Innovative Solutions for Stormwater and Wastewater Management

ENHANCING SAFETY AND PUBLIC HEALTH

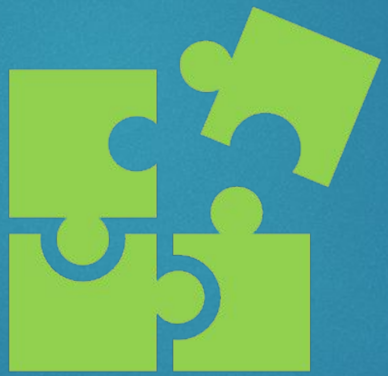
STELL

Introduction
Stormwater and Wastewater in Urban Settings

- Climate change issues
  - Drought
  - Flooding
  - Groundwater over-extraction
- Emerging contaminants, pollution management
  - Water degradation
  - Insufficient wastewater treatment
  - Ongoing damage to ecosystems
- Population expansion 1.2% per year, increased pressure on water quality, safety, health
  - Waterborne diseases
  - Poor investments, ‘silo’ solutions that don’t work long term
  - Economic considerations of infrastructure maintenance
  - Unsustainable development
  - Industrial pollution and nutrient overload for surface waters
- Emerging technologies and sustainable policy development

Objectives
Ecological Engineering Policy for Innovation

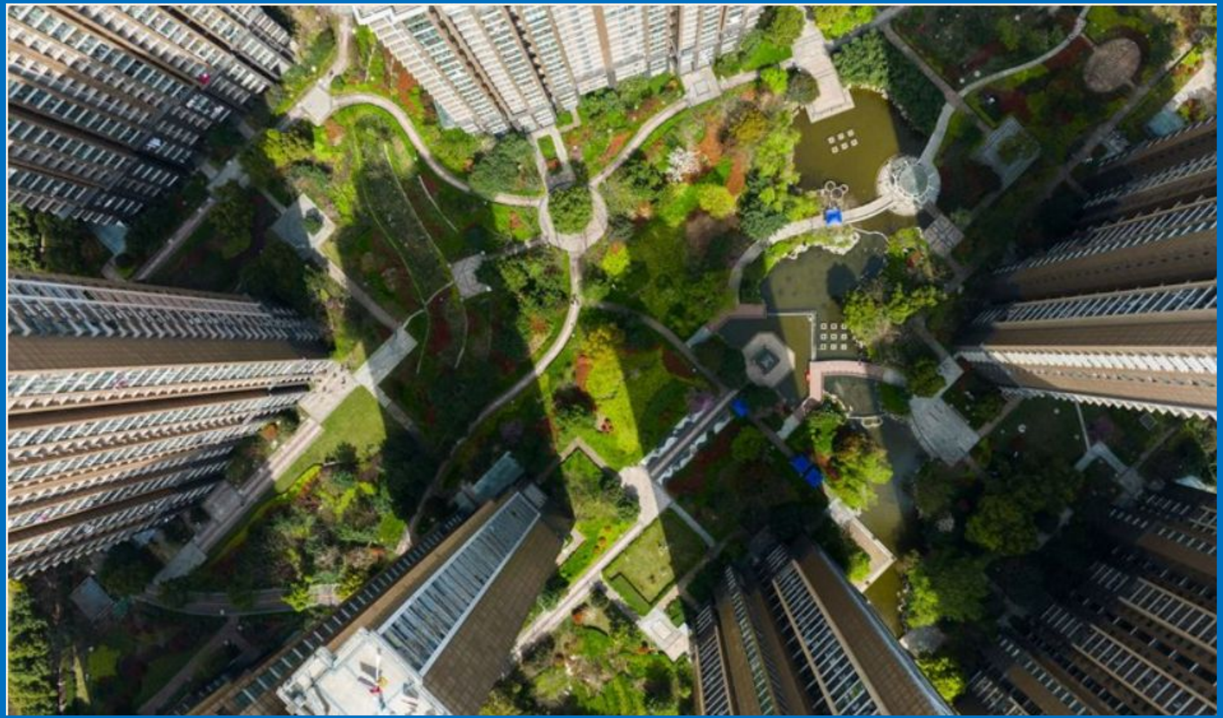
- Sustainable Development Policy
  - Getting the most from investments
  - Cost-recovery
  - Improve quality of life
  - Infrastructure planning that works
  - Allocating water strategically
  - Integrate environmental compliance, engineering, and infrastructure planning
  - Prioritize investments with environmental, social, technical, economic, and commercial interests



- Innovative Technology Implementation
  - Recycled water – integrate stormwater, wastewater, drinking water solutions with fit-for-purpose treatment methods
  - Source reduction
  - Pollution treatment, pollution prevention (air, water)
  - Conventional
  - Unconventional

Policies Supporting ‘Build with Nature’ Engineering

- Blend infrastructure and environmental into cohesive whole
- Promote human connection with nature
- Improve quality of life as well as water quality
- Reduce pollutant loadings, reduce water discharge requirements, improve air quality and pedestrian spaces, sustain pollinators and promote ecosystem health
- Biomimetic design can bridge disciplines by imitating natural processes, reducing installation and maintenance costs, can provide self-healing systems, provide ecosystem functions, and add to quality of life.
- Expand distributed water treatment systems in area-limited cities, reduce energy needs, and support flexible urban planning
- Case Study: Singapore



