Phytoremediation: Green Solutions for Pollution

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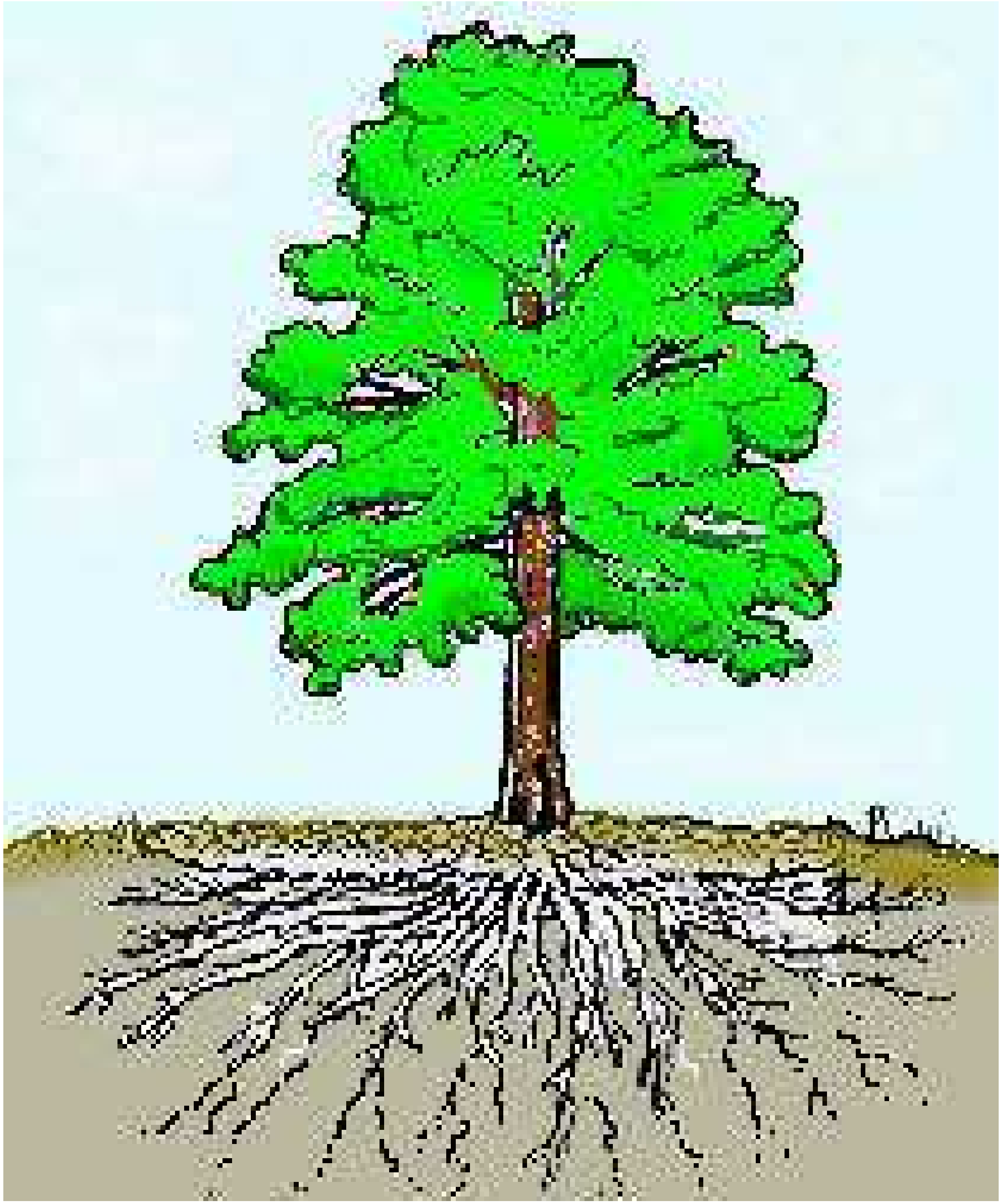
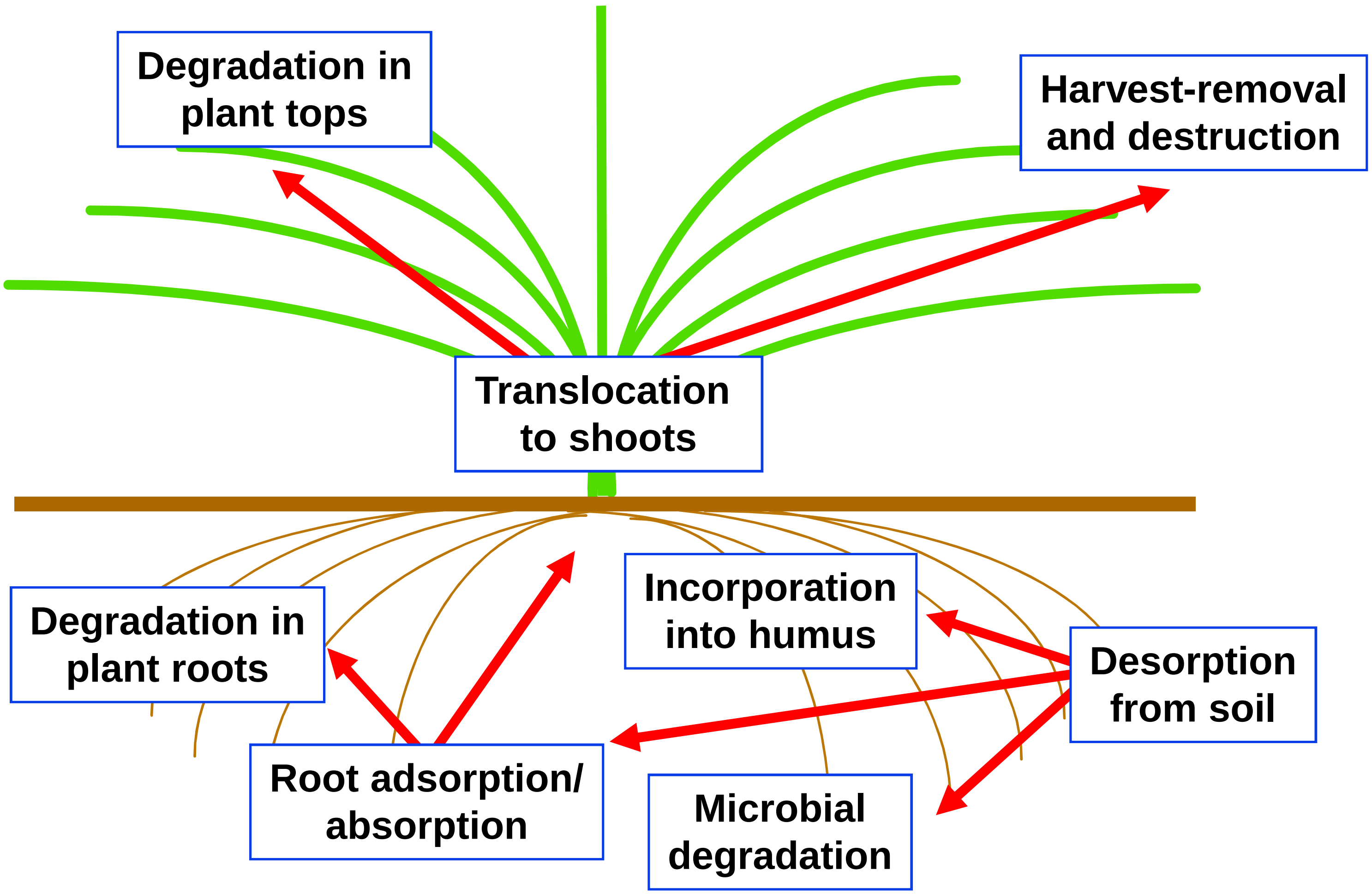
Phytoremediation

A technology that utilizes plants and their associated rhizosphere microorganisms to remove, transform, or contain toxic chemicals located in soils, sediments, groundwater surface water, and the atmosphere.



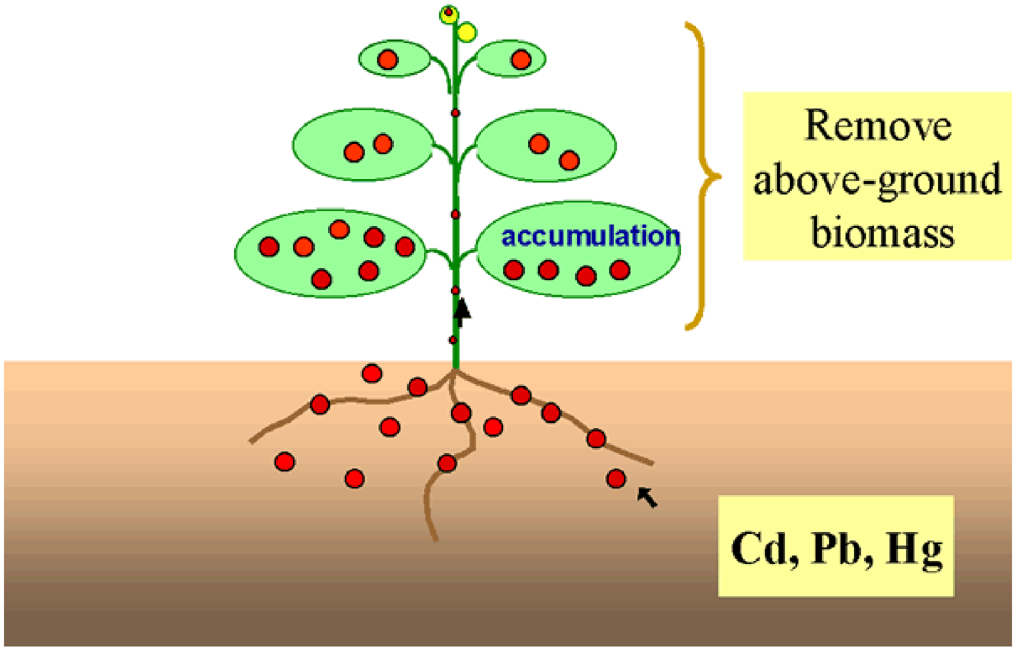
Phytoremediation of Organic-Contaminated Soils



Cunningham and Berti, 1993

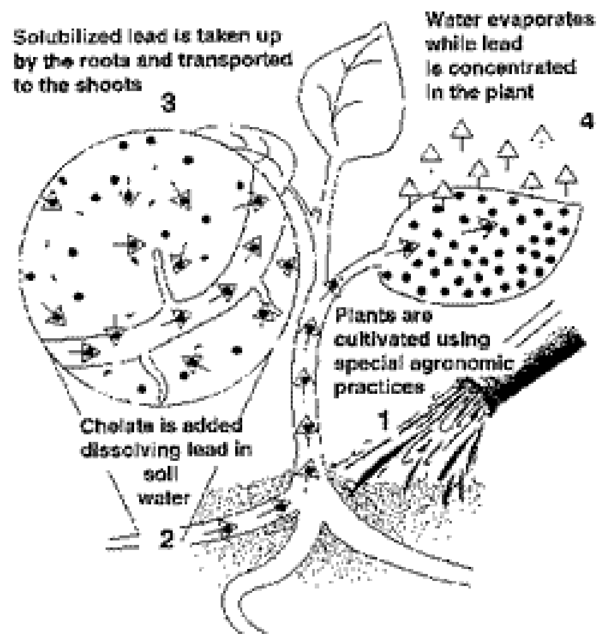
Do you think the process is different for non-organic materials?

PHYTOEXTRACTION



The uptake of contaminants by plant roots and translocation within the plants. Contaminants are generally removed by harvesting the plants. Because contaminants are concentrated in the plant material, this technology creates a smaller mass to be disposed of than does excavation. Technology is most often applied to metal-contaminated soils.

