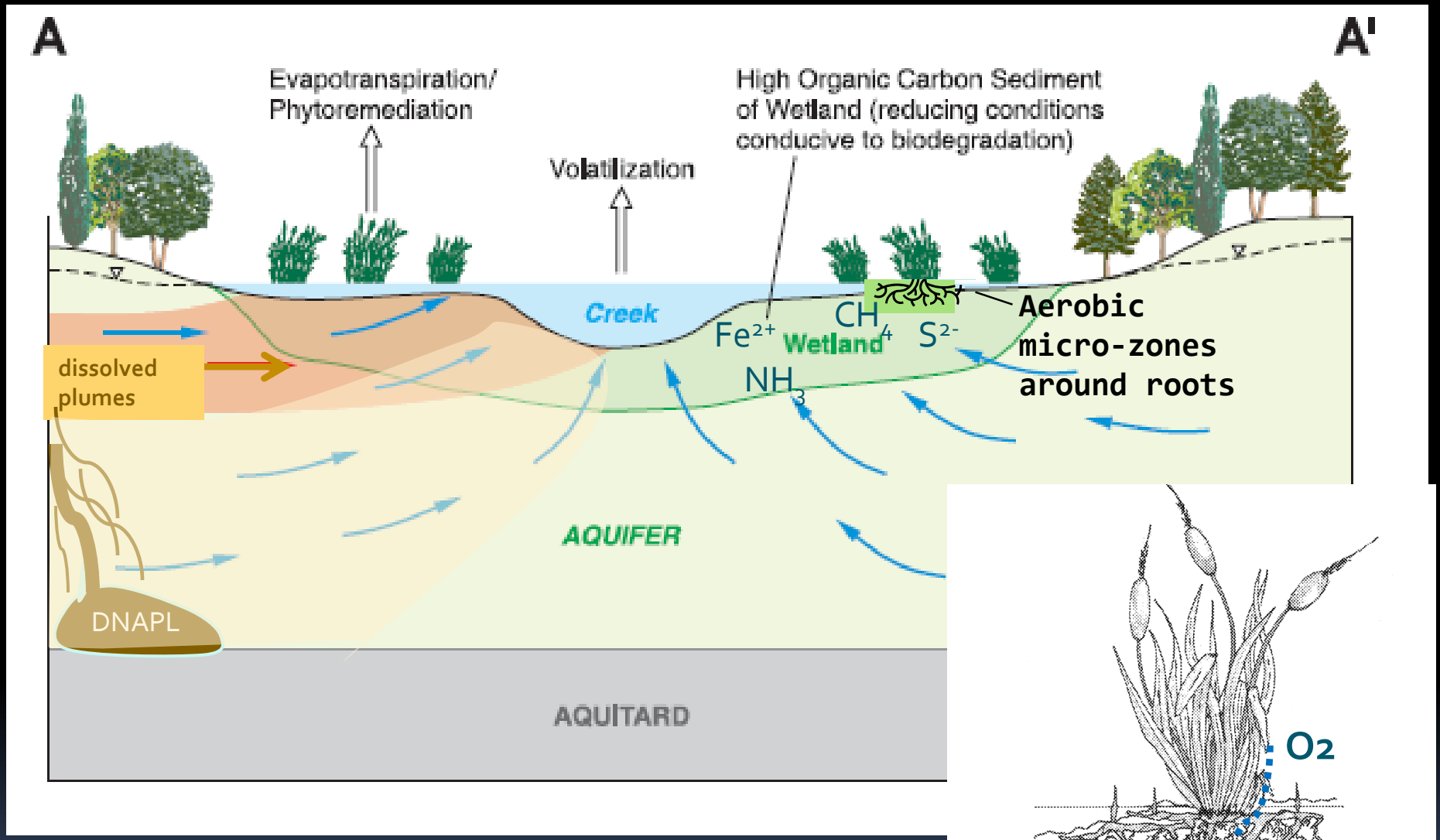
Reactive Barriers for the Passive Remediation of Chlorinated Solvents in Sediments and Groundwater Discharge

Michelle M. Lorah
USGS, Baltimore, Maryland

in cooperation with

DoD, Aberdeen Proving Ground
USEPA, Region III
NIEHS, Superfund Research Program



Stottmeister et al.(2003) *Biotech.Advances*

Conceptual model for chlorinated solvent contamination in wetland

(modified from Lorah et al., 2005)

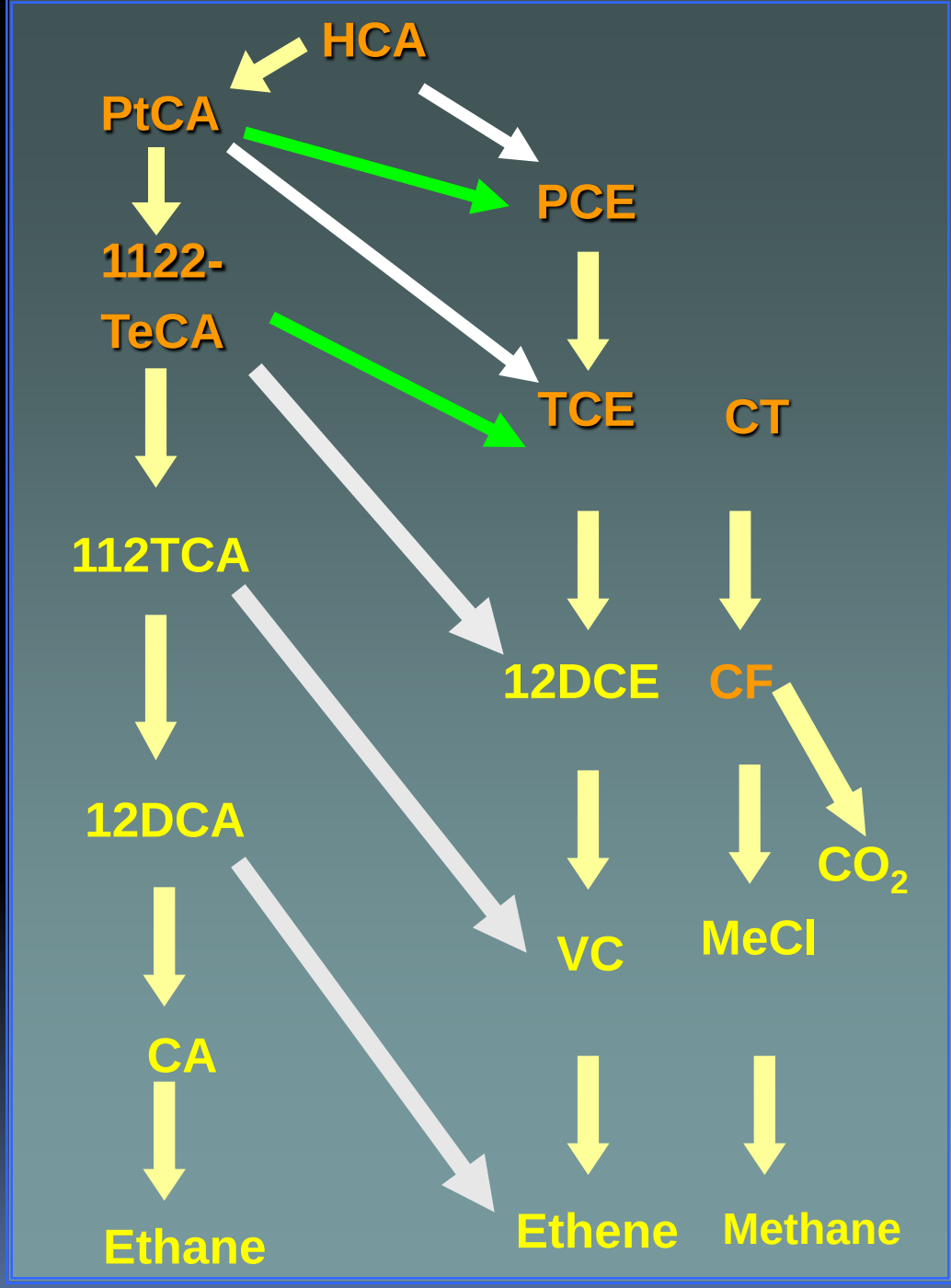
Chlorinated VOCs at West Branch Canal Creek and their anaerobic degradation pathways

Parent VOCs in orange

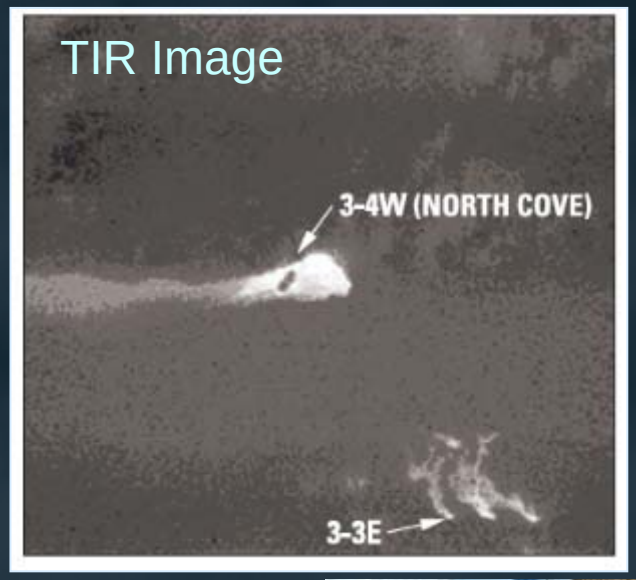
Chlorinated ethanes:
HCA= hexachloroethane
PtCA= pentachloroethane
1122TeCA= 1,1,2,2-tetrachloroethane

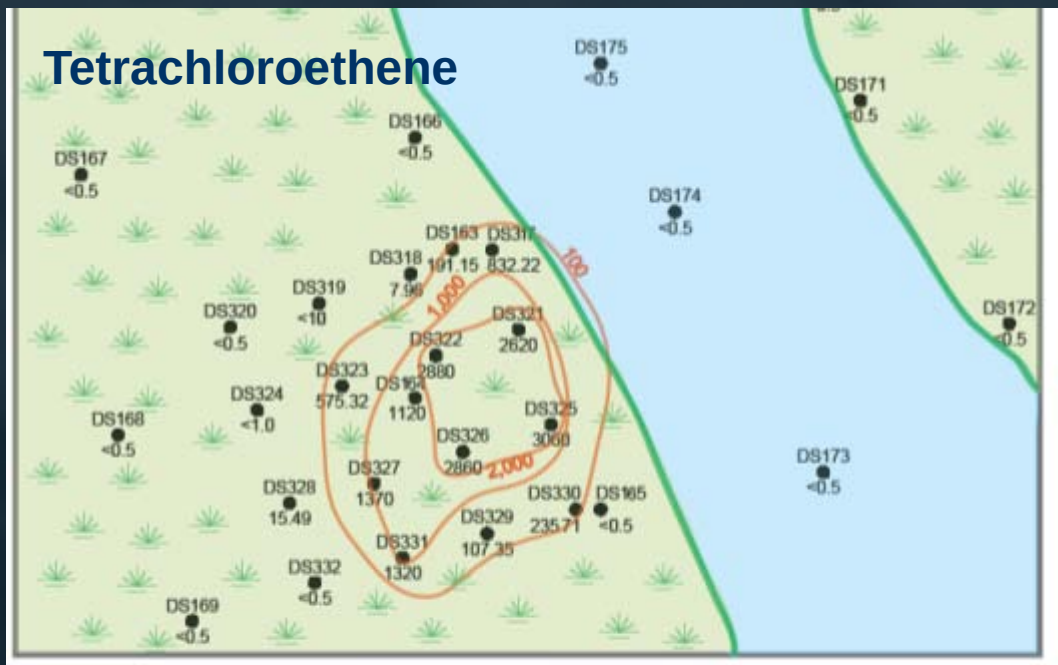
Chlorinated ethenes:
PCE= tetrachloroethene
TCE= trichloroethene

Chlorinated methanes:
CT= carbon tetrachloride
CF= chloroform



Site Characterization

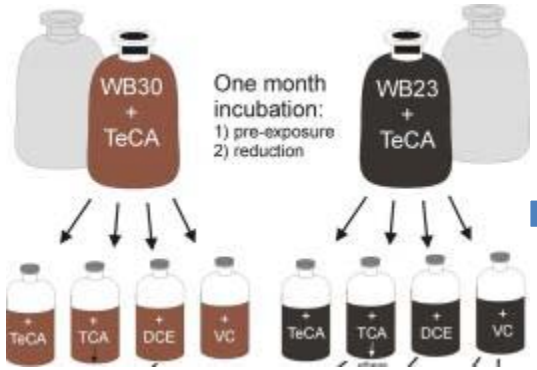


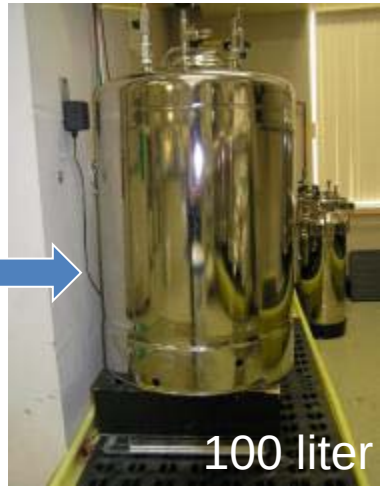


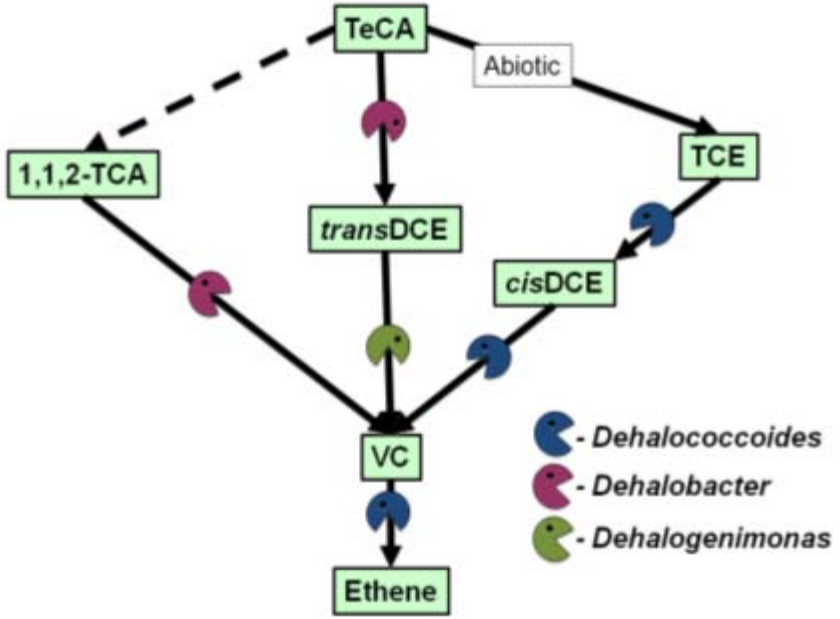
West Branch Canal Creek, APG

0 10 20 (ft)

