Treatment Wetlands

Wetland Ecology BIOL 5870 11/14/2017

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Goal: Improve downstream water quality and (sometimes) wildlife habitat (Clean Water Act "*fishable and swimmable*" basis)

Wastewater treatment is usually regulatory driven:

- What are they main "categories" of wastewater
- What are the major types of treatment processes

Approaches & key acronyms:

- BAT/BEAT: *Best (economically) Available Technology* - remove pollutants to achieve end-of-pipe regulatory standards for point sources
- BMP: *Best Management Practice* – for diffuse non-point sources of pollutants such as agricultural or urban stormwater runoff.

3 Main types of wetland treatment systems

- Natural (sometimes partially engineered)
- Surface flow (open water) – SF or FWS (free water surface
- Subsurface flow (water not exposed) SSF, VSB (vegetated submerged bed; Reed Beds; vegetated gravel filter; vertical vs horizontal, et al.)

Pollutants

- Conventional
  - organic matter (measured as BOD_5)
  - suspended sediment (TSS, turbidity)
  - nutrients (N and P)
  - other major or minor ions sometimes (sulfate, chloride, Fe, total salt/TDS/EC25)
  - disease causing organisms: parasites, bacteria, viruses, …

- *Priority* Pollutants
  - Heavy metals (Hg, Cd, Pb, Cr, Ni, Cu, Zn,…), organic compounds (pesticides, PCBs, PAHs, petroleum-solvents, munitions, …………………….)

- Wastewater itself is also classified as *Domestic* (your toilet P&P, sink and laundry drains); *Industrial*; *Agricultural*; and *Stormwater*

WHAT IS DOMESTIC WASTEWATER

(re state/fed water quality standards)

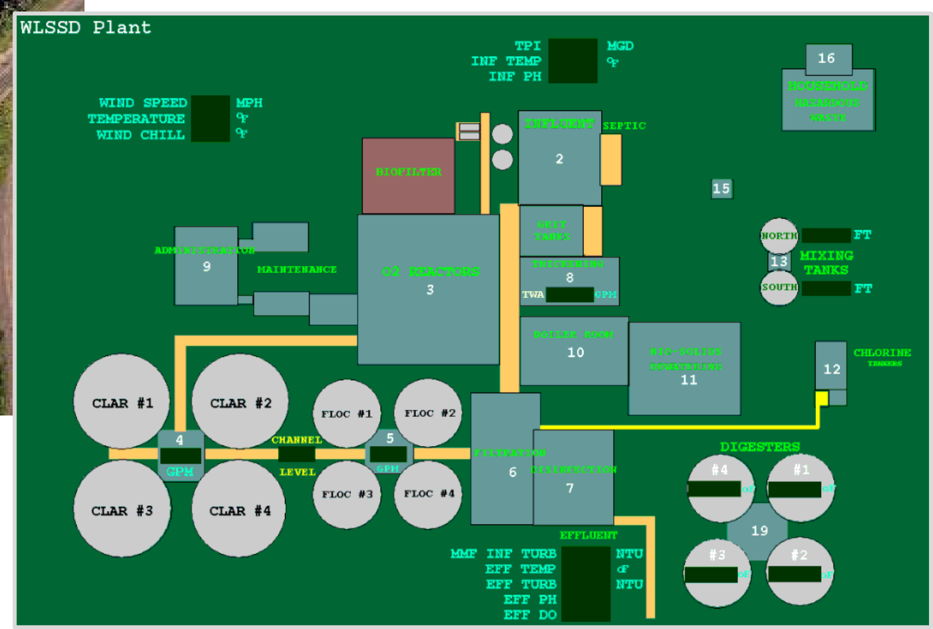
TSS (total suspended solids)	• smothers eggs and organisms; adsorption of P and contaminants • oxygen depletion
BOD5 (organic matter)	• eutrophication (+ direct O2 depletion)
Phosphorus (PO_4^{-3} phosphate)	• eutrophication
Nitrogen – NH_4^+ (ammonium-N) – NO_3^- (nitrate/nitrite -N)	• eutrophication • **O_2 depletion; toxicity to aquatic organisms** (ammonia) • **Methemoglobinemia** "(blue-baby" disease)
pathogens - bacteria, viruses, worms, protozoans	• Illness
contaminants (metals, pesticides, solvents, PCBs, PAHs…)	• Illness; toxicity to fish & wildlife; ecosystem "disturbance"

WASTEWATER TREATMENT PLANTS (BAT's)

PRIMARY	SECONDARY	TERTIARY (AWT)
mechanical settling & filtration	biological activated sludge	biological /chemical and mechanical
large solids removal (TSS)	organic matter breakdown (BOD)	N: $NH_4^+ \rightarrow NO_3^-$ (nitrification) $NH_4^+ \rightarrow NH_3$ gas (stripping; volatilization $NO_3^- \rightarrow N_2$ gas (denitrification) P: chemical precipitation, flocculation, settling, filtration, bacterial uptake contaminants (metals, pesticides, solvents, PCBs, …) disinfection

Scaling down from big cities to towns to little burgs to dispersed rural residences

- What are the costs per residence ?
- What are the operation & maintenance costs?
- Who can afford an Advanced Treatment Plant?



Small Community Sewage lagoons – passive treatment
(>300 in MN)

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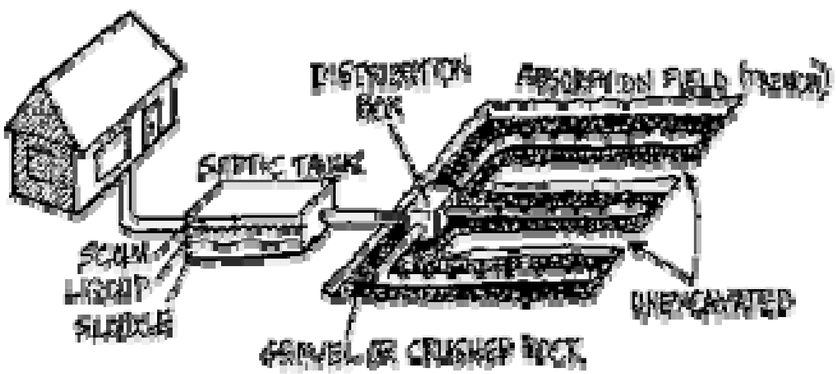
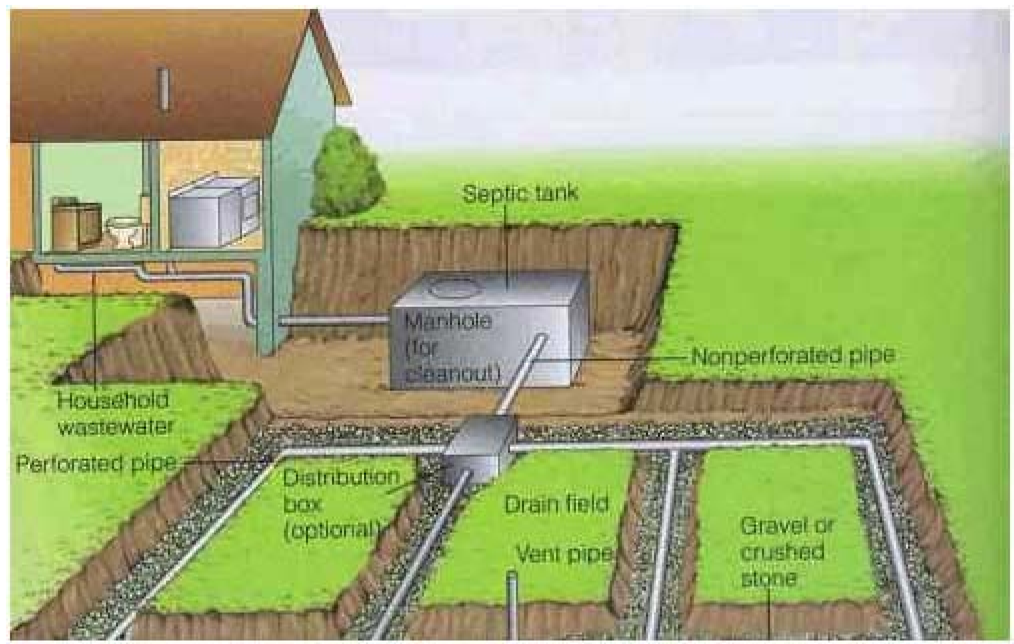


ONE TYPE OF ON-SITE SYSTEM



ON-SITE WASTEWATER TREATMENT

(Soil-based Best Available Technologies – BATs & BEATs)

PRIMARY (septic tank –solids)	SECONDARY (leachfield -organic matter)	TERTIARY (N,P, pathogens)
mechanical settling	biomat removes BOD	soil filtration of pathogens
grease traps	OK performance = not failing	P-adsorption to soil (Ca, Fe, Al "sites")
filters	soil filtration of TSS	NH4 ➔ NO3 (nitrification)
anaerobic digestion	aerobic decomposition by soil bacteria	NO3 ➔ N2 (denitrification if failing)
		vegetative uptake **(grass, shrubbery on leachfield)**

ON-SITE WASTEWATER TREATMENT

PRIMARY (septic tank)	SECONDARY (organic matter)	TERTIARY (N,P, pathogens)
TSS ~100 ppm	OK (<30ppm)	Not usually a design consideration
BOD_5 ~150 ppm	OK (<25ppm)	
TP ~10-20 ppm		<u>P-removal</u>: dependent on soil type & structure
TN ~50 ppm N NH_4 ~40 ppm N NO_3 ~0 ppm (anaerobic)		<u>N-removal</u>: nitrate mobility to GW
High fecal coliforms		<u>Fecals removal</u>: ultimately <200 cfu /100 mL at “some “ distance

Northern Minnesota: APPLICATIONS

- ~30 % of MN residences utilize individual on-site septic treatment systems

- >70 % in non-compliance (~ 340,000)

  ~ 58% along northshore of Lake Superior <u>failing</u>

- ineffective (at disinfection) when:
  - soil too porous (sandy)
  - soil too fine textured
  - < 3 ft of unsaturated soil
  - your wilderness site is clear-cut to make room for your leachfield

THE PROBLEM (cont)

- Septic tank + Leach field not designed for nutrient removal
- ineffective at P-removal when
  - soil adsorption low (e.g. sandy)
  - soil channelized (short circuits to ground /surface water)
- ineffective at N-removal when
  - almost always unless leachfield is enormous
  - NH4 transformed to NO_3 which leaches into GW
- impact on lakes and streams
  - >400 resorts in NE MN alone
  - recreational lakes
  - nearshore zone of Lake Superior

Issues & Problems

- 30% of Minnesotans use onsite (decentralized) septic treatment systems
- 50-70% failing or improperly designed (~350,000 residences)
- 'Limited' soils, wet spring, high water table, frozen soils, small lots, sensitive water supplies nearby
- immediate public health hazards
- longer-term nutrient /eutrophication
- development pressures on lakes
- conventional systems not working and no alternatives allowed

