



global environmental solutions

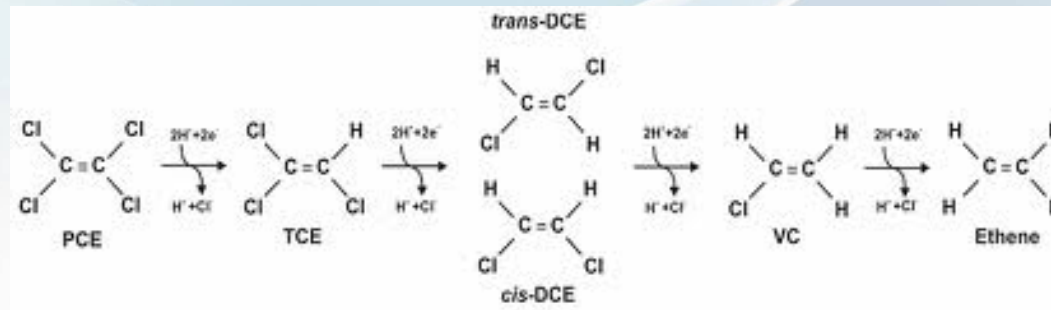
Enhanced Reductive Dechlorination to Treat PCE and TCE in a Deep Gravel Aquifer

Presented by Steven R. Hammer, P.E.
SLR International Corp
1800 Blankenship Road #440, West Linn, Oregon

October 2011

Reductive Dechlorination - Overview

- Reductive dechlorination is the anaerobic biodegradation of chlorinated ethenes.
- It occurs naturally at sites that are anaerobic and where the proper bacteria are present (but often is slow without enhancement).
- At other sites, it can be induced by creating anaerobic conditions and adding appropriate bacteria.

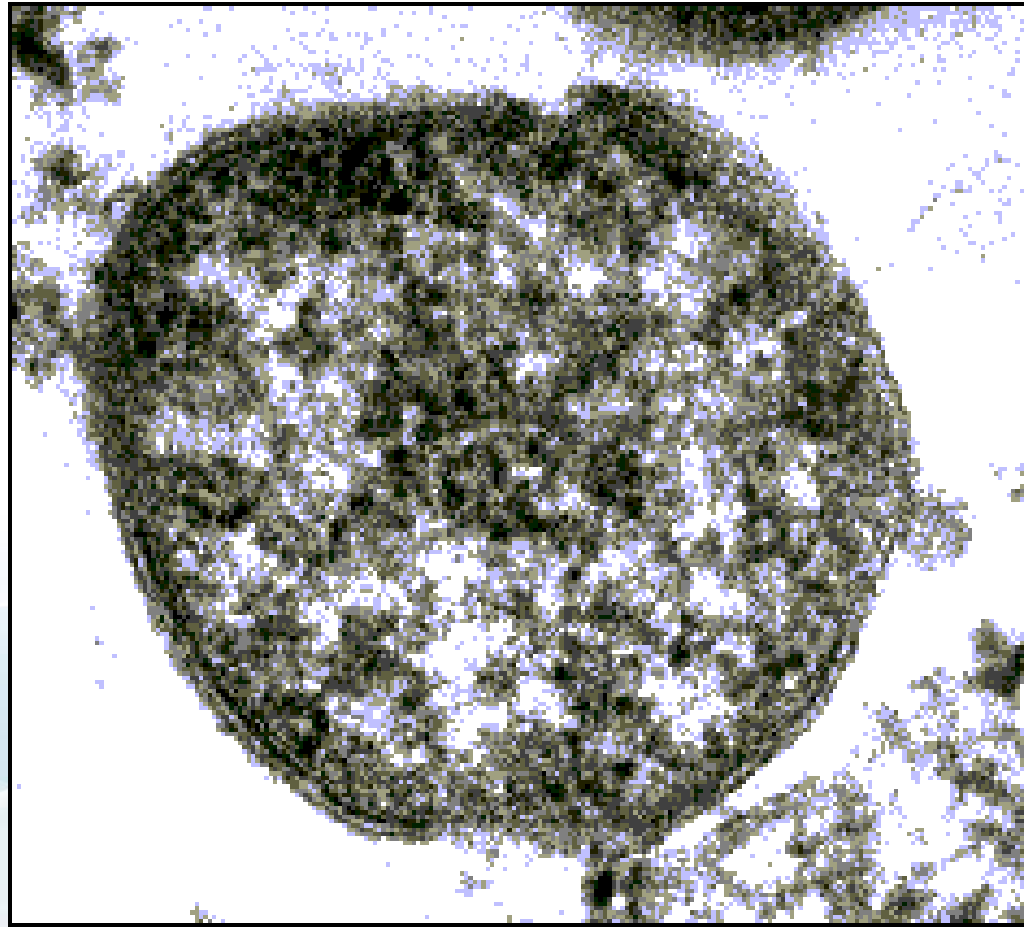


Conditions Conducive to Dechlorination

- Anaerobic – oxidation/reduction potential (ORP) in groundwater should be negative, and < -100 mV is preferred
- Neutral pH – the pH be greater than 6 or 6.5
- Presence of halorespiring bacteria
- Presence of a carbon food source for the halorespiring bacteria

How it Works

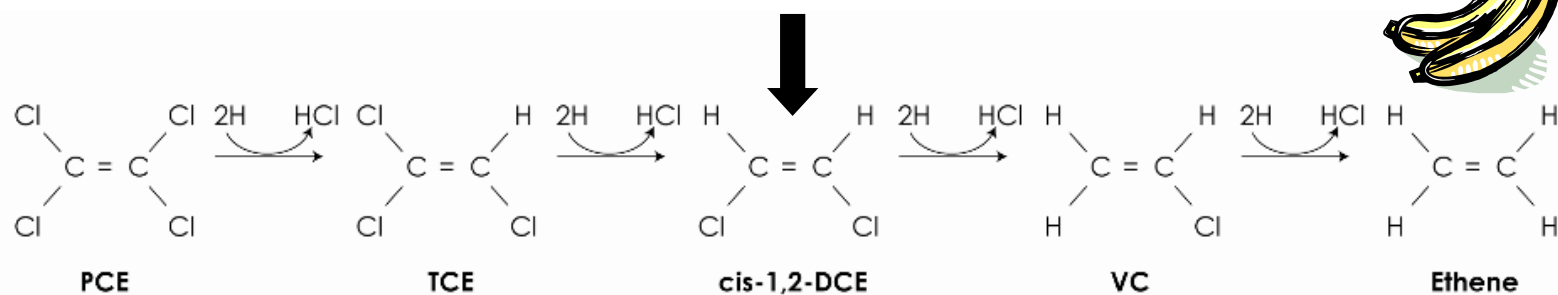
- Halorespiring bacteria use the carbon-chlorine bond for respiration rather than using oxygen for respiration.
- In the presence of a carbon food source, the bacteria sequentially remove chlorine atoms, reducing PCE to TCE, TCE to cDCE, cDCE to VC, and VC to ethene.
- There are many different bacteria that anaerobically degrade PCE and TCE. They are often present naturally.
- As far as we know, only *Dehalococcoides ethanogenese* breaks down cDCE to VC and VC to ethene.



Dehalococcoides Ethanogenese

First isolated in 1997

Can accumulate if DHC is
absent



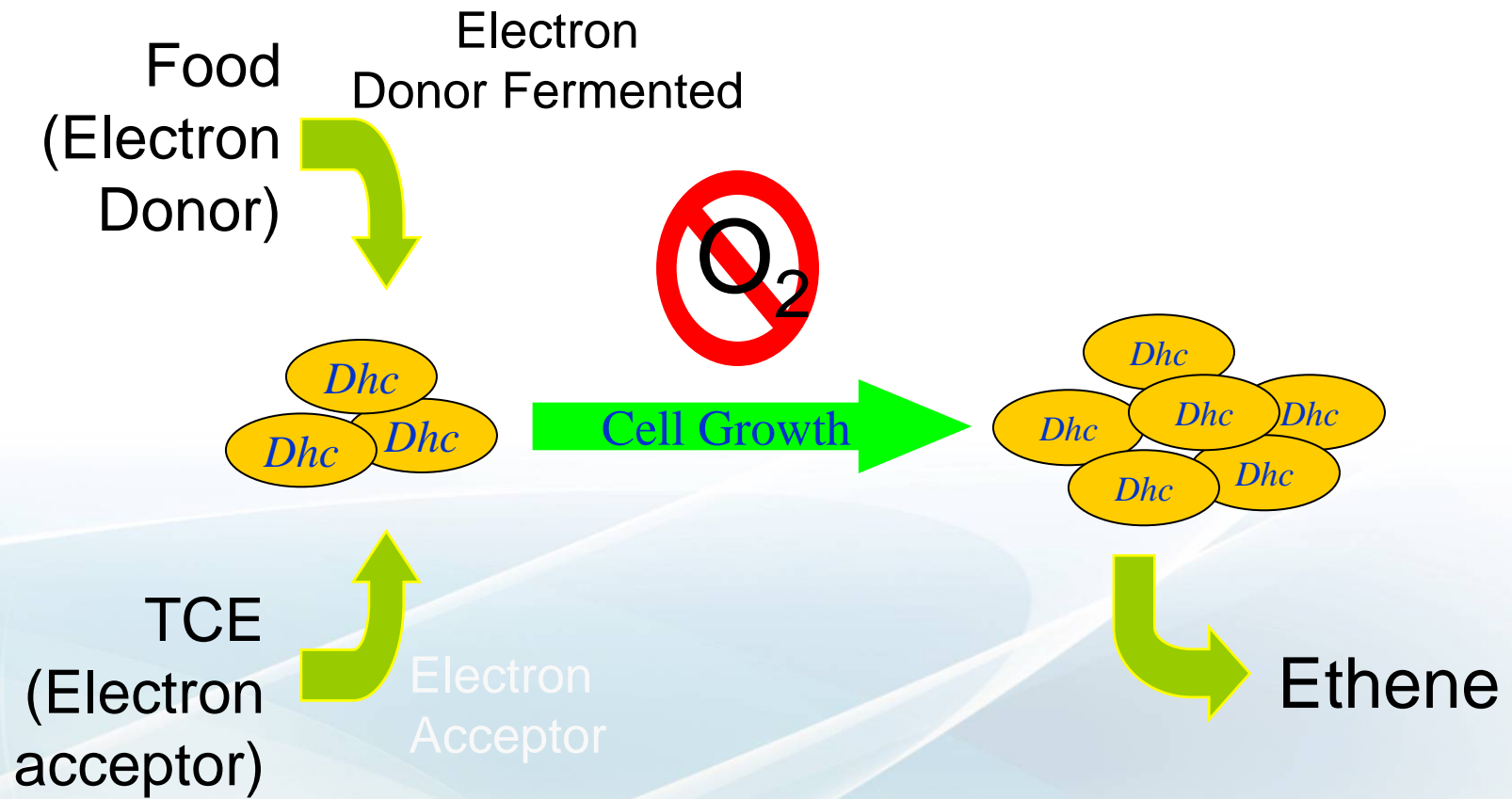
Dehalobacter
Dehalospirillum
Desulfitobacterium
Desulfuromonas
 + *Dehalococcoides*

Only *Dehalococcoides*

Ethene (aka. ethylene) is non-toxic,
produced by many fruit to stimulate
ripening

Enhancing Reductive Dechlorination

- At a site where conditions are appropriate (relatively low ORP, suitable pH), we can enhance natural biodegradation processes by adding carbon substrate (food), nutrients, and Dehalococcoides organisms.
- Many types of carbon substrates have been used:
 - Methanol and ethanol
 - Molasses, corn syrup, and lactate
 - Cheese whey
 - Emulsified soybean oil
- Dehalococcoides bacterial cultures can be purchased commercially.