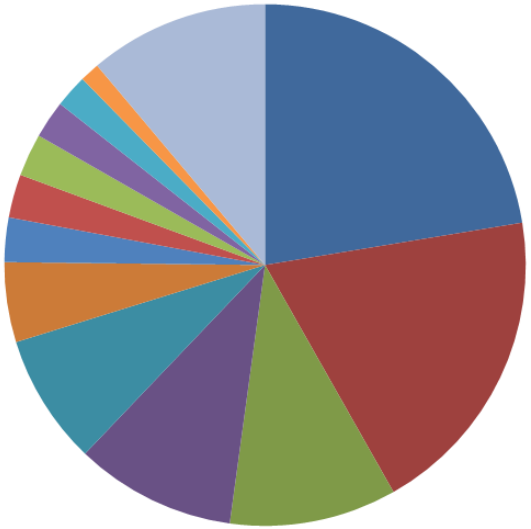
WBC-2 Dechlorinating Culture







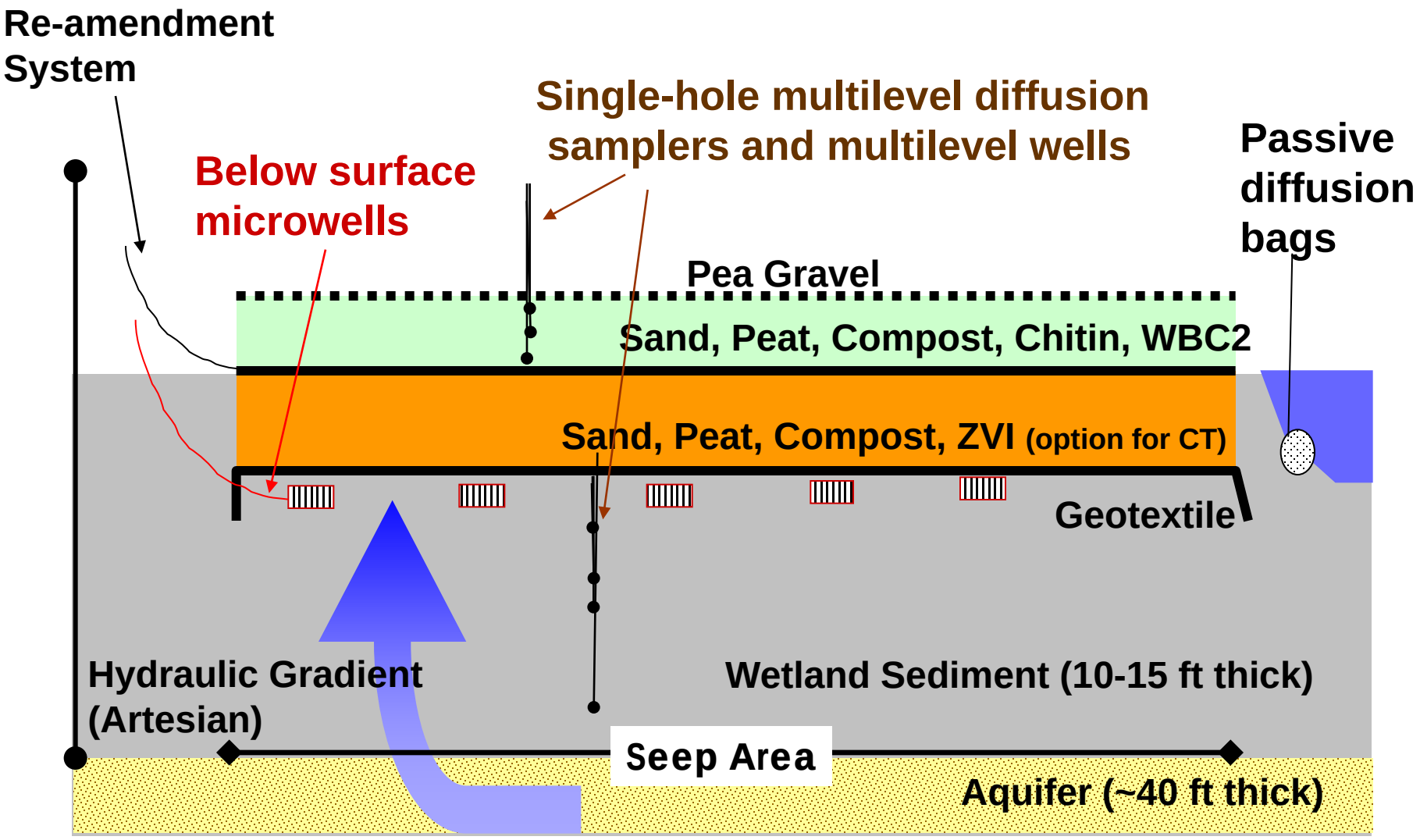
WBC-2 #1



Relative Abundances above 1%

- Otu00014 - Bacteria; Bacteroidetes; unclassified; unclassified; unclassified; unclassified; unclassified
- Otu00008 - Bacteria; Proteobacteria; Deltaproteobacteria; Desulfuromonadales; Geobacteraceae; Geobacter; unclassified
- Otu00013 - Bacteria; WWE1; [Cloacamonae]; [Cloacamonales]; [Cloacamonaceae]; W22; unclassified
- Otu00023 - Bacteria; Proteobacteria; Deltaproteobacteria; Desulfobacterales; Desulfobulbaceae; Desulfobulbus; unclassified
- Otu00004 - Bacteria; Tenericutes; Mollicutes; Acholeplasmatales; Acholeplasmataceae; Acholeplasma; unclassified
- Otu00040 - Bacteria; Chloroflexi; Anaerolineae; Anaerolineales; Anaerolinaceae; C1_B004; unclassified
- Otu00029 - Bacteria; Firmicutes; Clostridia; Clostridiales; Eubacteriaceae; Acetobacterium; unclassified
- Otu00002 - Bacteria; Proteobacteria; Gammaproteobacteria; Pseudomonadales; Pseudomonadaceae; Pseudomonas; stutzeri
- Otu00031 - Bacteria; Firmicutes; Clostridia; Clostridiales; [Mogibacteriaceae]; unclassified; unclassified
- Otu00017 - Bacteria; Chloroflexi; Dehalococcoidetes; Dehalococcoidales; Dehalococcoidaceae; Dehalogenimonas; unclassified
- Otu00003 - Bacteria; Proteobacteria; Epsilonproteobacteria; Campylobacterales; Campylobacteraceae; Sulfurospirillum; unclassif
- Otu00036 - Bacteria; Bacteroidetes; unclassified; unclassified; unclassified; unclassified; unclassified
- Other

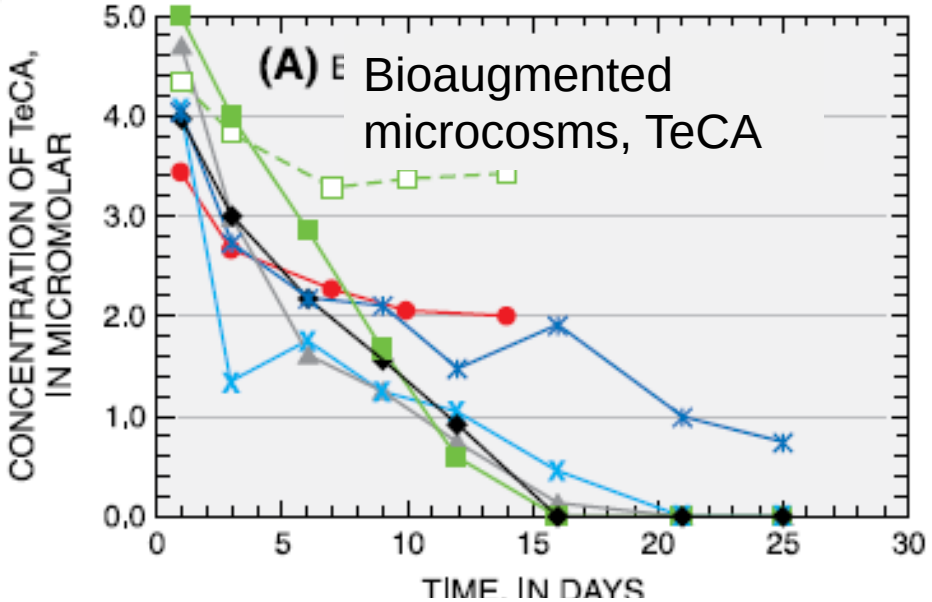
Reactive Barrier Design and Monitoring

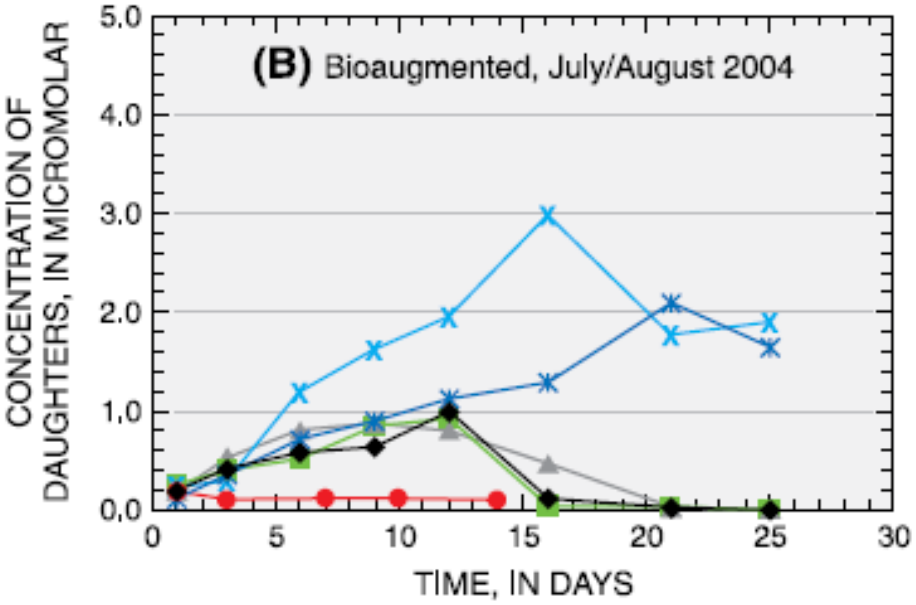


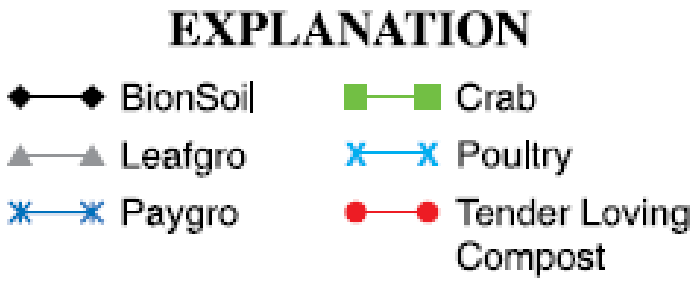
NOT TO SCALE

Microcosms: Wetland Sediment-Compost Mixtures

- Different composts tested for support of WBC-2 activity and VOC degradation
- Variable results with different composts for degradation of both parent and daughter compounds

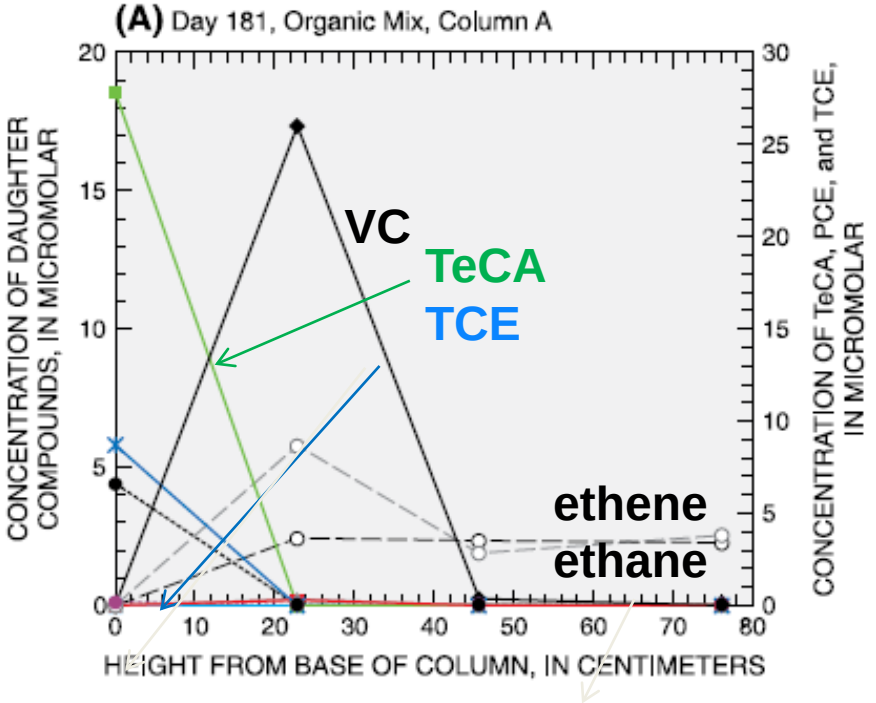


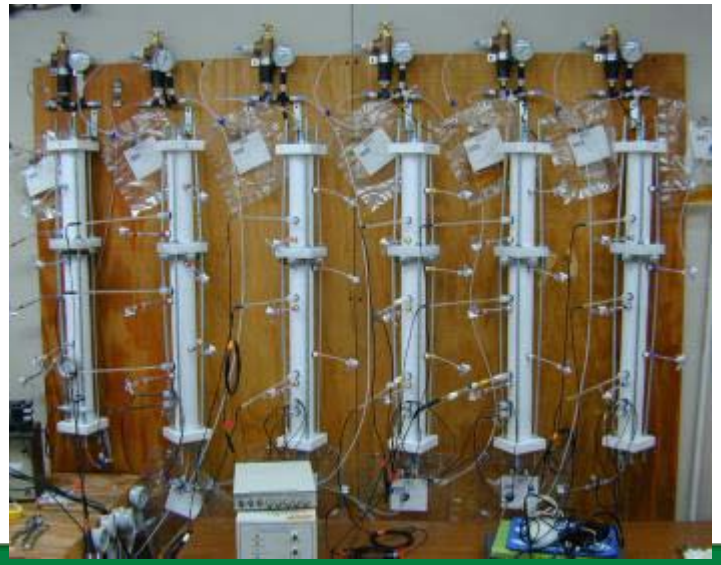




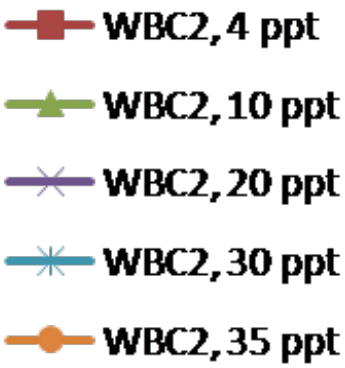
APG Reactive Barrier: Upward Flow Columns