Technologies – Conventional (Source Reduction, Treatment)

- Rainwater harvesting and permeable pavement residential/commercial solutions (source reduction)
- Green roofs, green walls (source reduction, pollutant uptake)
- Gross pollutant traps
- Vegetated swales, useful for passive soil and water remediation, some pollutant sequestration
- Constructed wetlands provide huge nutrient removal gains
- Vegetated bioinfiltration can encourage biofilms and specialized ecological engineering
- Biofilters using phytotechnologies

CASE STUDY: The Efficacy of Using Microbes, Fungi, and Plants in Passive Removal of Polycyclic Aromatic Hydrocarbons and Heavy Metals And Integrated Produced Water Management in a Desert Oilfield Using Wetland Technology

USING MICRO AND MACRO ECOSYSTEMS FOR POLLUTION PREVENTION, STORMWATER TREATMENT, AND SURFACE WATER PROTECTION

Introduction: Combining constructed wetlands principles on large and small scales

- Microbes currently used, but problematic
- Typical constructed wetlands require too much land
- Disposal is either not available or too expensive for contaminated water/soils
- Using large and small together = source load reduction, volumetric flow reduction, nutrient and pathogen passive removal

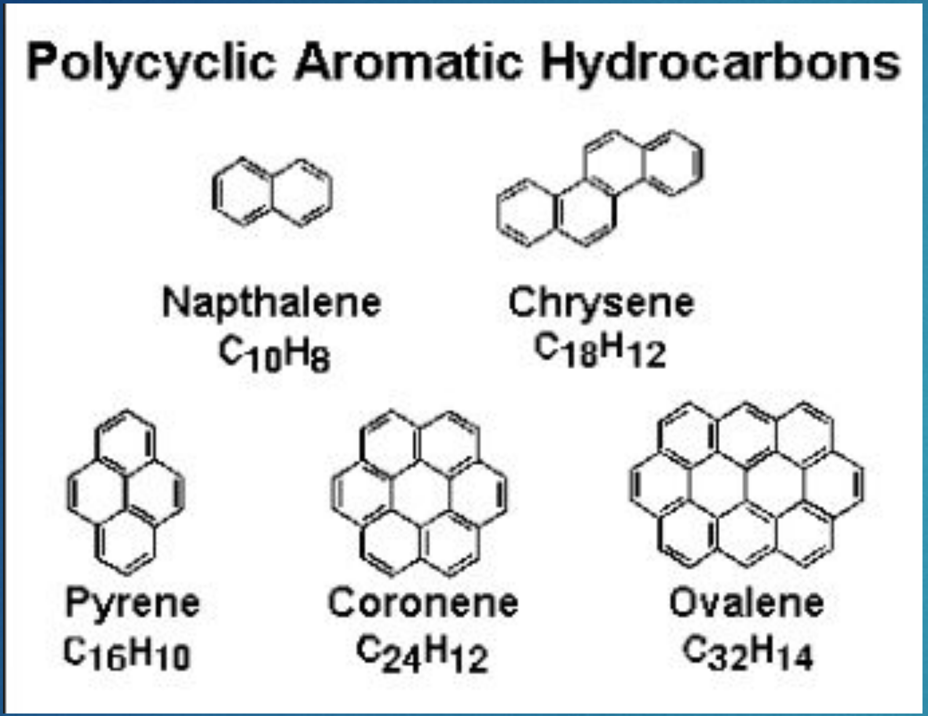
Example Infrastructure Application: Bailey Yard, Union Pacific Railroad.
Largest yard in the world, over 2850 acres and over 10,000 cars handled per 24 hrs

Contaminants of Concern

- PAH – complex and resemble lignin
- Nitrogen, Phosphorus, sediment
- Heavy metals

- What we care about:
  - PAH (comes in diesel fuel, kerosene, gasoline, and engine oil at most industrial areas)
  - Metals, zinc, lead, and cadmium, in particular
- Very similar to heavily urbanized area stormwater concerns

What a PAH looks like:

