PAH Transport and Bioremediation in Superfund Soils

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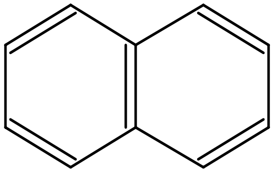
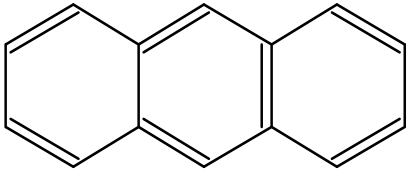
PAH Sources

- Three of the twenty top hazardous substances are polyaromatic hydrocarbon (PAH) compounds
- PAHs are formed during the incomplete burning of coal, oil and gas, garbage or other organic substances
  - sources include vehicle exhaust, asphalt roads, coal, coal tar, wildfires, agricultural burning, and hazardous waste sites
  - commonly found in coal-tar production plants, coking plants, bitumen and asphalt production plants, coal-gasification sites, and municipal refuse incinerators

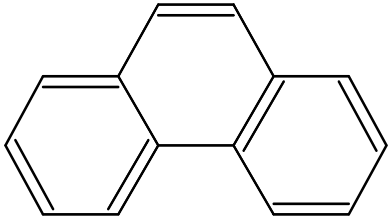
Typical PAH Structures



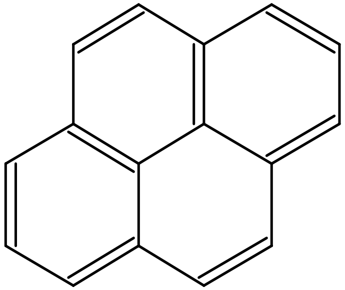
Naphthalene



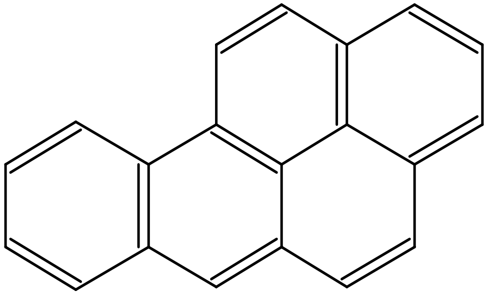
Anthracene



Phenanthrene



Pyrene

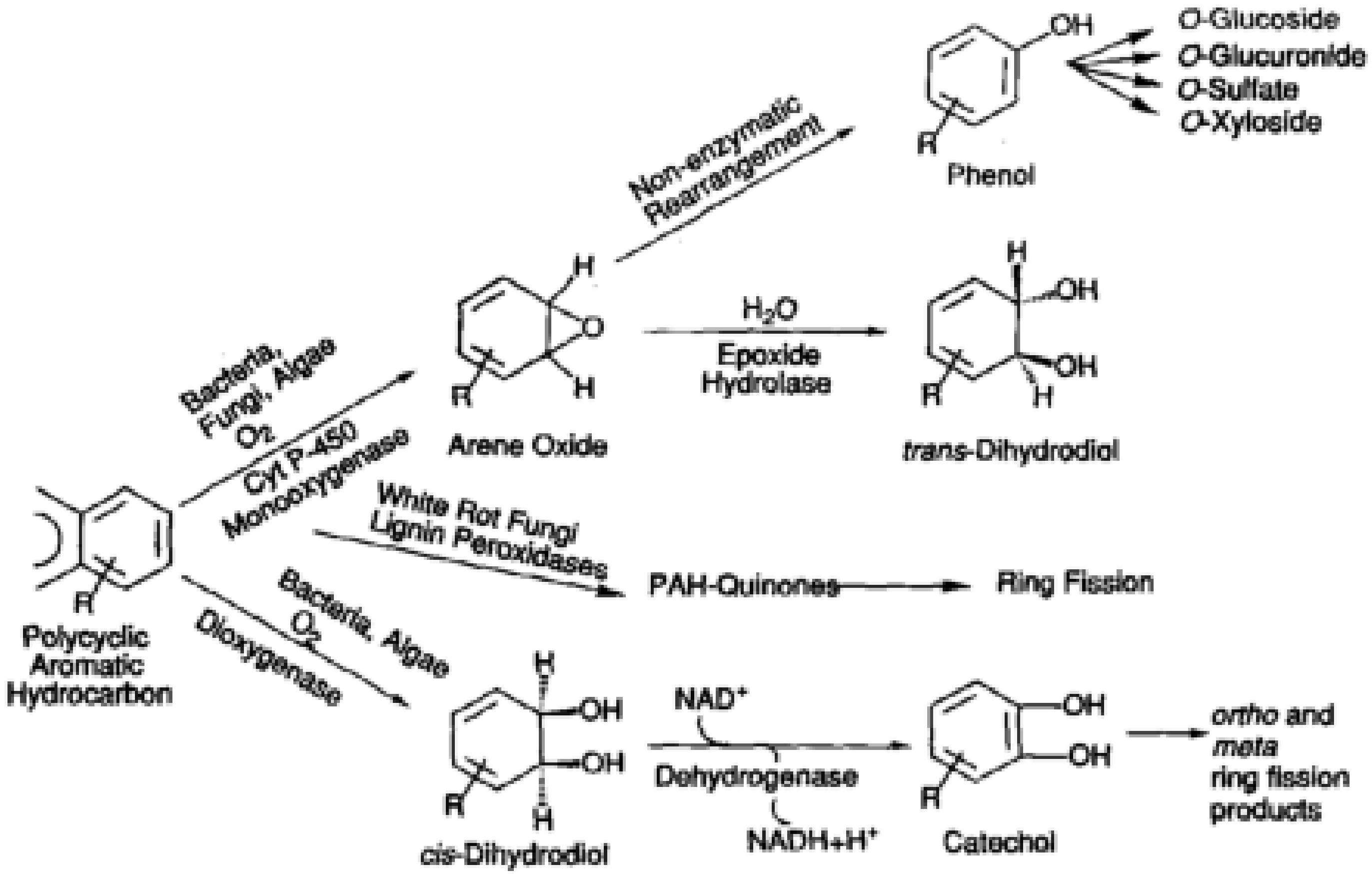


Benzo[a]pyrene

Concerns with PAHs

- Contaminated sites often contain high concentrations of these potentially mutagenic or carcinogenic materials
- Microbial biodegradation of these PAHs in the soil is becoming an attractive remediation alternative
  - effectiveness of in-situ bioremediation of PAHs is often hampered, though, by their low water solubility, the lack of appropriate organisms, the lack of needed nutrients, or the need for oxygen

PAH biodegradation



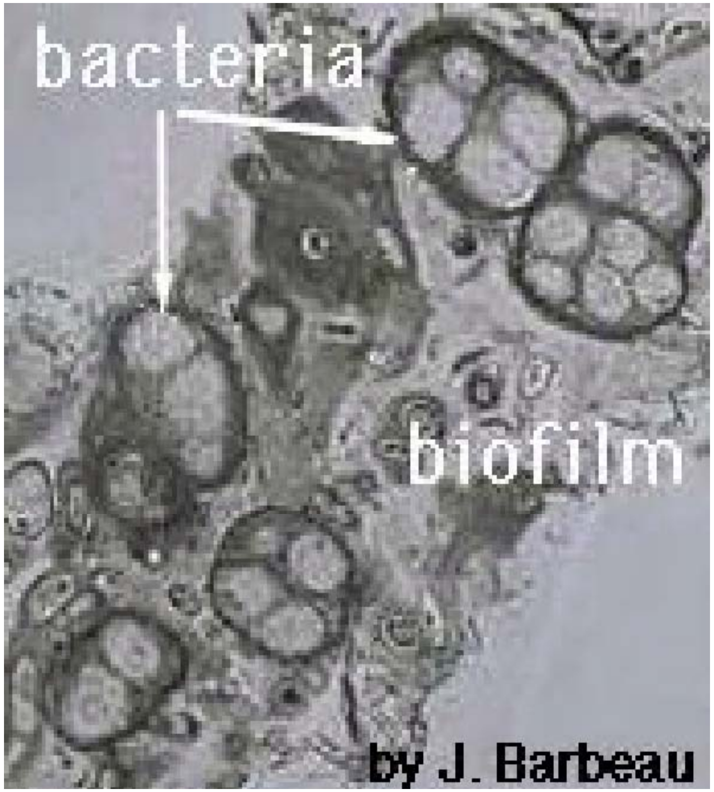
Improved Bioremediation

- In situ bioremediation relies on biodegradation of the PAHs by microbes growing in the soil, attached to soil particles in “biofilms”
- To be effective, the rate and extent of biodegradation needs to be increased
  - Need new technologies for this – will a “biowall” be a better technique?

Questions

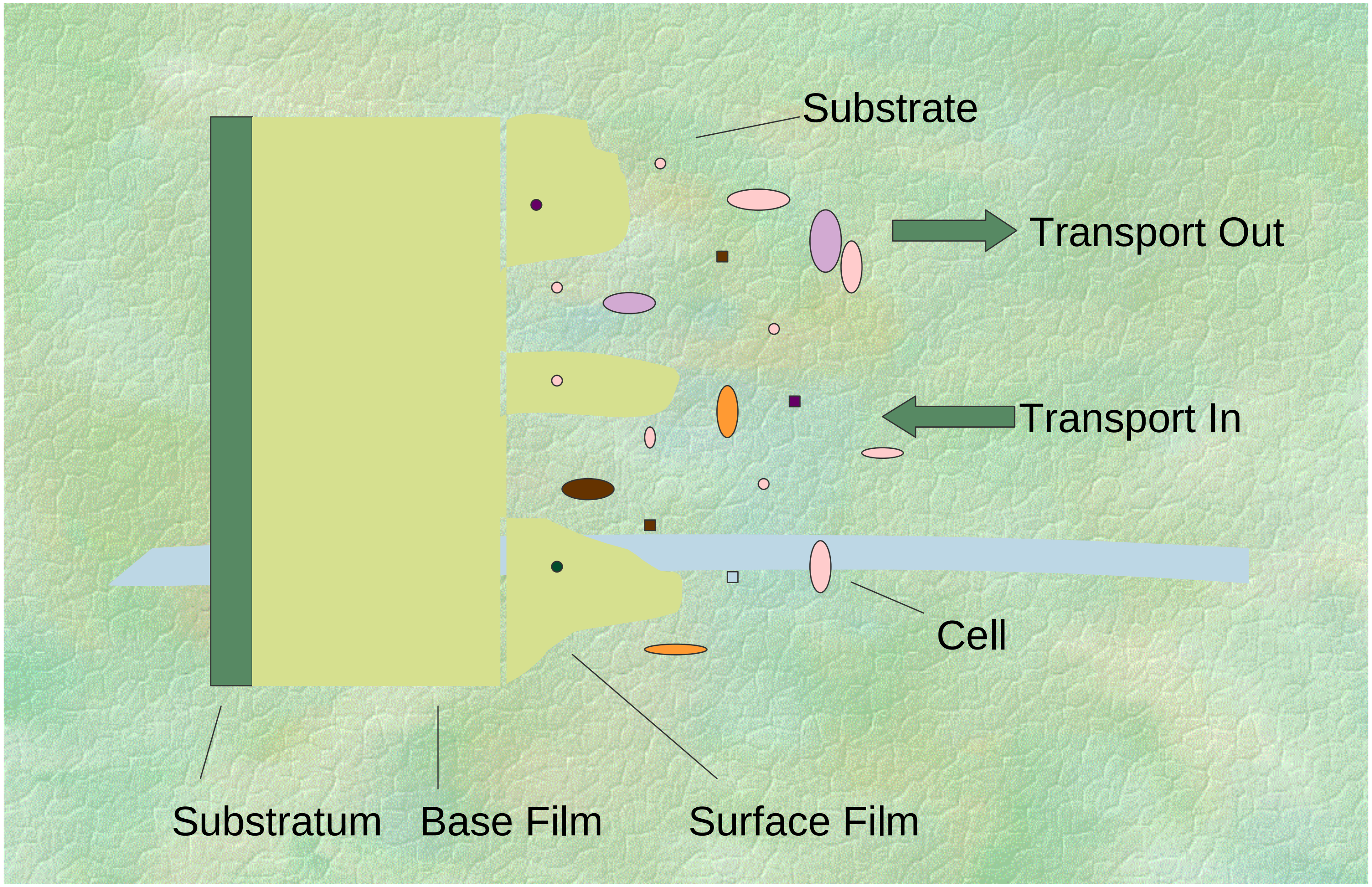
- What is a biofilm?
- What is the structure of a biofilm?
- What is the connection between biofilms, soil and hazardous waste renovation?
- Is the biofilm structure important for wastewater and soil water metabolic processes?