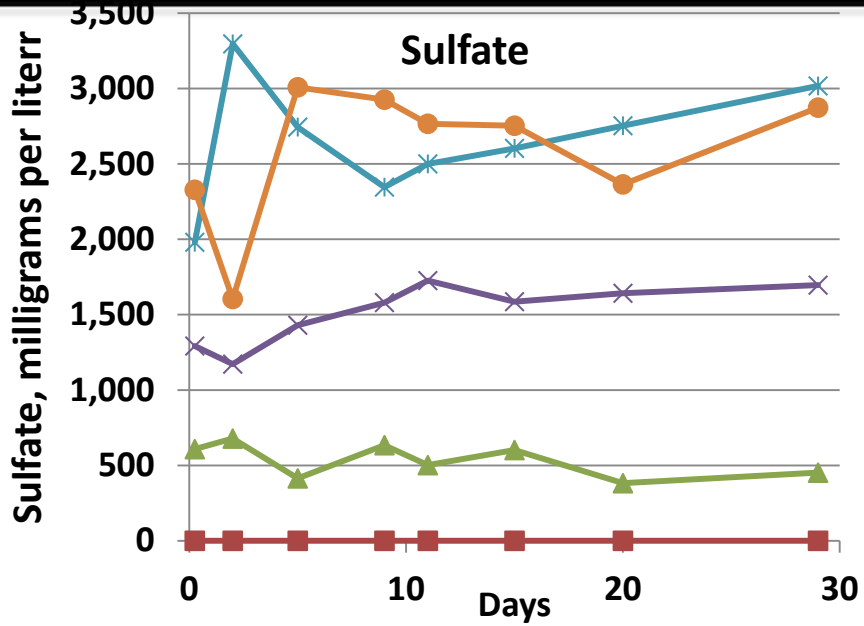
Contaminant	k (day^{-1})	$t_{1/2}$ (hrs)
1122TeCA	3.4	4.8
Chloroform	2.3	7.2
Carbon tetrachloride	2.8	5.9
Tetrachloro-ethene	1.4	12
Trichloroethene	3.0	5.5

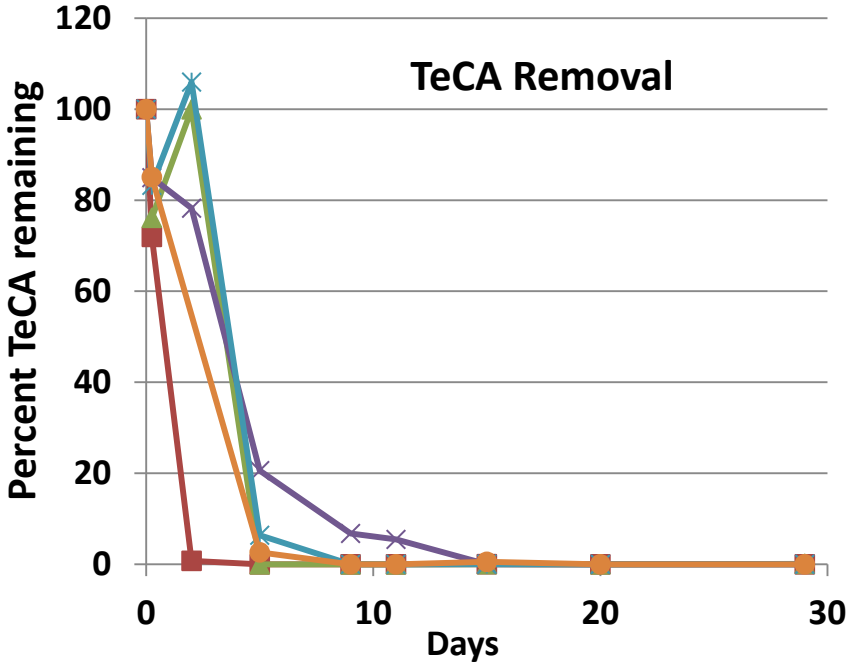


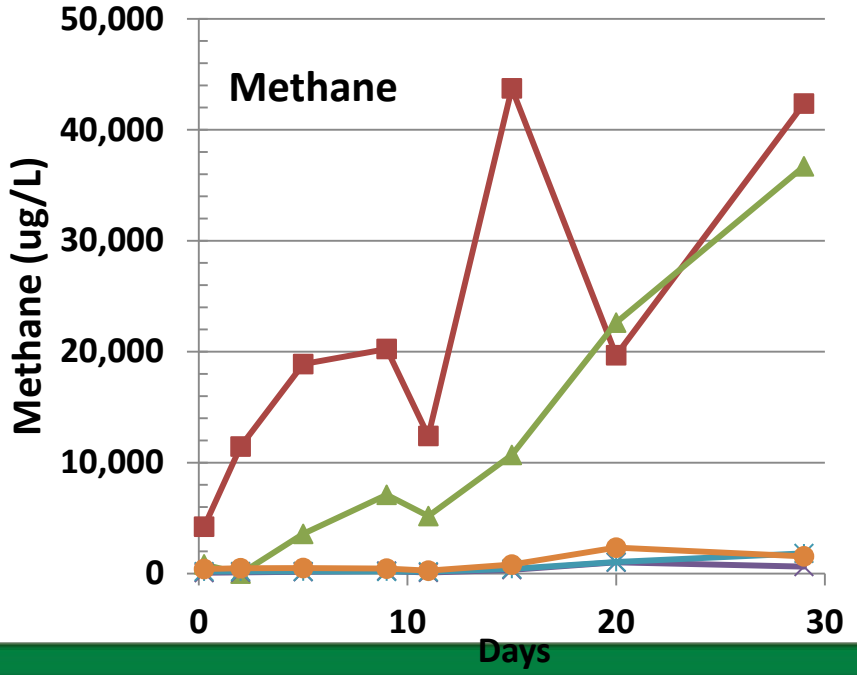


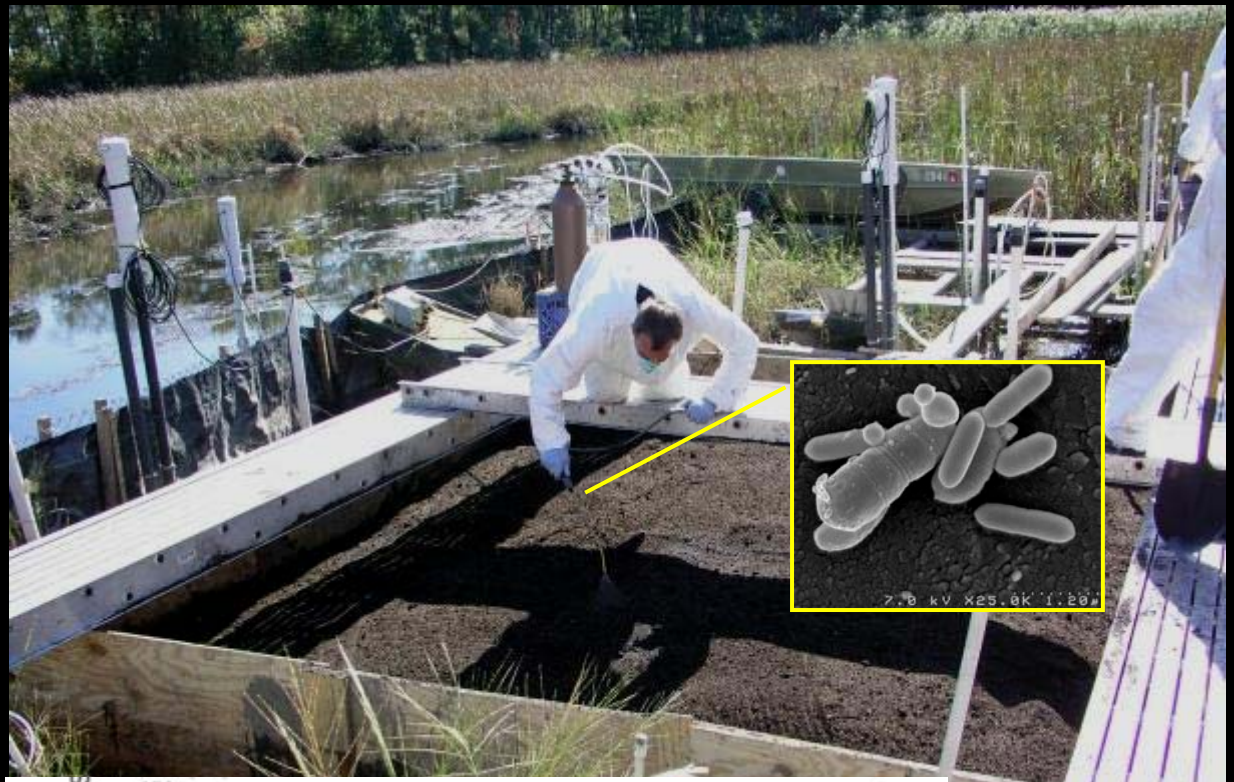
Salinity microcosms



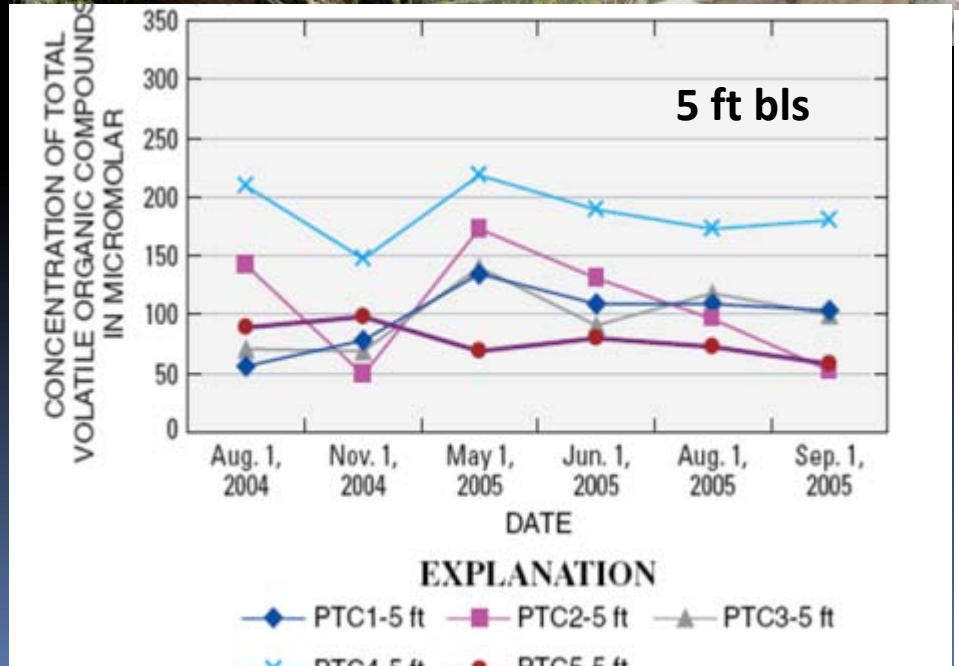


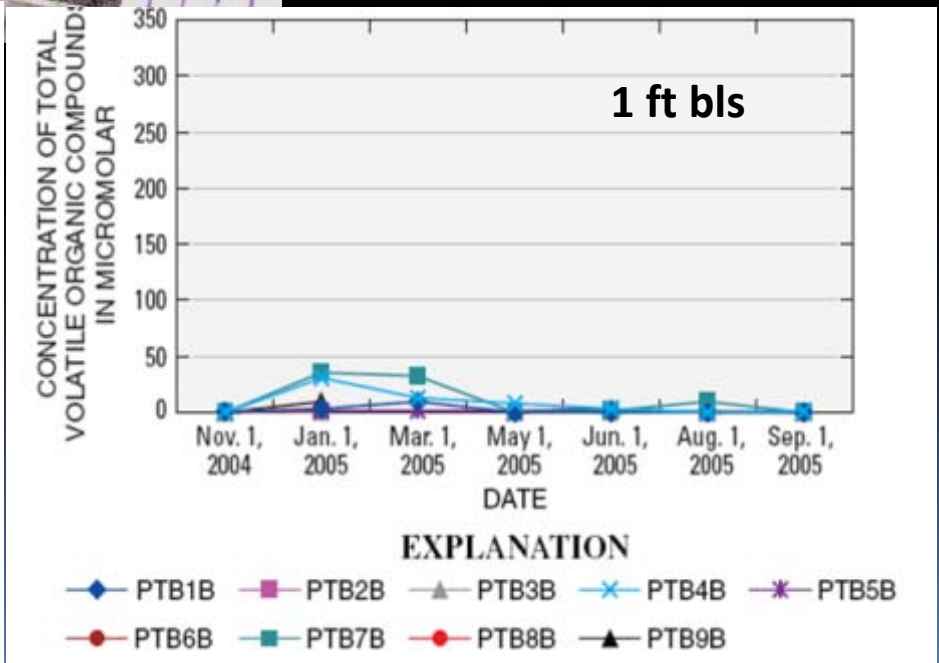




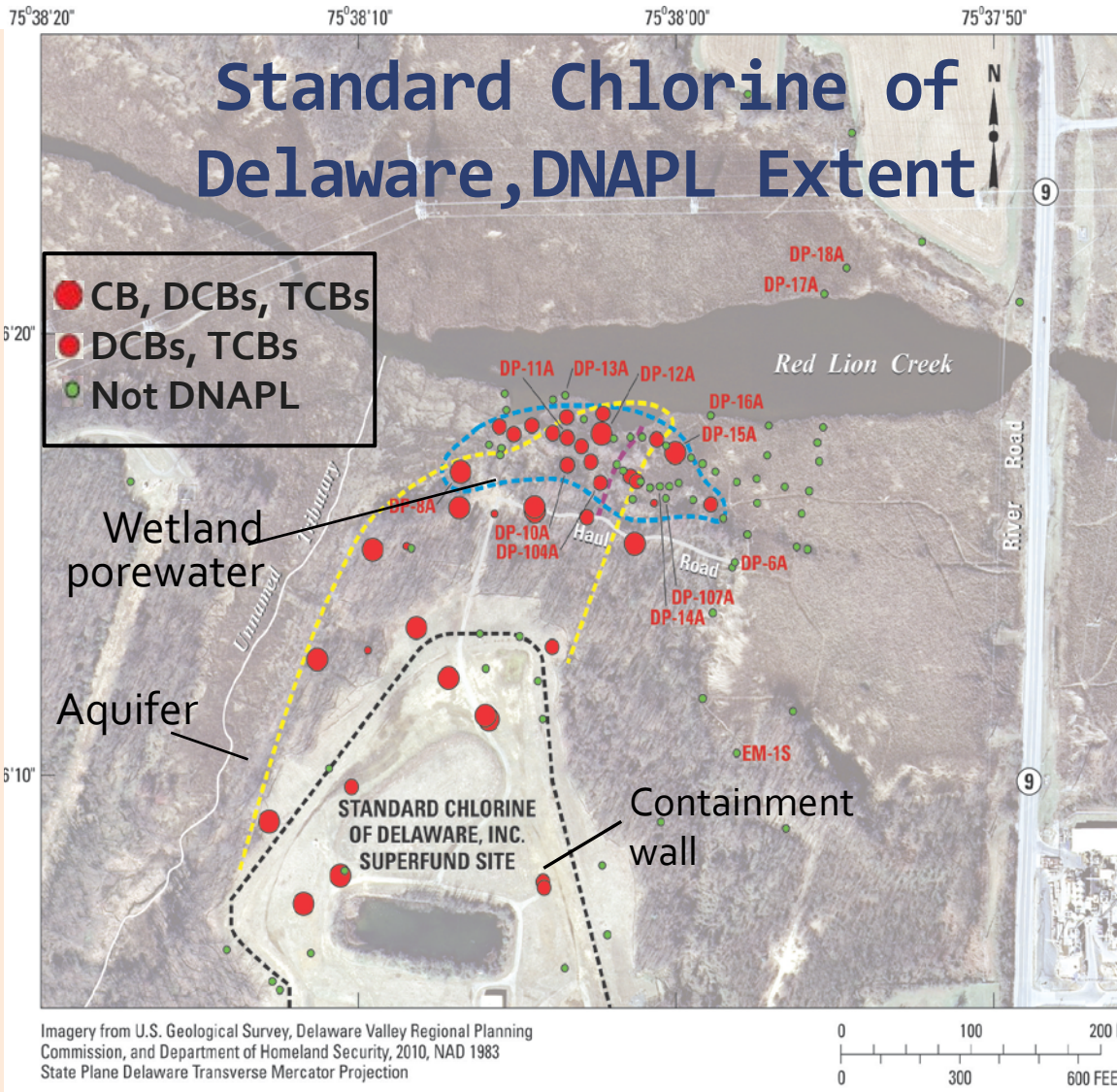


Reactive Barrier- West Branch Canal Creek, APG





- Chemical plant 1966-2002; EPA Superfund 2002
  - 1981- 5,000 gal CB
  - 1986 storage tanks- 579,000 gal 14DCB and TCBs
- Abuts Red Lion Creek, part of Delaware River watershed
- Treatment in uplands, but not in wetlands
- Half of water flow to Red Lion Creek is from Columbia Aquifer