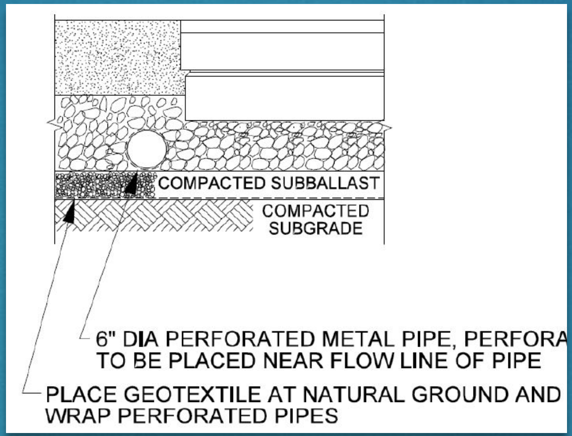


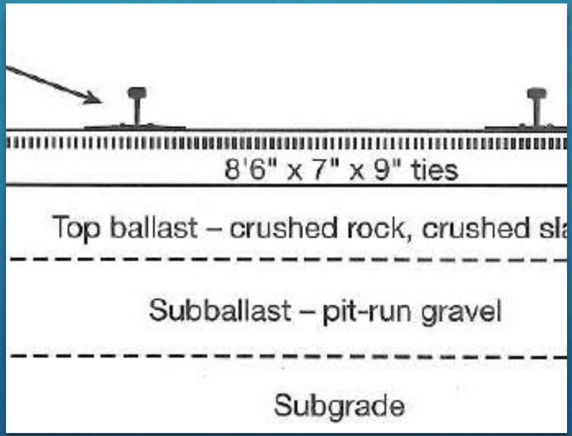
Chemically

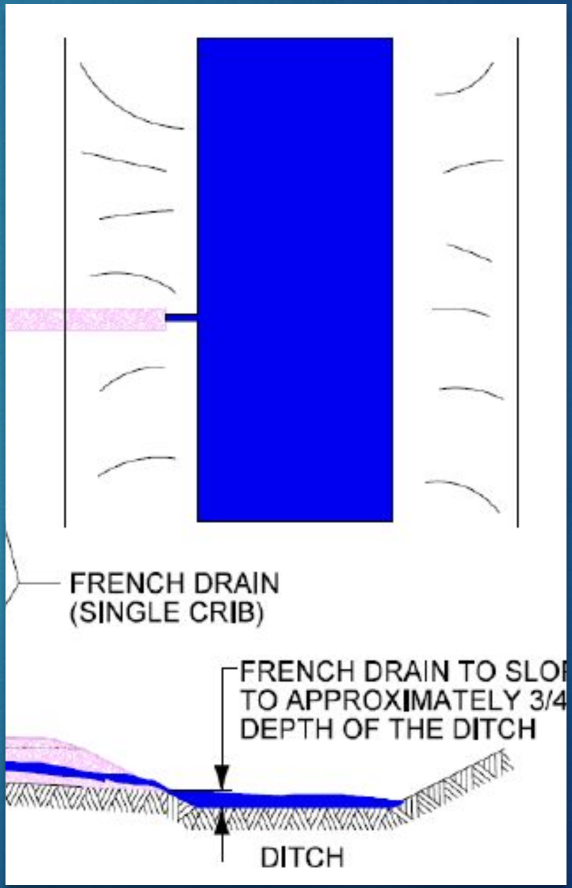
In the field

Pilot Test Structure 1: Use constructed wetland principles with existing infrastructure to reduce costs and improve contaminant uptake

- This is the road bed the test is imitating. Note the subgrade and ballast compacted with a drain in the upper right. The test described is a close approximation to this set up.
- A similar structure could be used with conventional 'green infrastructure' to encourage more plants and microbial systems to thrive.

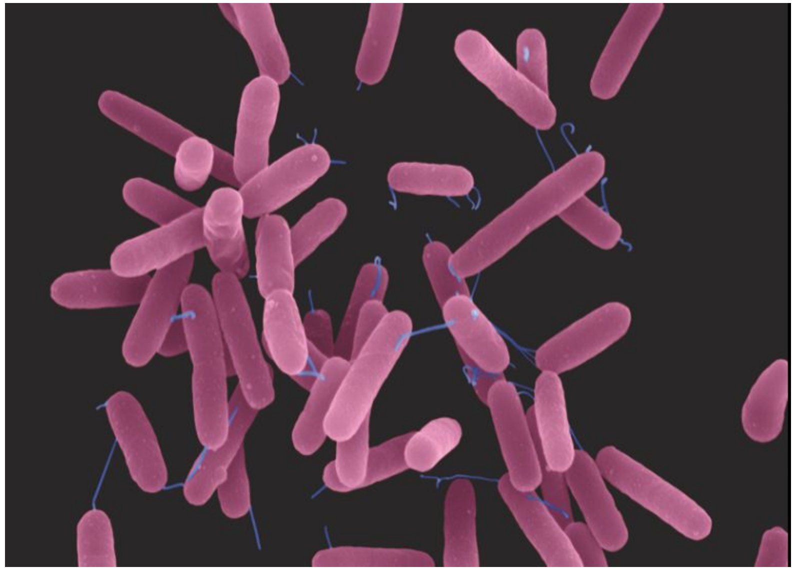






Selected Species

- Saprophytic Fungi
  - Pleurotus ostreatus
  - Aspergillus niger
- Arbuscular Mycorrhizal Fungi
  - Glomus claroideum
  - Glomus brohultii
- Microbes
  - Pseudomonas aerginosa PA01
  - Geobacter sulfurreducens
  - Kluyvera ascorbata SUD165
- Plants
  - Sedum alfredii
  - Pteris vittata
  - Arabidopsis halleri
  - Elsholtzia splendens