What is a Biofilm?



- Biofilms are colonies of microbial cells encased in an organic polymeric matrix and attached to a surface
- Allows for mixed microbial communities, concentration of nutrients, protection from antibiotics and from desiccation, etc.

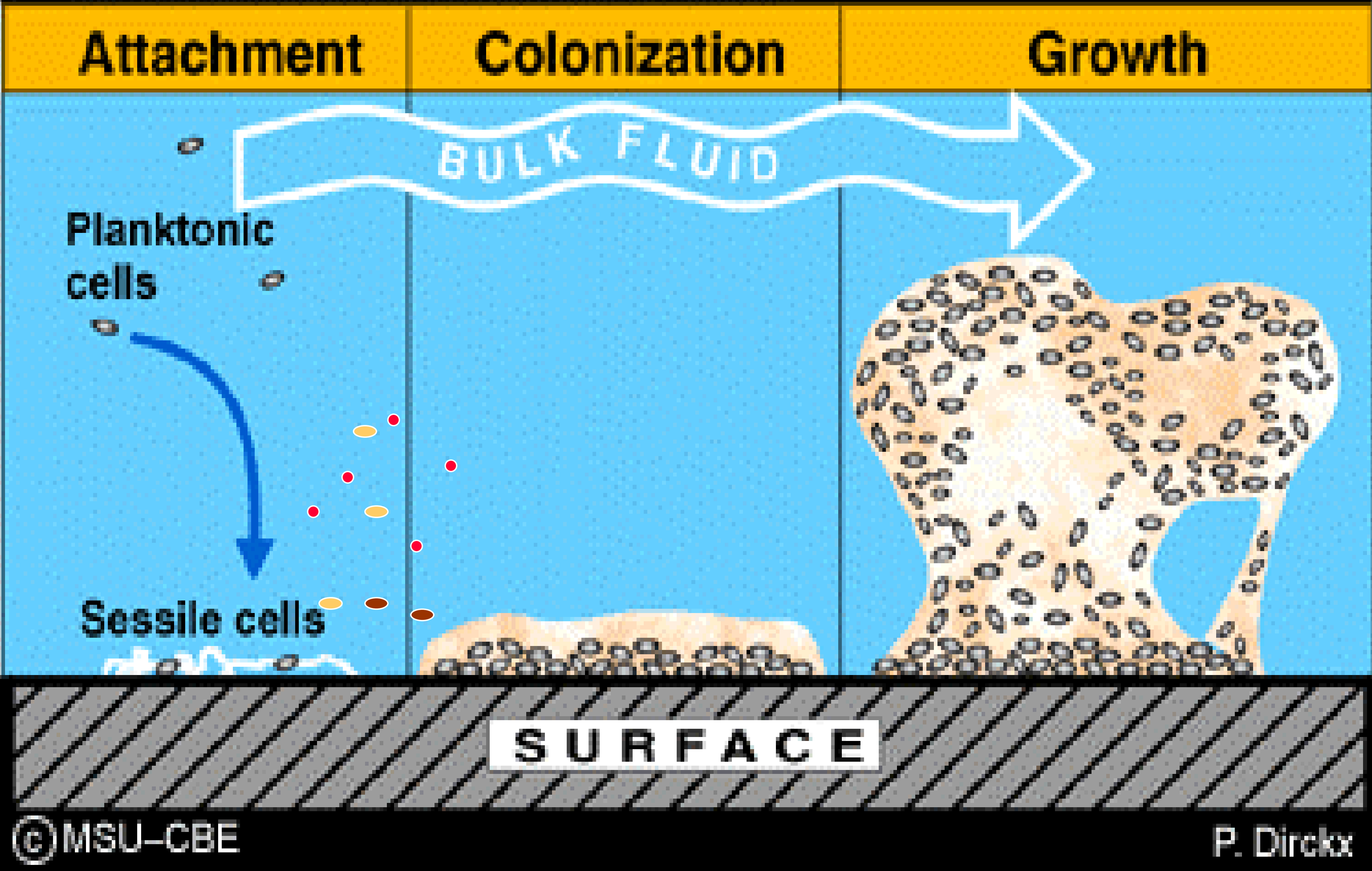
Biofilm Composition



What is a Biofilm's Structure?

- There is **no** one biofilm structure.
- Biofilm structure governed by many factors:
  - microbial community
  - substrate being metabolized
  - substrate/nutrient concentrations
  - system hydrodynamics

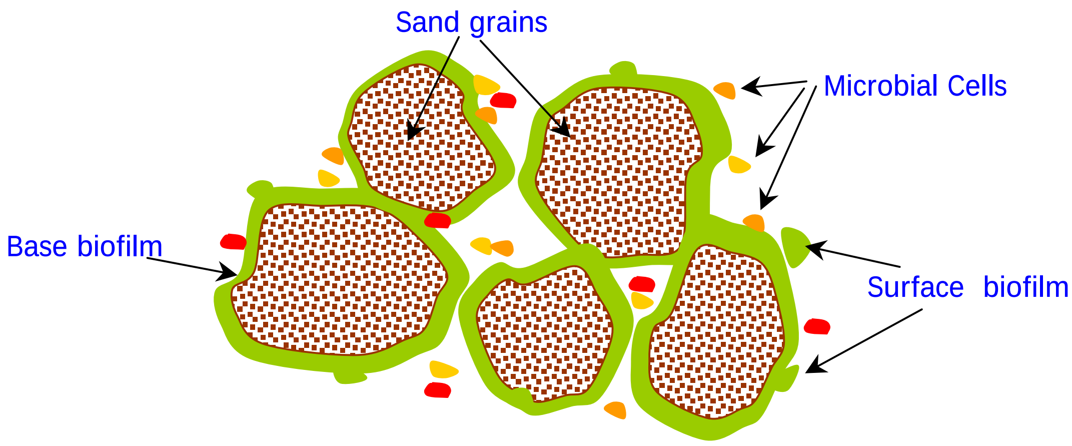
Biofilm formation:



How does this apply to soils?

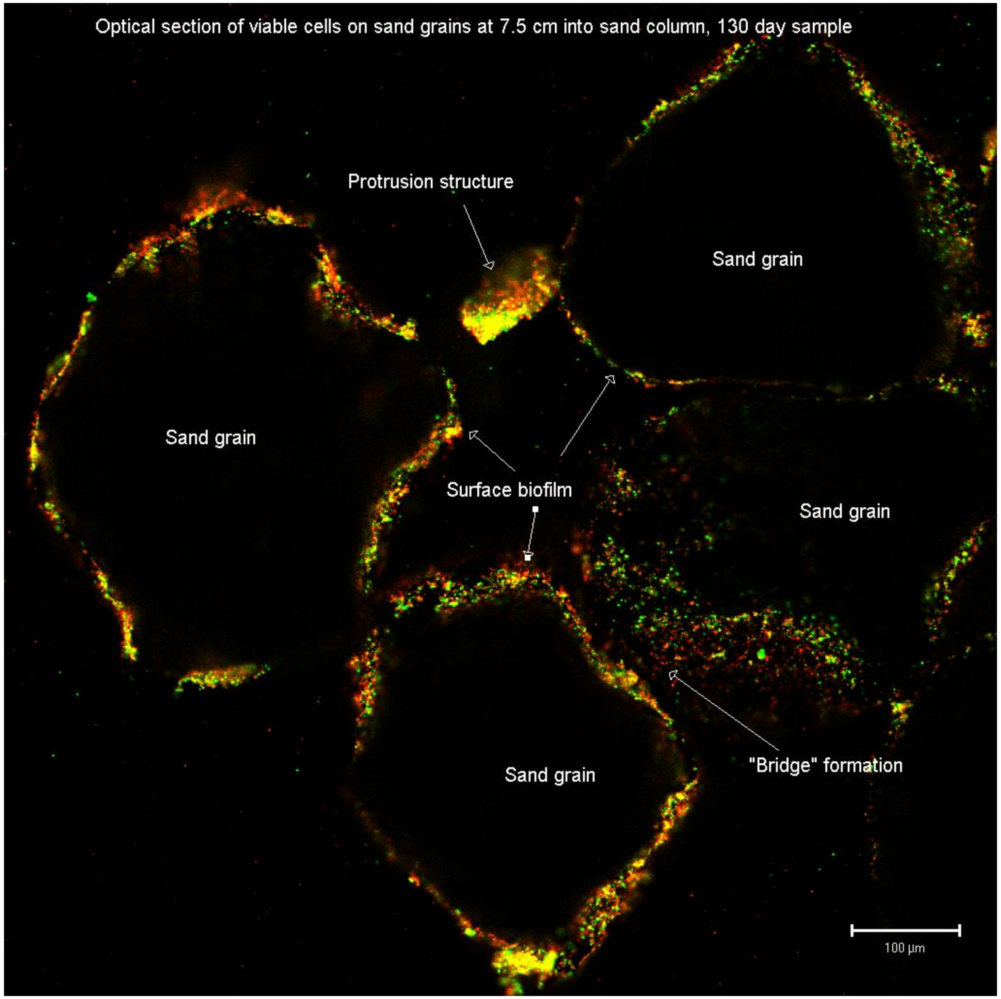
- Limited understanding of porous media biofilms for PAH biodegradation
  - difficult to study biofilm structure
  - few biofilm studies for hydrophobic substrates
  - historical focus on single microbial species
  - few studies on mixtures of PAHs
  - few studies on impacts of other contaminants, such as metals or surfactants

Soil Biofilms

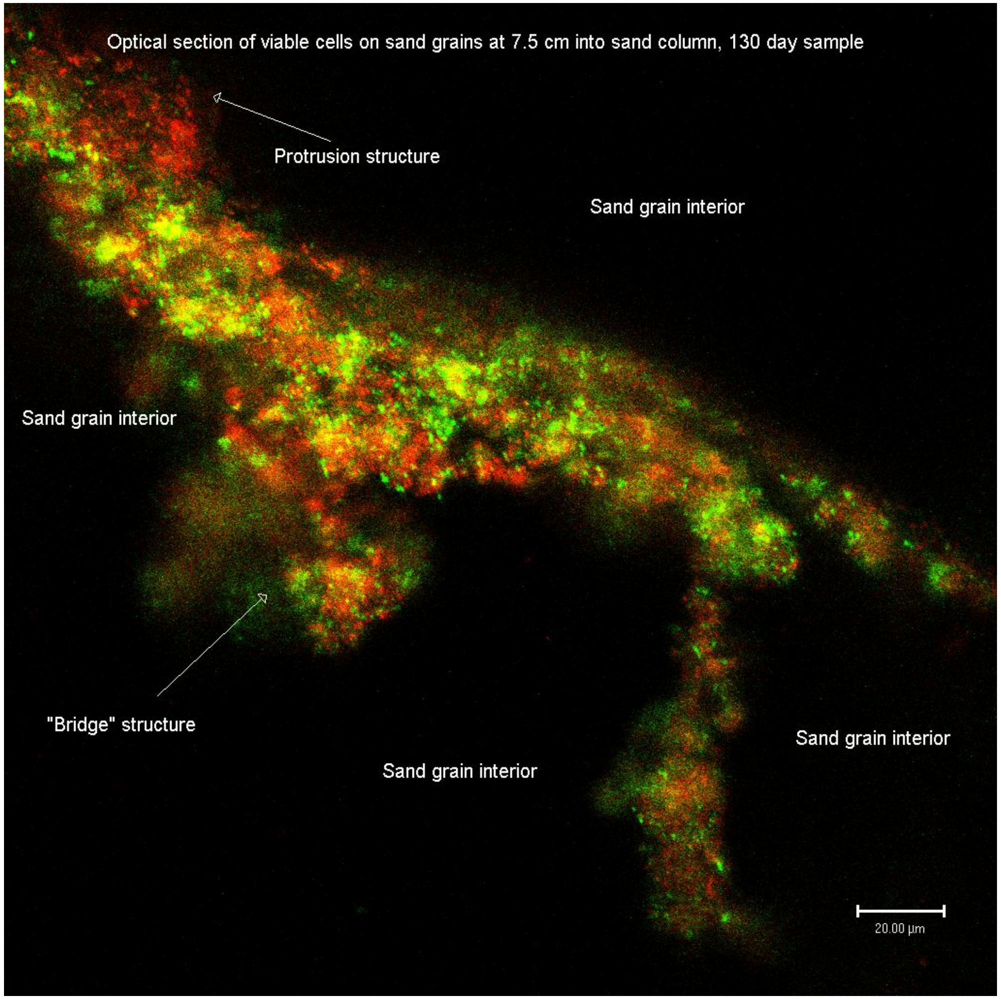


- Continuous surface films (5-15 μm in thickness)
- Variety of aggregate structures (5-30 μm in diameter)
- EPS, extracellular polymeric substances, which protrude from the surface film and form bridges to adjacent sand grains