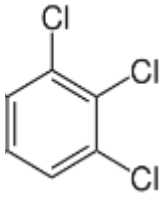
Biodegradation Pathways

Anaerobic (reductive dechlorination)

- CB serves as terminal electron acceptor
- Separate e- donor required
- rate decreases with decreasing number Cl

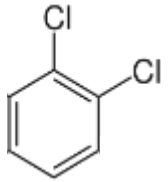
Aerobic (oxidation)

- O_2 required as electron acceptor
- CBs utilized as C and e^- donor
- rate increases with decreasing number Cl
- Short-lived intermediates



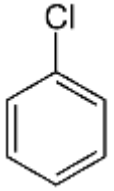
70 (124TCB)

Trichlorobenzenes*
135TCB,124TCB, 123TCB



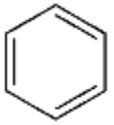
75 (14DCB)

Dichlorobenzenes*
14DCB, 13DCB, 12DCB



100

Chlorobenzene*



5

Benzene *

CO_2, CH_4

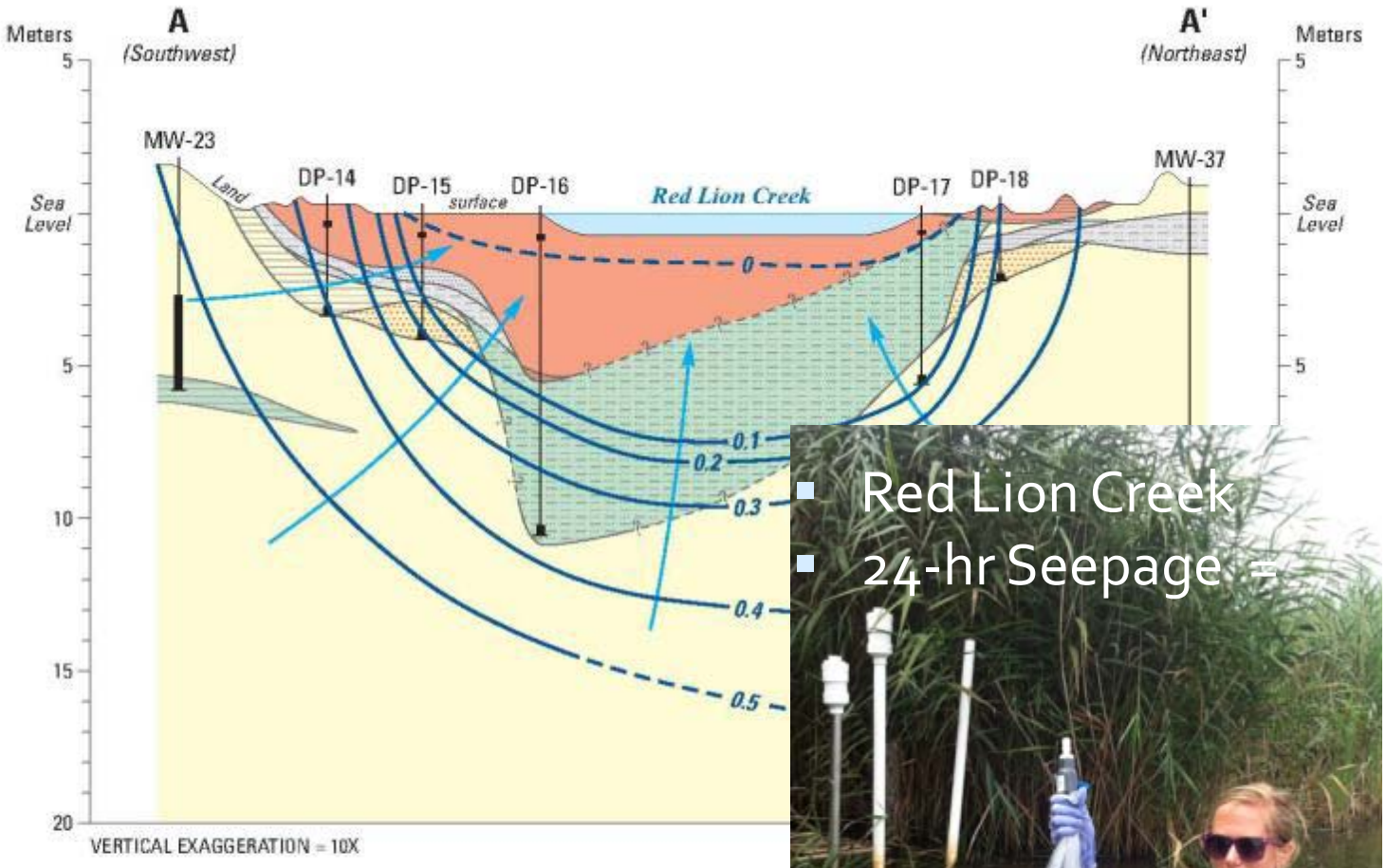
Drinking Water MCL µg/L

Aerobic CO2, HCl

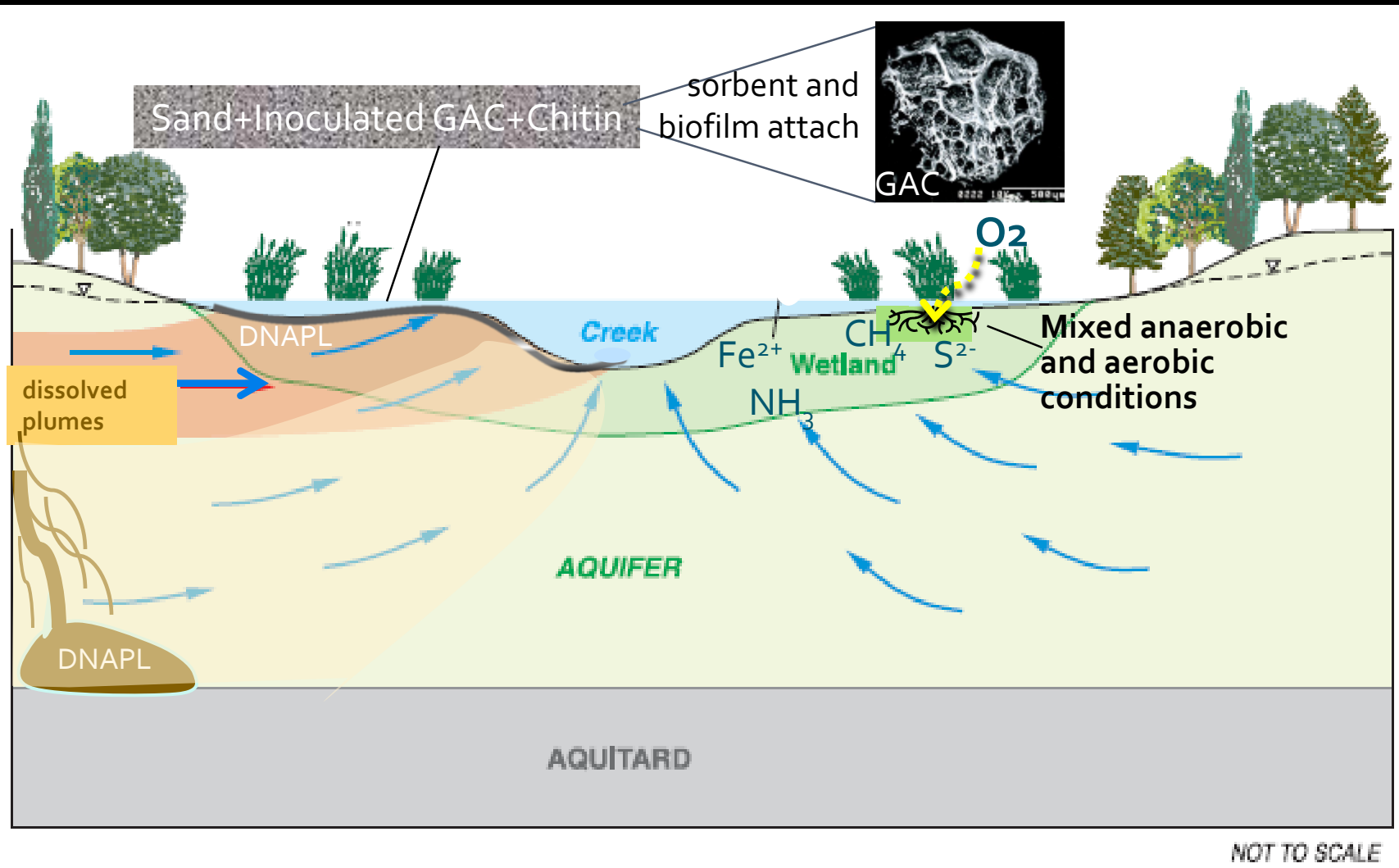
* Parent contaminant

Wetland Study Area, SCD

- Upward flow at all sites
- Seepage measured on wetland surface and creek bottom



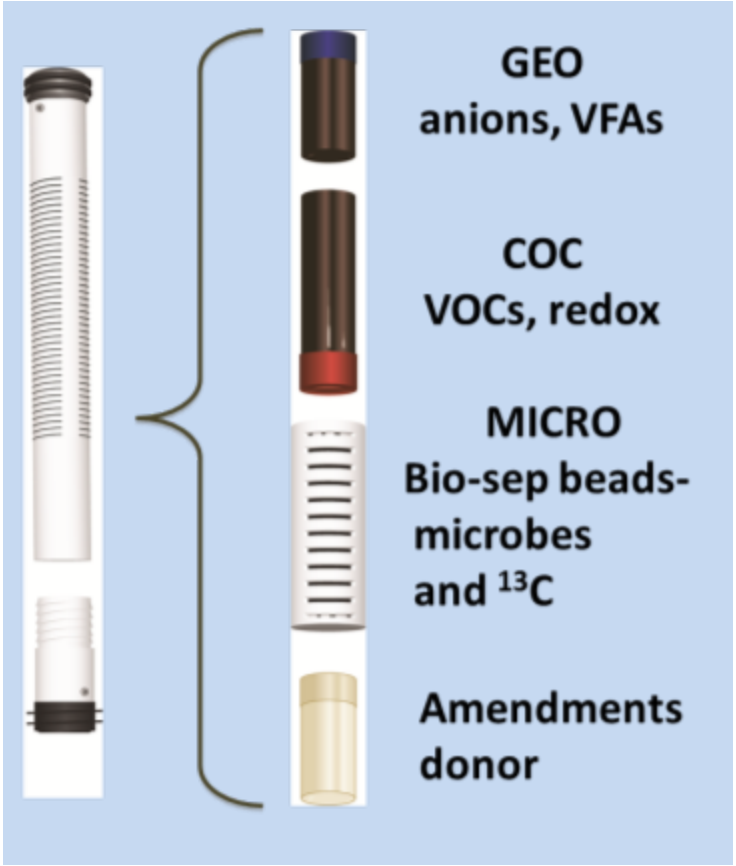
- Red Lion Creek
- 24-hr Seepage =



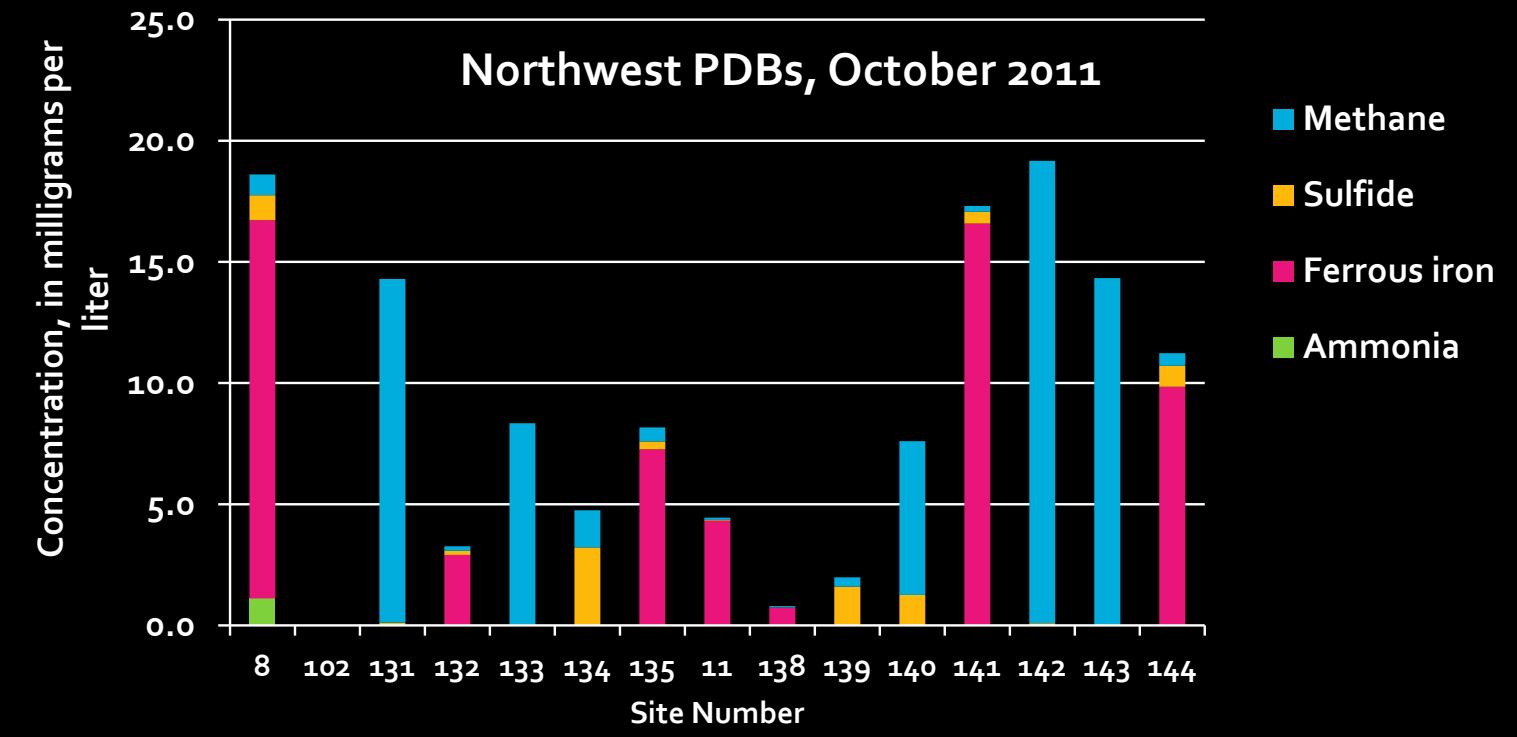
Conceptual model for contamination and dual-biofilm reactive barrier in wetland

