both plumes originated in a release of liquid TCE. The plume at St Joseph, MI originates in a industrial park, while the plume at the Picatinny Arsenal NJ originates in a release from a degreasing vat at a plating shop. The cross section of the plumes are depicted in Figure 1 and 2. Both plumes have high concentrations of TCE in the core of the plume (over 25,000 ug/liter), are devoid of oxygen or nitrate, contain low concentrations of iron (II) and methane (generally less than 10 mg/liter), and have relatively low concentrations of sulfate (generally less than 15 mg/liter). Both plumes have

concentrations of dissolved organic carbon that are elevated over background. The ground water in both plumes is cold, near 10 degrees Celsius. The water is hard, with pH near neutrality.

Both plumes discharge to surface water. The interstitial seepage velocity of the plumes are very similar. The seepage velocity of the TCE plume at St. Joseph, MI (corrected for retardation) is near 0.1 m/day, while the velocity of the plume on the Picatinny Arsenal varies from 0.3 to 1.0 m/day. For purposes of calculation, 0.3 m/day is used in this abstract.

Monitoring

The plume at St. Joseph, MI was characterized by four transects that extended across the plume, perpendicular to ground water flow. At each point in each transect, water was sampled in 1.5 m vertical intervals extending from the water table to a clay layer at the bottom of the aquifer. Each transect contains at least twenty sampling points. Table 1 compares the average concentration of TCE, cis-DCE, and vinyl chloride in each transect, as well as the highest concentration encountered. The most distant transect was sampled from the sediments of Lake Michigan. The plume was encountered approximately 1.5 m below the sediment surface, 100 m from the shore line.

The plume of TCE at the Picatinny Arsenal is monitored by a series of well clusters installed along the center-line of the plume. Table 1 presents data from the monitoring well in a cluster that had the highest concentration of TCE. The data were collected in 1989.

Extent of attenuation

Dechlorination in the plume at St. Joseph is extensive. Vinyl chloride and cis-DCE accumulated near the spill, then were degraded as the plume moved down gradient (Table 1).

Table 1. Attenuation of TCE in ground water with distance from the source and residence time in the aquifer. (1, 2, 3)

Location	Distance from source	Time in aquifer	TCE	cis-DCE	Vinyl Chloride
	(meters)	(years)	Average conc. (ug/liter) *Highest conc. (ug/liter)*		
St. Joseph	130	3.2	6,500 *68,000*	8,100 *128,000*	930 *4,400*
St. Joseph	390	9.7	520 *8,700*	830 *9,800*	450 *1,660*
St. Joseph	550	12.5	15 *56*	18 *870*	106 205
St. Joseph	855	17.9	<1 *1.4*	<1 *0.8*	<1 *0.5*
Picatinny	240	2.2	25,000	220	4
Picatinny	320	2.9	10,000	35	1
Picatinny	460	4.2	1,400	310	6

Dechlorination in the plume at Picatinny Arsenal was also extensive. Comparing the location with the highest concentration to the point of discharge, dechlorination destroyed approximately 90% of the TCE. Vinyl chloride and cis-DCE did not accumulate to an appreciable extent. Because the plume at Picatinny Arsenal discharged to surface water before dechlorination was complete,

the U.S. Army installed and continues to operate a pump-and-treat system on the plume.

Comparison of attenuation due to dilution and dechlorination

The plume at St. Joseph, MI has high concentrations of TCE at its core, while the concentration of chloride in the aquifer is low. This makes it possible to estimate the contribution of dilution by comparing the accumulation of chloride from reductive dechlorination to attenuation of chloroethenes. Table 2 portrays the accumulation of chloride, and reduction of total organic chlorine along the flow path.

Table 2. Comparison of the relative attenuation of TCE, cis-DCE, and vinyl chloride with the attenuation of chloride in the plume at St. Joseph, MI. (1, 2)

Distance from source	Chloride Ion	Organic Chlorine	TCE	c-DCE	Vinyl Chloride
(meters)	(mg/liter)		Highest conc. (ug/liter)		
background	14				
130	55	~~104~~ 151	~~4,000~~ 68,000	128,000	4,400
390	109	.15	8,700	9,800	1,660
550	71	0.8	11	828	205
855	57	<0.1	1.4	0 .8	0.5

Table 2 compares water from the most concentrated sample in each transect. Based on Koc relationships and the fraction of organic carbon in the aquifer, approximately 60% of the TCE in the aquifer should be in solution. TCE was largely depleted, and sorption of cis-DCE and vinyl chloride in the aquifer should be minimal. We will assume that the organic chlorine in ground water represents the pool of chlorine available for dechlorination to chloride.

Near the source the concentration of chloride, plus potential biogenic chloride, minus background chloride was 145 mg/liter. Only 38% of this quantity was actually chloride. Total organic and inorganic chlorine attenuated with distance downgradient. By the time the plume reached the lake, the concentration of total chlorine minus background was 43 mg/liter, which is significantly higher than background. Apparently the plume was attenuated three- to four-fold due to dilution. Total attenuation of chloroethenes was at least 100,000-fold.