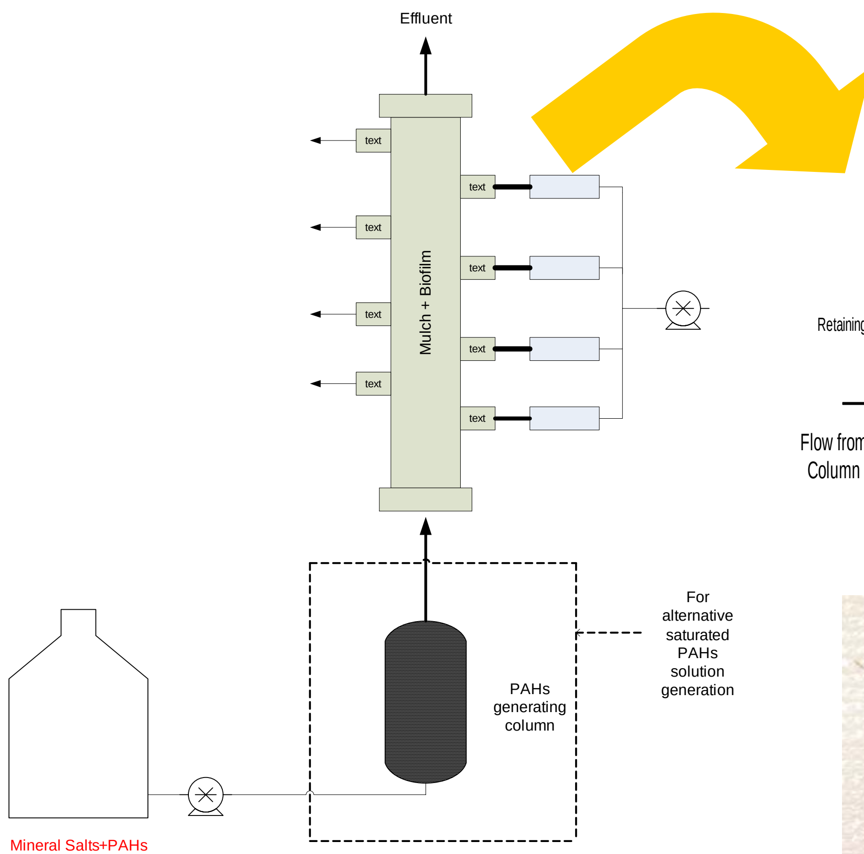
Confocal micrograph of biofilm on sand particles

