Headquarters U.S. Air Force

Integrity - Service - Excellence

PHYTOSTABILIZATION

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Parsons Engineering Science, Inc.

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Acknowledgements

- **AFCEE/ERT**
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  - **Victor Hauser**

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TECHNOLOGY OVERVIEW

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Definition

- **Phytostabilization or Phytohydraulics:**

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

  (USEPA, 2000)

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How Does it Work?

- Plants Could Act as an ***Extraction Well***
  - Removes Contaminated Groundwater Through ***Transpiration*** leading to ***Phytovolatilization***
  - Could Minimize Migration
- Plants Could Act as a ***Bioreactor***
  - Cells Within Plant Could Transform Chlorinated Solvents leading to ***Phytodegradation***
- Plants Could Act as a ***Carbon Source***
  - Adds Carbon to Root Zone/Subsurface Through Root Exudation
  - Could Degrade Chlorinated Solvents Through ***Reductive Dechlorination***
- Plants Could Act as a ***Containment System***
  - Humic/Fulvic Compounds Could Bind Chemicals in Root Zone
  - Plant Tissue Could Bind Chemicals in Roots/Stem/Leaves

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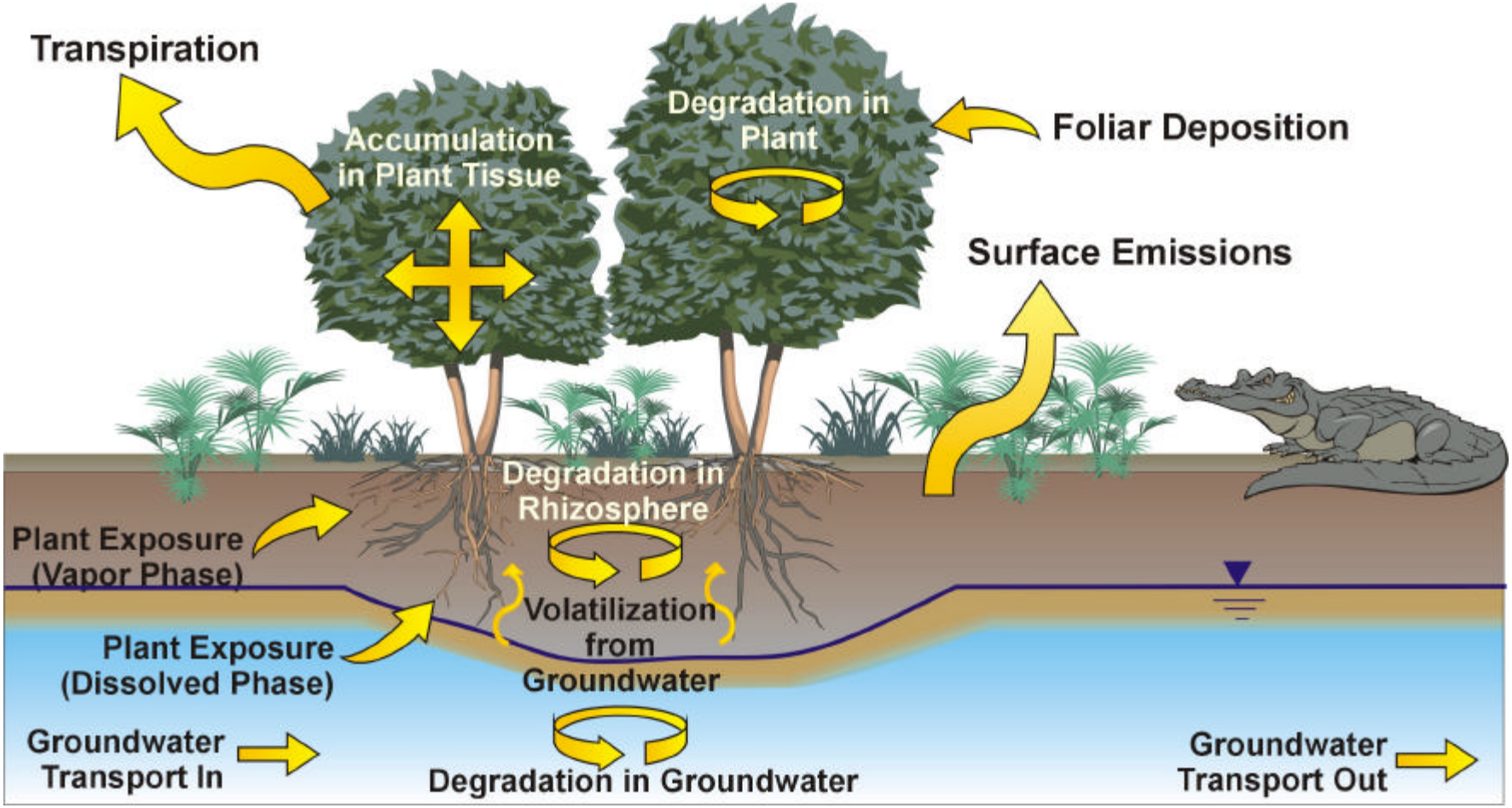
Attenuation Mechanisms