Sedum alfredii Hance

Arabidopsis halleri

Pteris vittata

Elsholtzia splendens

Research Hypotheses

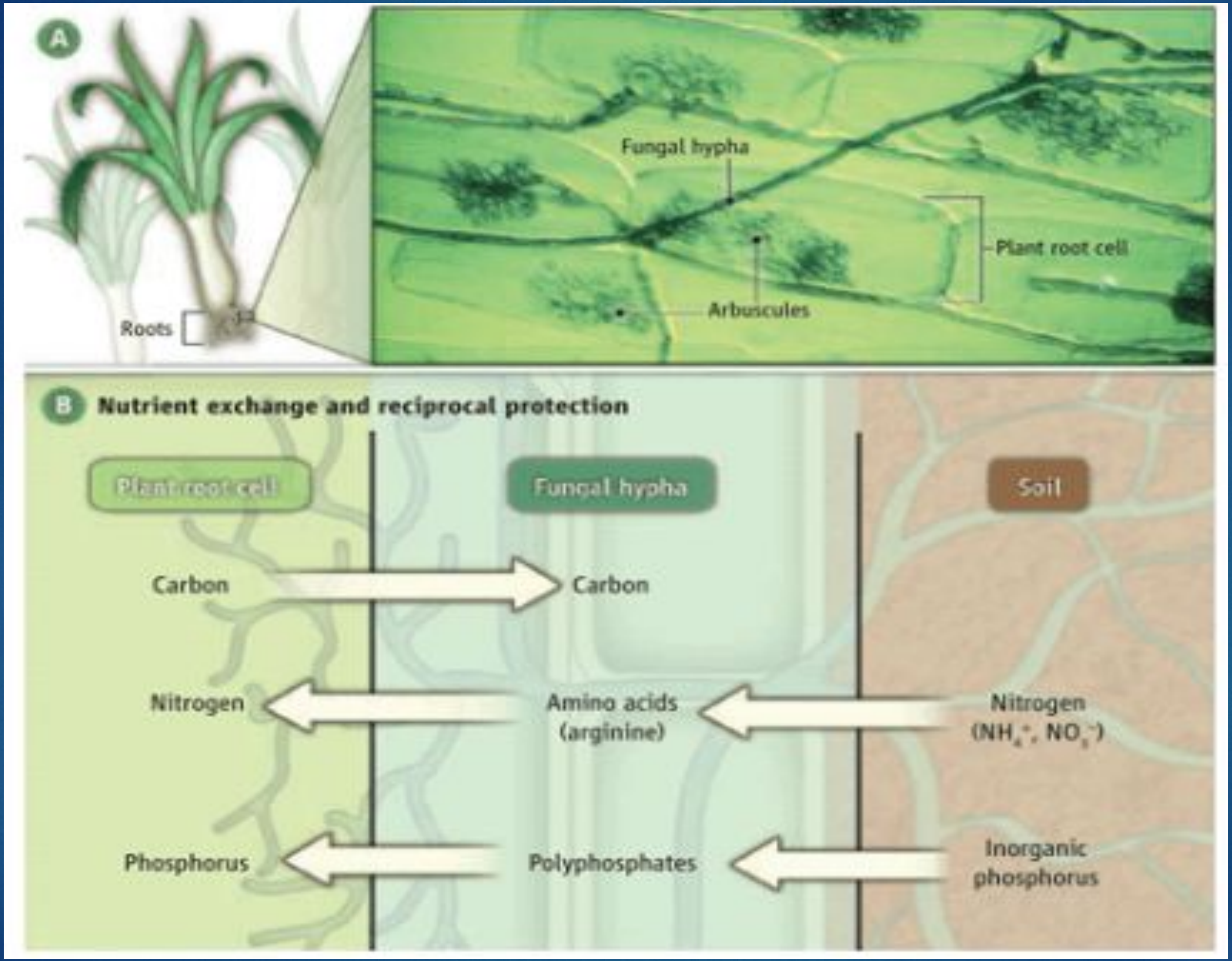
Bacteria can degrade PAH, but are sensitive to water quality, amount, and contaminant loading

Plants can metabolize more organics and provide metal hyeraccumulation under variable moisture conditions and flows, but are sensitive to contaminant loading and do not influence E. coli levels.

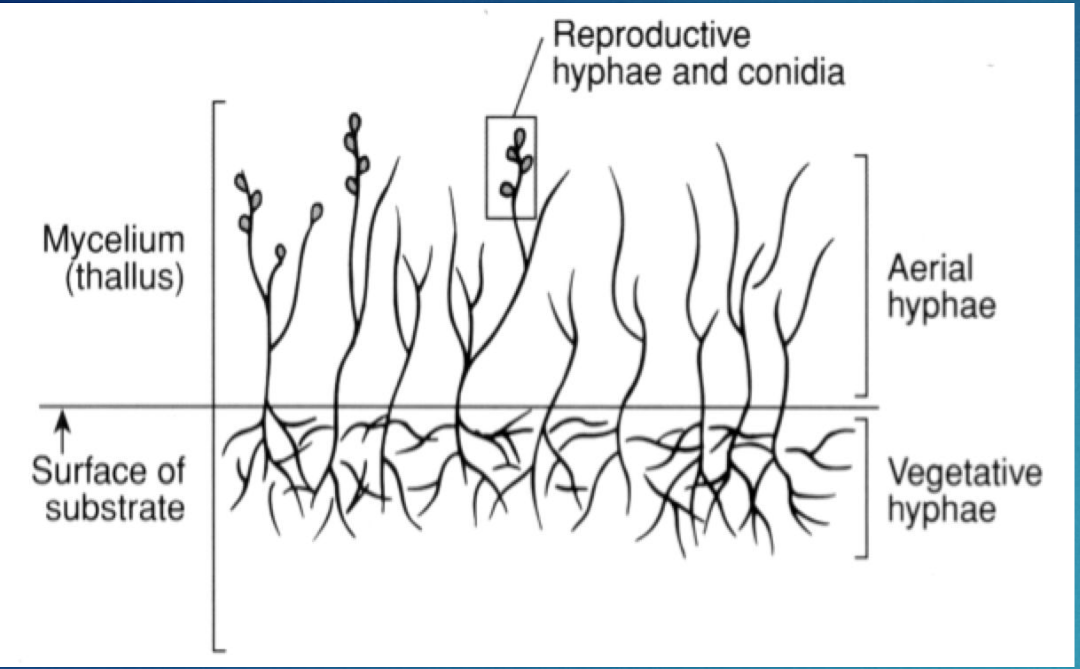
Fungi are tougher, provide more nutrient transfer, but metal management still challenging. Fungi encourage protozoa that consume E. coli and can provide the framework for biofilms on infrastructure that can stabilize moisture content and nutrient availability.