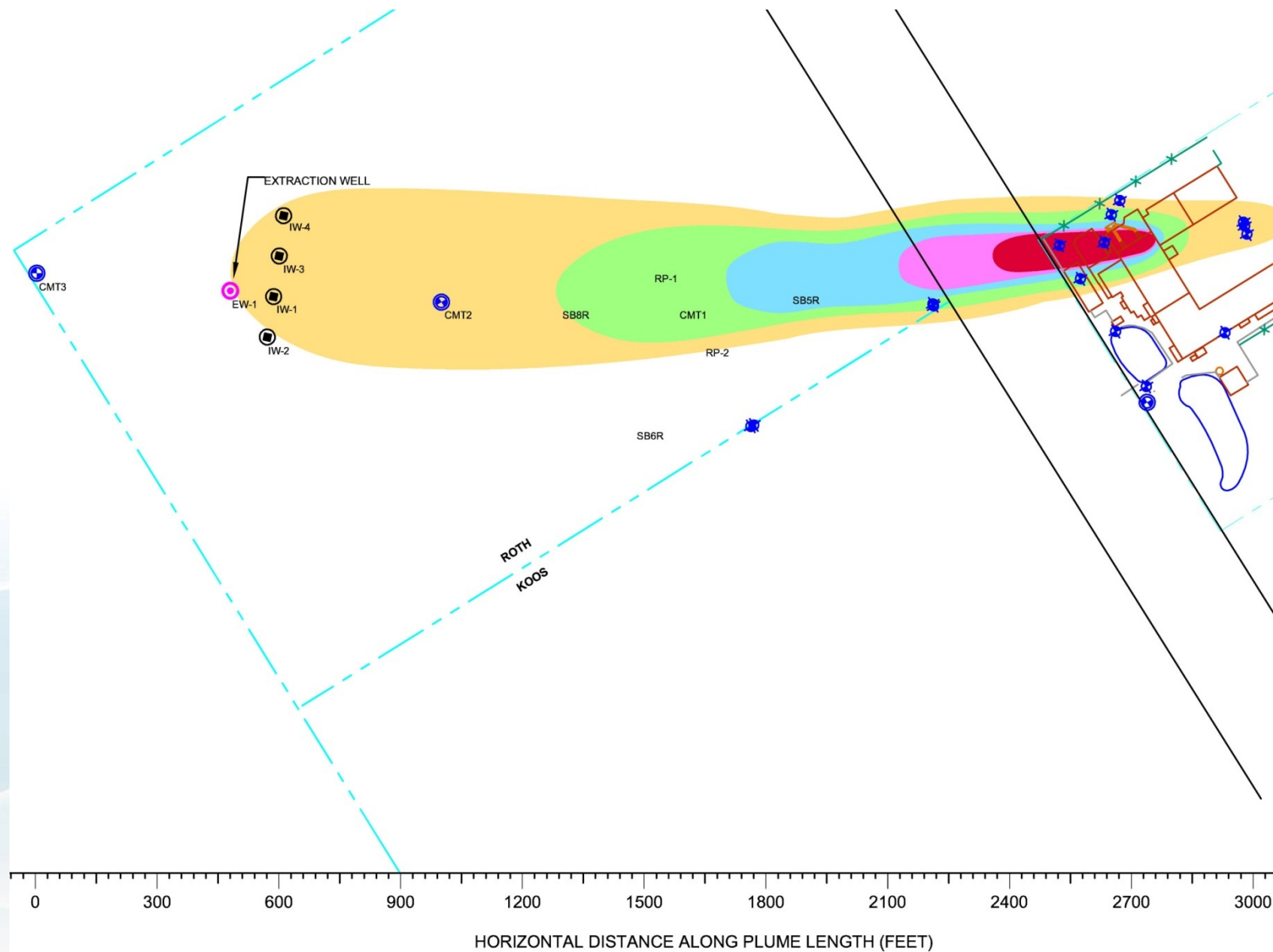


Reductive Dechlorination in a Deep Aquifer – Albany, Oregon

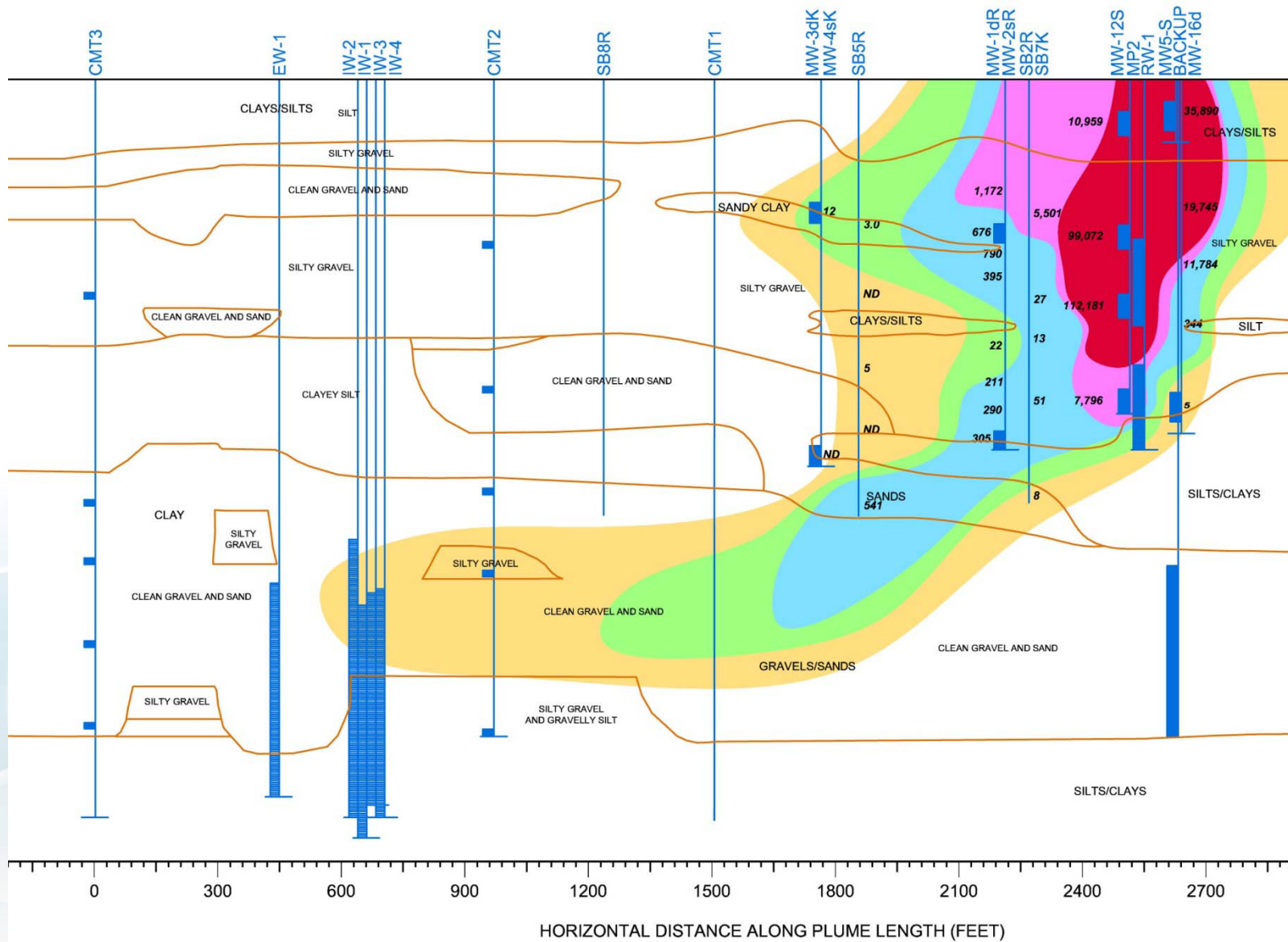
- Titanium Casting Facility in Albany, Oregon
- Historically used PCE and TCE
- Historical release to soil and groundwater
- Investigation begun in 1988
- Excavation to remove impacted soils in 1988
- On-site and off-site groundwater investigation through 1998, including wells and soil borings
- We became involved in the project in 1998

Reductive Dechlorination in a Deep Aquifer – Albany, Oregon

- Depth to groundwater is less than 10 feet
- Lithology:
 - 20 feet of silt
 - 70 feet of sand and gravel (Shallow and Intermediate Zones)
 - 10 feet of silt
 - 80 feet of sand and gravel (Deep Zone)
- PCE and TCE present in on-site and off-site groundwater
- Investigation showed that the plume had migrated off-site into a deep (100 ft to 160 ft below ground surface) sand and gravel aquifer



1998: Plume has migrated under the freeway and underneath a farmer's field



1998: Plume has migrated into the deep zone off-site.



Client's site from across the freeway.

Deep Zone Investigation and Feasibility Study

- Financials limited the amount of investigation that could be conducted in the deep zone.
- The groundwater flow direction in the deep zone was approximated from the flow direction in the shallow and intermediate zones.
- Multi-level (CMT) wells were installed in a farmer's field across the freeway from the site, along the presumed plume centerline.
- There were no downgradient receptors affected by the plume

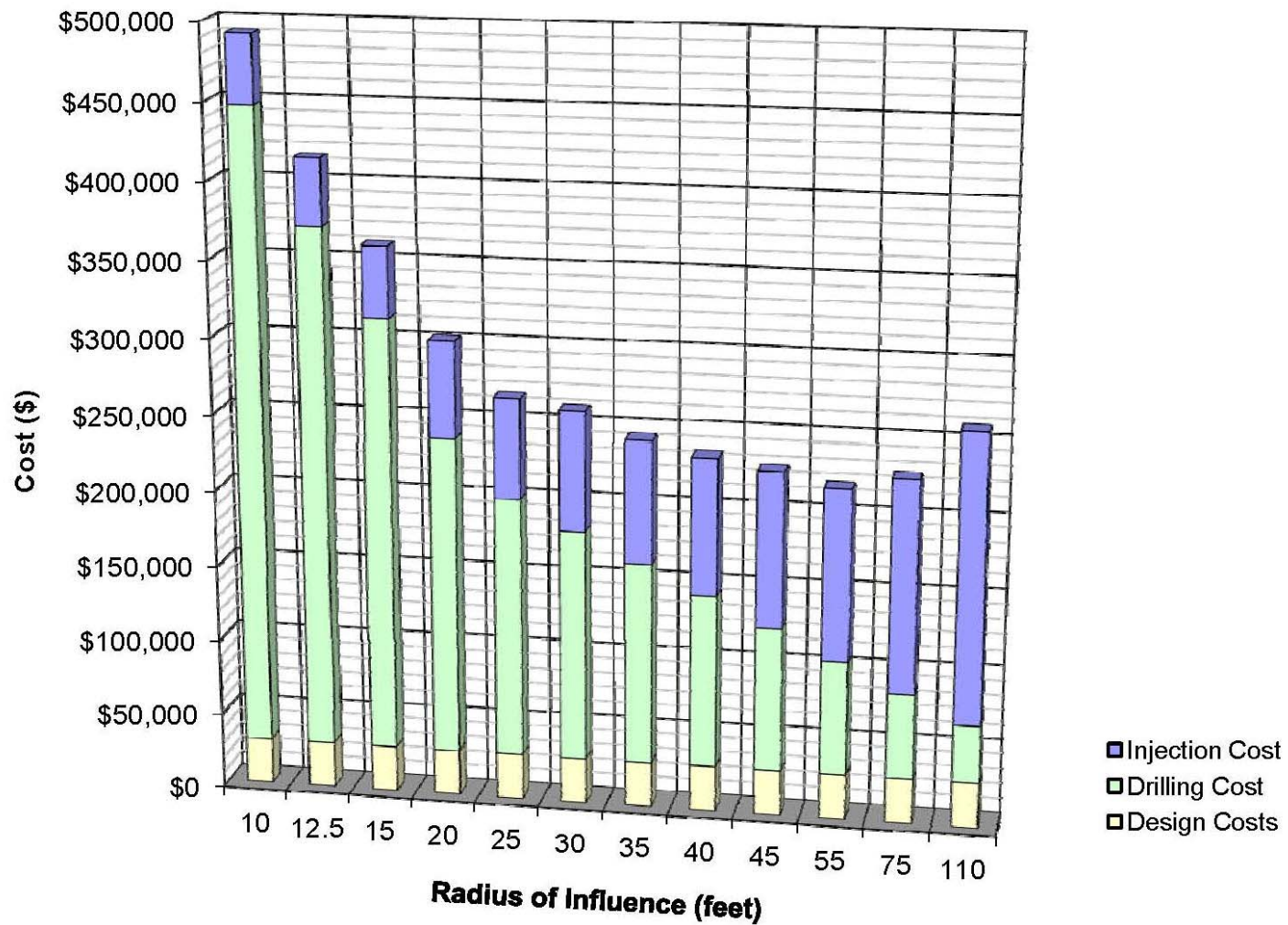
Feasibility Study Process

- The Feasibility Study and Record of Decision process resulted in the approval of a permeable reactive barrier using enhanced reductive dechlorination to target the bulk of the mass of the plume.
- The goal was to target the higher concentration portions of the plume to maximize contaminant destruction for an affordable expenditure.
- A key design factor is that the remedial action was to be conducted in an area where power and water is not readily available.