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State of the Technology

- Hydraulic Control
  - Numerous field trials in progress Þ Waiting for results
  - Carswell Air Force Base (Former)
- Phytovolatilization (Through the Tree to Atmosphere)
  - Lab/field trials Þ none to some
- Phytodegradation (Degradation within Tree)
  - Lab/field trials Þ some more than others
- Reductive Dechlorination
  - Some geochemistry changes
- Hill Air Force Base, Utah
  - Evaluating phytovolatilization and phytodegradation effects with Utah State University

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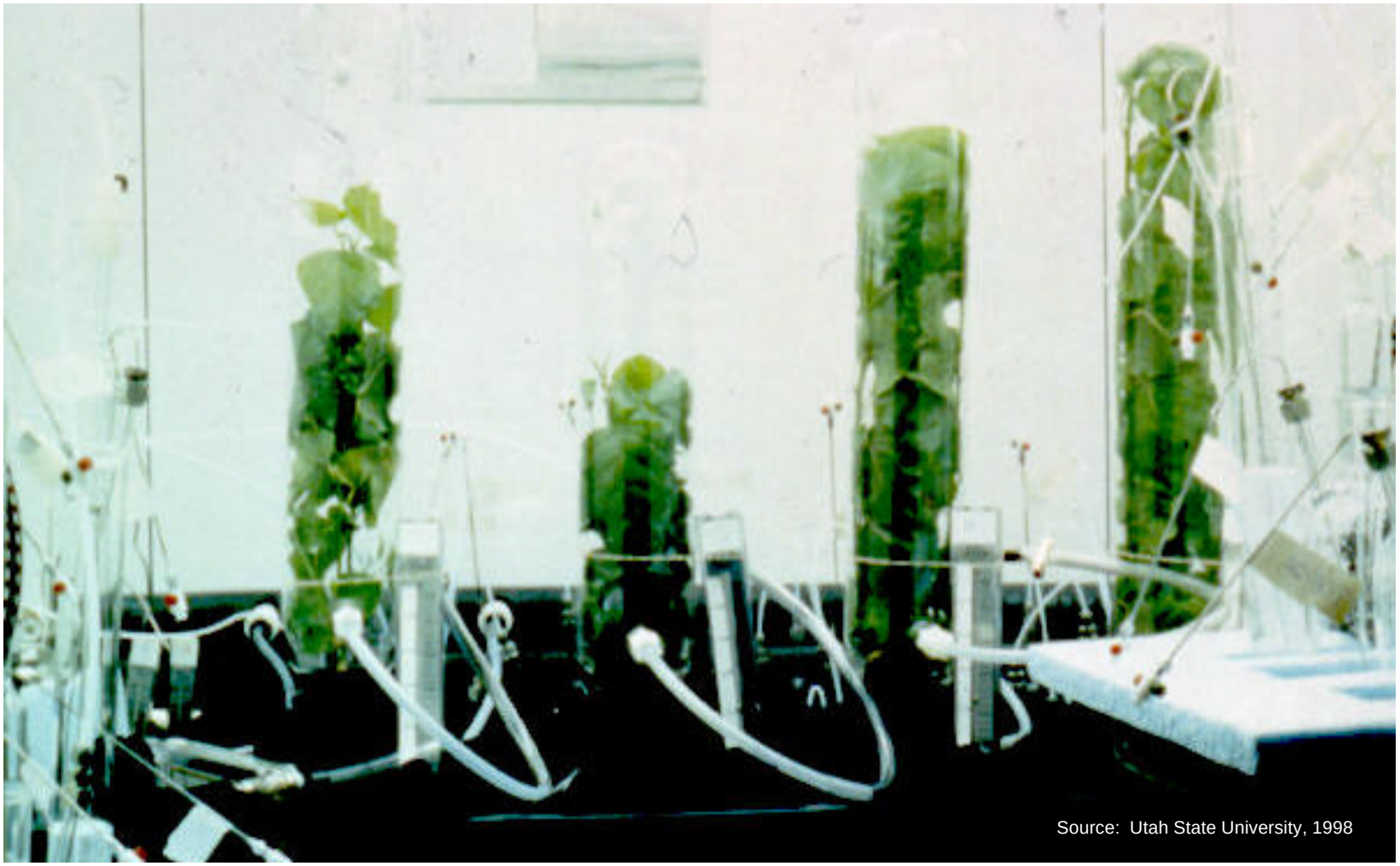
Academic Pursuits