Ecosystem Management

- AM fungi can move or metabolize mineralized byproducts from the saprophytic fungi
- This feeds more nutrients to plants
- Takes out contaminants from the soil column

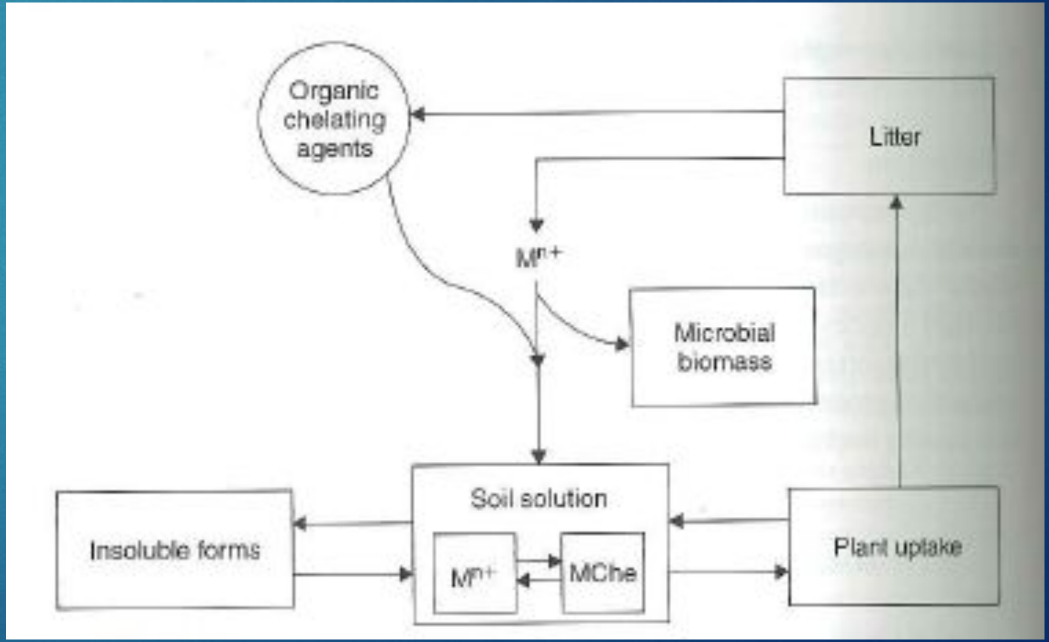


On big and small scales, wetlands and microbial ecosystems move nutrients



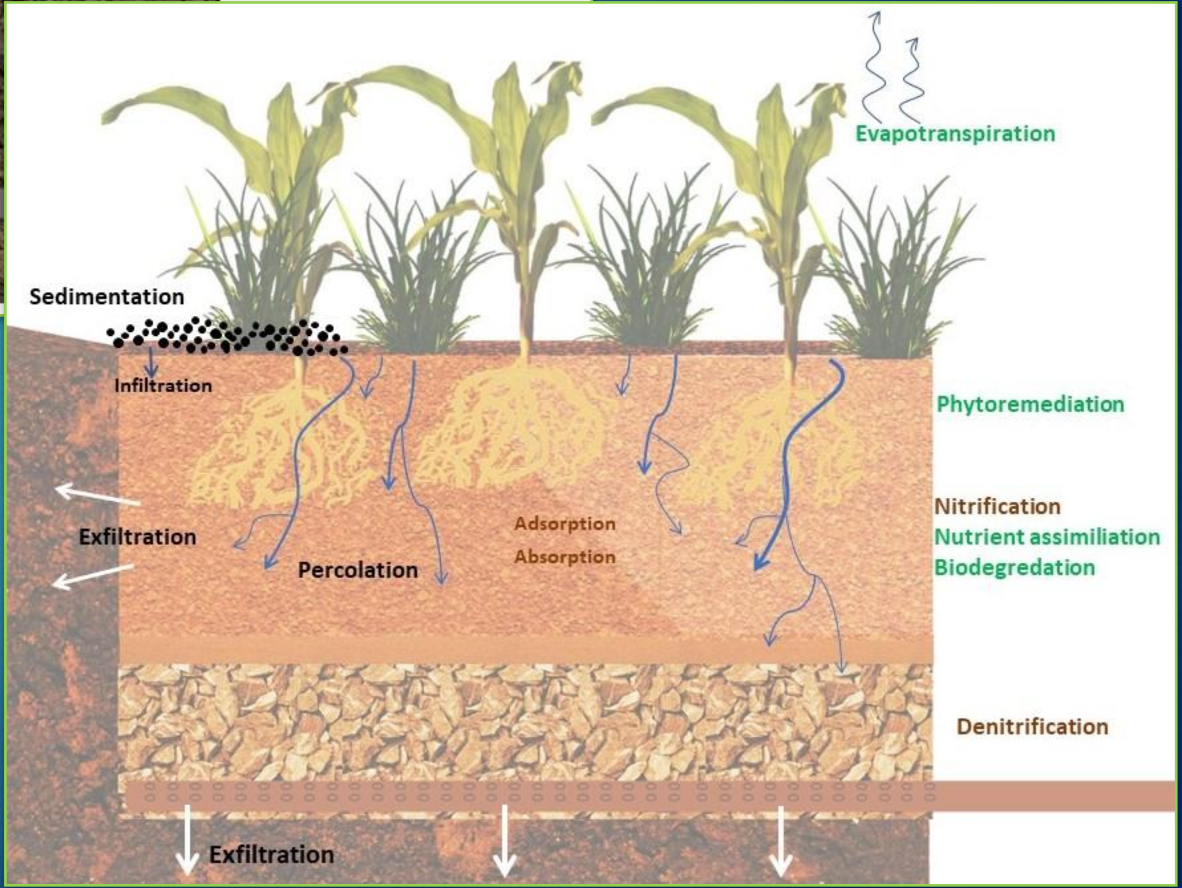
Mycelia morphology: same or similar morphology on big or small scales. Constructed wetlands work the same as microscopic ecosystems and biofilms, just with greater loading and flow rates (and often availability of sunlight)

