Reach Symposium 2010

Remediation of Pollution in Natural Systems

Saumyen Guha
Department of Civil Engineering
IIT Kanpur

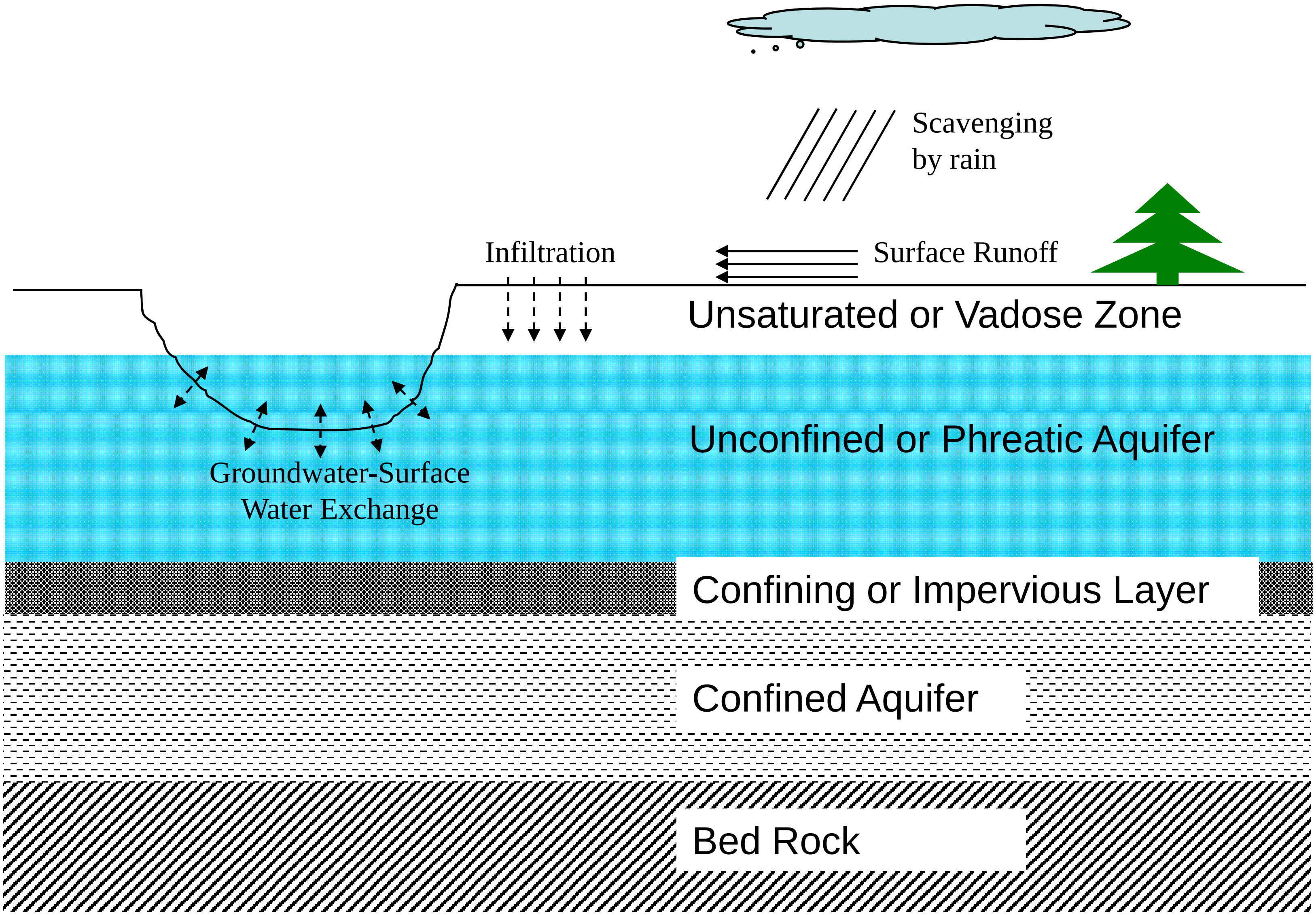
Outline

- Natural Systems
- Pollution in the Natural Systems
- Some Example Problems
- Overview of ongoing research at IIT Kanpur on Natural System Pollution

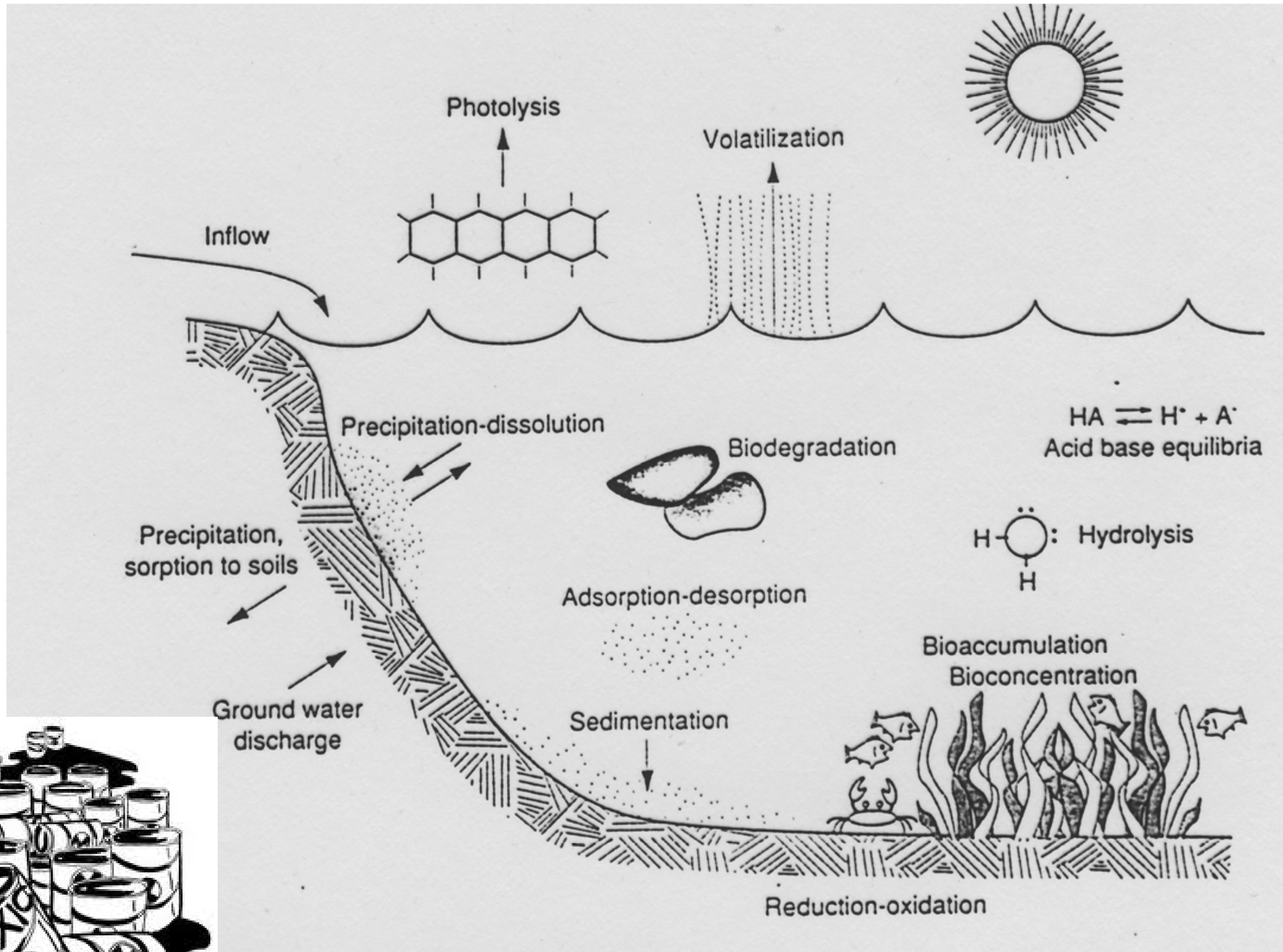
Natural Systems: Water, Air, Soil

- Atmosphere: Troposphere
- Terrestrial Water Bodies (Fresh Water): Rivers, Lakes, Ponds
- Soil and Groundwater
- Transition Water Bodies: Estuary, Wetlands, Lake connected to sea
- Sea and Ocean (Saline)