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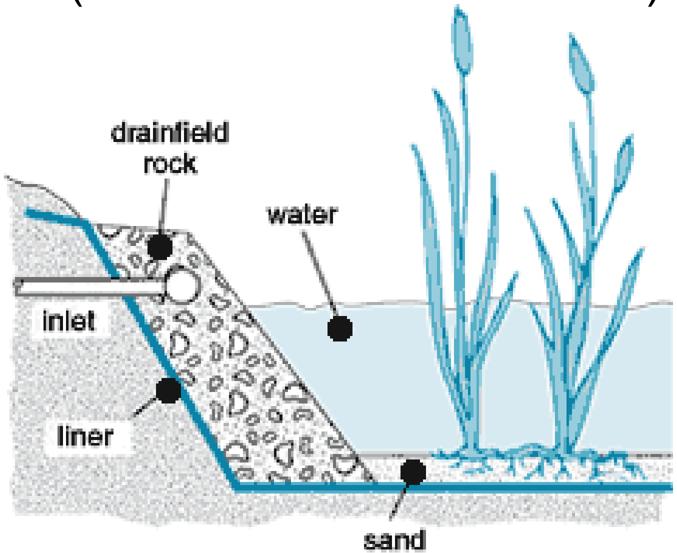
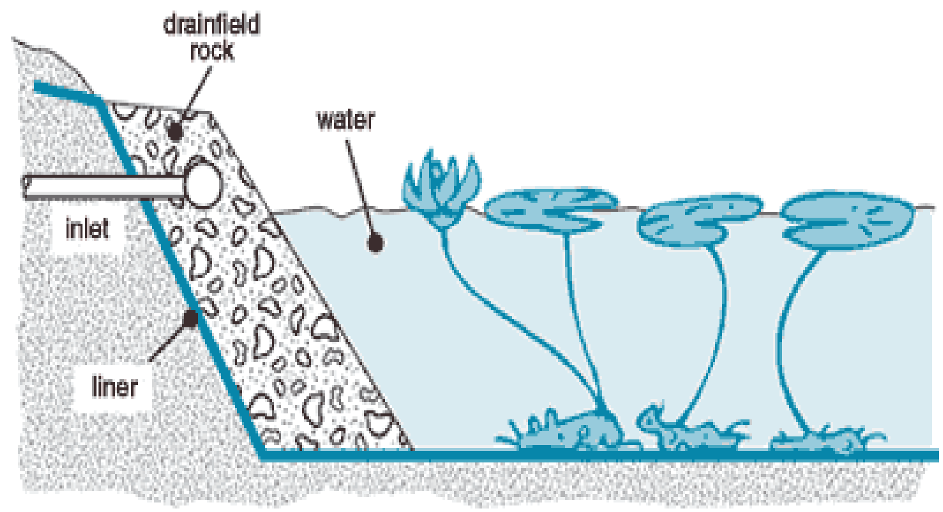
Advantages & Disadvantages of each?

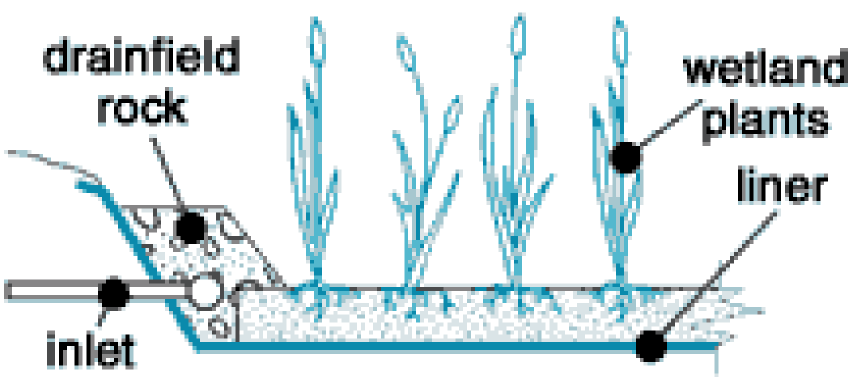
Varieties of Constructed Wetlands (CWs)

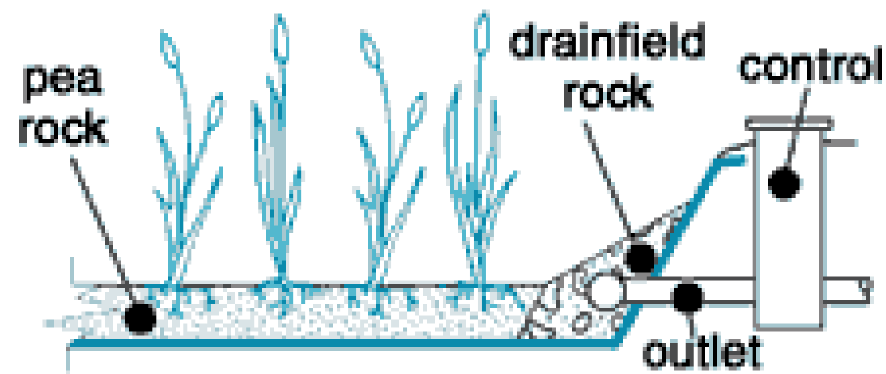
Open water SF wetland
(Free water surface = FWS)



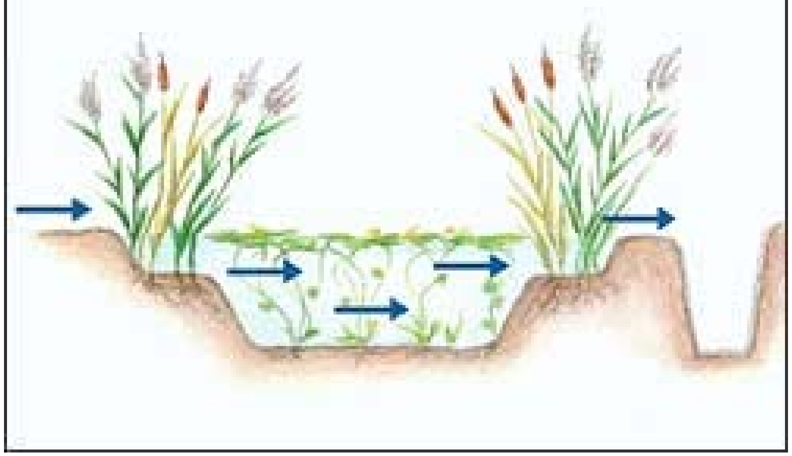
Hydroponic SF wetland



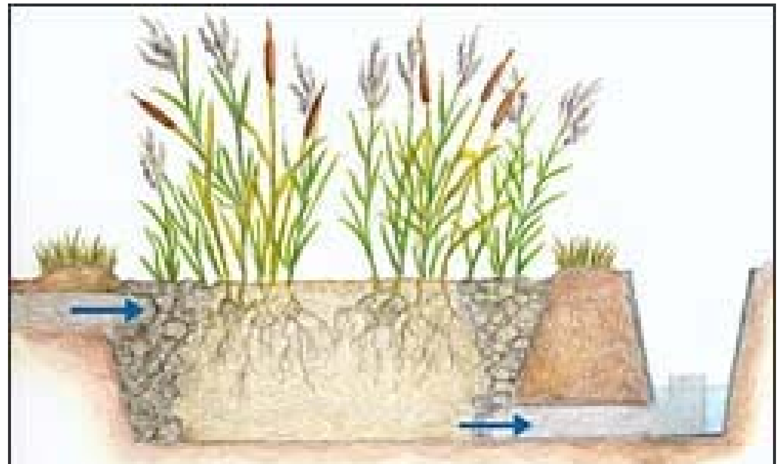




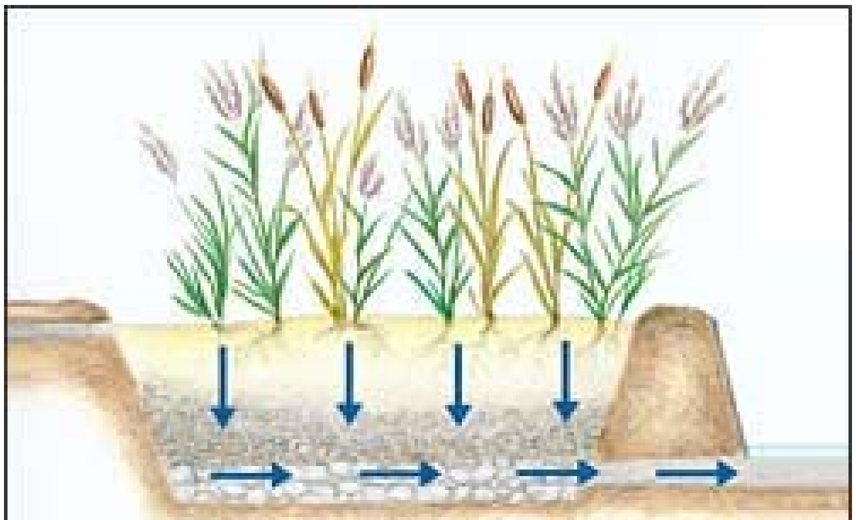
Subsurface flow SSF wetland (VSB= vegetated submerged bed)
also = HF = horizontal flow submerged bed; also = "reed" beds)



Surface Flow (SF or FWS)



Subsurface Flow (horizontal)



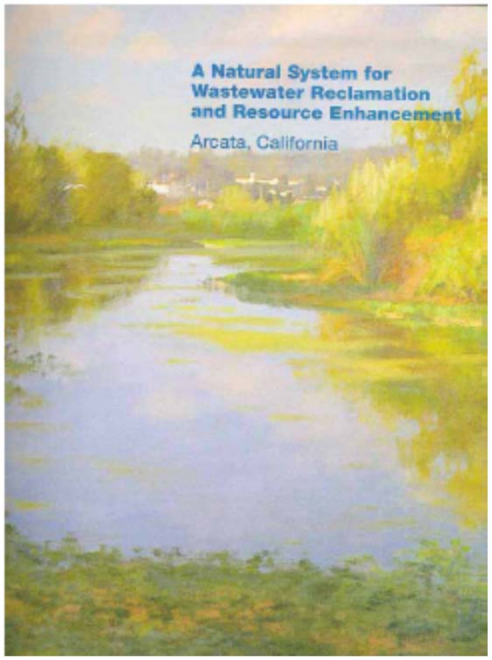
Subsurface Flow (vertical)

How do they differ in terms of filtration and oxygen regimes?

These are the major factors affecting treatment efficiency (performance) and cost.

Arcata, CA – Wastewater Reclamation

Marsh and Wildlife Sanctuary (and restoration)



- Was industrial wasteland
- Unchlorinated primary effluent being discharged into Bay
- Built clarifiers and lagoons to produce 2^{o} effluent
- Reconfigured effluent discharge to marshes for polish and City parkland
- Salmon nursery

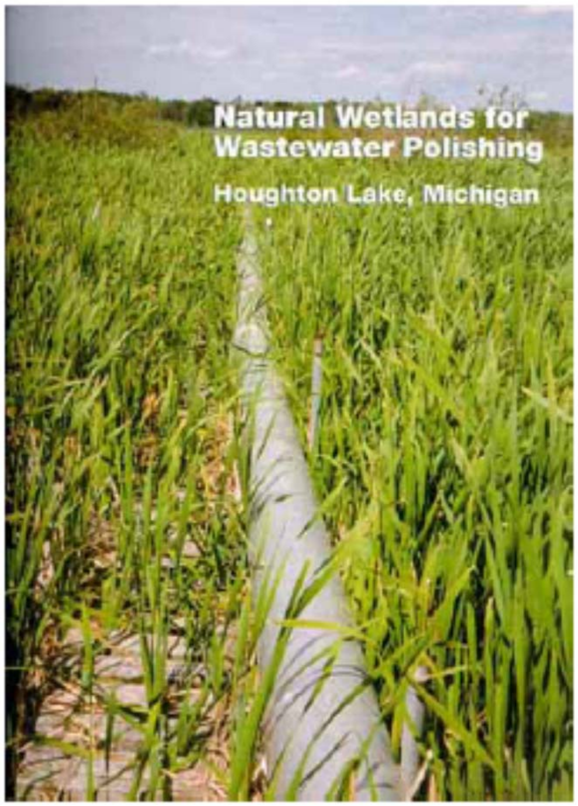
1 Robert Gearheart Marsh: Completed in 1981, this marsh was built from pastureland and now uses treated wastewater as the sole water source.