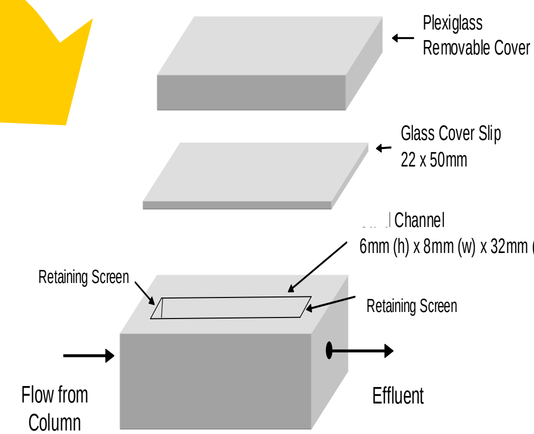


Close-up of sand biofilm

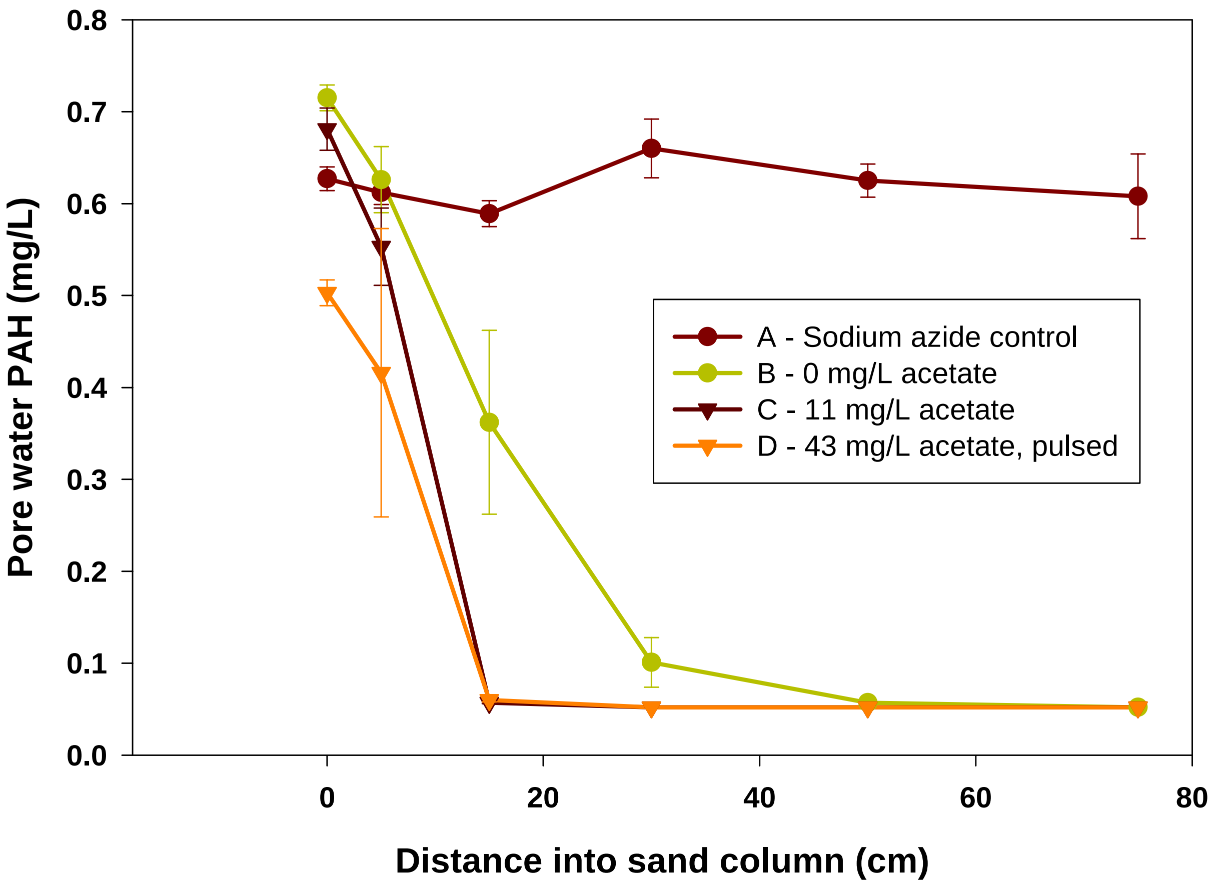


Experimental Set-up

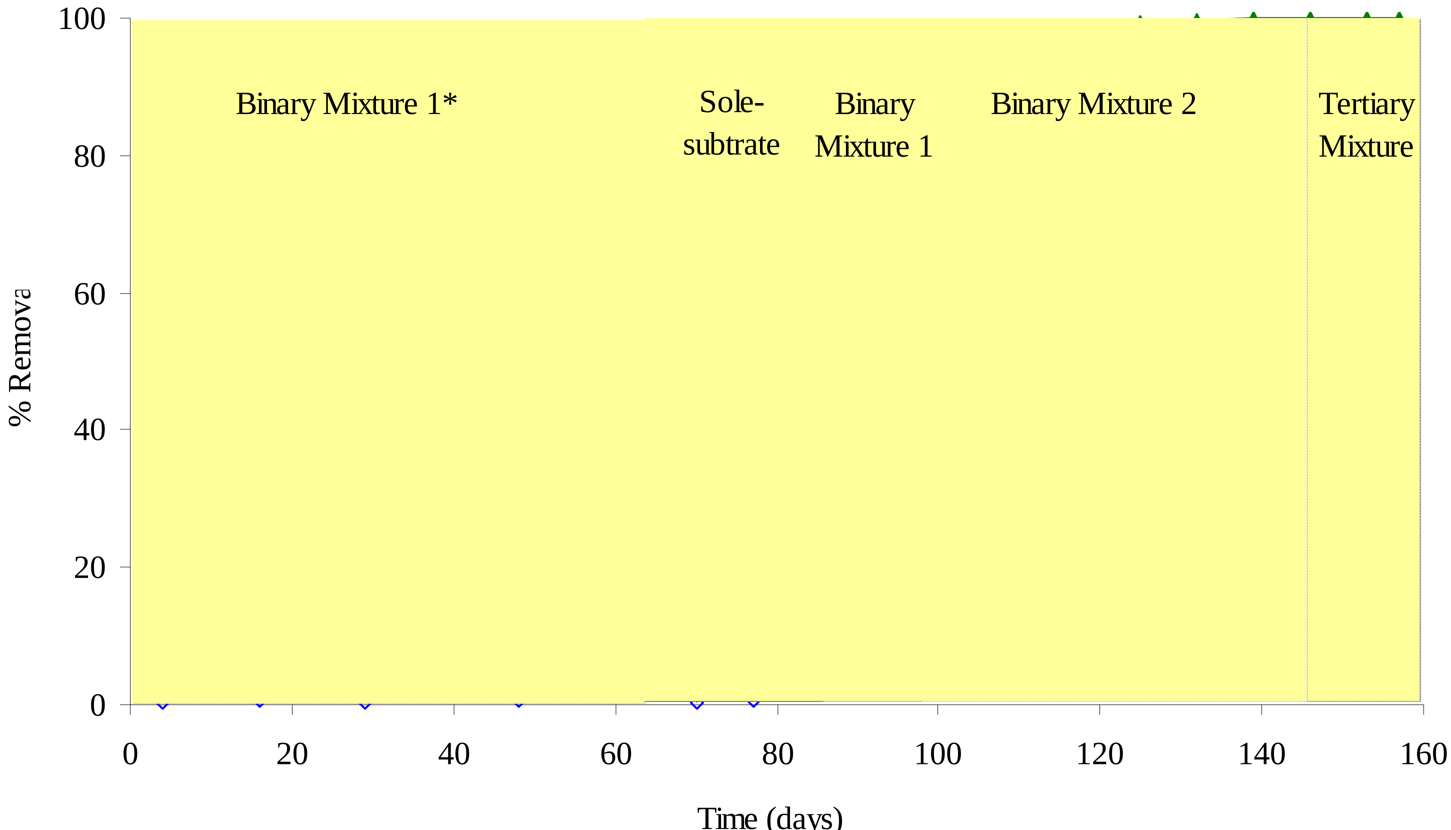




Naphthalene removal in sand column

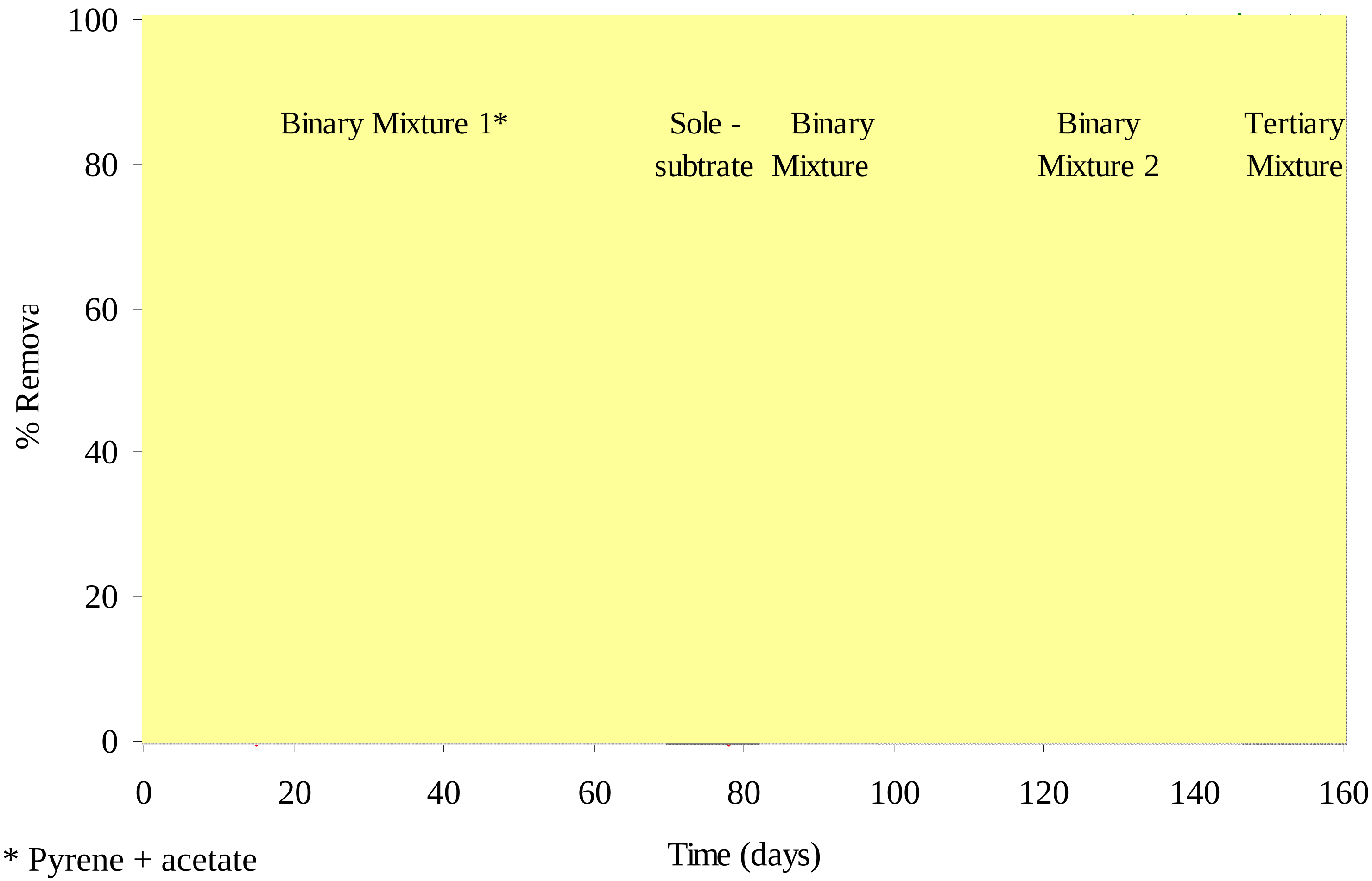


Biodegradation of Mixtures (Phenanthrene)



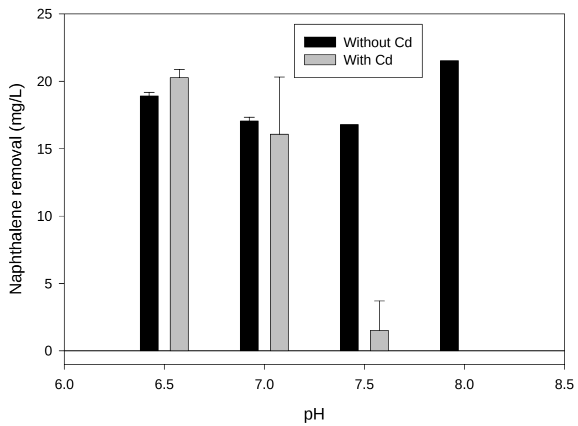
* Phenanthrene + acetate

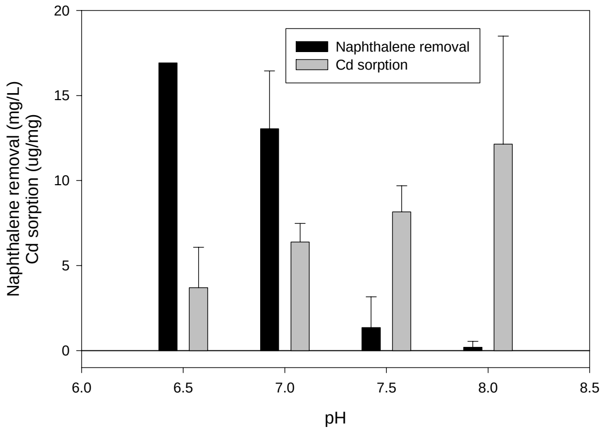
Biodegradation of Mixtures (Pyrene)

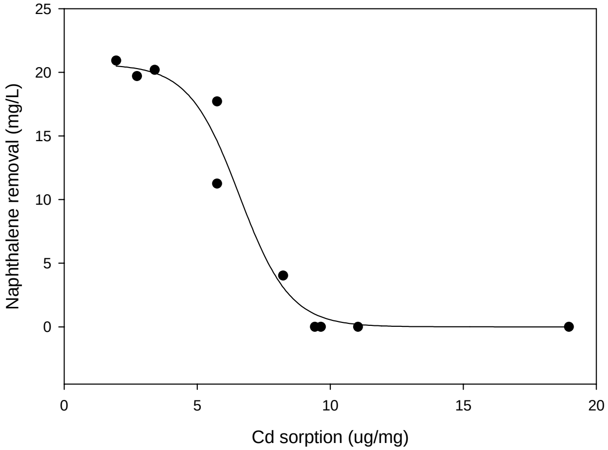


* Pyrene + acetate

Effect of pH on bioremediation in presence of cadmium





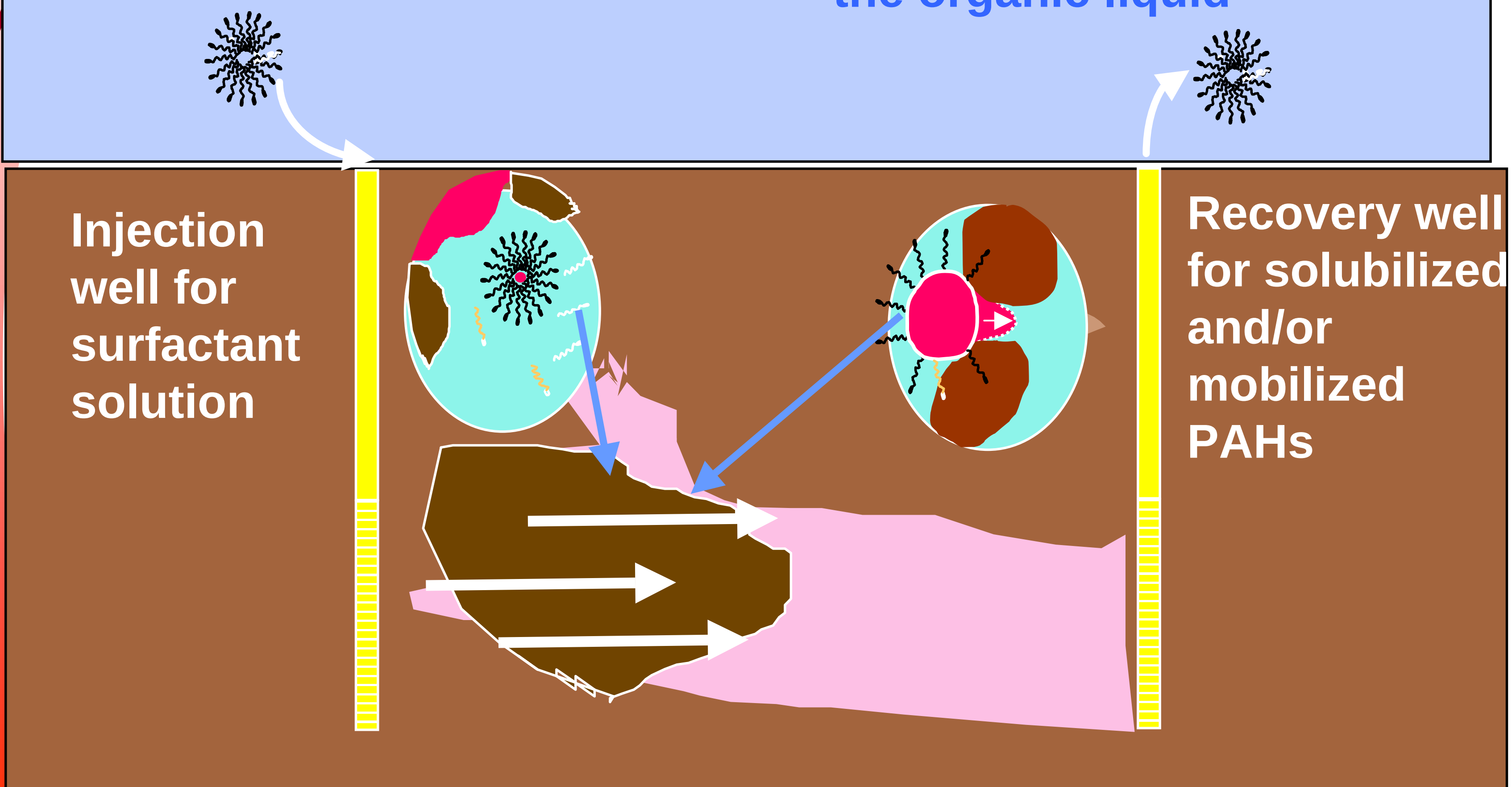


Surfactant Enhanced Aquifer Remediation

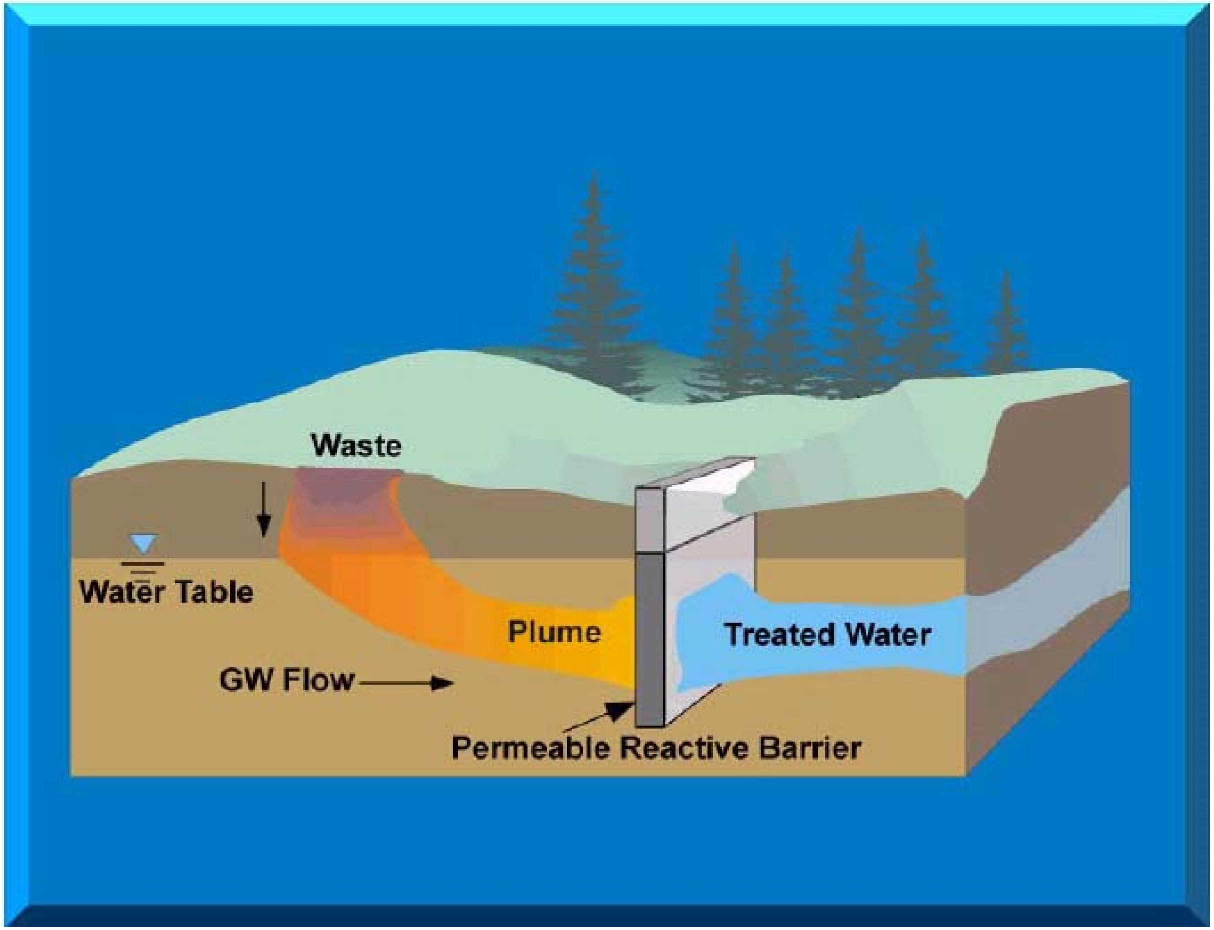
Surfactant micelles can dramatically increase aqueous solubility