Natural Systems Interaction

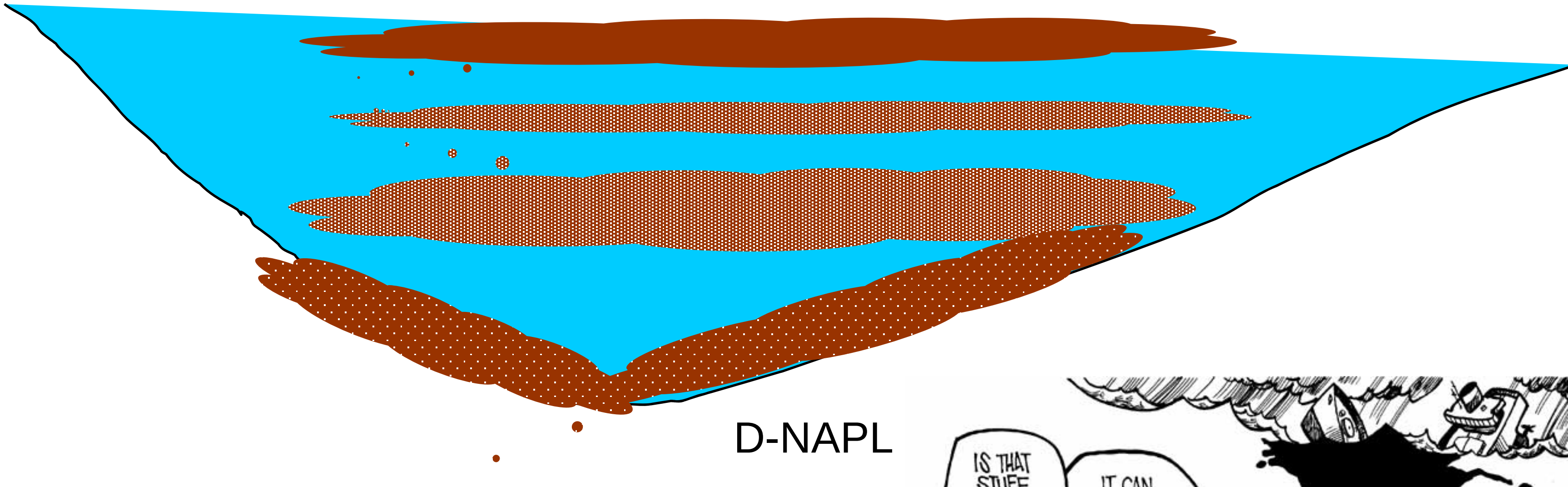


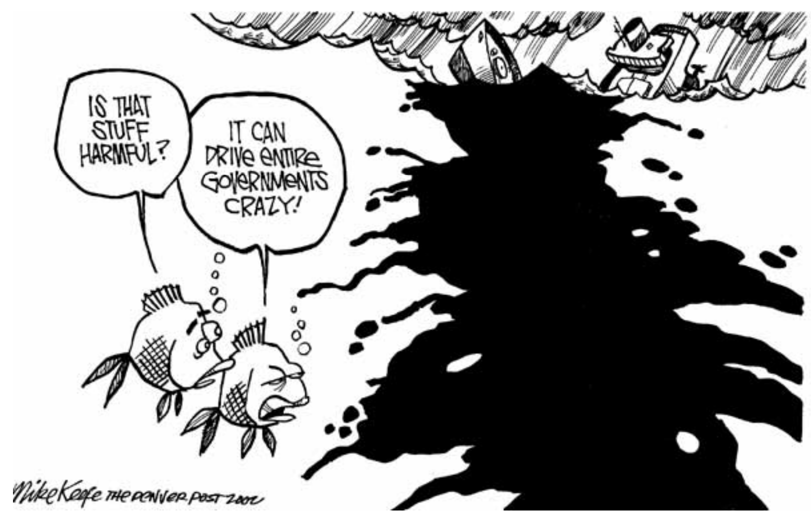
Natural Attenuation Processes



We will NOT address the municipal waste and fecal pathogenic contamination.