Source: Utah State University, 1998

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Work in the Field

Source: Parsons ES, 1998

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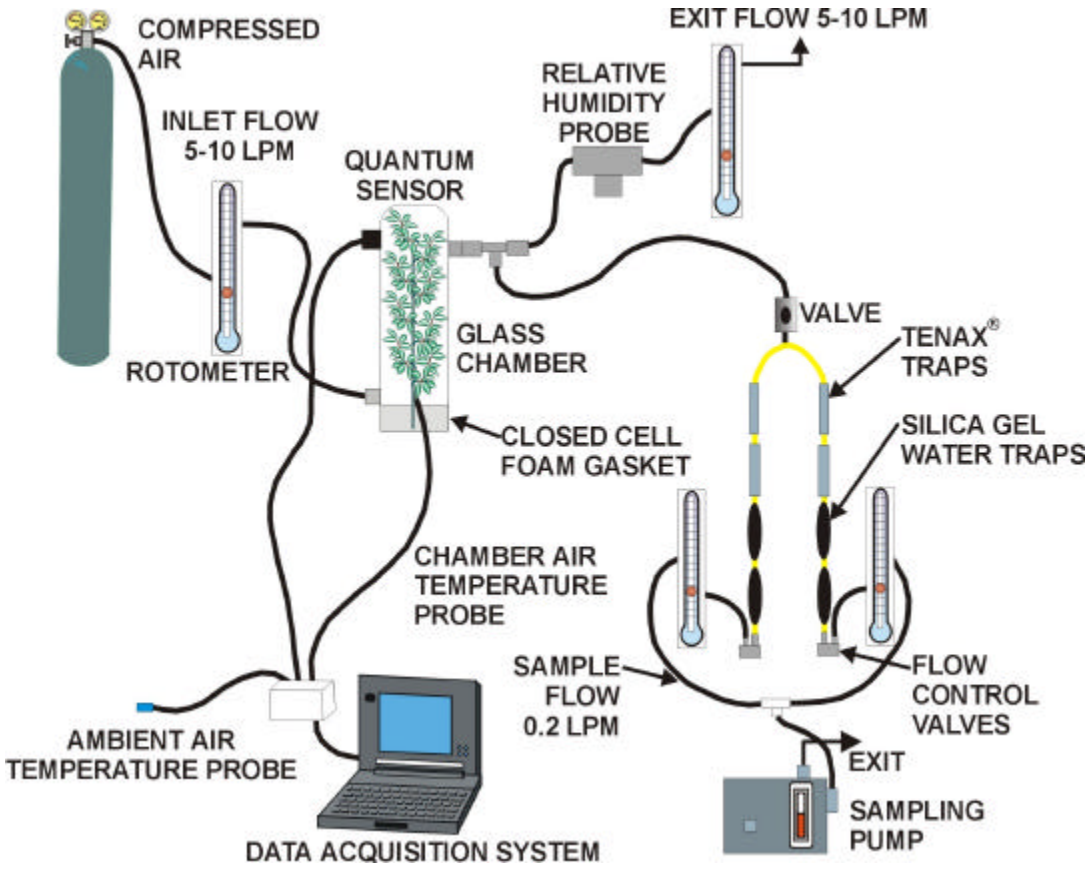
Work in the Field



Source: Utah State University, 1998

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What Needs To Happen?

- Need To Have a Water Deficit
  - More Evapotranspiration than Precipitation
  - Evapotranspiration/Precipitation Ratio > 1.0
- Trees Need to Come Into Contact with Contaminants
  - Direct Groundwater Uptake
  - Bring Groundwater to Trees (e.g., irrigation)
- Need Large Amounts of Below/Above Ground Biomass
  - Requires Large Planting Areas
  - Requires High Density Plantings
  - Requires Relatively Fast Growing Tree Species
- Trees Need to Act Like Pump and Treat System