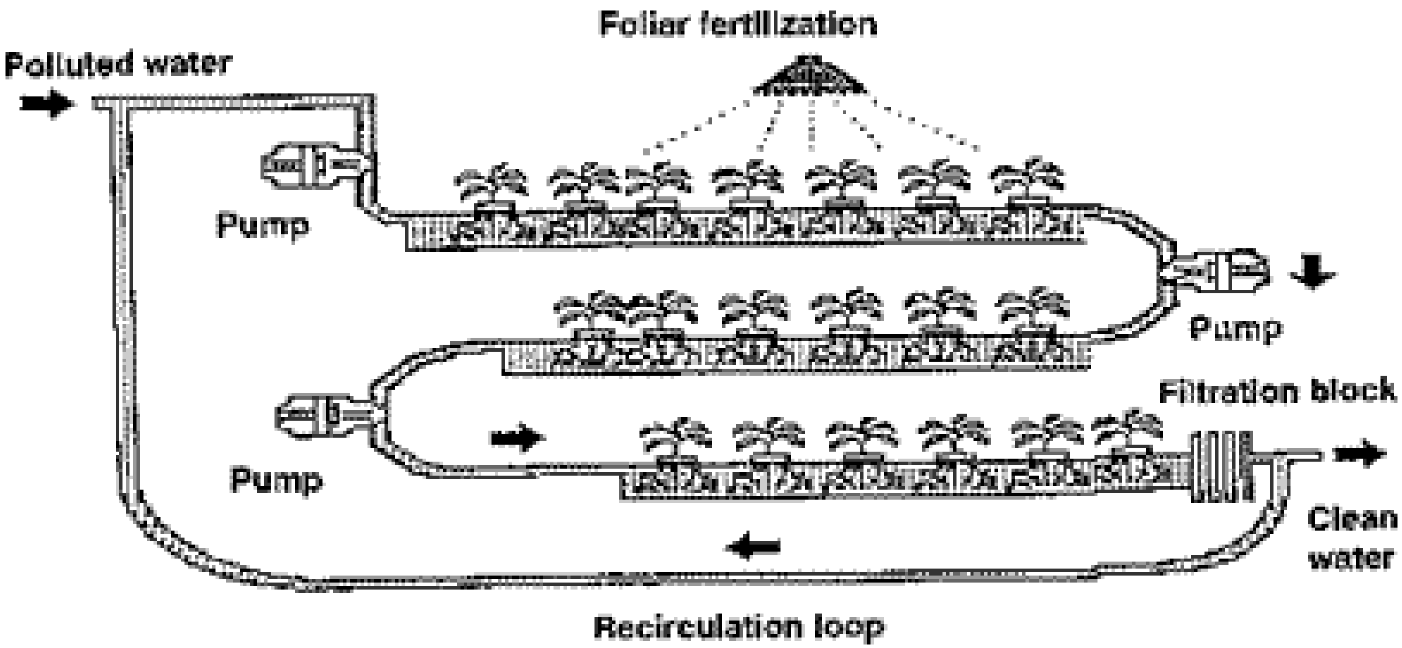
Brake fern accumulates arsenic



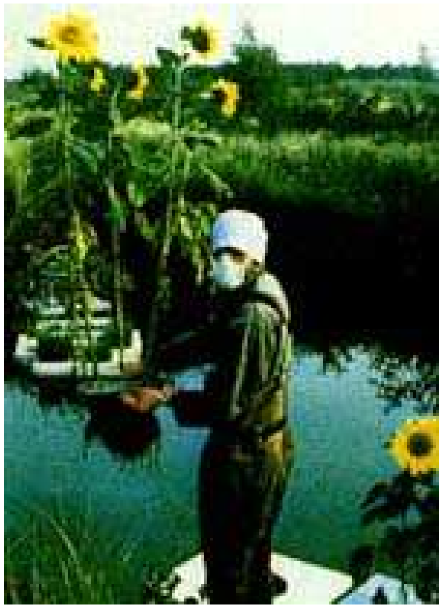
Indian mustard accumulates lead

Rhizofiltration

– The adsorption or precipitation onto plant roots, or absorption into the roots of contaminants that are in solution surrounding the root zone, due to biotic or abiotic processes. This technology works best with hydroponics.



- Lead
- Cadmium
- Copper
- Nickel
- Zinc
- Chromium
- Cesium
- Strontium
- Uranium

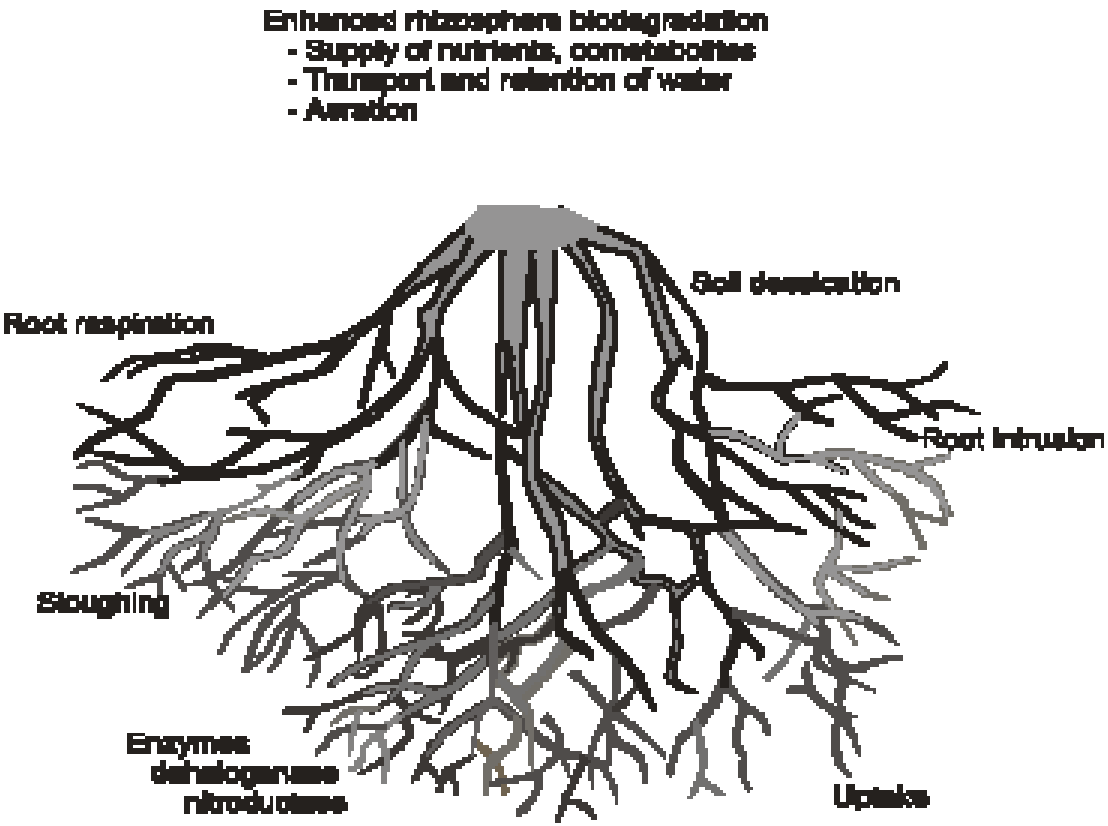


Phytostabilization

- Immobilization of a contaminant in soils through the absorption and accumulation by roots, adsorption onto roots, or precipitation with the root zone of plants.
- The use of plants and plant roots to prevent contaminant migration via wind and water erosion, leaching, and soil dispersion.

Rhizodegradation

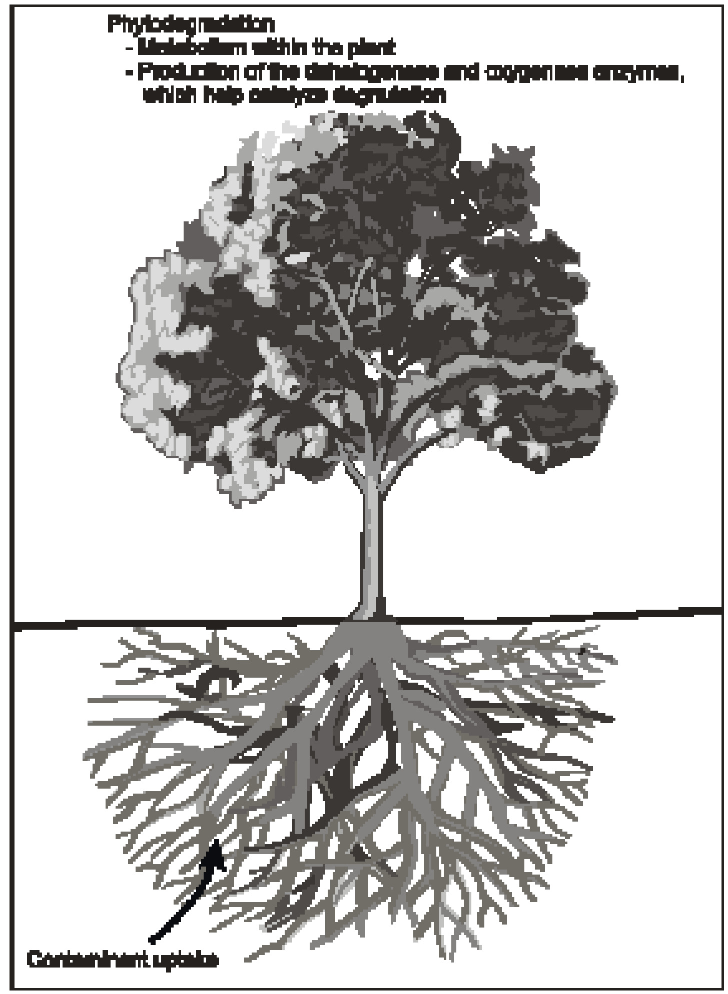
- The breakdown of an organic contaminant in soil through microbial activity that is enhanced by the presence of the root zone. Also known as plant-assisted degradation, plant-assisted bioremediation, and enhanced rhizosphere biodegradation.



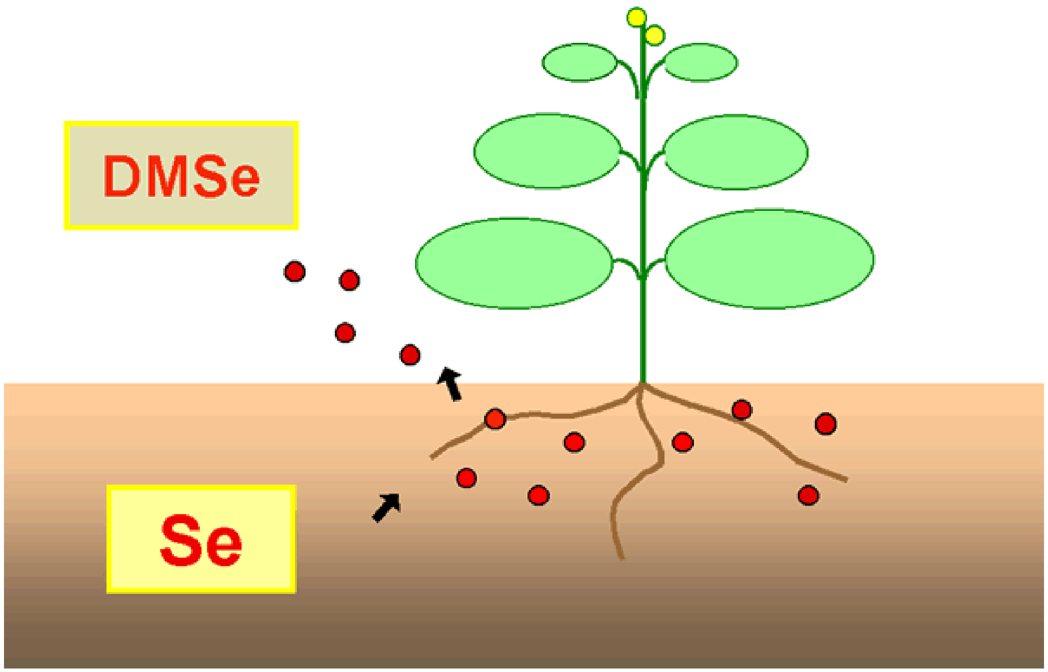
Phytodegradation (Phytotransformation)

- The breakdown of contaminants taken up by the plants through the metabolic processes within the plant, or the breakdown of contaminants, or the breakdown of contaminants external to the plant through the effect of compounds (such as enzymes) produced by the plant.

Parrot Feather (***Myriophyllum aquaticum)***
found to degrade TNT.