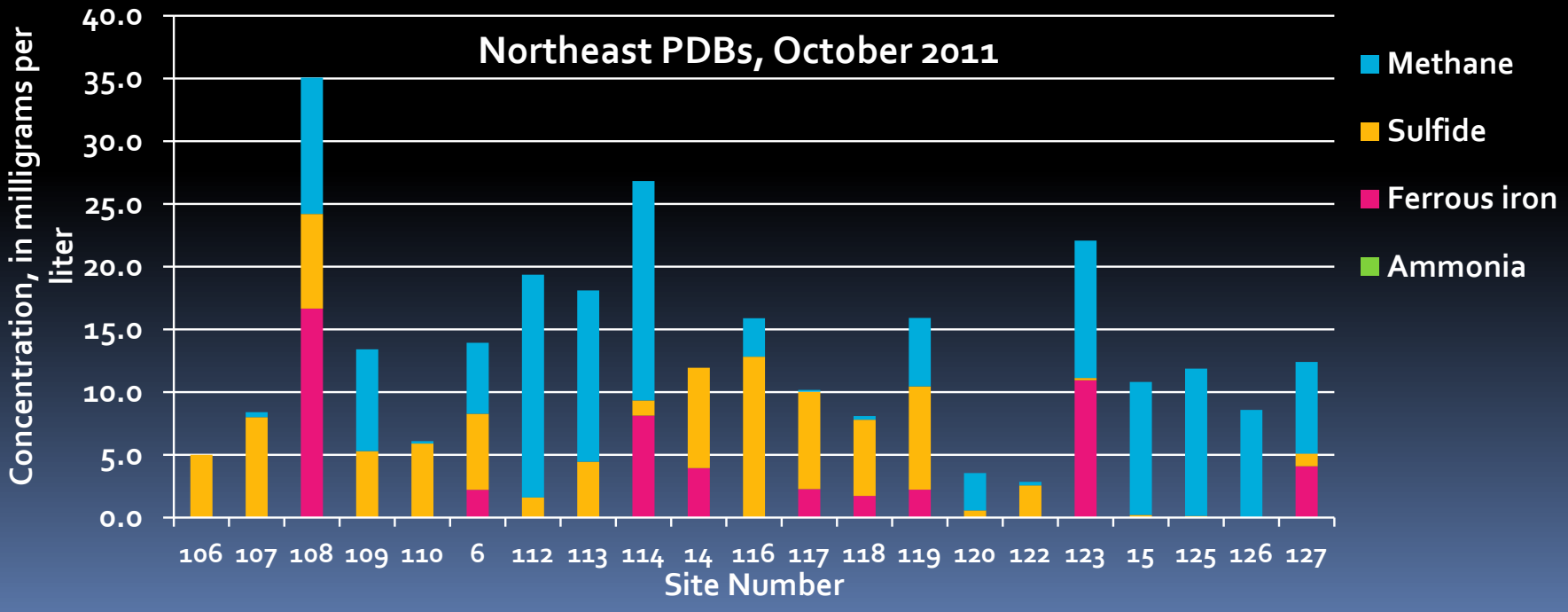
Approach to evaluate natural and enhanced biodegradation

- *In situ* microcosms with Bio-Traps (Microbial Insights)
  - Stable isotope probing (^{13}C-labeled 14DCB, CB, B)
  - Microbial species and functional genes for biodegradation
- Evaluate biodegradation processes in flow-through bioreactors
  - Upflow fixed film bioreactors
  - Mimic growth in subsurface
  - Allows changing conditions

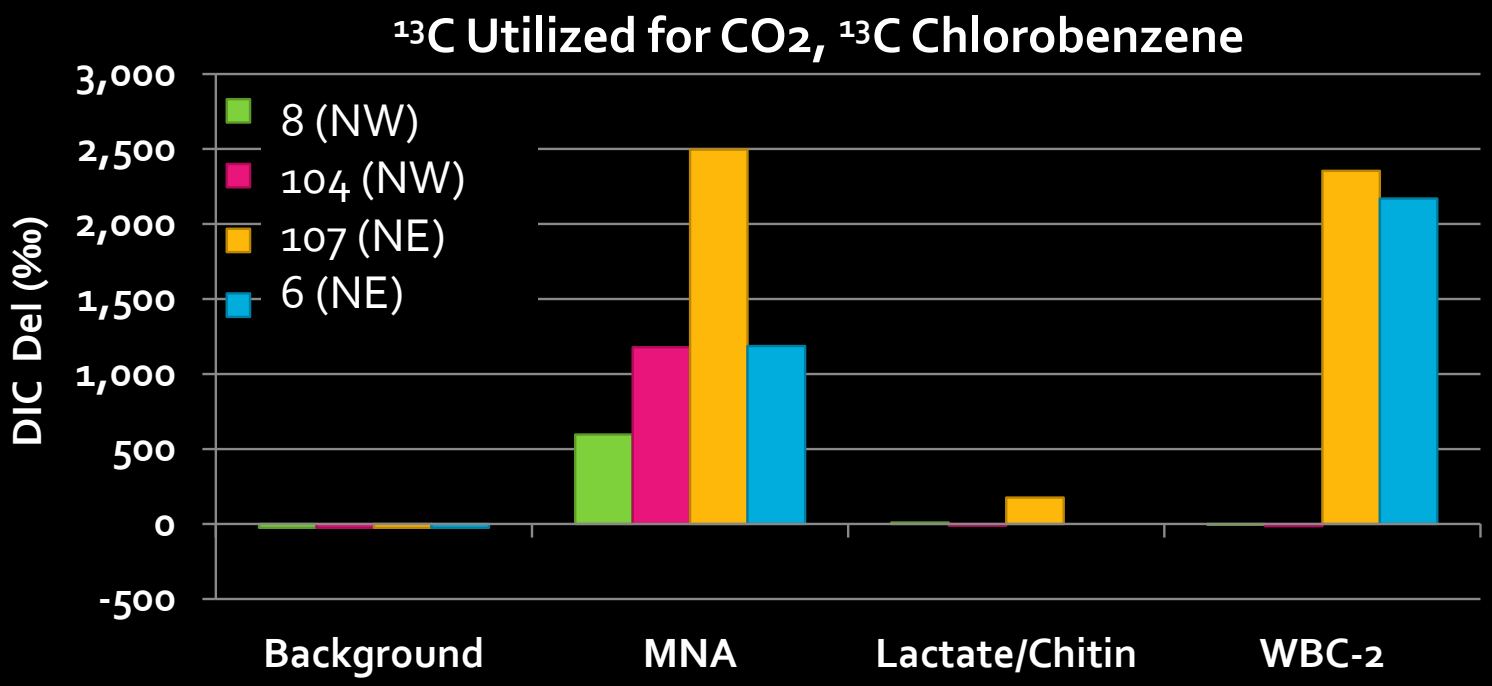


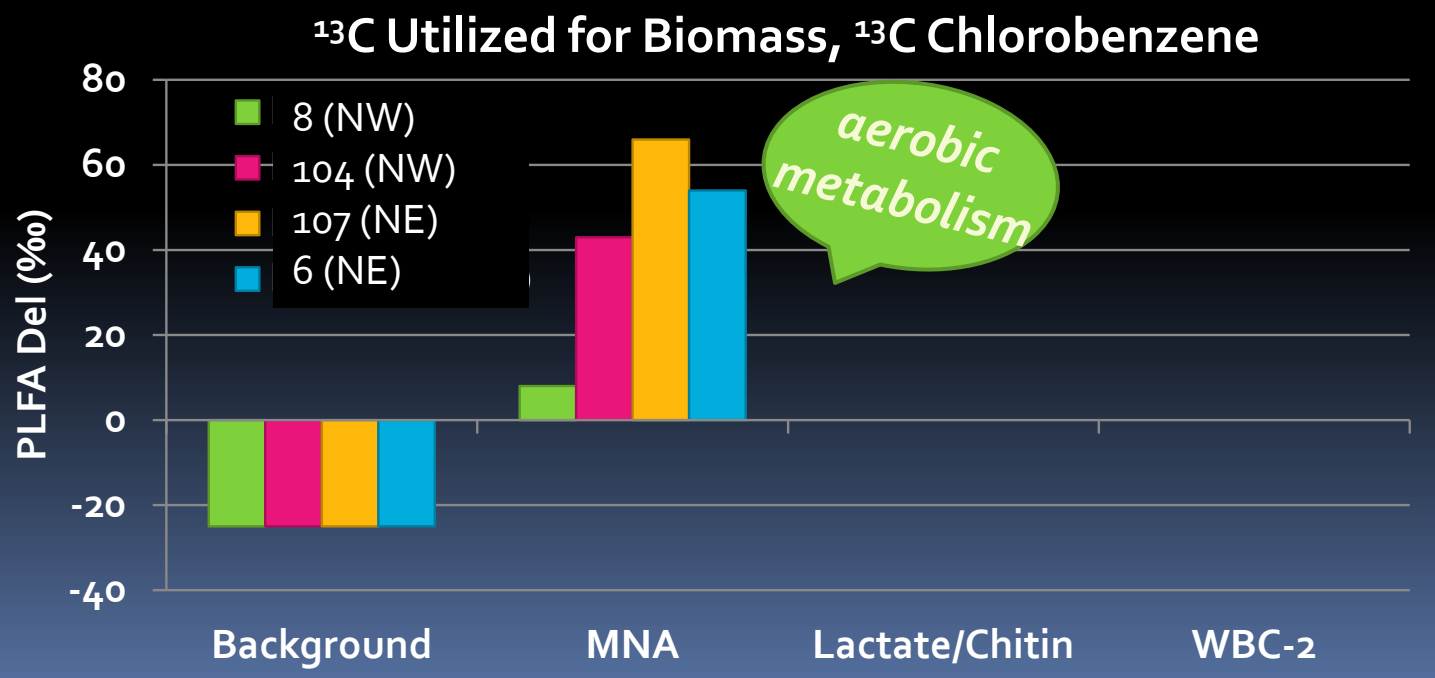
Bioreactor polypropylene support matrix for biofilms


Northwest PDBs, October 2011
Concentration, in milligrams per liter
25.0
20.0
15.0
10.0
5.0
0.0
8
102
131
132
133
134
135
11
138
139
140
141
142
143
144
Site Number
Methane
Sulfide
Ferrous iron
Ammonia

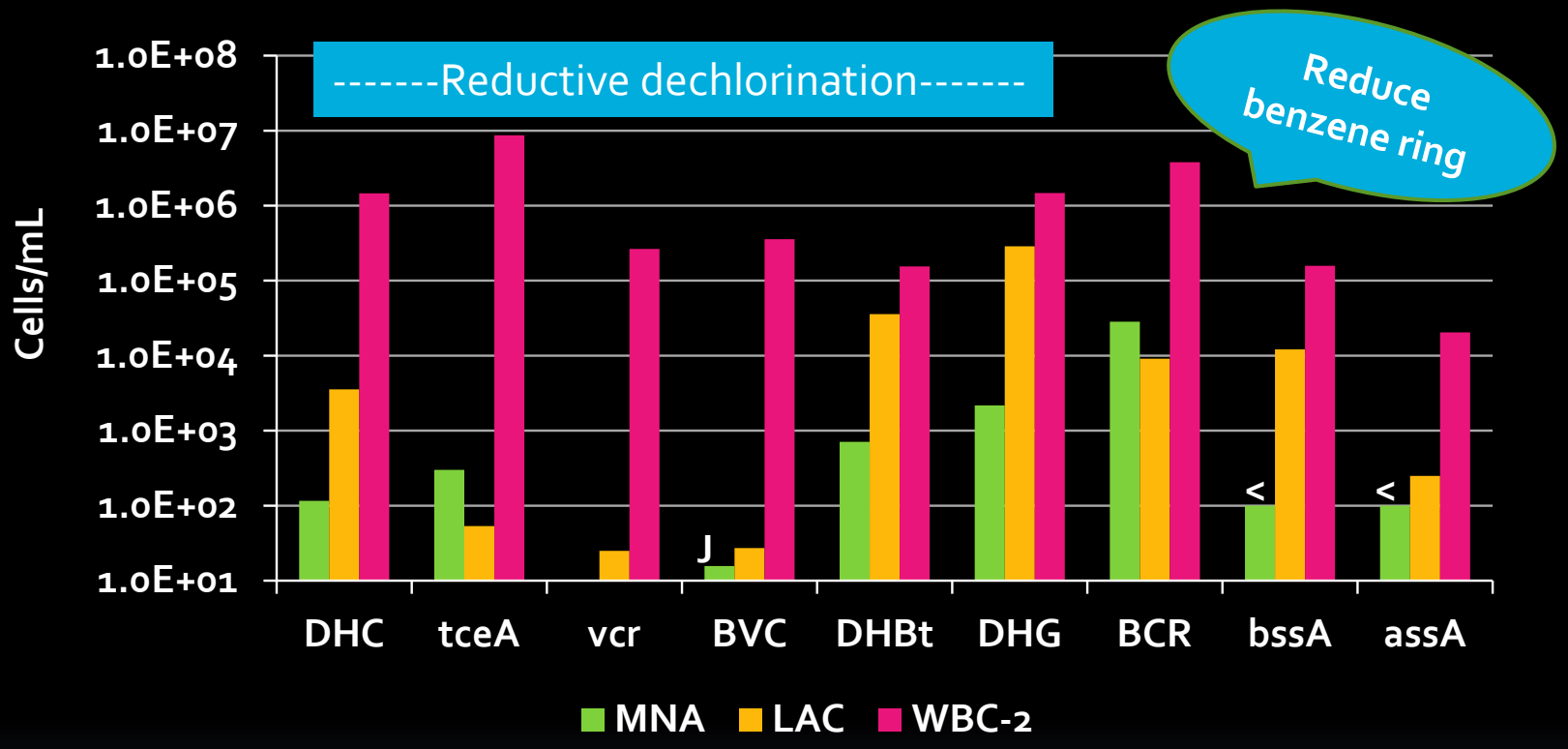

Northeast PDBs, October 2011
Concentration, in milligrams per liter
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
106
107
108
109
110
6
112
113
114
14
116
117
118
119
120
122
123
15
125
126
127
Site Number
Methane
Sulfide
Ferrous iron
Ammonia

Bio-Traps: ^{13}C-labeled Chloro-benzene





QuantArray Microbial Analysis- Anaerobic



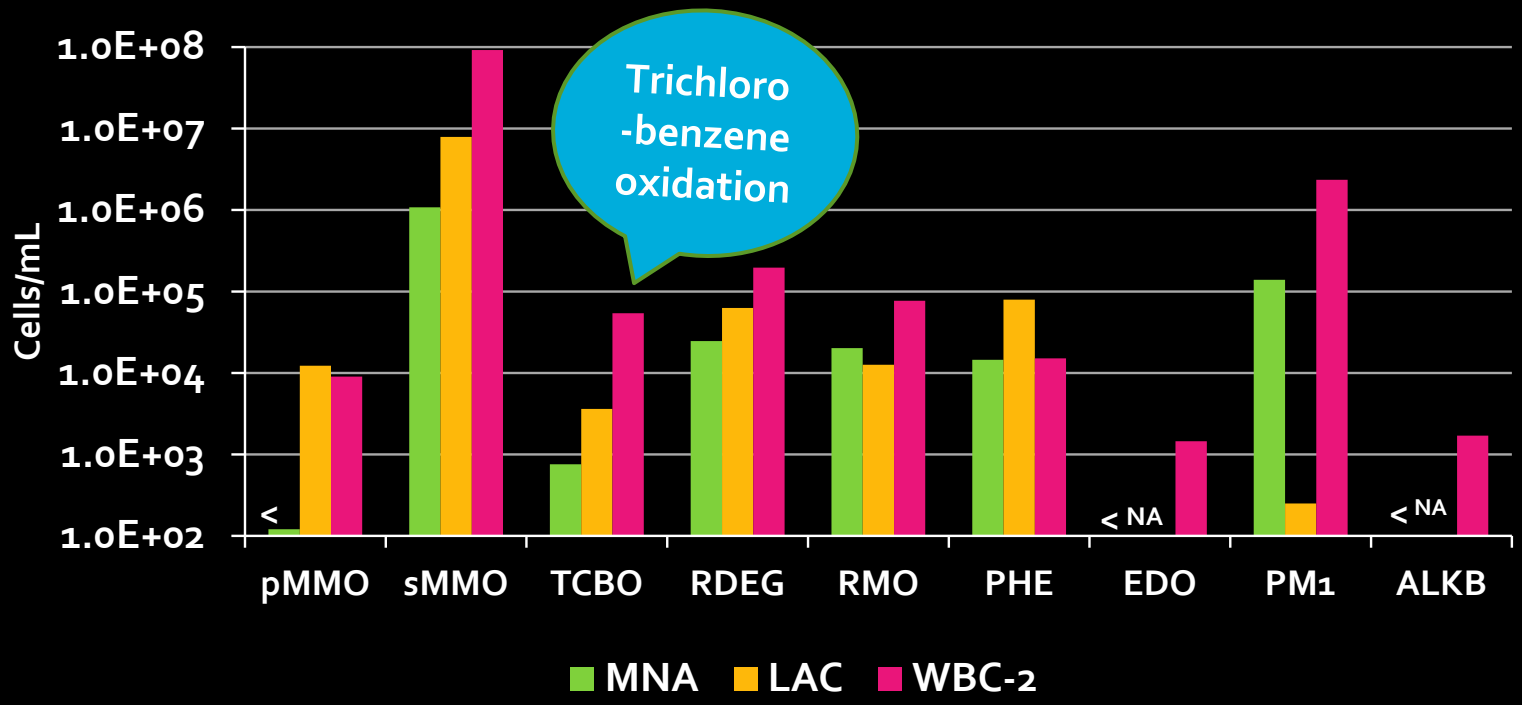
Reductive dechlorination:

DHC , Dehalococcoides spp.
TCE, tceA reductase
VCR, vinyl chloride reductase
BV1 , vinyl chloride reductase
DHBt, Dehalobacter spp.
DHG, Dehalogenimonas spp.