Cost Evaluation

- Drilling wells to 160 feet bgs is expensive.
- We completed a cost analysis to balance the cost of drilling wells versus the cost of labor and fluids required for injection.
- More wells = smaller radius of influence, less injection fluids, and less labor
- Less wells = greater radius of influence, more injection fluids, and more labor
- We decided upon four 4-inch injection wells with a target injection radius of influence of 50 feet.

Enhanced Reductive Dechlorination Cost Evaluation Implementation Cost Versus Radius of Influence





The drilling crew.



We had some uninvited spectators.



global environmental solutions



Plume Nailed!

- We had a limited amount of data on the location of the deep zone plume: two wells we thought were along the plume centerline.
- We collected discrete samples while drilling the injection wells, with plans to go to the north or south, depending on what we found.
- We successfully straddled the width of the plume with the four injection wells.

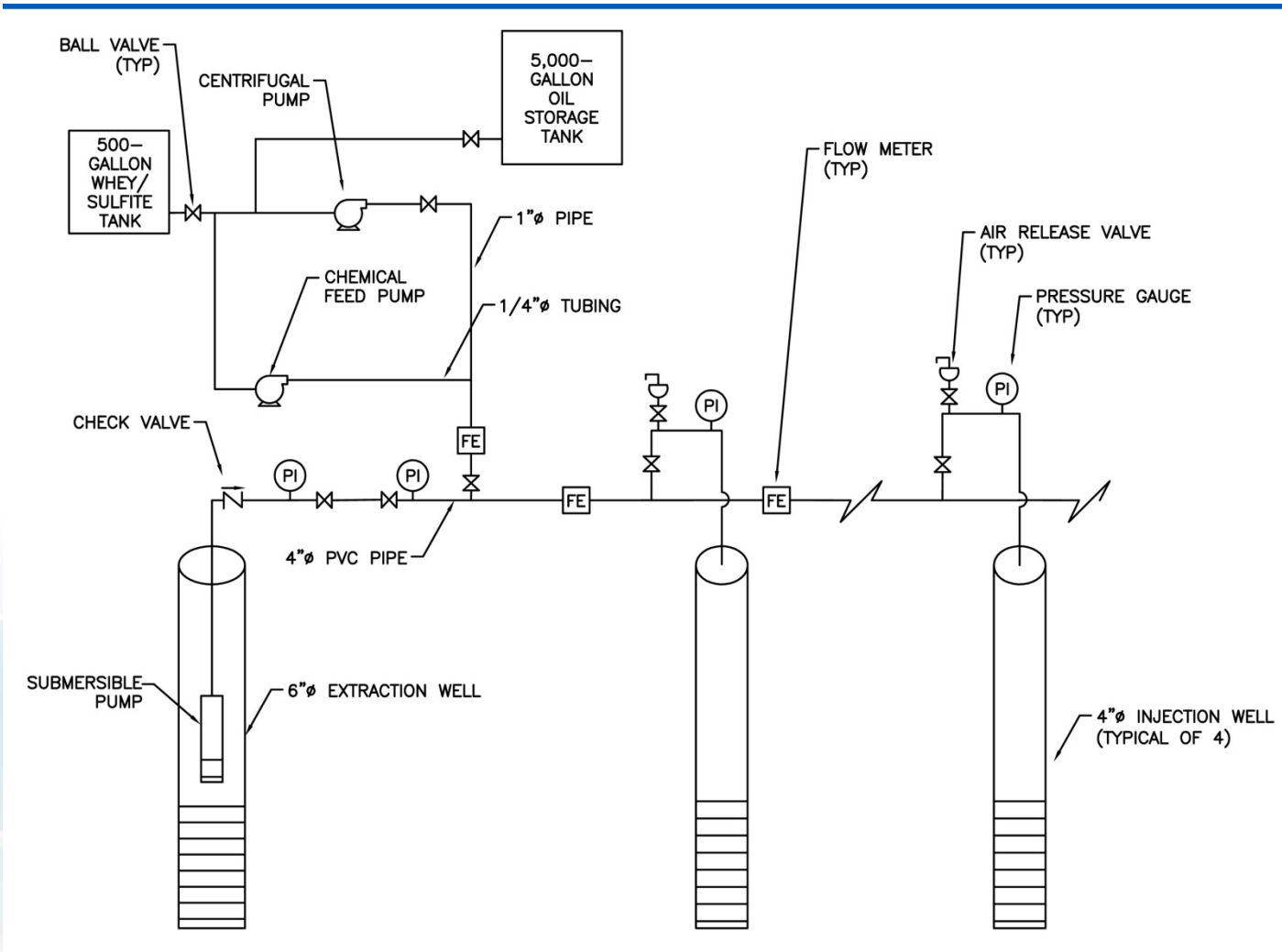
Depth (ft bgs)	IW4	IW3	IW1	IW2
90				
100				
110				
120	19	95	210	39
130				
140	<1.0	2.3	18	12
150				
160	<1.0	9.7	1.7	<1.0
170				

The Injection Program

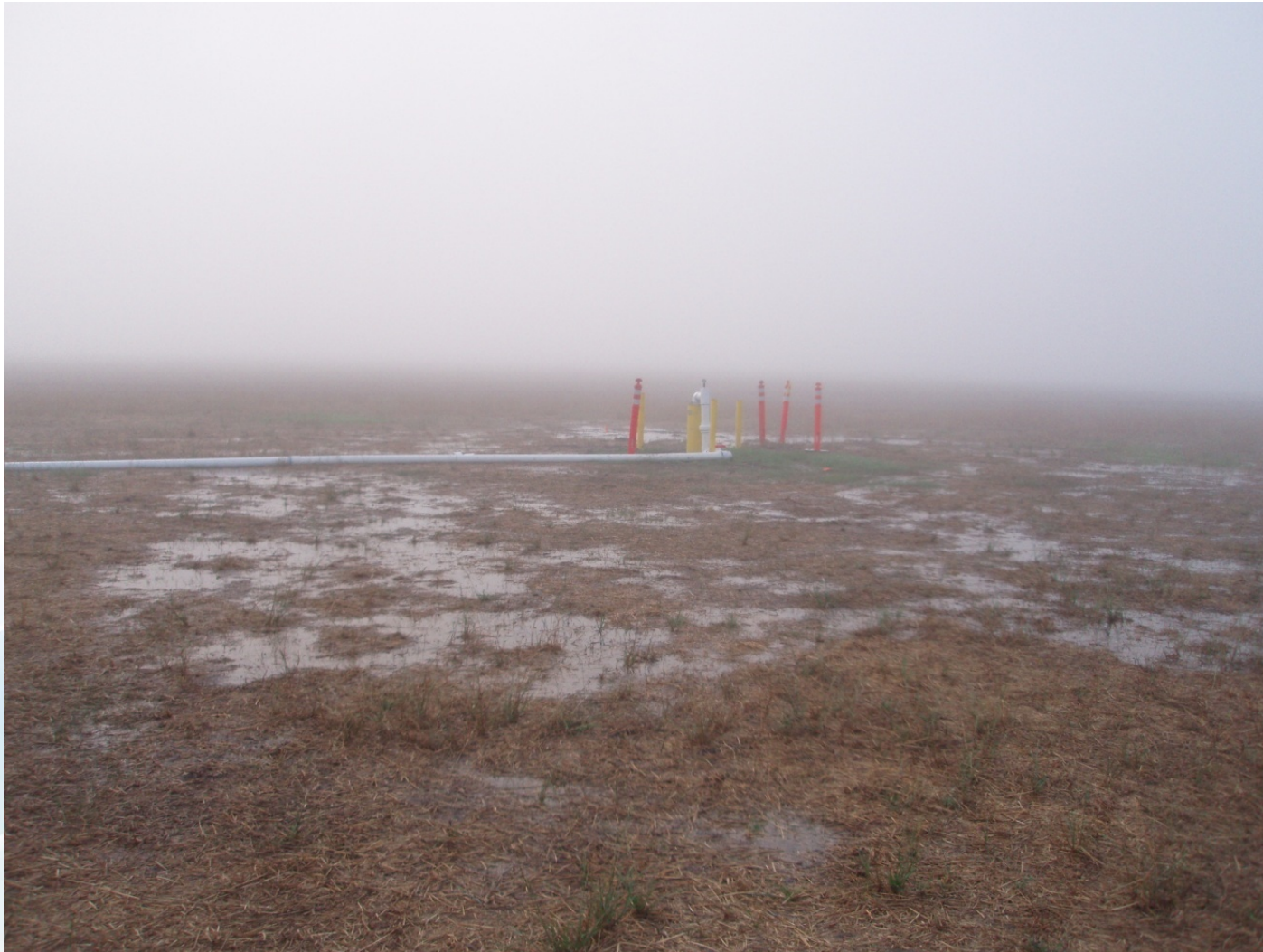
- Injections conducted in Fall 2008.
- Because we wanted the barrier to last, we selected emulsified soybean oil as the carbon substrate (ESO)
- We purchased 40,000 gallons of ESO from RNAS and 40 Liters of KB-1 *Dehalococcoides* culture from SiRem.
- To ensure that conditions would be anaerobic for survival of the KB-1, we primed the injection wells with a diluted mixture of powdered cheese whey and Vitamin B12, followed by chase water to push the solution into the formation.

The Injection Program

- To minimize injection time, we built a piping manifold so that we could inject into more than one well at a time.
- ESO and cheese whey were stored in rented tanks.
- We used a diesel generator for power.
- ESO was mixed into clean water in-line using flow meters to control the mix.
- Injection water was pumped at approximately 100 gpm from an extraction well downgradient of the injection wells.
- Water was injected at rates ranging from 20 gpm to 50 gpm.



Injection System Configuration



Weather in Oregon can be less than ideal...



ESO storage tank and cheese whey mix tank.



Injection equipment.



Injection Equipment.



Mixing cheese whey.



Mixing cheese whey.

