In Situ and *Ex Situ* Bioremediation Technologies for Groundwater Contaminated with Chlorinated Solvents

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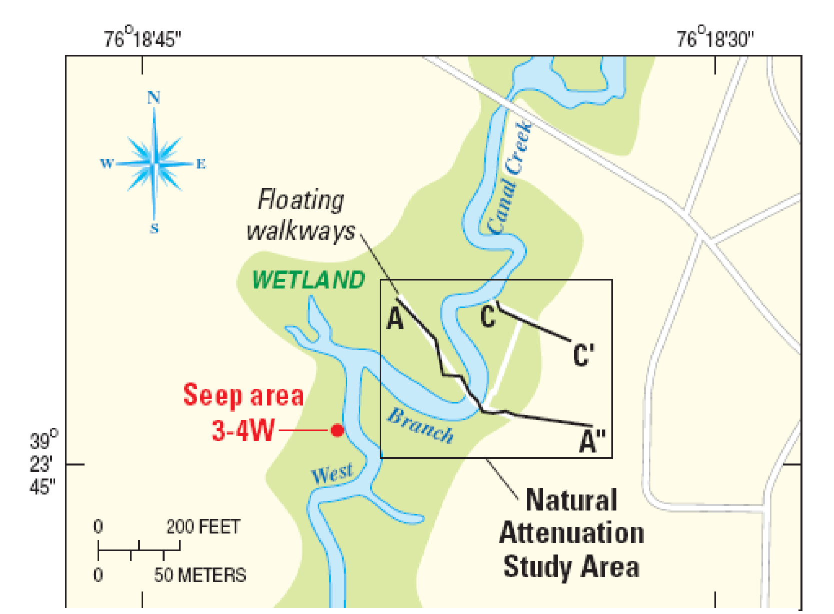
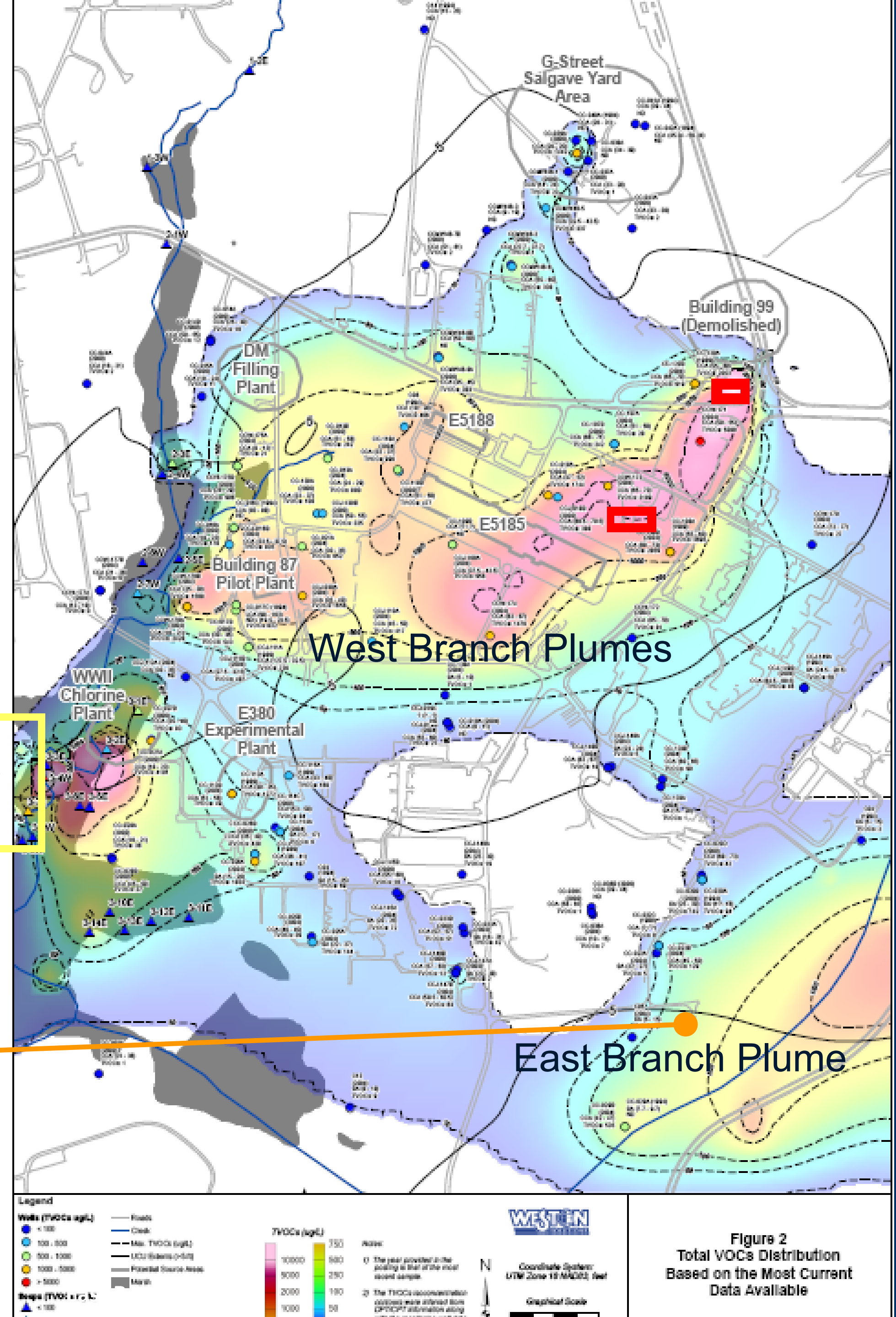


In situ test area, Seep 3-4W



Canal Creek Groundwater Treatment Plant- *Ex situ* test

Canal Creek Area, Aberdeen Proving Ground, Maryland

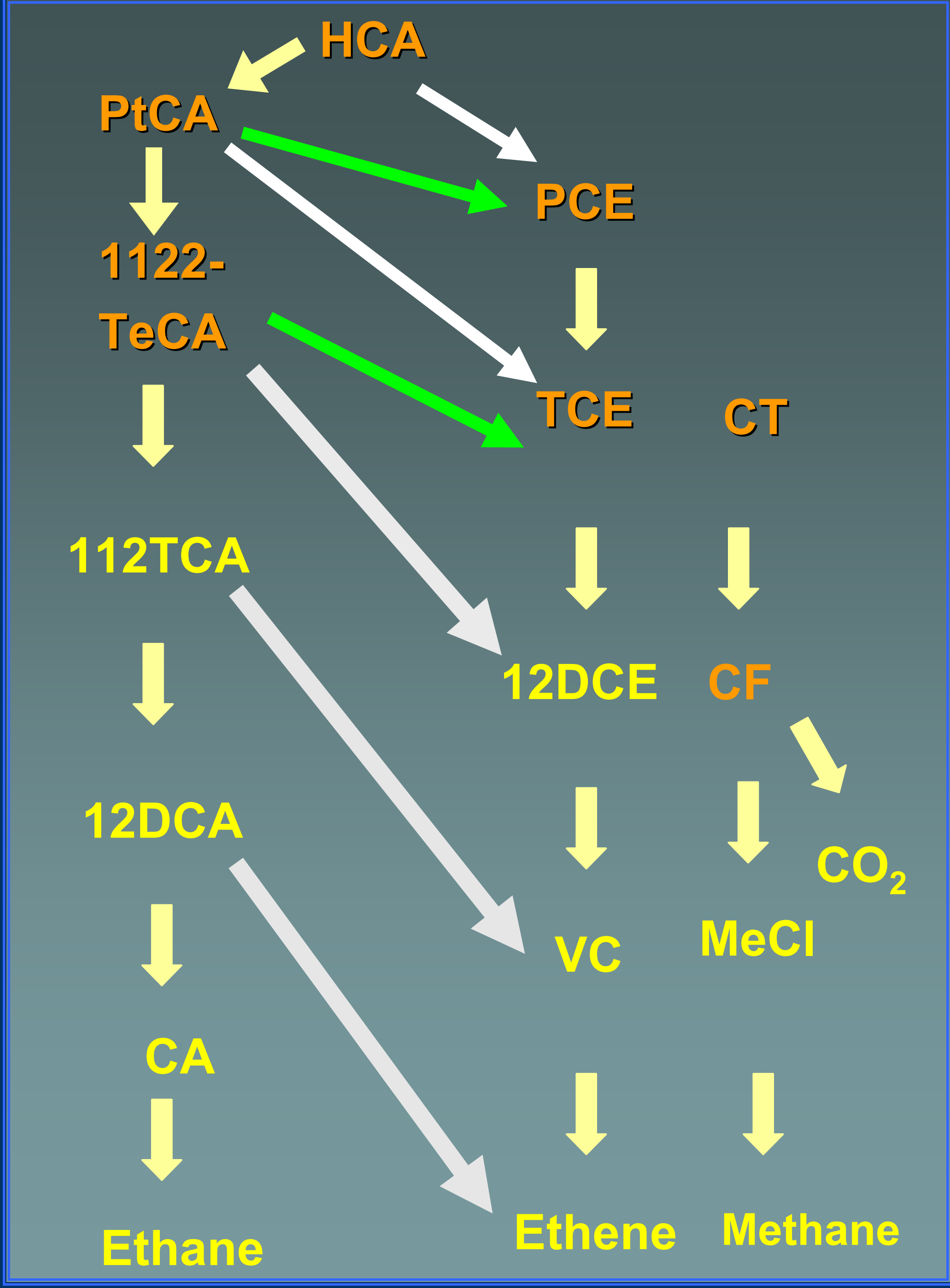
Chlorinated VOCs at West Branch Canal Creek and their anaerobic degradation pathways