and / or

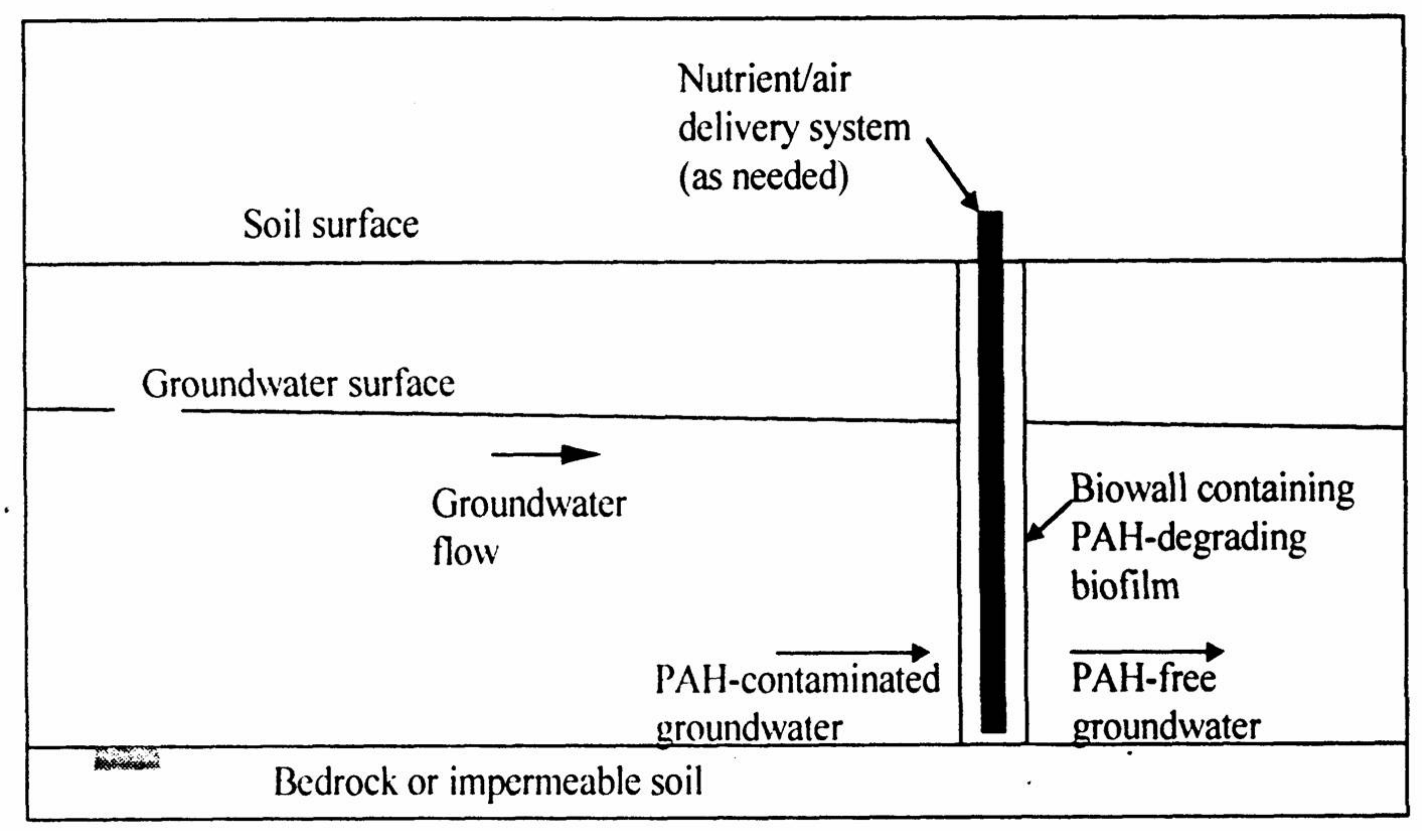
Surfactants can reduce interfacial tension, increasing the mobility of the organic liquid