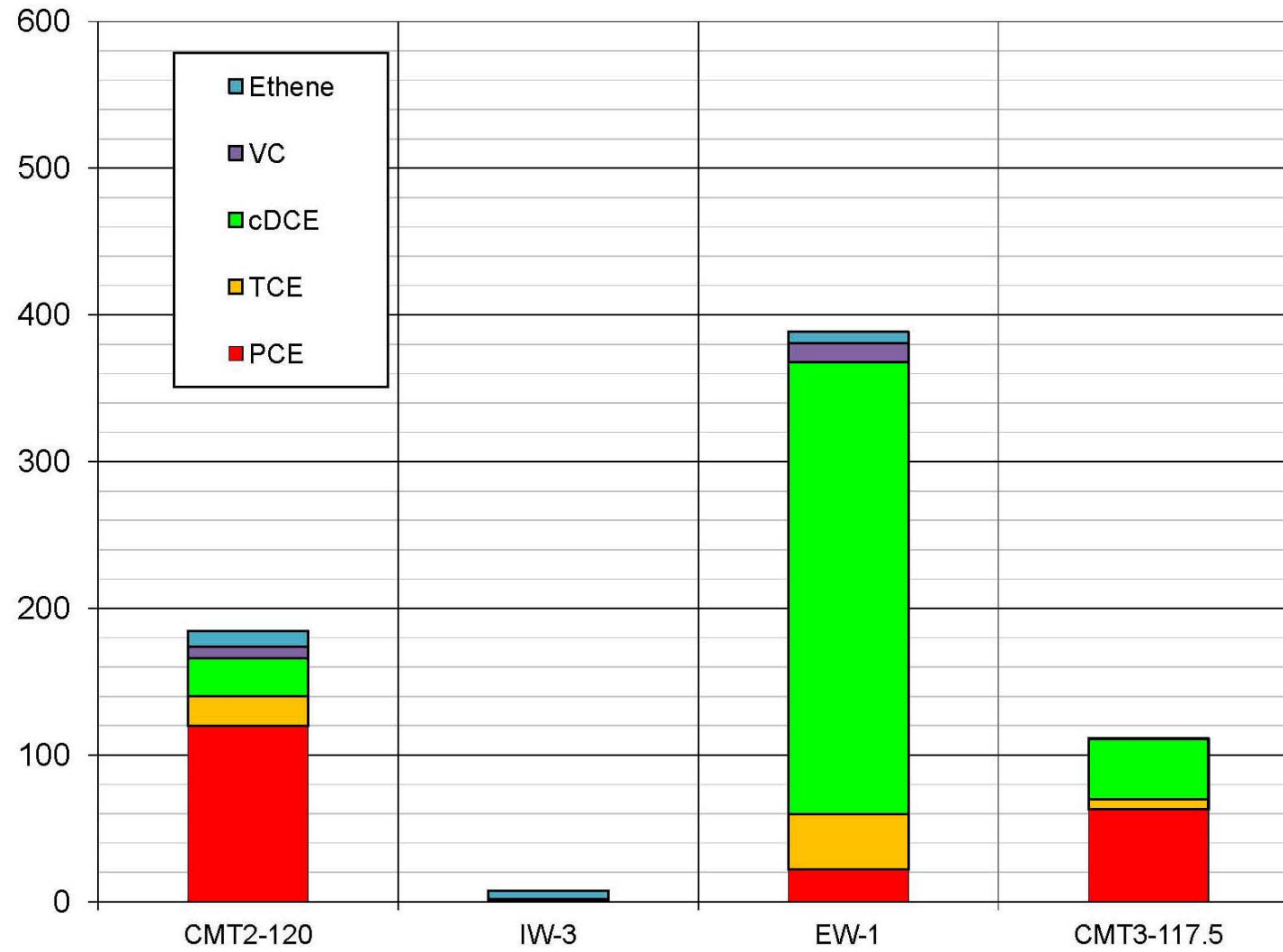


Injection well.

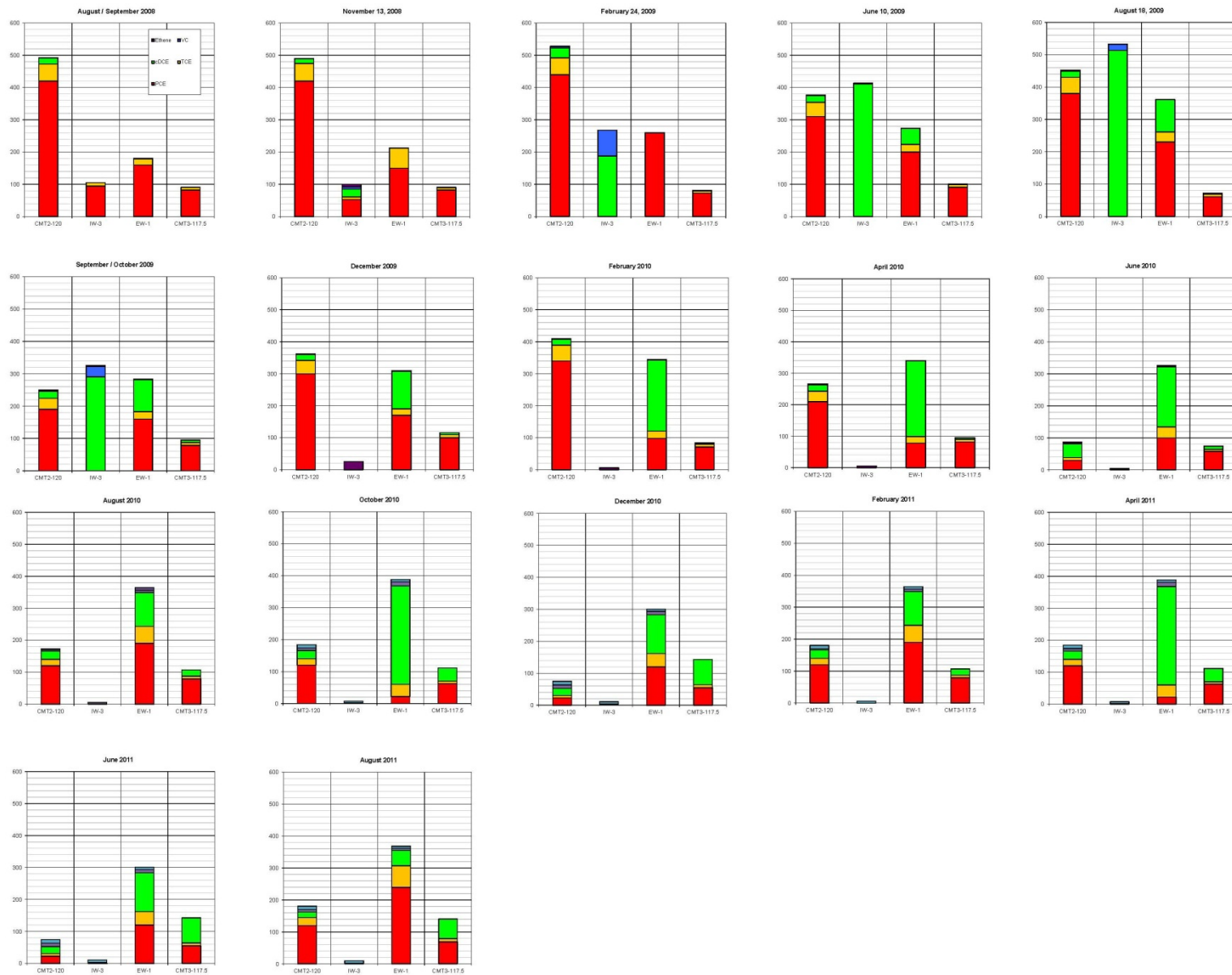
Results

- Three years later, the results are good.
- Injection Wells:
 - Dehalococcoides populations in the injection wells are in the 1×10^7 to 1×10^8 range.
 - ORP is still negative in the injection wells.
 - Chlorinated solvents are gone from the injection wells.
- Extraction Well:
 - Dehalococcoides populations in the extraction well (100 feet downgradient) are in the 1×10^6 range.
 - ORP has been reduced in the extraction well.
 - Chlorinated solvents in the extraction well are showing signs of biodegradation.

