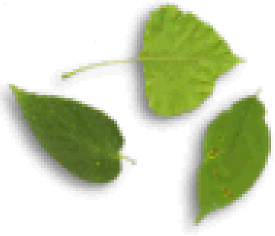
Phytoremediation of Persistent Organic Pollutants



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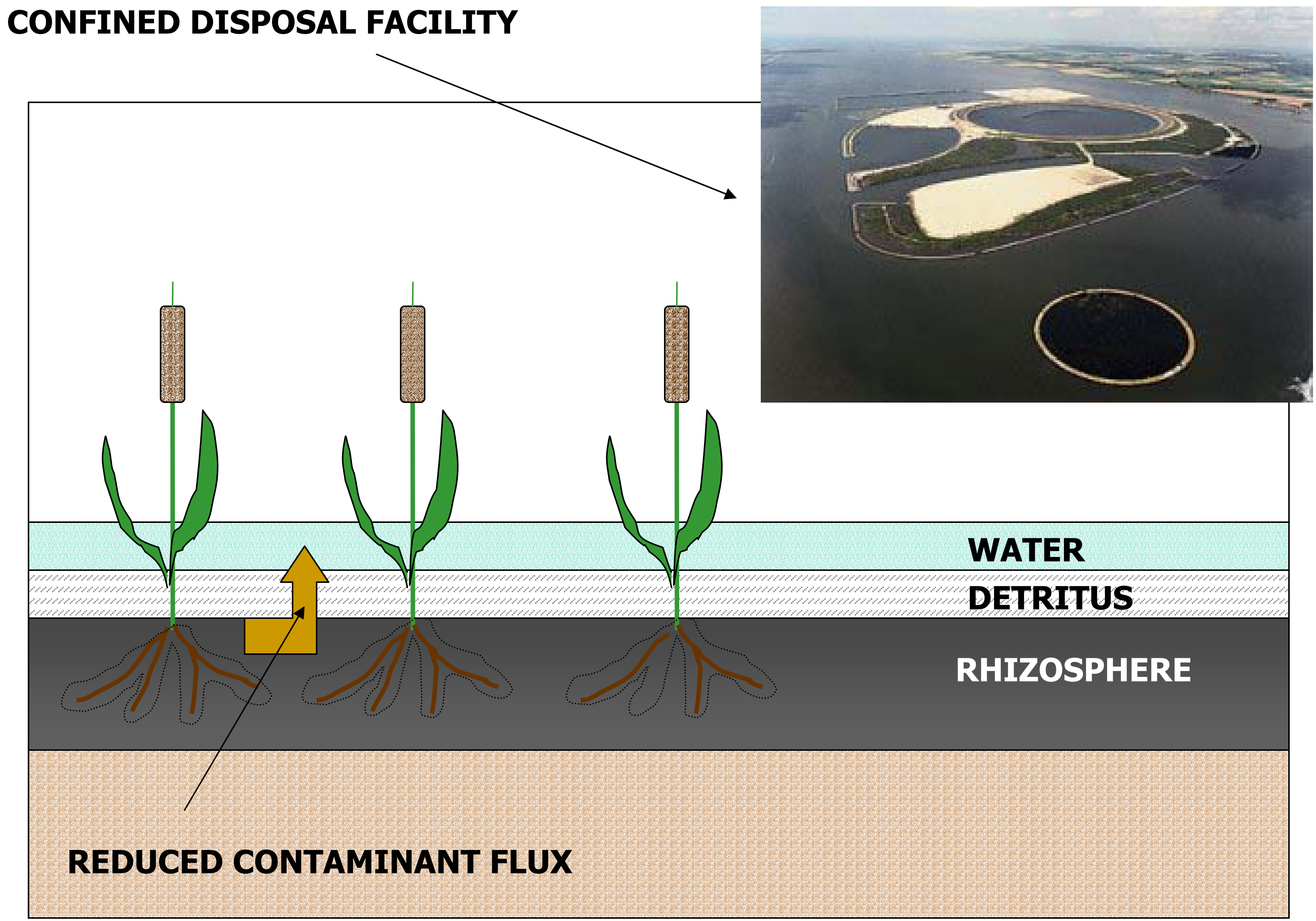
Louisiana State University

Outline

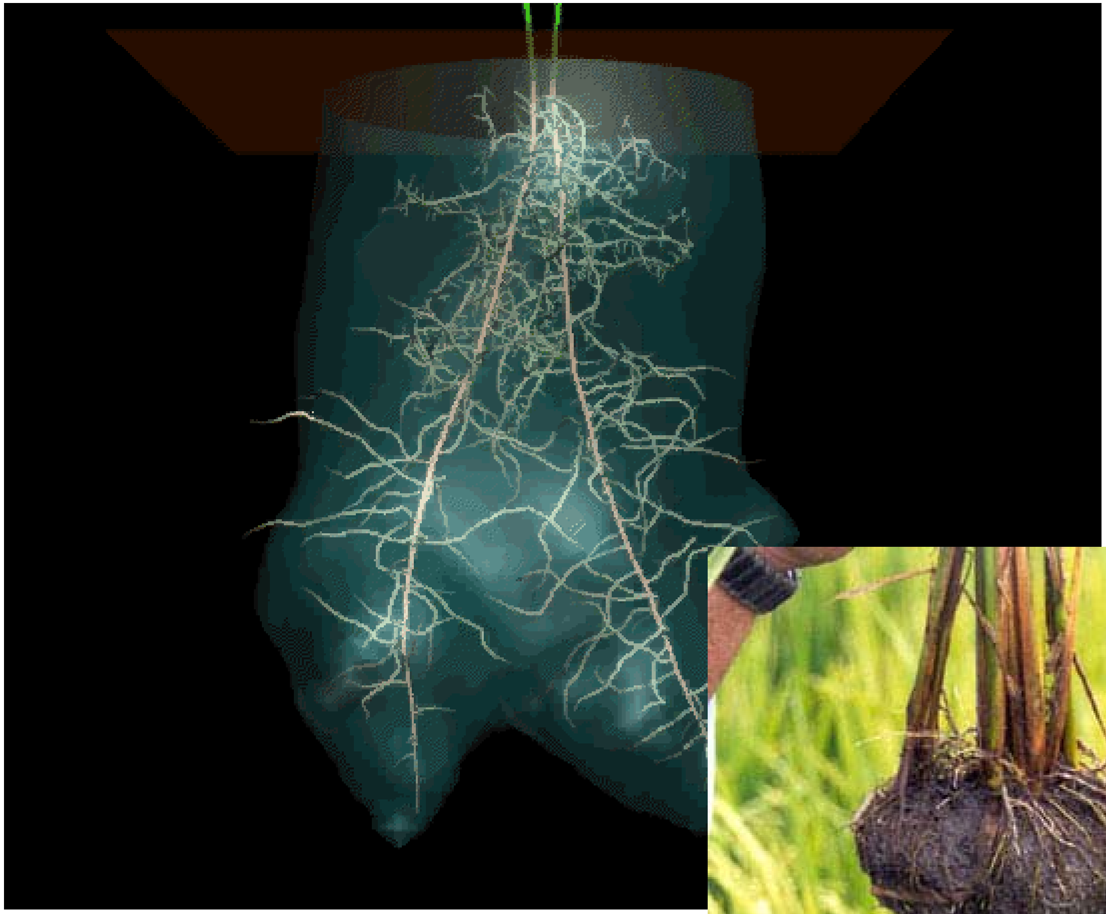
- Technology description
  - Laboratory and greenhouse evidence for mechanism
- Applications of technology
  - Pilot and proposed full-scale systems
- Observations
- Future Directions

Technology Description

- Rapid contaminant attenuation for certain chlorinated organics is observed in *vegetated* sediments (i.e., wetlands). In these sediments, enhanced biological processes (aerobic and anaerobic biodegradation and plant uptake) have been observed in the root zone that drives rapid natural recovery.
- By vegetating sediments contaminated with chlorinated compounds, root matter and exudates will serve as a source of hydrogen for halorespiring organisms that can biodegrade the target compounds.