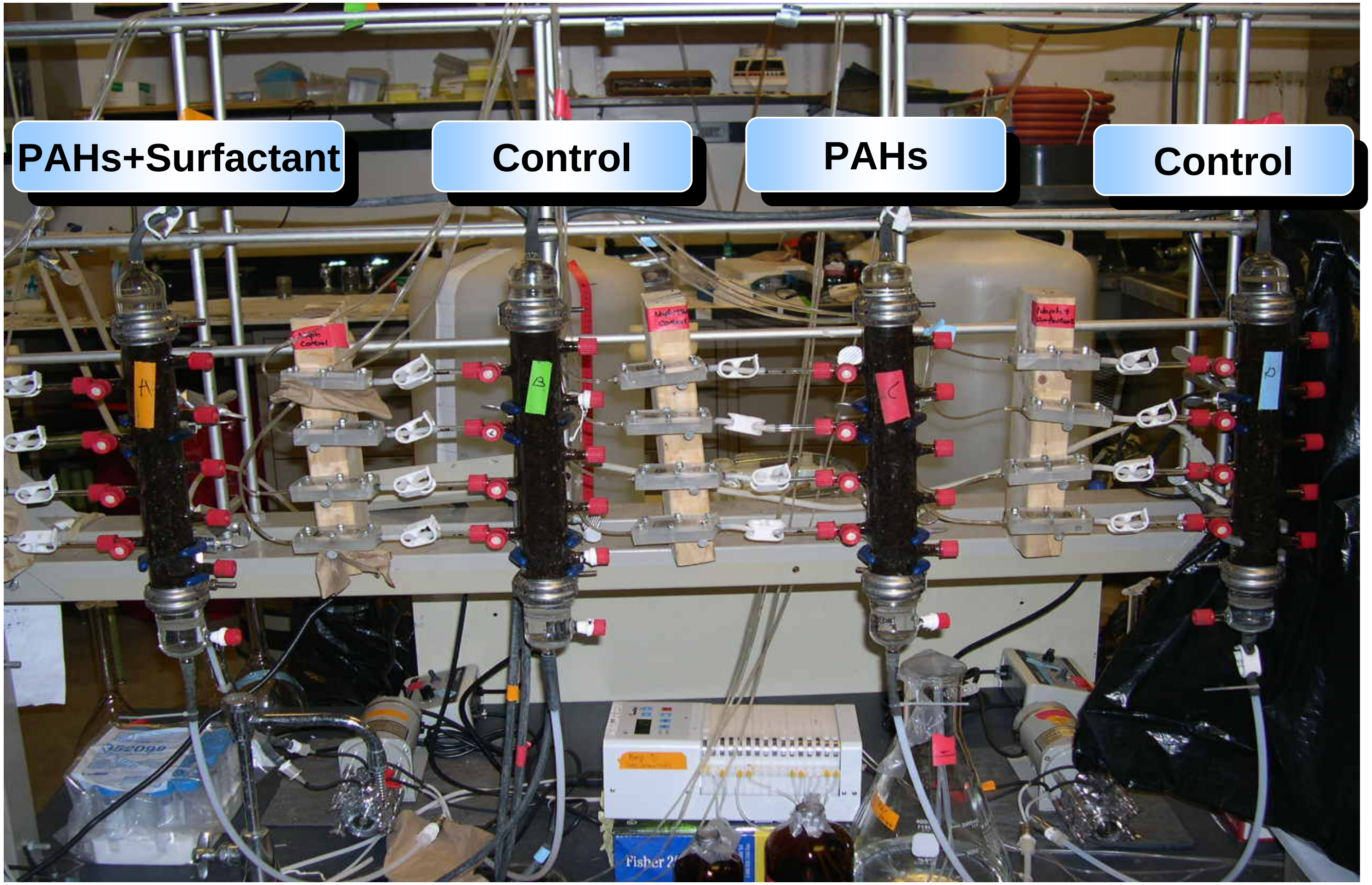
Permeable Reactive Barrier



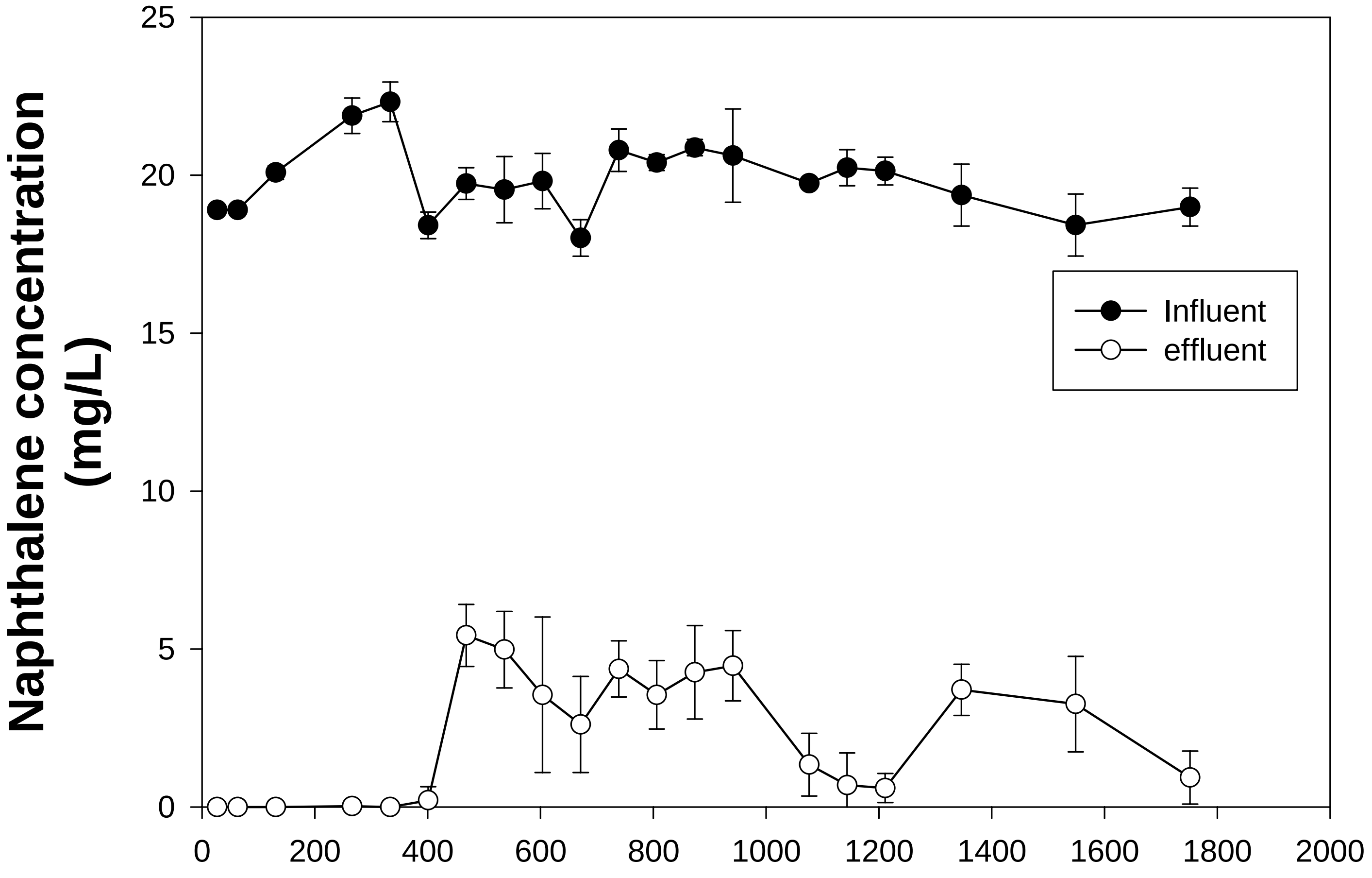
Biowall for PAH removal



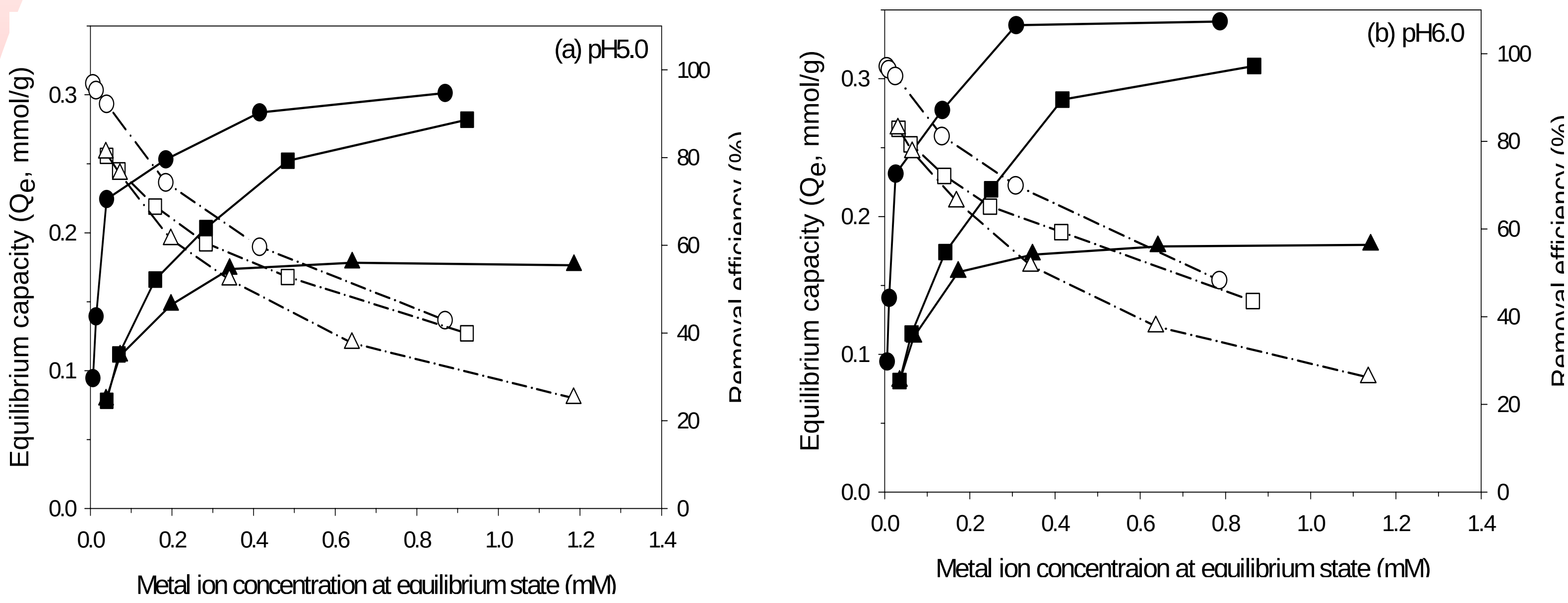
Lab-scale Permeable Barrier Reactor



Naphthalene removal through mulch



Heavy metal removal by soil biofilm

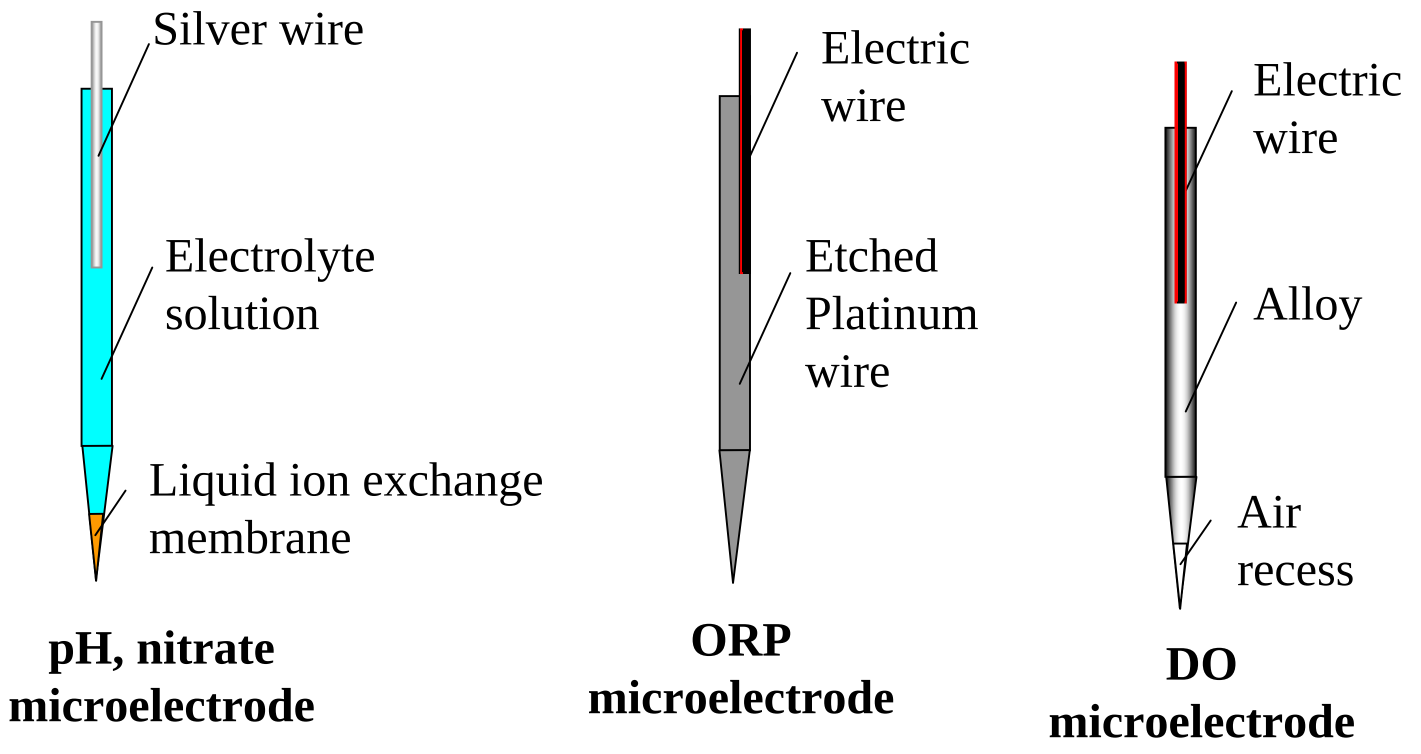


Adsorption capacities of H mulch (filled symbols) and removal efficiencies of metal ions (open symbols) based on concentration of metal ions ((■,□) Cu, (●,○) Pb, and (▲,△) Zn).

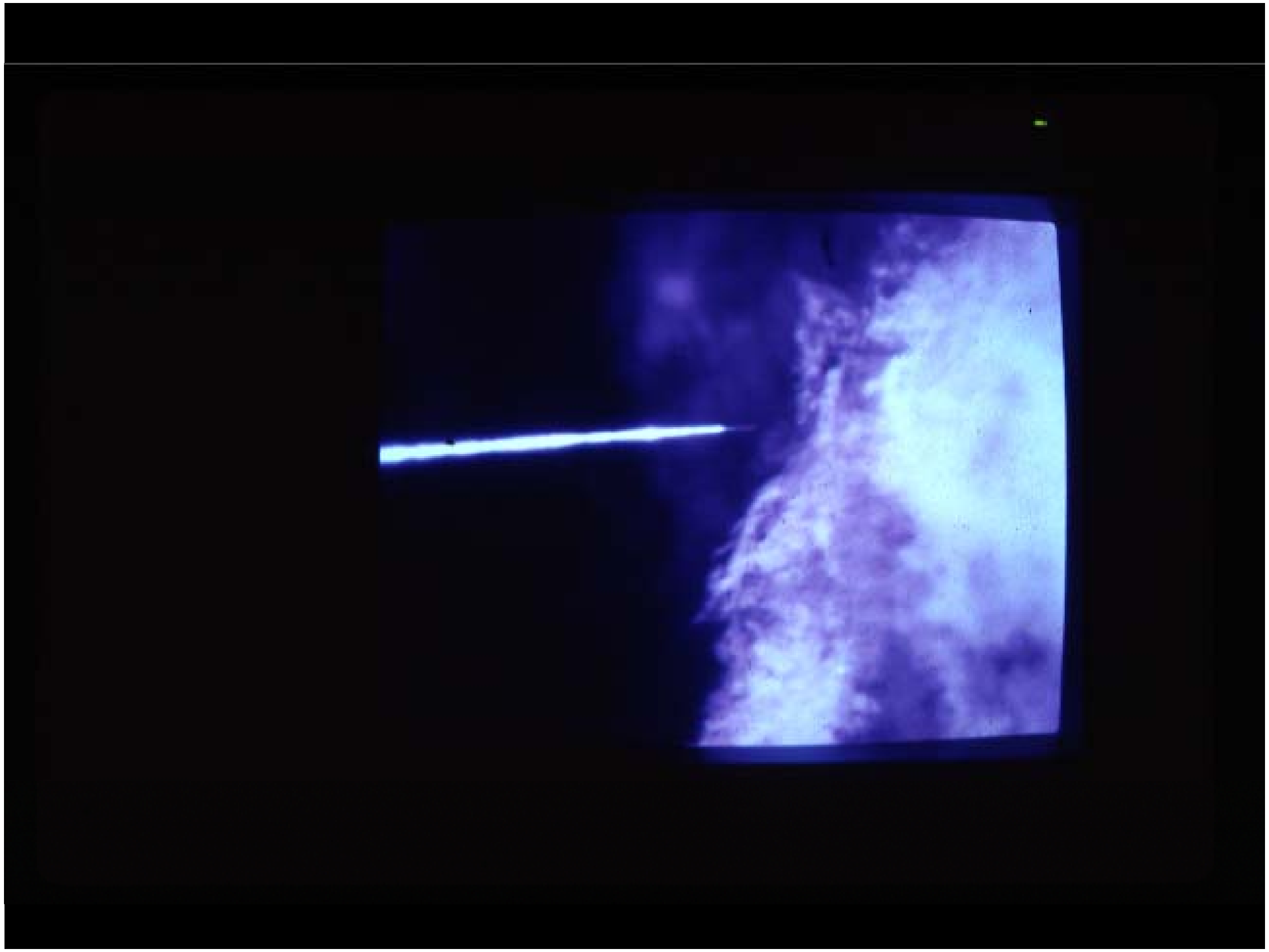
Why Use Microelectrodes?