October 2010

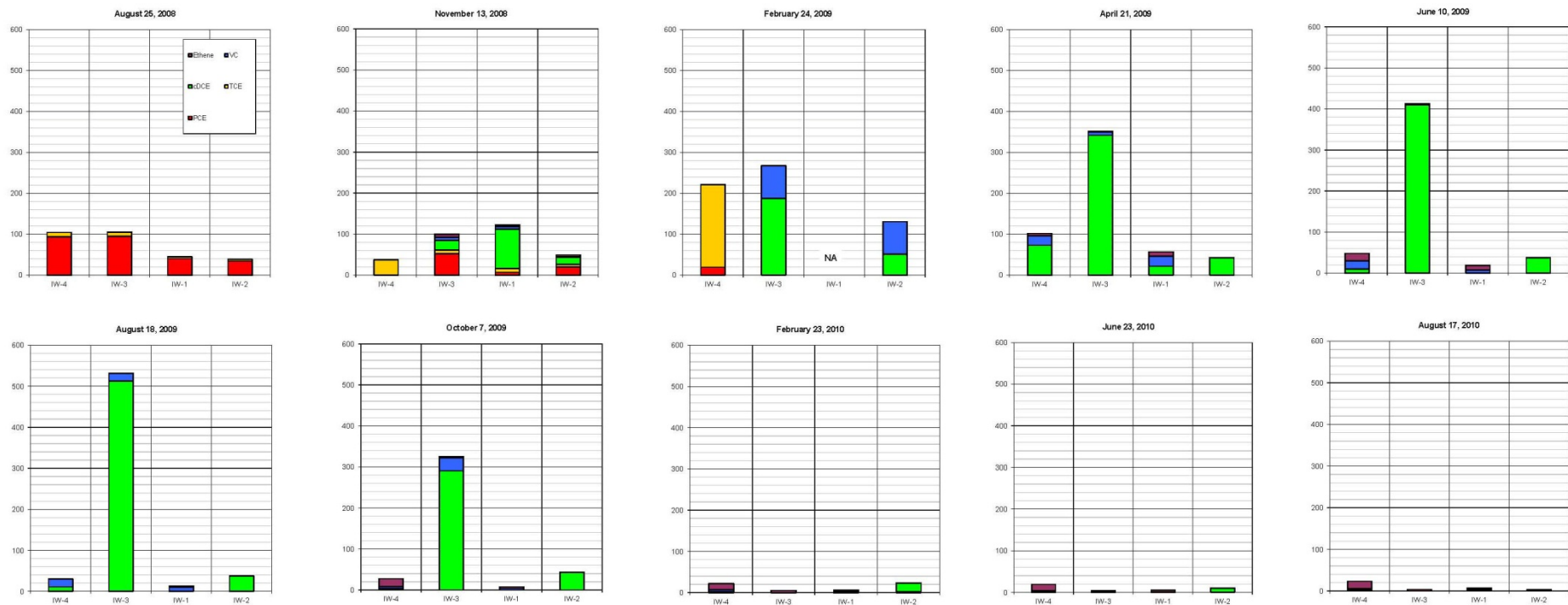


Two Years Later



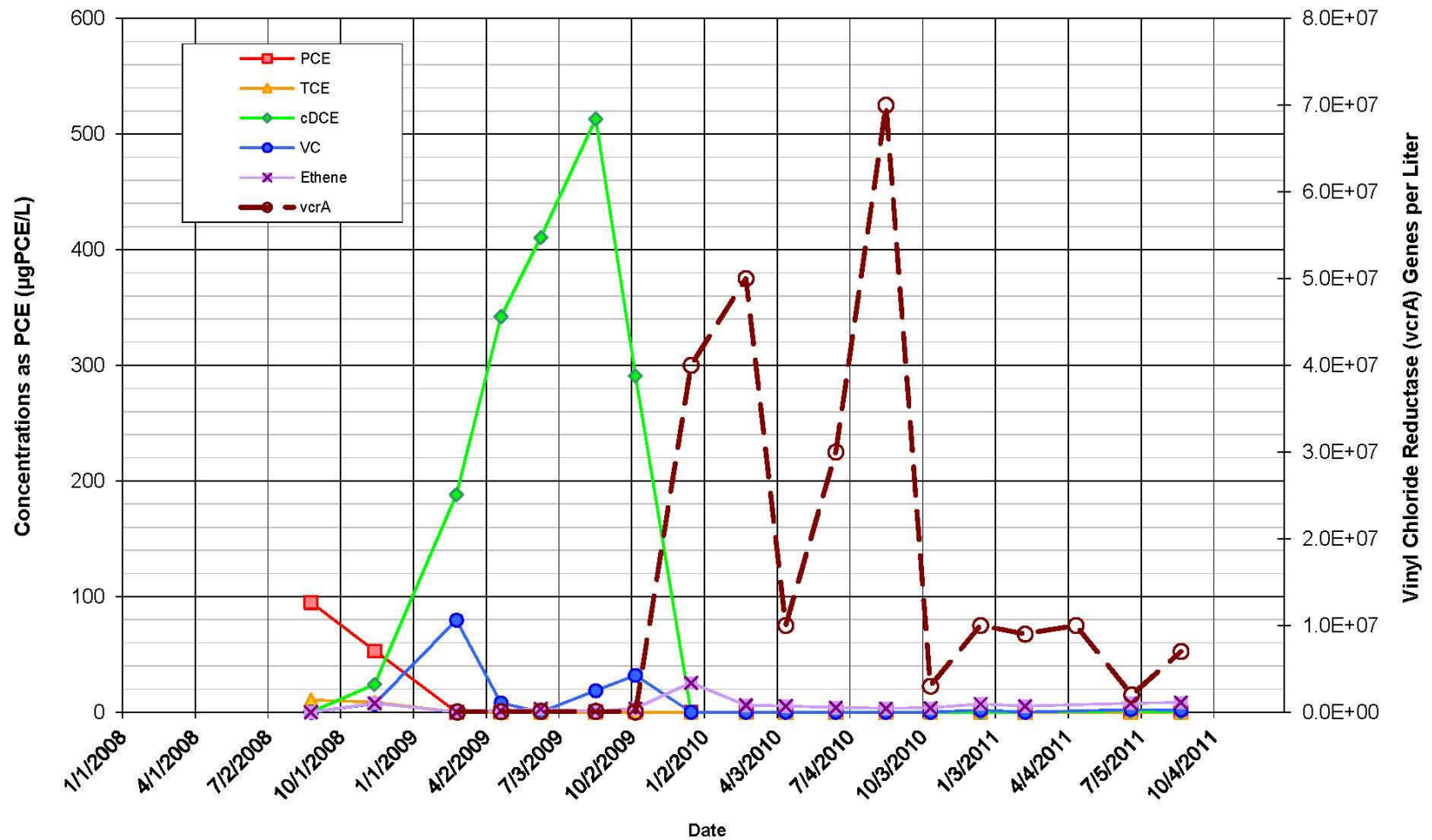
Chlorinated Solvent Concentrations Along the Length of the Plume
global environmental solutions



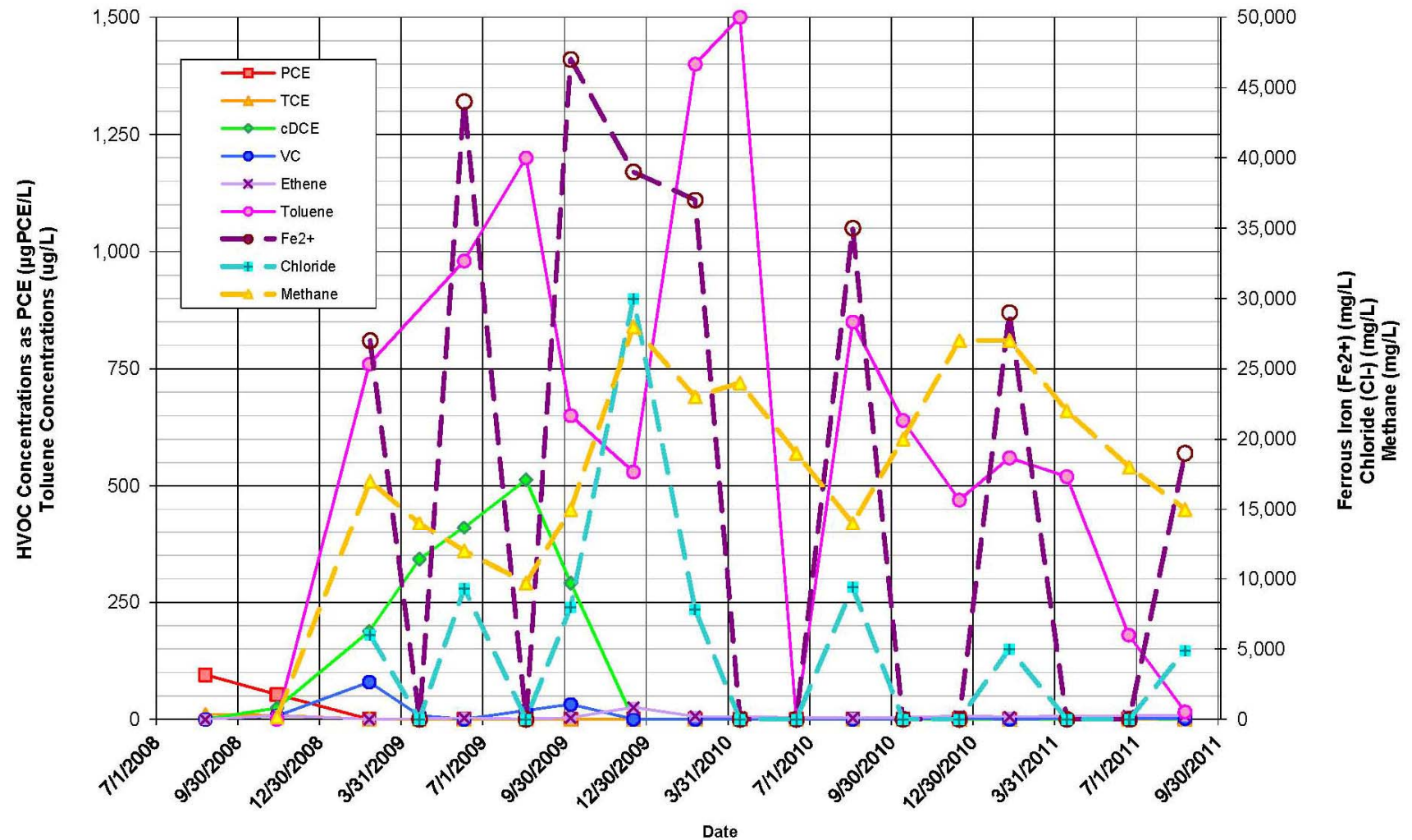


Plume Cross Section (North to South from Left to Right)

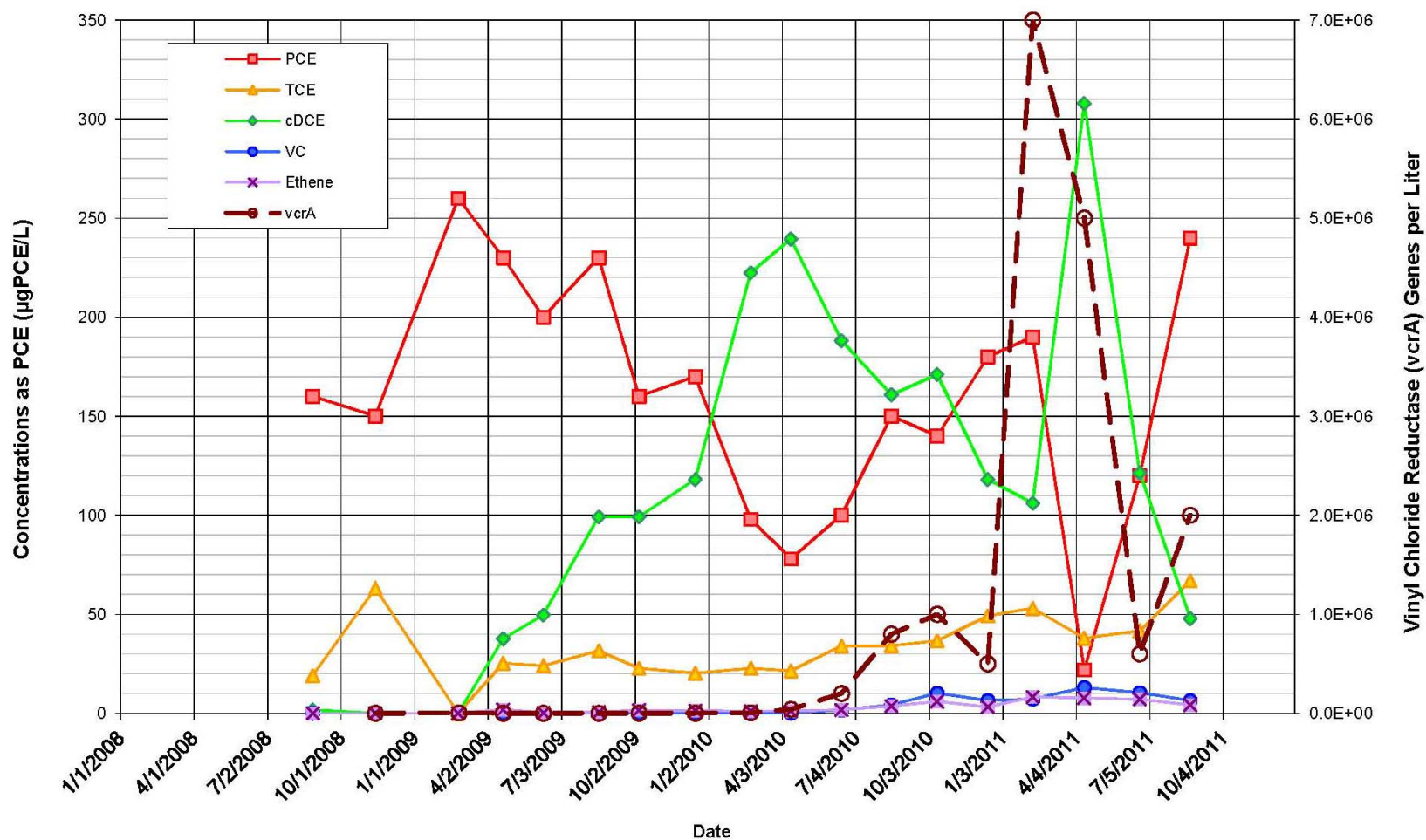
Graph 3. Historical HVOC Concentrations in IW-3