CONFINED DISPOSAL FACILITY
WATER
DETRITUS
RHIZOSPHERE
REDUCED CONTAMINANT FLUX




Proposed mechanisms

- Reductive dechlorination is enhanced in vegetated sediments because the root surface serves as a location of enhanced activities of dehalorespiring and other degrading microbial populations
- By vegetating sediment contaminated with chlorinated organic compounds, belowground root matter will serve as source of H_2, overcoming redox potential limitations in sediments.

I

Rapid dechlorination observed in rhizosphere

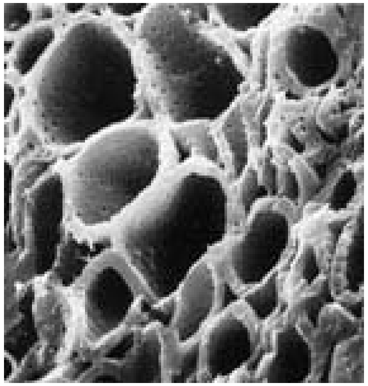
II

Root matter stimulates dechlorination rate

III

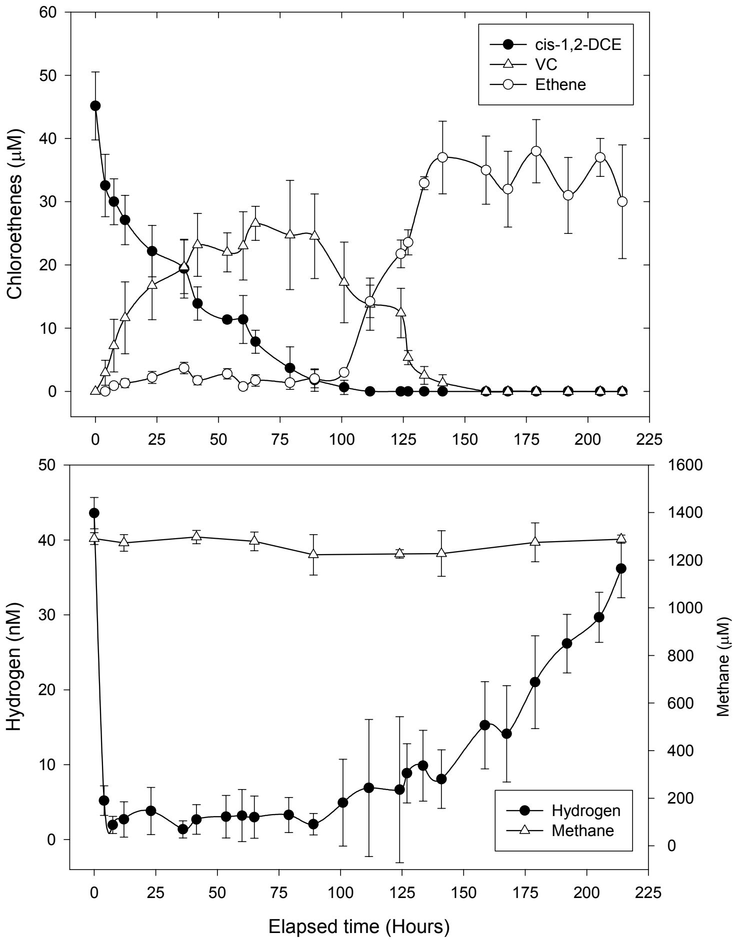
Halorespiring organisms identified

IV



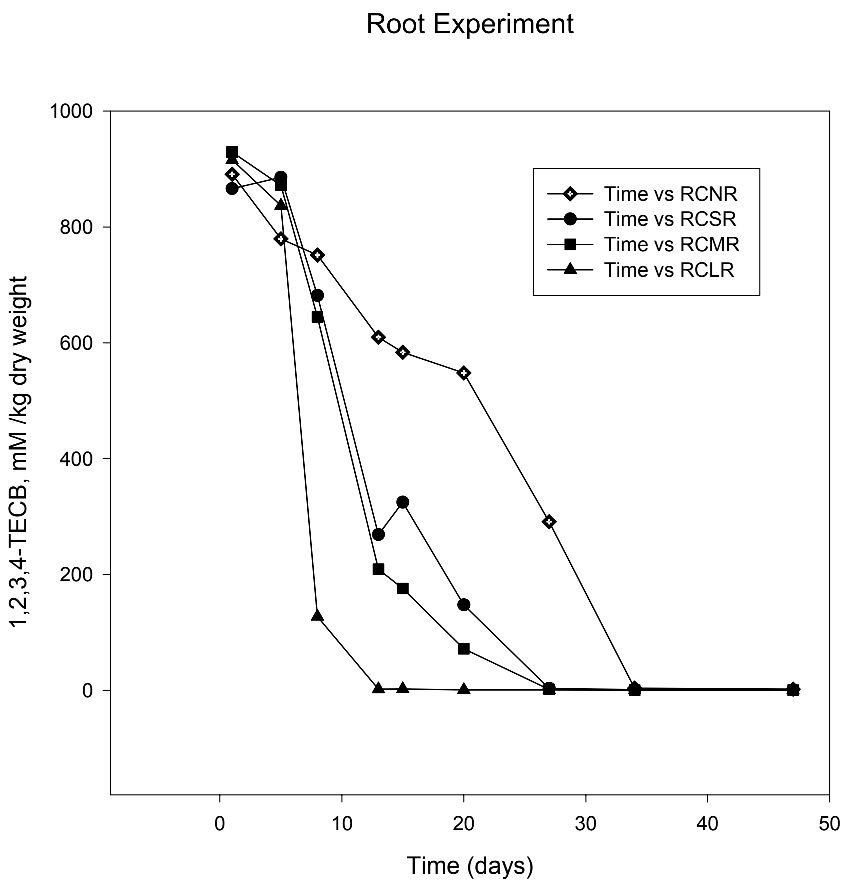
Root sorption is key mechanism for desorption-resistant, weathered compounds