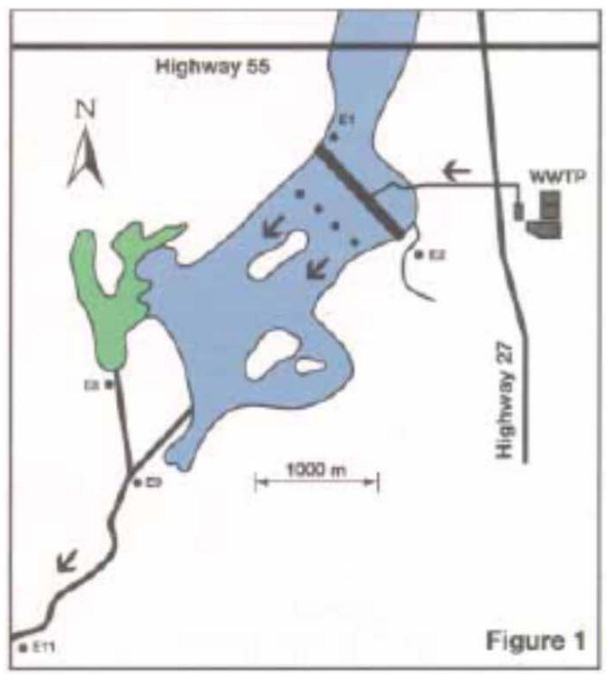
2 George Allen Marsh: Also completed in 1981, this marsh was built on an abandoned log deck and is enhanced with wastewater.

3 Dan Hauser Marsh: The final marsh to be irrigated with treated wastewater before returning to the treatment plant for disinfection and release into to the bay. This marsh was a barrow pit for the closure of

CWs for both Treatment and Wildlife Habitat

- Many famous ones (e.g. Houghton Lake, MI) would have a very difficult time nowadays
  - Public health, mosquitos, wetland conservation, …

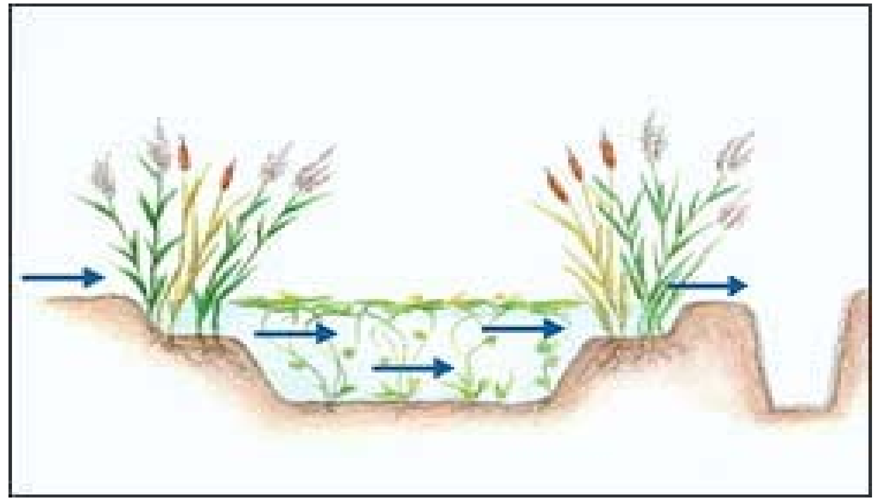




The wetland treatment site is located southwest of the lake. The land belongs to the State of Michigan and is dedicated to public and research uses. Dots indicate water monitoring stations.

Wastewater from the Chevron oil refinery in Richmond, Calif., on the edge of San Francisco Bay, has been treated by constructed wetlands (foreground) since 1988. These wetlands are also being tested for how they accumulate and volatilize selenium from the wastewater. (Photo courtesy Peter J. Duda, Chevron Products Co.)

Surface Flow (SF) or
Free water surface (FWS)



- Simulate natural ponded wetlands
- Water flows over natural soil sealed with clay or a plastic liner (liner is typical for small to moderate sizes)
- Often used for polishing where human or wildlife health risks are small and so habitat value, and water re-use are important.
- Typically require more area (and volume) than subsurface flow systems to avoid enormous blooms of algae; if loaded with secondary treated wastewater are basically a second or third stage sewage lagoon.
- More oxygenated than SSF because of air exposure. Good at nitrifying to eliminate ammonium (converts to nitrate; good at BOD breakdown because of high O_2
- Pathogen removal based more on retention time exposure to natural environment rather than physical filtration
- Large systems may be naturally vegetated or at least not hand planted as intensively as SSF systems

- Much more cost-effective than SSF at large sizes need by larger communities because of lack of substrate (no gravel or little gravel)

- Also often created by modifying existing wastewater lagoons or natural channels or wetlands

- No reason not to have mixtures of SF and SSF wetlands to provide multiple microbial habitats (± O2)

New Zealand SF CWs

[http://www.iees.ch/EcoEng021/EcoEng021_F4.html]

Photo 1: Surface-flow wetlands providing advanced secondary treatment at Kaiwaka after 2-stage waste stabilisation ponds.

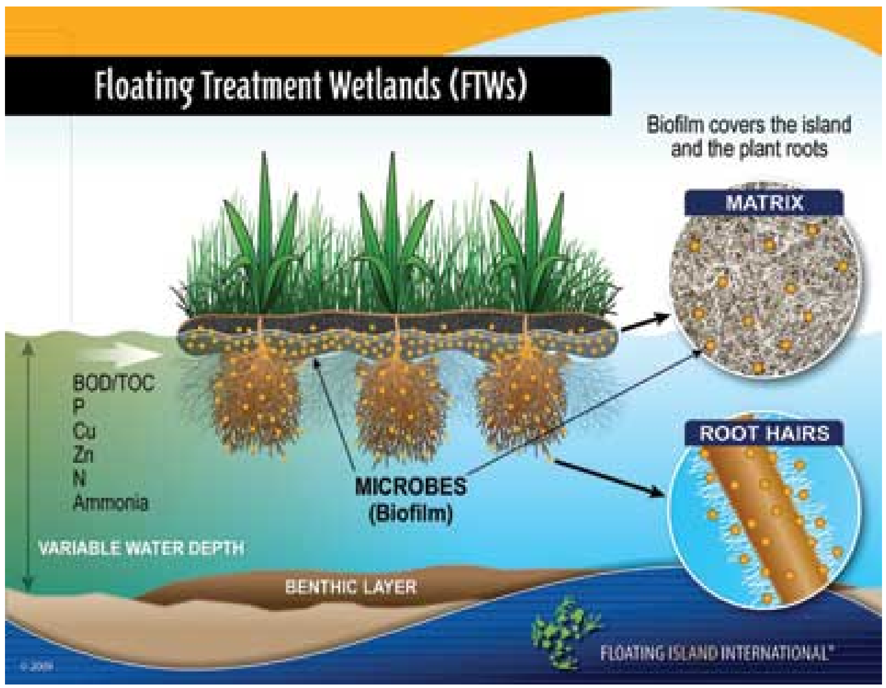
Photo 4: Surface-flow wetlands providing tertiary treatment after aerated lagoons at Beachlands-Maraetai. The final discharge is UV disinfected and dispersed into restored wetland and pond areas that drain to a nearby stream.

May be landscaped to be “more” attractive to home owners

Floating Wetlands help boost nitrogen removal in lagoons

By Mark A. Reinsel

High nutrient loading and eutrophication of surface waters continue to be topics of great concern in the wastewater treatment community. Floating treatment wetlands (FTWs) have been shown effective in substantially reducing nutrient levels in several studies involving smaller-scale lagoon treatment plants.

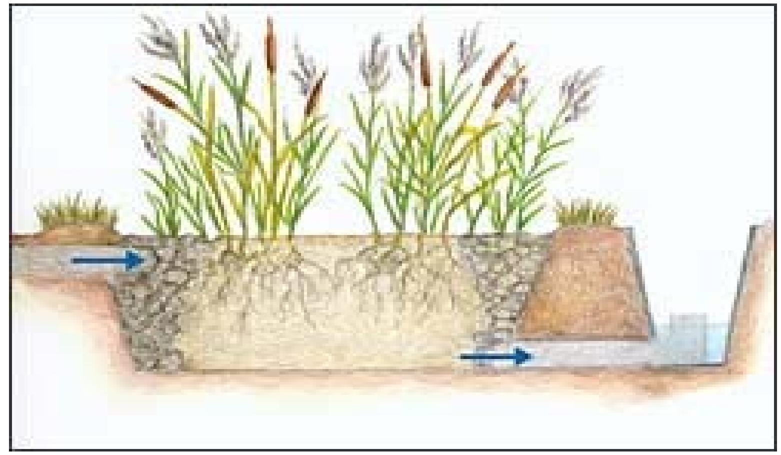


The key feature of these floating islands, developed by Floating Island International (FII), is their high surface-area-to-footprint ratio, which enables them to perform a wetland's function in a fraction of the space. Applications include polishing of municipal wastewater, direct treatment of raw wastewater, ponds and lakes impacted by septic systems and/or waterfowl, and waterways degraded by agricultural runoff.

The Sweetwater Wetlands and Recharge Project is a 24.3 ha (60 ac) facility built by Tucson Water to combine effluent treatment, recharge, and research with a natural park setting that offers educational and wildlife viewing opportunities to the community. RECHARGE ALSO

Subsurface Flow (SSF) or Vegetated Submerged Bed (VSB) or Rock Reed Filters (Reed Beds)

- Force the water horizontally subsurface as a “plug” flow through a porous medium – usually gravel
- Graded sizes of gravel from coarse at the beginning to smaller near the outflow; must be designed considering hydraulic conductivity
- Usually a landfill type of impermeable plastic liner underlays the gravel with a thin layer of sand to protect the liner.
- O2 influx is a problem when used for high BOD primary-treated or septic tank wastewater. Influx from roots not as great as once thought and they may remain anaerobic, thus reducing rates of coupled nitrification/denitrification.
- Substrate trucking is a major cost and becomes prohibitive for larger sized systems.
- May be coupled with FWS wetlands or other aerobic sand or gravel systems to maximize N-removal rates.



- Typically planted by hand
- No mosquito issues because water level below surface
- simple and low maintenance
- shallower is better because of root depths but this reduces retention time
- freezing an issue of concern especially if shallow (~ 0.3-0.5m instead of 0.8-1.0 m deep)
- TSS and BOD removal usually 90% within the first 25% of the bed length for “standard” designs
- P-removal a function of substrate adsorption; Fe is especially good.

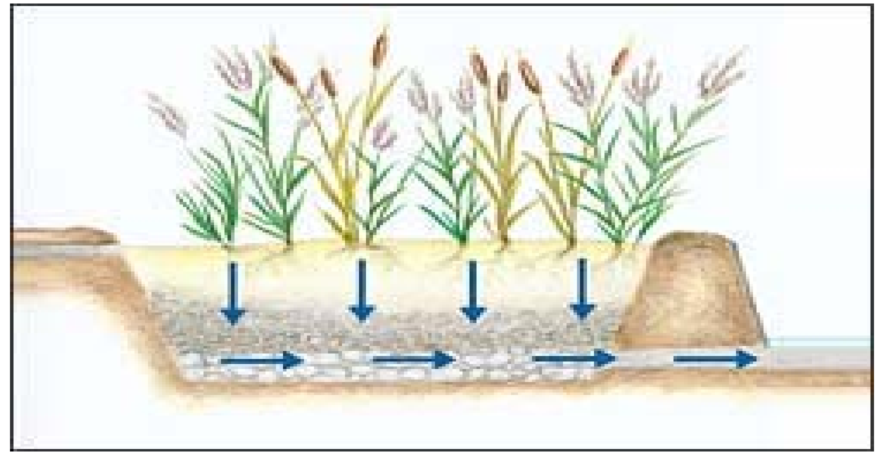
New Zealand SSF CWs

[http://www.iees.ch/EcoEng021/EcoEng021_F4.html]

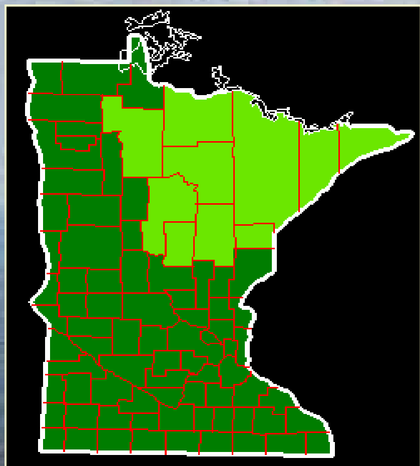
Photo 2: One of two small subsurface-flow constructed wetlands receiving motor camp wastewaters after septic tank treatment at Waipoua Forest Park.