Graph 4. Historical HVOC Concentrations and Other Parameters in IW-3



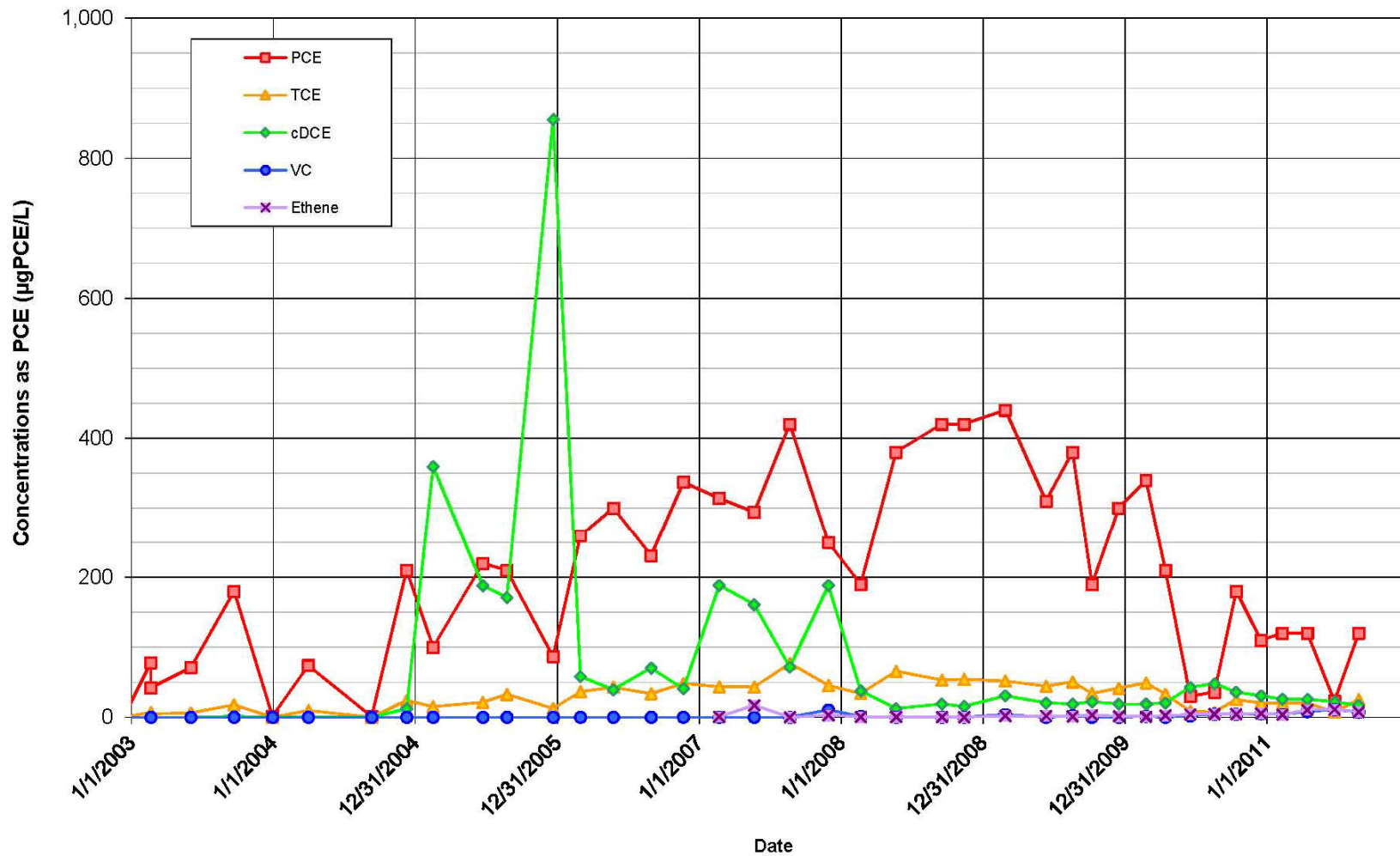
Graph 6. Historical HVOC Concentrations in EW-1



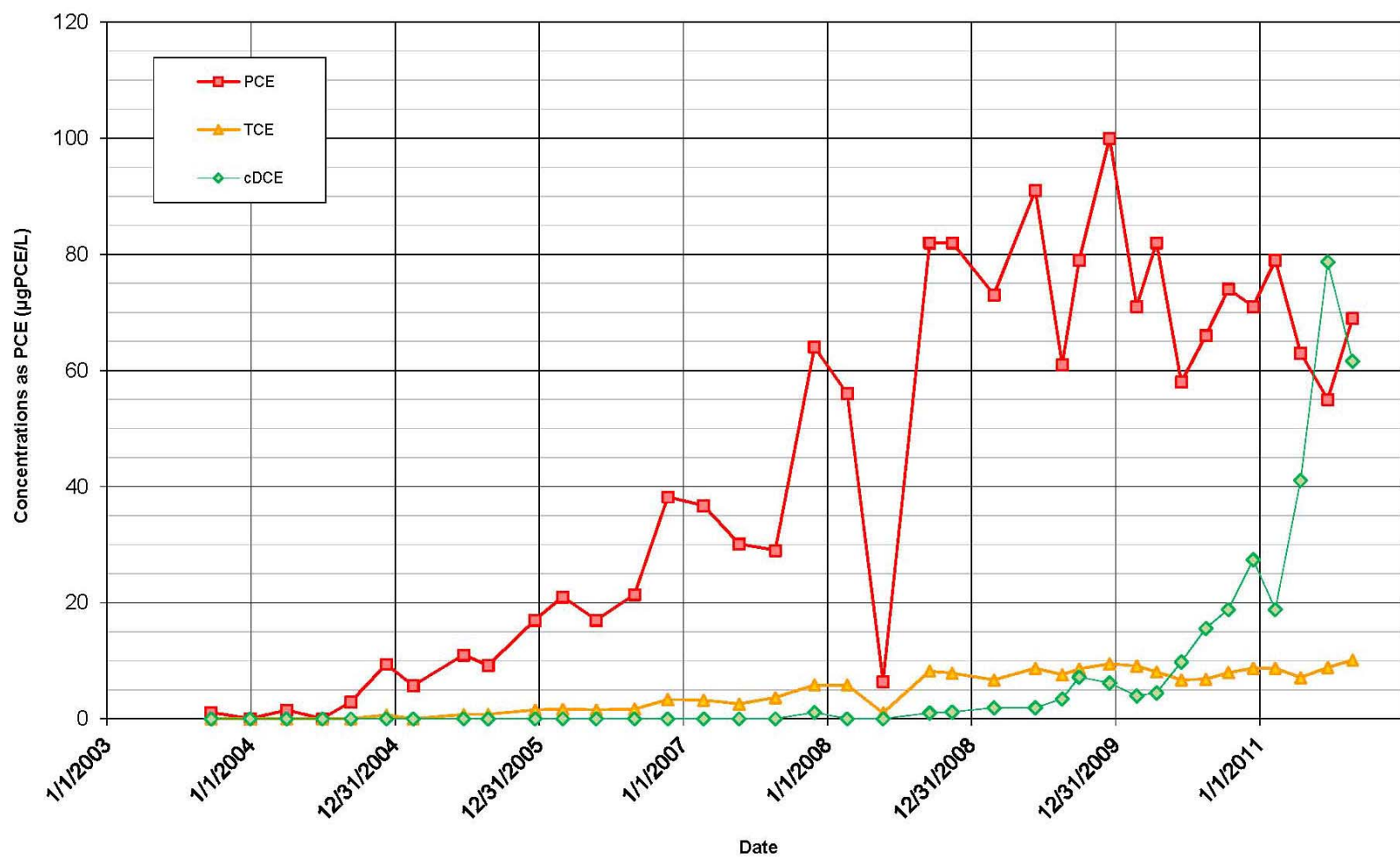
Results

- Upgradient Well:
 - Concentrations are declining.
 - The bulk of the chlorinated solvents appear to have moved past this well.
 - Do we perform another injection at the original location?
- Downgradient Well:
 - Overall chlorinated solvent concentrations are rising.
 - Degradation products are appearing.
 - At 160 feet depth, all of the impact is now cDCE
 - Do we perform another injection downgradient of this well?

Graph 7. Historical HVOC Concentrations in CMT2-120



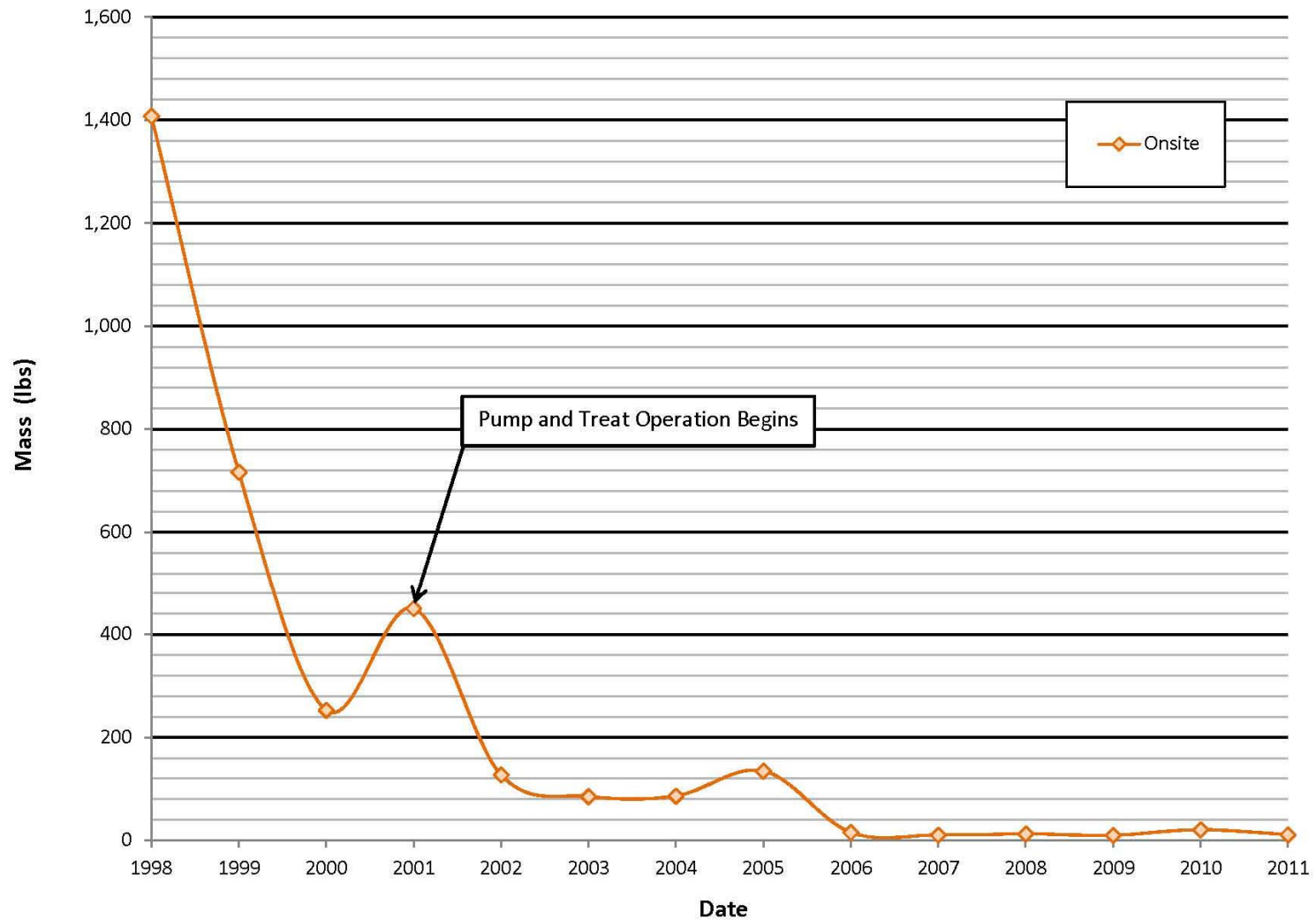
Graph 10. Historical HVOC Concentrations in CMT3-117.5