Oil Spill

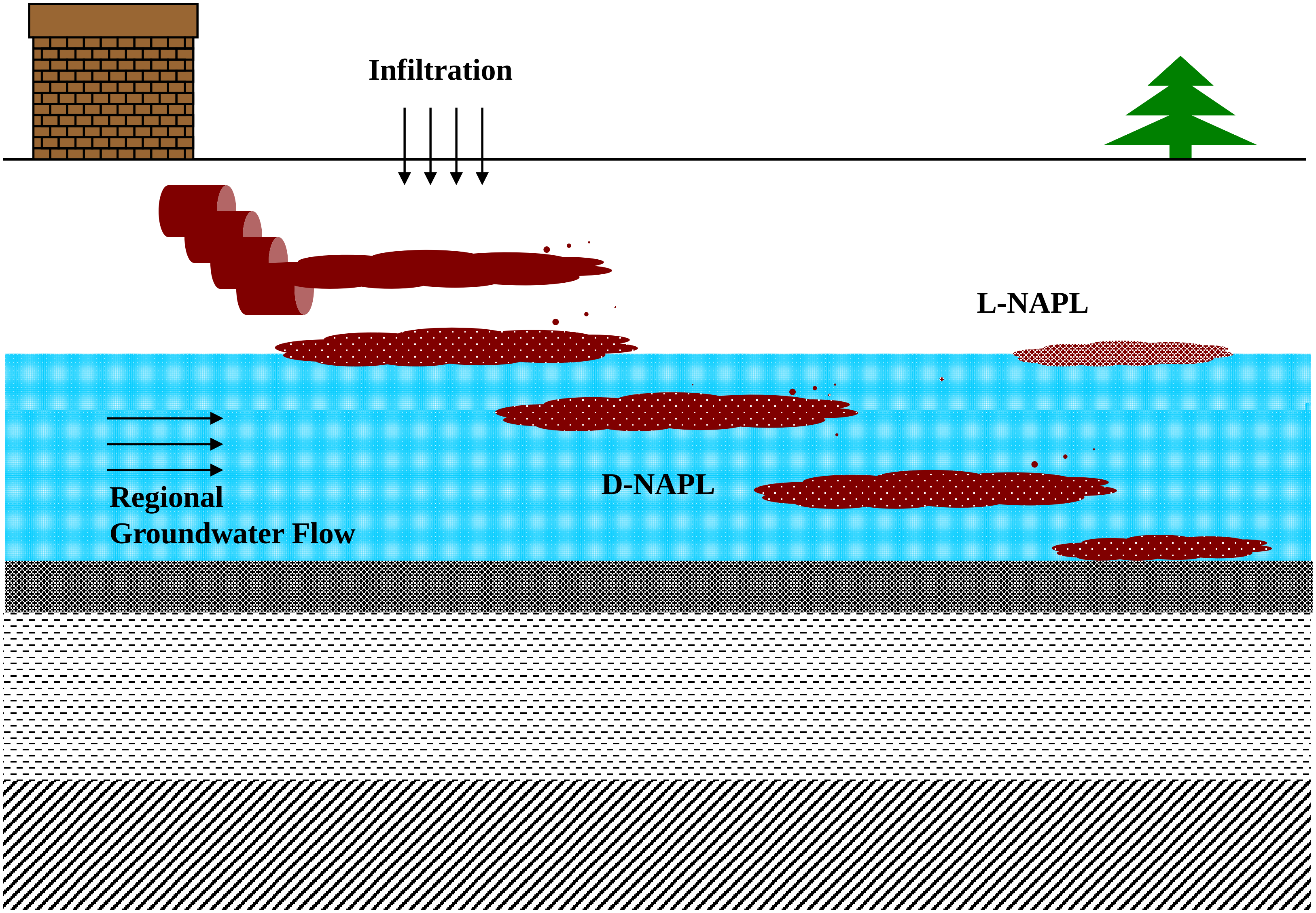




NAPL: Non-Aqueous Phase Liquid

L: Light   D: Dense

Pollution in the Subsurface



Arsenic Problem in the Ganges Delta

[Guha et al. (2005), Env. Eng. Sci., V. 22, 870-881; Acharyya et al. (1999), Nature, V. 401, 545; Nickson et al. (1998), Nature, V. 395, 338]

- **Arsenic is present in the Quatenary sediments**
- **Arsenic was precipitated in the aerobic environment**
- **Present on the soil as inner-sphere complex in the amorphous iron oxy-hydroxide**
- **Why is it coming in the water in the last 20-30 years ?**

Other Examples

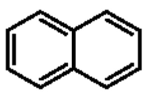
- Uncontrolled Pesticide Application
- Mining
- Byproduct of intervention strategies

  e.g., THM

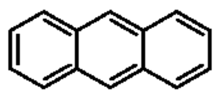
Compounds or elements are carcinogenic and/or teratogenic and/or endocrine disruptors at very low concentrations.

Biodegradability

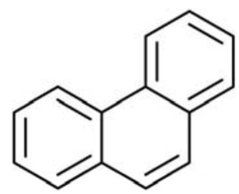
Eventual Disappearance from Nature is through Biodegradation. Can we predict their persistence ?



