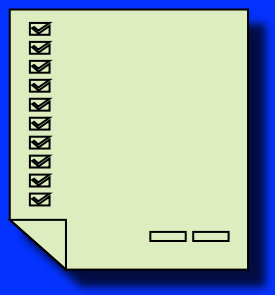
Rapid & Complete In Situ Bioremediation of Chlorinated Solvents Using Enhanced Anaerobic Dechlorination (EAD)

Roadmap

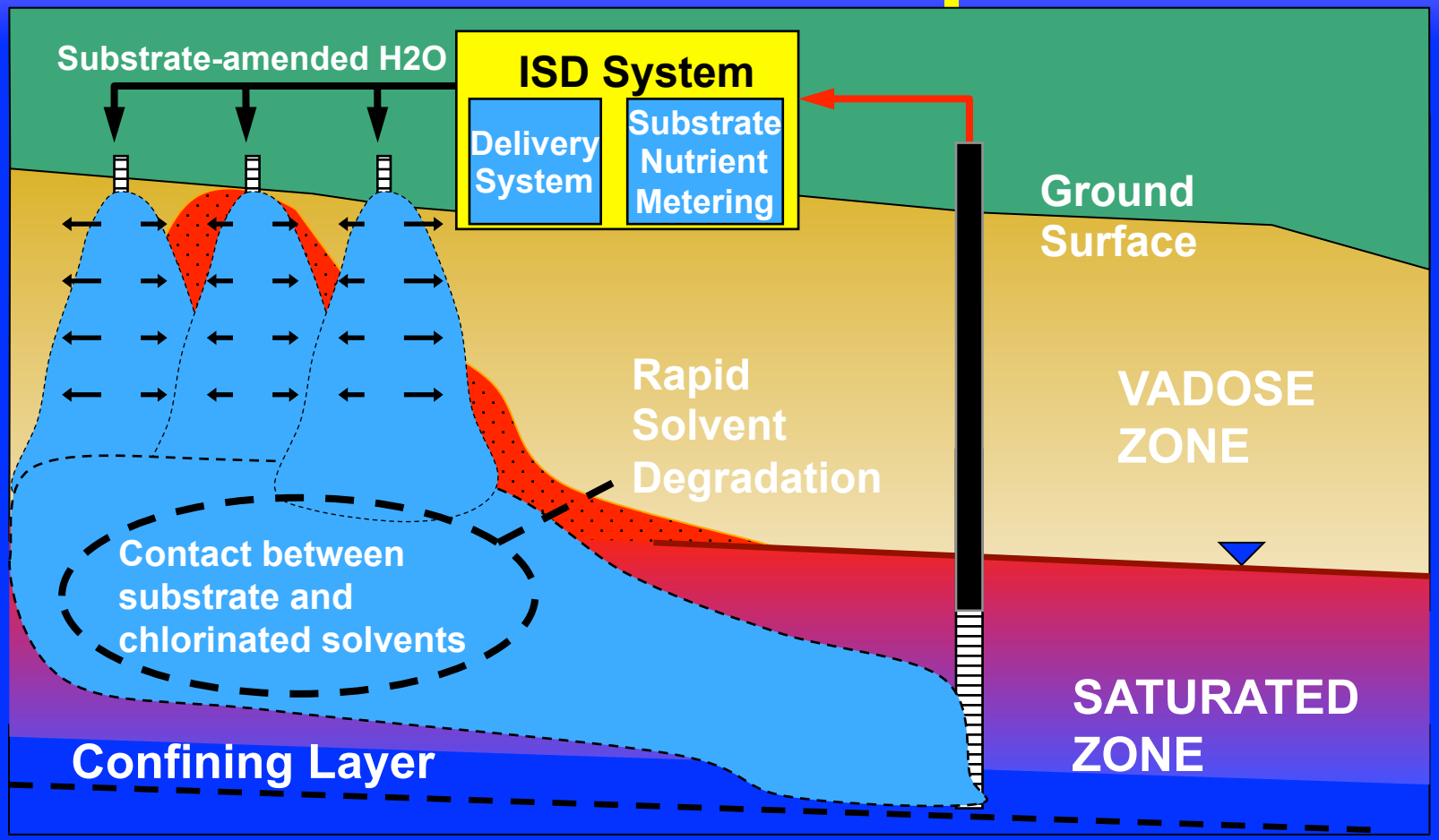
ISD™ **In Situ Delivery Systems**

1) Its All About Delivery: Our ISD™ systems provide a powerful delivery platform to support **site-wide** anaerobic degradation of chlorinated solvents