Kinetics of reductive dechlorination in ground water

Table 3 compares first-order rate constants calculated between transects in the plume at St. Joseph, MI and between monitoring wells in the plume at Picatinny Arsenal. Field-scale estimates of rates are also compared to attenuation in microcosms constructed from material collected along the flow path at Picatinny Arsenal. There is surprising agreement in the rates of dechlorination of TCE within the same plume, between plumes, and between microcosm studies and field-scale estimates. Nine separate estimates vary less than an order of magnitude.

Table 3. Rates of Reductive Dechlorination of TCE, cis-DCE, and Vinyl Chloride in Ground Water. Residence Time Refers to Time in the Segment of the Plume being Described, or Incubation Time of Microcosms. (1,2,3,4,5)

Location	Distance from source	Time from source	Residence time	TCE	cis-DCE	Vinyl chloride
	(meters)	(years)	(years)	Apparent Loss Coefficient (1/year)		
Field Scale Estimates						
St. Joseph	130 to 390	3.2 to 9.7	6.5	0.38	0.50	0.18
St. Joseph	390 to 550	9.7 to 12.5	2.8	1.3	0.83	0.88
St. Joseph	550 to 855	12.5 to 17.9	5.4	0.93	3.1	2.2
Picatinny	240 to 460	2.2 to 4.2	2.0	1.4	produced	produced
Picatinny	320 to 460	2.9 to 4.2	1.3	1.2	produced	produced
Picatinny	0 to 460	0.0 to 4.2	4.2	1.0		
Picatinny	240 to 320	2.2 to 2.9	0.7		1.6	
Picatinny	0 to 250	0.0 to 2.3			0.5	
Laboratory Microcosm Studies						
Picatinny	240	2.2	0.5	0.64	0.52	
Picatinny	320	2.9	0.5	0.42	9.4	
Picatinny	460	4.2	0.5	0.21	3.1	

The rates of degradation of vinyl chloride and cis-DCE were comparable to the rates of degradation of TCE (Table 3)..

The rates of attenuation in the two plumes are slow as humans experience time. In particular, they are slow compared to the time usually devoted to site characterization. However, in plumes with a long residence time, on the order of decades, they have significance for protection of waters that receive the plumes.

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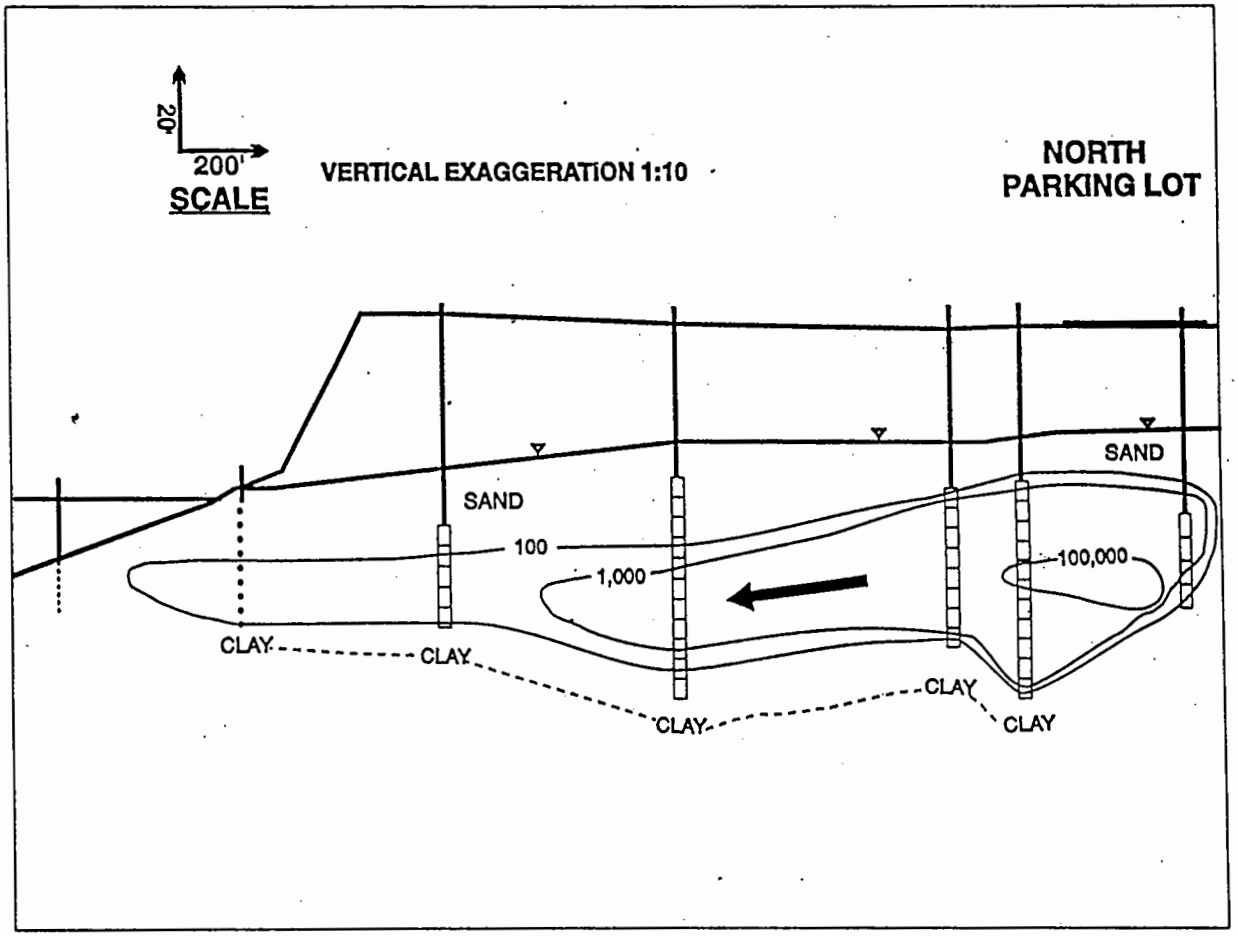