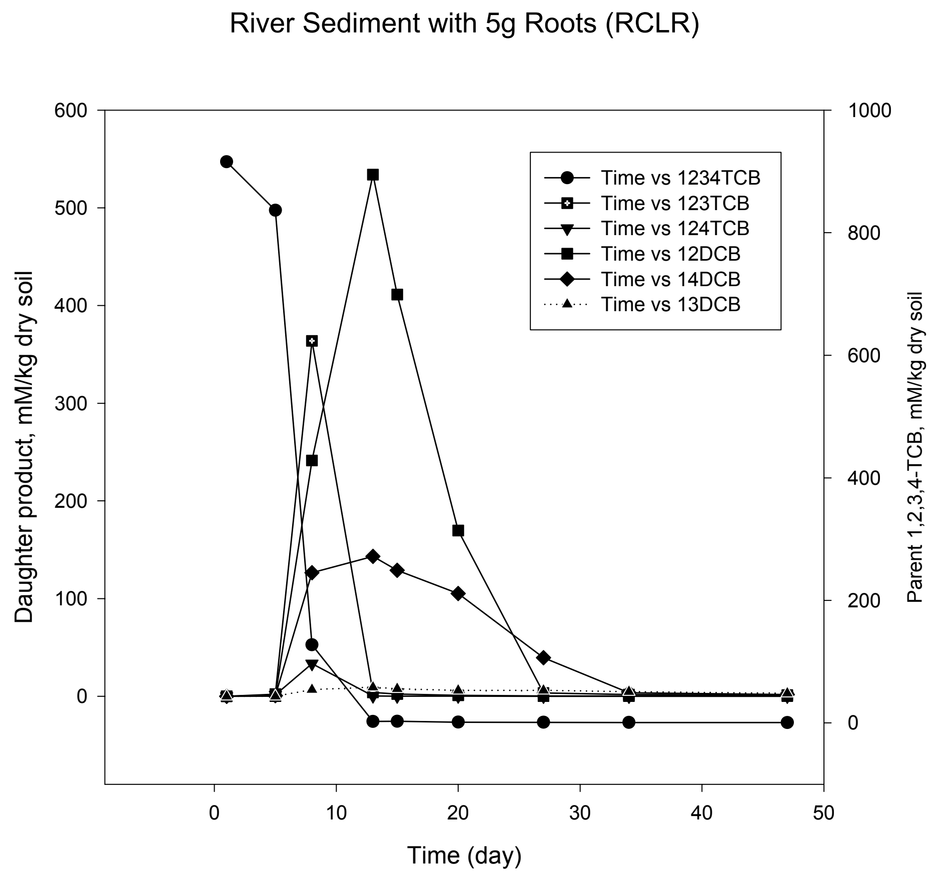
I



Rapid dechlorination of chlorinated solvents observed in rhizosphere

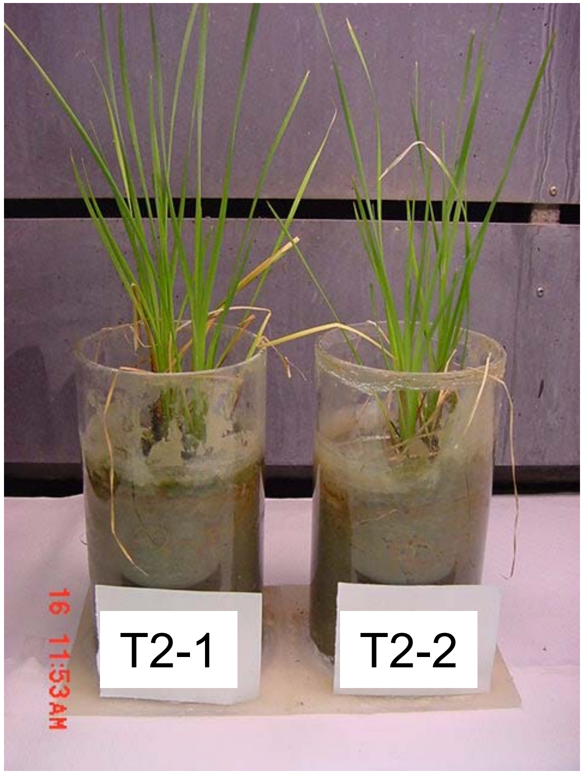
II. Root matter stimulates dechlorination rate