PHYTOVOLATILIZATION

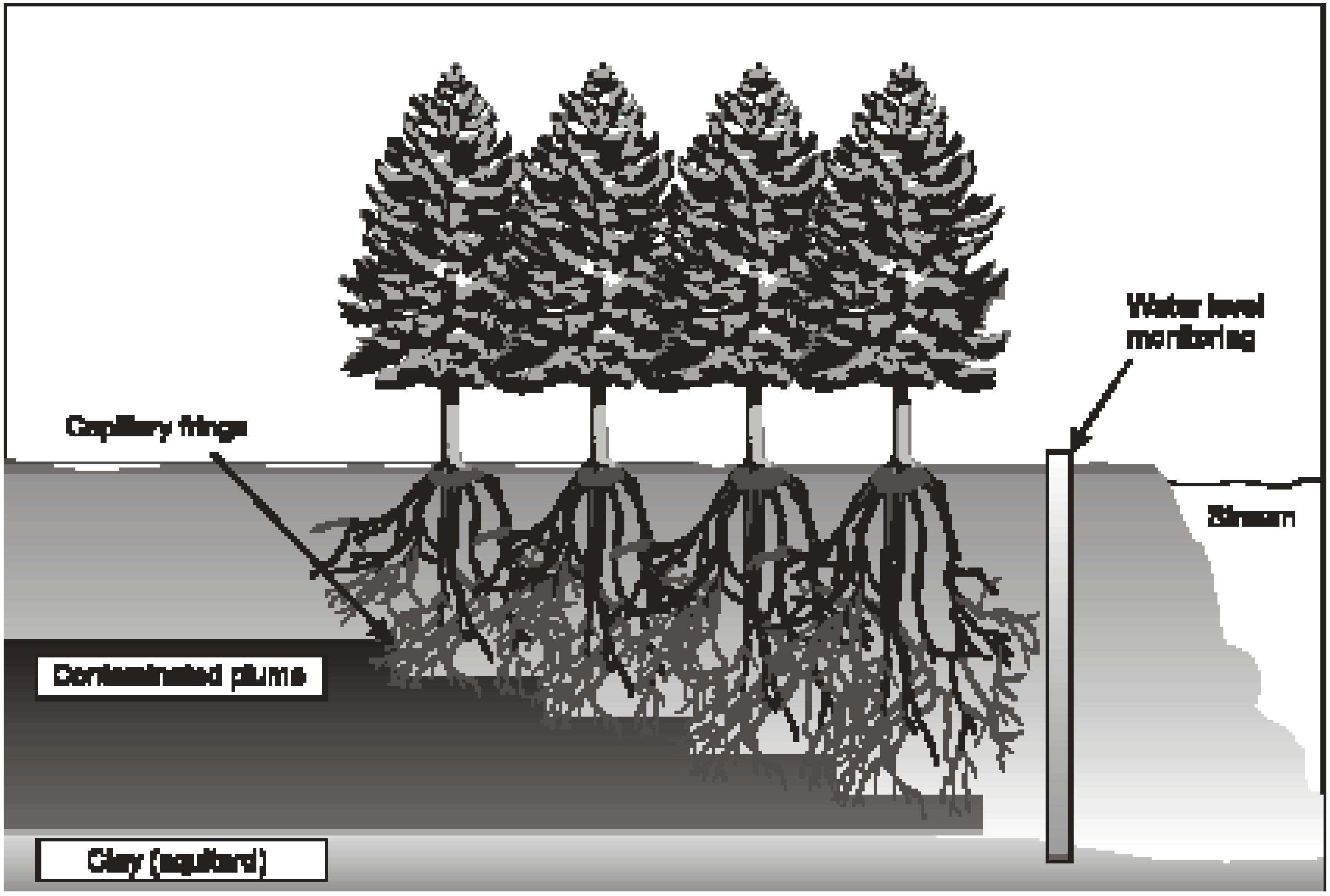


The uptake and transpiration of a contaminant by a plant, with the release of the contaminant or a modified form of the contaminant to the atmosphere from the plant through uptake, plant metabolism, and transpiration.

USDA soil scientist Gary Bañuelos evaluates canola plants grown for cleaning selenium-rich soils. In studies on livestock, he is testing the potential use of high-selenium canola forage as feed.

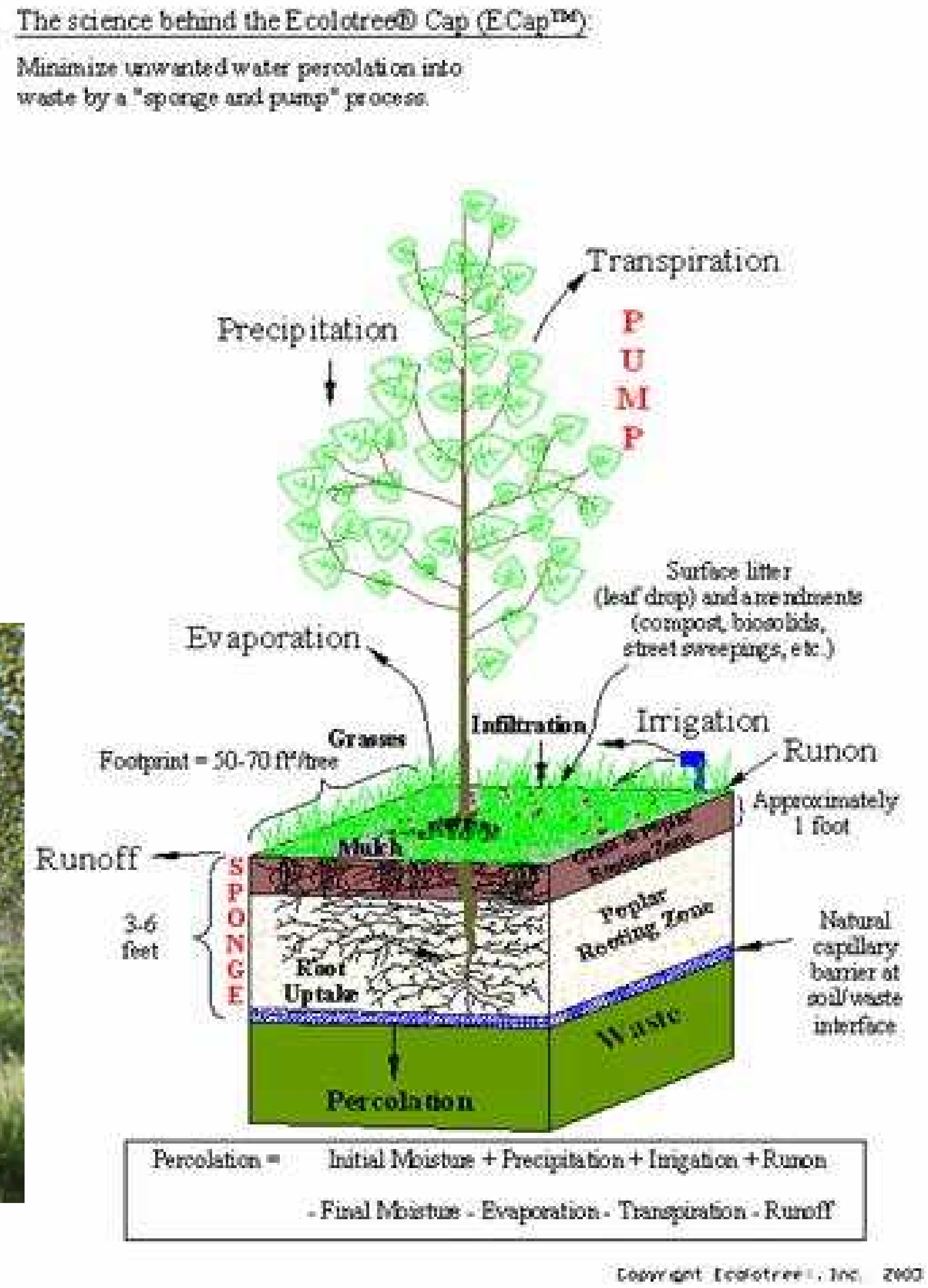
Hydraulic Control

- The use of plants to remove groundwater through the uptake and consumption in order to contain or control the migration of contaminants.



Vegetated Cover Systems

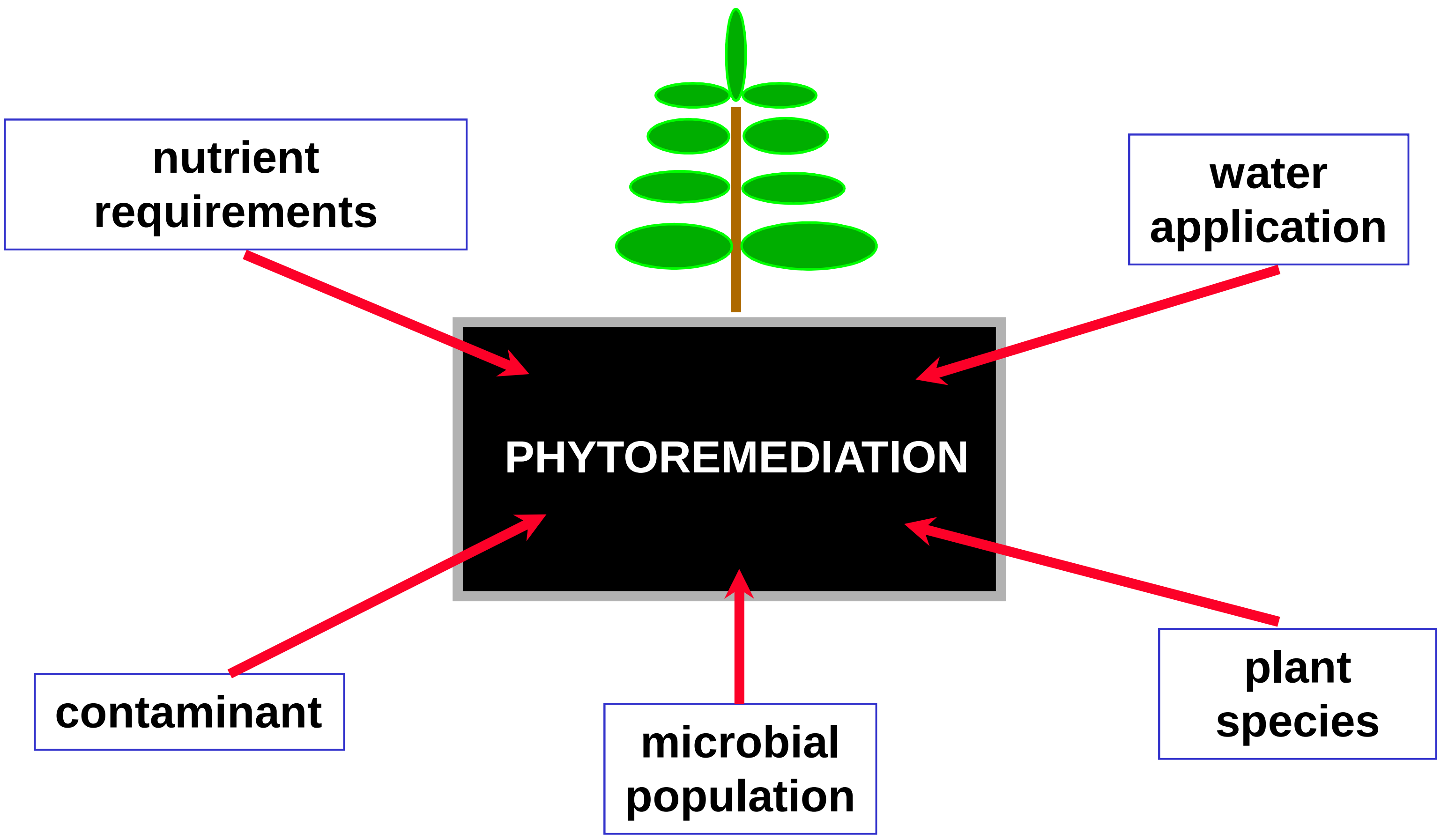
- A long-term, self-sustaining system of plants growing in and/or over materials that pose environmental risk; a vegetated cover may reduce the risk to an acceptable level and generally requires less maintenance.



Riparian corridors/buffer strips

– Vegetation generally applied along streams and river banks to control and remediate surface runoff and groundwater contamination moving into the surface water body.