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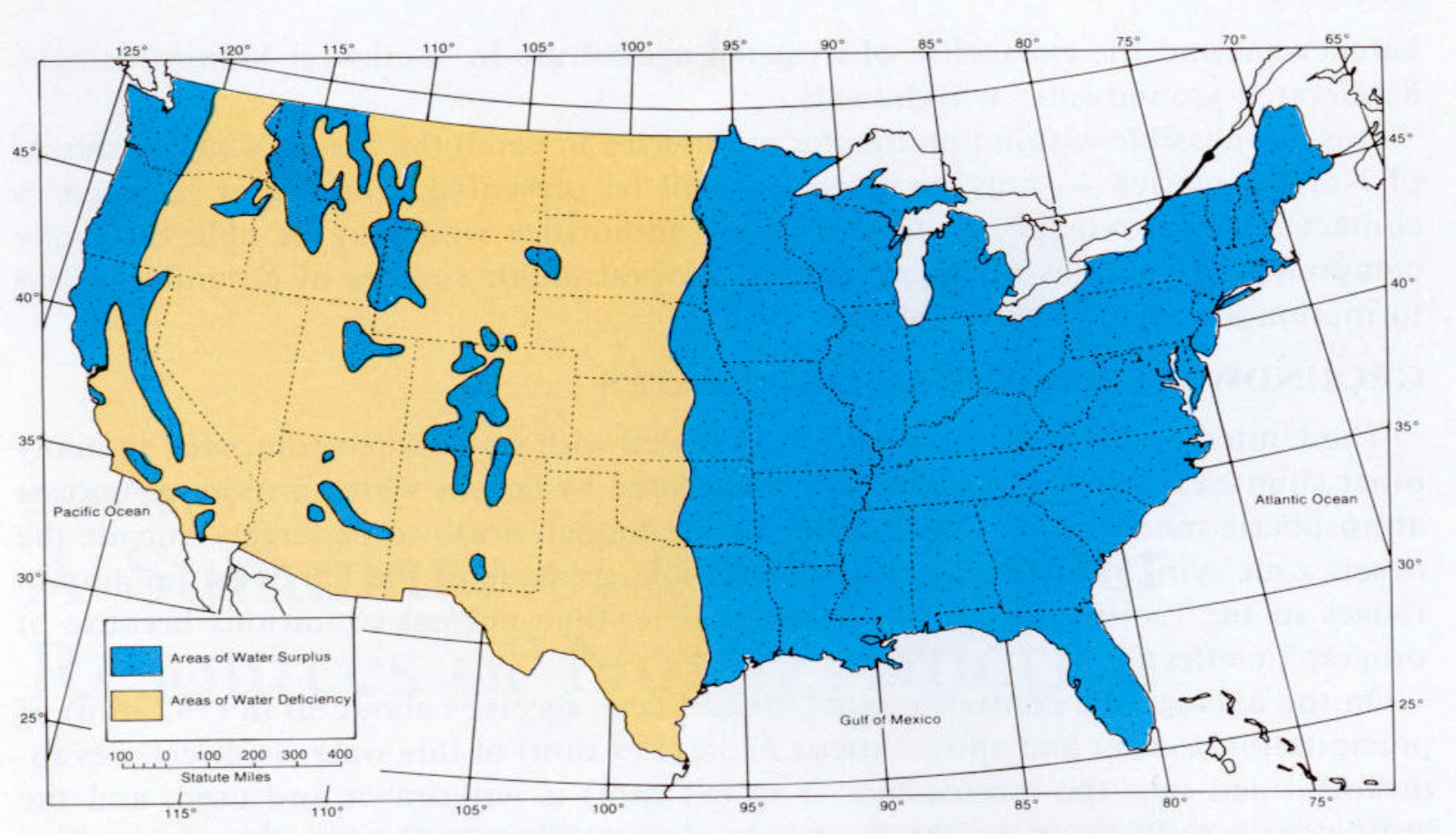
Water Surplus/Deficiency



Source: Driscoll, 1986

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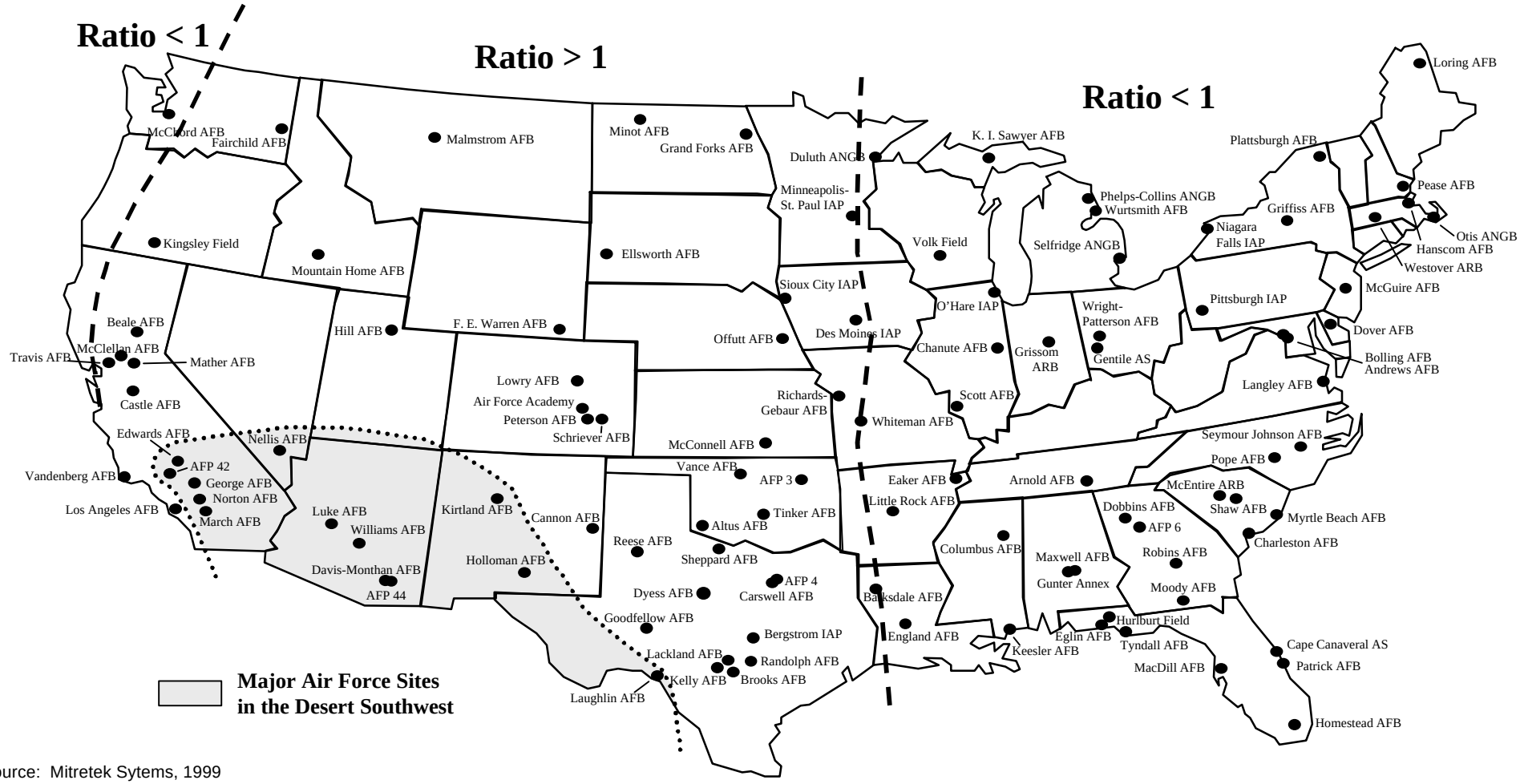
Pan Evaporation to Precip Ratios