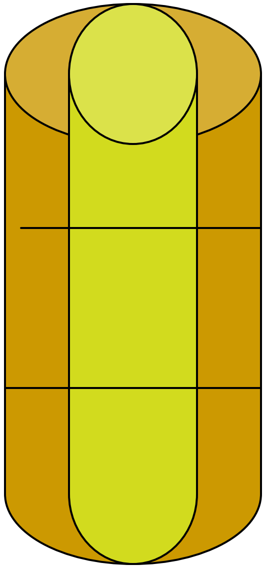





TC-1 10/5
PC-1 10/5
7 5:08PM

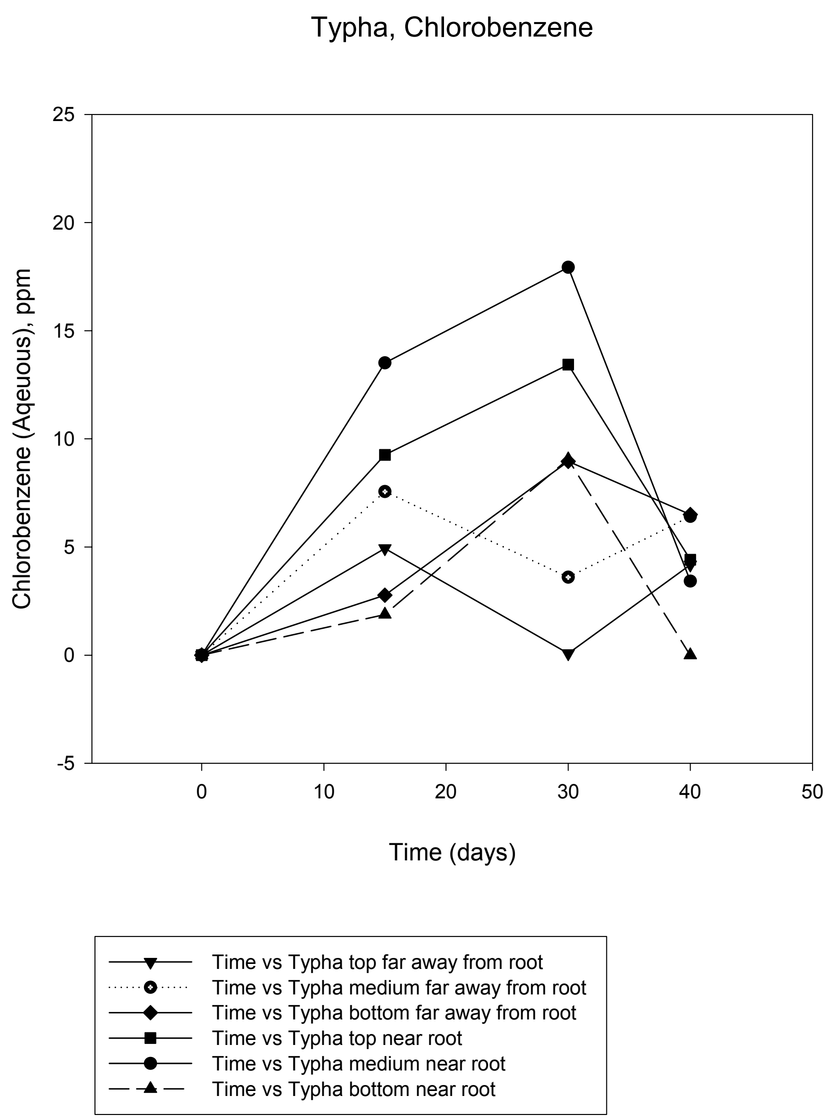
II



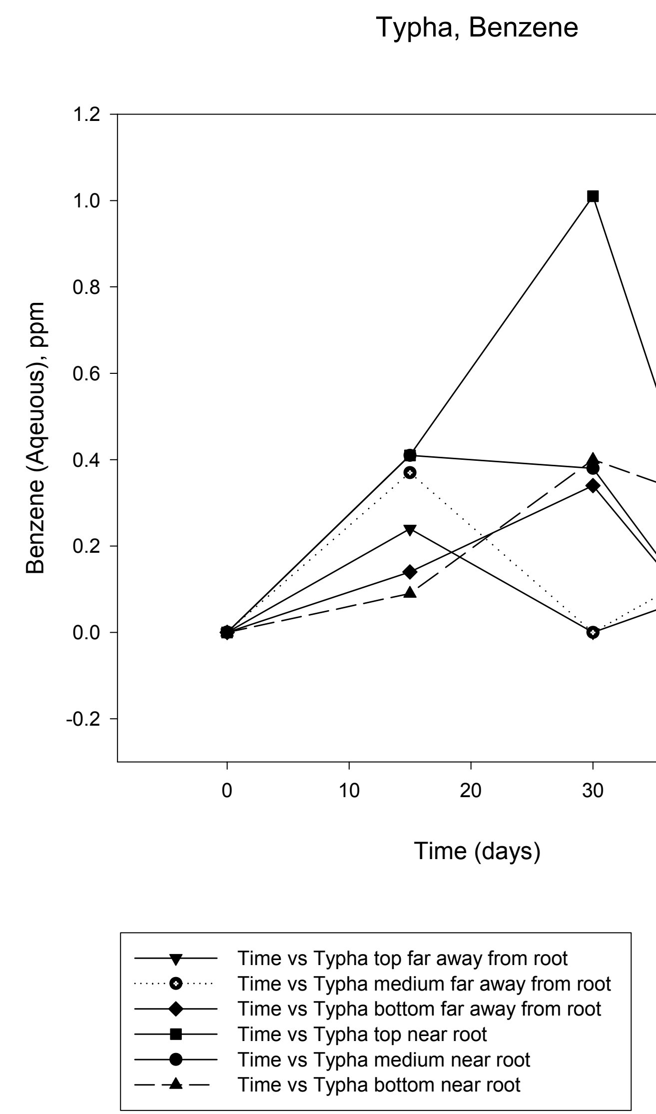


Core dissection approach

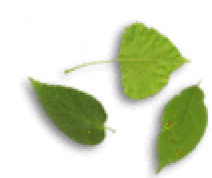
II



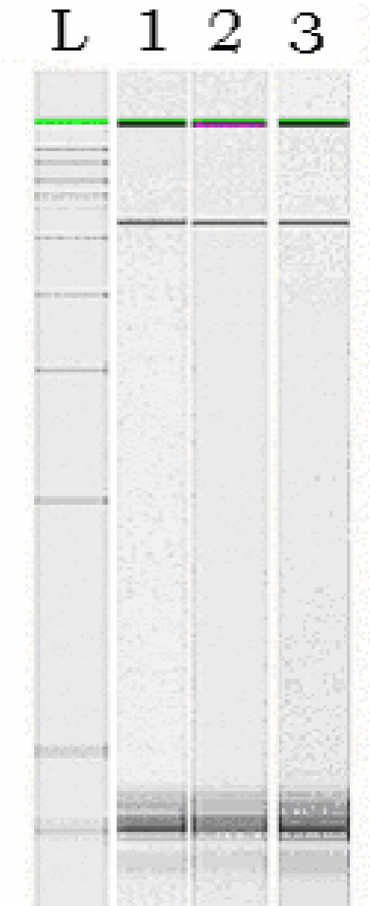
Typha, Chlorobenzene
Chlorobenzene (Aqeuous), ppm
25
20
15
10
5
0
-5
0
10
20
30
40
50
Time (days)
Time vs Typha top far away from root
Time vs Typha medium far away from root
Time vs Typha bottom far away from root
Time vs Typha top near root
Time vs Typha medium near root
Time vs Typha bottom near root



Typha, Benzene
Benzene (Aqeuous), ppm
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
0
10
20
30
40
50
Time (days)
Time vs Typha top far away from root
Time vs Typha medium far away from root
Time vs Typha bottom far away from root
Time vs Typha top near root
Time vs Typha medium near root
Time vs Typha bottom near root

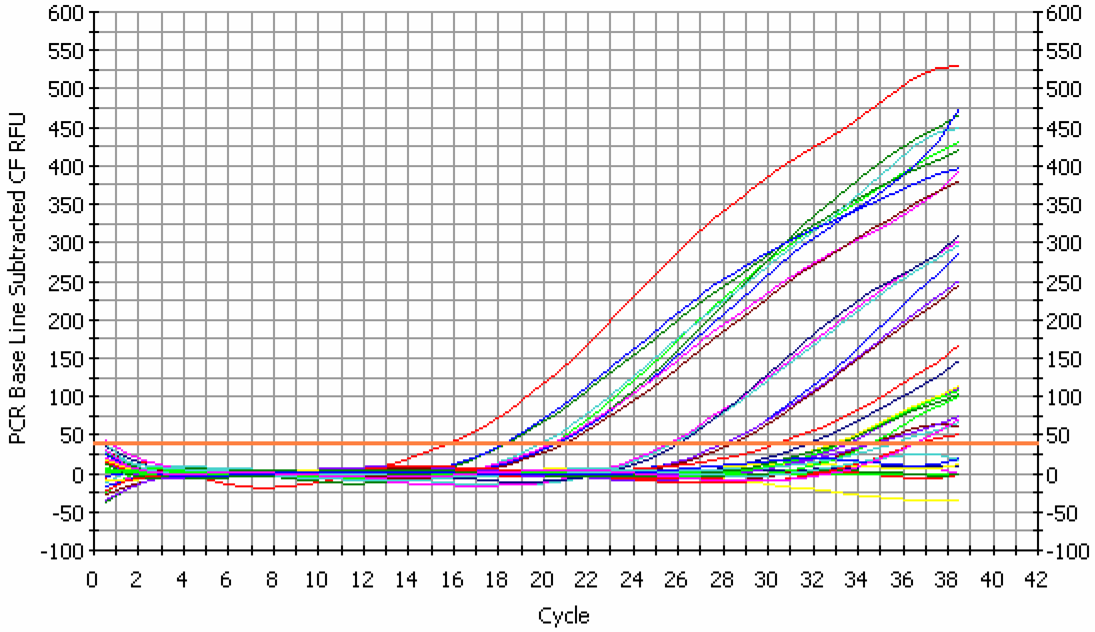


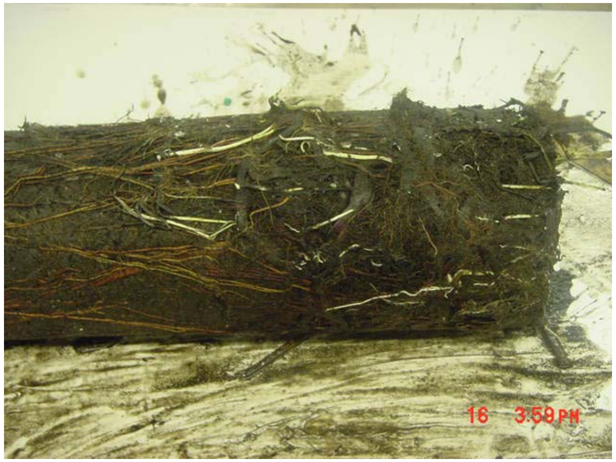
III. Halorespiring organisms identified



Detection of *Dehalococcoides* 16S rDNA sequences in constructed wetland mesocosms. Lane L – Ladder; Lane 1 – microcosm derived from bottom section of constructed wetland; Lane 2 –microcosm derived from middle section of constructed wetland; Lane 3 –microcosm derived from top section of constructed wetland.