Parent VOCs in orange

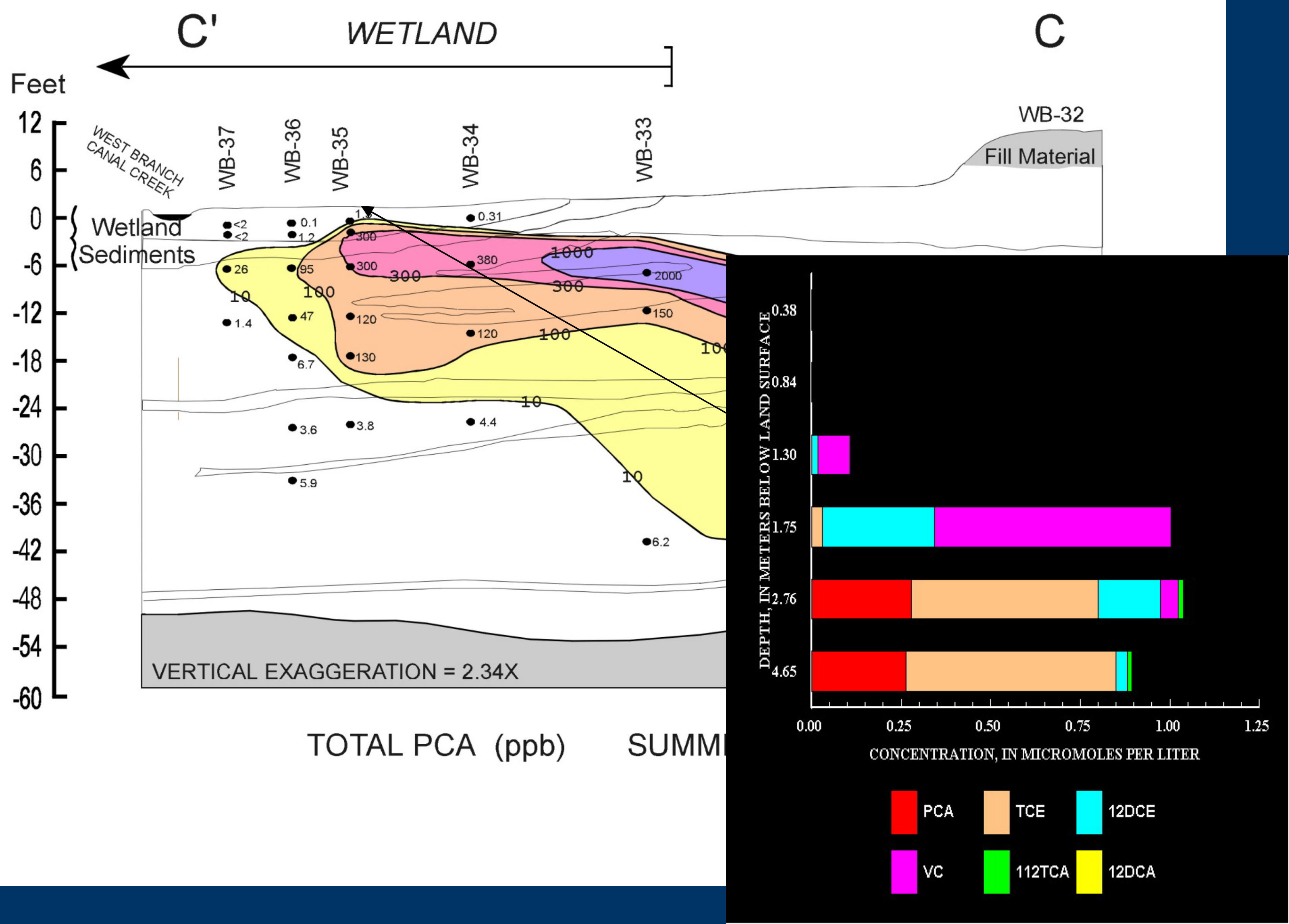
Chlorinated ethanes:
HCA= hexachloroethane
PtCA= pentachloroethane
1122TeCA= 1,1,2,2-tetrachloroethane

Chlorinated ethenes:
PCE= tetrachloroethene
TCE= trichloroethene

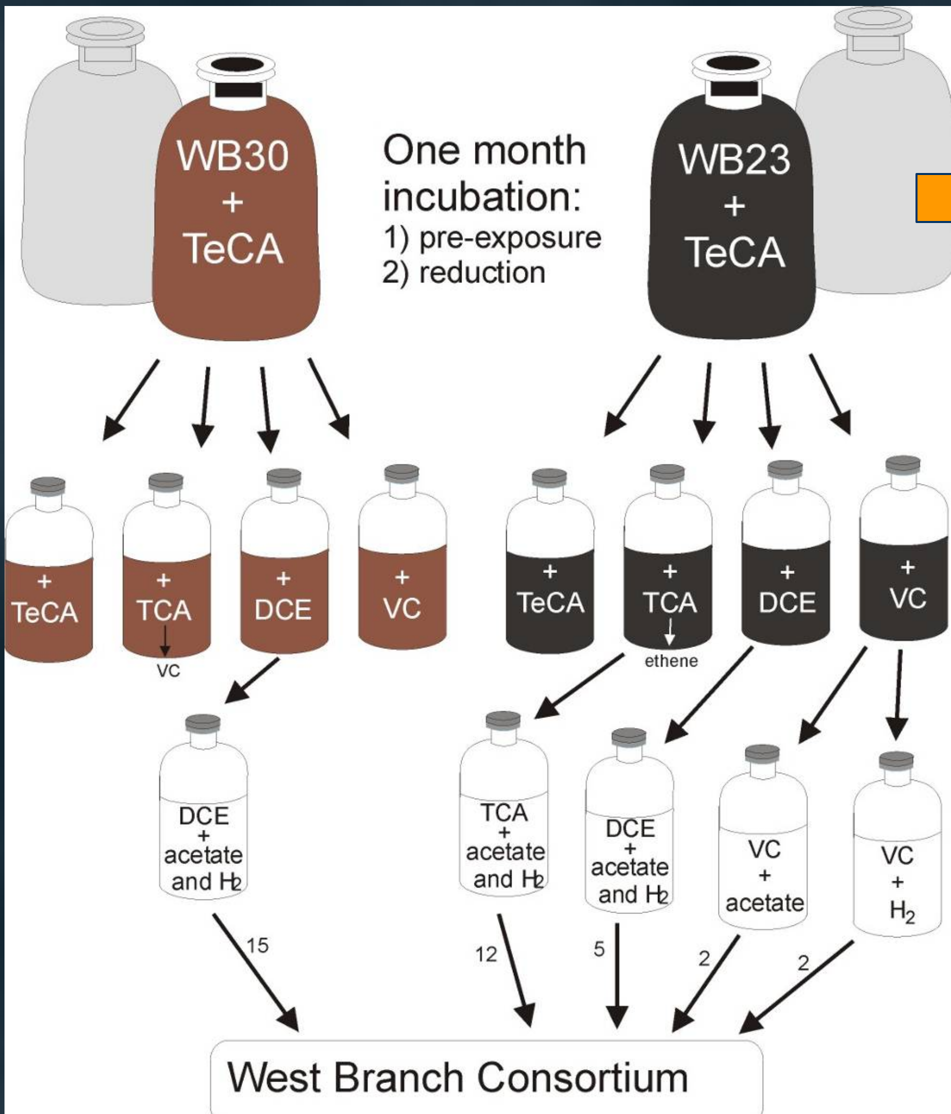
Chlorinated methanes:
CT= carbon tetrachloride
CF= chloroform