Source: Mitretek Sytems, 1999

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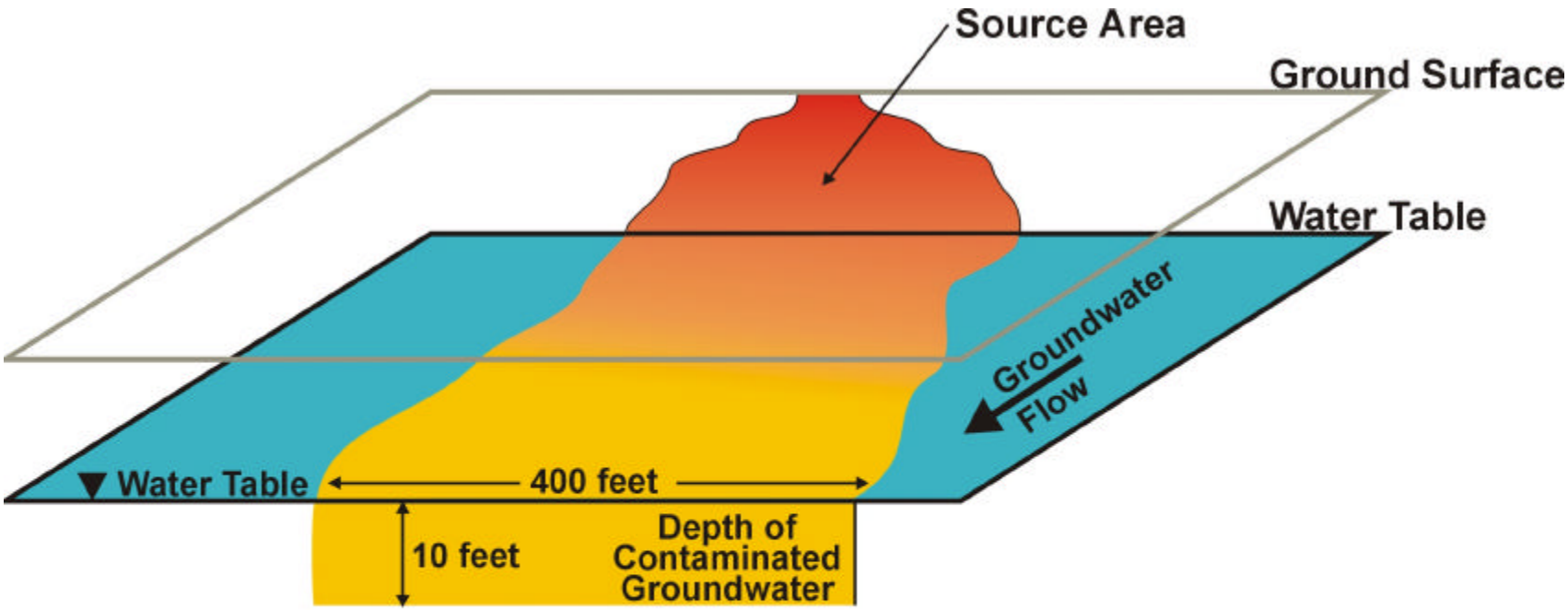
Groundwater Capture



$$\text{Groundwater Velocity} = \frac{Ki}{\theta}$$

Groundwater Volumetric Flowrate = (Groundwater Velocity) x (Plume Cross-Sectional Area)