Example results for Archae RT probes

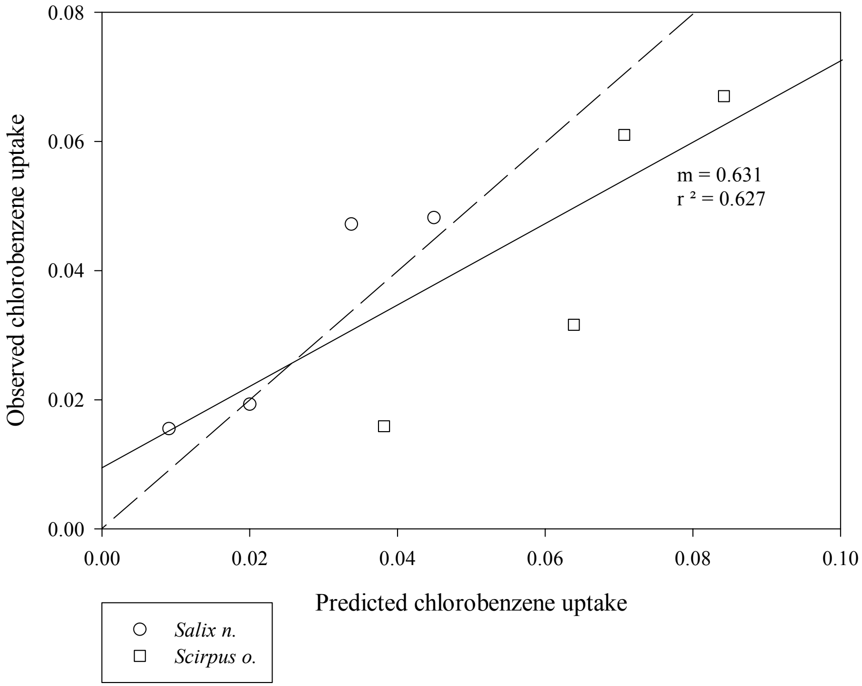




Depth	†C_T
Soil 12-15”	34.5
Soil 15-18”	31.7
Soil 18-21”	33.4
Root 12-15”	ND
Root 15-18”	ND
Root 18-21”	36.5

†1:100 dilutions of DNA extracts

IV

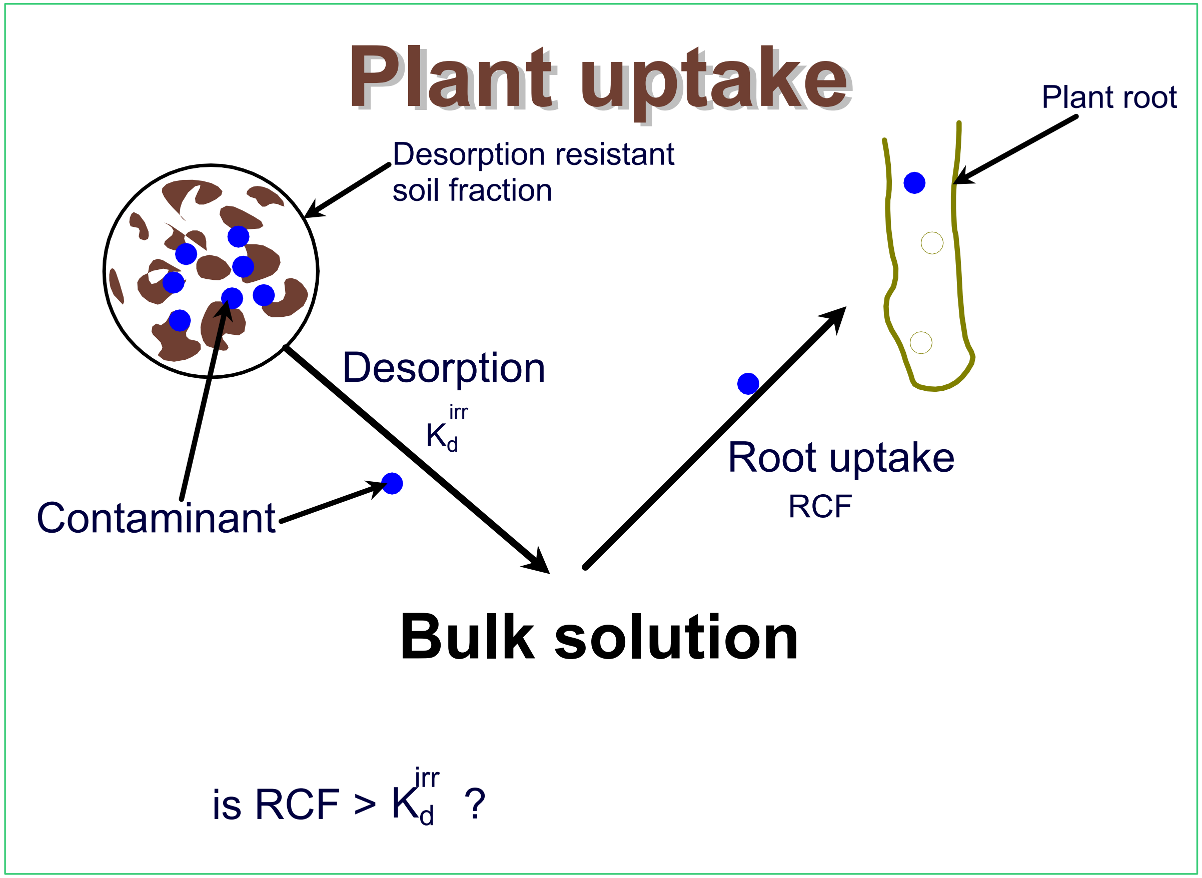


$$Plant\ uptake_{t1-t2} = TSCF \cdot Trans_{(t1-t2)} \cdot ((\frac{q_1^{res} \cdot q_{\max}^{res} \cdot f}{K_{oc}^{res} \cdot OC \cdot q_{\max}^{res} \cdot f - q_1^{res} \cdot K_{oc}^{res} \cdot OC} + \frac{q_2^{res} \cdot q_{\max}^{res} \cdot f}{K_{oc}^{res} \cdot OC \cdot q_{\max}^{res} \cdot f - q_2^{res} \cdot K_{oc}^{res} \cdot OC}) / 2) +$$

$$\left[r_m \cdot K_r \cdot \left(\frac{q_2^{res} \cdot q_{\max}^{res} \cdot f}{K_{OC}^{res} \cdot OC \cdot q_{\max}^{res} \cdot f - q^{res} \cdot K_{OC}^{res} \cdot OC} \right) \right]$$