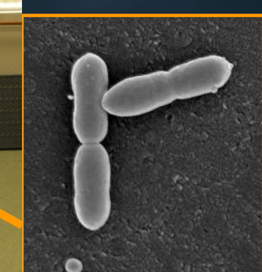


Natural Attenuation in Wetland

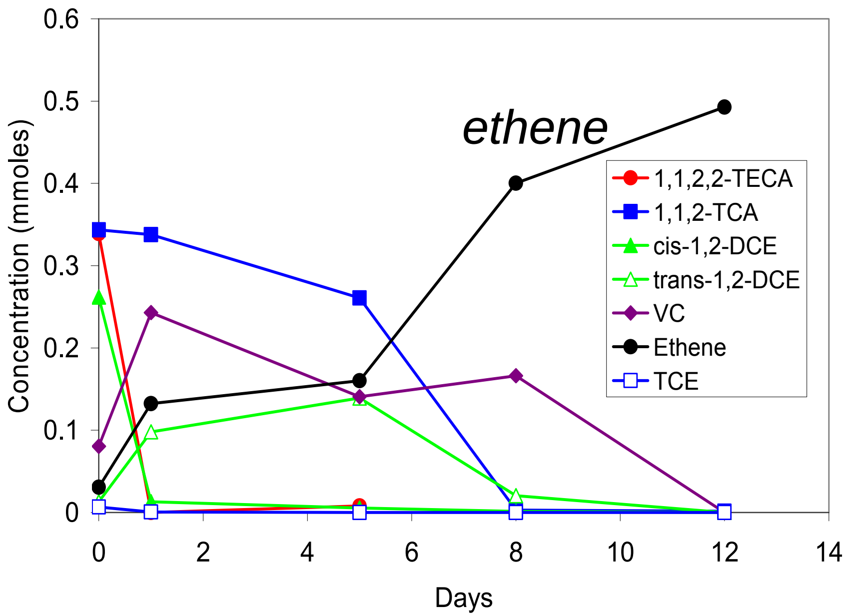


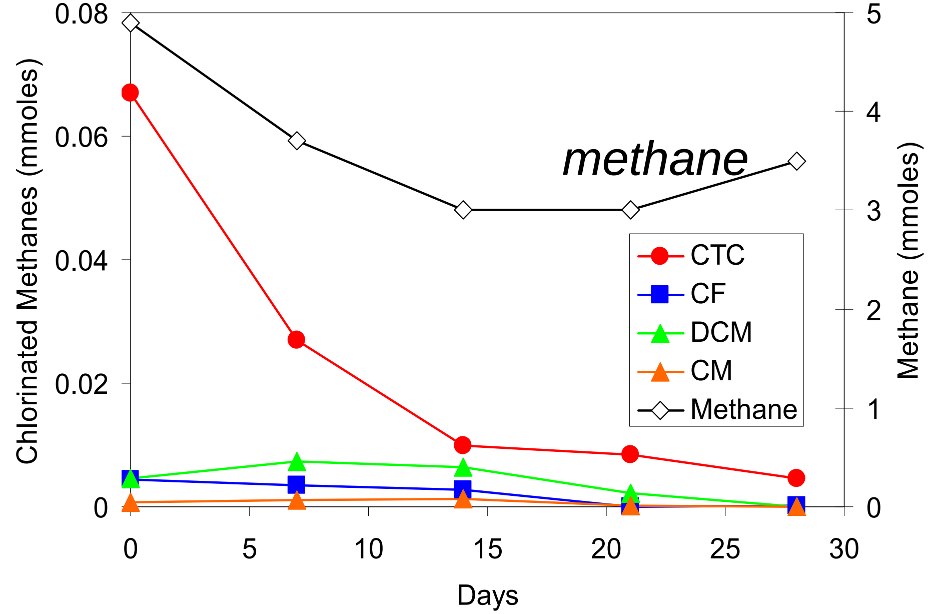
Development of WBC-2 Microbial Consortium





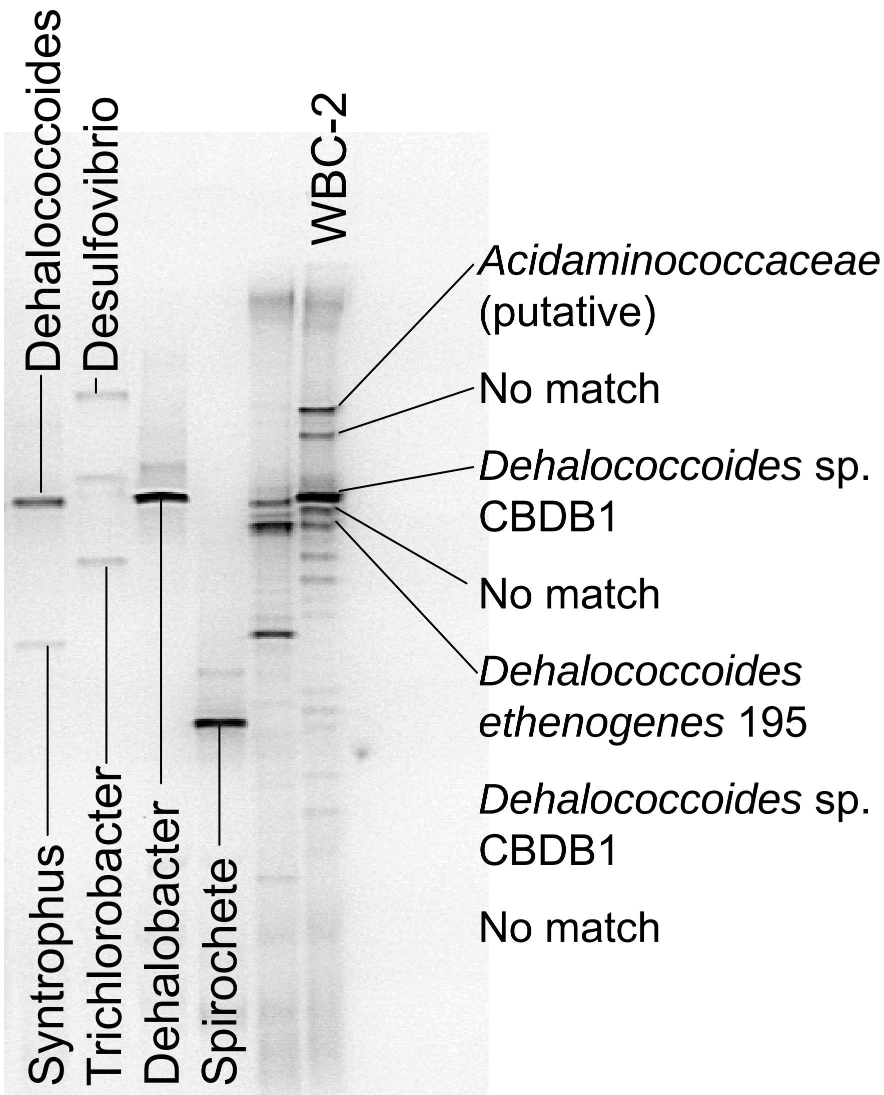
WBC-2 Substrate Range
Chlorinated Ethanes, Ethenes, Methanes





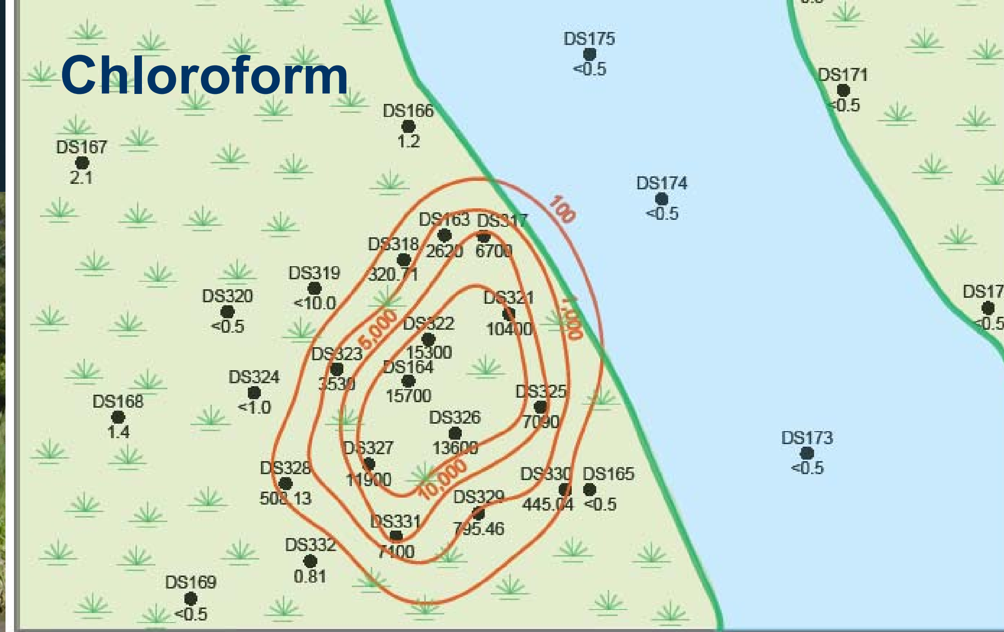
- ► Sediment-free culture with consistent dechlorination ability
- ► Regularly fed 5 mg/L TeCA, 112TCA, cis12DCE, and lactate and ethanol (e^- donors)
- ► Degrades carbon tetrachloride and chloroethene/ethane degradation unaffected
- ► WBC-2 degradation stable since 2003