Photo 3: One of three gravel-bed subsurface-flow wetlands treating sewage from Waikeria Prison after the activated sludge treatment

Vertical flow - Subsurface Flow (VSF) or Vegetated gravel filter



- Newer design with less research done until last 10 yrs
- Designed to maximize O2 transport
- works like a standard one-pass, intermittently dosed gravel or sand filter
- Excellent BOD, TSS and ammonium removal (N converted to nitrate)
- May denitrify also
- maintenance comparable to sand and gravel filters (pressure dosing; a bit more effort than the very passive SSF constructed wetland.
- some designs introduce passive diffusion or forced air at the bottom
- may be coupled with SSF cell to maximize N removal



Cold climate performance of alternative, on-site domestic wastewater treatment systems

Barb McCarthy, Rich Axler, Jeff Crosby, Jim Anderson, Randy Hicks and a host of techs, 4 grad students, 5 undergrads, 10-20 agency folk and of course the MES/SG Extension wizards

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- impact on lakes and streams
  - >400 resorts in NE MN alone
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  - nearshore zone of Lake Superior

OUR REGIONAL EFFORTS BEGAN IN 1995

Demonstration & Research Projects:

NERCC
(Northeast Regional Correction Center)

GRAND LAKE
(10 home cluster)

IRRRB
(Targeted resorts via Northern Lights Tourism Association)

PURPOSE-

EVALUATE THE USE OF 'NON-STANDARD' SYSTEMS ON DIFFICULT SITES

Issues & Problems

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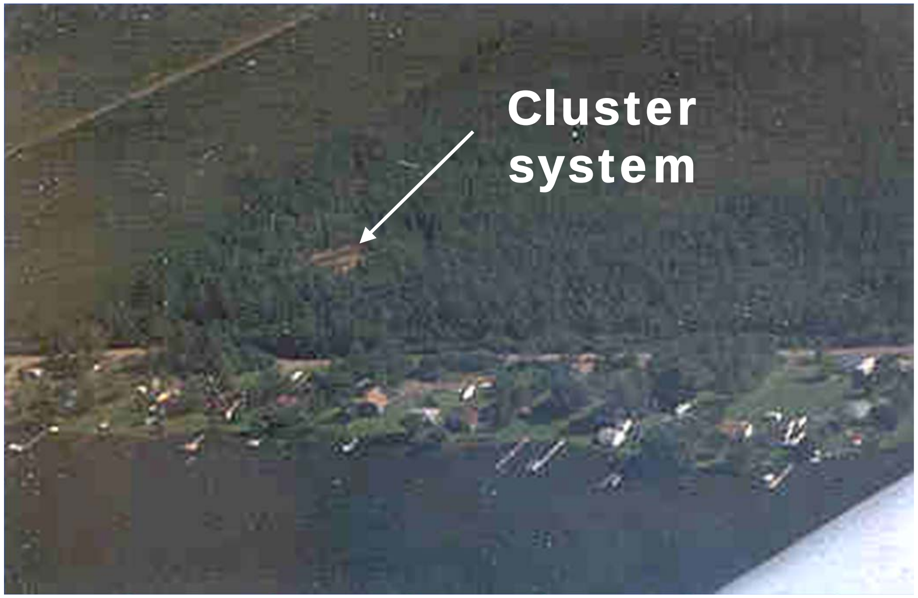
- 50-70% failing or improperly designed (~350,000 residences)
- 'Limited' soils, wet spring, high water table, frozen soils, small lots, sensitive water supplies nearby
- immediate public health hazards
- longer-term nutrient /eutrophication
- development pressures on lakes
- conventional systems not working and no alternatives allowed

Other obstacles – and there are more…

- Big pipe versus onsite or clusters
- Local vs state "turf" rivalries and control issues;
- Management, operation and maintenance knowledge gaps (science-based)
- Technology transfer to state and county planning and regulatory agencies; to contractors; to resort and homeowners, banks, realtors, …
- Statutory requirements (performance-based code vs prescriptive codes)
- comprehensive land-use planning vs regulation by septic system permit

Grand Lake Cluster Treatment System

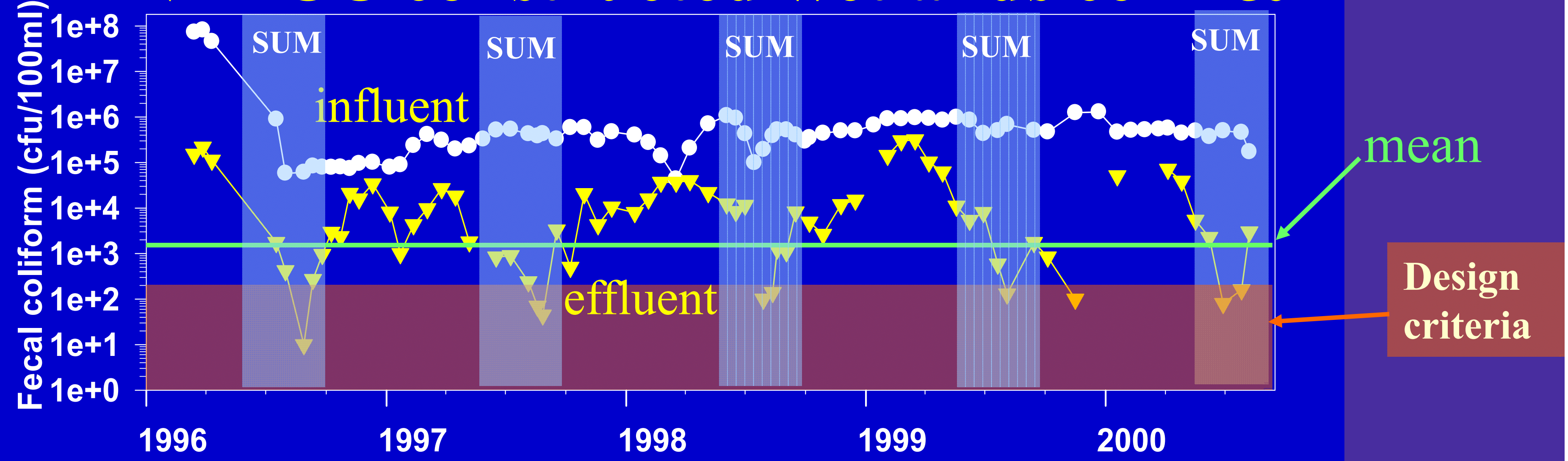


NERCC Constructed Wetland

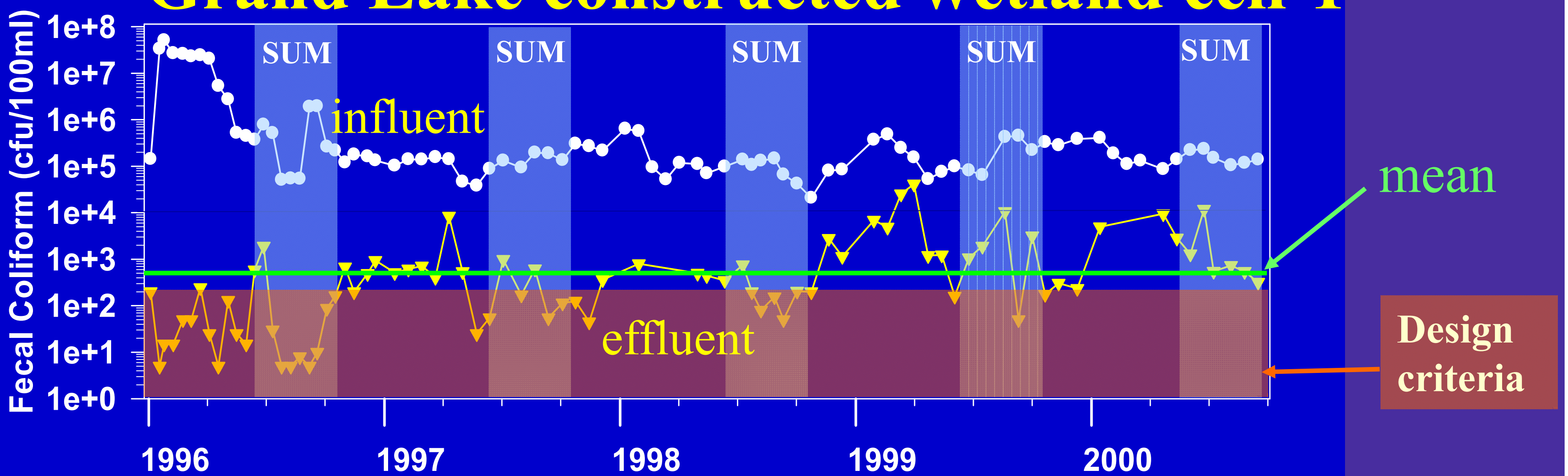
- Sub-surface flow (SSF)
- Gravel filled
- Planted with *Typha* and *Scirpus* (cattail and bullrush)
- 2 cells in series, each ~37 m^2 surface area
- Designed retention time 13 days
- Areal loading rate 2.7 g BOD/m^2/d
- Began receiving STE in Nov 1995

Subsurface Flow Constructed Wetlands to ‘gravity’ trench for dispersal

NERCC constructed wetlands cell 1&2



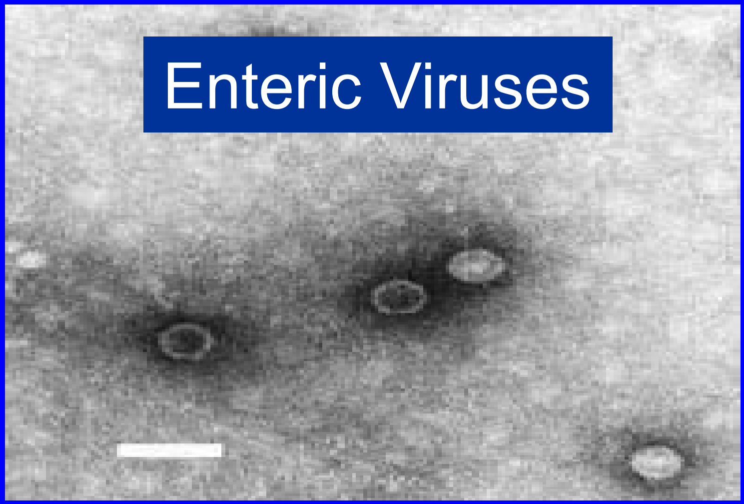
Grand Lake constructed wetland cell-1



Pathogen Removal

How well do these advanced technologies work at removing pathogens?

Wastewater Pathogens



Salmonella Results for . . .