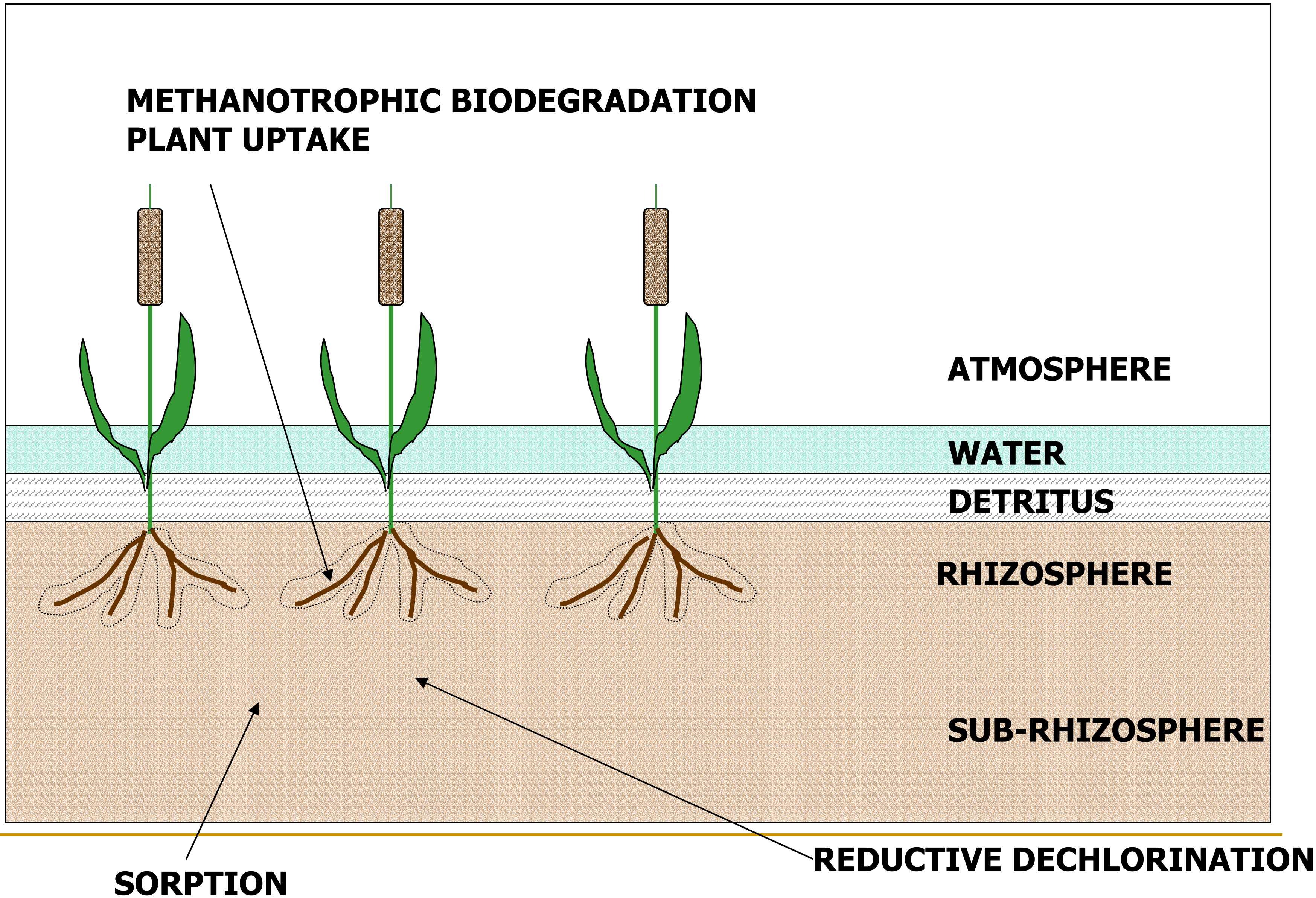
Root sorption the major uptake mechanism for wetland plant uptake of desorption-resistant chlorobenzene

Repartitioning of desorption-resistant organics to the root surface, predictable from simple equilibrium relationships



Application: Treatment Wetland Concept for VOCs

- A constructed wetland to treat both chlorinated and non-chlorinated VOCs maximizing biodegradation, minimizing volatilization while operating year-round
- Wetland is constructed as an alternative discharge point for the groundwater plume within the site boundary either passively intercepting the plume or serving as a component of a pump and treat system


METHANOTROPHIC BIODEGRADATION
PLANT UPTAKE
ATMOSPHERE
WATER
DETRITUS
RHIZOSPHERE
SUB-RHIZOSPHERE
REDUCTIVE DECHLORINATION
SORPTION

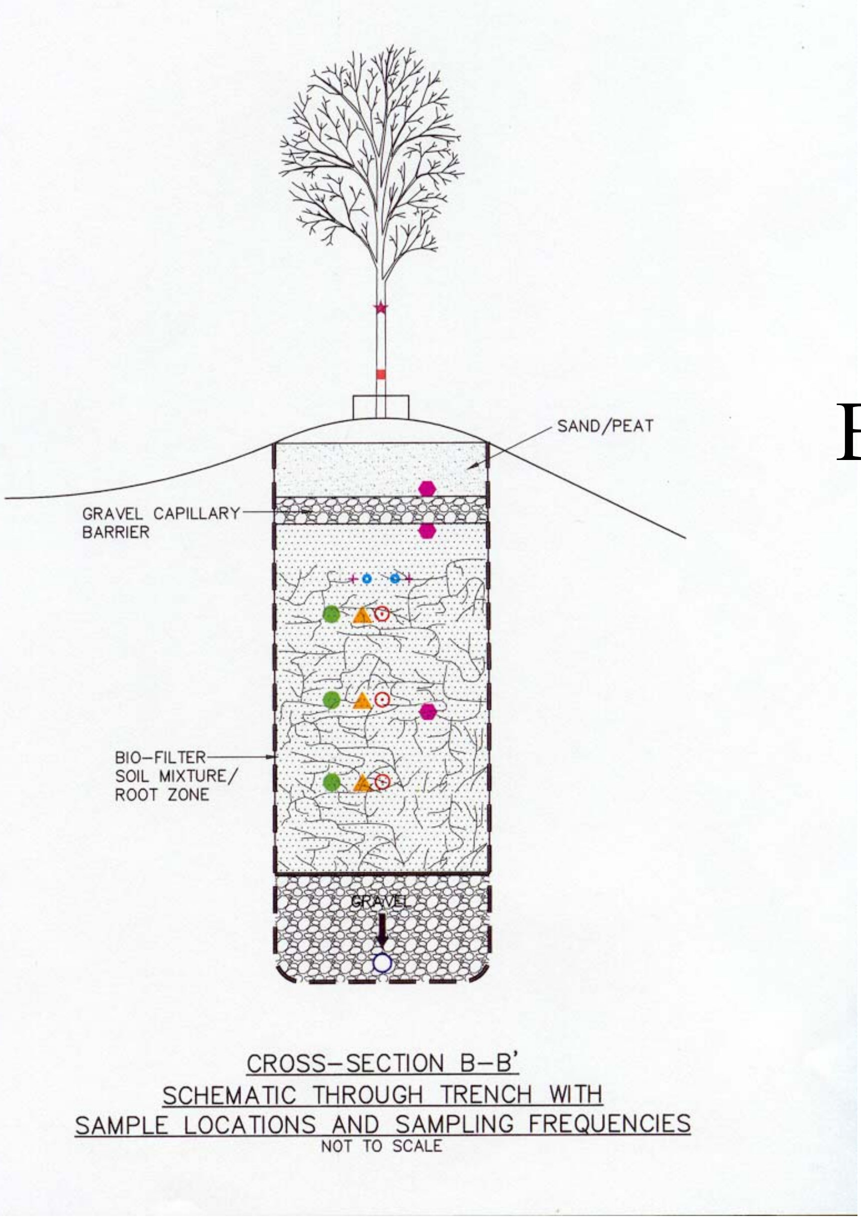
Example sites where wetland systems proposed or piloted