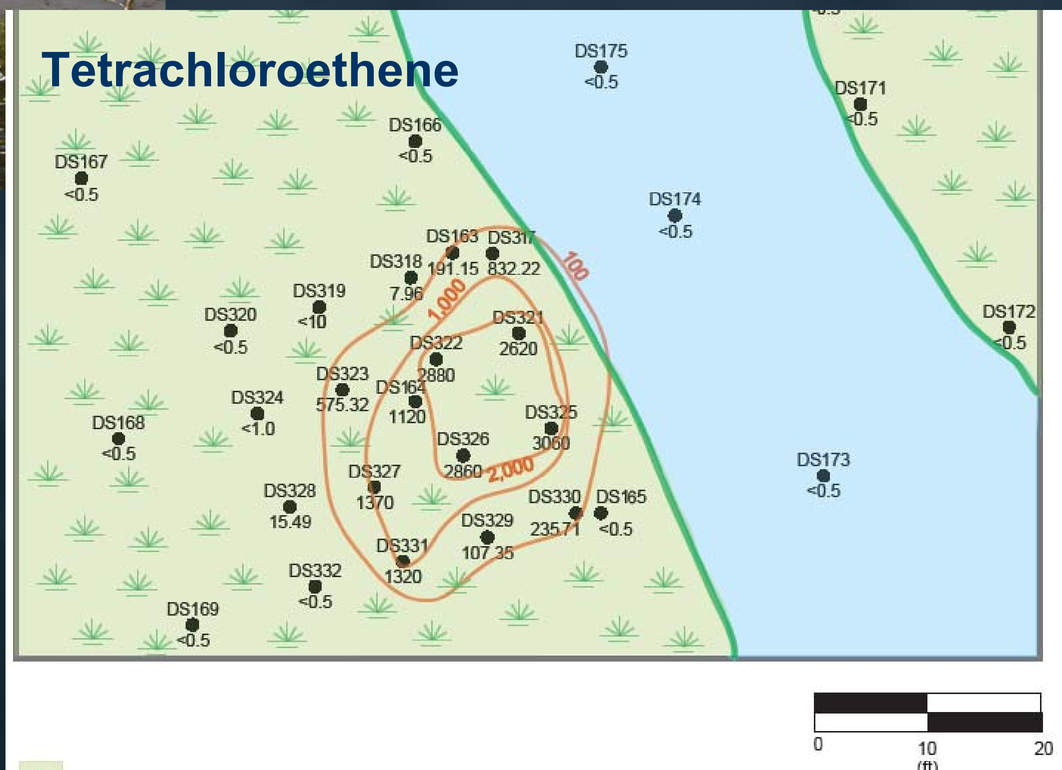
WBC-2 Microbial Composition



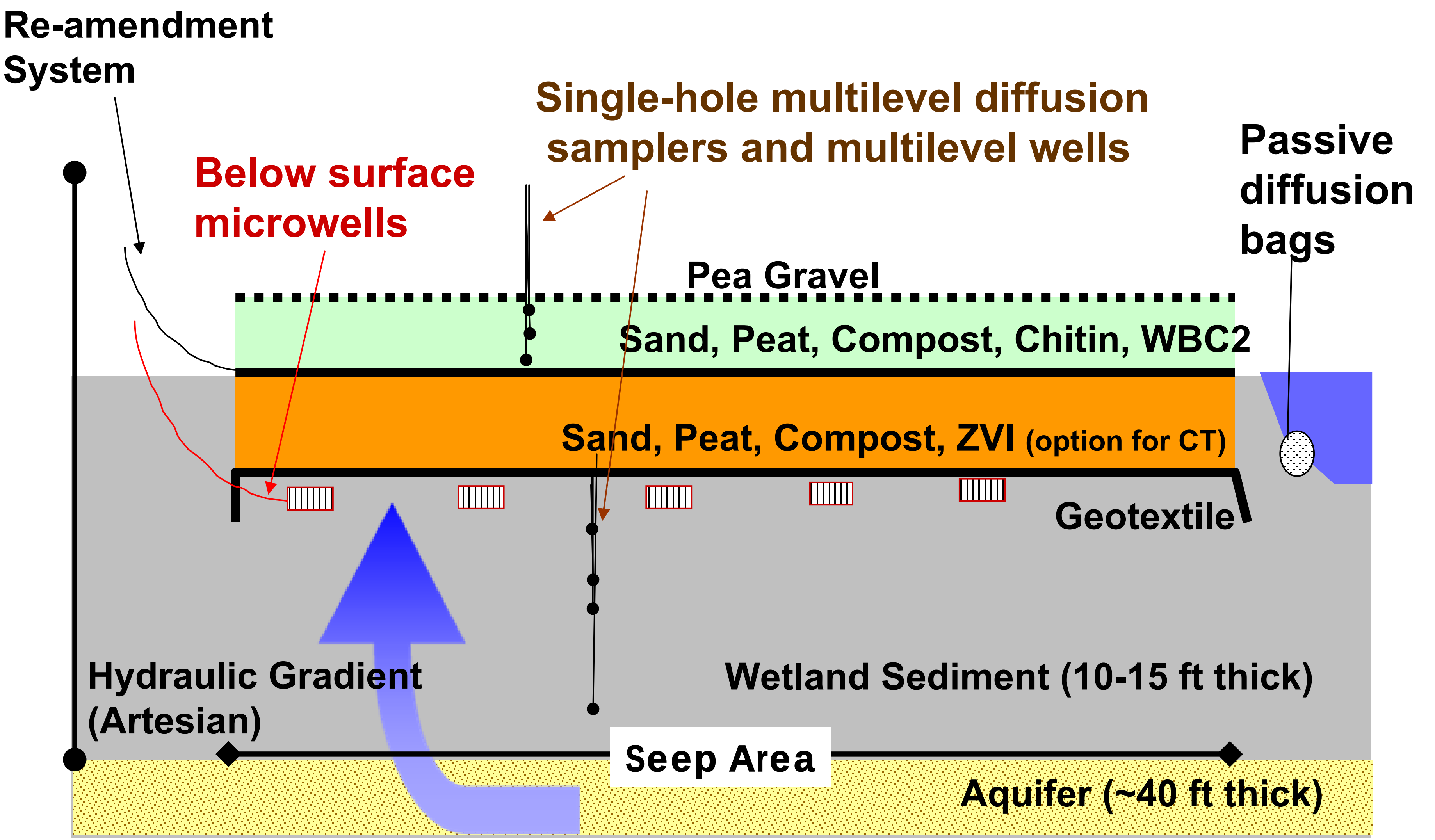
- Contains at least 17 and 21 distinct *Bacteria* phylotypes based on DGGE and clone library analysis, respectively
- *Acetobacterium* (40%), *Dehalobacter* (19%), and Acidaminococcacea (9%) most prominent; *Dehalococcodies* 5%
- Diversity thought to support substrate range