BTEX, PAHs and alkanes:

BCR, Benzoyl coenzyme A reductase
bssA, benzylsuccinate synthase
assA, alkylsuccinate synthase

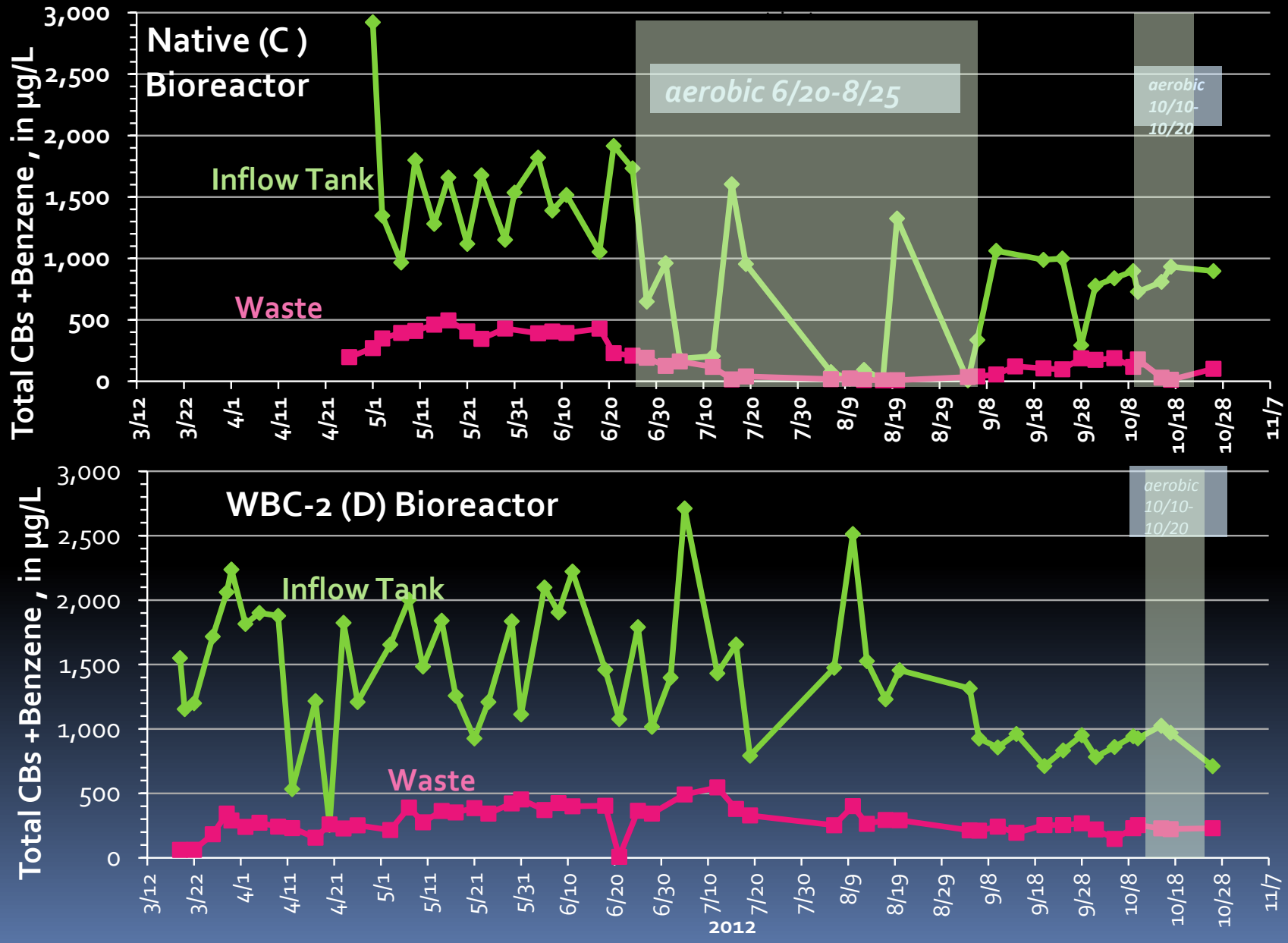
QuantArray Microbial Analysis- Aerobic



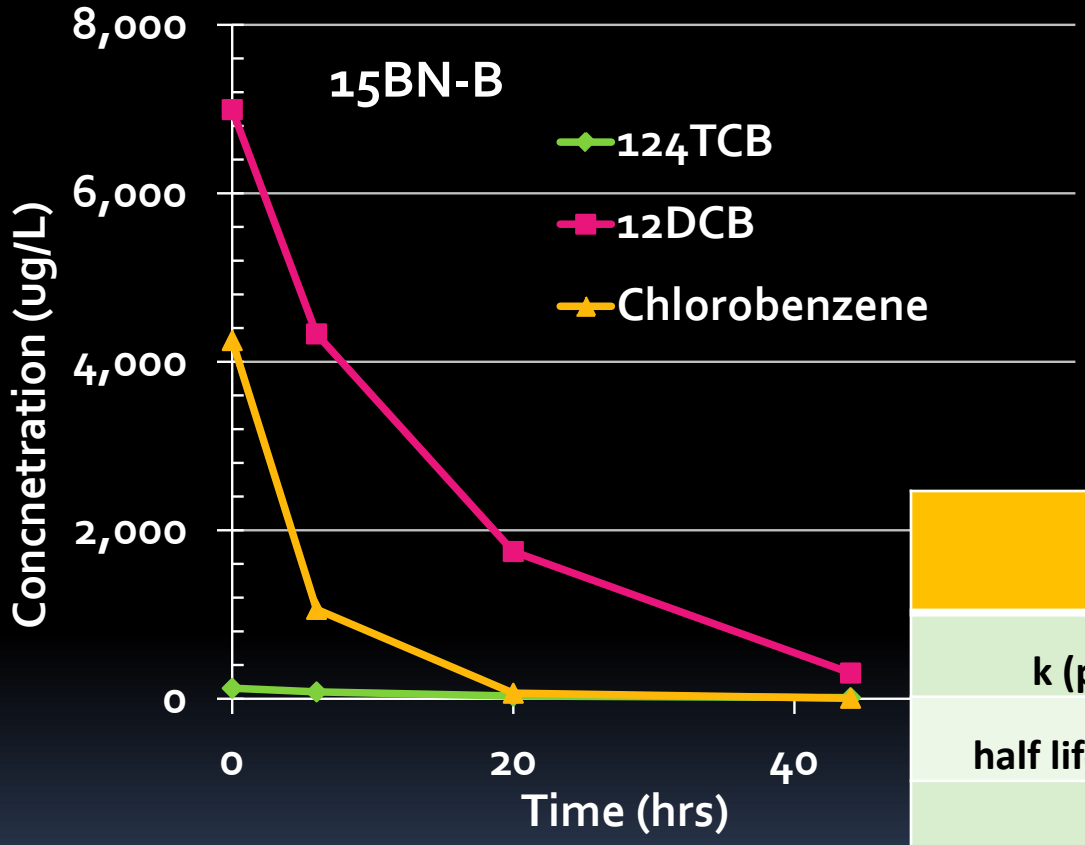
pMMO, particulate methane monooxygenase
sMMO, soluble methane monooxygenase
TCBO, trichlorobenzene dioxygenase
RDEG, toluene monooxygenase 2
RMO, toluene monooxygenase

PHE, phenol hydroxylase
EDO, ethylbenzene/isopropyl-benzene dioxygenase
PM1, Methylibium petroliphilum PM1
ALKB, alkane monooxygenase

SCD Bioreactors

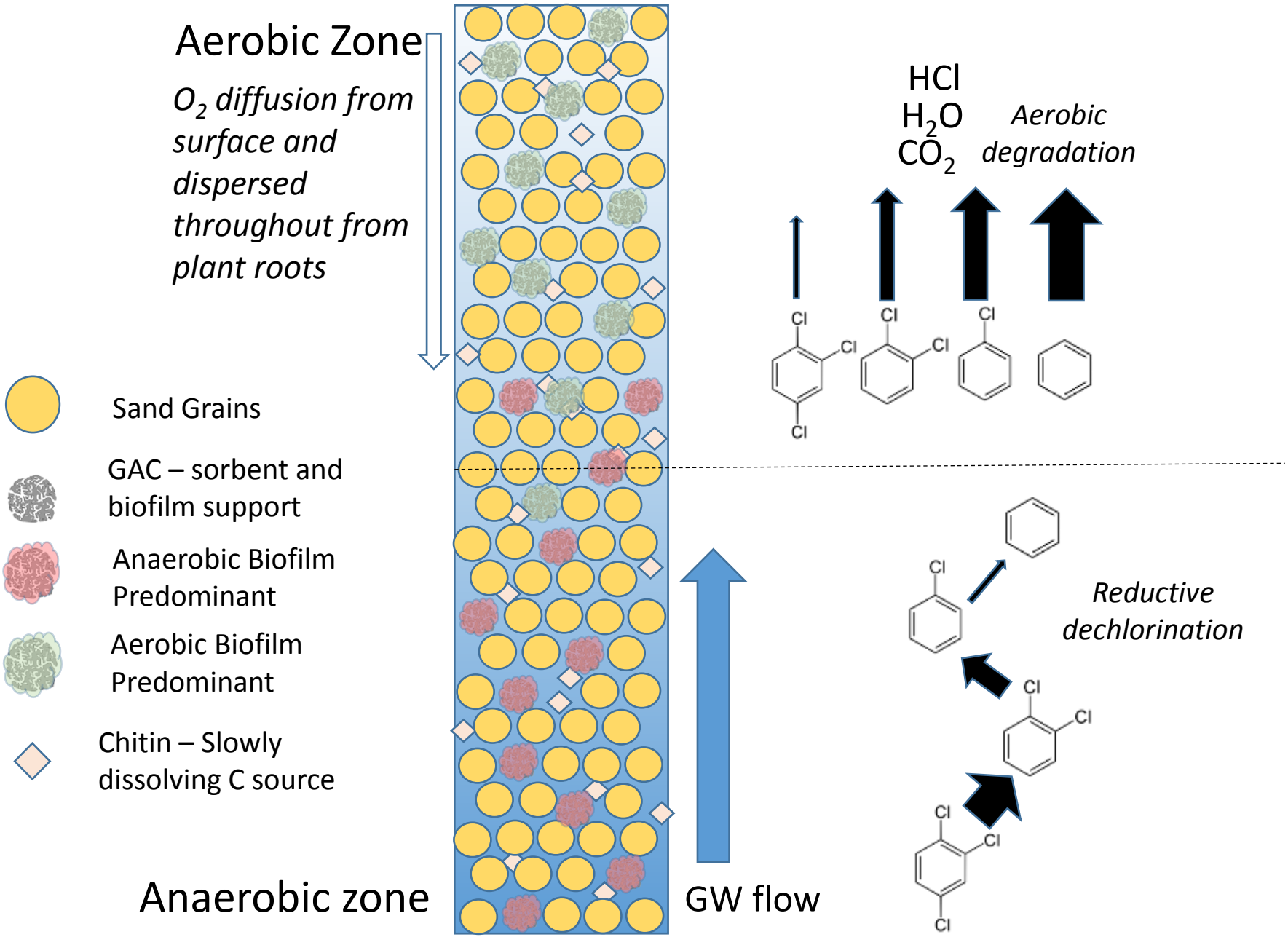


Aerobic Native Culture (15B)