Figure 1. Cross Section of the Plume at St. Joseph, MI as it leaves the Industial Park and enters the Sediments under Lake Michigan. Concentrations are ug/liter Total Chloroethenes.

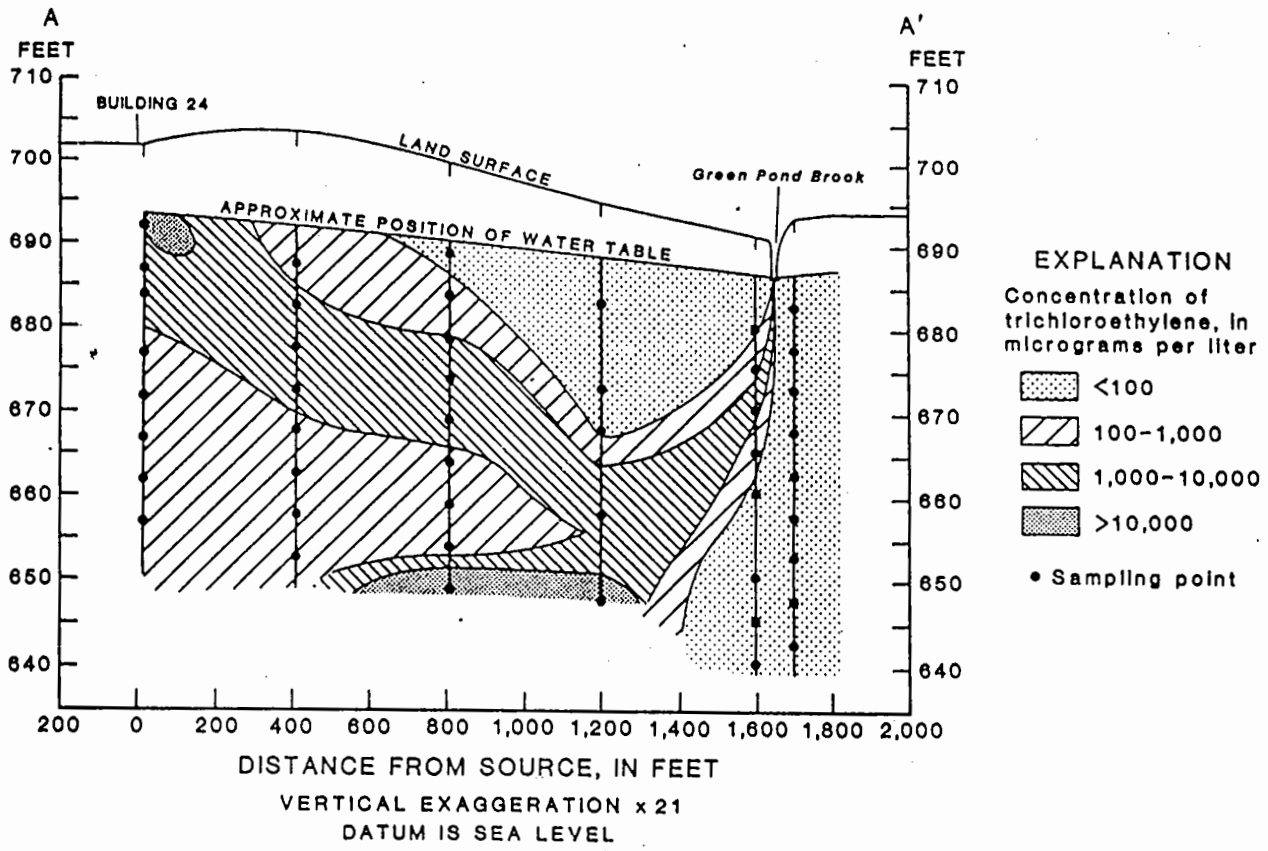

Figure 2. Cross Section of the Plume at Picatinny Arsenal, NJ as it moves from it Source near Building 24 and discharges at Green Pond Brook.

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16. ABSTRACT

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The half life for attenuation of TCE and its dechlorination products was approximately six months in both plumes. The rates of attenuation in the two plumes are slow as humans experience time. In particular, they are slow compared to the time usually devoted to site characterization. However, in plumes with a long residence time, on the order of decades, they have significance for protection of waters that receive the plumes.

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