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Water Extraction

Extraction Well

$$Q = \frac{K(H^2 - h^2)}{1{,}055 \log R / r}$$

Source: Driscoll, 1986

Plants

$$Q = PET \times K_c \times LAI \times A \times f_{gw}$$

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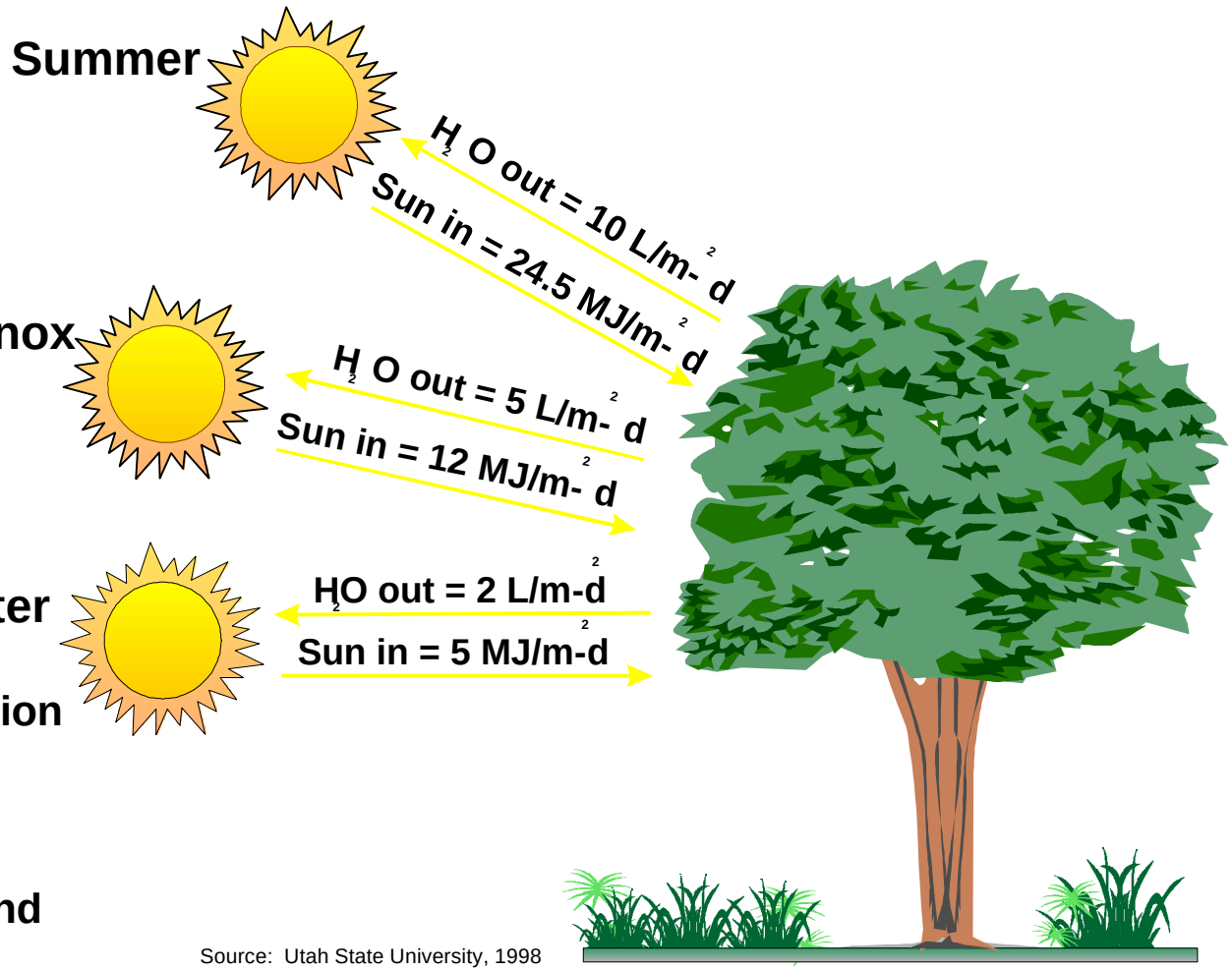
Solar Powered Extraction



A function of:

- Solar energy interception
- Access to water
- Leaf color
- Surface roughness/wind