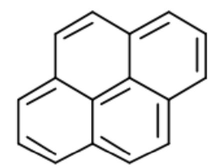
Napthalene



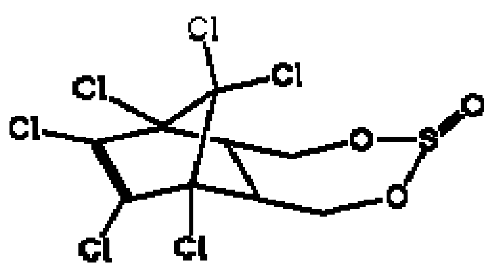
Anthracene



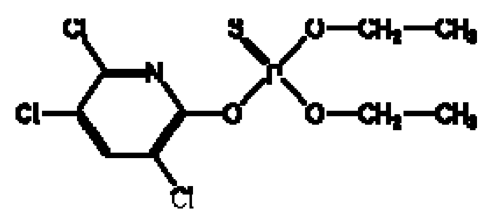
Phenanthrene



Pyrene

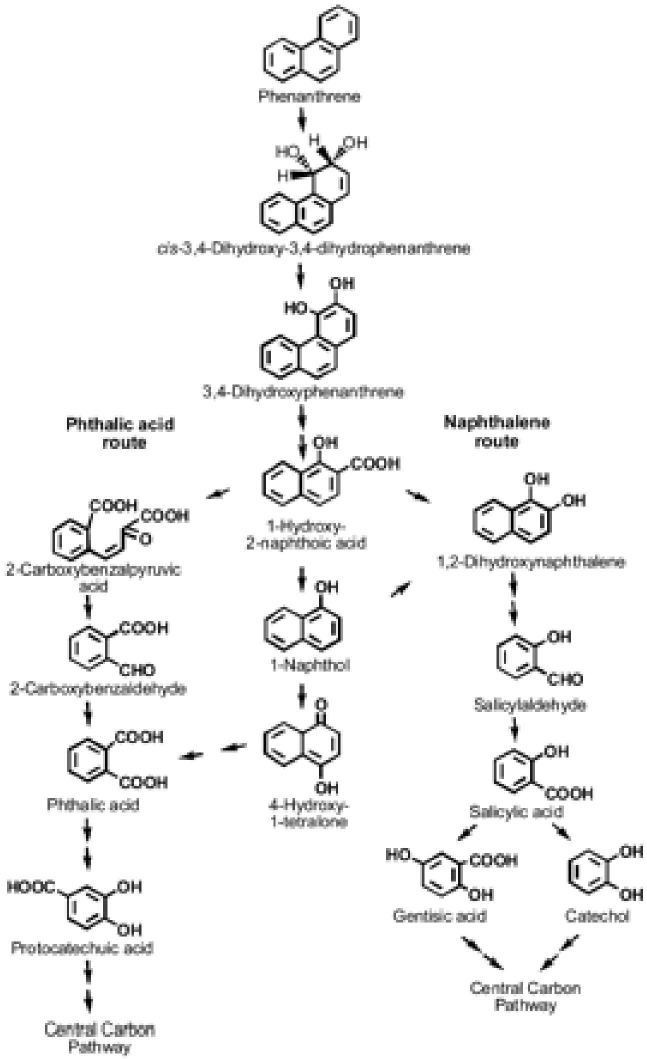


Endosulfan

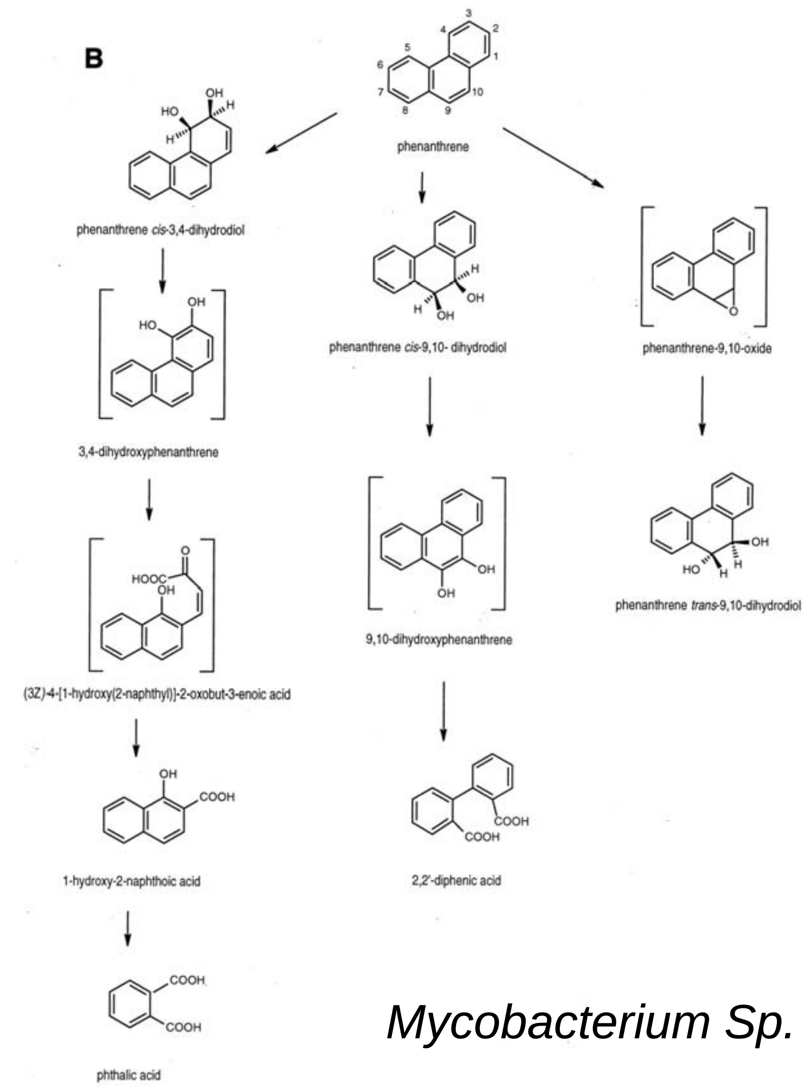


Chlorpyrifos

Pathways: Microbial Ecology



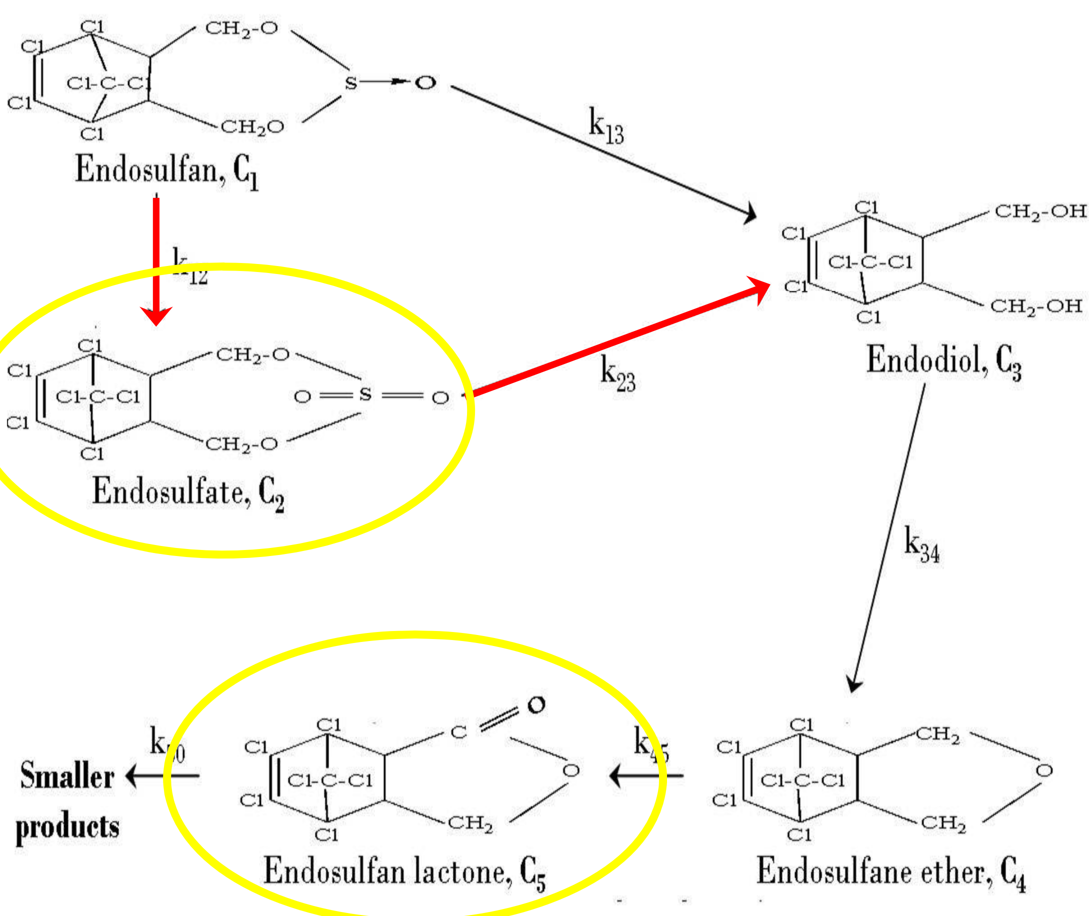
Pseudomonas Sp.-Napthalene pathway, Alcaligenes, Bacillus, Aeromonas and Micrococcus Sp.-Phthalic Acid pathway



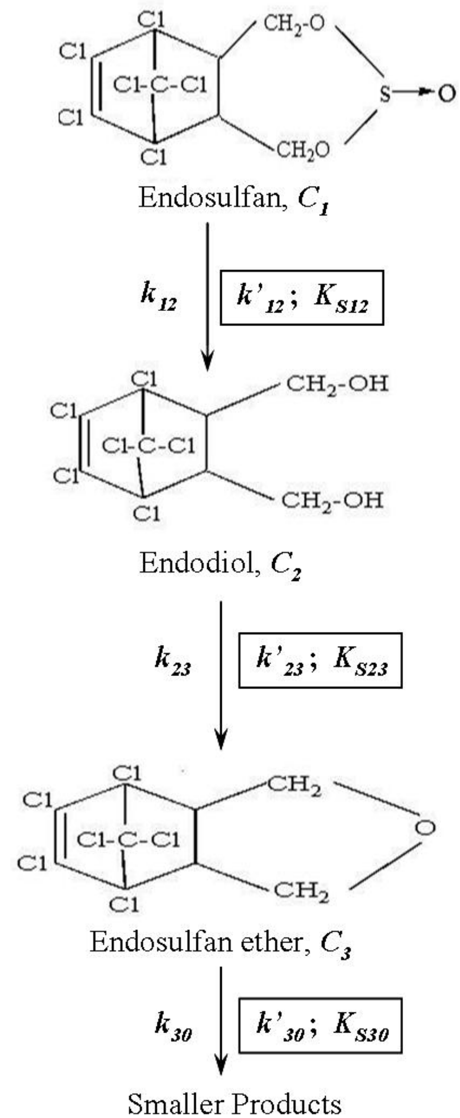
Mycobacterium Sp.

Pathways: Redox Condition

Tiwari and Guha (2010)



Aerobic Environment



Anaerobic Environment

Biodegradation

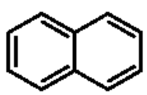
- Determination of rate or kinetics
- Elucidation of pathways
- Pathways and Kinetics in different Redox Conditions

[Guha and Jaffe 1996; Tiwari and Guha 2010]

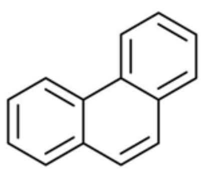
Can we translate the laboratory results for prediction in nature ?

Biodegradation of Mixtures

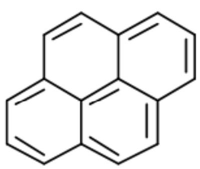
How do they interact during biodegradation ? Do they compete ? Do they inhibit ? Are some of them toxic to the bacteria ?