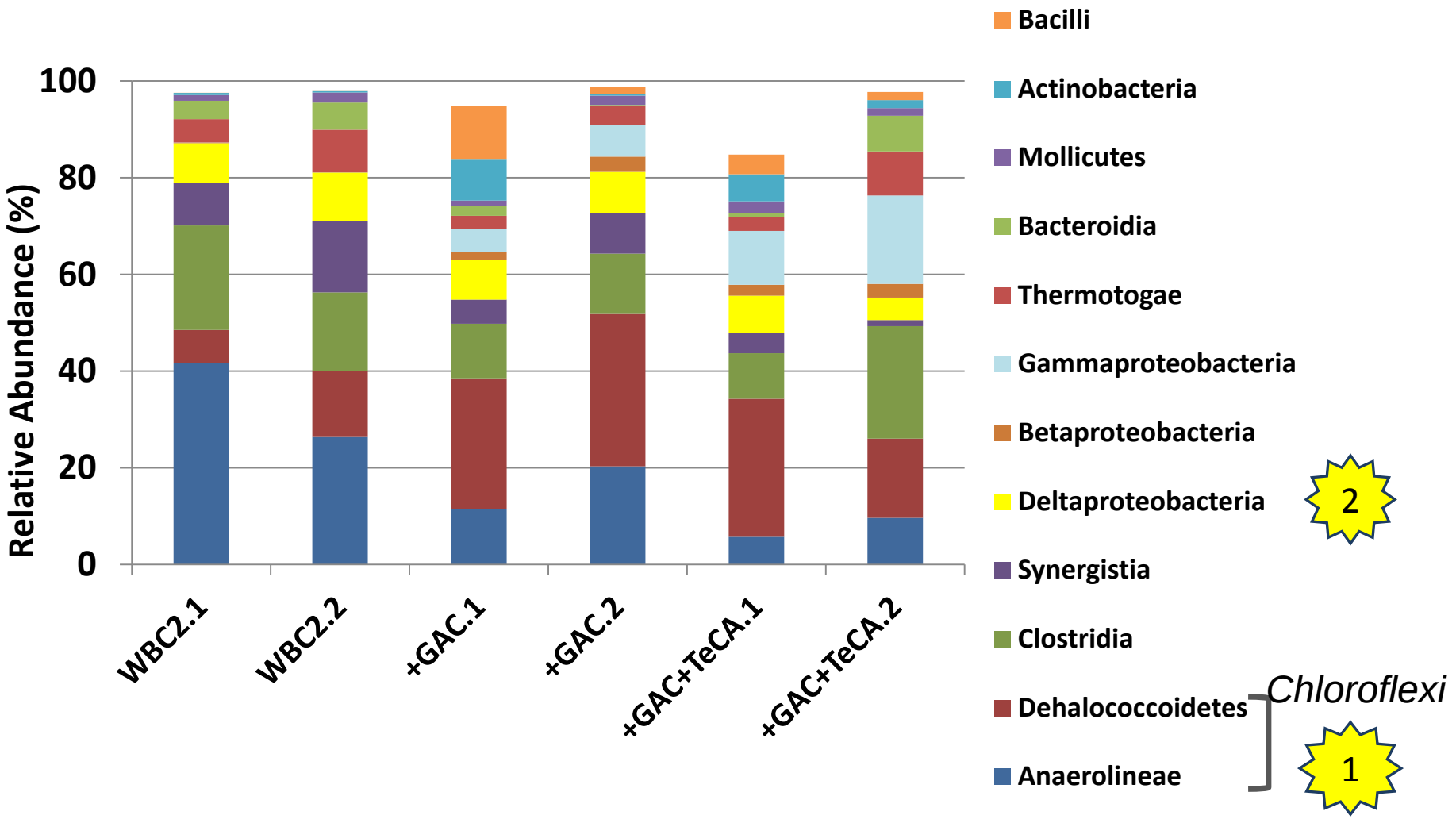


	124TCB	12DCB	CB
k (per hr)	0.051	0.071	0.15
half life (hrs)	13.6	9.8	4.6
r^2	.972	.999	.968

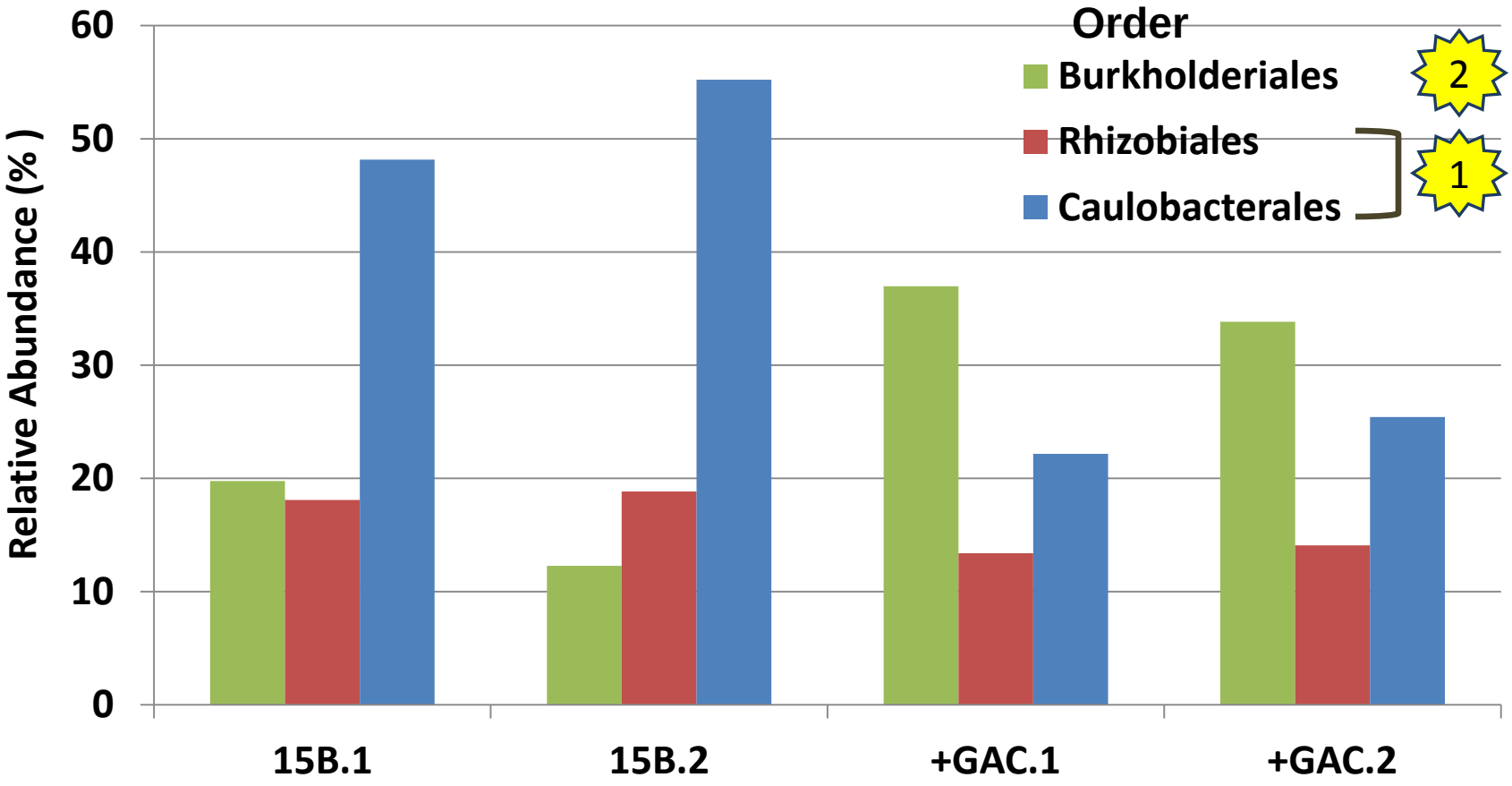
Reactive Barrier Concept



GAC with WBC-2: Classes >1% Abundance



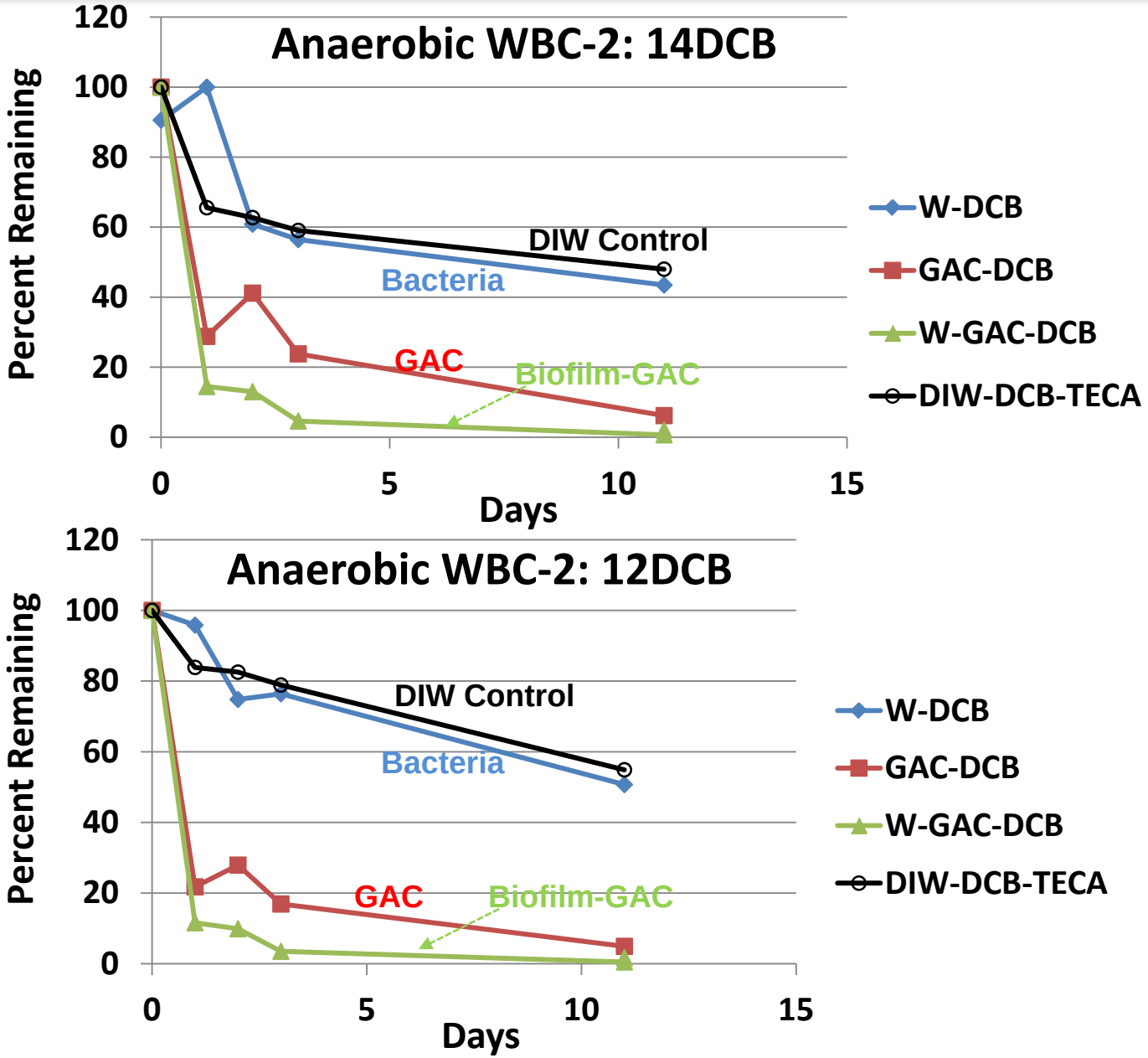
GAC with 15B: Proteobacteria, Order



- *Significant increase in the Betaproteobacteria group Burkholderiales on GAC.*

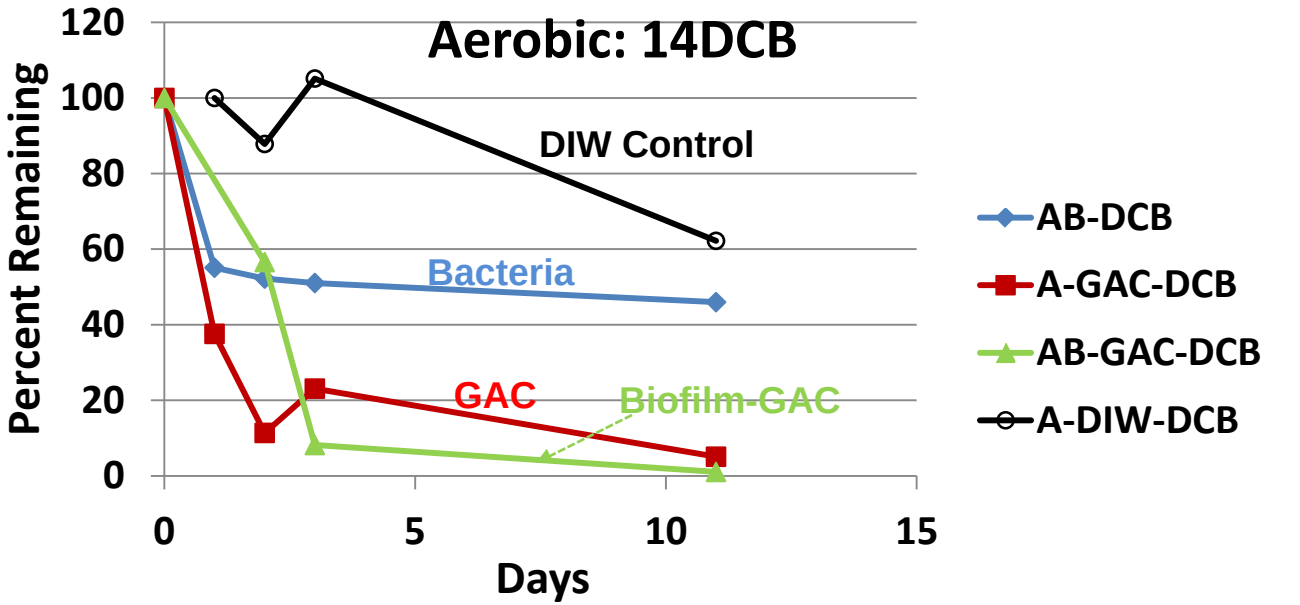
Microcosm Results: Anaerobic WBC-2 Biofilm on GAC

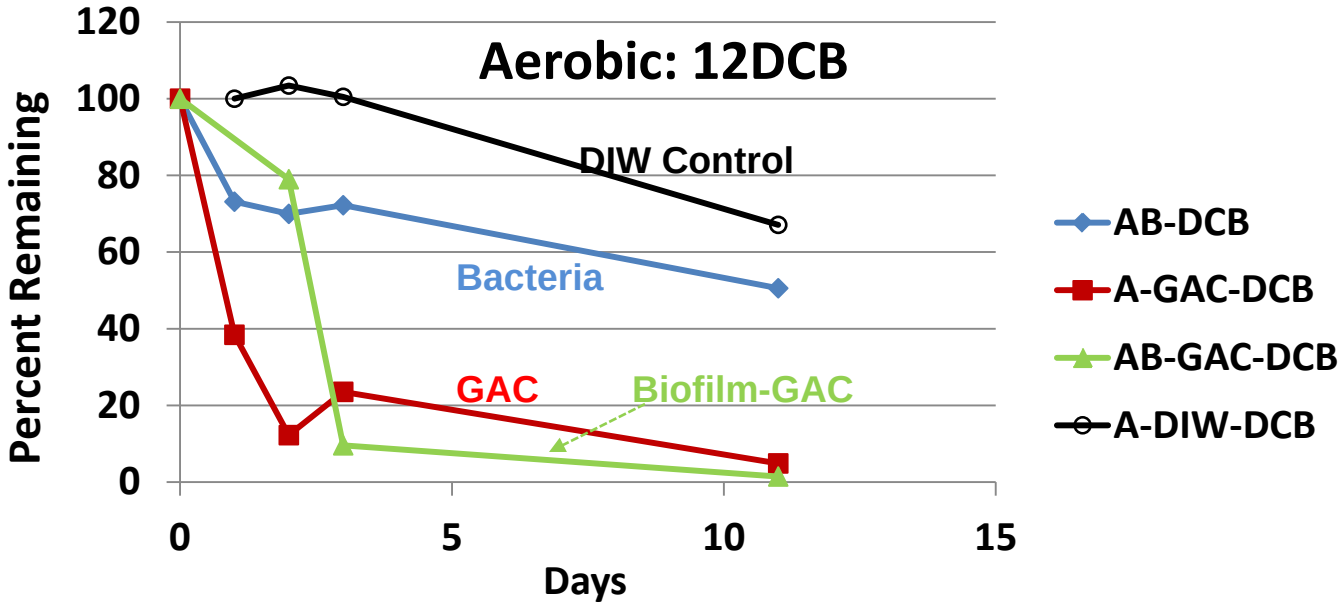
- Slight decrease in CBs with culture in mineral media compared to DIW
- Rapid sorption to GAC with and without anaerobic biofilm
- Distinctly faster overall CB removal in biofilm-GAC



Microcosm Results: Aerobic 15B Seeded on GAC

- *Delay in sorption to GAC with aerobic biofilm*
- *Slightly faster overall CB removal in biofilm-GAC*