- For the past 15 years our lab has been using microelectrodes (3-15 μm tip diameter) to study biofilms in engineered biological systems used in the treatment of wastewater.
- The research has focused on operationally important parameters such as dissolved oxygen (DO), pH, ammonium, nitrate, sulfide, and redox potential.
- These tools allow us to investigate the mechanisms and functions of biofilms in-situ.

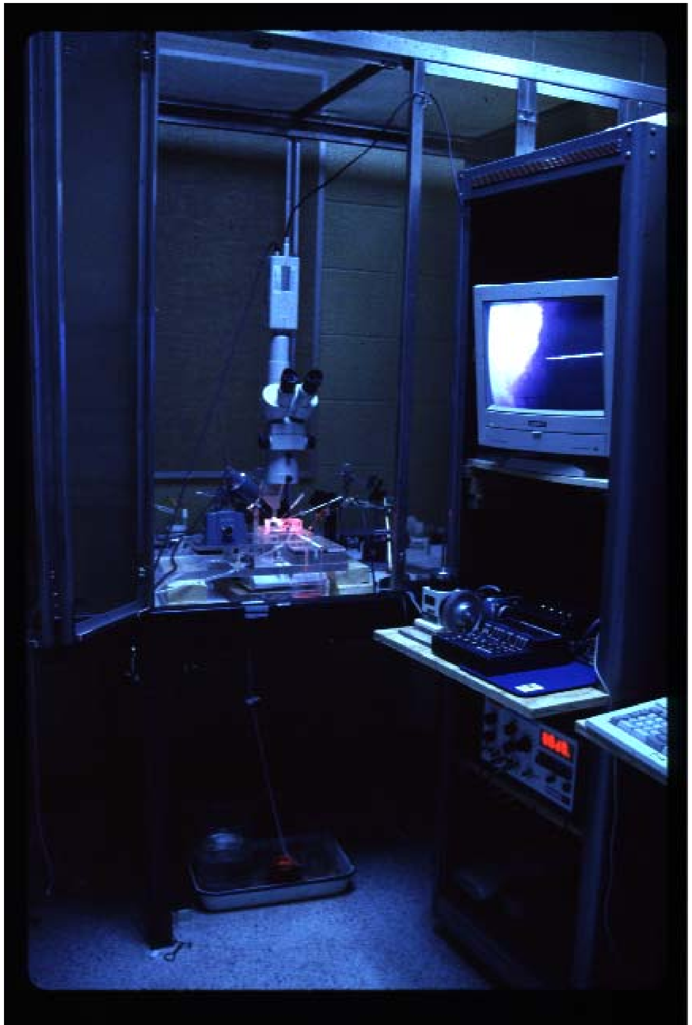
Microelectrode Construction



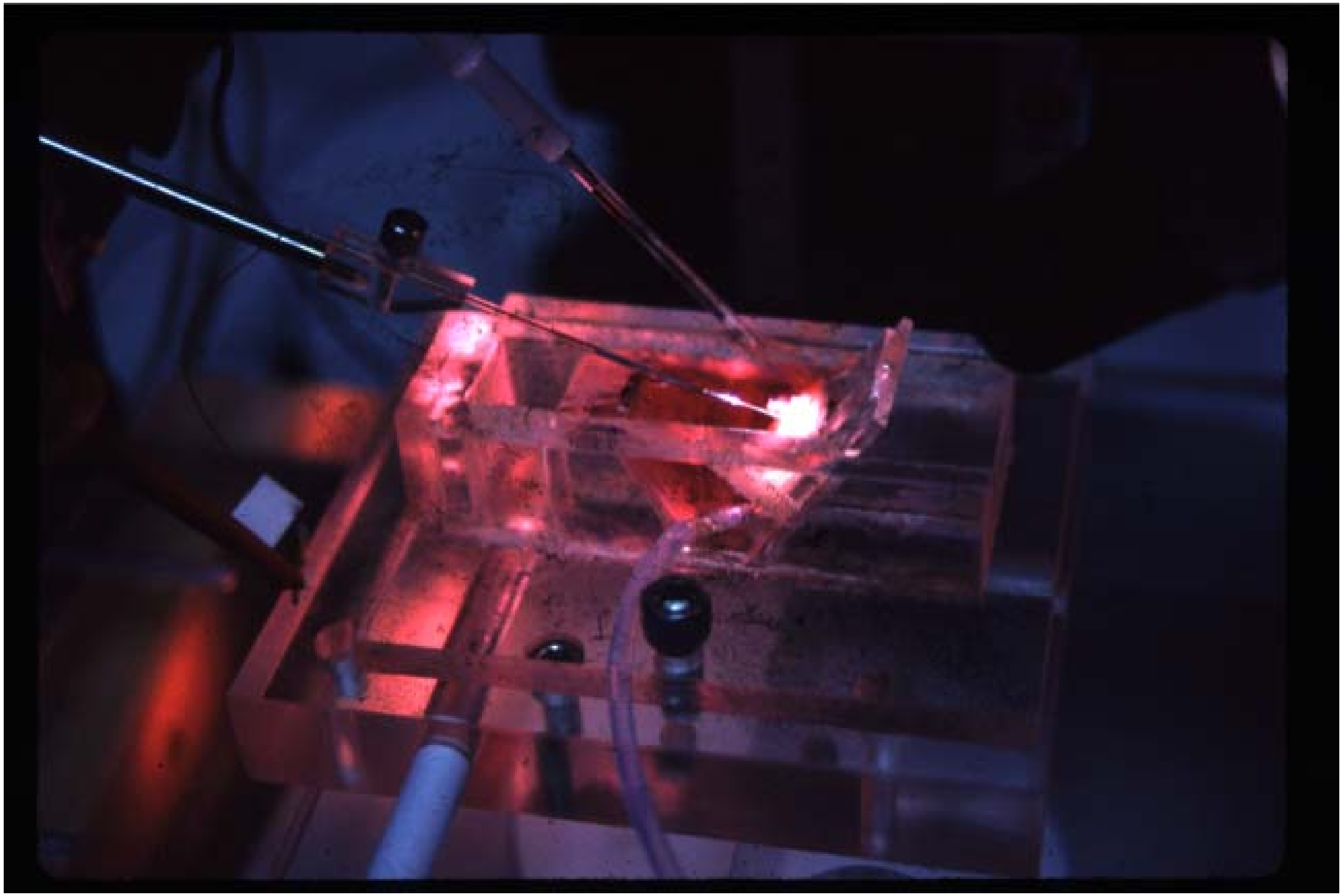
Microelectrode Approaching Biofilm



Microelectrode Analytical System



Microelectrode Flow Cell



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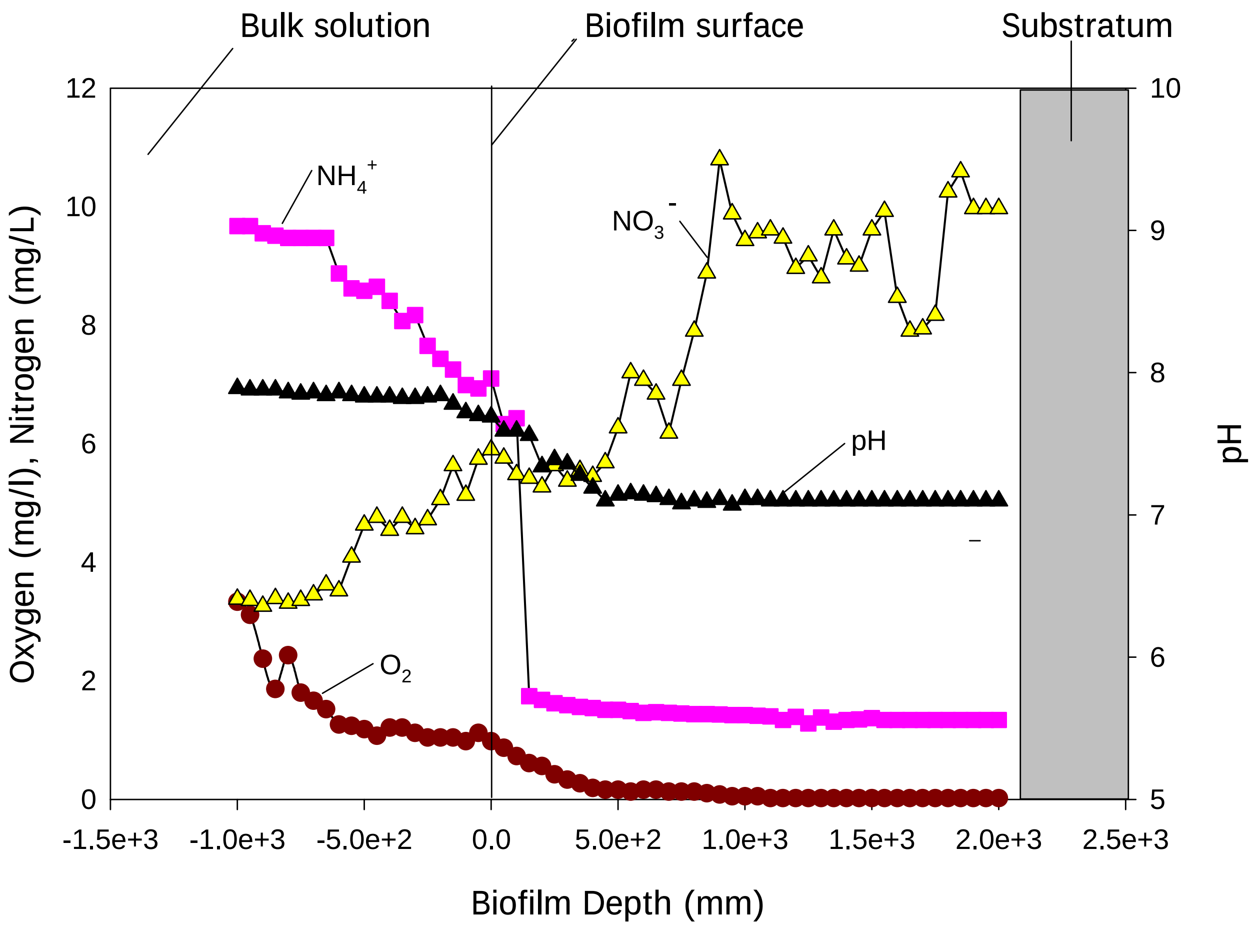
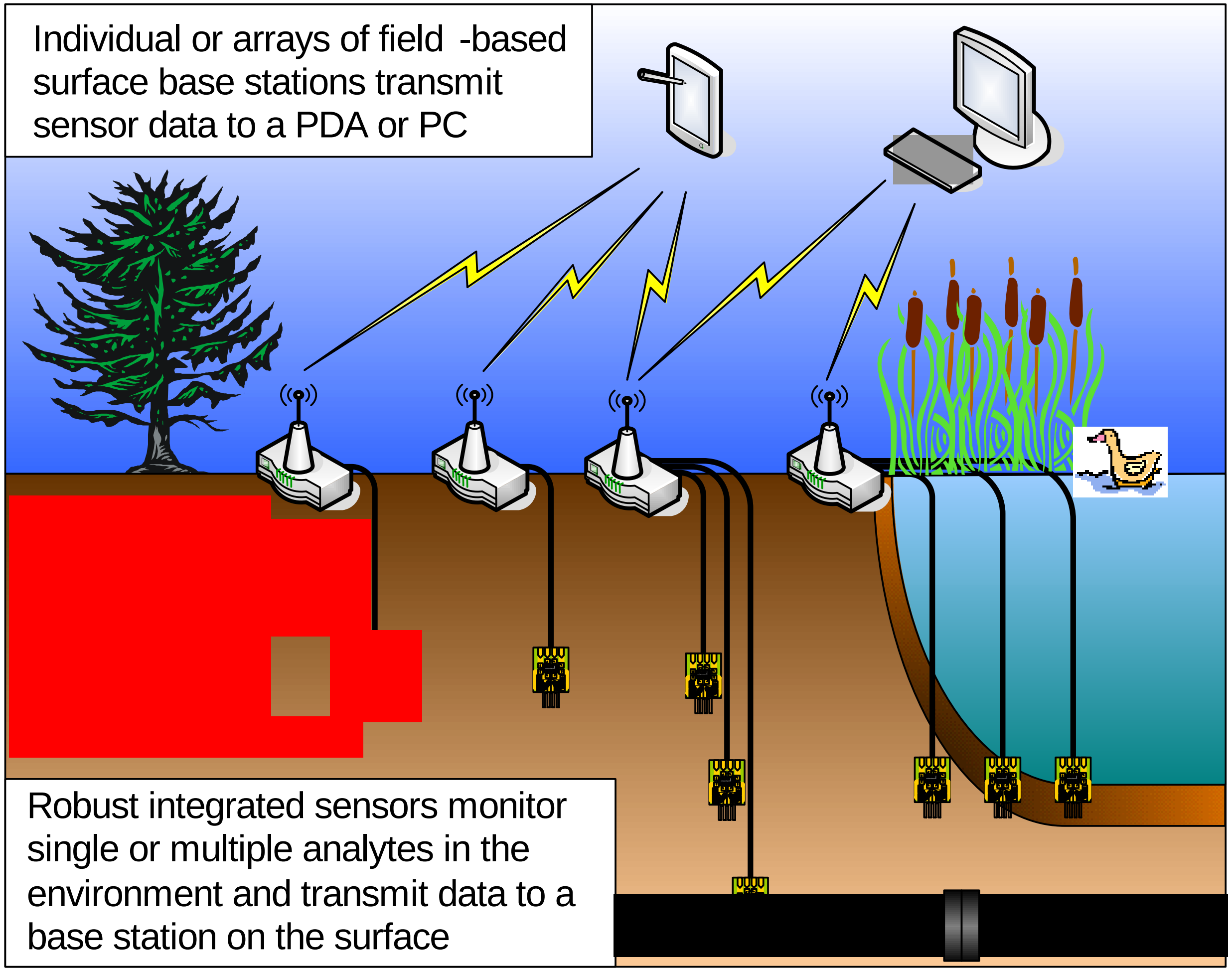
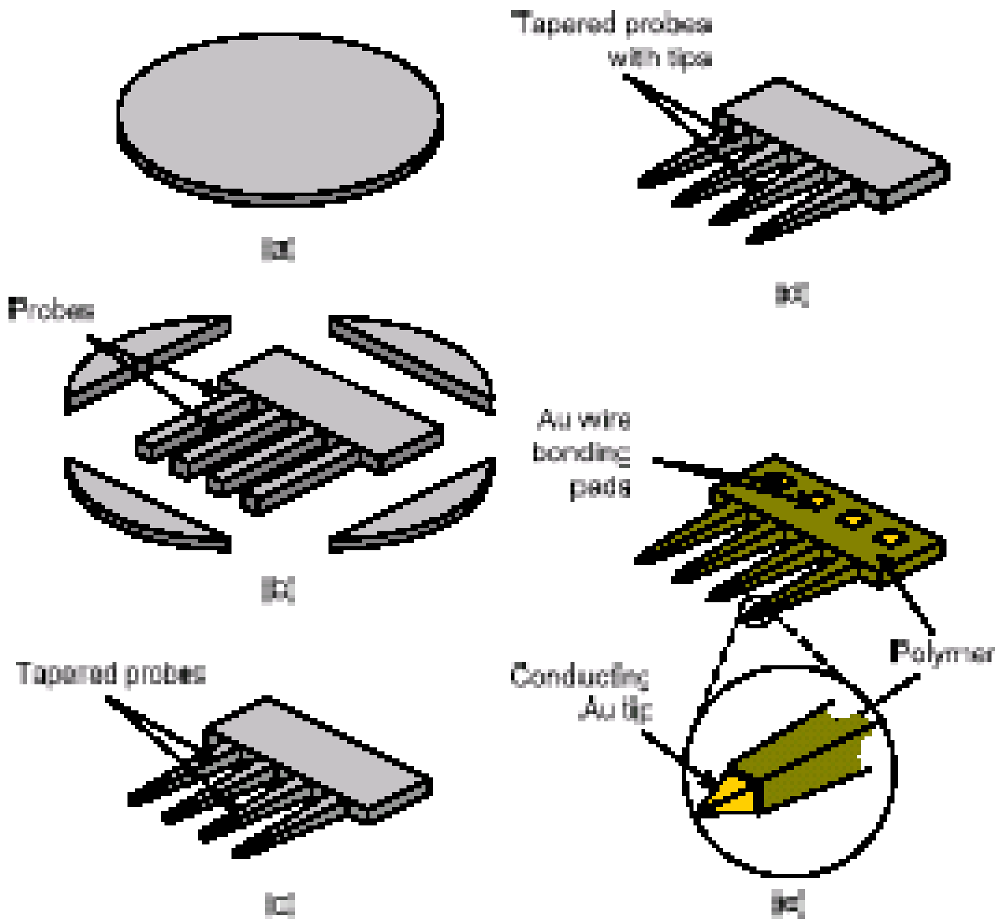
Microprofiles in an Aerobic/Anaerobic Biofilm