Summer

Treatment System	Inflow Salmonella (total CFU x 10^8)	Treatment System Effluent Salmonella (total CFU x 10^8)	Salmonella Reduction (%)	Salmonella Reduction ($\log_{10}$)
Wetland 1	145,000	0.812	99.994	5.3
Wetland 2	145,000	566	99.6	2.4

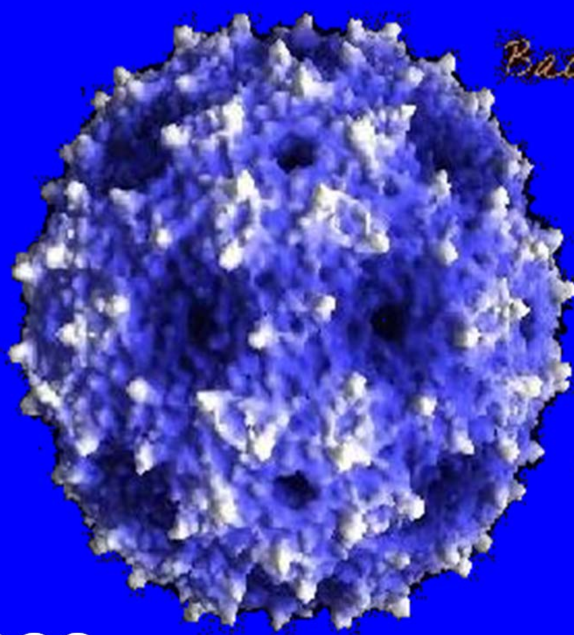
And Salmonella Results for. . .

Winter

Treatment System	Inflow Salmonella (total CFU x 10^8)	Treatment System Effluent Salmonella (total CFU x 10^8)	Salmonella Reduction (%)	Salmonella Reduction ($\log_{10}$)
Wetland 1	114,000	4,760	95.8	1.4
Wetland 2	114,000	5,770	94.9	1.3

MS2 Bacteriophage

- Genus Levivirus, family *leviviradae*
  - Includes Qβ and PRD-1
- Icosahedral symmetry
- ssRNA phage
- 24nm in diameter
- Infects only “male” bacteria
- Found in 26% of human feces



NERCC CW Summary - 1

1. SSF CW are a viable option in Minnesota, despite our severe climatic conditions

2. SSF CW can achieve 2º standards, but with reduced performance expected during the coldest months (Dec-Apr)

3. permitting may require averaging, not grab sampling (summer ET & runoff event variability)

Conclusions

- **All systems removed >90% of virus regardless of season**
- Peat filter removed greatest amount of all indicator organisms
- Effluent temperature had negligible effect on virus removal
- MS2 removal not significantly less than traditional indicator removal
- Indigenous phage better indicator of virus removal than fecal coliforms

What Is Phytoremediation?

- Use of green plants ("**Green**" technology) for *in situ* risk reduction and/or removal of contaminants from soils and water

- An aesthetically pleasing technique used to remediate sites with low to moderate contamination levels

- Used to clean up metal and organic pollutants or render them harmless

Barren area due to soil's high Zn and low pH in Palmerton, PA.. Contaminated by a zinc smeltry operated from 1890 to 1980

What can phytoremediation be used for?

Organic compounds, e.g.

- Crude oil
- Explosives
- Landfill leachates
- Pesticides
- Polyaromatic Hydrocarbons (PAHs)

Metals e.g.

Copper	Hg	Se
Nickel	Cr	Ag
Zinc	Pb	Actinides

How does phytoremediation work?

- Phytoremediation is a generic term used to collectively describe the the ways in which plants can be used to remediate sites

- Plants can break down (degrade), stabilize, and remove pollutants from sites

- Some technologies will only work with metals, some with organic contaminants

Treating Contaminated Sites

At metal contaminated sites plants can be used either to stabilize or remove the pollutants from the soil and ground water using:

Phytoextraction

Rhizofiltration

Phytostabilization

Plants are used to clean up sites polluted with organic contaminants using slightly different techniques:

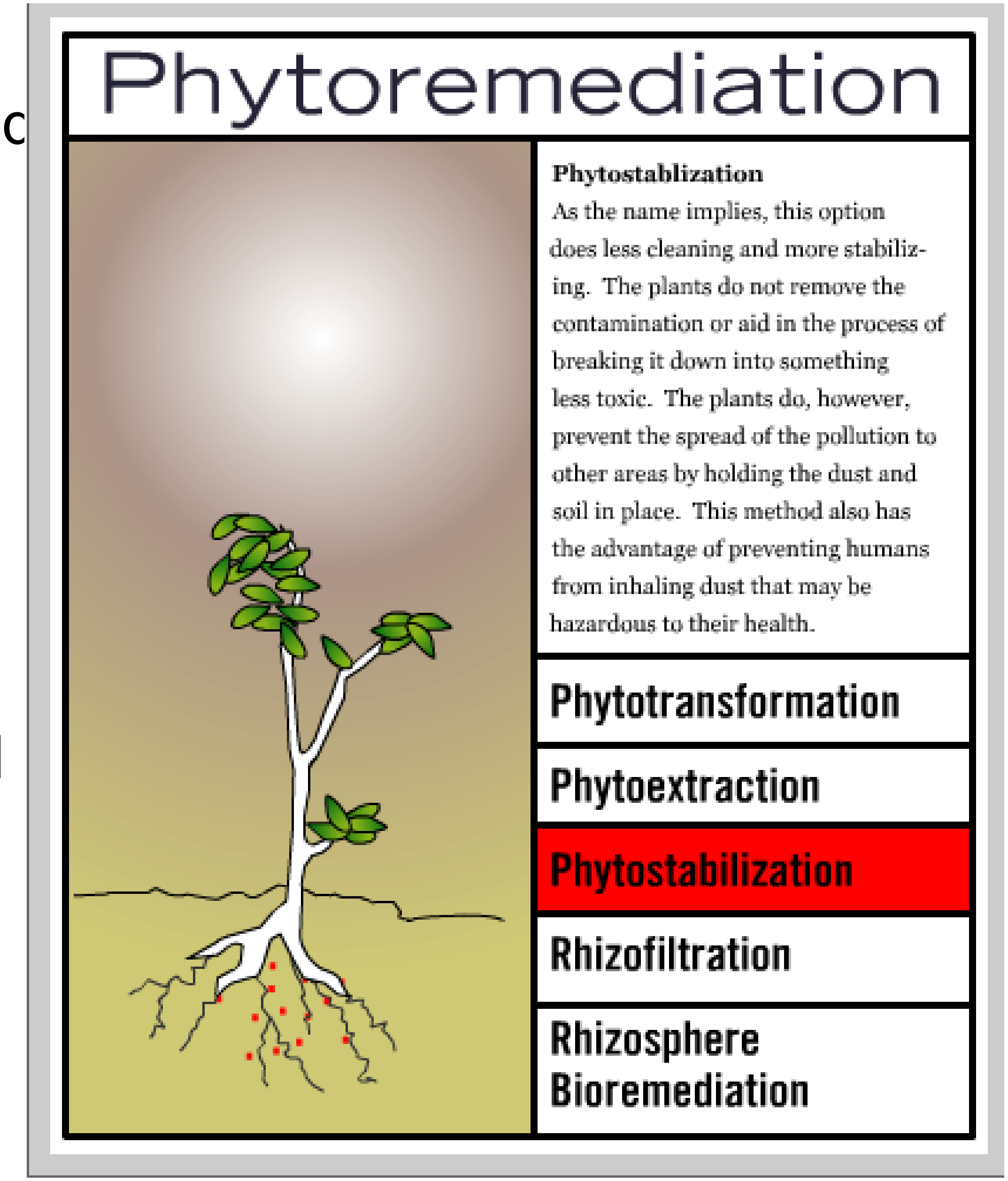
Phytodegradation

Phytovolatilization

Rhizodegradation

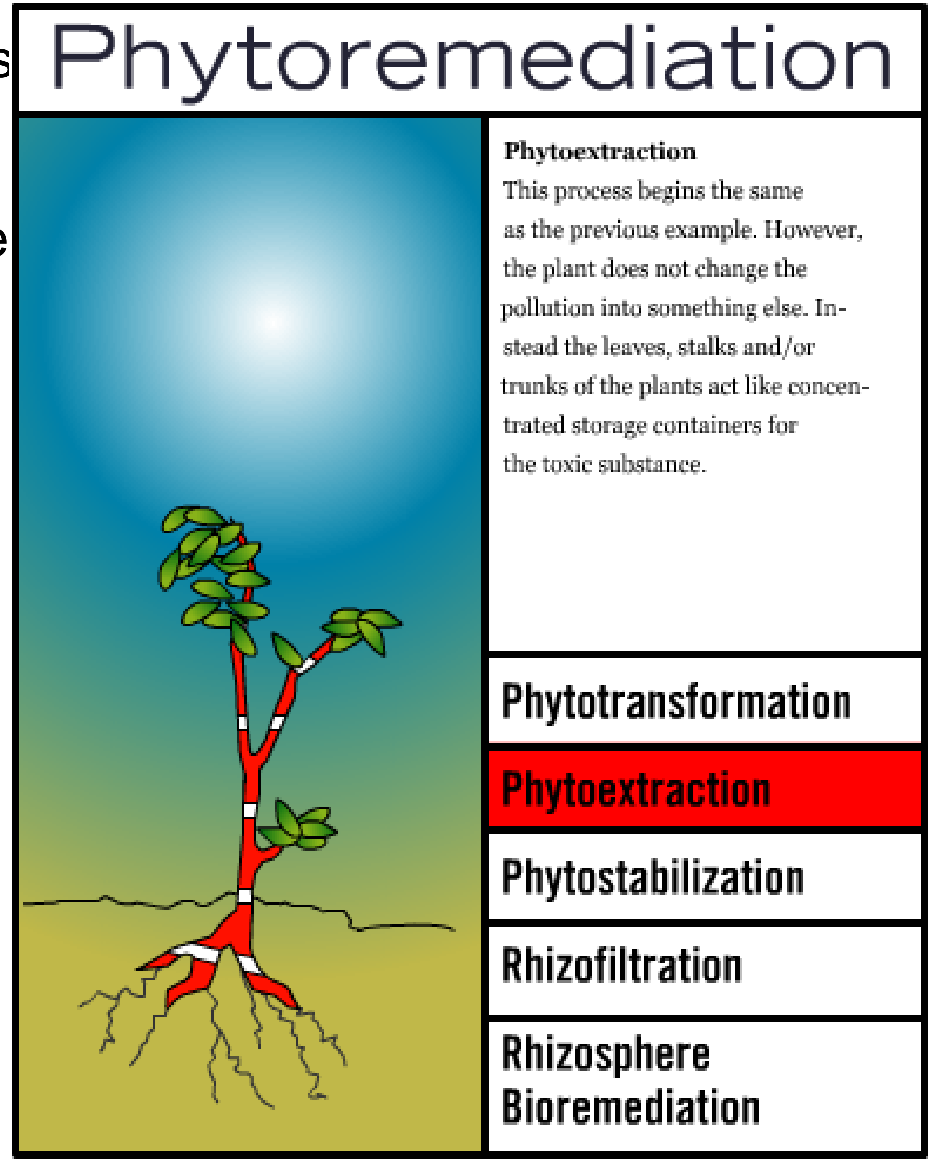
Phytostabilization

- Plants immobilize water and soil contaminants by stabilizing soil and dust
- Contaminants adsorbed onto roots, or precipitated within *root rhizosphere* preventing migration and reducing *bioavailability*
- As roots become saturated with pollutant they are harvested (possibly stems and leaves also)