Metabolic process exploited here for metal hyperaccumulation



Bioretention Cell (BRC) – Schematic:

Optional discharge pipes can lead to additional water storage zones, such as a cistern or surface water outlet



BRC – Fundamental Mechanisms:

- physical (black label),
- biochemical/chemical (brown label)
- biological (green label)
- Infiltration/percolation (blue arrows)
- exfiltration (white arrows)

Results: ***Traditional Macro-Constructed Wetlands Microsystem Infrastructure Innoculation***

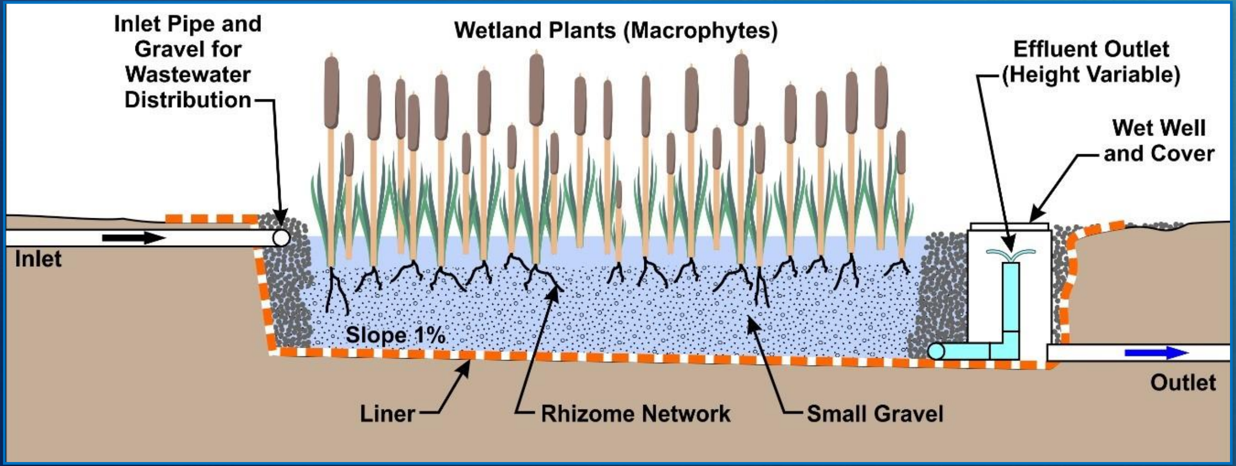
- Plants can move those metals into their vacuoles or consume and remove from the soil column
- We can then process them as solid waste
- Dig and dump costs over a million dollars per ton and assuming a small site of 10 acres can generate well over 180 tons, loss of soil, loss of habitat, and loss of land may be unnecessary.
- Inexpensive perennial landscaping and grasses monitored for water flow rate, water quality, soil quality, leaf sampling, and dry weight of annual grasses