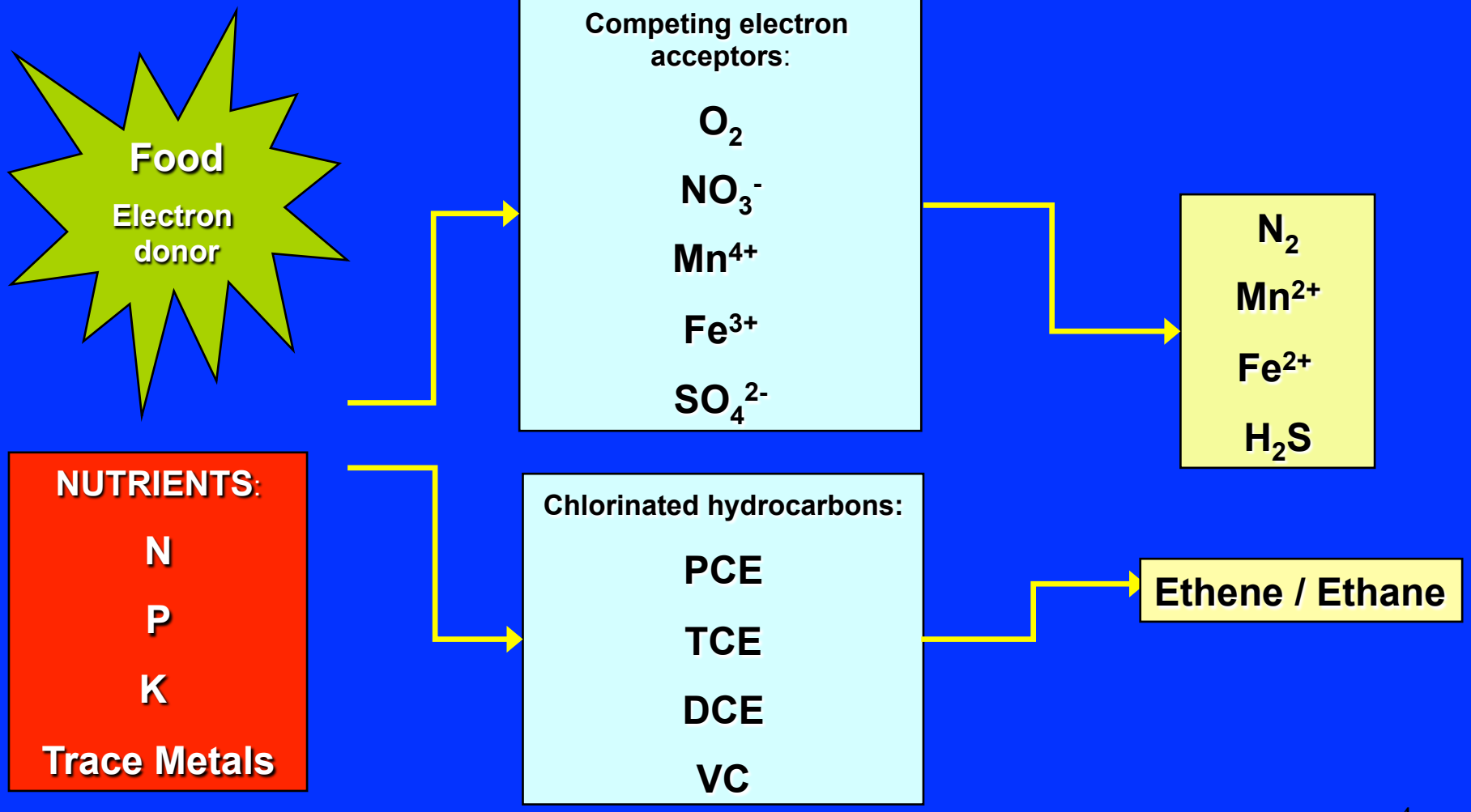
2) ***Full-scale Case Study:*** Field applications of our ISD groundwater recirculation approach validates this remediation strategy

ISD Concept



- Effective substrate delivery via 24/7 GW recirculation - NO SLUG INJECTIONS
- Highly soluble substrate, plus nutrients, to grow active biomass in porespace
- Max. microbial activity, ↓ ORP, methanogenic cond., ↑ dissolution, no rebound

EAD Process


Food
Electron donor
NUTRIENTS:
N
P
K
Trace Metals
Competing electron acceptors:
O_2
NO_3^-
Mn^{4+}
Fe^{3+}
SO_4^{2-}
Chlorinated hydrocarbons:
PCE
TCE
DCE
VC
N_2
Mn^{2+}
Fe^{2+}
H_2S
Ethene / Ethane