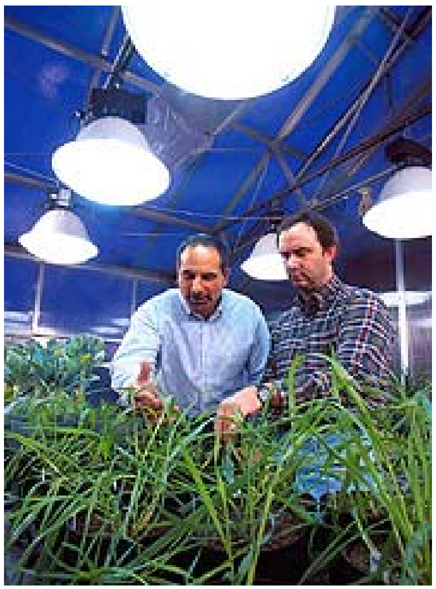
Phytoextraction (Phytoaccumulation)

- Uptake by roots and translocation to above-ground tissues; good for metals in soil
- *Hyperaccumulator* plants absorb large amounts of pollutants compared to other species
- One or more species of plant may be used depending on the site and the contaminants
- Harvested and disposed of safely. Metals may be recycled
- May need to be repeated several times
- Zn, Cu, Ni absorbing plants are current favorites but Pb, Cr, Se absorbing plants being researched



Harvesting

Heavy metals in Poland



Wheat for
removing Al

Cabbage for Zn control, Silesia, Poland

- Hyperaccumulators like *Thlaspi sp.* (AlpinePennycress) possess genes that regulate the amount of metals taken up by roots and translocated

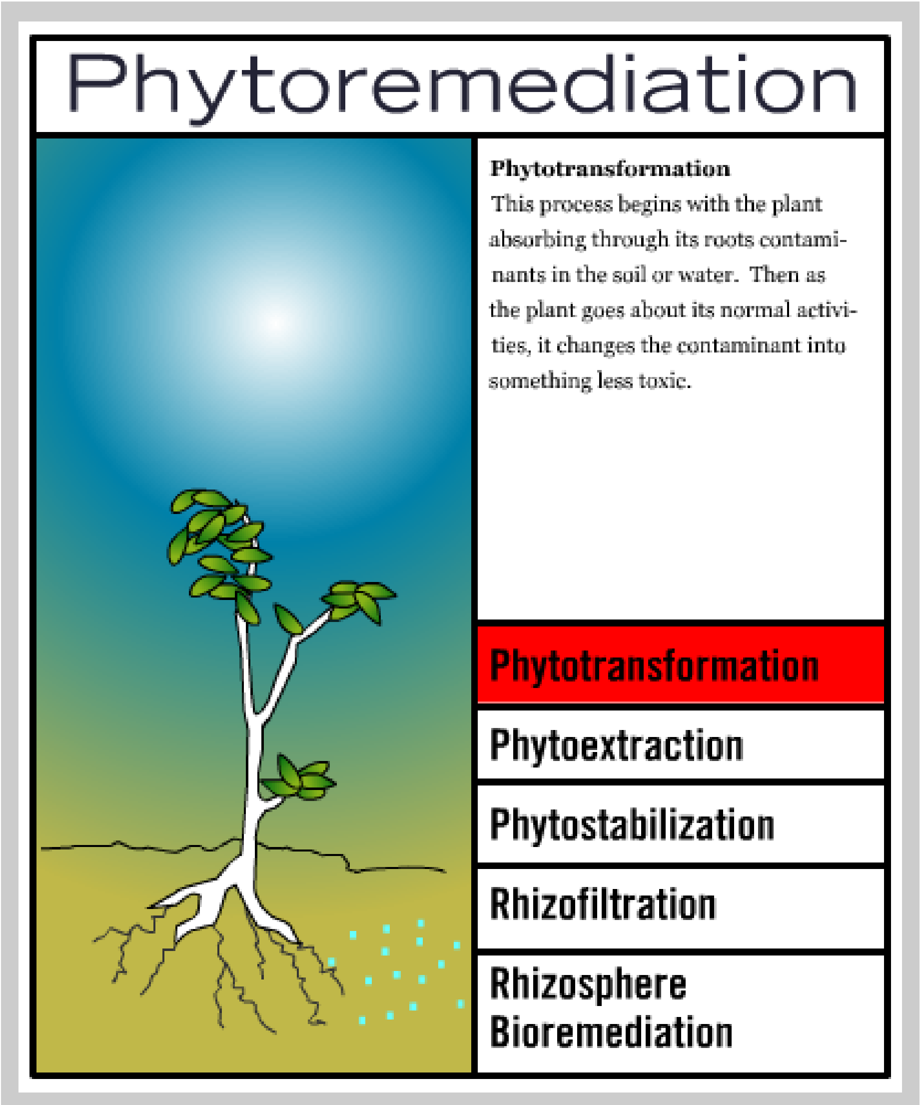
- Typical plant:
  - may accumulate ~100 ppm Zn and 1 ppm Cd (poisoned by 1000 ppmZn /20 ppm Cd in shoots

- Thlaspi:
  - 30,000 ppm Zn and 1,500 ppm Cd in its shoots

http://www.ars.usda.gov/is/AR/archive/jun00/soil0600.htm

Phytodegradation (Phytotransformation)

- Breakdown of contaminants by plant metabolic processes (internally or externally)
- Complex organic pollutants degraded by plant enzymes; may be incorporated as new plant fibers
- Technology well adapted for use on sites polluted with ammunition waste, herbicides, and chlorinated solvents

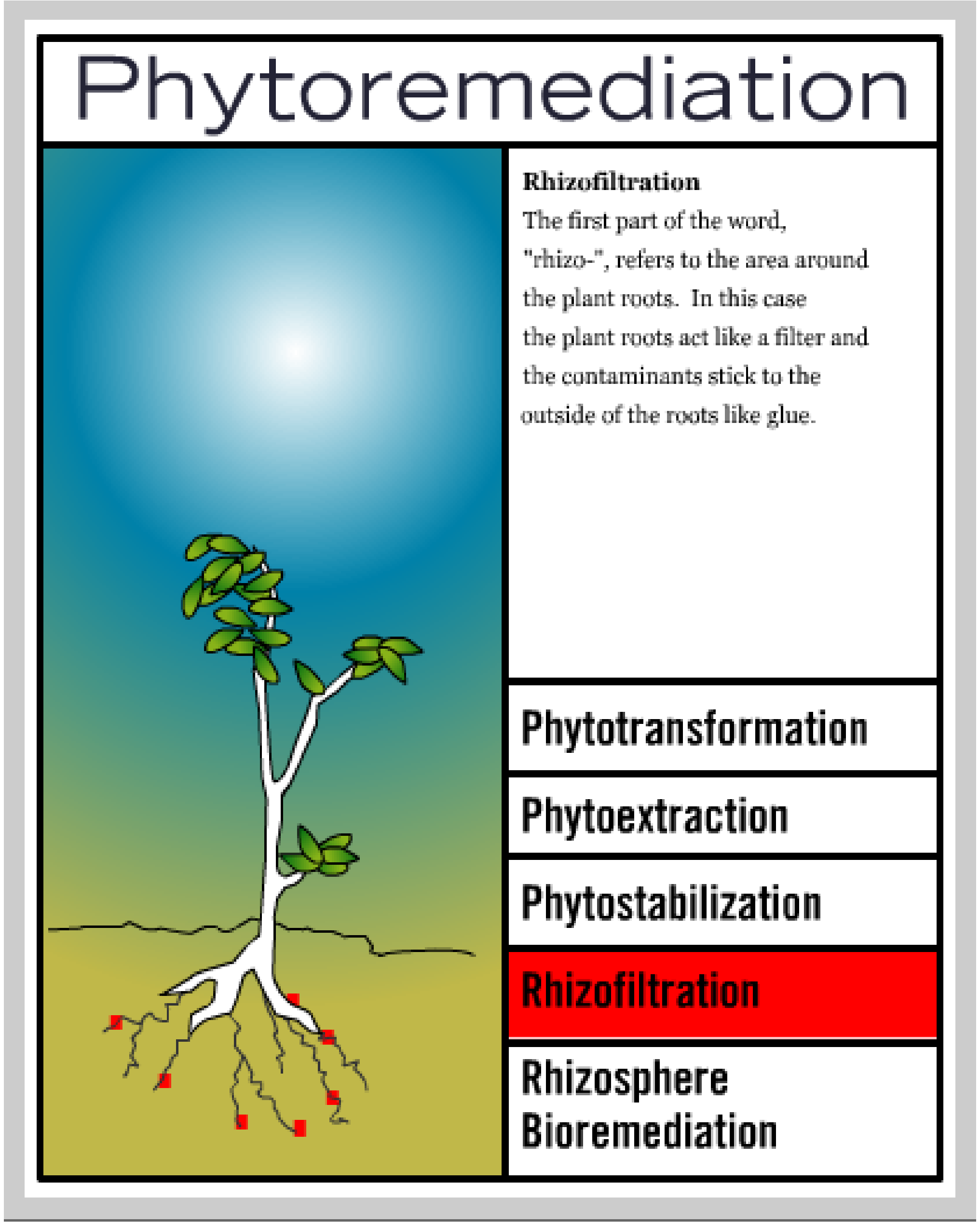


Phytovolatilization

- When a plant releases it's contaminants into the atmosphere (through transpiration)
- Occurs as plants transpire along with water the contaminants in the water
- Contaminants evaporate (volatilize) into the air
- Poplar trees reported to volatilize 90% of the TCE (trichloroethylene) they take up

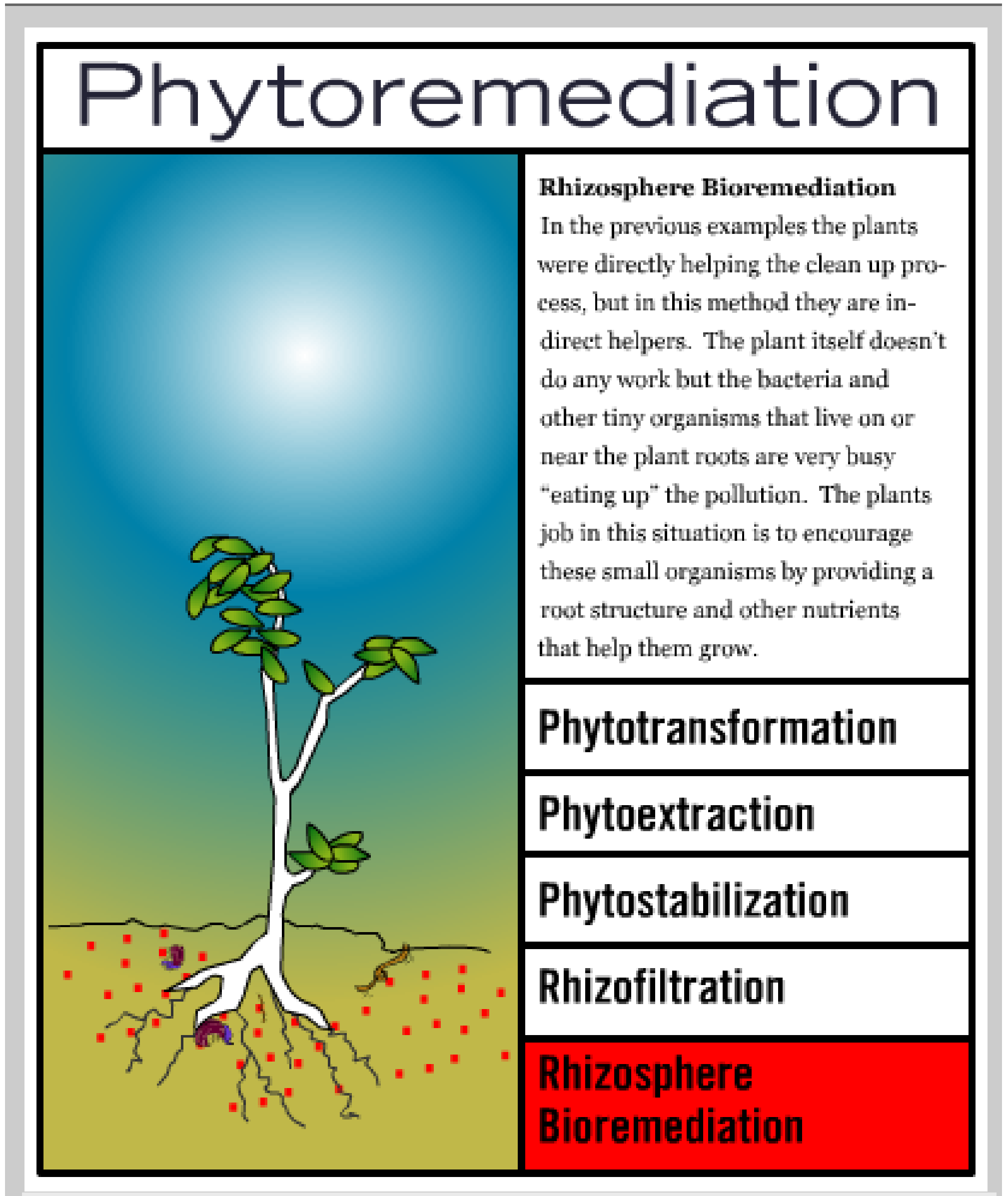
Rhizofiltration

- Similar to *phytoextraction* but targets groundwater rather than soil pollution
- Plants raised in greenhouses in water
- Contaminated water is substituted for clean water to acclimate plants after sufficient growth
- Plants then transferred to polluted site where they take up the polluted water and clean up the site