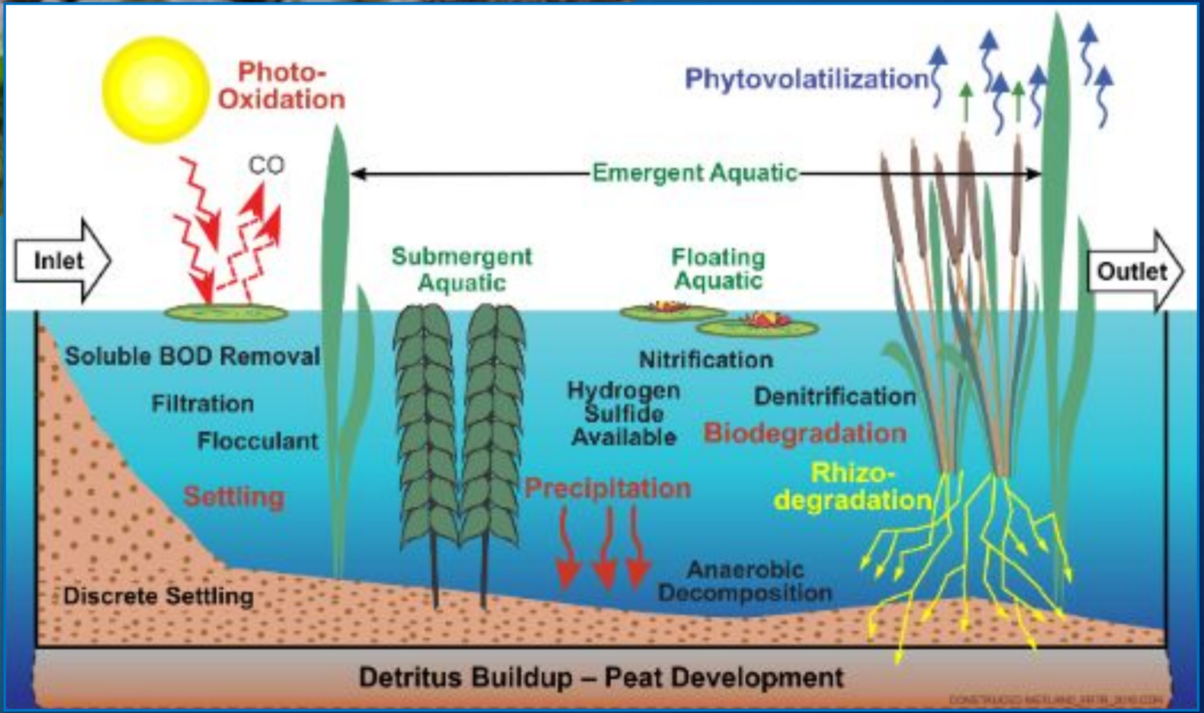
- AM fungi infected plants showed 95-125% increase in heavy metal uptake, 'free-of-oil' effluent (up to 97% reduction in laboratory tests)
- Potential for phytomining using heavy accumulator plants
- Survival rates between 60-90% in constructed wetlands for 115,000 cubic meters/day flow rates
- 360 ha Surface Flow Constructed Wetlands, 500 ha of evaporation ponds (Oman)
- Wildlife habitat, migration corridor
- Reuse of treated effluent for irrigation from the facility approved for local distribution

Conventional Treatment – Biorentention

- Swales, including vegetated swales
- Example – Bioretention of stormwater from a downspout
- CWs, both surface flow (SF) and SSF

Ponds and lagoons may also fall into this category, with more water and different plant requirements