Pilot-Test Area 3-4W



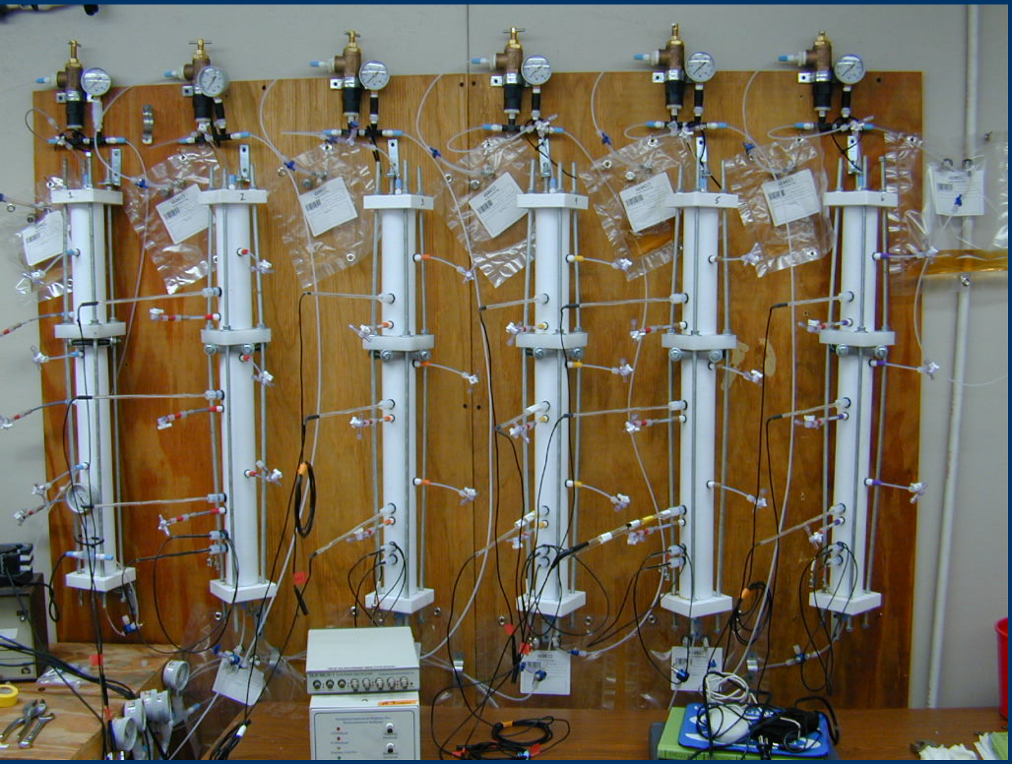


Reactive Mat Design and Monitoring



NOT TO SCALE

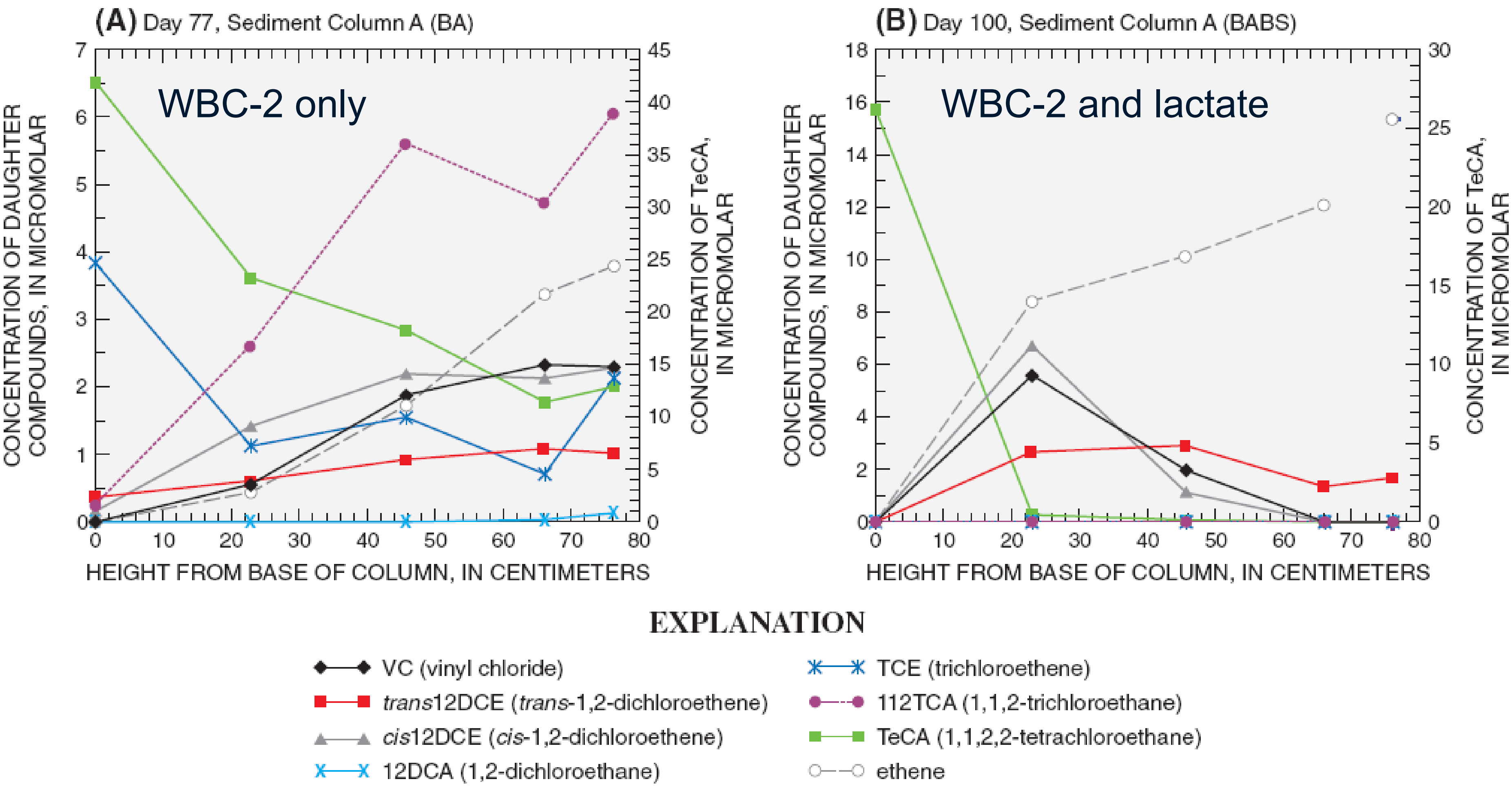
Flow-Through Column Tests - Biomat



Simulate biomat layers

- Continuous upflow columns
- Establish similar discharge rates/concentrations to field
- Evaluate sediment only, compost/peat mix, and iron layer before compost/peat mix
- Measure VOCs, redox, culture behavior, hydraulic properties

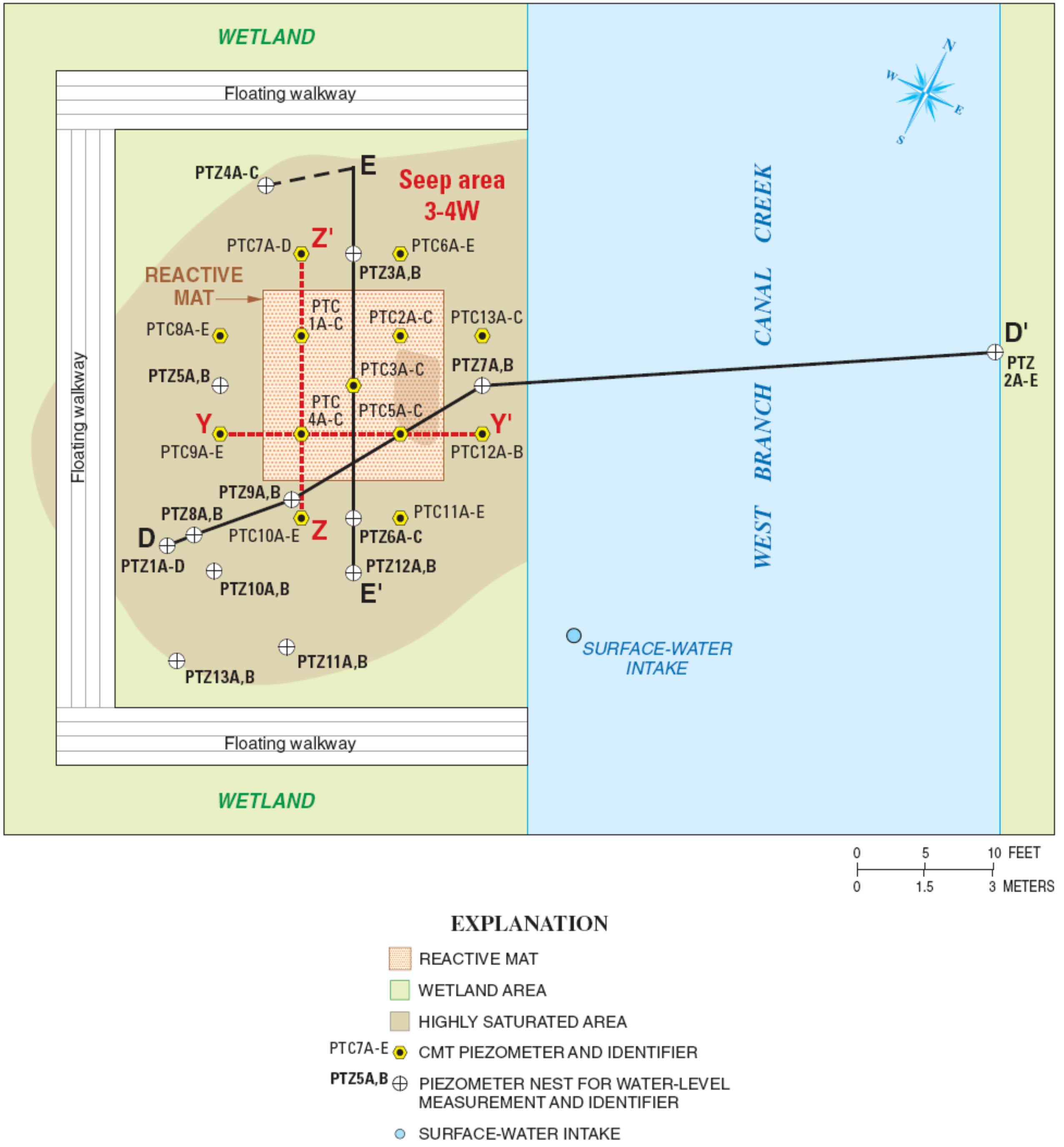
Degradation of VOCs by WBC-2 seeded sediment in columns

