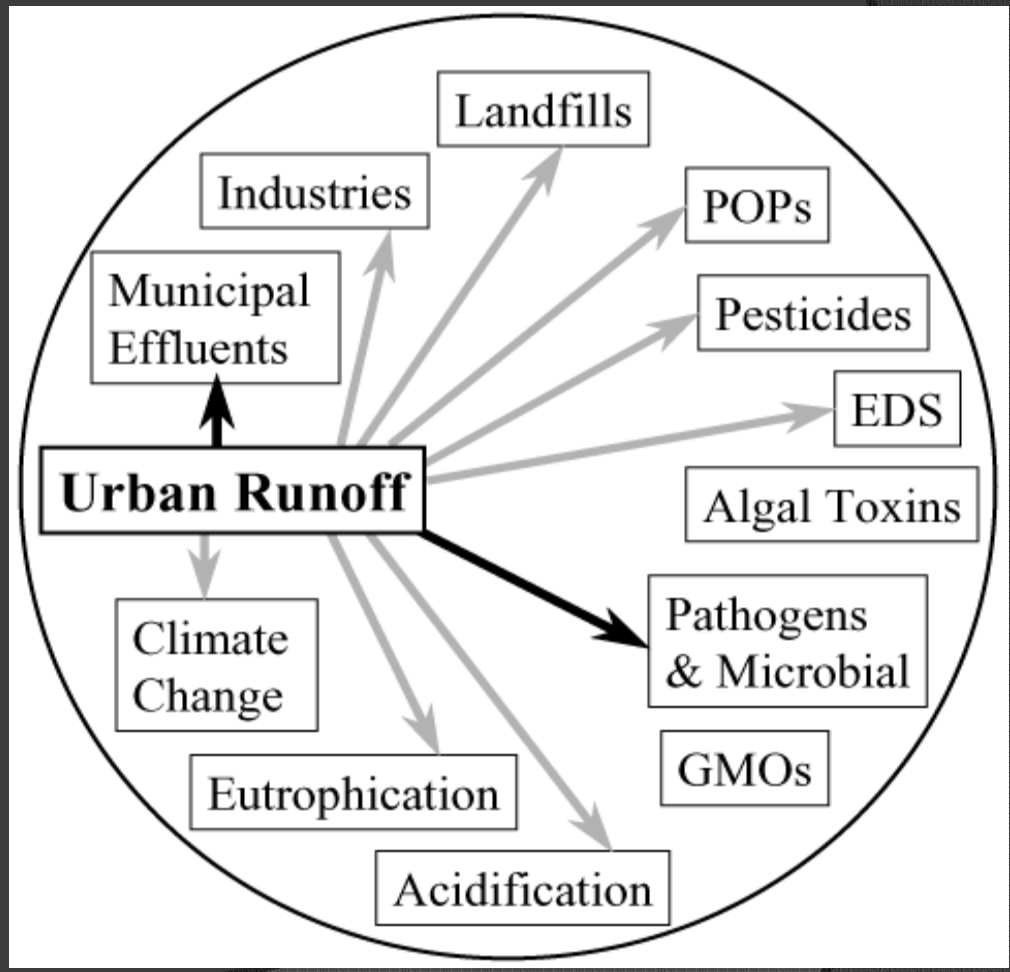
MANAGING EXPECTATIONS: A REVIEW OF POLYCYCLIC AROMATIC HYDROCARBON DEGRADATION AND REMEDIATION BEHAVIOR IN THE CONTEXT OF STORMWATER MANAGEMENT USING PHYTOTECHNOLOGIES

Julia Africa
Harvard Graduate School of Design
Masters of Design Candidate
Sustainable Design Concentration
December 3, 2009