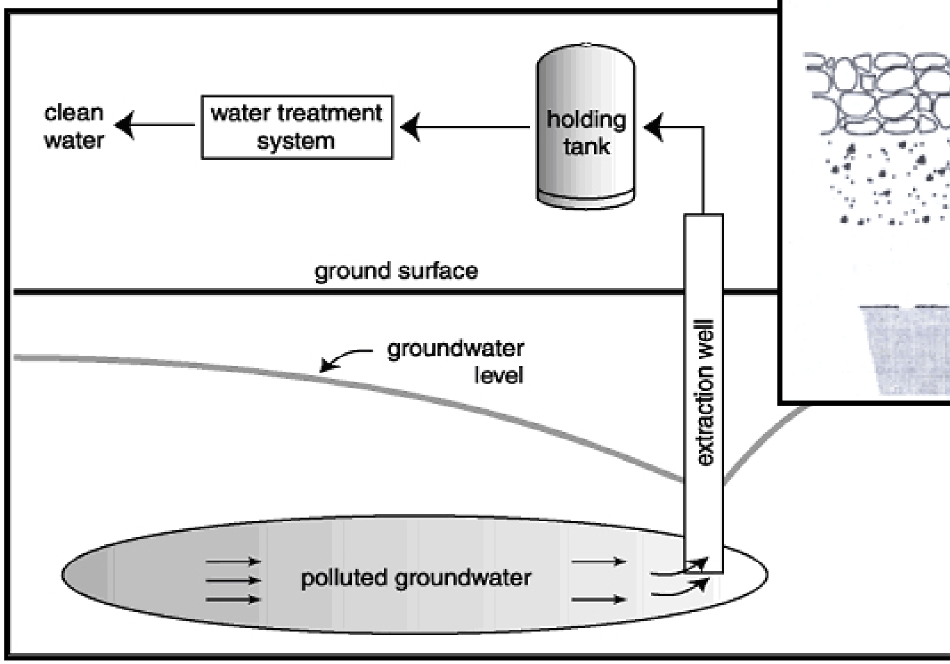
Factors Affecting Phytoremediation



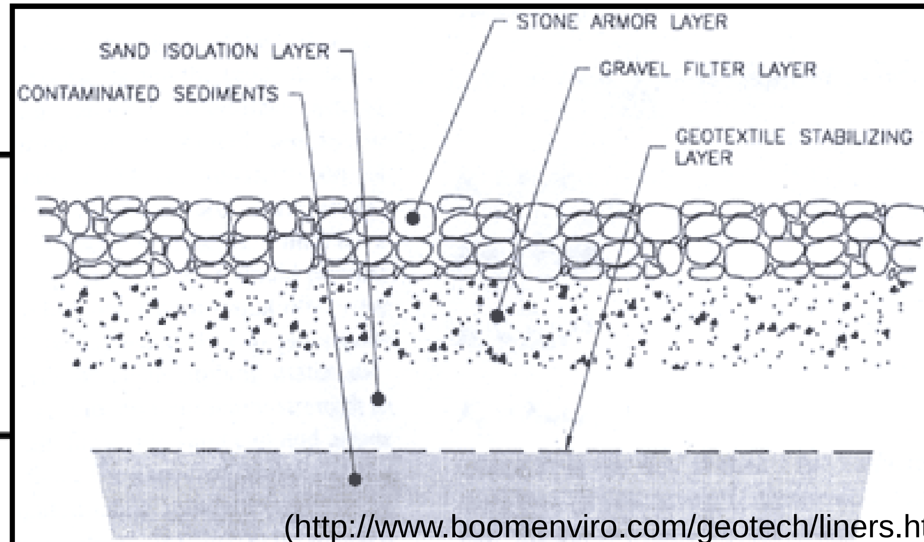
Case Studies

Traditional Remediation

- Pump-and-Treat
- Landfill capping



Envirotools.org



(http://www.boomenviro.com/geotech/liners.htm)

Phytoremediation of Groundwater

- Hydraulic Control
  - The use of plants to remove groundwater through the uptake and consumption in order to contain or control the migration of contaminants.
- Phytodegradation (Phytotransformation)
  - The breakdown of contaminants taken up by the plants through the metabolic processes within the plant, or the breakdown of contaminants, or the breakdown of contaminants external to the plant through the effect of compounds (such as enzymes) produced by the plant.
- Phytovolatilization
  - The uptake and transpiration of a contaminant by a plant, with the release of the contaminant or a modified form of the contaminant to the atmosphere from the plant through uptake, plant metabolism, and transpiration.

Phytoremediation Effectiveness

The water balance at a site determines the flow pattern in the aquifer and provides a first estimation of phytoremediation potential at the site.

Inflow – Outflow = Change in Storage

Design Approach

- Detailed information about the aquifer
- Estimation of evapotranspiration rates
- Local pattern of aquifer recharge
- Effects on plume location and potential for phytoremediation

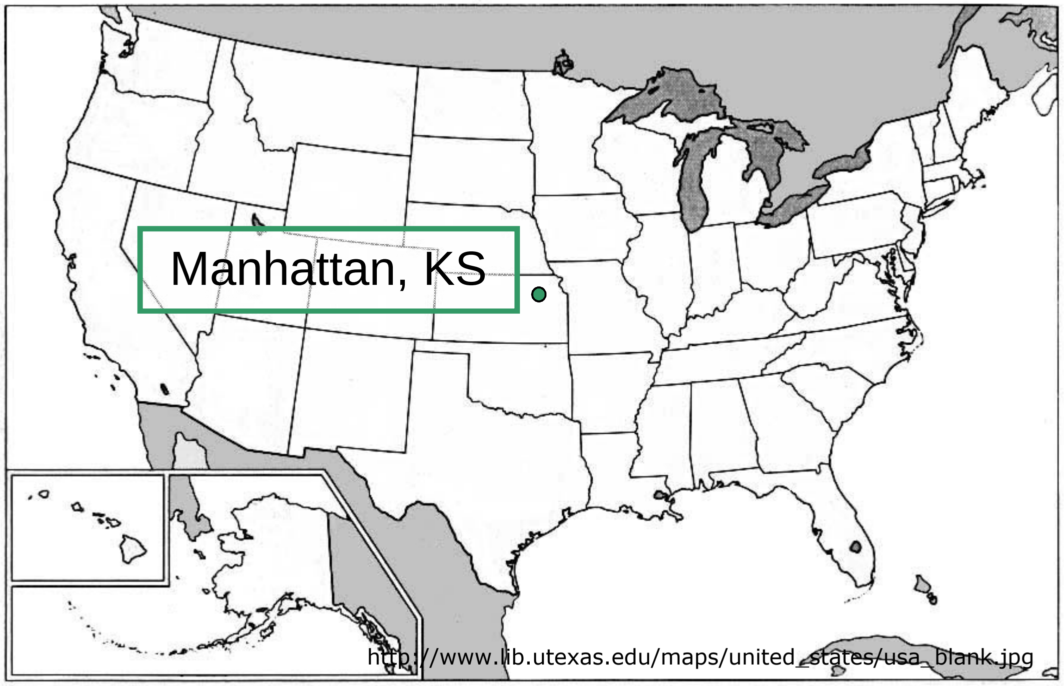
Old Chemical Waste Landfill

- Between 1960 and 1988, Kansas State University used the site for its hazardous and low level radioactive wastes.
- The site was officially closed in 1989.
- The contaminant plume was monitored quarterly.

Spring of 2005:

Two rows of poplars over the area of highest contamination

Seven rows down gradient from the hot spot to impede plume migration and enhance the uptake of contaminant



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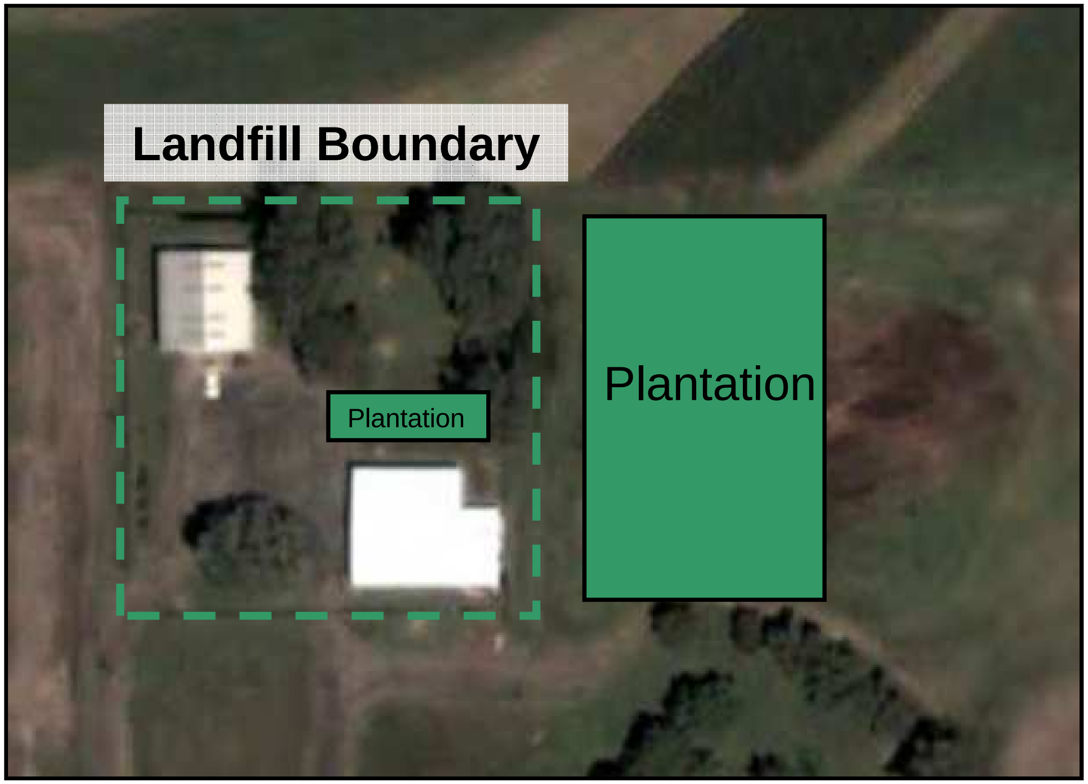


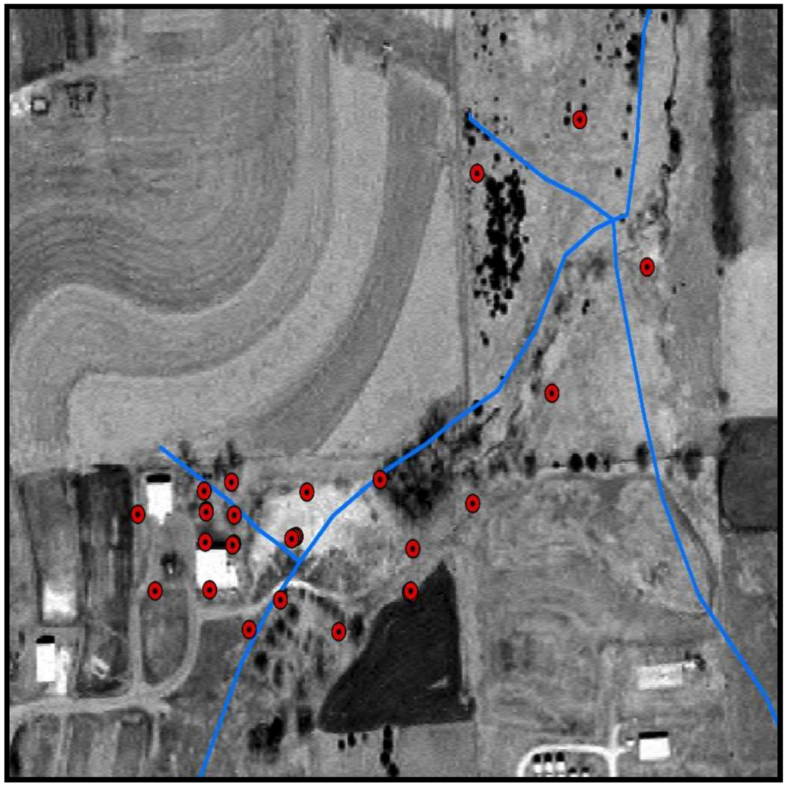
Earth.google.com

Contaminant: 1,4 Dioxane

Dioxane:

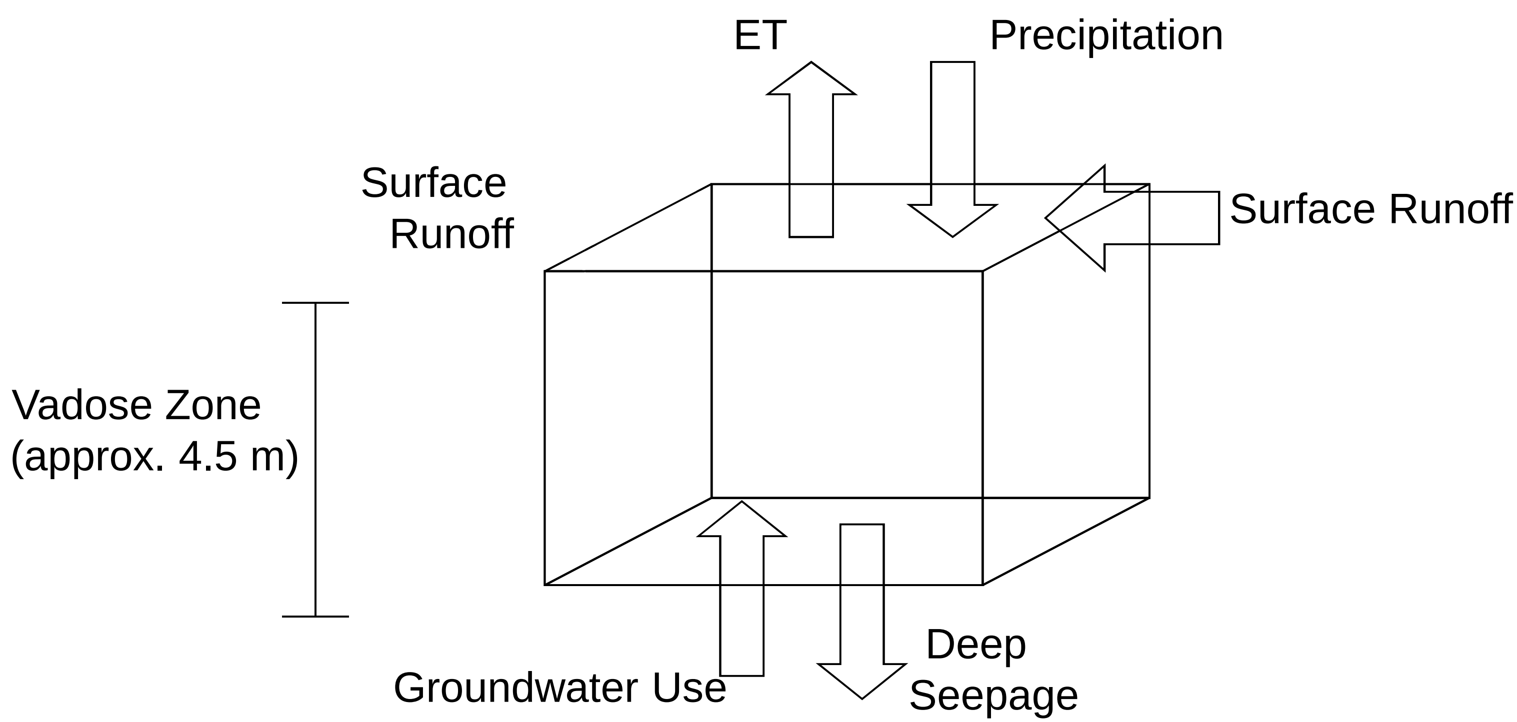
- has the same volatility as water
- moves freely through plants
- is resistant to biodegradation
- is easily photodegraded in the atmosphere
- unlike other volatiles, does not yield potent greenhouse gases or ozone degraders

- Dioxane moves freely through willow and poplar trees in the laboratory.



Water Balance Methodology

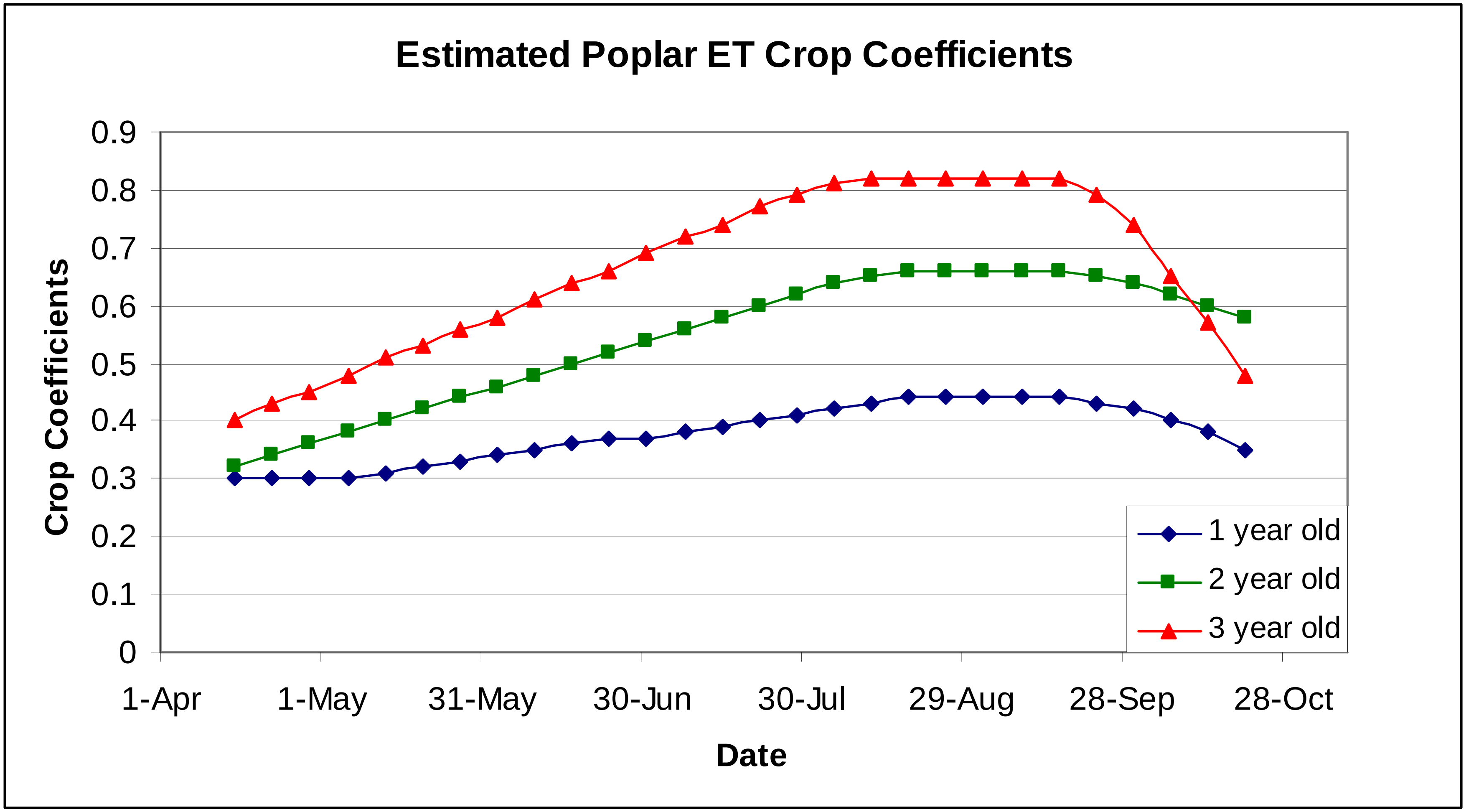
By assessing the inputs, outputs, and potential storage in the system, it is possible to estimate the required evapotranspiration for plume control.



Water Balance Methodology

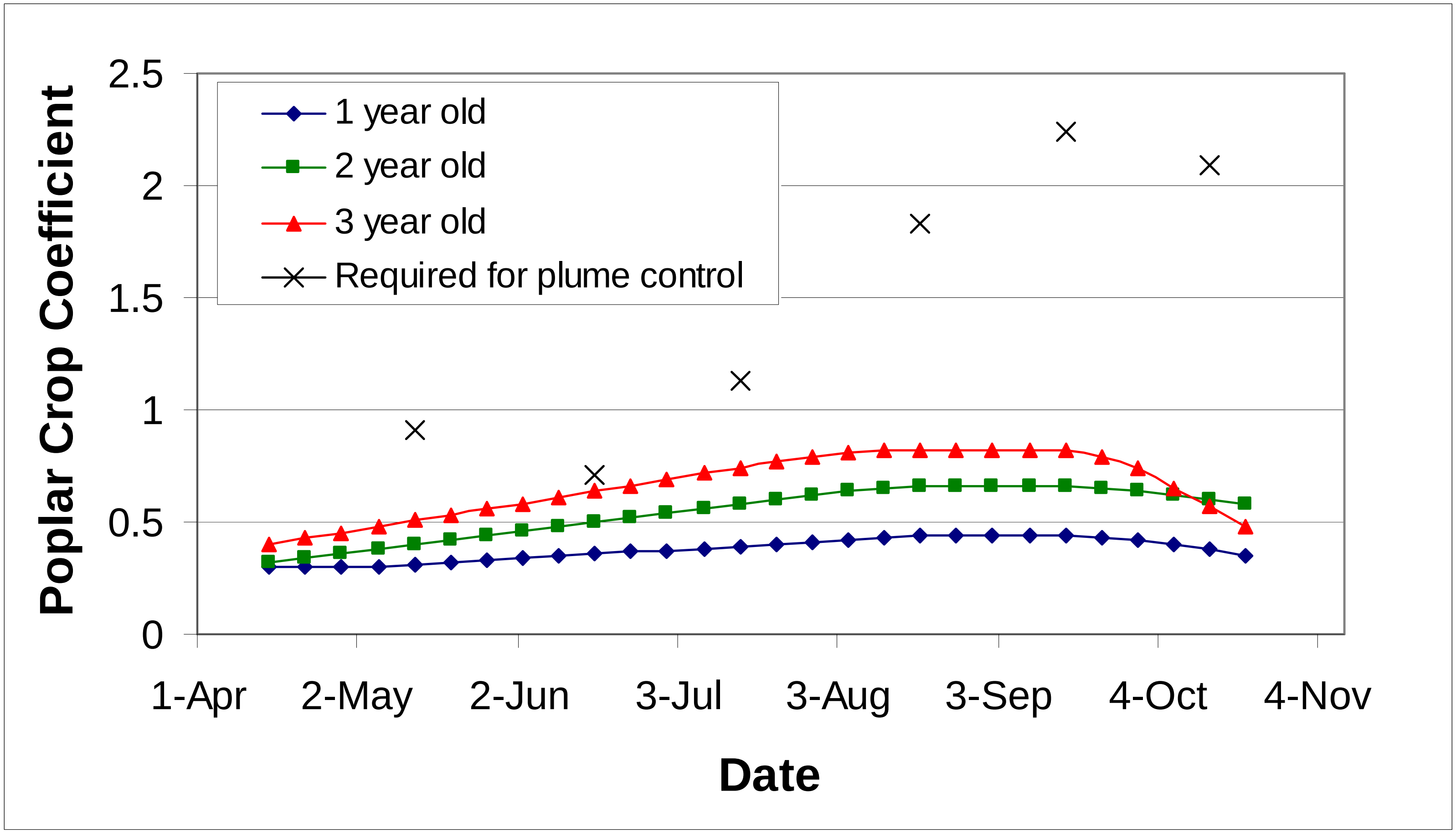
- Surface Runoff
  - SCS Curve Number method
  - Digital flow grid using GIS
- Precipitation
- Evapotranspiration
  - Penman-Monteith equation
  - Crop coefficient for young poplars
- Deep Seepage / Groundwater Uptake
  - Solinst Model 101 Water Level Meter
- Soil Water in Vadose Zone
  - 12 neutron probe access tubes 3 m in depth
    - (CPN Soil Moisture Gauge)
  - 2 tensiometers: 30 cm and 1 m depth

Water Balance Methodology - ET



Gochis, D. J., and R. H. Cuenca. 2000. Plant water use and crop curves for hybrid poplars. *Journal of Irrigation and Drainage Engineering* 126(4): 206-214.