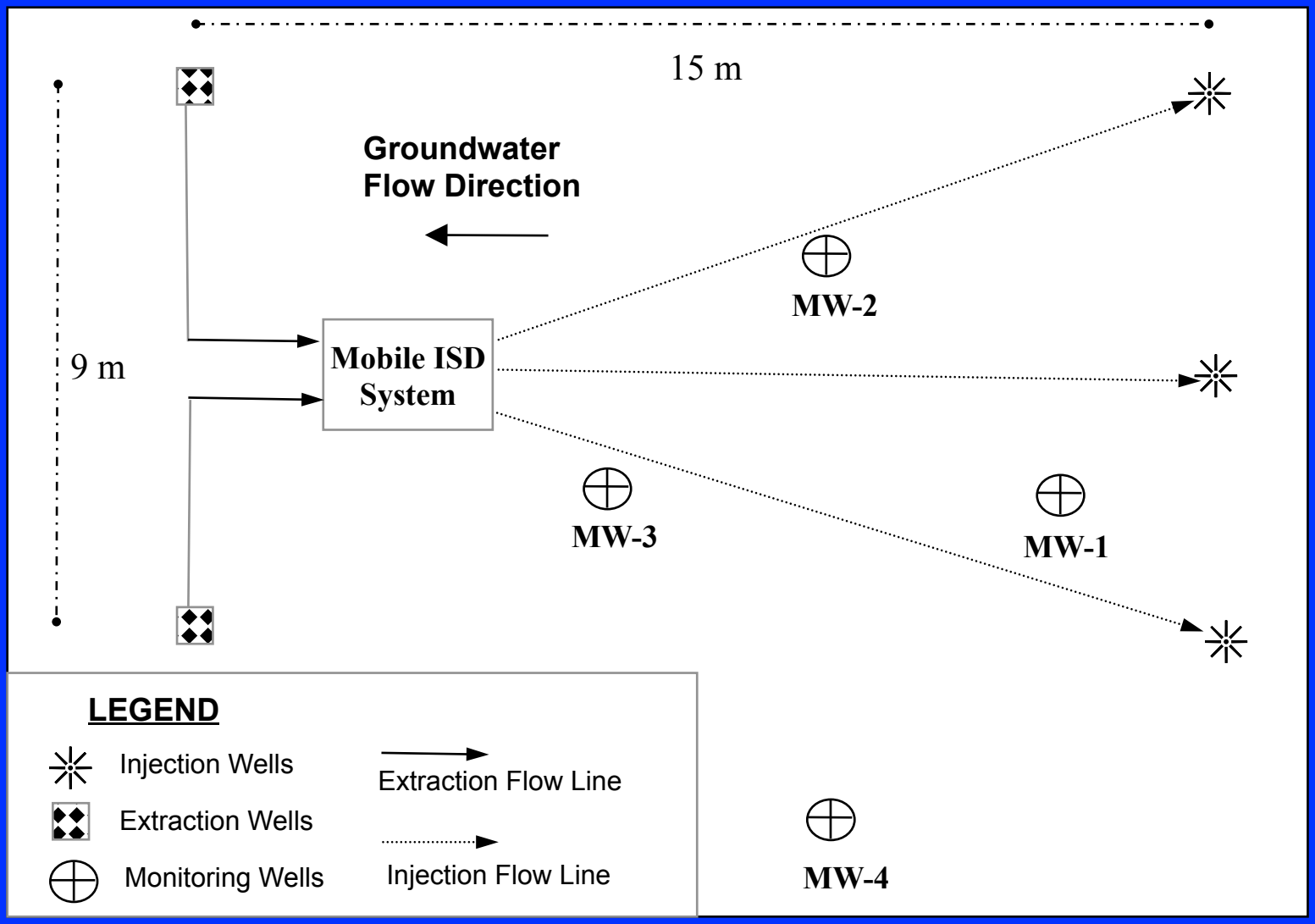
ETEC's EAD Process

- **Advantages of Groundwater Recirculation w/ ISD™**
  - Programmable Automation
  - Direct hydraulic influence and capture
  - Contact – dissolved & adsorbed (source, distal plume)
  - Biomass generation, site-wide activity
- **Inexpensive Electron Donor - CarBstrate™**
  - Nutrient-amended Carbohydrate – low cost ($2/lb)
- **Installation/Interpretation Services**
  - Equipment installation & training
  - Monthly Interpretation/Evaluation of Data
- **Timeframe**
  - ISD results in months vs. years
  - Minimal O&M and cost (pulsed vs. continuous)

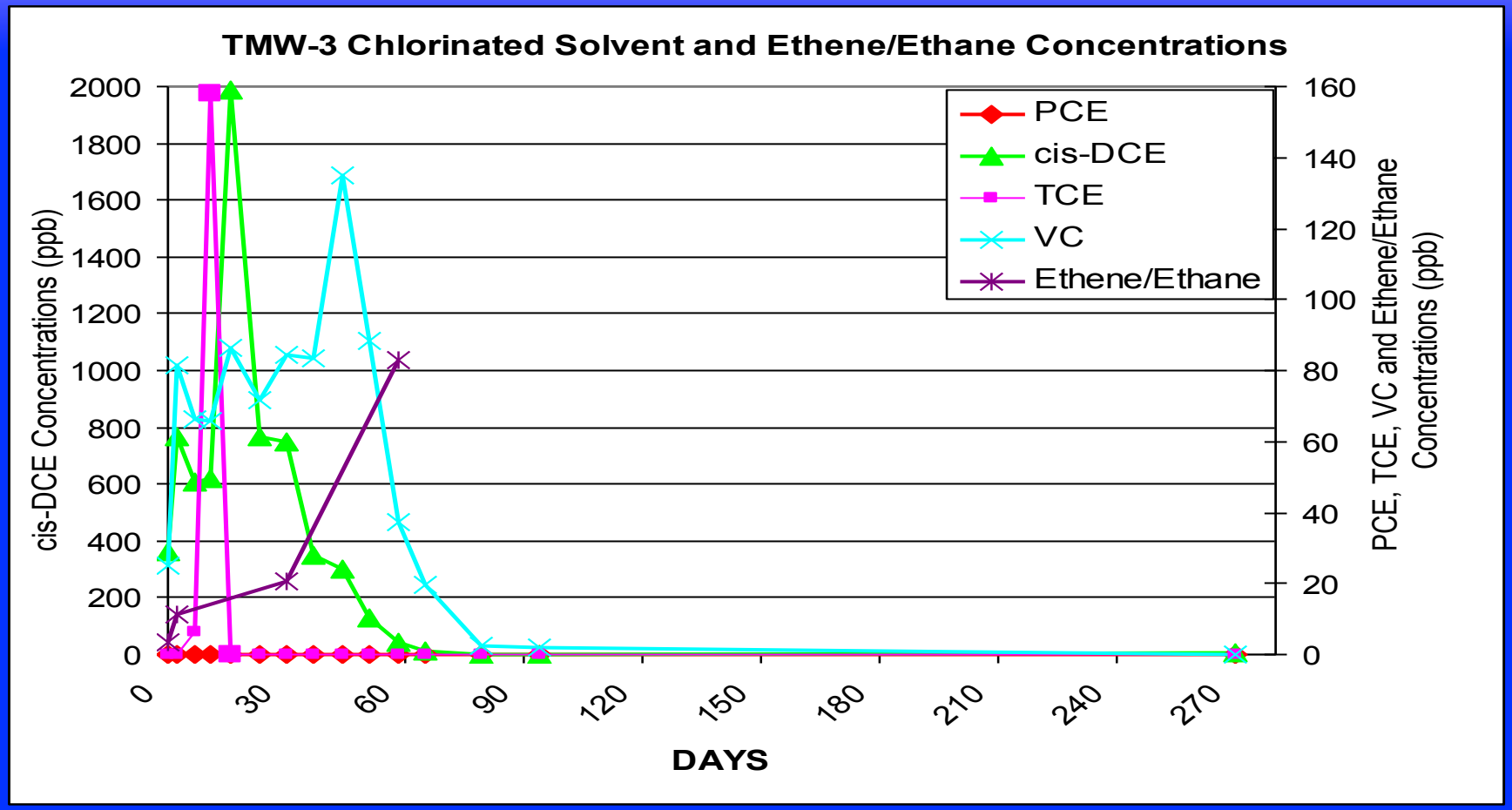
Pilot-scale Data:

Industrial Site
Eugene, Oregon

OR Case Study Site Plan



TMW-3 Results



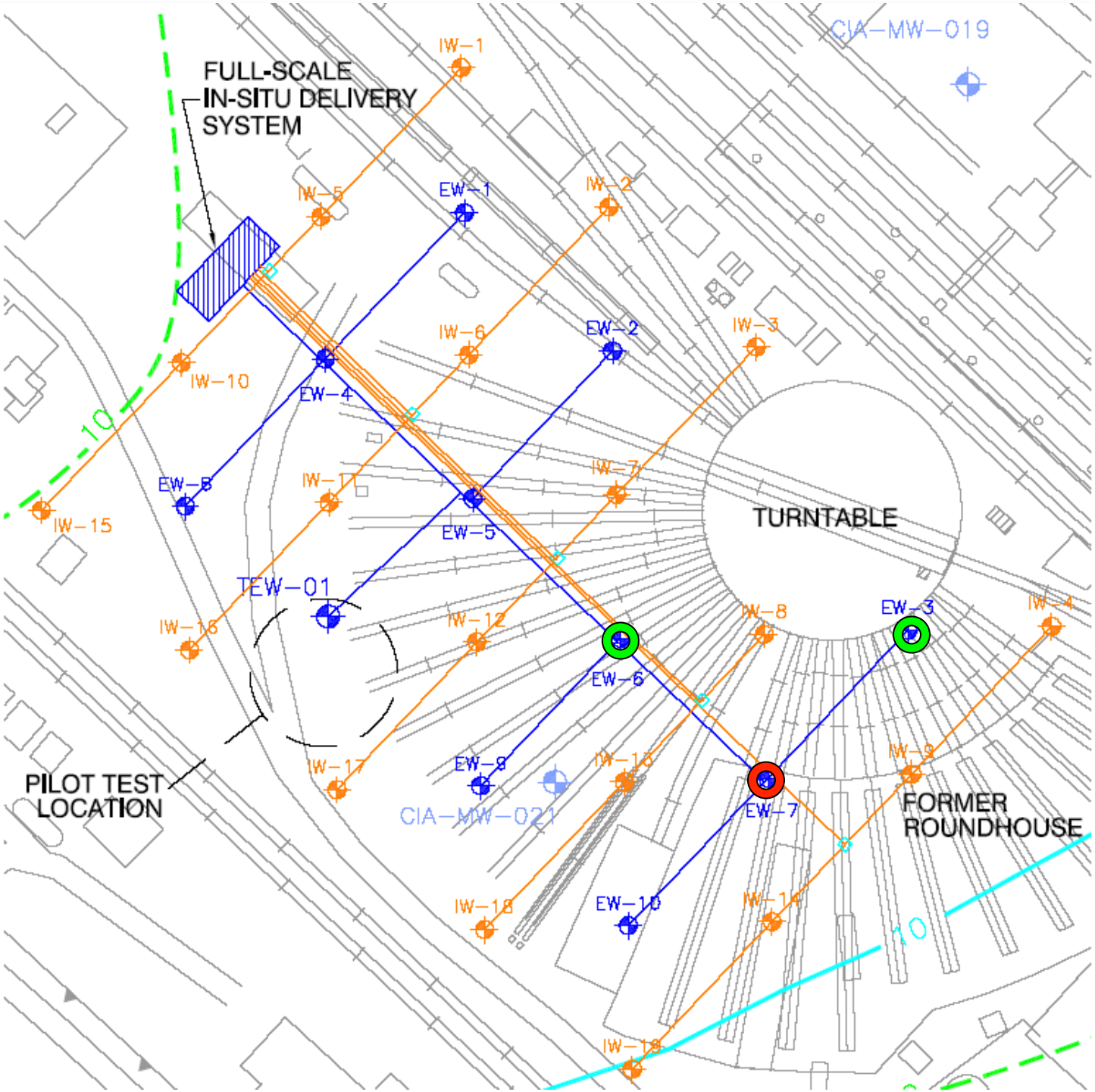
- **Operating Parameters**
  - 3 weeks
  - 178,000 liters recirculated
  - 180 kg of CarBstrate™
- **Observations**
  - CAH concentrations increased 2-3 fold during 1st week, no PCE at TMW-3
  - DCE from 360 to 2,000 ppb
  - Initial total CAH 3.8 µmol/L, with a high of 22.3 µmol/L
  - 8 months, no rebound, cis-DCE and VC (6 and <1 ppb)

Full-scale Case Study:

Industrial Site
Eugene, Oregon

2006 Full-scale RA

- **Solid pilot-test data showing rapid, complete dechlorination of solvents supported full-scale in situ remedial action**
- **Full-scale conducted from June-Sept 2006 to remediate source area (122 m x 91 m x 6 m) using 31 Injection/extraction wells**
- **150-lpm ISD system, touch-screen and flexible PLC system**
- **12-18 month estimated timeframe to reduce CAHs by 90%, achieved goal in 6 months**



Environmental Technologies
www.etecllc.com

Full-scale system has 11 EWs and 20 IWs. To date, most data has been collected from EW-3, 6, 7, and 10. Samples collected from EW-7 shows source zone concentrations.

Over 3 months:

Recirculated over >8.7 million liters in 3 months

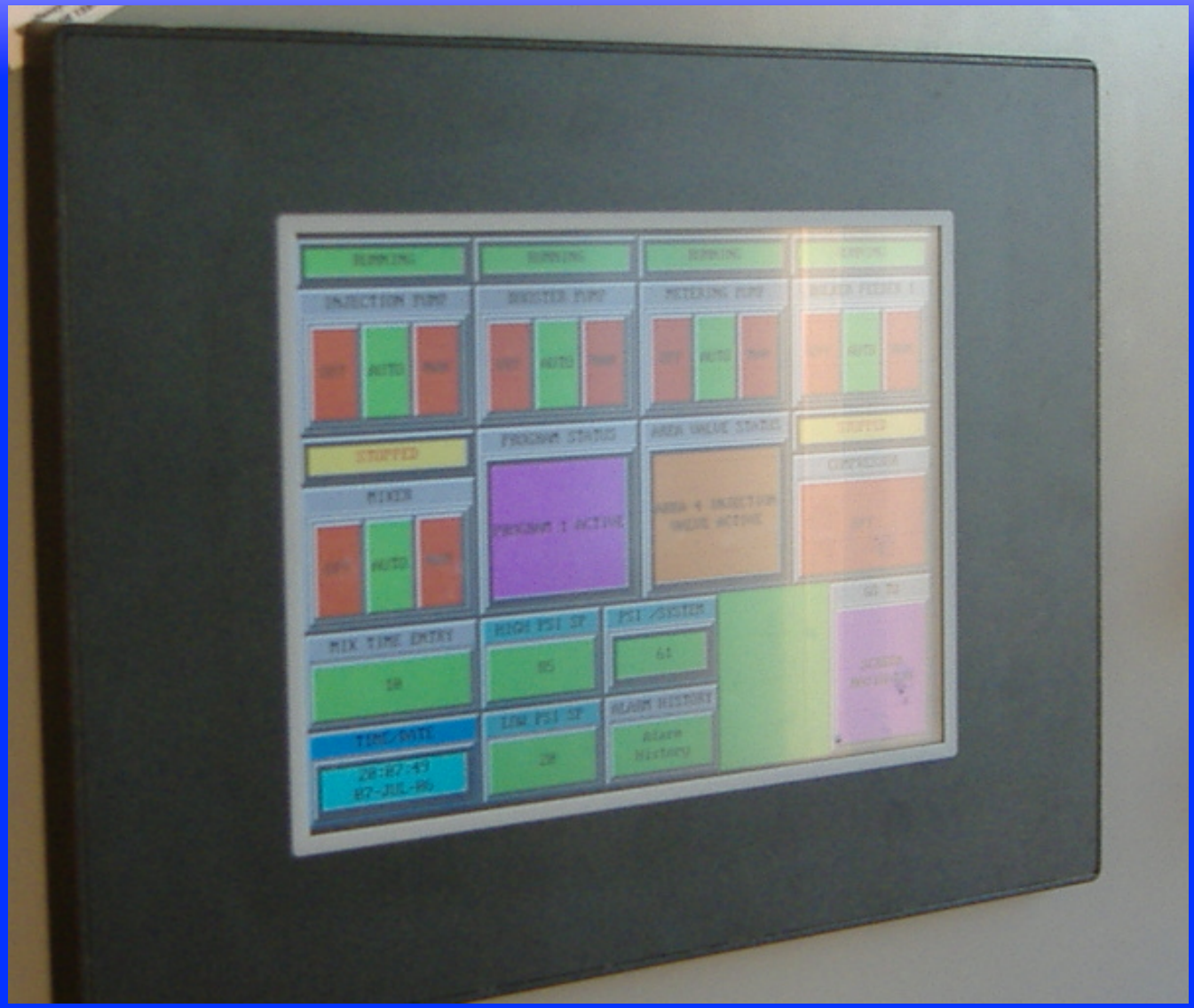
Introduced 3,720 kg substrate

1-visit/week

Minimal down time

Minimal Fouling

Some LNAPL (diesel and Bunker C)



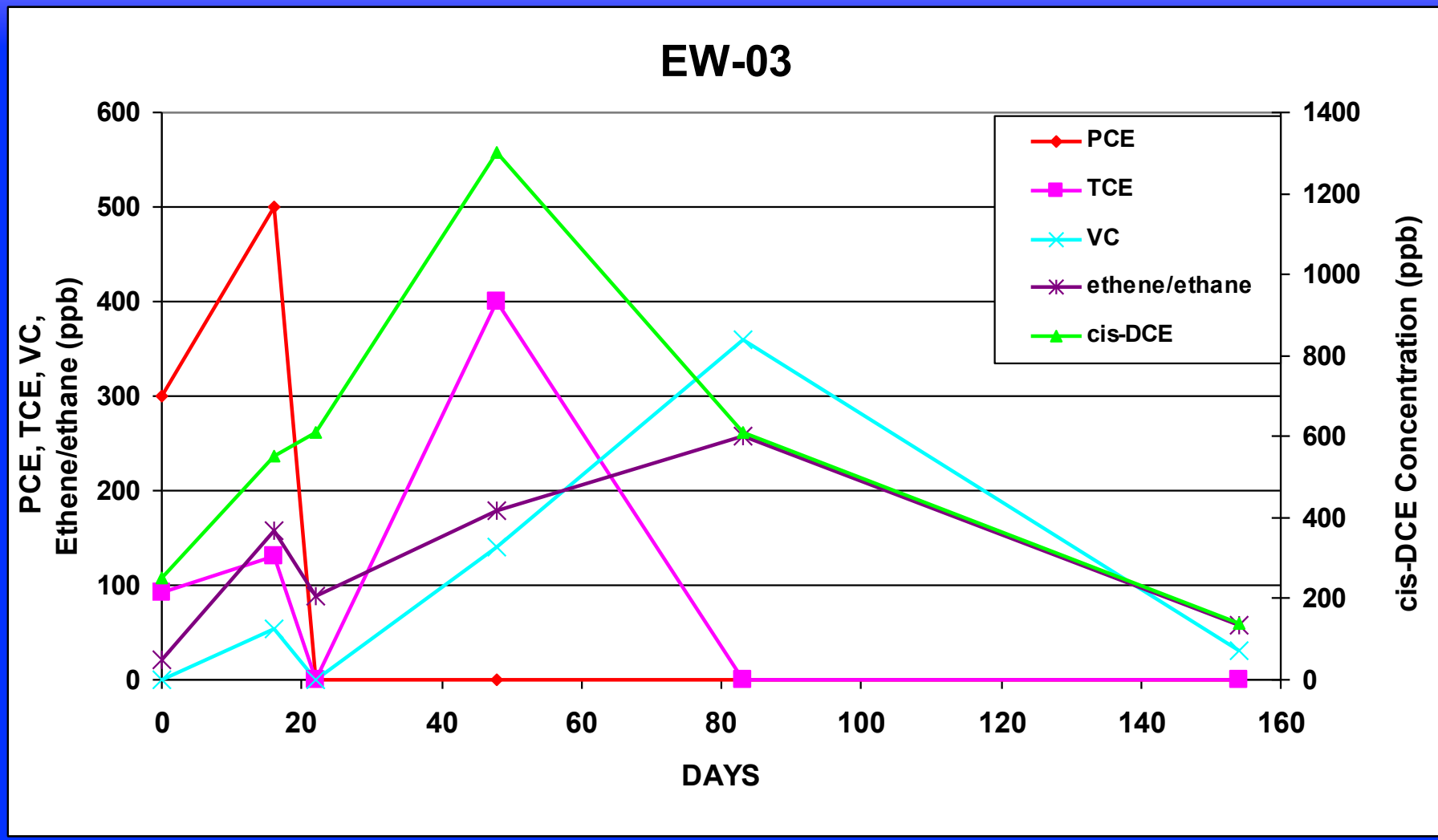
Touch Screen PLC:

Alarm Conditions, Troubleshooting

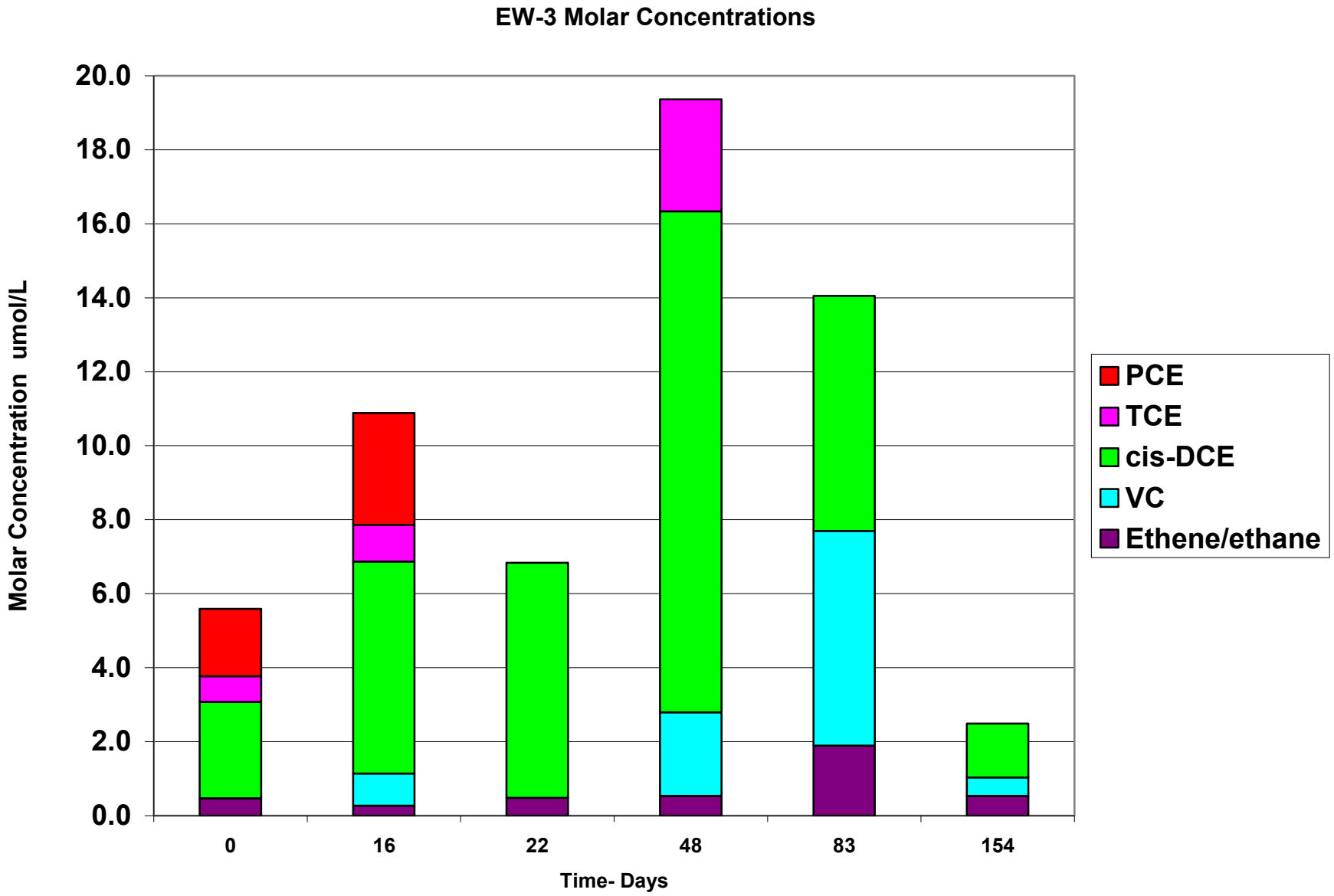
Flexible injection times

Auto-dialer/ Telemetry

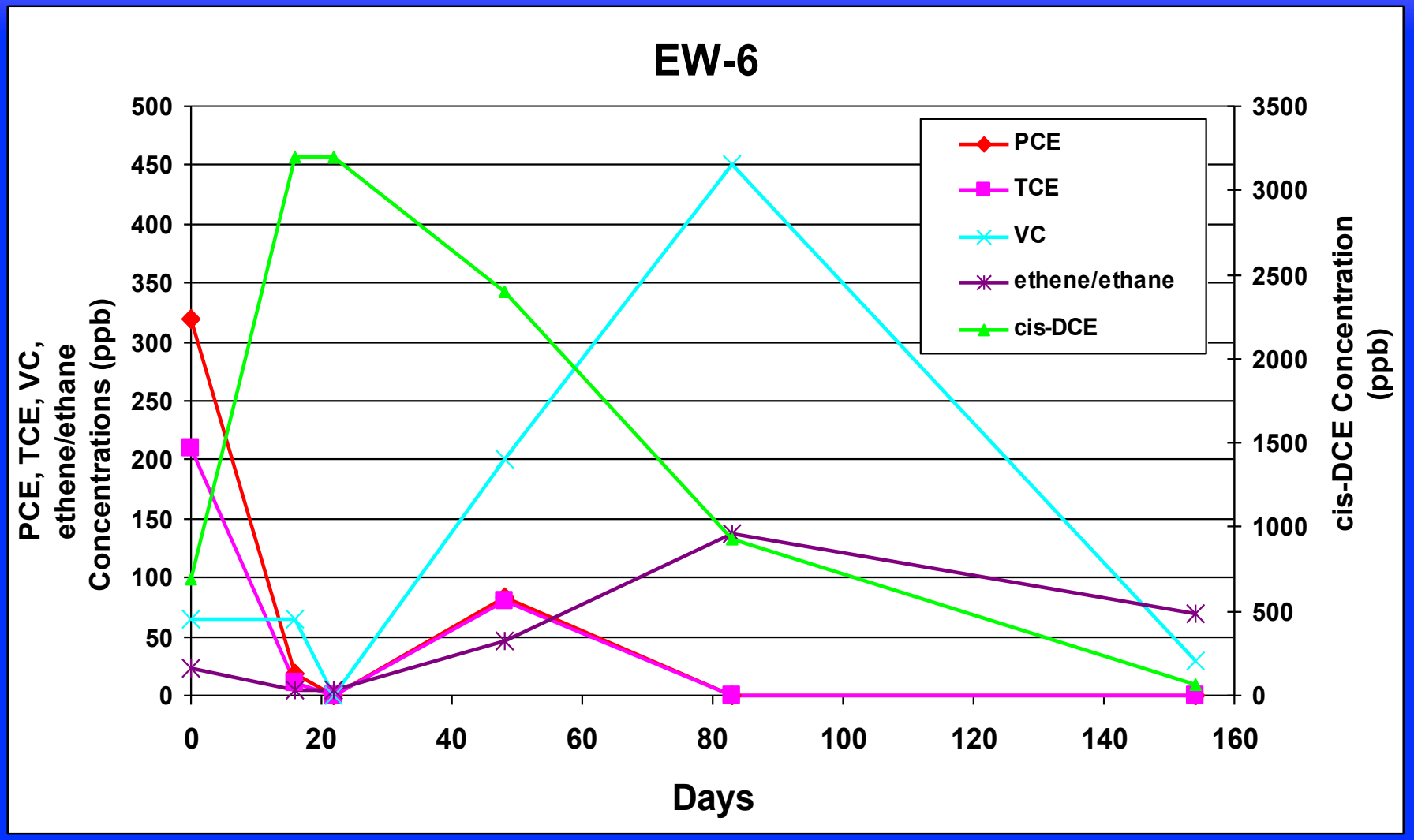
2006 Results