What's wrong with this picture

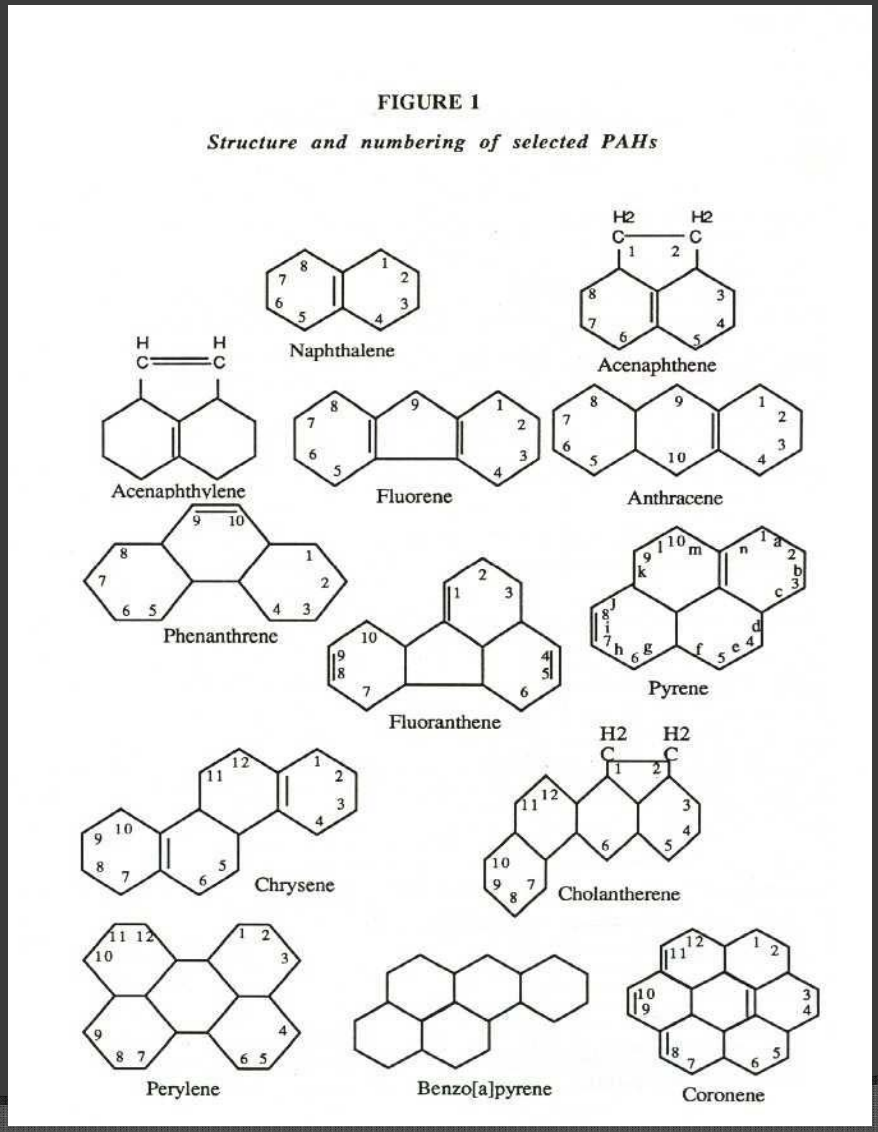
stormwater composition



polycyclic aromatic hydrocarbons

- Sources
- Structure
- Health impacts
- Mechanisms for degradation
  + microbial
  + fungal
  + plant-based
  + the ‘kitchen sink study’
- Some conclusions for swales and other urban applications

PAH structure



- PAHs are hydrocarbon compounds with one or more benzene rings bonded together.
- PAHs are produced by a wide range of anthropogenic and natural activities. As constituents of crude oil, refined petroleum products, and incomplete combustion of coal, oil, wood and other organic matter, they are widely distributed in the environment.

Common urban sources of PAHs

Health impacts

- **Benzene is a known carcinogen, and several other PAHs are suspected carcinogens** (Benz[a]anthracene , Benzo[b]fluoranthene, Benzo[k]fluoranthene, Benzo[a]pyrene, Chrysene, Dibenz[a,h]anthracene, Indeno[1,2,3-c,d]pyrene)
- **HMW PAHs have been demonstrated to suppress the germination and growth of plants**
- **Stream and estuary systems may be particularly vulnerable to surges of contaminated run-off.**
- **Health risks, as well as resistance to degradation, increase with number of benzene rings (~ molecular weight); the bioavailibility of PAHs is believed to decrease almost logarithmically with increasing molecular mass.**

Environmental behavior

- PAHs with log Kow values ≥ four are not considered to be mobile; PAHs with log Kow values ≤ four can bioconcentrate in the foodchain
- Conventional treatment methods of contaminated soil include incineration or the use of soil amendments (sequestration)
- Favorable PAH degradation circumstances include the presence of low molecular weight PAH species, recent PAH emission or deposition, moderate soil pH, presence of appropriate PAH degrading bacteria, and plants to facilitate decomposition by virtue of large surface area or uptake affinity

Microbial degradation

•Sphingomonas, Burkholderia, Psuedomonas and Mycobacterium bacteria
•Microbial amendments
•Biofilms
•Biosurfactants