Preliminary Water Balance Conclusions



Evapotranspiration ET

- Reduces average net recharge of the aquifer
- May prevent plume diving and down gradient migration
- May create upward flux of water or provide hydraulic control

Case Study

Orlando PCE/TCE Site

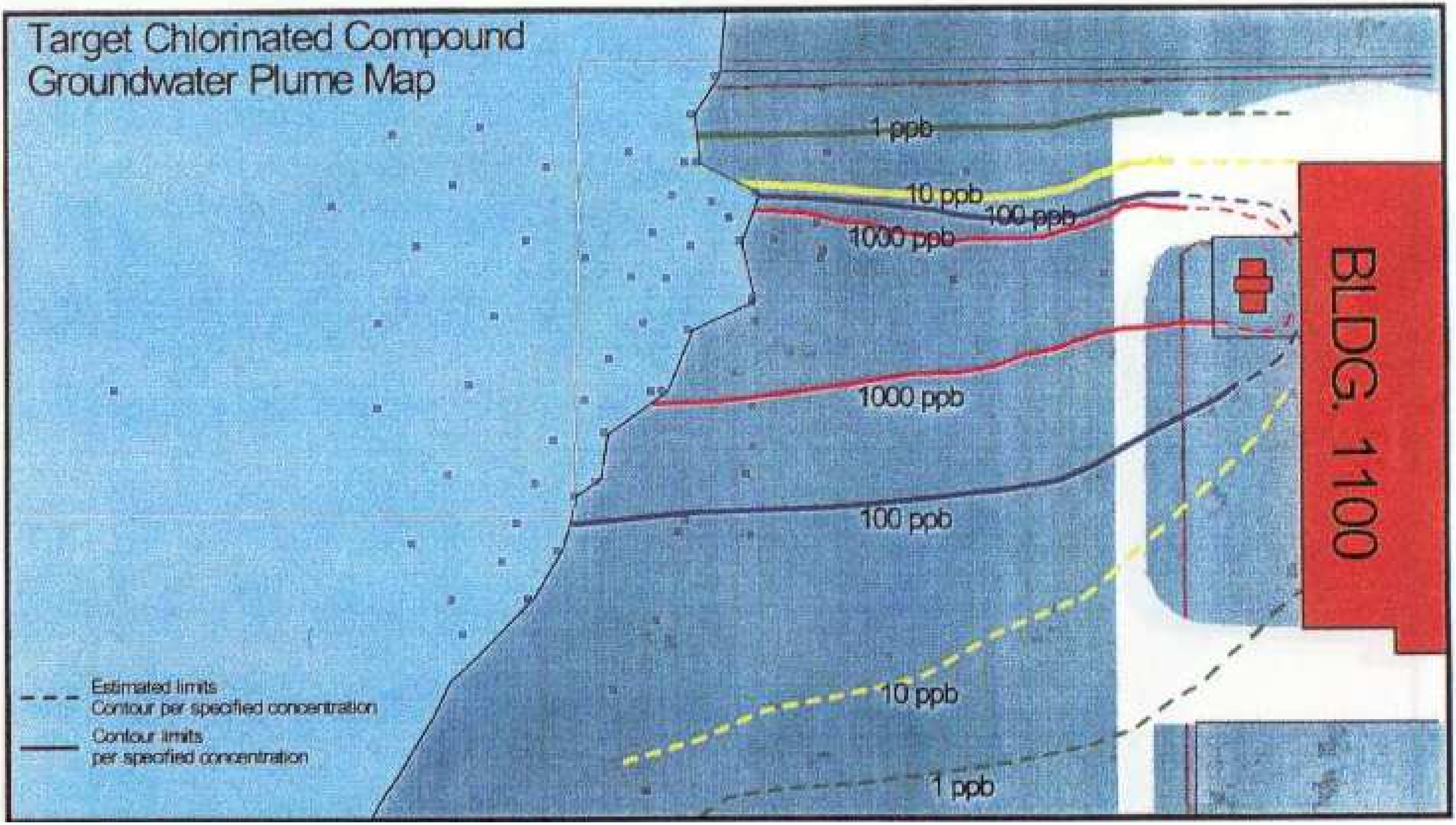
- BRAC site
- PCE/TCE source in a sump
- Flow toward and discharge into Lake Druid
- Flow Path Land Use
  - Building>Paved>Ditch>Grass>Jungle>Shore

Orlando PCE/TCE Site

Evapotranspiration Estimates

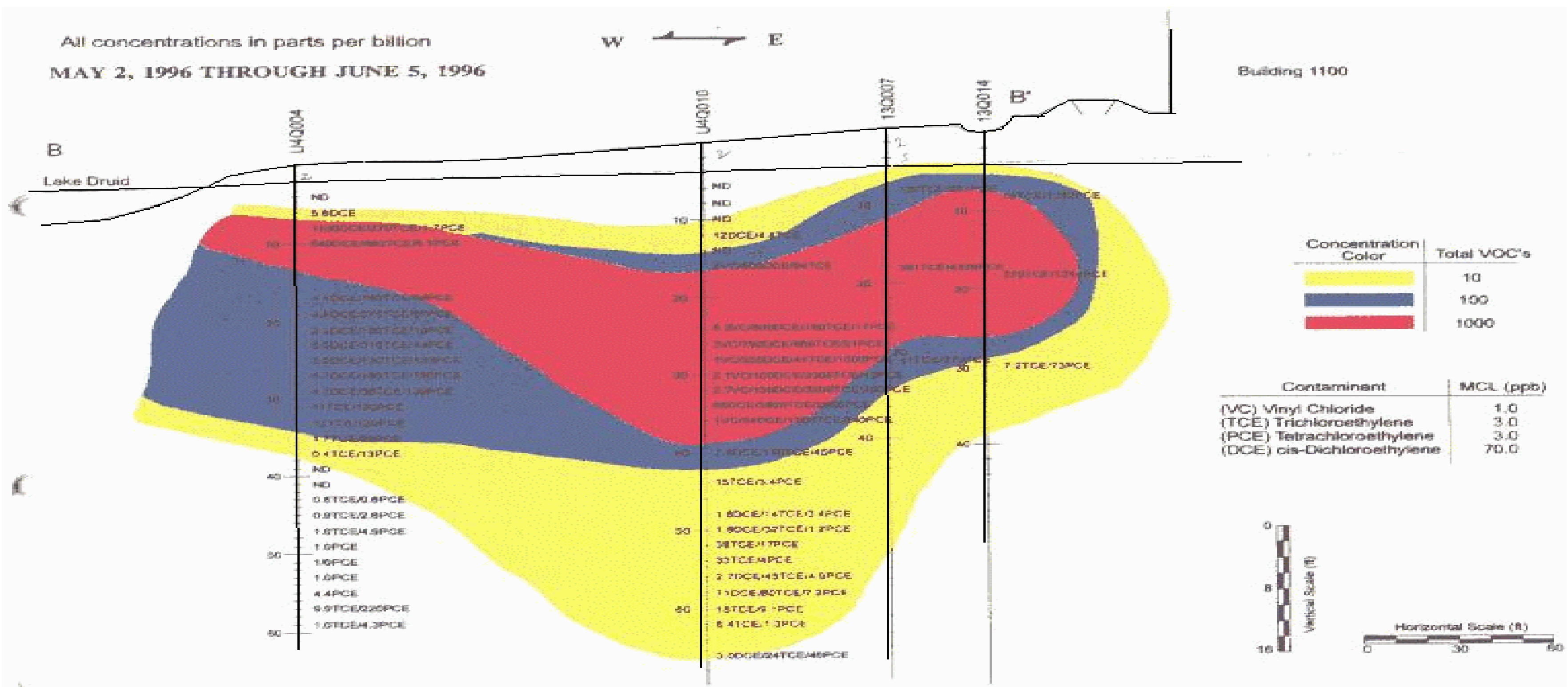
- Central Florida---130 cm/year (Florida Agricultural Extension Service)
- Orange Groves---50 cm/year (USGS Report 96-4244)
- Site Specific---80 cm/year (Vose et al.)
  - contribution of understory not determined

- Precipitation Estimate---140 cm/yr

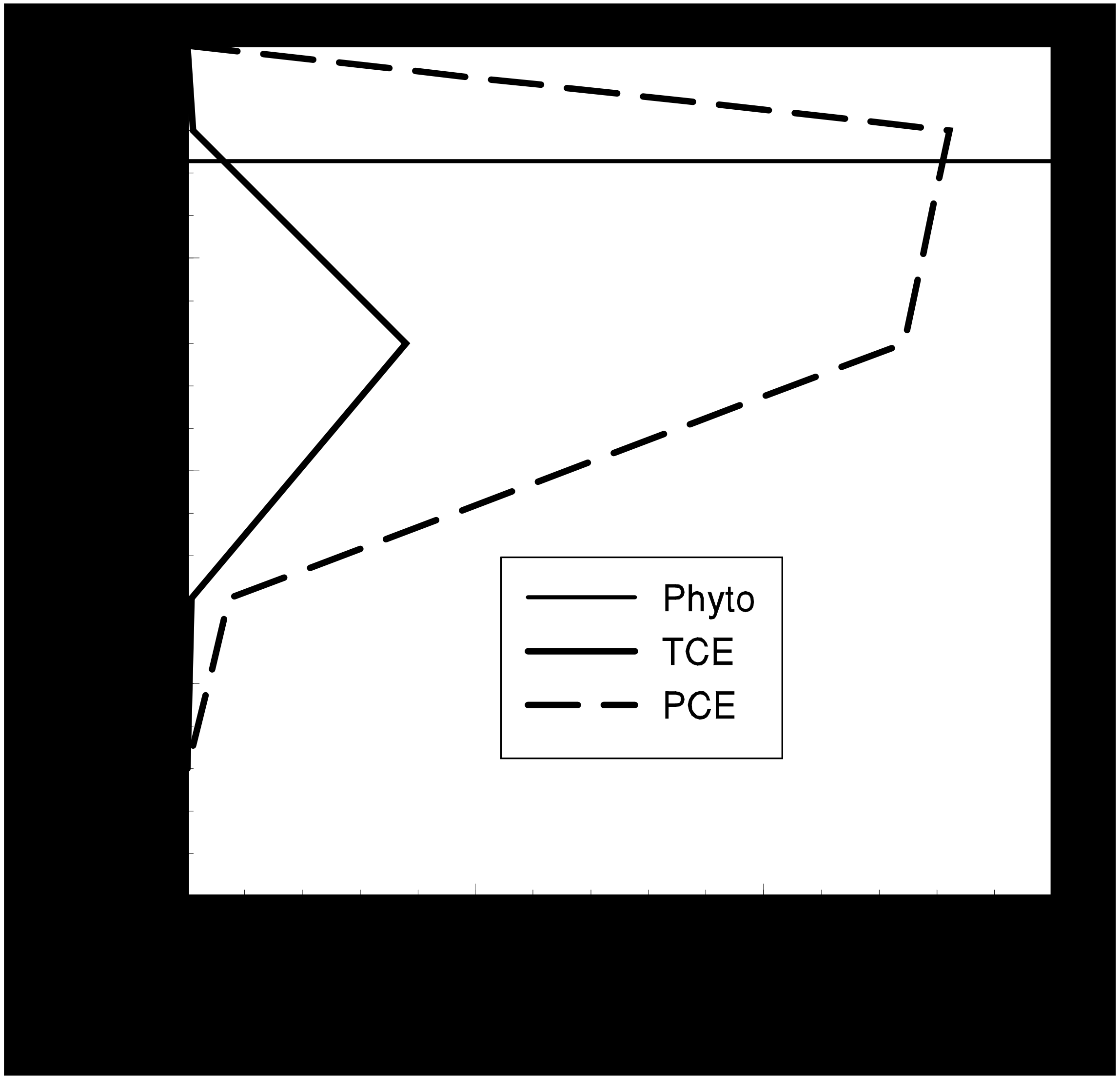

Target Chlorinated Compound
Groundwater Plume Map
1 ppb
10 ppb
100 ppb
1000 ppb
BLDG. 1100
1000 ppb
100 ppb
10 ppb
1 ppb
Estimated limits
Contour per specified concentration
Contour limits
per specified concentration

Orlando PCE/TCE Site

- Observed plume diving
  - from vertical contaminant distribution
  - dramatic/short distance/local