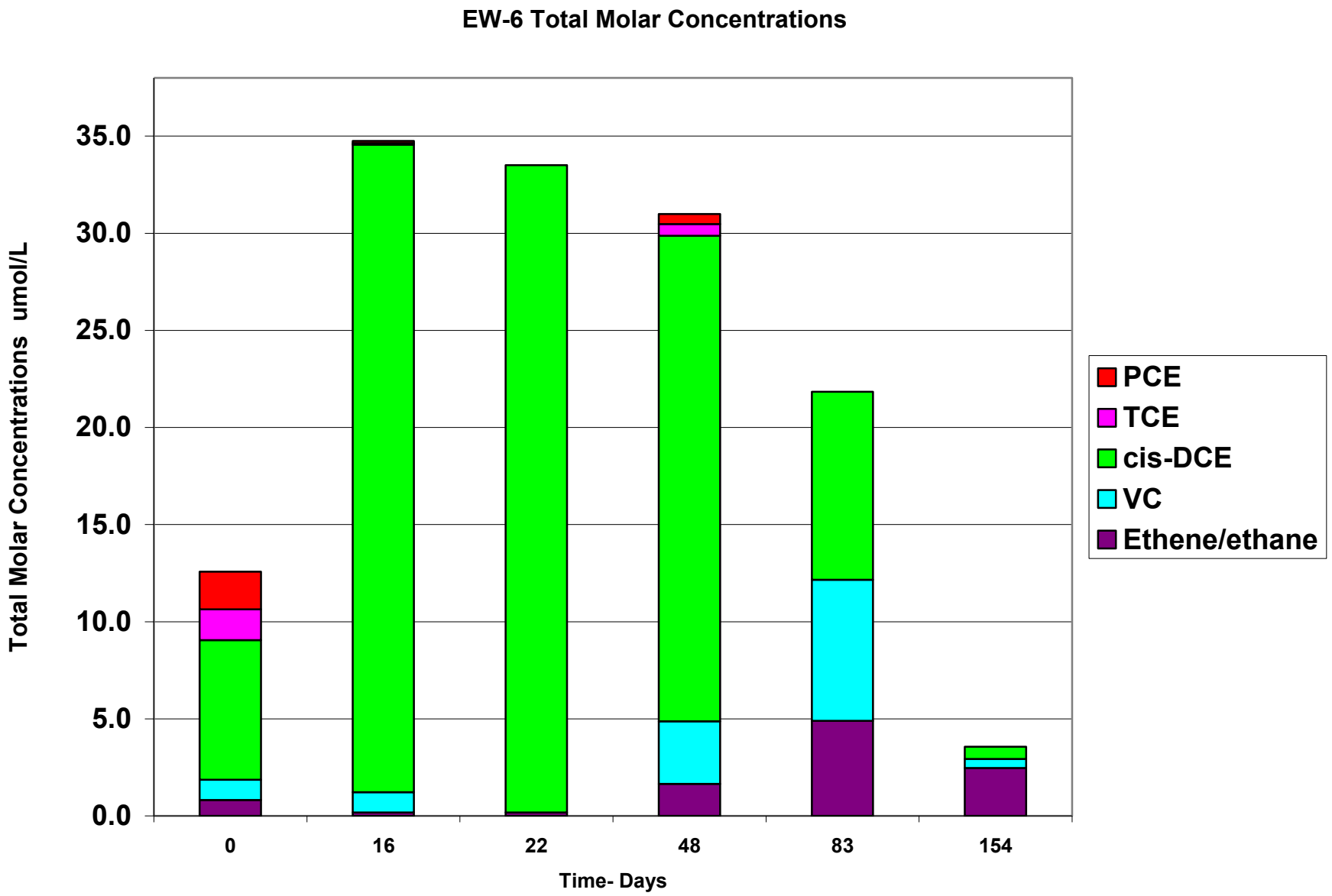


- Cis-DCE increased significantly, then began to decline. A max concentration of 500 ppb PCE should generate 291 ppb of cis-DCE, but we see up to 1,300 ppb.