Napthalene



Phenanthrene



Pyrene

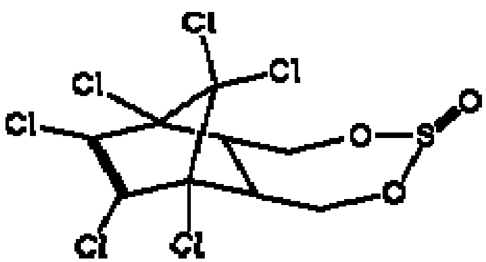
$$\mu = \frac{\mu_{max} C}{K_S + C}$$

$$\mu_i = \frac{\mu_{max,i} C_i}{K_{S,i} + \sum_{j=1}^{N} \frac{K_{S,i}}{K_{S,j}} C_j} \qquad i = 1, 2, \cdots N$$

$$\text{Total Biomass Growth Rate } \mu_T = \sum_{i=1}^{N} \mu_i$$

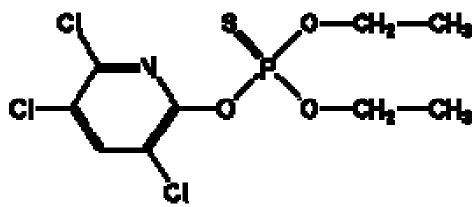
[Guha et al. (1999), Biotech. Bioeng., V. 65, 491-499]

Biodegradation of Mixtures



Endosulfan

Chlorpyrifos

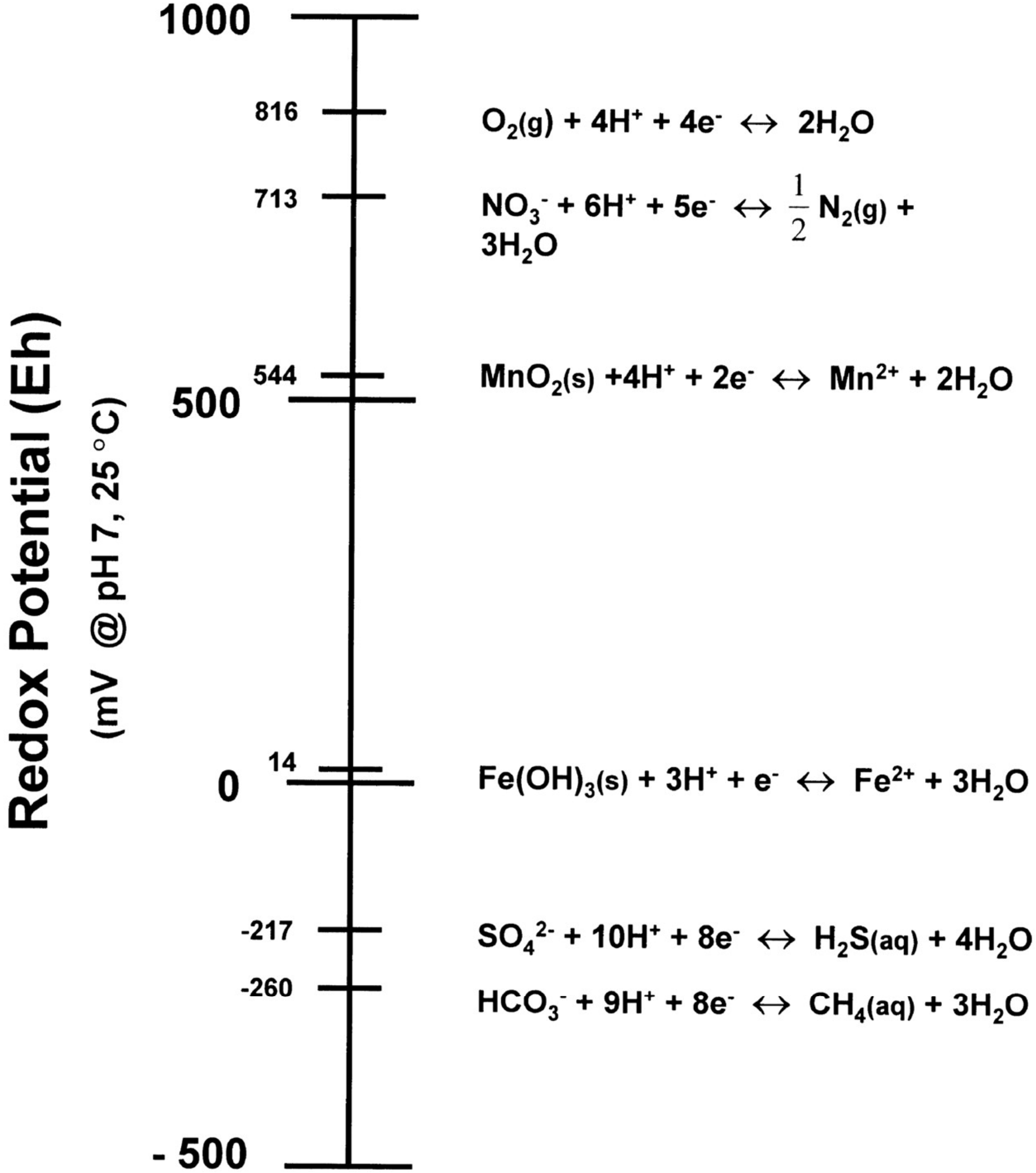


Conversion	***k*** (I order) or ***k′*** (Monod), d^{-1}	
	Single	**Mixed**
ES → ESS (Monod)	0.899±0.082	0.367 ± 0.034
ES → ED	0.002±0.023	0.081 ± 0.009
ESS → ED(Monod)	0.407±0.050	0.187 ± 0.027
ED → ESE	0.875±0.177	0.418 ± 0.034
ESE → ESL	2.636±1.539	0.520 ± 0.056
ESL → others	0.470±0.065	0.137 ± 0.015

Inhibition does not appear to follow any of the known models, e.g., competitive, uncompetitive, non-competitive Michaelis Menten models.

Tiwari and Guha (2010)