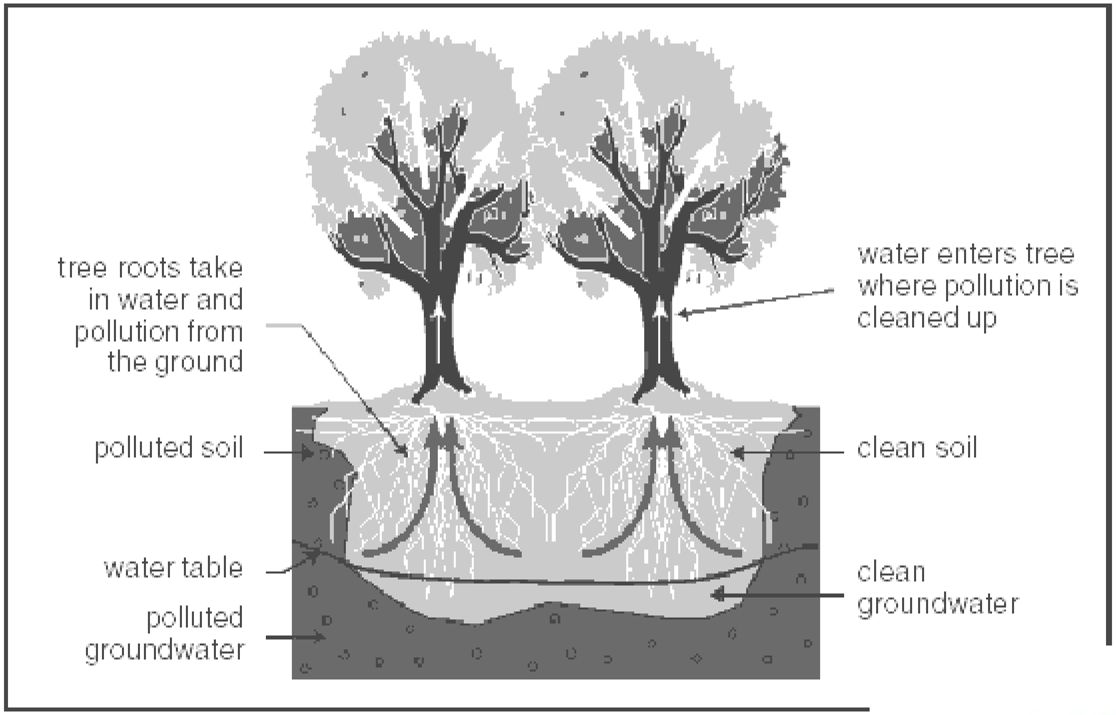


Rhizodegradation

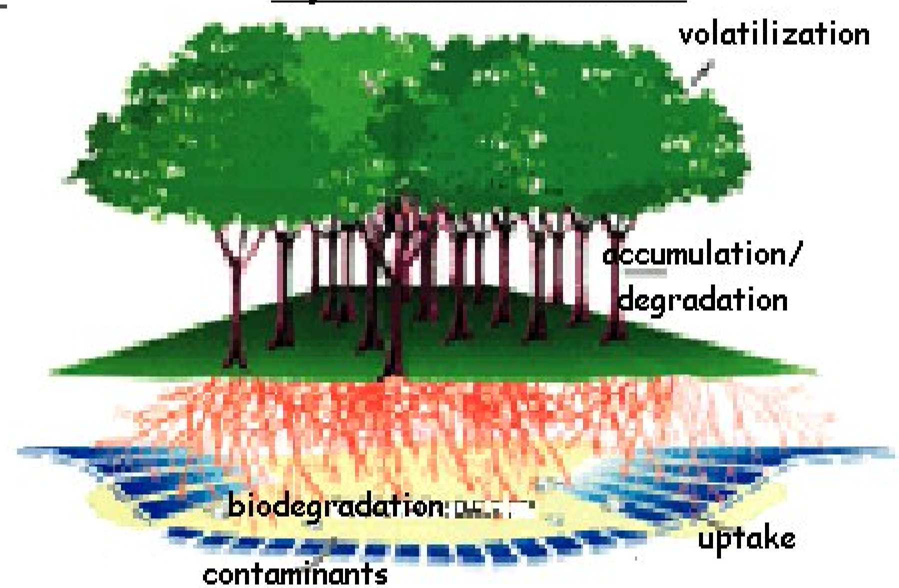
- Breakdown of soil contaminants by soil microbes enhanced by the rhizosphere
- Root exudates increase microbial activity at the rhizosphere; may also stimulate certain “bugs”
- Also called “ *rhizosphere bioremediation*”; often much slower than phytodegradation (???)



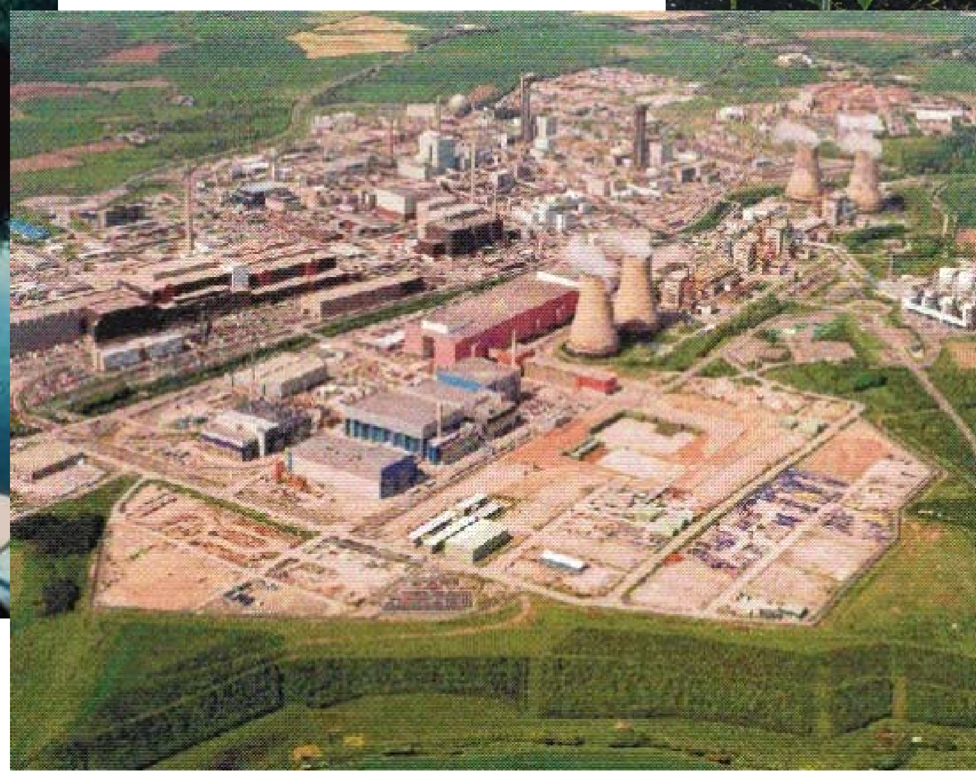
http://illumin.usc.edu/multimedia.php



Phytoremediation Overview



Great Britain: Plutonium & Uranium

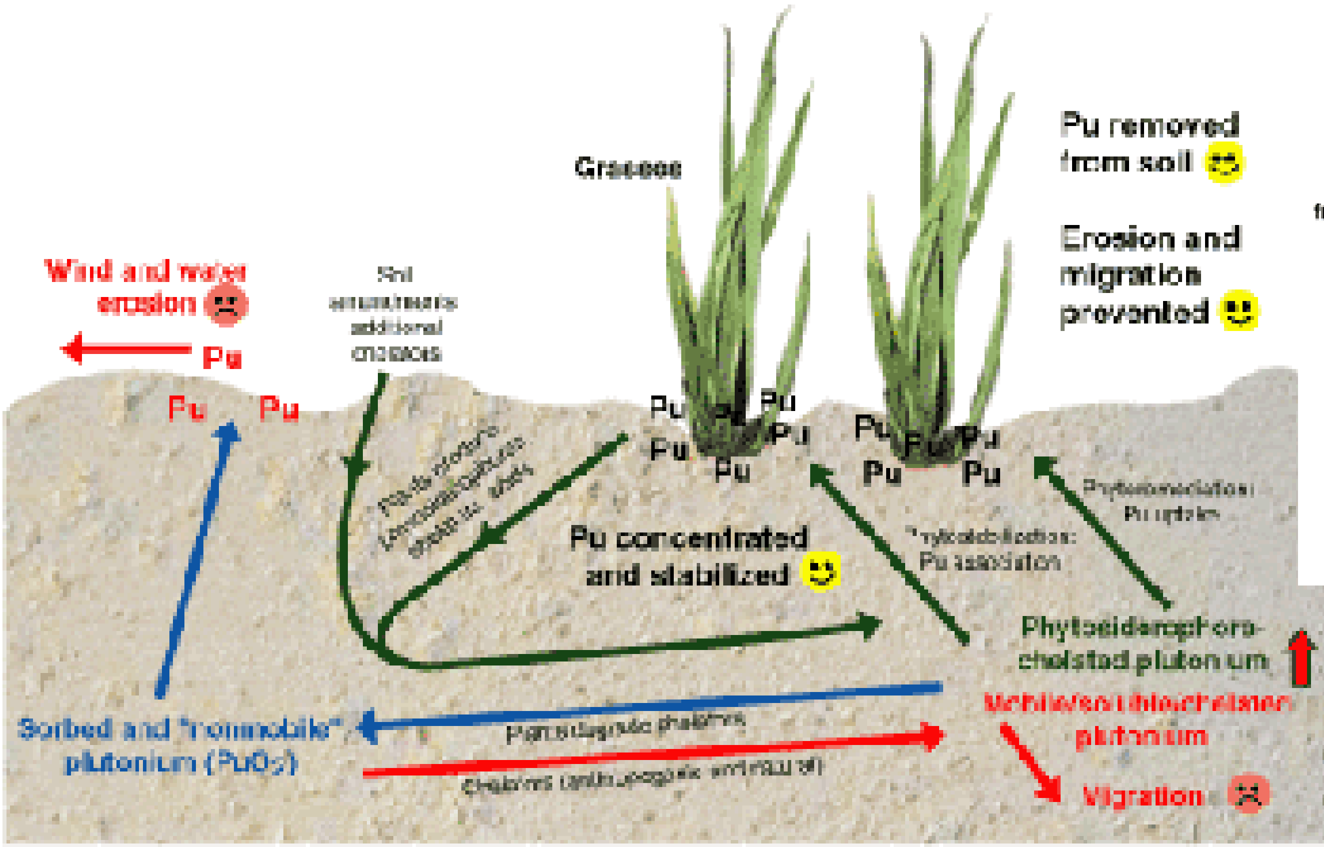


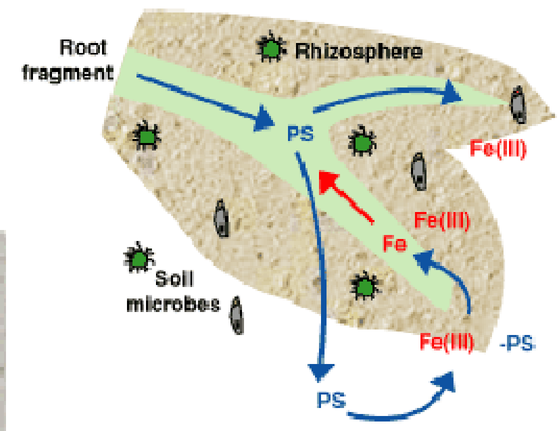
Military Base Cleanups

Repair of Army equipment since 1950's: included the luminising of military equipment with Ra^{226}.