Source: Utah State University, 1998

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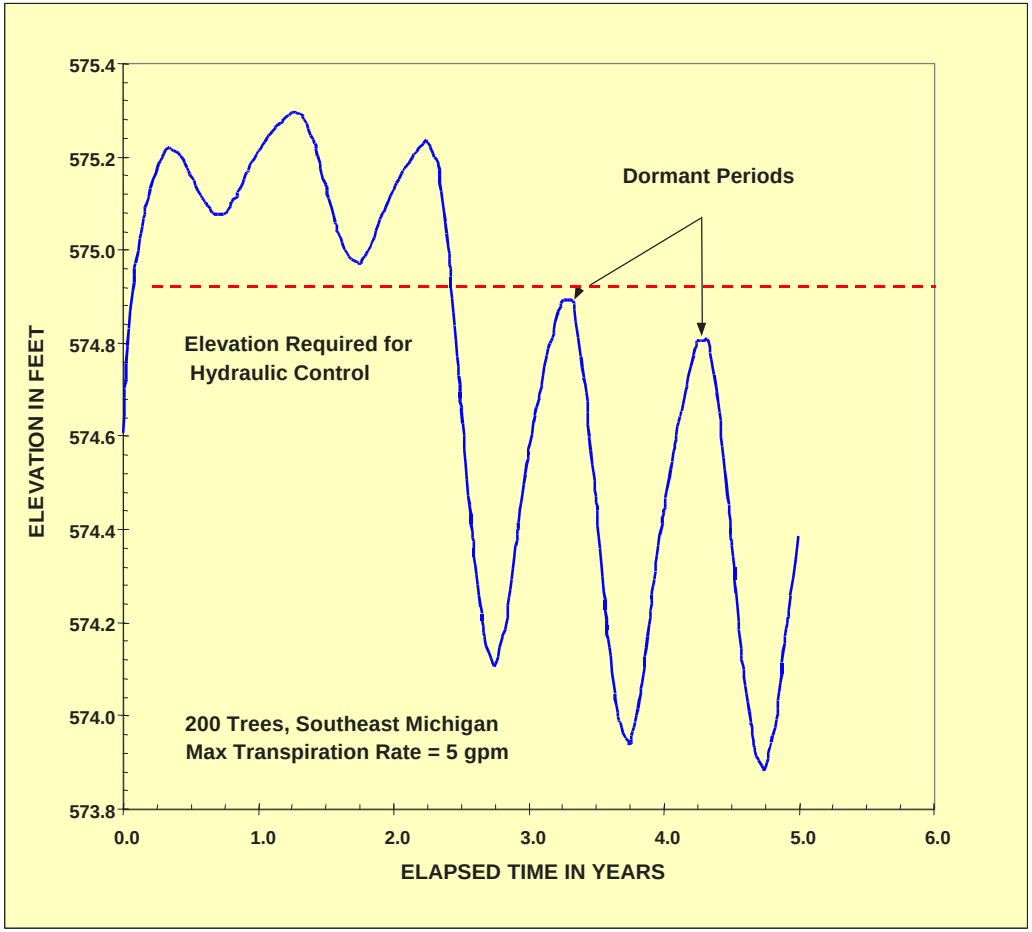
Potential Groundwater Extraction



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WILL IT WORK AT MY SITE?

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Threshold Questions

- What are my objectives?
  - Plume containment
  - Groundwater recovery/treatment
  - Secondary treatment
  - Residual treatment
- What is my time frame?
  - Does it need to happen in a hurry?
- What is the risk tolerance at the site?
  - Do I have some room for error?
  - Can I reduce that risk some how?

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A Bit More Detail

- Need Positive Responses to Threshold Questions
- Feasibility Issues
  - What is my depth to groundwater?
    - 0-10 ft bgs Þ Favorable
    - 10-20 ft bgs Þ ????
    - > 20 ft bgs Þ Consider Pump and Irrigate Technique
  - Is the weather favorable?
    - PET/PRECIP Ratio > 1.0 Þ Favorable
    - PET/PRECIP Ratio < 1.0 Þ Will need to do some work
  - Am I dealing with a contaminant that has some history with phytoremediation?