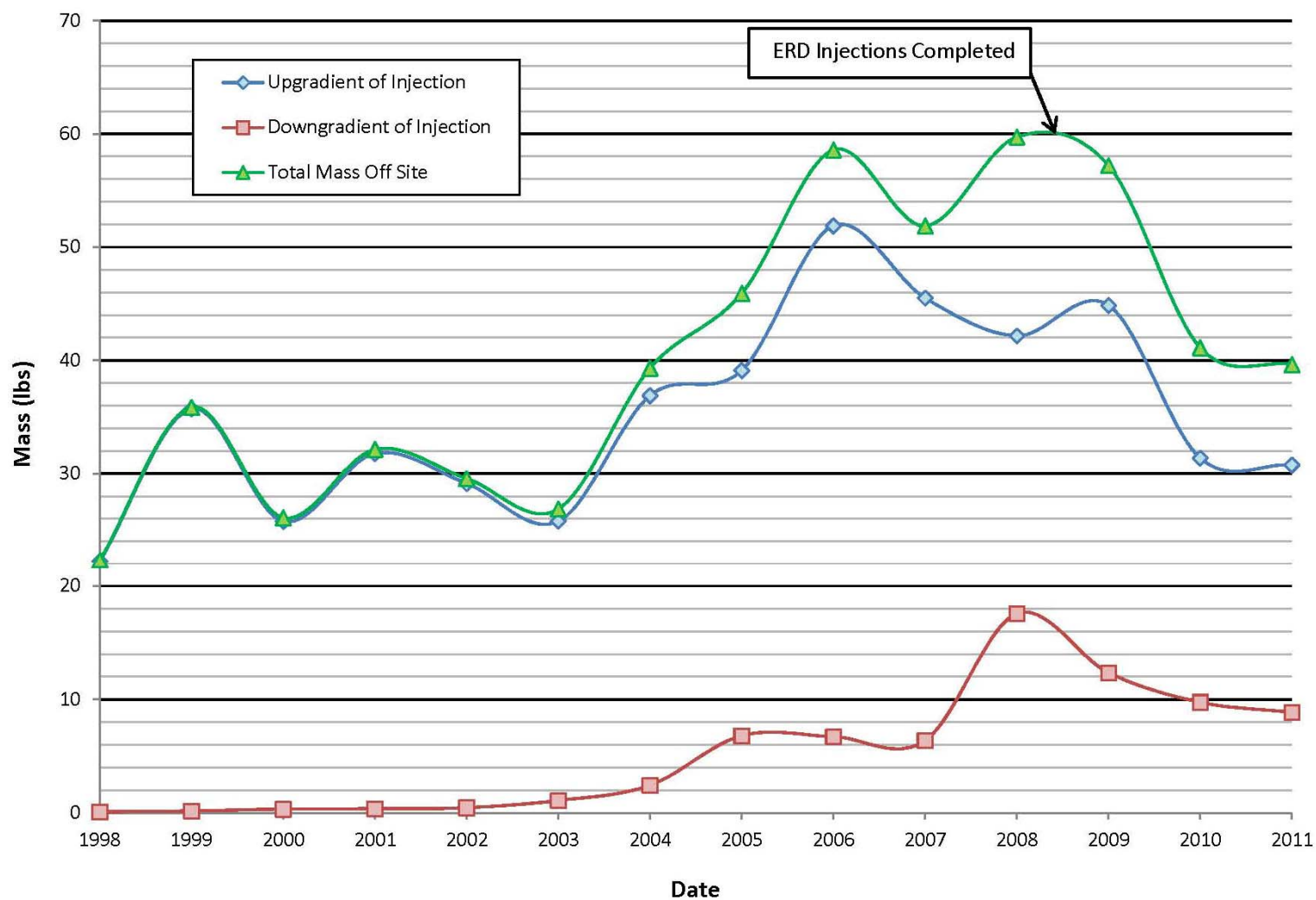
Conclusion

- Reductive dechlorination has been successful at this site.
- Estimated reduction in on-site mass due to pump and treat of 98%
- Estimated reduction in off-site mass due to enhanced reductive dechlorination of 34%

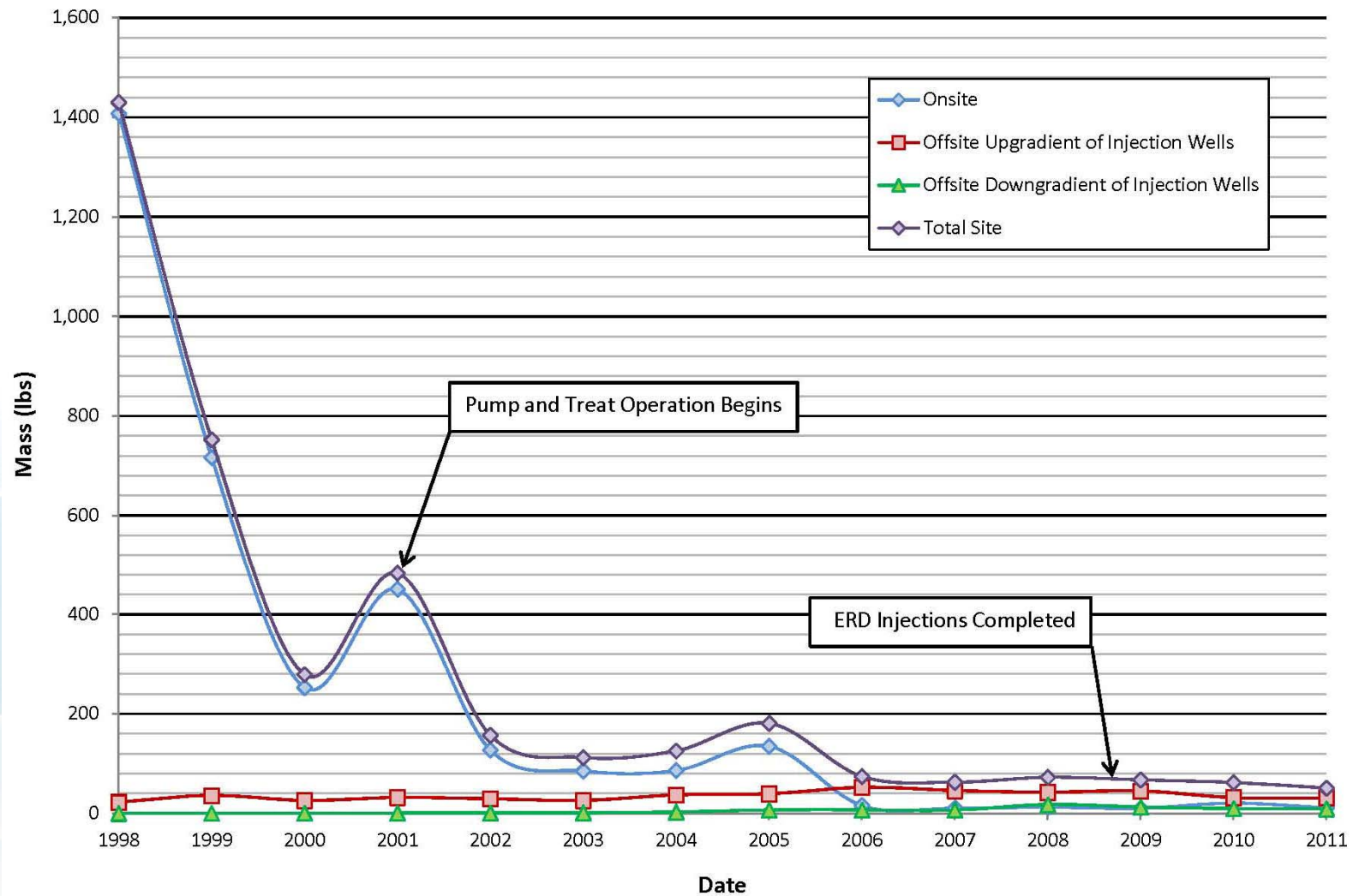
Estimated Chlorinated Solvent Mass in Onsite Groundwater