Waste, in keeping with the practices of the time, was burned and buried on the site, principally by dumping on to the river flood plain

Plutonium Clean-up (don’t forget the other crap there also: Ni, Cd, ????)





Relative plant uptake availability for actinides
neptunium > uranium > curium > americium > plutonium
function of solubility under environmental conditions.

Whoops -

Neglected to consider tidal action and site was flooded;

PCB’s from dumped transformers at LaSalle Electric Utilities (Illinois) – Superfund Site

26 varieties of willows and 16 varieties of poplar
(Jed Isebrands, USFS – Gr Rapids, MN)

Also solvents:
tetrachloroethylene
perchloroethlyene
other stuff

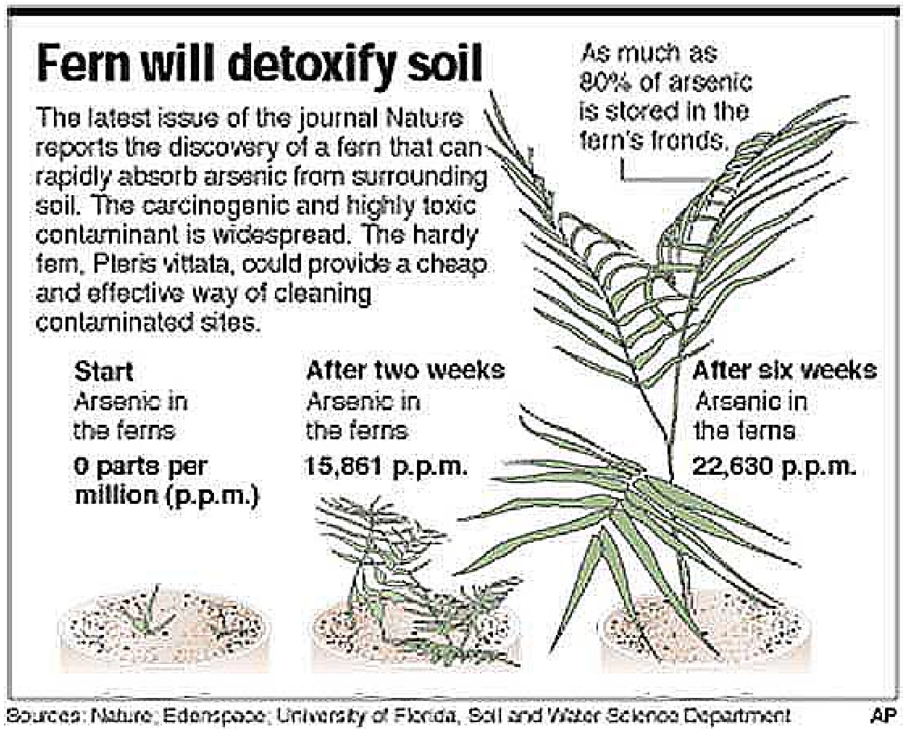
Engineers like to call these processes "Hydraulic Control of Contaminants"

- Plants act as hydraulic pumps when their root systems are large and sit within the water table
- As the plants constantly transpire they draw water through their roots. Contaminants in the water will also be drawn up into the plant
- Reduces risk of contaminants reaching the groundwater and drinking water supplies (like an extraction well pumping out groundwater plumes)
- Applications: ***Riparian Corridors, Buffer Strips & Vegetative Caps***

Riparian Corridors/Buffer Strips

- These are phytoremediation strategies that may also use other methods such as phytovolatilization
- Riparian corridors: plants transplanted along rivers and streams for remedial purposes. Buffer strips are applied to the perimeter of landfill sites (Note- these are also BMPs for mitigating urban, agric, logging, construction site runoff and erosion)
- Prevent contaminants leaching into the ground and surface water

Hydrocarbons



Vegetative Cover (Phytostabilization)

- long term caps of soil and plants growing over landfills
- plants control soil erosion and minimize the amount of water percolating through the waste
- can enhance the breakdown of the underlying waste
- more aesthetically pleasing than the alternative clay or plastic caps
- But – must deal with food web risks; may create habitat that attracts animals

Can Phytoremediation be used at all sites?

- Good for cleaning up metal and organic polluted sites
- finishing (polishing) step when used with other methods of remediation in heavily polluted sites ("*process train*")
- usually slower than other methods and limited to the root depth of the remedial plants
- limited to low to moderate polluted sites
- trees have allowed remediation of deeper polluted sites than the use of small plants
- Deep pollution may be treated by pumping polluted water to the surface where the plants can reach it (irrigation)
- Further research (*forever*) needed to investigate food web effects, and contaminant stability in detritus

Advantages of Phytoremediation Compared to Classical Remediation

- Less disruptive to the environment
- Disposal sites not needed
- Avoids excavation and transport of polluted soils and water
- Has the potential to treat more than one contaminant at any site
- Much cheaper than conventional methods

Disadvantages of Phytoremediation

- Dependant on growing conditions of the plant
- Success is dependent on plant tolerance
- Contaminants may be recycled as tissues senesce
- Very lengthy process
- Food web effects may be a major problem (e.g.Kesterson selenium example)

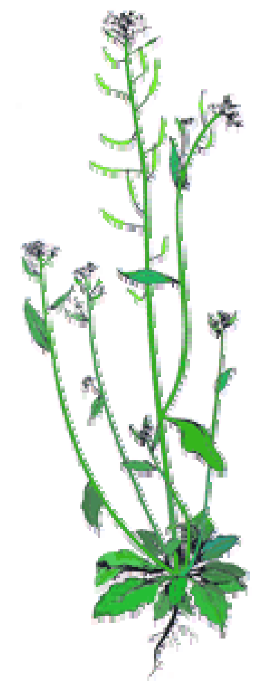
Biotechnology

- Mercury detoxifying genes (*MerA* &*MerB*) have been introduced into *Arabidopsis sp*
- Plants detoxified methylmercury to elemental Hg and volatilized it
- Same inserts have been used in tobacco, poplar, and bulrush

Arabidopsis thaliana is a small flowering plant widely used as a model organism in plant biology. A member of the mustard (Brassicaceae) family, which includes cultivated species such as cabbage and radish

Common = Wall cress; mouse-ear cress

Norwegian = vårskrinneblom



Risk Assessment

- It is unknown what ecological effects ingestion of plants may have
- “Fallout” from senescing tissues may re-enter food chain
- Volatilized pollutants may be at unsafe levels
- Exposure to contaminant is prolonged as the process is slow
- Genetically engineering plants has its own set of real and perceived issues (however, not for food)

Lots and lots of research and applications in last decade

RESEARCH

- HYDROPONICS
- PHYTOREMEDIATION
- ETHYLENE STUDIES
- RESPIRATION AND CARBON USE EFFICIENCY
- SPECTRAL IMAGING
- SUPER-DWARF CROPS
- LETTUCE STUDIES
- DIGITAL CAMERA IMAGING
- LUNAR CROP PRODUCTION & FAILURE ANALYSIS
- WATER STRESS STUDIES
- PHOTOBIOLOGY / LIGHT STUDIES
- TURFGRASS RESEARCH FOR LOW LIGHT

William Doucette, J. Chard, B. Moore, W. Staudt, and J. Headley

- Trichloroethylene in Edible Fruit Growing Above Shallow Groundwater Roots
  William Doucette, J. Chard, B. Chard, C. Crouch,
  B. Bugbee, and K Gorder - 2003
  - PLATFORM PRESENTATION AT:
    24th Annual Meeting of the Society of
    Environmental Toxicology and Chemistry
  Nov 9-13, 2003; Austin, TX

- Uptake, Metabolism, and Phytovolatilization of TCE by Indigenous Vegetation
  William Doucette, B. Bugbee, S. Smith, C. Pajak, and J. Ginn
  - BOOK CHAPTER IN:
    Phytoremediation: Transformation and Control
    of Contaminants (McCutcheon and Schnoor, eds.)

- Determination of Sulfolane and Diisopropanolamine Uptake by Hydroponically Grown Catttails
  Julie Chard, W. Doucette, and M. Petersen,
  B. Moore, W. Staudt, and J. Headley - 2004
  - PRESENTED AT POSTER SESSION:
    4th International Conference on Remediation
    of Chlorinated and Recalcitrant Compounds
  May 24-27, 2004; Monterey, CA

- Greenhouse Study to Determine the Uptake of Trichloroethylene by Fruit Trees
  Brandon Chard, W. Doucette, J. Chard, B. Bugbee, and K. Gorder
  - PRESENTED AT POSTER SESSION:
    4th International Conference on Remediation
    of Chlorinated and Recalcitrant Compounds
  May 24-27, 2004; Monterey, CA

- Rhizosphere Effects on Strontium Uptake in Crested Wheatgrass
  Julie Chard, and B. Bugbee- 2003
  - American Society of Agronomy
  Nov 2-6, 2003; Denver, CO

http://www.clu-in.org/techfocus/default.focus/sec/Phytotechnologies/cat/Overview/

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Phytotechnologies

Overview

Phytotechnology is broadly defined as the use of vegetation to address contaminants in soil, sediment, surface water, and groundwater. Cleanup objectives for phytotechnologies can be contaminant removal and destruction, control and containment, or both. Phytoremediation (i.e., contaminant removal and destruction) is a phytotechnology subset (ITRC 2009). A layman's discussion of plant-based remediation can be found in A Citizen's Guide to Phytoremediation, which is also available in a Spanish translation.

While phytotechnologies generally are applied in situ, ex situ applications (e.g., hydroponics systems) are possible. Typical organic contaminants, such as petroleum hydrocarbons, gas condensates, crude oil, chlorinated compounds, pesticides, and explosive compounds, can be addressed using plant-based methods. Phytotechnologies also can be applied to typical inorganic contaminants, such as heavy metals, metalloids, radioactive materials, and salts (ITRC 2009).

Six major plant mechanisms enable phytotechnologies to remove, destroy, transfer, stabilize, or contain contaminants:

- Phytoextraction
- Phytodegradation

- Overview
- Guidance
- Application
- Training
- Additional Resources

- Technology Focus Home
- Suggest Resource
- Comments

http://www.biobasics.gc.ca/english/View.asp?x=742