- RESOLVE (CERCLA), North Dartmouth, MA
- SRSNE (CERCLA), Southington, CT
- Aberdeen Proving Ground (CERCLA), Edgewood, Md (3 sites)
- Landfill site in central North Carolina
- Industrial facility in Louisiana (RCRA)

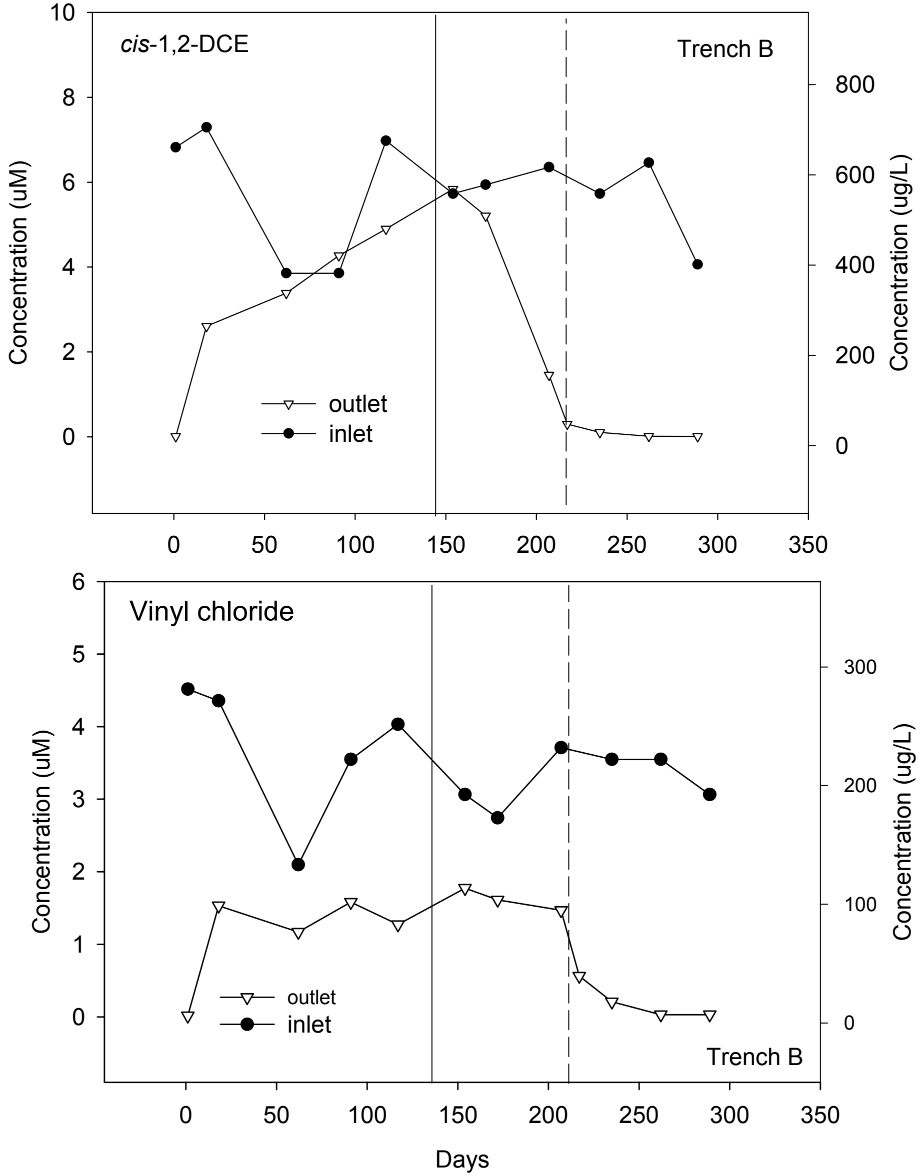
ReSolve CERCLA site

- Chemical recycling and process facility in North Dartmouth, MA
  - NPL listed in 1983
- PCBs, and chlorinated solvents including TCE, methylene chloride, toluene and others (DNAPL)
  - Two-tiered groundwater pumping, containment and treatment system in place since 1998
- Motivation-reduce annual O&M costs on mechanical system