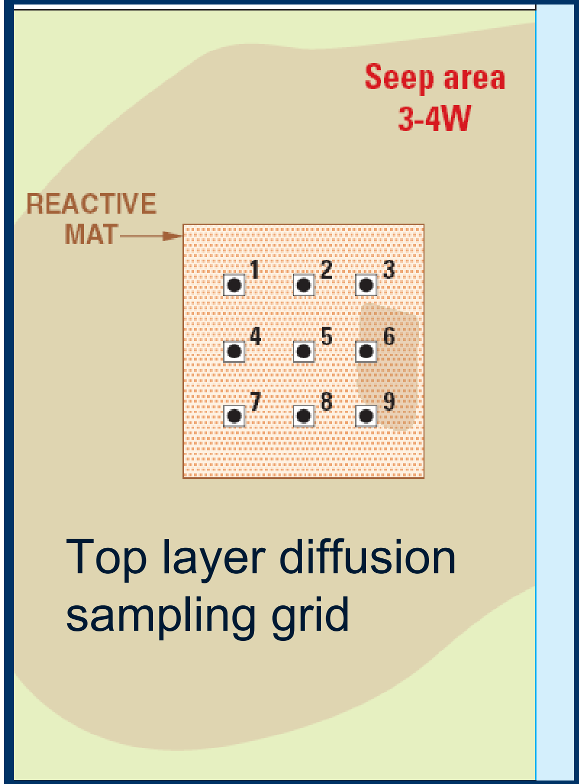


Bioreactive Mat Construction

Sprayed WBC2 between each wheelbarrow load of material

Reactive Mat Location and Monitoring Network

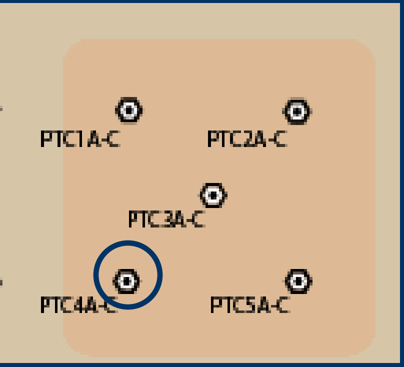


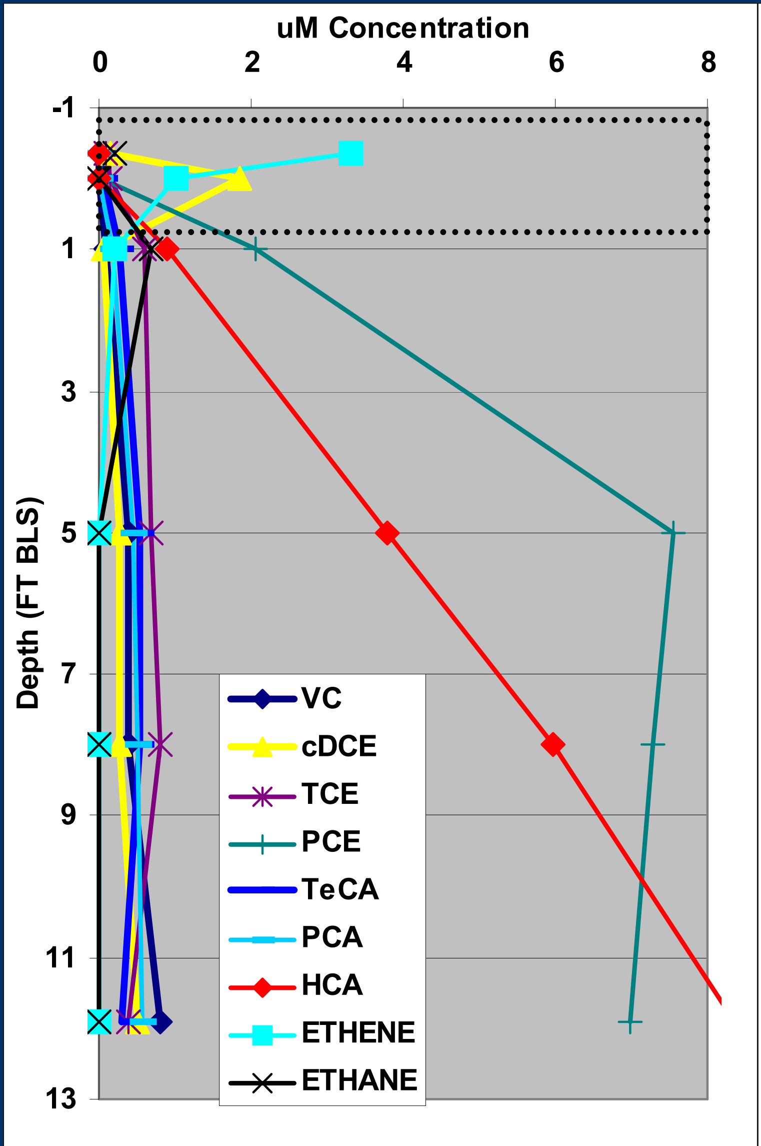


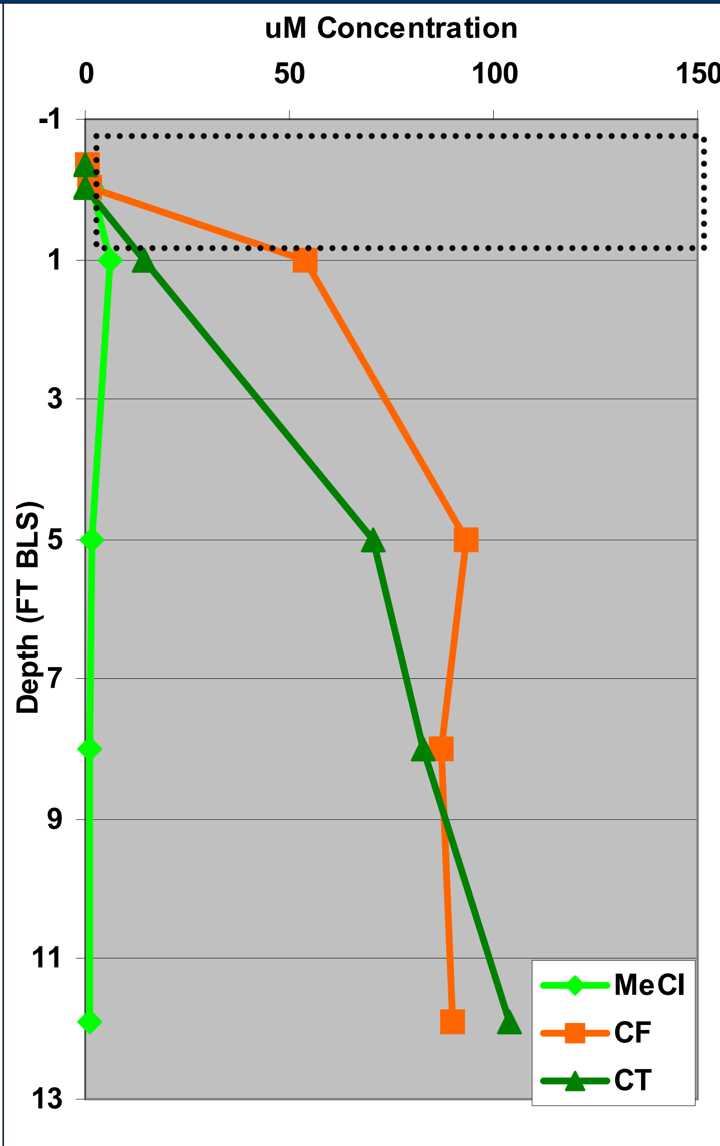
Top layer diffusion sampling grid

Reactive Mat – VOC Removal

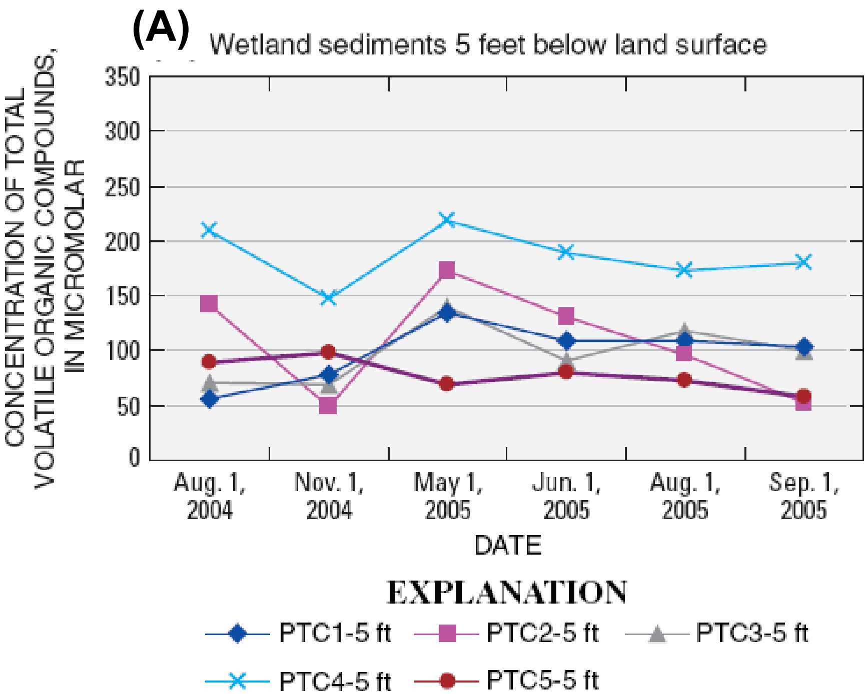
- Consistent vertical profiles of VOC reduction through mat, increased ethene/ethane
- 95 to 99% mass removal

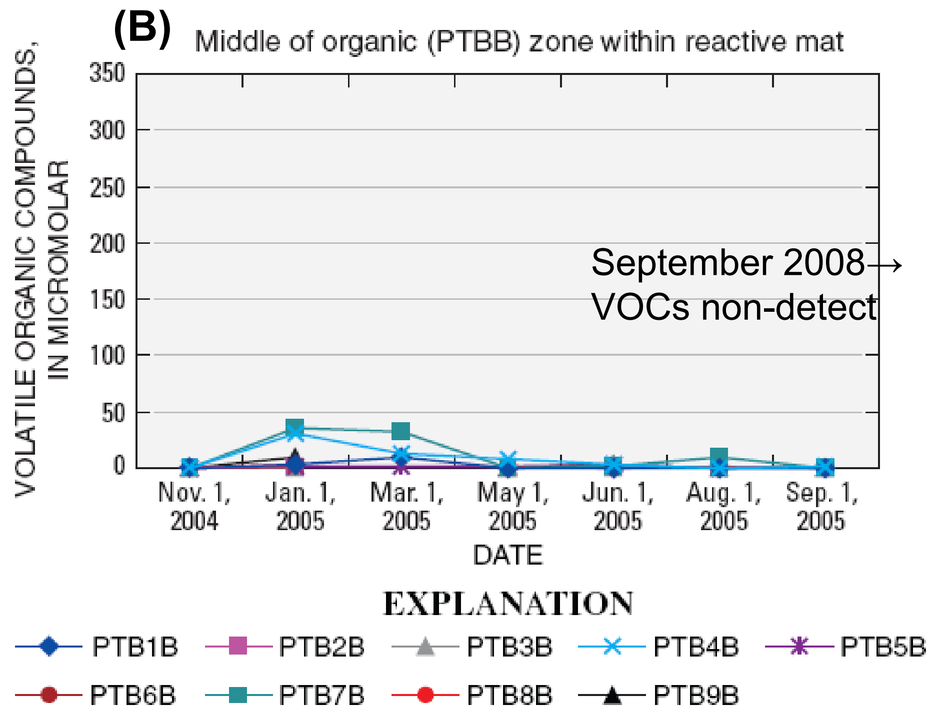






Sustainability of Degradation





(A) Consistent upward flow of VOC to mat over 1 year monitoring period

(B) Consistent VOC degradation within reactive mat over 1 year monitoring period

October 2008 sampling- still effective 4 years after emplacement.