Column Testing

Sand Columns:
Medium Sand+
5 % GAC +
3 % Chitin

Sediment Columns:

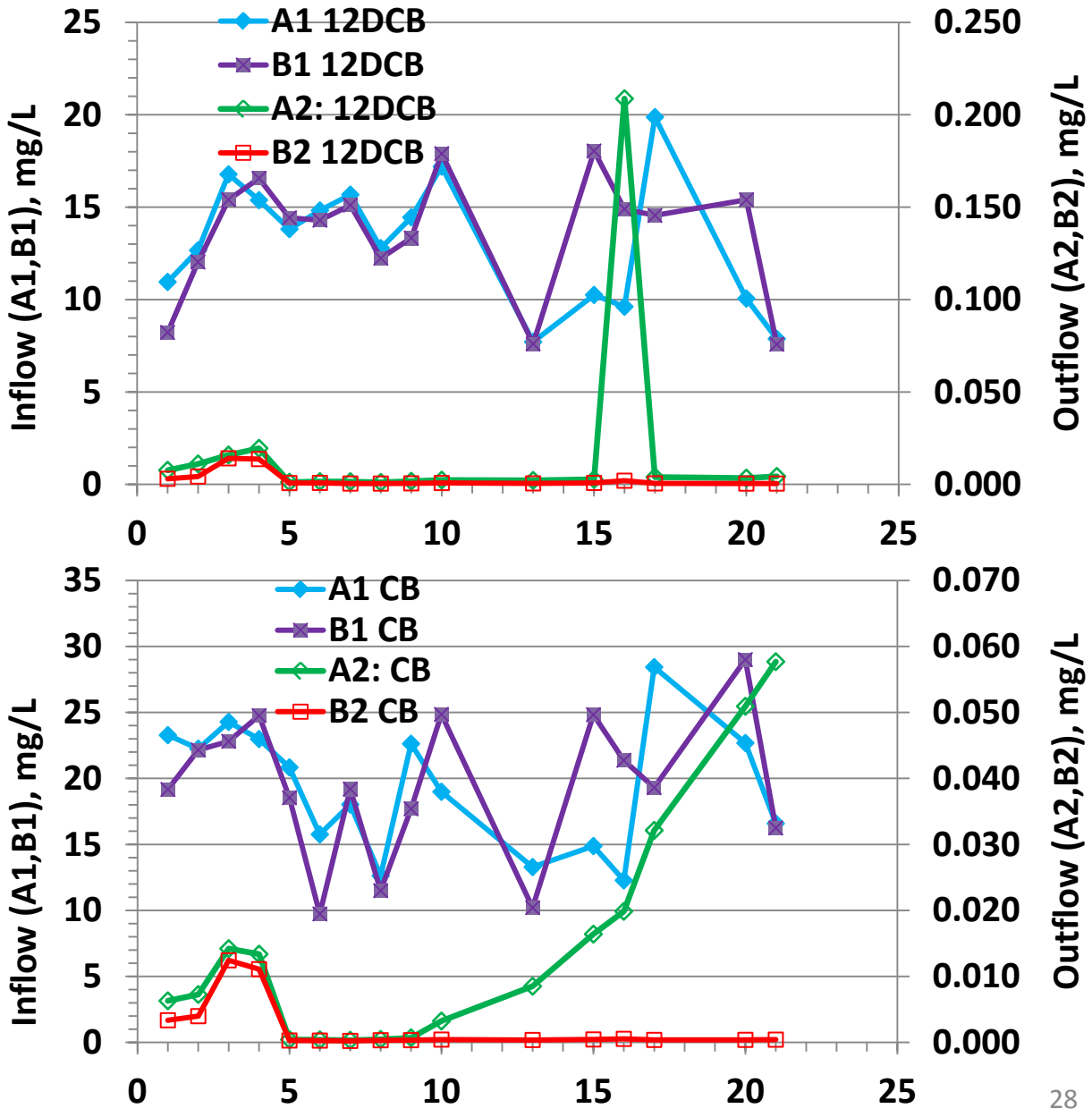
in progress- no data yet
5 % GAC +
3 % Chitin

Sand Columns:

Medium Sand+
HRT= 0.45 day

A= WBC2-GAC
B= WBC2+15B-GAC

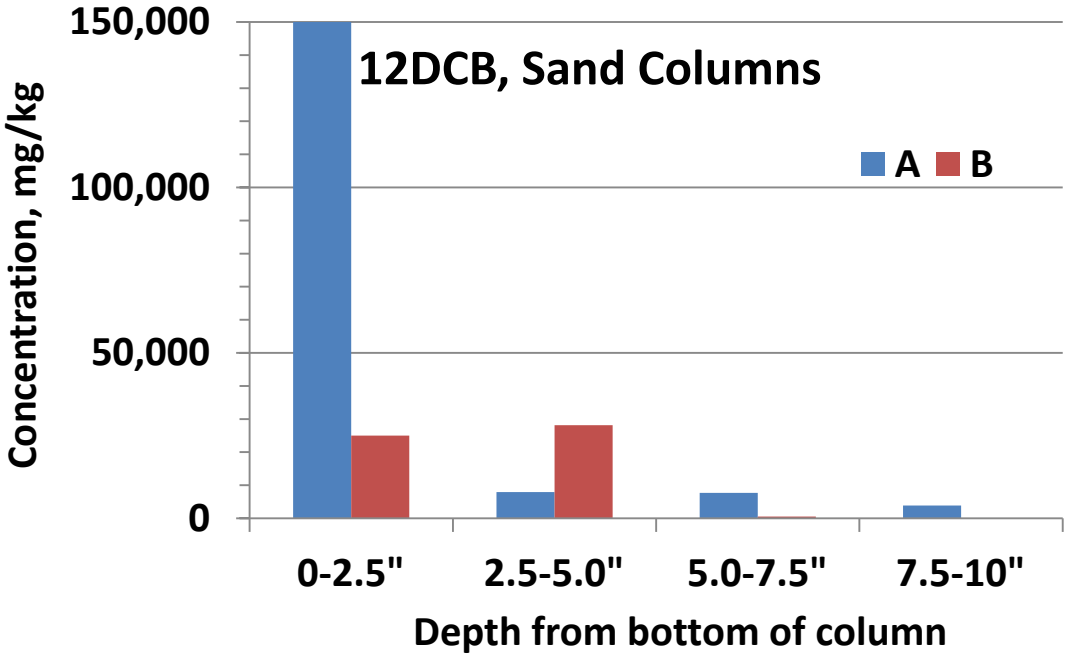
- *Outflow VOC concentrations very low in both columns*
- *Greater CB removal column with both the anaerobic and aerobic culture*

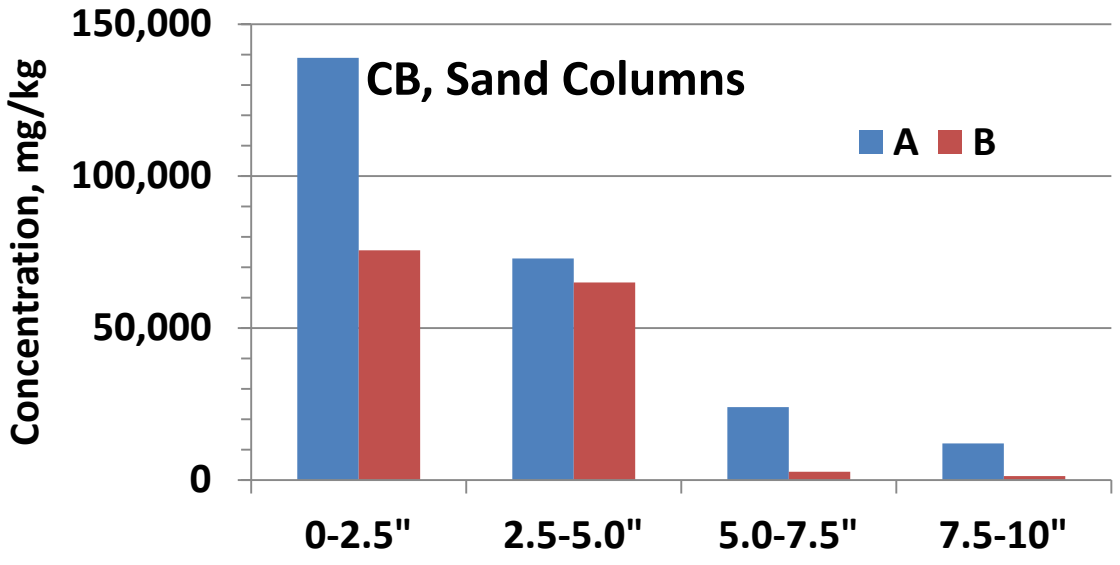


Sand Columns:
Sediment methanol extract analysis

A= WBC2-GAC
B= WBC2+15B-GAC

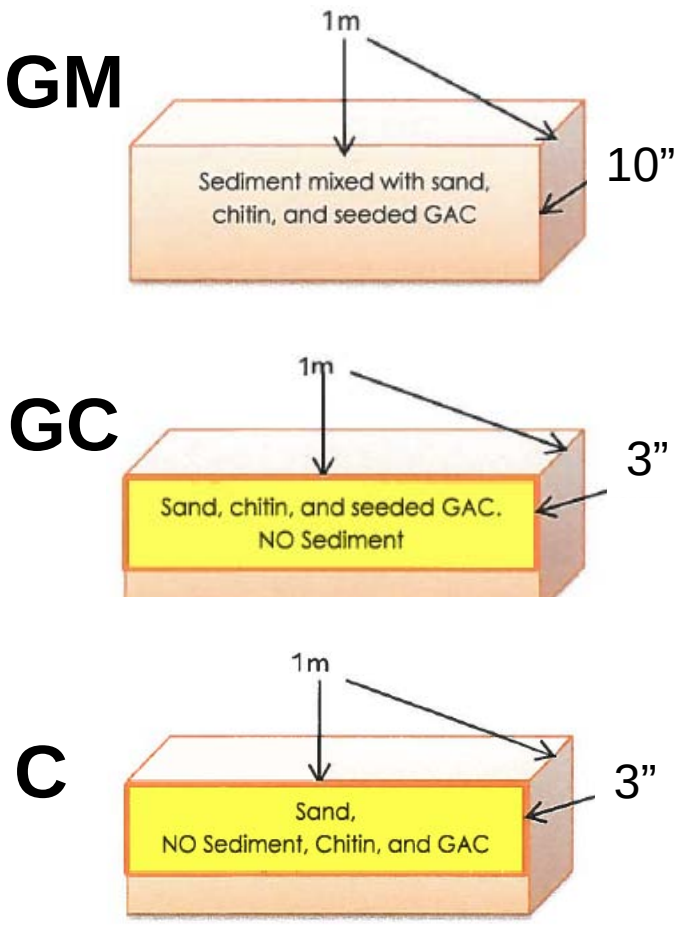
Generally, less VOCs remaining in the columns that contained both the WBC-2 and 15B cultures

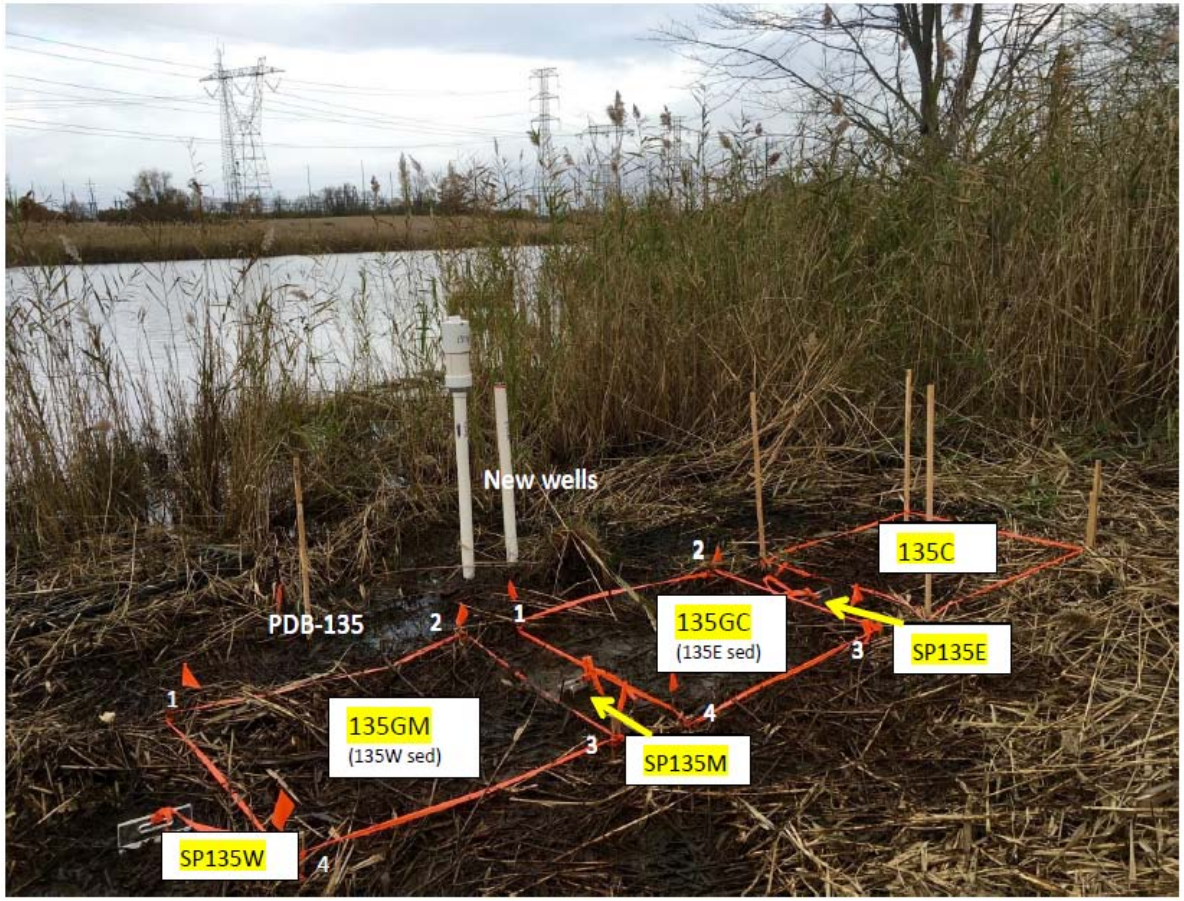





USGS
science for a changing world
.....lab testing ongoing but also
started small-scale field pilot tests

Barrier Reactive Pilot Test Plots





TOTAL	Sand	Chitin	GAC
pounds	783	30	43

Site 135 test area with 3 plots and pre-installation sampling.

40 L of each culture

15B aerobes grown in lab in 5 days

WBC-2 in anaerobic cylinder from Sirem Lab
(20L mixed with DI-H20 for GAC seeding)

Buckets of pre-measured sand-chitin-seeded GAC dumped in plot and mixed into sediment to depth of 10 inches with small auger or “egg-beater” attachments on drill.

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Site characterization

Feasibility evaluation

Technology development

Pilot test remediation

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Dr. Michelle Lorah

Jessica Teunis

Mastin Mount

Michael Brayton

Dr. Charles Walker

Roberto Cruz

Emily Majcher

Anna Baker

Luke Myers

NRP Collaborators:

Dr. Isabelle Cozzarelli

Dr. Denise Akob

Johns Hopkins University

Dr. Ed Bouwer

Steven Chow, PhD student

Geosyntec Consultants

Dr. Neal Durant

Dr. Amar Wadhawan