Resolve CERCLA site—North Dartmouth, MA



BFP Cross-section

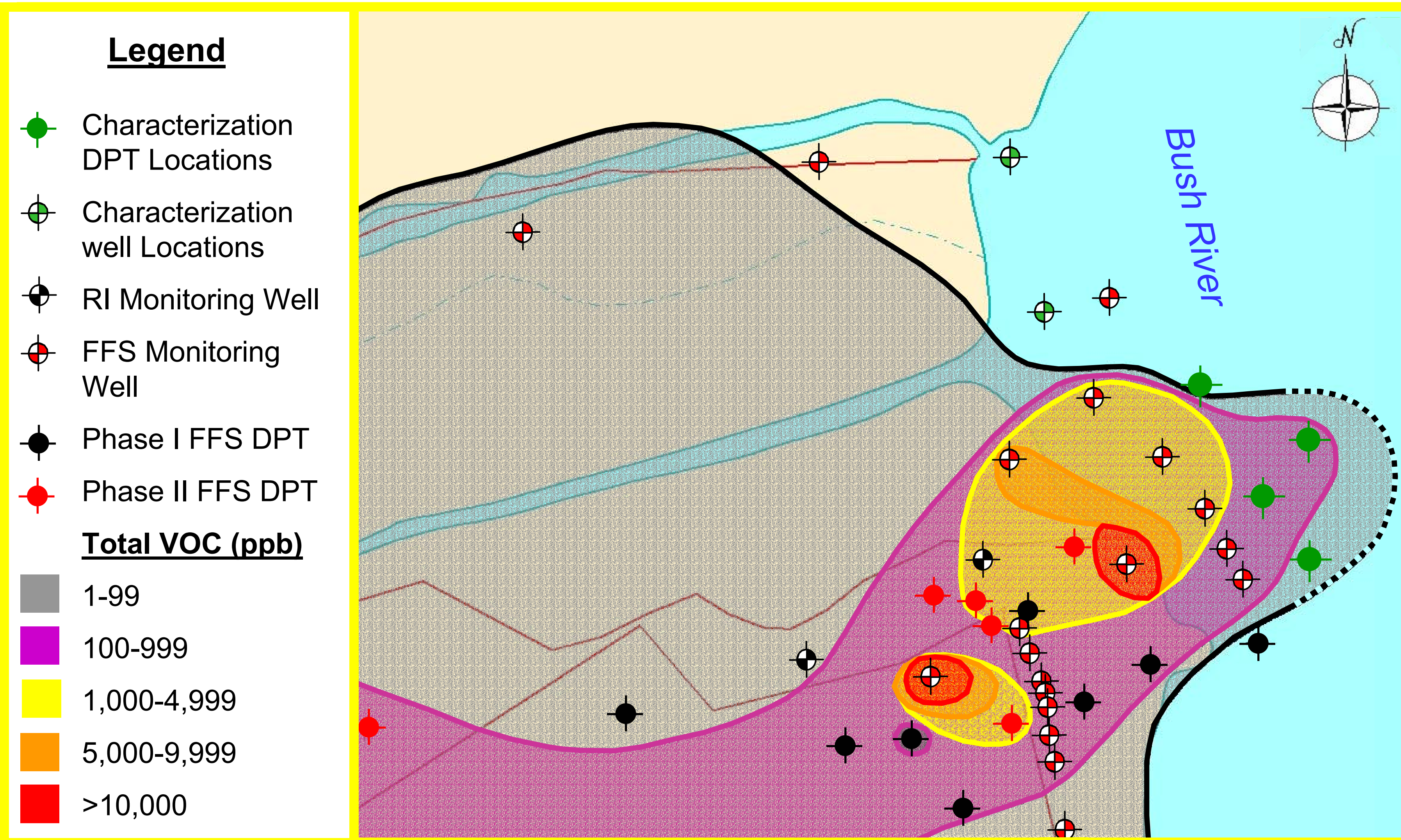


Trench B inlet/outlet results

Solid line indicates the time when the water levels were raised in the system.
Dashed line indicates time of microbial inoculation.

22nd Street Landfill

Offshore Groundwater VOC Plume



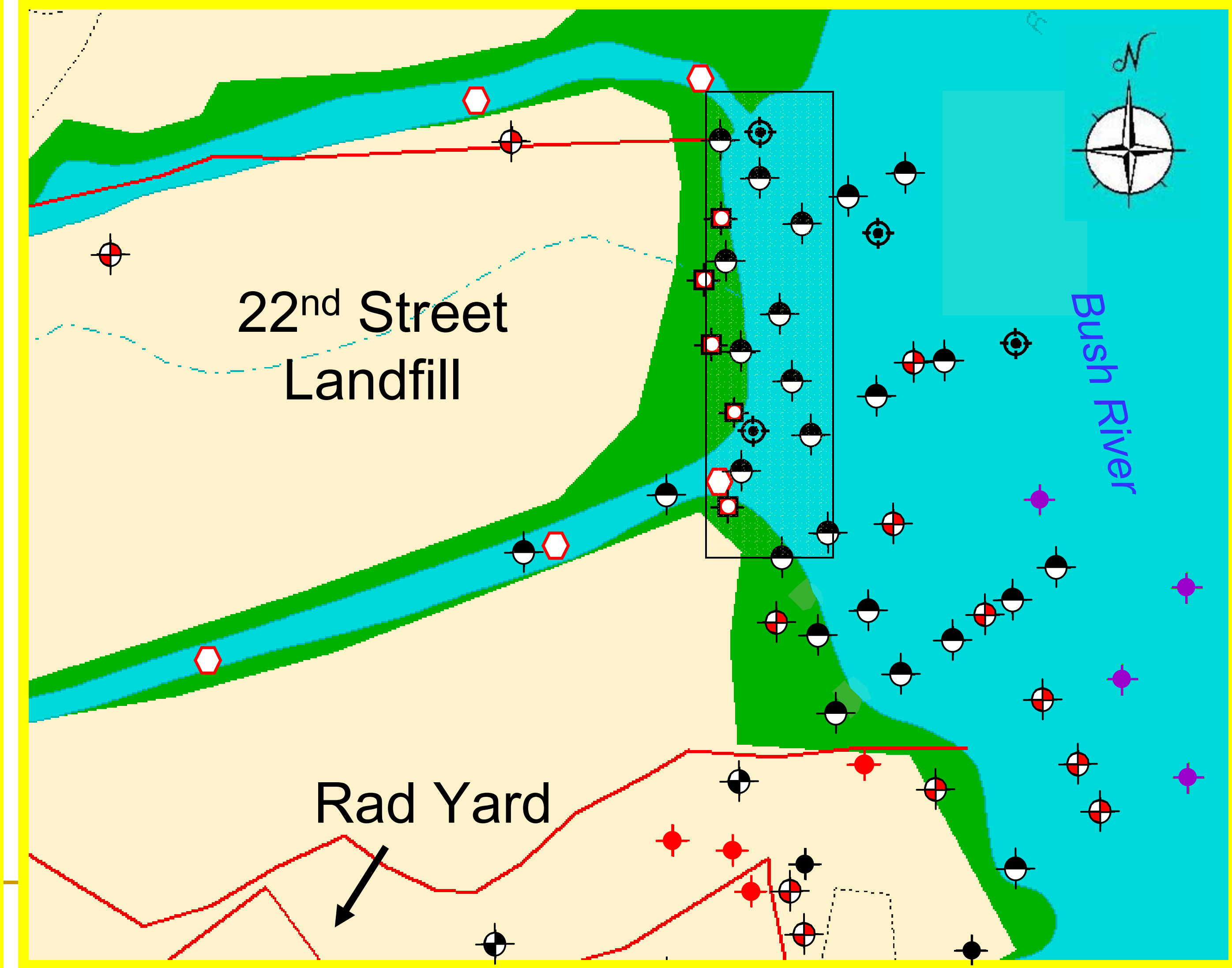
Remedial options for 22nd Street Landfill

- Passive barrier treatment an option for multiple sources (several plumes, landfill leachate, shoreline erosion of landfill)
- Treatment wetland one type of passive barrier built similar to existing natural marshes in other areas of the site. Wetland is constructed as an alternative discharge point for the groundwater plumes within the site boundary, to intercept landfill leachate and prevent erosion

22nd Street Landfill Characterization Sampling Locations

Legend

- Dialysis Sampler Locations
- Pore Water Leachate Sample
- Geotechnical Boring
- DPT Locations
- Surface Water Samples
- RI Monitoring Well
- FFS Monitoring Well
- Phase I FFS DPT
- Phase II FFS DPT



Field Observations

- Halorespiring populations can be maintained in the plant rhizosphere when appropriate redox conditions are maintained. This has resulted in very efficient removal of chlorinated solvents in groundwater over short travel distances
- To date, vegetation type is a consideration only in that high root biomass is desired.
- Temperature is important consideration as well as a ensuring that there is a source of halorespiring microorganisms
- Strong regulatory acceptance of technology to date

Applications to dioxin/furans/PCBs

- Halorespiring microorganisms important for dechlorination of dioxins (*Ballerstedt et al., 2004; Bunge et al., 2003*); PCBs (*Wu et al., 2002*) and chlorobenzenes (*Jayachandra et al., 2003; Holscher et al., 2003*).
- Floodplain sediments amenable to wetland creation with vegetation (up to a meter of water depth). Deeper river sediments would require CDFs.
- A significant body of knowledge on wetland creation and restoration. This expertise can be exploited to assist in application of a plant-based remediation concept for sediments.

Future needs

- Pilot/greenhouse studies are needed to apply plant-based remedial approaches to specific dioxin/PCB/furan contaminated sediments
- Bioavailability issues: Can we screen for good and bad candidate sediments by evaluating relative roles of organic carbon, soot and oil/grease as sorptive phases?
- Microbial community structure analysis: need to screen sediments for “starting” halorespiring populations

Questions?