Application of WBC-2 in an Anaerobic Bioreactor for the Canal Creek Groundwater Treatment Plant

Advantages of Fixed Film Anaerobic Bioreactor System

- Mechanically simple with low energy costs and maintenance
- Very low production of waste solids (sludge)
- Highly resistant to upsets and toxic shock
- Insignificant pretreatment of water (no bag filters needed)

  - ❖ *An anaerobic culture is available that can degrade the suite of chlorinated VOCs in the treatment plant influent*
  - ❖ *WBC-2 has been grown previously on a common bioreactor support medium in a static batch, where it retained its full dechlorinating ability*
  - ❖ *Extensive testing of WBC-2 in lab and field has shown its robustness and ability to obtain high rates of degradation*

Treatment Plant Influent

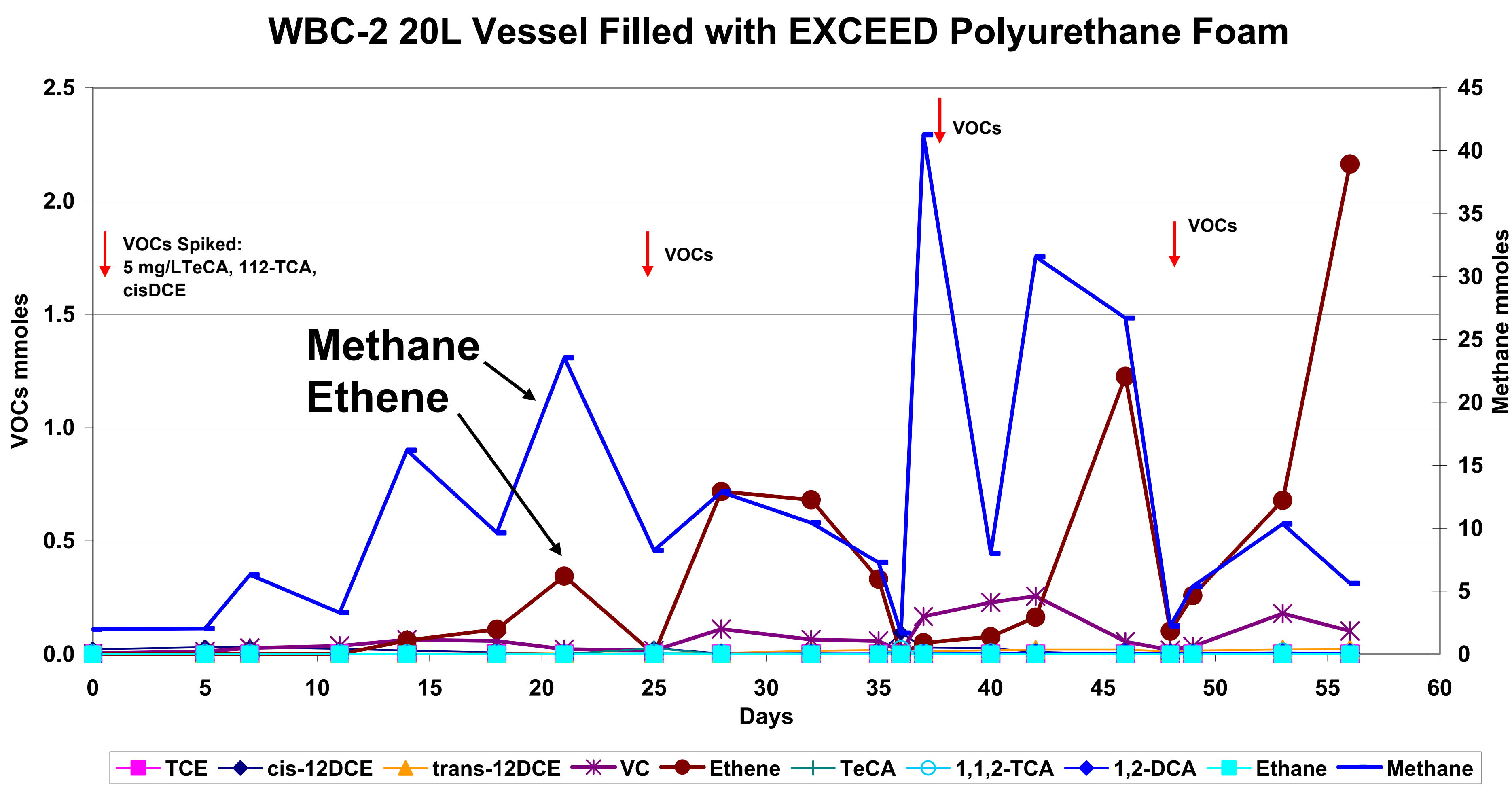
Contaminant	(µg/L)	(µM)
1,1,2,2-tetrachloroethane (TeCA)	190	1.13
1,1,2-trichloroethane (112TCA)	4.7	0.04
1,,2-dichloroethane (12DCA)	4.2	0.04
Carbon tetrachloride (CT)	15	0.10
Chloroform (CF)	5.6	0.05
Tetrachloroethene (PCE)	2.8	0.02
Trichloroethene (TCE)	130	0.99
Vinyl chloride (VC)	71	1.14
cis- and *trans*-1,2-Dichloroethene (12DCE)	167	1.72
Total VOCs	590	4.5
Maximum Total VOCs	*1,000*	*7.6*

Degradation rates in mat columns-

Rates for initial VOC= 40 μ M

Contaminant	Mean rate Constant (day^{-1})	Half-Life (hour)	Rate (μM/day)
1,1,2,2-tetrachloroethane (TeCA)	3.43	4.85	140
Chlorofo		7.20	92
Carbon		5.88	113
Tetrachloroethene (PCE)	1.40	11.9	56
Trichloroethene (TCE)	3.04	5.47	122

More than 4 times the degradation rate in static culture vessel



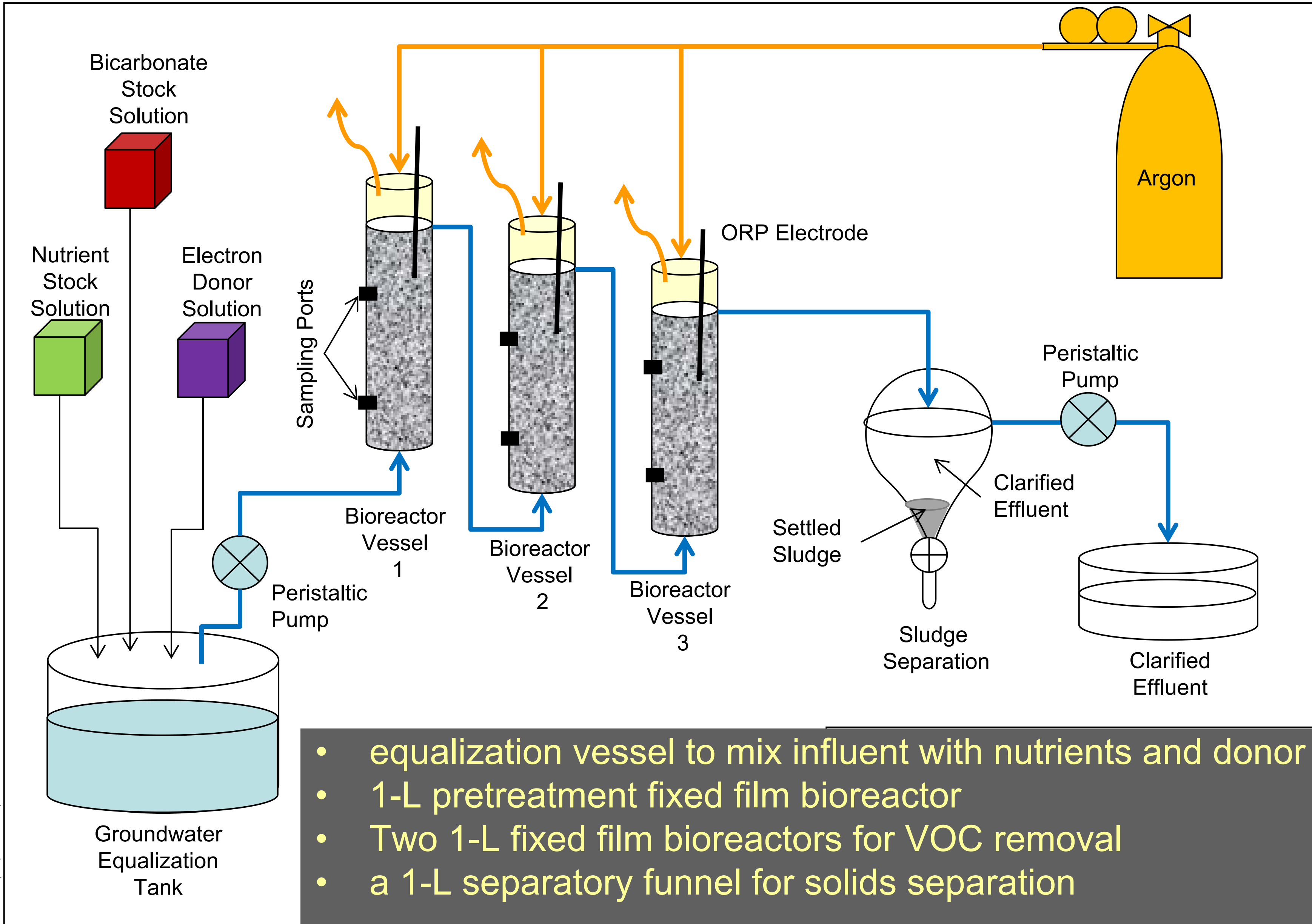
❖ *WBC-2 has been grown previously on a common bioreactor support medium in a static batch, where it retained its full dechlorinating ability*

Bioreactor Study Objectives

Conduct pre-design testing necessary to evaluate the effectiveness of WBC-2 for treating chlorinated VOCs in a bioreactor application

- optimal hydraulic retention time to achieve efficient VOC degradation and meet discharge criteria
- optimal electron donor
- nutrient and electron donor utilization rates
- oxygen consumption rate and design constraints to maintain anaerobic conditions in the bioreactor
- typical equilibration/growth rate for WBC-2 following a change in flow or upset to the system
- sludge production rates and handling requirements

Bench Test Bioreactor



- equalization vessel to mix influent with nutrients and donor
- 1-L pretreatment fixed film bioreactor
- Two 1-L fixed film bioreactors for VOC removal
- a 1-L separatory funnel for solids separation