Redox Condition

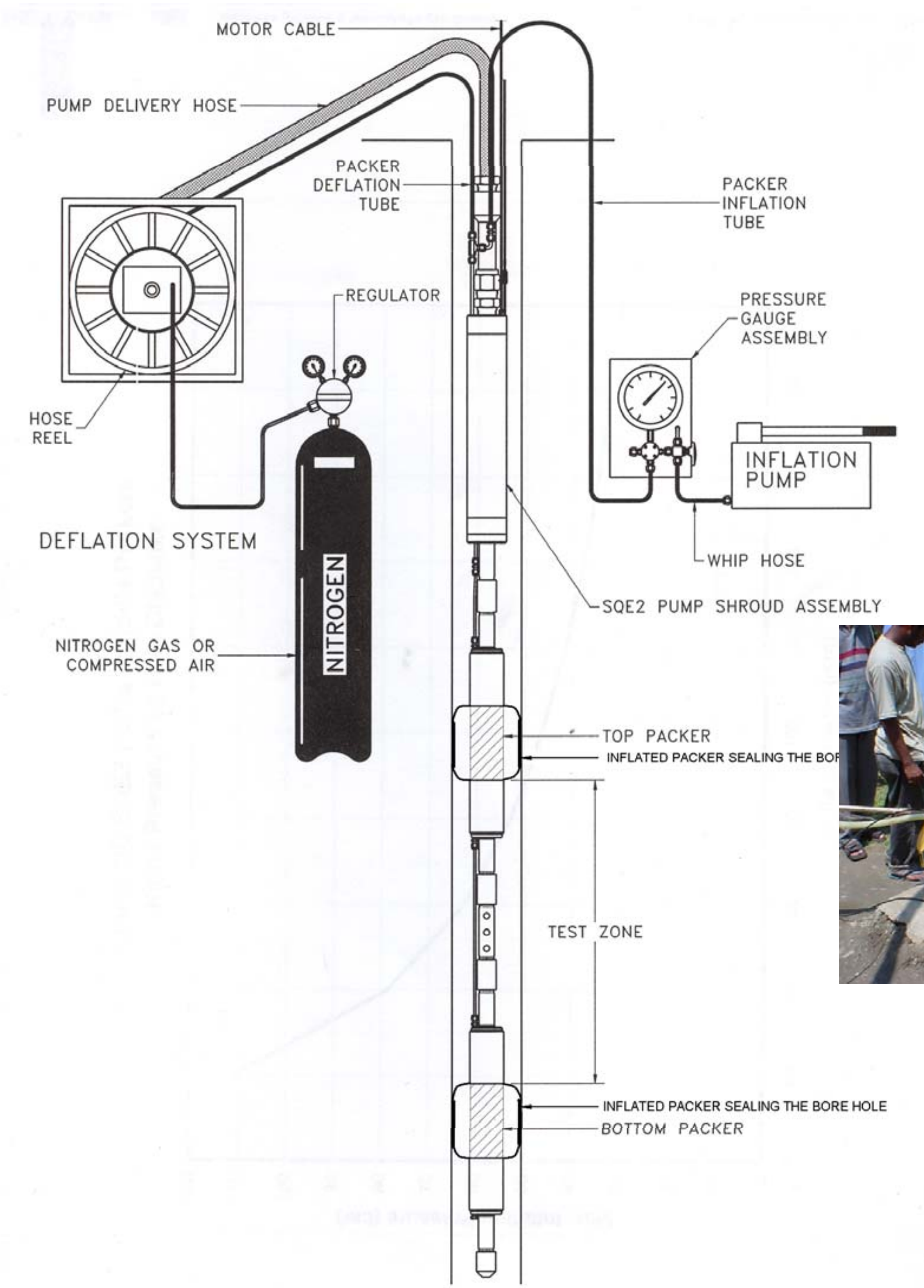


Aerobic

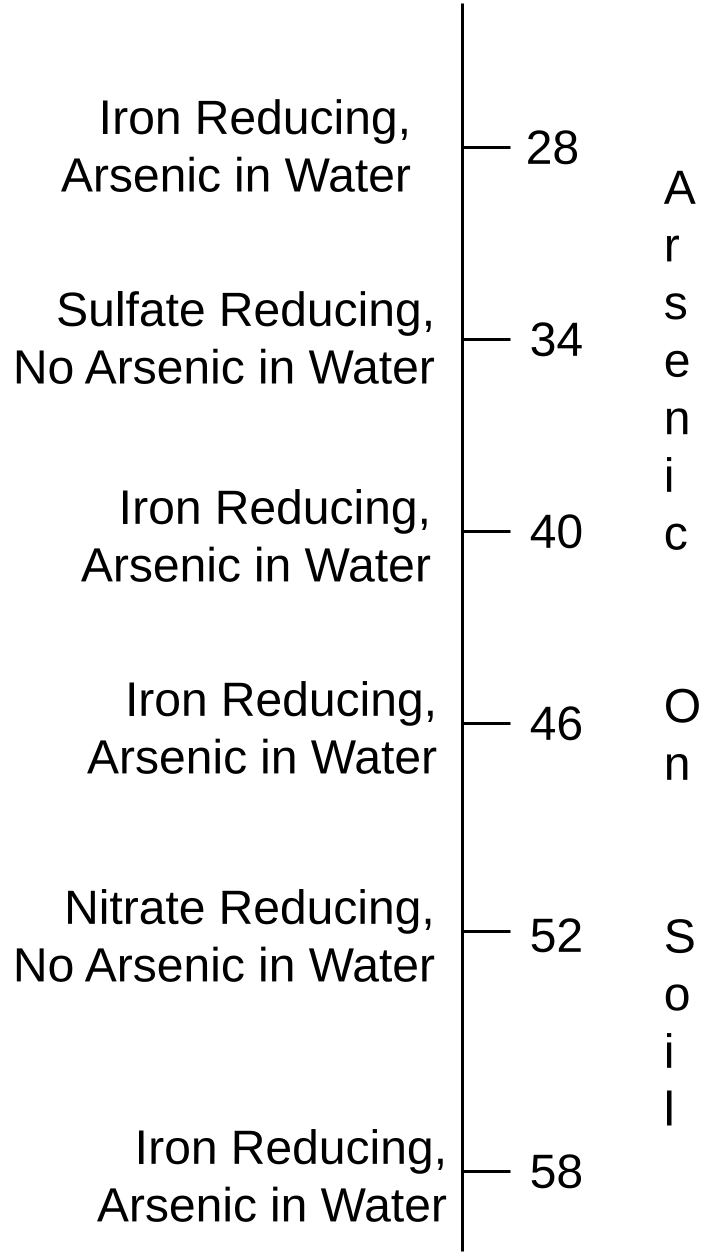
Anaerobic

Energy Yield with respect to terminal electron acceptors (Respiration Agent):

$O_2 > NO_3^- > Mn(IV) > Fe(III) > SO_4^{2-} > CO_2$


MOTOR CABLE
PUMP DELIVERY HOSE
PACKER DEFLATION TUBE
PACKER INFLATION TUBE
REGULATOR
PRESSURE GAUGE ASSEMBLY
HOSE REEL
INFLATION PUMP
DEFLATION SYSTEM
WHIP HOSE
NITROGEN
SQE2 PUMP SHROUD ASSEMBLY
NITROGEN GAS OR COMPRESSED AIR
TOP PACKER
INFLATED PACKER SEALING THE BOR
TEST ZONE
INFLATED PACKER SEALING THE BORE HOLE
BOTTOM PACKER

Redox Condition and Arsenic Problem in the Ganges Delta



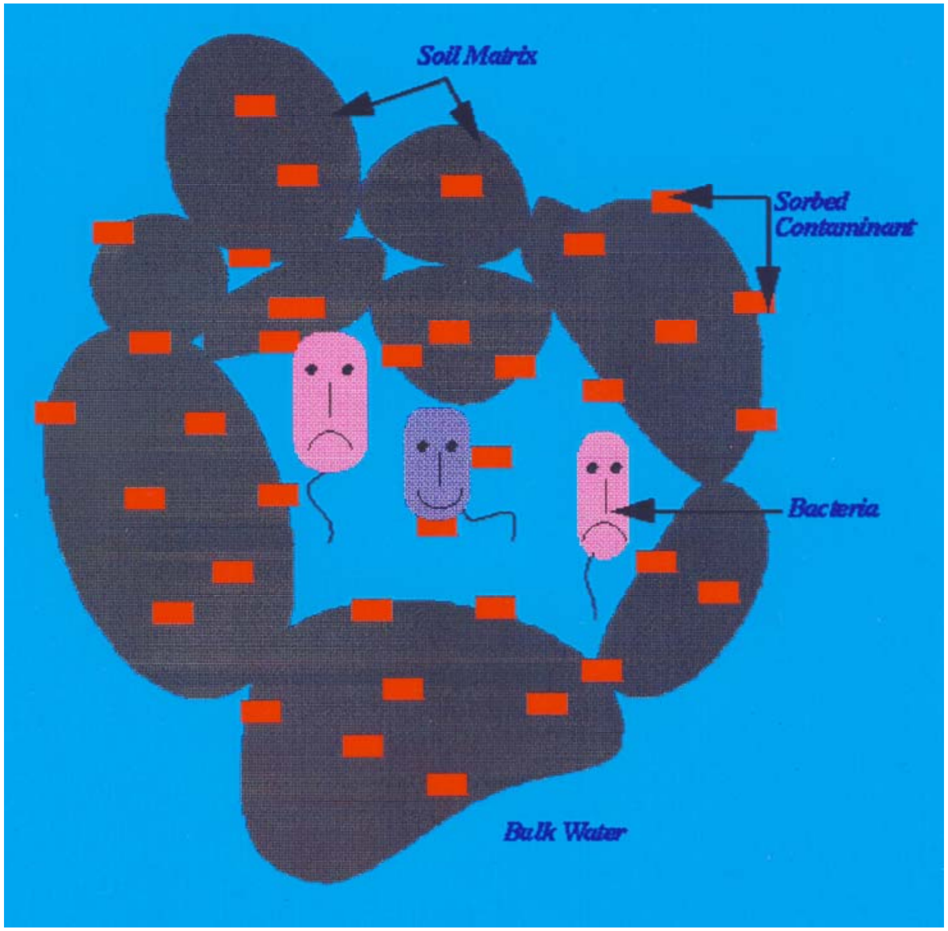
[Guha et al. (2005), Env. Eng. Sci., V. 22, 870-881; Acharyya et al. (1999), Nature, V. 401, 545]