(Johnson 2005; A Venosa, EPA)

Fungal degradation

Soil can be inoculated directly by mixing PAH-contaminated soil with organic matter containing mycelia of white rot fungi (Lestan 1996) which possess “an extracellular oxidative enzyme system capable of degrading high molecular weight polymeric compounds and facilitating their ultimate mineralization” (Harvey 2002)

Composting PAH polluting plants with white rot fungi

Oxidation by cytochrome P-450 in the digestive tracts of worms and other nematodes may produce metabolites that are more bioavailable than the host compound (Harvey 2002)

Plant-based degradation

- + Structural role: root exudates nourish microbial, bacterial and fungal communities
  + Optimal plant physiology: large below-ground root mass, small above-ground mass
  + LMW PAHs tend to be more phytotoxic than HMW PAHs (Henner 1999)
  - The bad news:
  →Plants may indirectly promote phystostabilization and decrease bioavailability in soil
  → PAHs sorbed onto soil particles are often too big to fit through cell walls
  → Lignification (limits on fine root hair growth and accelerated death)
  → Other plants (zucchini) secrete LMW organic acids, possibly as part of a nutrient acquisition strategy, likely increasing the bioavailability of PAHs

  Time limited capacity for PAH uptake = bad news for bioswales

...everything but the kitchen sink

- Huang, X-D., El-Alawi, Y., Penrose, D., Glick, B., Greenberg, B. (2004). A multi-process phytoremediation system for removal of polycyclic aromatic hydrocarbons from contaminated soils. Environmental Pollution. 130: 465-476.

- Landfarming (volatilization, photoxidation)
- "Plant growth promoting rhizobacteria"
- Microbial amendments
- Phytoremediation (tall fescue)

- Creosote-contaminated soil given this protocol exhibited a 95% reduction in total hydrocarbons and 78% reduction in 16 priority PAHs consisting of HMW species such as Benzo[a]pyrene, Dibenzo[a,l]pyrene,Benzo(g,h,i)perylene and Indeno(1,2,3-cd)pyrene.