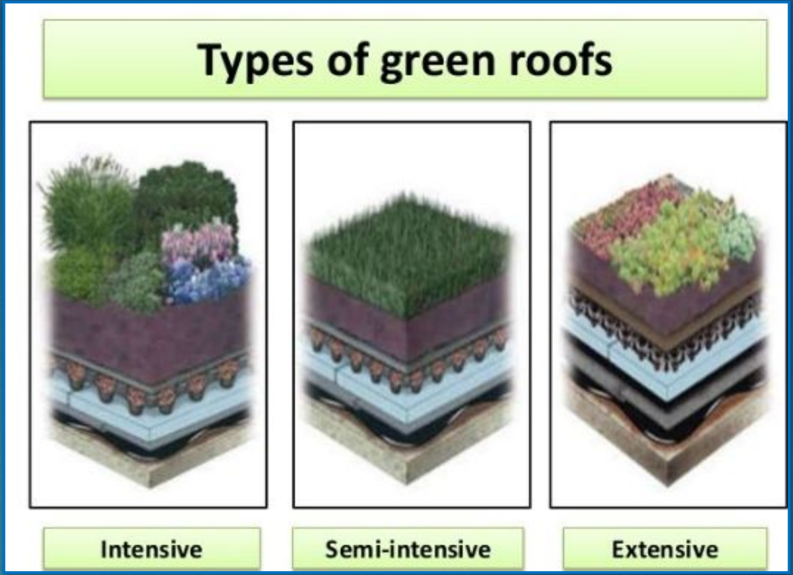




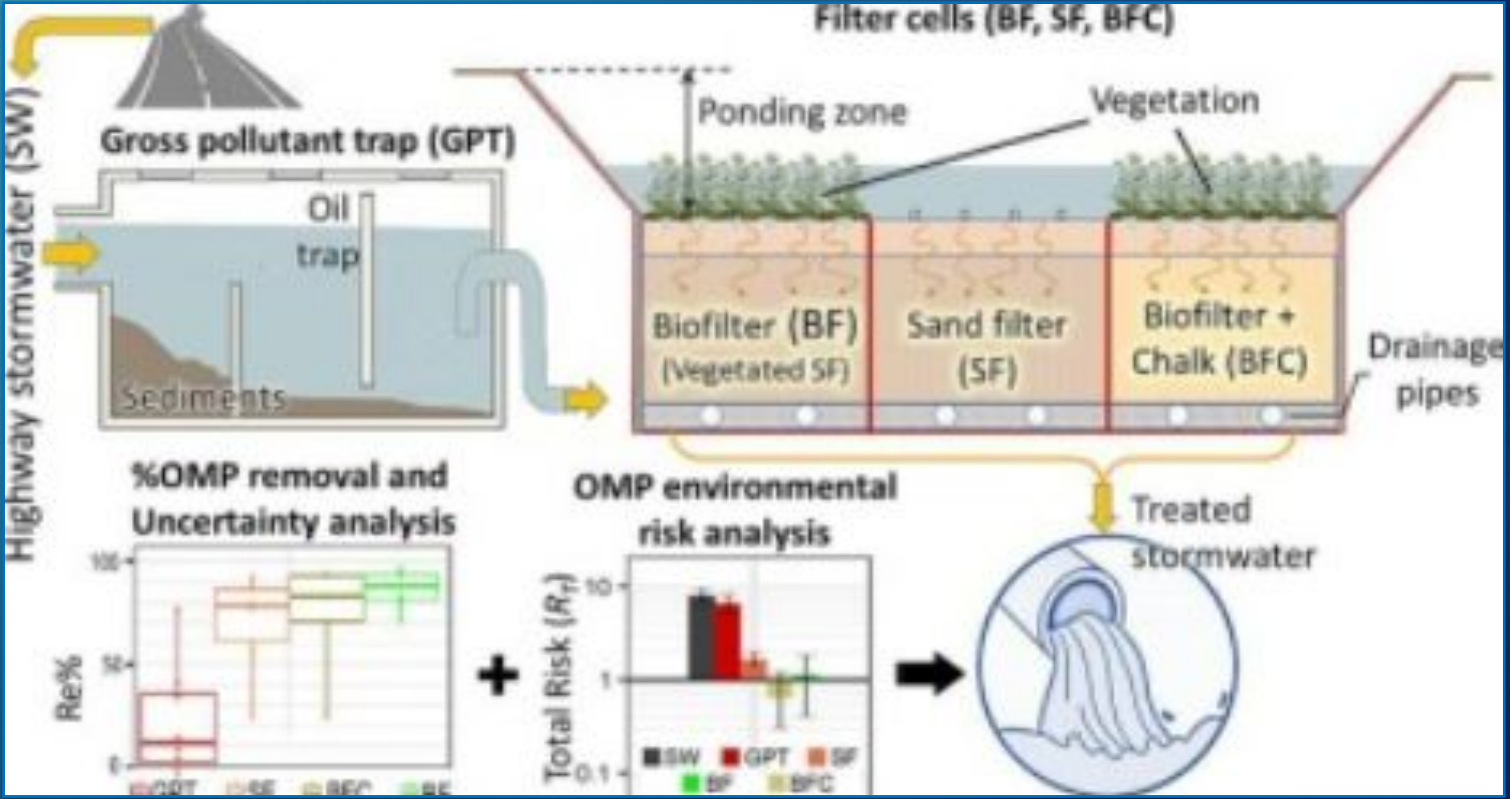
Conventional Treatment – Review

Source Reduction:

- **Gross pollutant traps (GPTs)**
- Permeable pavements with filtration
- Green walls/green roofs
- Biofiltration systems
- Many cities offer reimbursement or other benefits for installing source reduction systems on property, both industrial and commercial



green roofs (pictured) provide conventional source reduction via filtration, along with energy savings and counteracting the urban heat island effect



The Hope

- Constructed wetland principles are flexible, adaptable to many different contaminants, land uses, and climates
- Reduce expense and keep industrial activities humming
- Reduce human exposure to liability and maintenance activities
- Produce cleaner water, self-healing soils
- Provide habitat buffers and wildlife safe-havens for diversity and ecosystem resilience

Technologies - Alternative

- High-rate fiber filters (small footprint, high throughput)
- Deep bed filtration, packed bed filtration
- Membrane and membrane hybrid systems
- Sand/GAC filter with filter bed discharge, fluidized bed reactors
- Aerated gravel beds, fixed film reactors (for high septic contributions in places subject to ‘shock’ loading)
- Aquatic treatment systems (multi-purpose utilization of swamp fisheries, biomass production facilities, and seasonal agriculture using macrophytic plants within streams and slow-moving watercourses)
- Anaerobic digestion for high BOD loads in high amounts, generating biogas and bio-oil for energy recovery
- Combine with upstream detention, biofilters, or wetlands when available
  - Pictured: a peat-based, horizontal-subsurface flow (SSF) constructed wetland (CW) suitable for the foothills grassland ecoregion
  - Properly designed CWs can continue to remove ammonium, even in frozen conditions (Büngener et al 2023)

Conclusion

- Sustainable solutions are the best way to save money, protect public health and environment
- Green solutions require not only technology, but policy changes
- Long-term water resource protection will rely on unifying treatment methods and approaches

- Integrating infrastructure and ecological engineering applications can:
  - Save money
  - Increase pollutant removal and protection
  - Improve resource use
  - Improve quality of life
  - Improve relationships within communities
  - Cover more area for less cost