Bioavailability

– Low Solubility

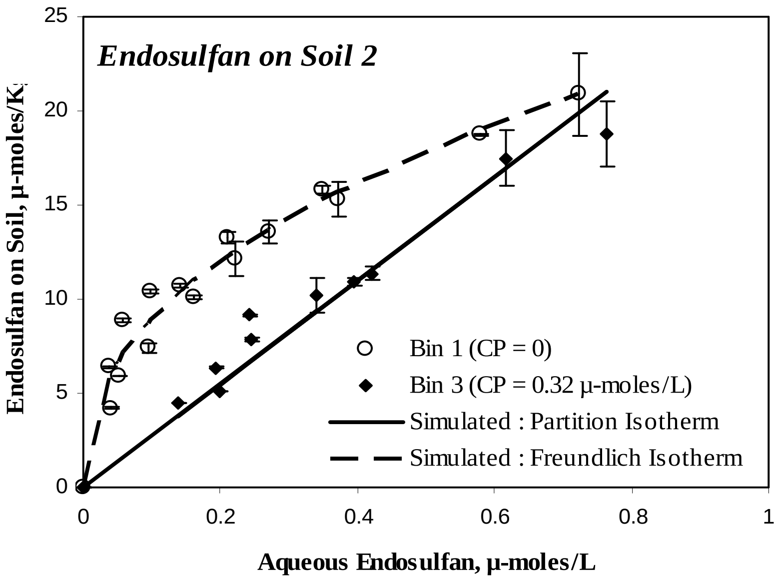
– Adsorbed or Partitioned on Soil

– Little is available to the bacteria for biodegradation



Sorption or Partition

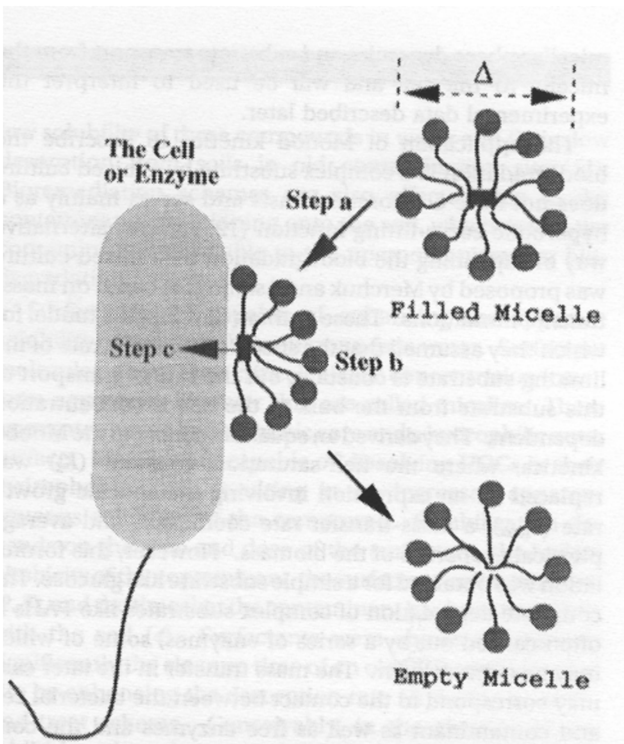
- **Multiple mechanisms**
- **Extrapolation to field conditions are often difficult**
- **Multiple compound interaction makes it more complex**

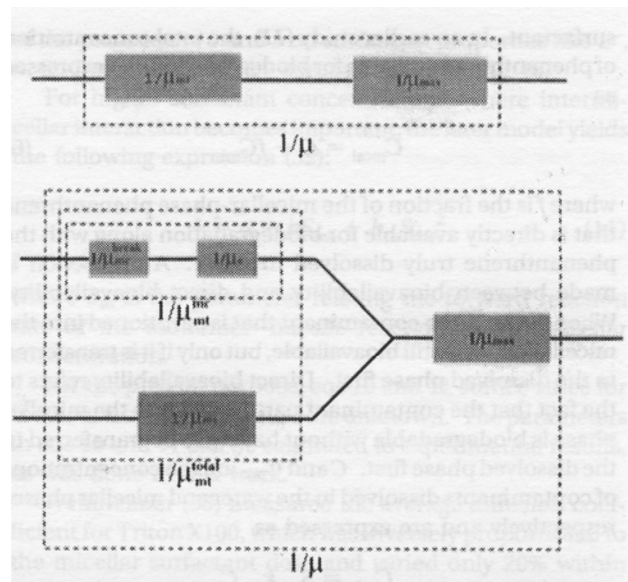


Tiwari and Guha (2010)

Increasing Bioavailability

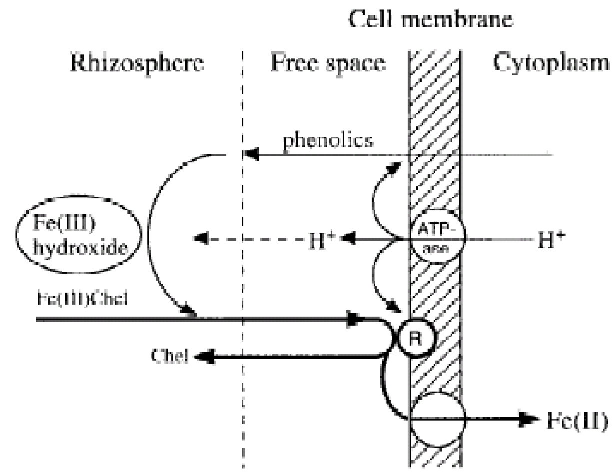
Adding Surfactant for example:

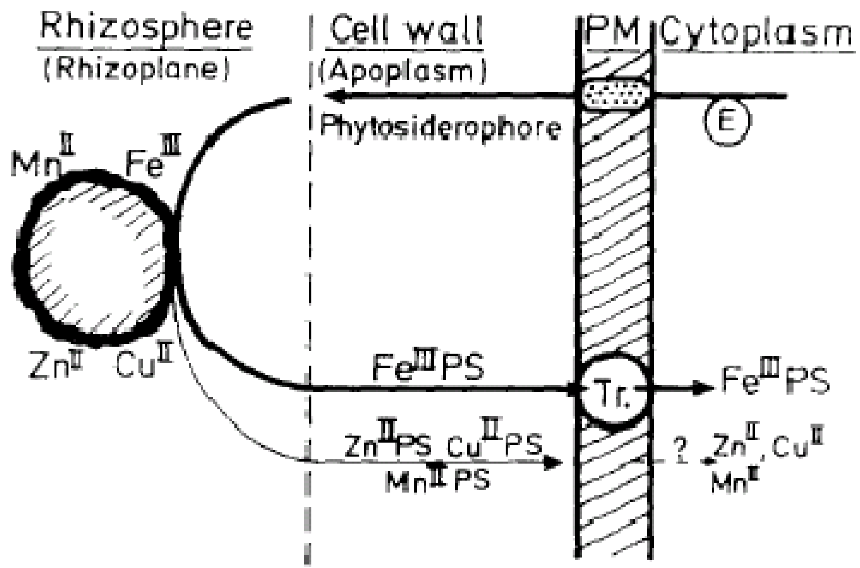




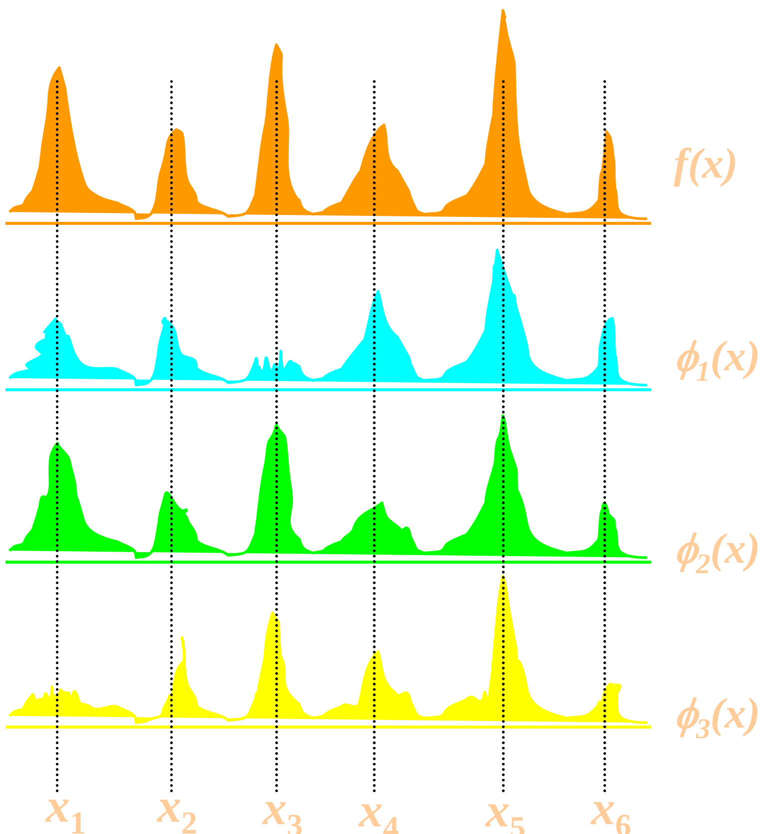
Guha and Jaffe 1996a, 1996b; Guha et al. 1998a, 1998b; Brown et al., 1999

Metal Uptake by Rice Plants





Microbial Ecology



- **Deconvolution Algorithme: apriori (Dey and Guha 2008)**
- **Method development for analyzing Signature**
- **Deconvolution Algorithme: posteriori**

$$f(x) = c_1\phi_1(x) + c_2\phi_2(x) + c_3\phi_3(x)$$

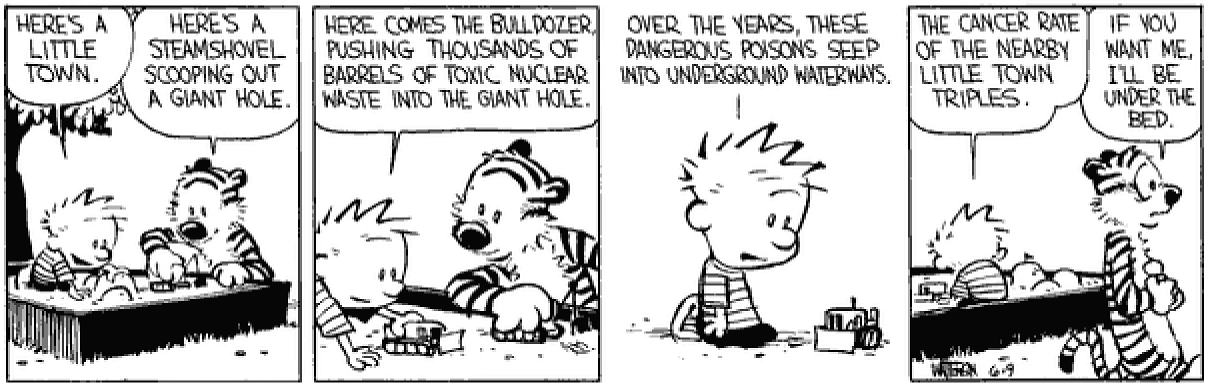
Some other areas

- Modeling Flow and Transport
- Numerical Method Development
- Different Remediation Strategies
- Risk Assessment!
- Toxicity and Health Effects!
- Gene probe for identification of existence of a degrading population.
- GEMs: only academic interest, irrelevant for environmental application.

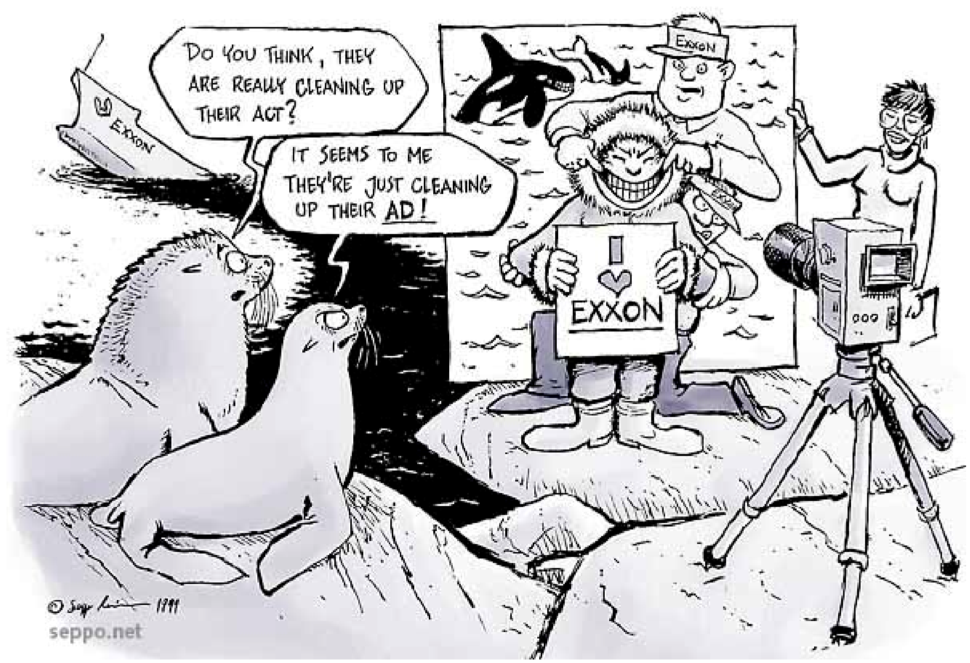
Summary

- Natural System are immensely complex and almost always pose multi-disciplinary problems.

- “Spherical Cow” or “Cylindrical Horse” approximations are often necessary to analyze the systems. Caution has to be taken to avoid over simplification!


HERE'S A LITTLE TOWN.
HERE'S A STEAMSHOVEL SCOOPING OUT A GIANT HOLE.
HERE COMES THE BULLDOZER, PUSHING THOUSANDS OF BARRELS OF TOXIC NUCLEAR WASTE INTO THE GIANT HOLE.
OVER THE YEARS, THESE DANGEROUS POISONS SEEP INTO UNDERGROUND WATERWAYS.
THE CANCER RATE OF THE NEARBY LITTLE TOWN TRIPLES.
IF YOU WANT ME, I'LL BE UNDER THE BED.

Thank You


DO YOU THINK, THEY ARE REALLY CLEANING UP THEIR ACT?
IT SEEMS TO ME THEY'RE JUST CLEANING UP THEIR AD!
EXXON
I ♥ EXXON
seppo.net