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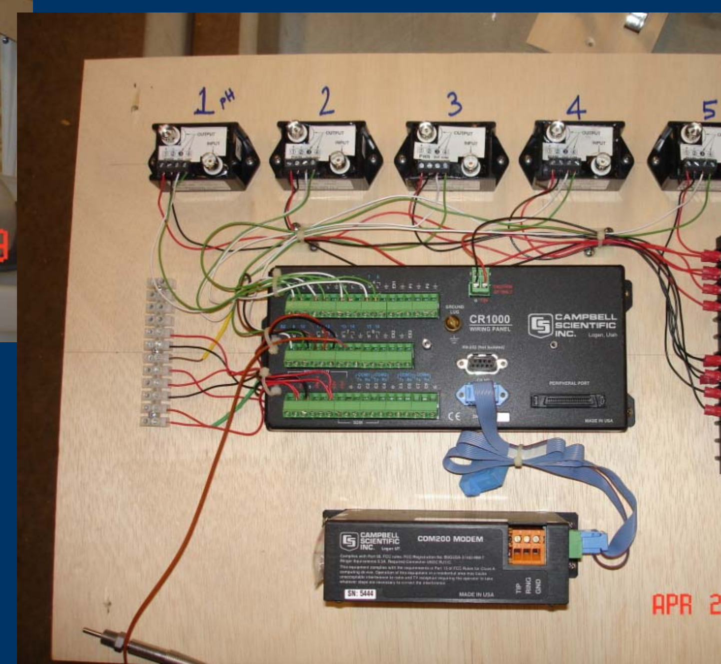
1 pH
2
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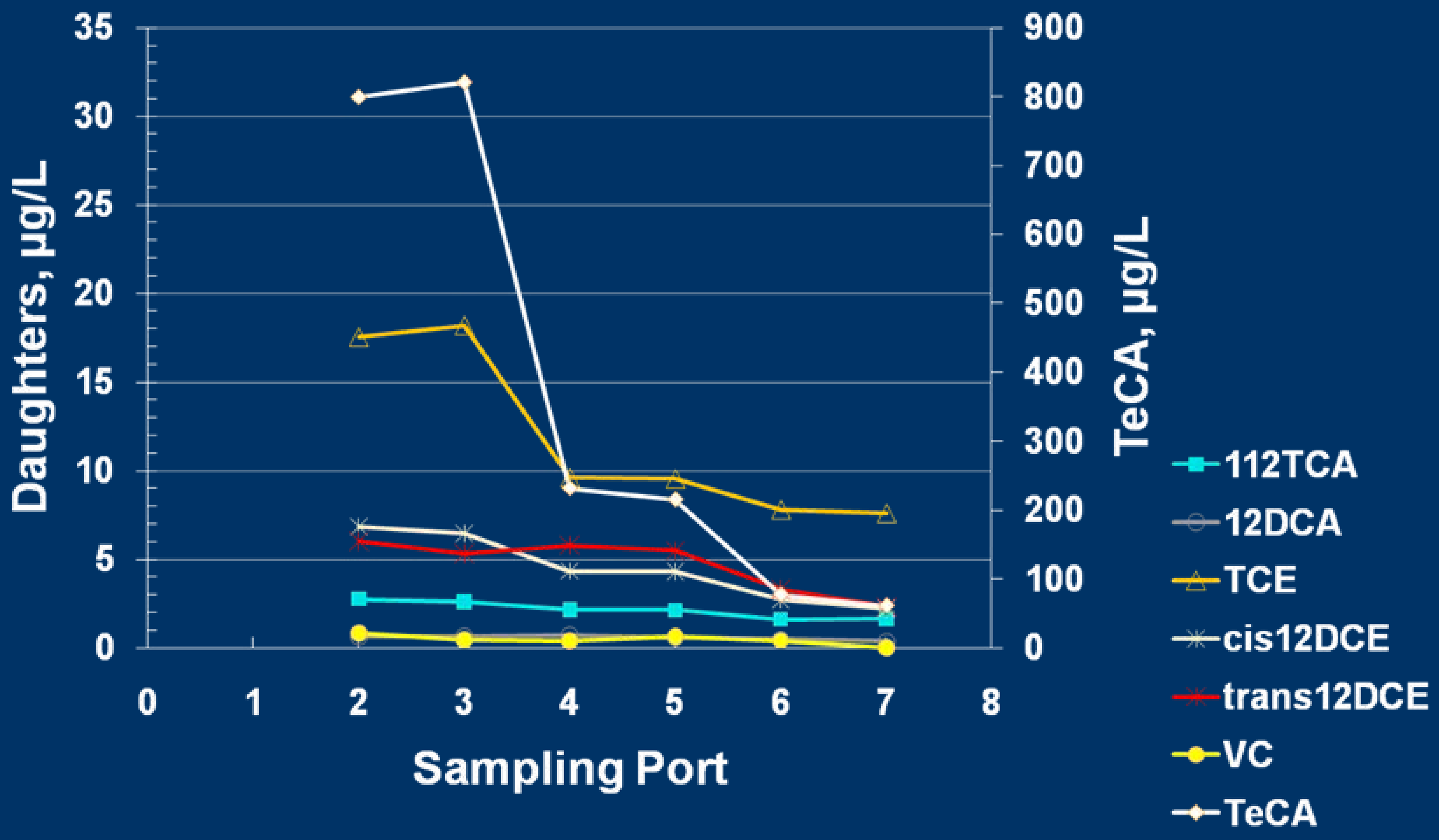
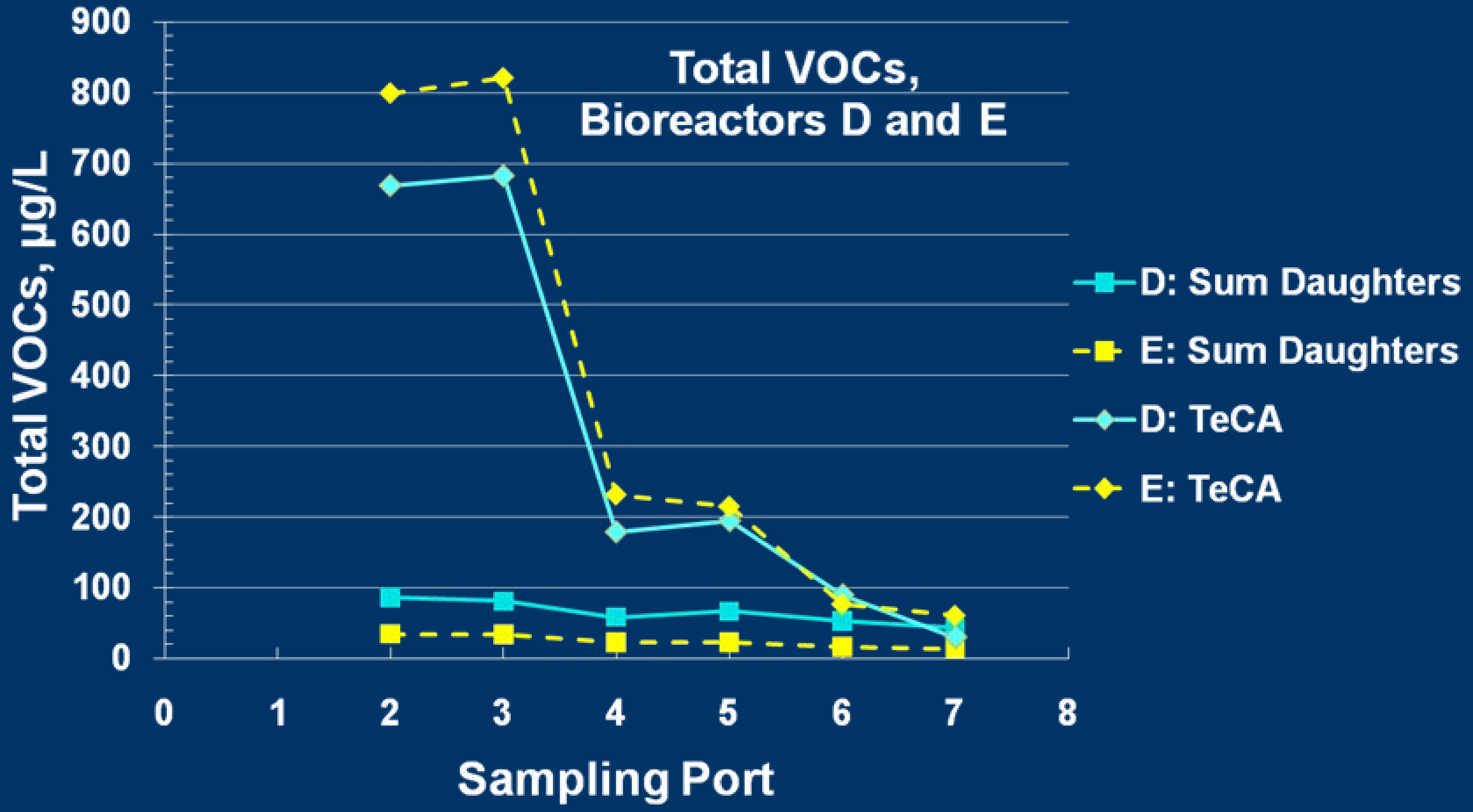
CR1000
WIRING PANEL
CAMPBELL SCIENTIFIC INC.
COM200 MODEM

Bioreactor Bench Test Results



Bioreactor Bench Test Results



Bioreactor: Donor Testing

- Microcosms show dissolvable packing peanuts (corn starch) and corn syrup are inexpensive possibilities
- Currently testing a lower grade lactate
- Small-scale hydrogen generators (electrolysis cells) have been made and will be placed in-line in one of the bioreactor bench tests

Conclusion: *in situ* bioremediation application of WBC-2 was successful and preliminary results show promise for *ex situ* application in bioreactors

USGS Other Current Studies:

- WBC-2 application for RDX and perchlorate bioremediation, White Sands Missile Range, New Mexico
- WBC-2 application for chlorobenzenes bioremediation in wetland area, Standard Chlorine Superfund site, Delaware

Cooperative Research and Development Agreement (CRADA) between USGS and GeoSyntec.

Questions?