Contaminant Distribution at Source



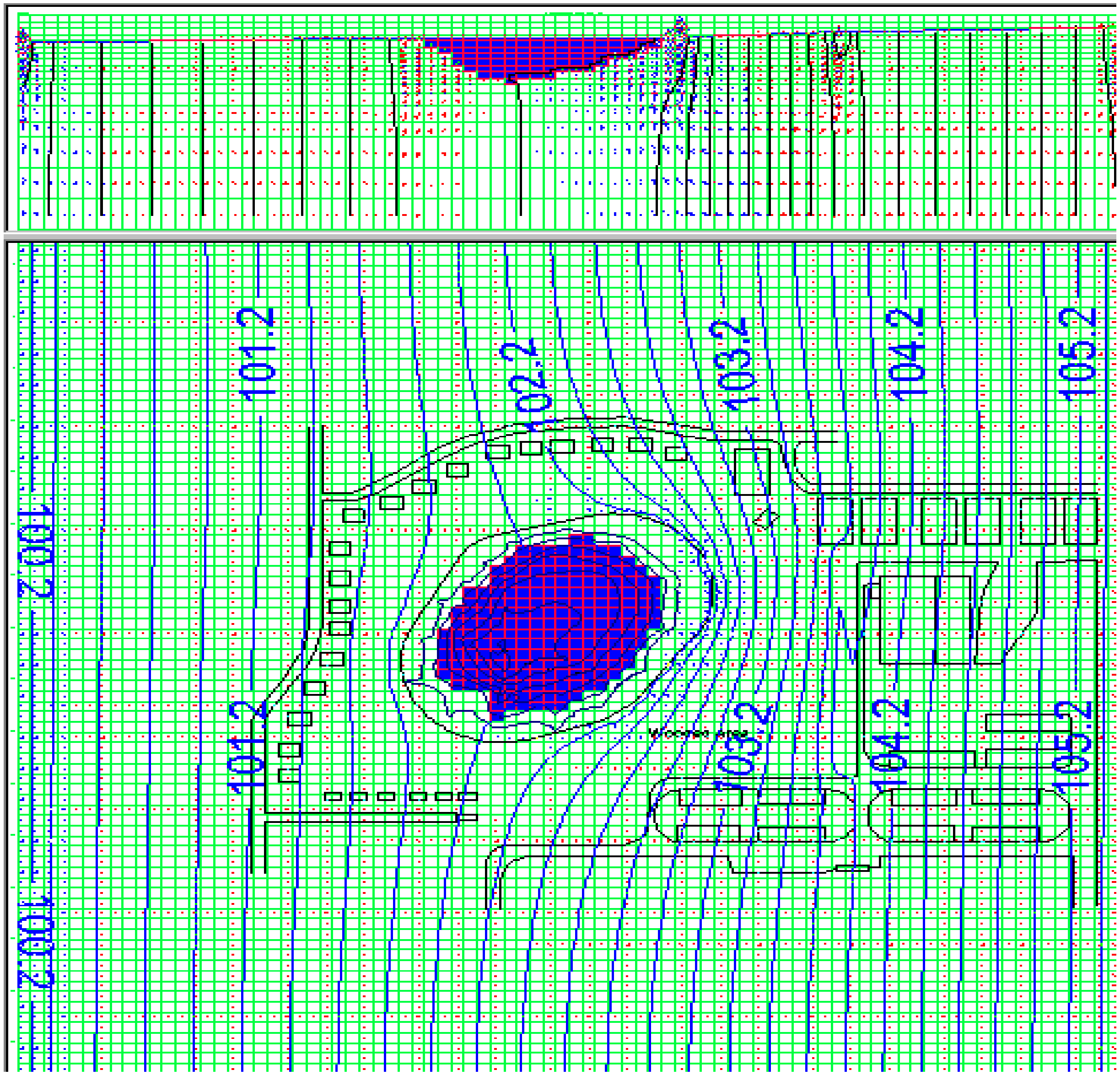
Numerical Model

- MODFLOW 3D, Steady State Ground Water Flow
- Based on USGS regional flow model
  - source of calibrated parameters, boundary conditions
- Fine scale layering to simulate plume diving and ET losses
- Two layers of differing conductivity
  - upper 10 ft/d Ks, 3.8 ft/d vertical
  - lower 40 ft/d Ks, 17 ft/d vertical
- Fine layering to define Lake Bathymetry
  - 11--2 foot thick layers
  - lower layers 5 or 10 feet thick
  - 18 layers total

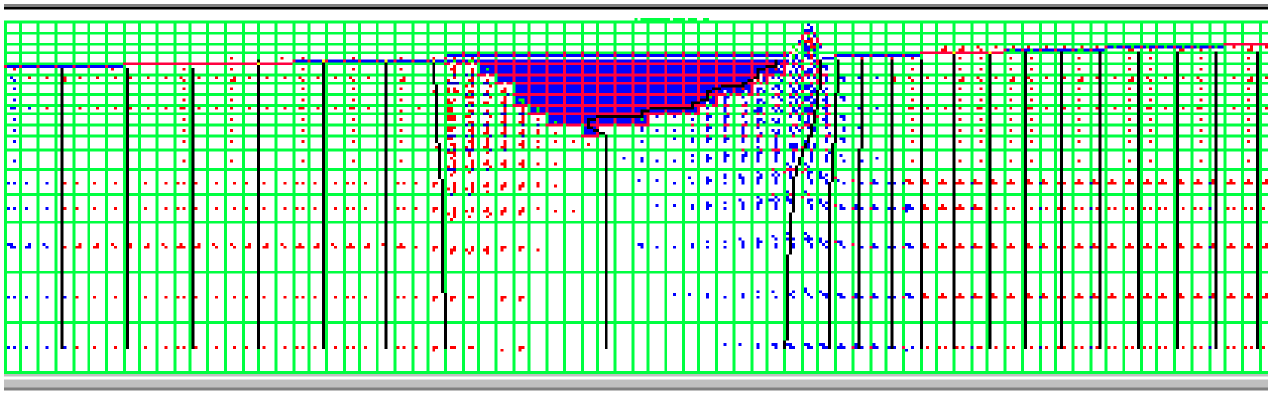
MODFLOW Model

- Simulate
  - existing conditions with enhanced recharge from ditch
  - Plume diving with diversion of water from ditch
  - ET with trees planted through parking lot (no recharge), but ET at 50, 80 and 130 cm/yr

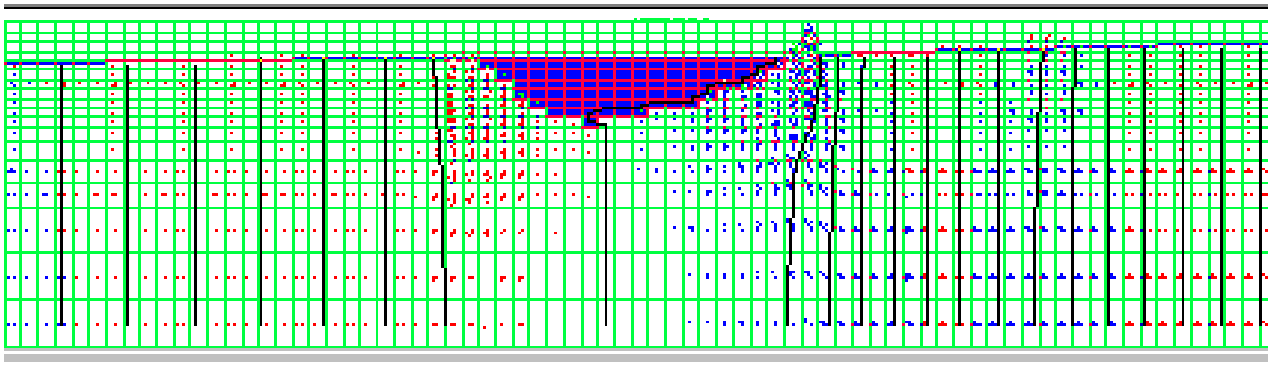
Orlando Current Conditions



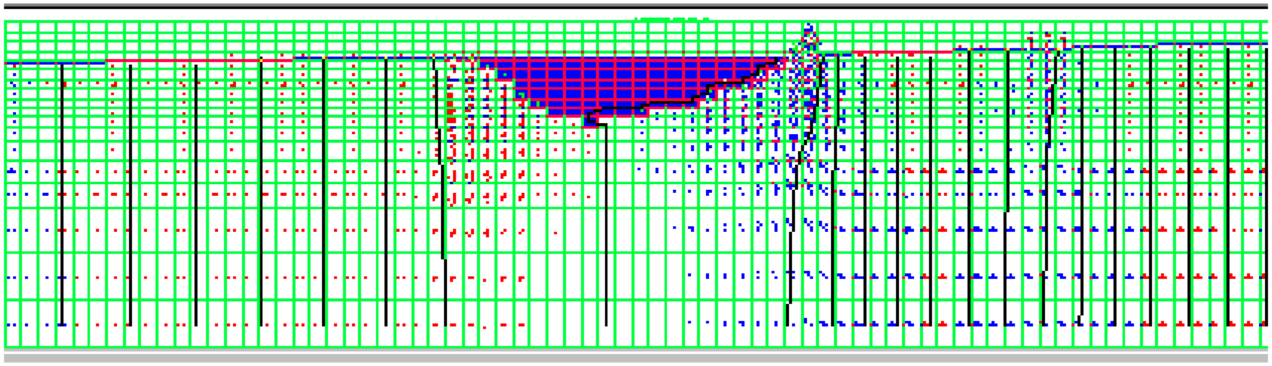
Comparison of Water Usage



Re-route Recharge



Tree Plantation using 80 cm/yr



Tree Plantation using 130 cm/yr

Orlando PCE/TCE Site

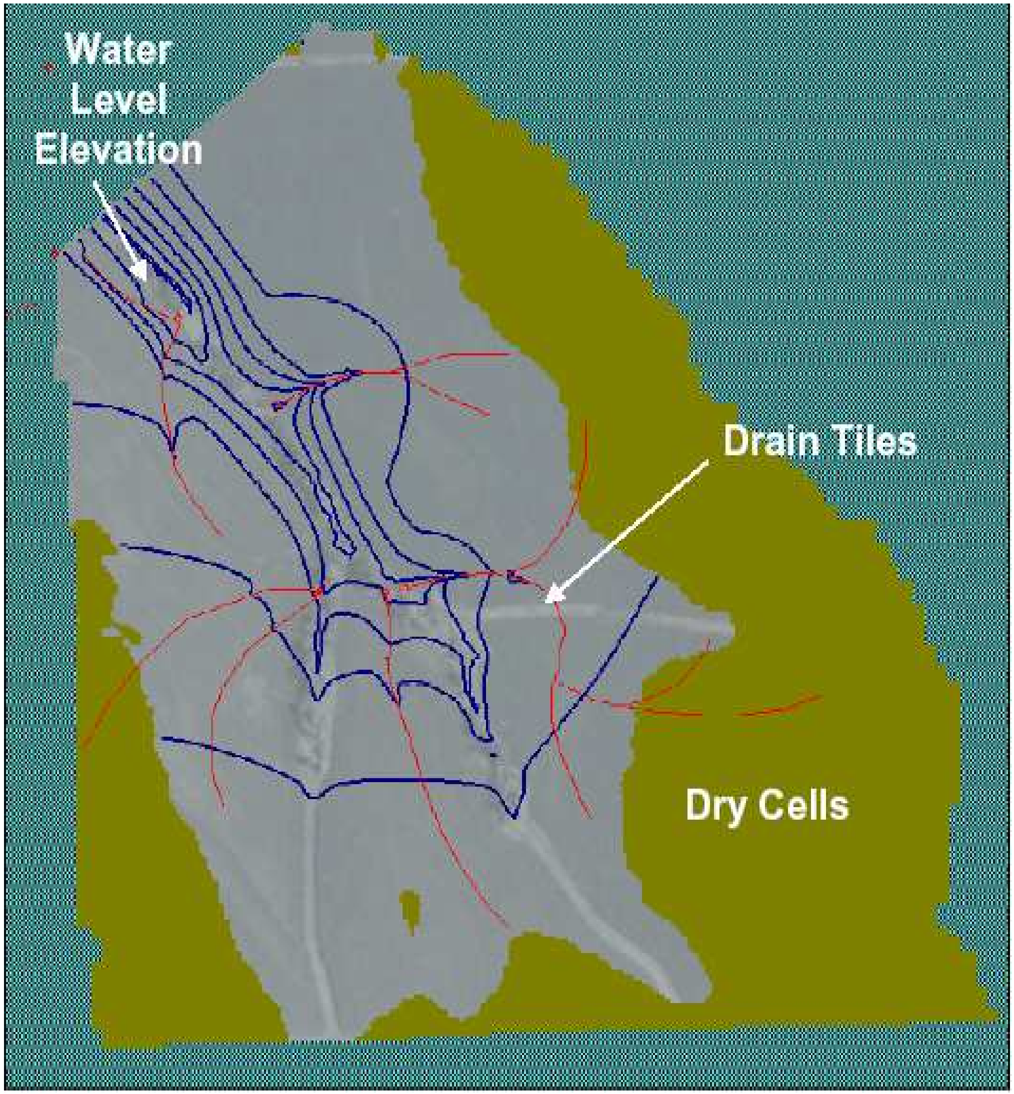
- Penetration depth:
  - 80 cm/yr ET; upward gradient to 23 ft
  - 130 cm/yr ET; upward gradient to 30 ft
- Contamination depth is 34 ft