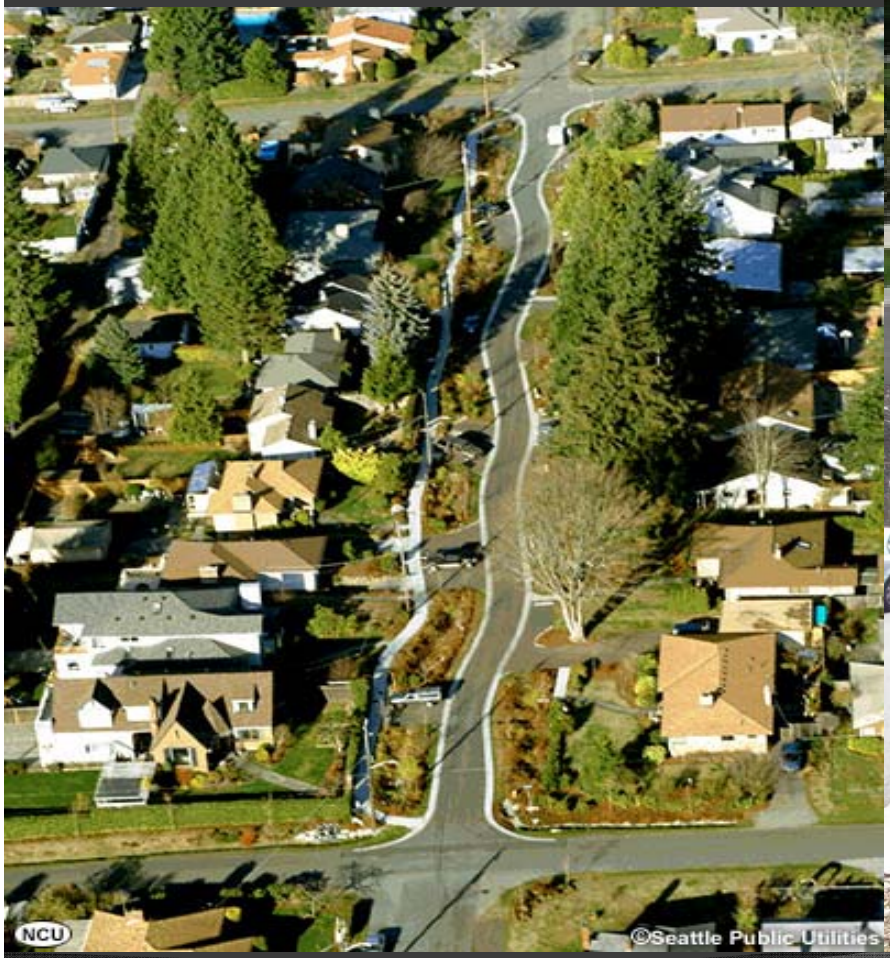
- Reporting issues

Plants studied for PAH tolerance

- Maize
- Ryegrass + Maize
- White Clover
- Creeping Red Fescue
- Tall Fescue (Festuca arundinacea)
- Perennial Ryegrass (L. perenne)
- Maize and Ryegrass
- Willows (Salix viminalis L. 'Orm')
- Tall Fescue (Festuca arundinacea)
- Wheat
- Perennial Ryegrass
- Alfalfa (Medicago sativa L)
- Ryegrass (Lolium perenne)
- Leek (Allium Porrum)

Cucumber (Cucumis sativus)
Onion (Allium Cepa)
Parsley (Petroselinium sativum)
Zucchini (Cucurbita)
Leek (Allium Porrum)
Reed (Phragmites australis)
Alfalfa (Medicago sativa L)
Hemp (Cannibus sativa L)
Mustard (Sinapis alba L)
Lupin
Oat + Mustard + Pea
Mustard + Oat + Cress
Ryegrass + Corn + Oat + Pea
Hemp + Mustard
Pea + Cress + Pansy

Implementation: Seattle's natural drainage system



http://www.seattle.gov/util/About_SPU/Drainage_&_Sewer_System/Natural_Drainage_Systems/Natural_Drainage_Overview/index.asp

E*vue

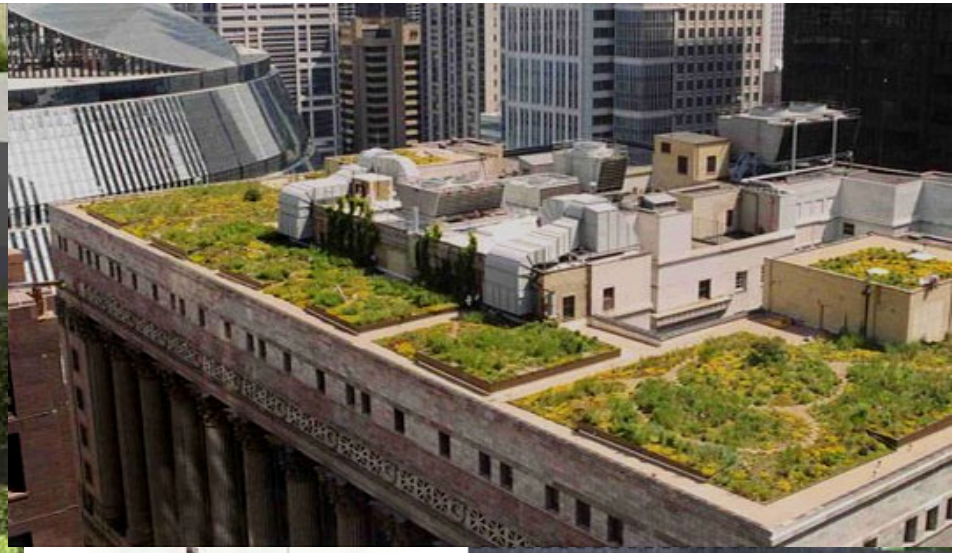
emergent vegetation of the urban ecosystem

"This website has two purposes: to help people identify the plants that are growing all around them, and to introduce the concept that many of these plants, despite being categorized as weeds, are actually performing important ecological functions in the urban ecosystem, such as water filtration, soil stabilization and pollution remediation."

Peter Del Tredici
Lecturer in Landscape Architecture
Harvard Graduate School of Design

Plants are classified by Latin Name, Common Name, Ecological Preference, Environmental Function, Cultural Significance

http://www.gsd.harvard.edu/loeb_library/information_system projects/E_vue/index.html



- How can we better exploit the potential for phytotechnologies in an urban context for low-level, mundane, ubiquitous urban pollutants?
- What is the lifespan of an urban swale (or vegetated filter), and what can we reasonably expect of soil, plants and microbes when rebounding from repeated inundation?
- Revising the expectation that 'the plants will take care of it' with more rigorous monitoring and appropriate expectations

http://www.clu-in.org/studentpapers/