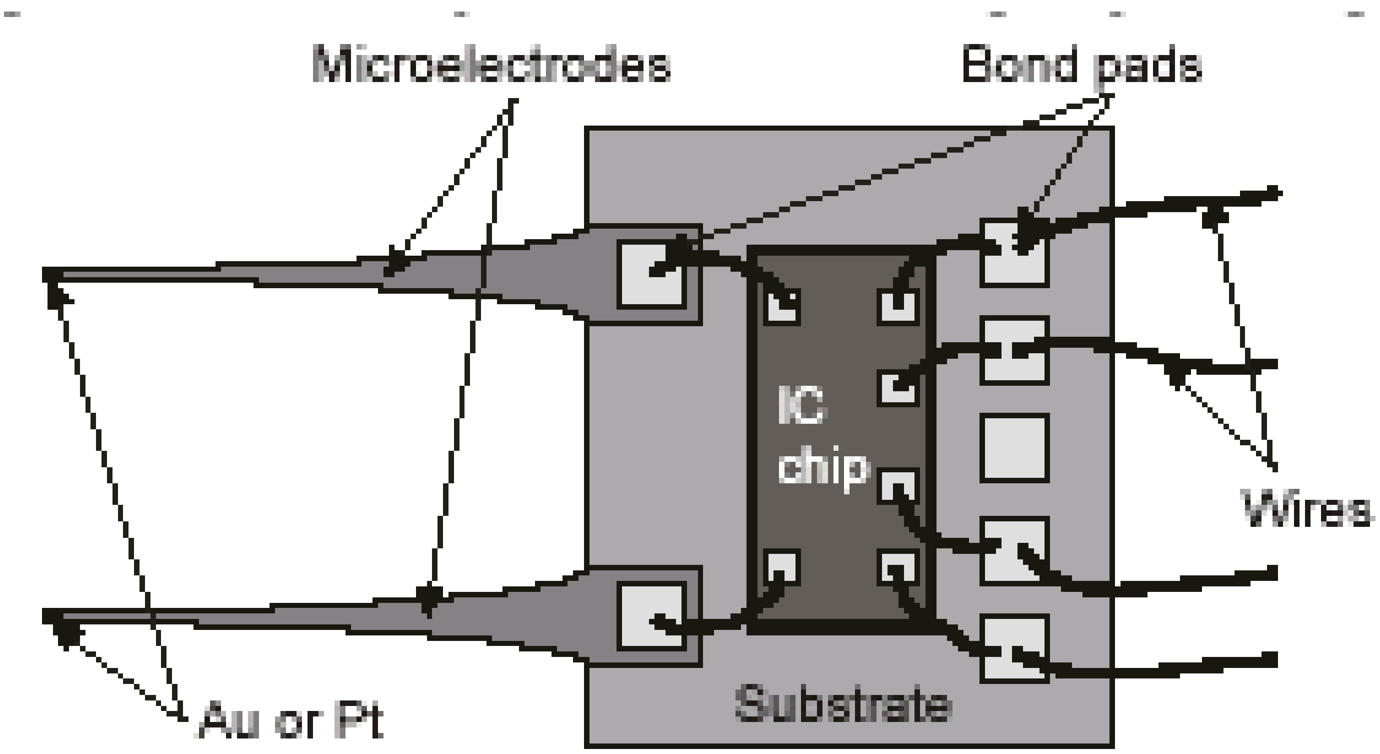
Proposed Field Array of Microsensors



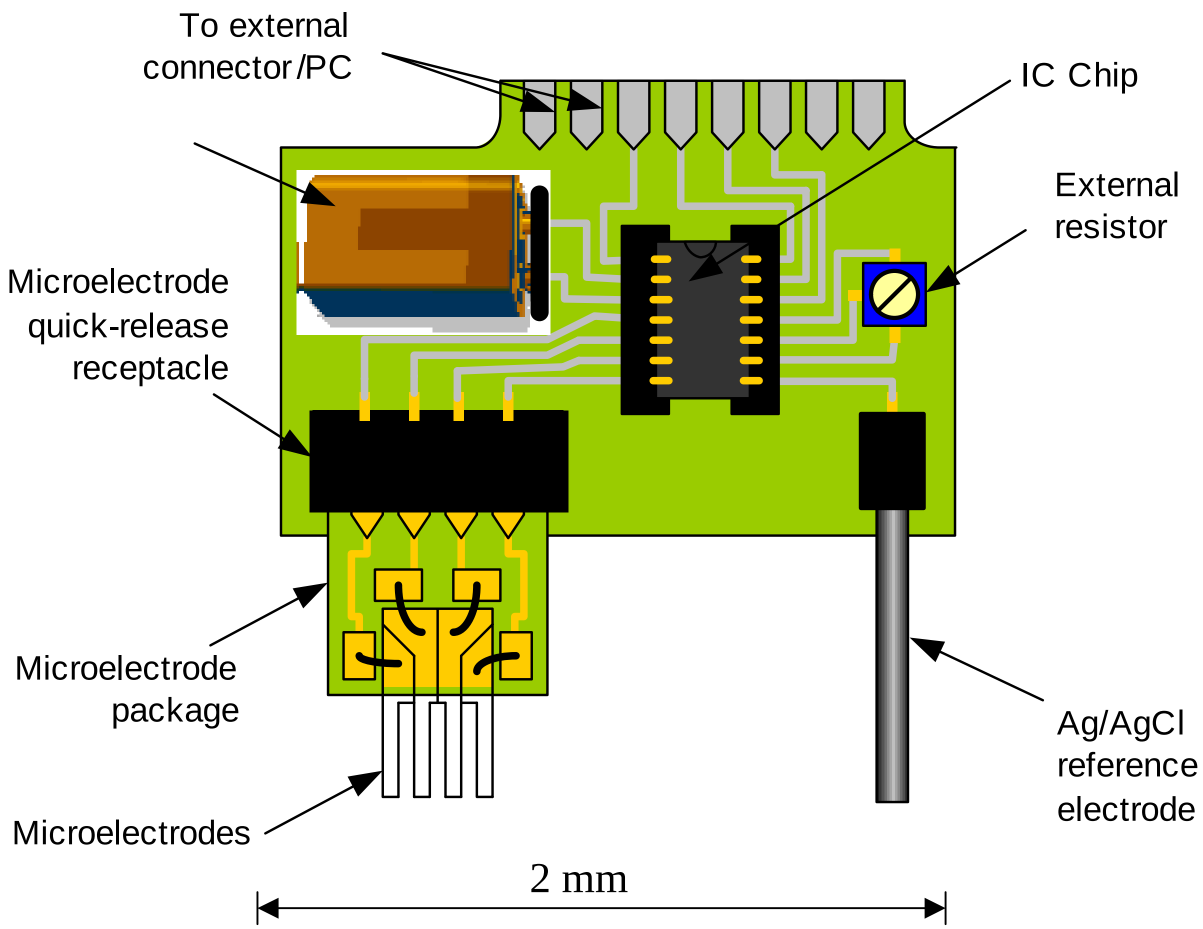
Microelectrode production process



Microelectrode connected to signal processing chip



Proposed new generation microelectrode



Summary

- PAHs are significant problems at Superfund sites, but can be controlled using in-situ bioremediation
- More research must be done on PAH bioremediation using complex mixtures of PAHs, metals, surfactants, etc.
- Biowalls have potential for PAH remediation
- Microelectrodes can be very useful for bioremediation research