Conclusions--Orlando

- Numerical model with fine scale vertical discretization needed for 3D flow features.
- Potential to control plume by diversion of runoff.
- Existing vegetation is ineffective in removing water/contaminants
- Tree plantation at source potentially affects a maximum of 77% to 88% of the contaminant depth.
  - ET = 80 to 130 cm/yr
  - Recharge = 0

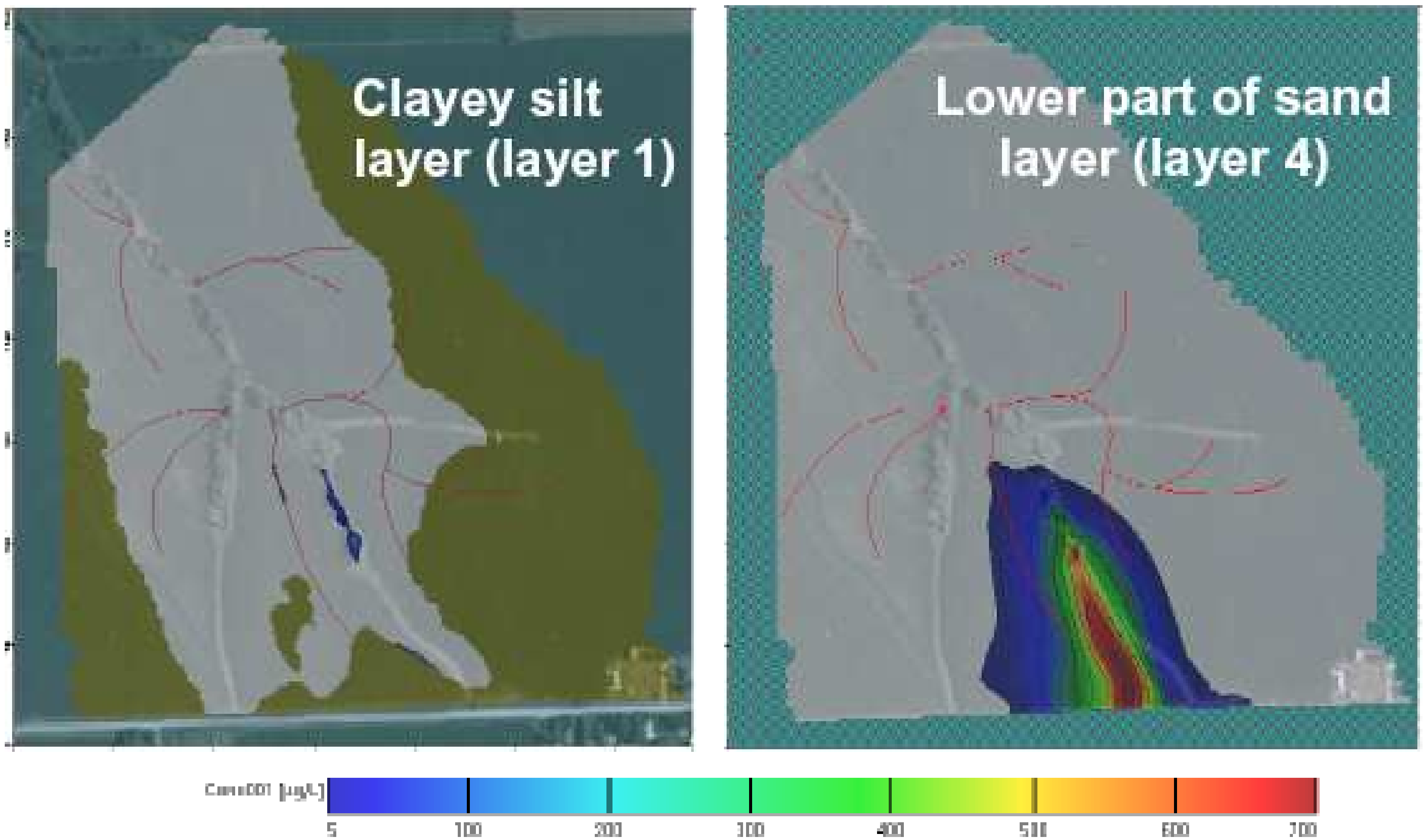
Case Study

Carbon Tetrachloride Site



- Boundaries
  - No flow
  - Constant head
- Drains
  - Creek
  - Tile Drains
- Hydraulic Conductivity
  - Silt layer
  - Sand layers

Carbon Tetrachloride Site
current condition



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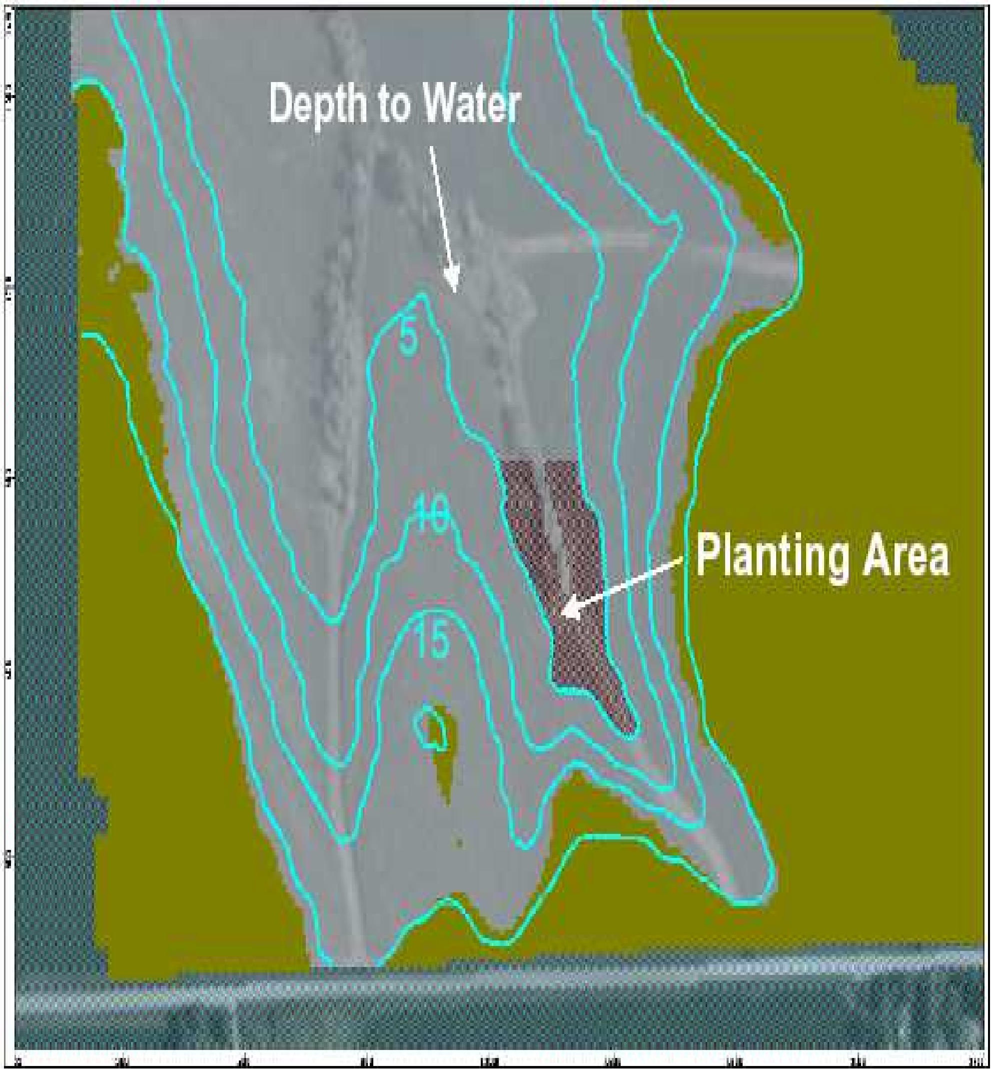
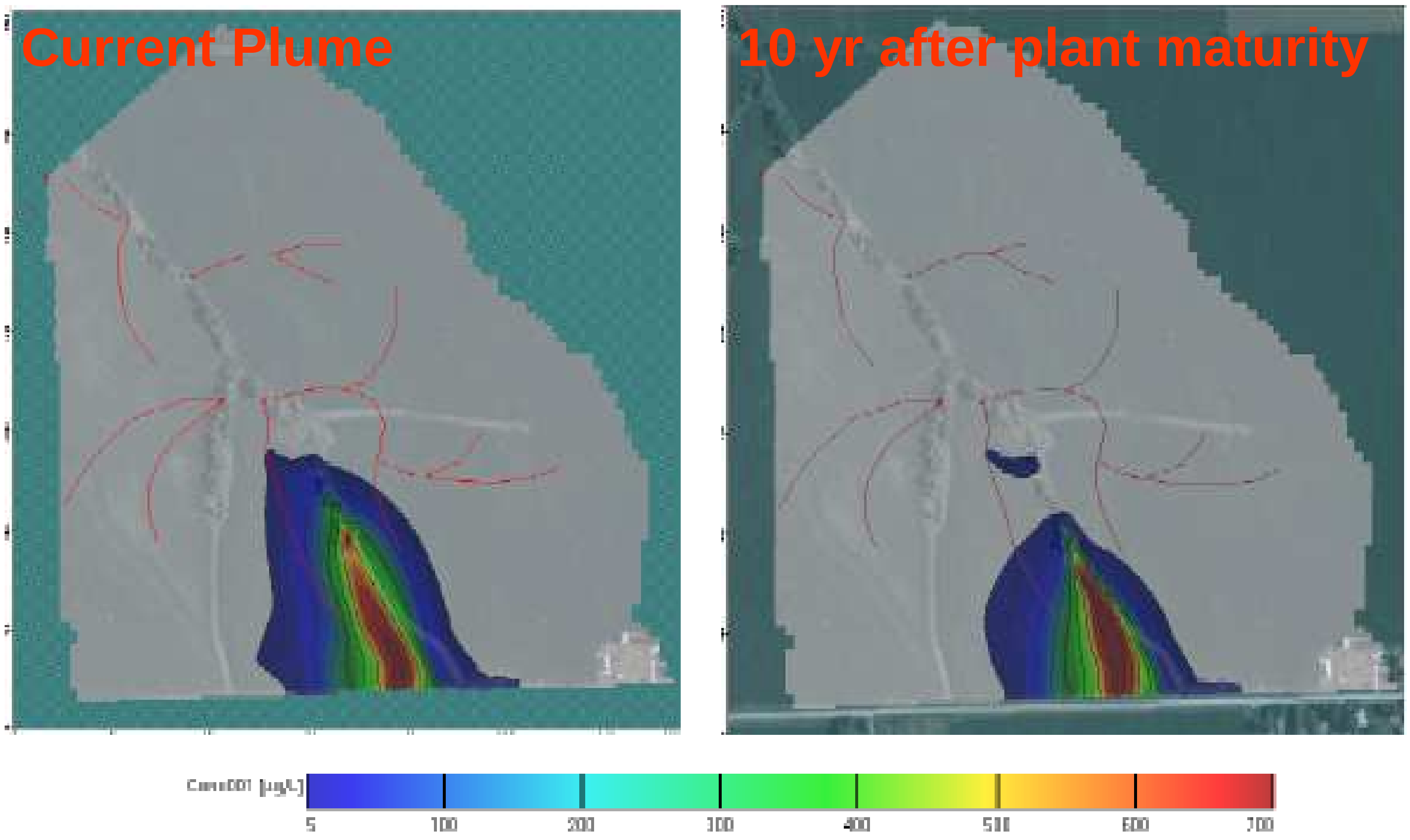


- Planting area
  - Near discharge of plume
  - 1.5 acres
  - <= 5 feet
- Planting density
  - 653 trees
  - 10 ft x 10 ft spacing
- Water use
  - 50 L per tree per day

Carbon Tetrachloride Site

10-year maximum draw down of 9 feet

Carbon Tetrachloride Site



Conclusions

- Vertical characterization is required for delineating plumes, especially when considering phytoremediation
- Localized recharge distribution controls plume diving (accepting stratigraphy)
- ET estimates have uncertainty
  - generally bounded by pan evaporation rates