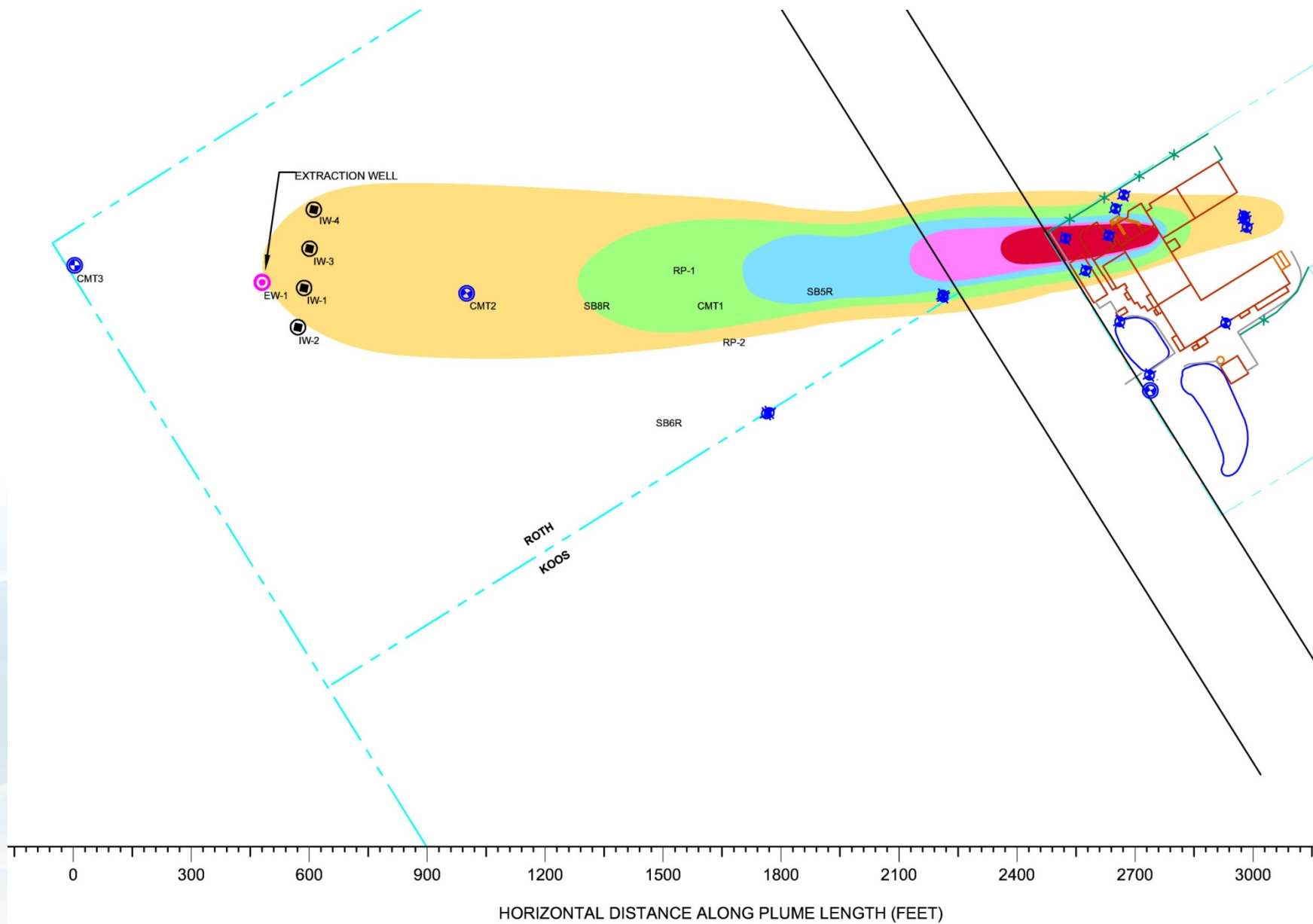


Estimated Chlorinated Solvent Mass in Offsite Groundwater

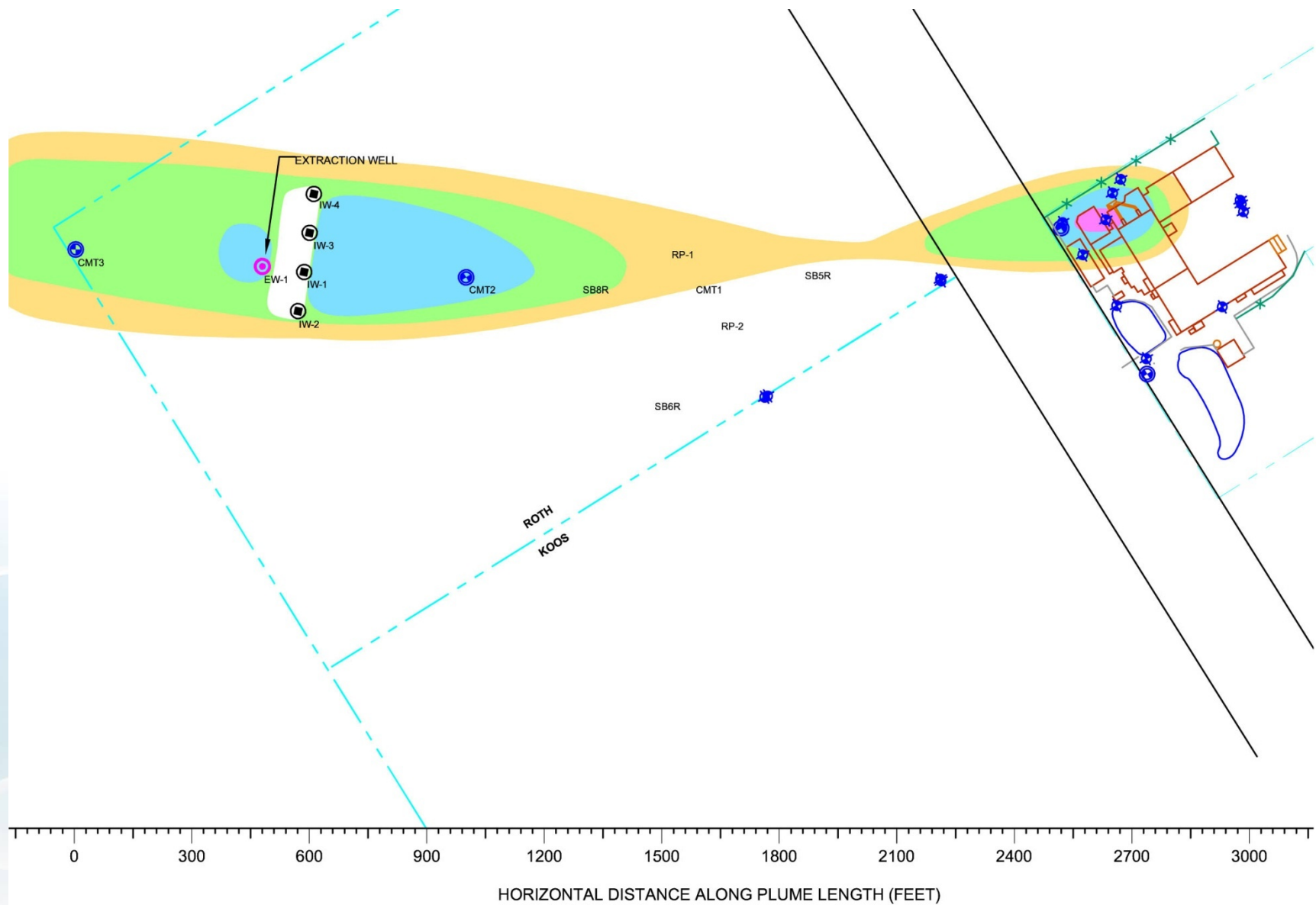


Estimated Chlorinated Solvent Mass in Onsite and Offsite Groundwater

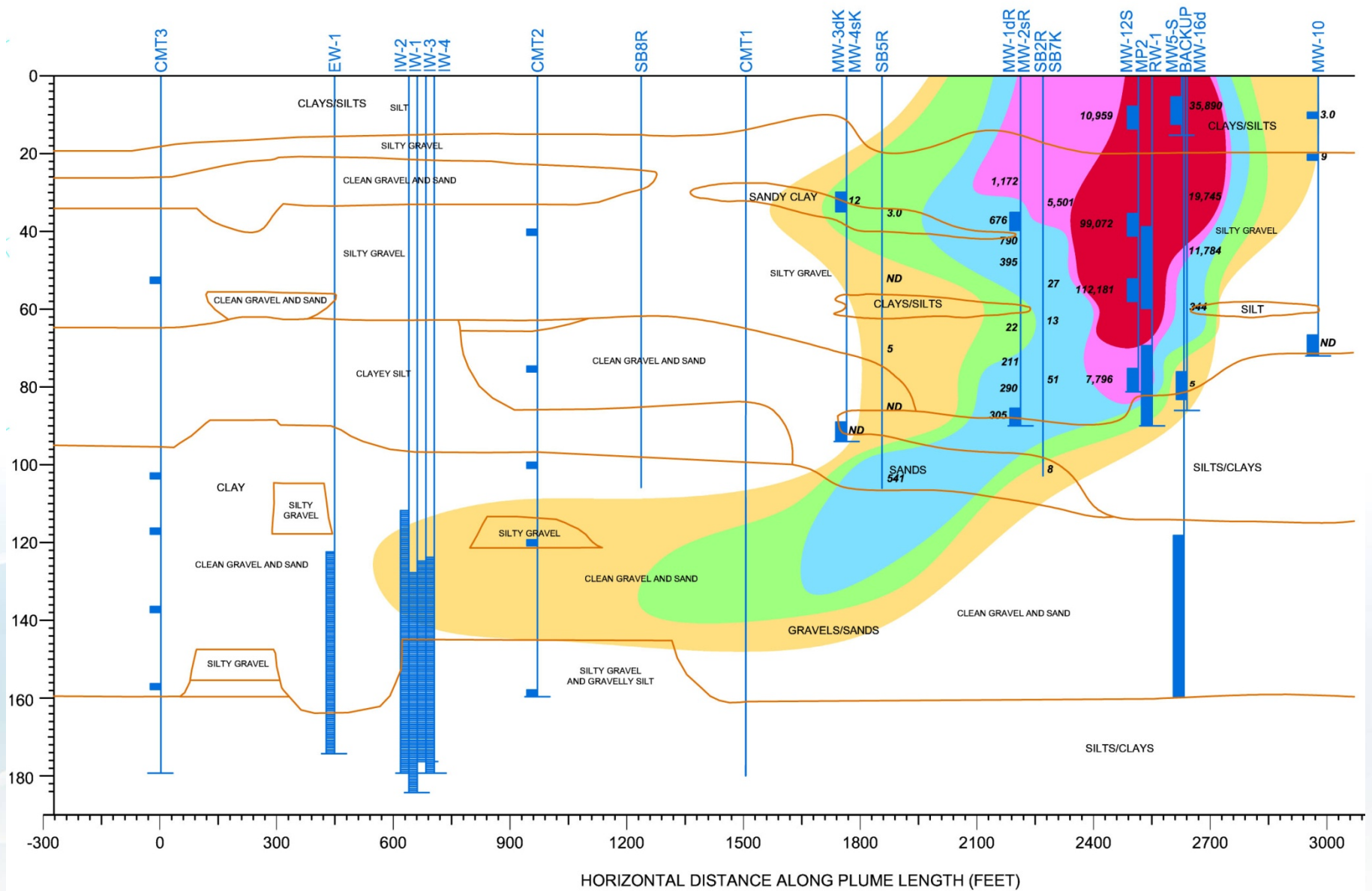




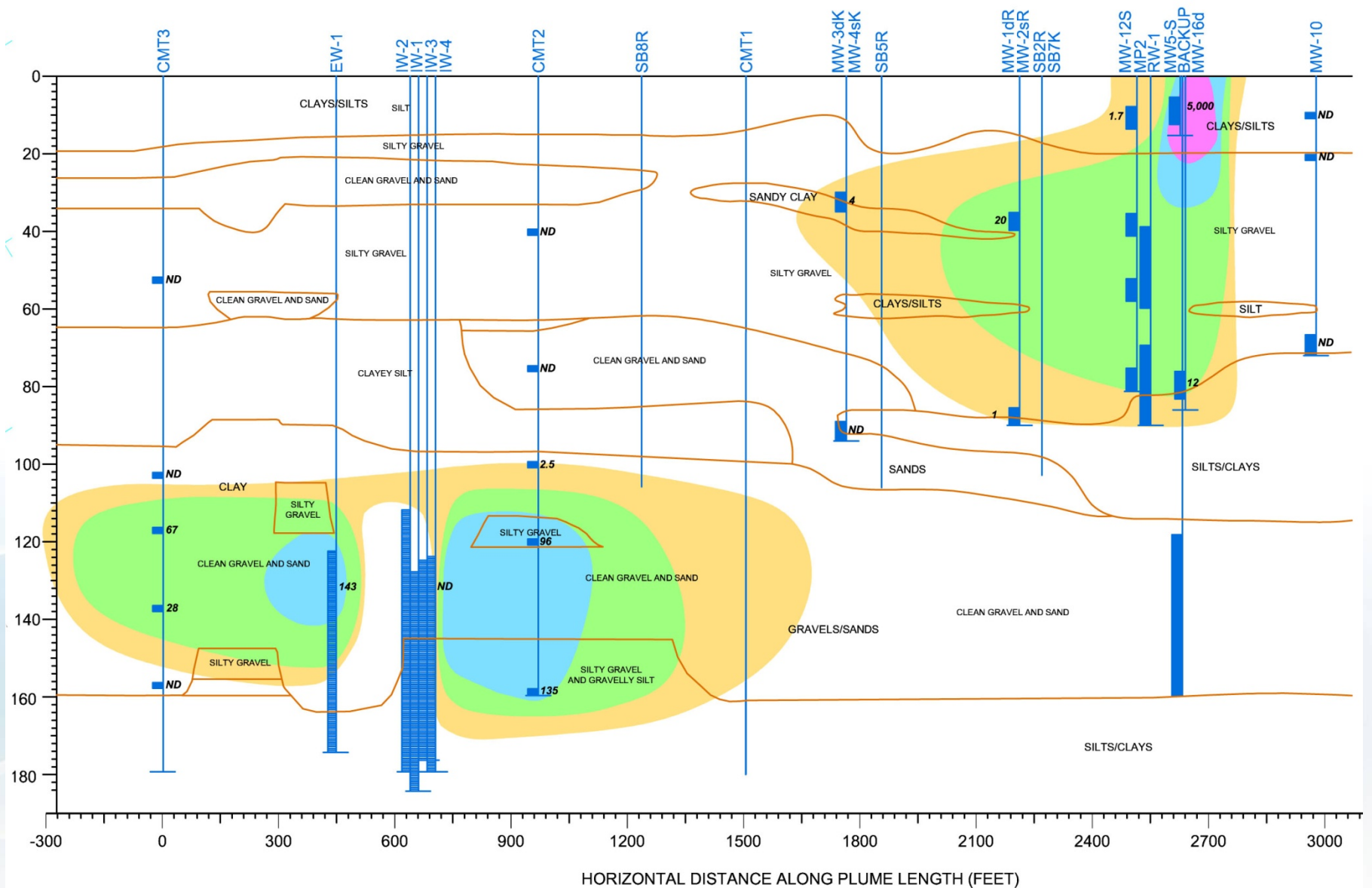
1998: Plume has migrated under the freeway and underneath a farmer's field



2011: The “head” of the higher concentration portion of the off-site plume is being treated by the barrier.



1998: Plume has migrated into the deep zone off-site.



2011: The pump and treat system has cut off contaminant flow into the deep zone, and the barrier is treating deep zone contamination.

global environmental solutions