EW-3 Molar Concentrations
Molar Concentration umol/L
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
0
16
22
48
83
154
Time- Days
PCE
TCE
cis-DCE
VC
Ethene/ethane

2006 Results



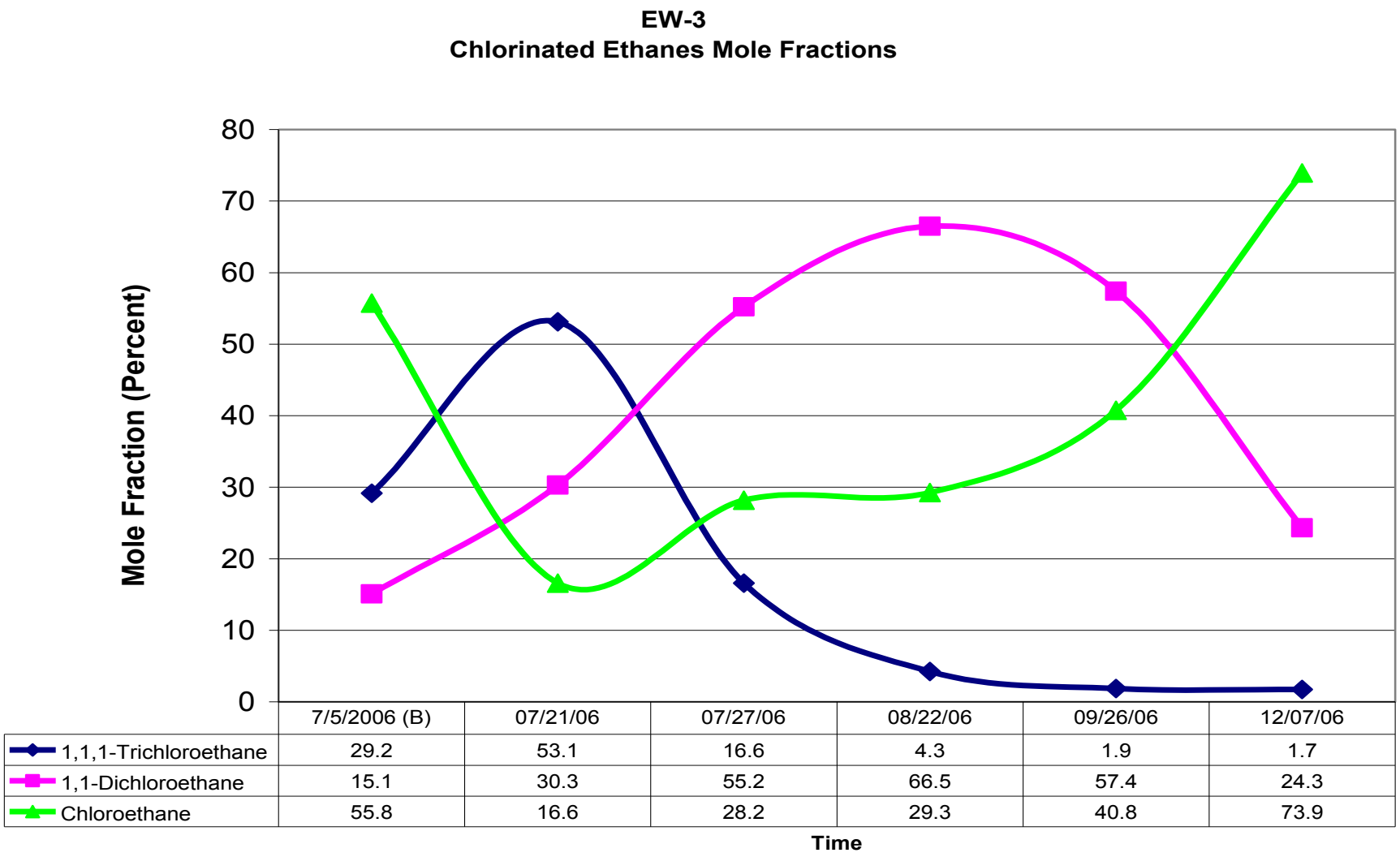

EW-6 Total Molar Concentrations
Total Molar Concentrations umol/L
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
0
16
22
48
83
154
Time- Days
PCE
TCE
cis-DCE
VC
Ethene/ethane

EX-7

Date	PCE (ppb)	TCE (ppb)	cis-DCE (ppb)	VC (ppb)	Ethene/ethane (ppb)
8/22/06 Day 48	6,700	4,400	10,000	<200	50
9/26/06 Day 83	330	<100	3,500	1,100	763
12/6/06 Day 154	220	55	160	22	5.1

- Observations
  - First sample event shows significant concentrations of PCE/TCE even after 48 days of recirculation, with dechlorination to cis-DCE ongoing during this time.
  - No significant VC after 48 days, and ethene still low.
  - VC increased significantly, but nothing compared to the parent concentrations
  - Generated biomass expected to continue to stimulate dechlorination for another year

Chlorinated Ethanes



	7/5/2006 (B)	07/21/06	07/27/06	08/22/06	09/26/06	12/07/06
1,1,1-Trichloroethane	29.2	53.1	16.6	4.3	1.9	1.7
1,1-Dichloroethane	15.1	30.3	55.2	66.5	57.4	24.3
Chloroethane	55.8	16.6	28.2	29.3	40.8	73.9

Full-scale Comments

- Approach rapidly transforms ppm levels SITE-WIDE!
- Enhanced desorption observed during recirculation
- No downgradient change in cVOC concentrations; hydraulic capture successful!
- LNAPL did not prevent implementation
- Nutrient demand (N and P) higher than calculated
- Results very similar to pilot-test. Shut-down Sept. 2006, TOC low at all locations, now biomass acting as substrate over the next several months/years. No cost associated with this, except analytical/sampling labor.
- Chlorinated Ethanes treated site-wide
- Overall Costs ~$270K, treatment area 68,000 CM: $4/CM

CONCLUSIONS

- Soluble substrate + nutrients + recirculation + infrastructure = rapid dechlorination
- Works w/ varying conditions (low/high flow, ppm or ppb, co-mingled or not)
- Control subsurface conditions/microbial needs (NOT ABOUT THE BUGS)
- Total Mass of Solvents is Higher, Desorption is crucial to achieve low level remedial goals
- Nutrient Concerns (rapid uptake), higher than theoretical
- Limited Biofouling (pressure inj., pulsed delivery)
- Site Characterization & Infrastructure are CRITICAL!
- Nitrate/phosphate, some metals (hex chrome), perchlorate, 1,4-dioxane, treatment possible with this approach
- Cost Range is cheaper than excavation/disposal ($2-8/CM)
- Time comparison is like no other biological approach, kinetics much higher