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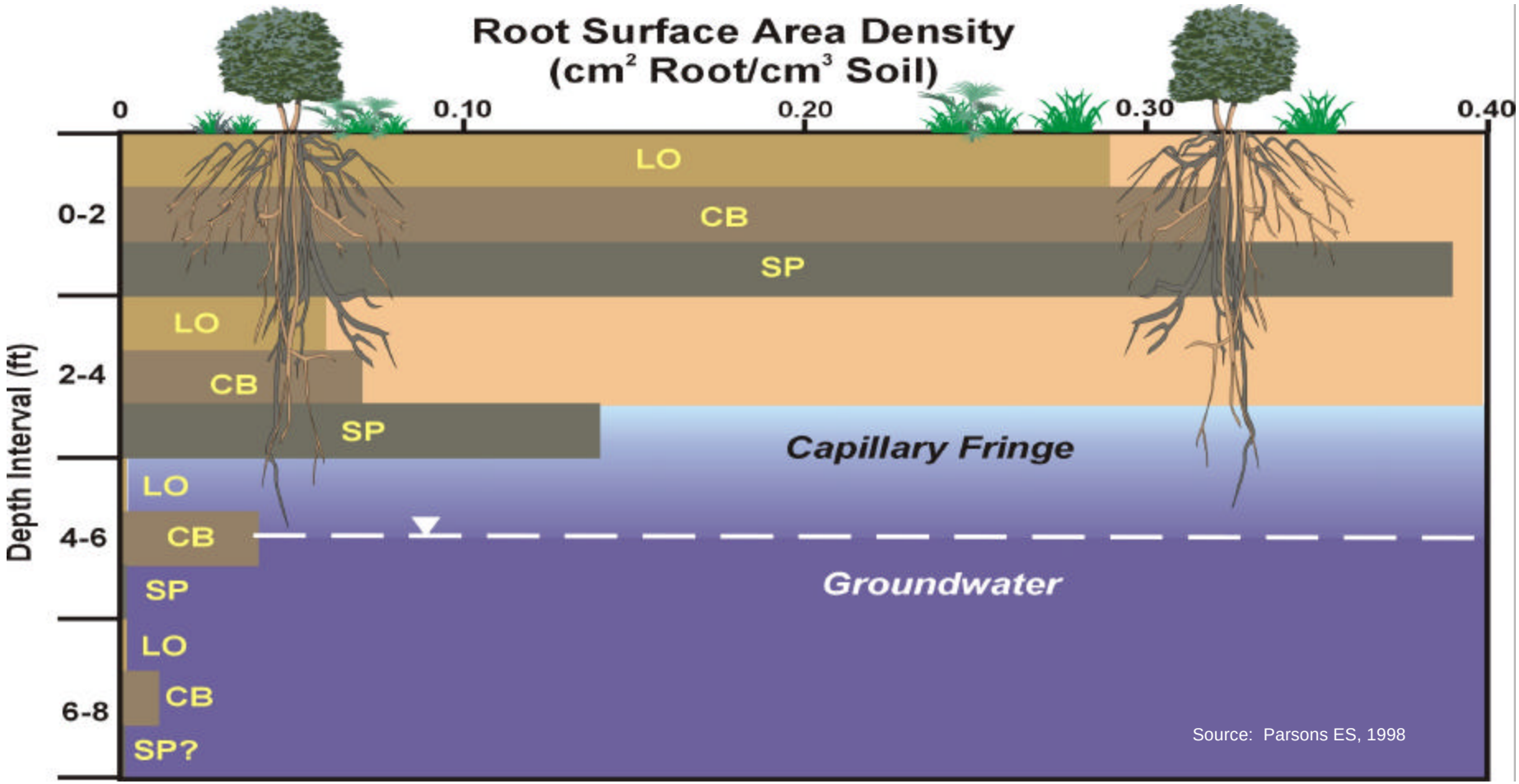
Water Surplus Problems



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A Bit More Detail (cont)

- How much room do I have?
  - Depending on site conditions, large area (acres in size) may be necessary
  - Slow moving groundwater Þ Favorable
  - Groundwater modeling may be required
- What are my soils like?
  - Tight soils; hard pans; near surface debris could cause problems
  - More expensive planting methods may be required

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Other Potential Issues

- **Potentially long start-up period**
- **Seasonal variations**
- **Height restrictions**
- **“BASH” Concerns**
- **Growing regulator acceptance**

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AFCEE/ERT DEMONSTRATION OVERVIEW

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Demonstration Objectives

- **Evaluate the ability or inability of engineered tree plantings to hydraulically control groundwater/contaminants**
- **Refine and calibrate a water balance model to be used as a technology screening tool at other Air Force installations**
- **Aid in the development of a protocol document**
  - ***Draft Protocol for Controlling Contaminated Groundwater by Phytostabilization*** **(Mitretek, 1999)**

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Demonstration Program

- **Prior demonstration project evaluated plant uptake of contaminants in 1996-1997**
- **New focus on hydraulic control/water balance**
- **Two Current Bases**
  - ***Travis AFB, California (planted Nov 98 and Apr/Jul 00)***
  - ***Altus AFB, Oklahoma (planted Apr 99)***
- **Five New Bases**
  - ***Hill AFB, Utah; Ellsworth AFB, South Dakota; Fairchild AFB, Washington, Whiteman AFB, Missouri; Offutt AFB, Nebraska***
- **Small Trees/Simple Irrigation System**
- **Operation, Maintenance, and Monitoring Over Several Years**
- **Cost and Performance Documentation**

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DEMONSTRATION SITES

Travis Air Force Base, CA

- **Building 755**
  - **Battery and Electric Shop**
  - **Former sump and leach field Þ source**
  - **Groundwater contamination (TCE)**

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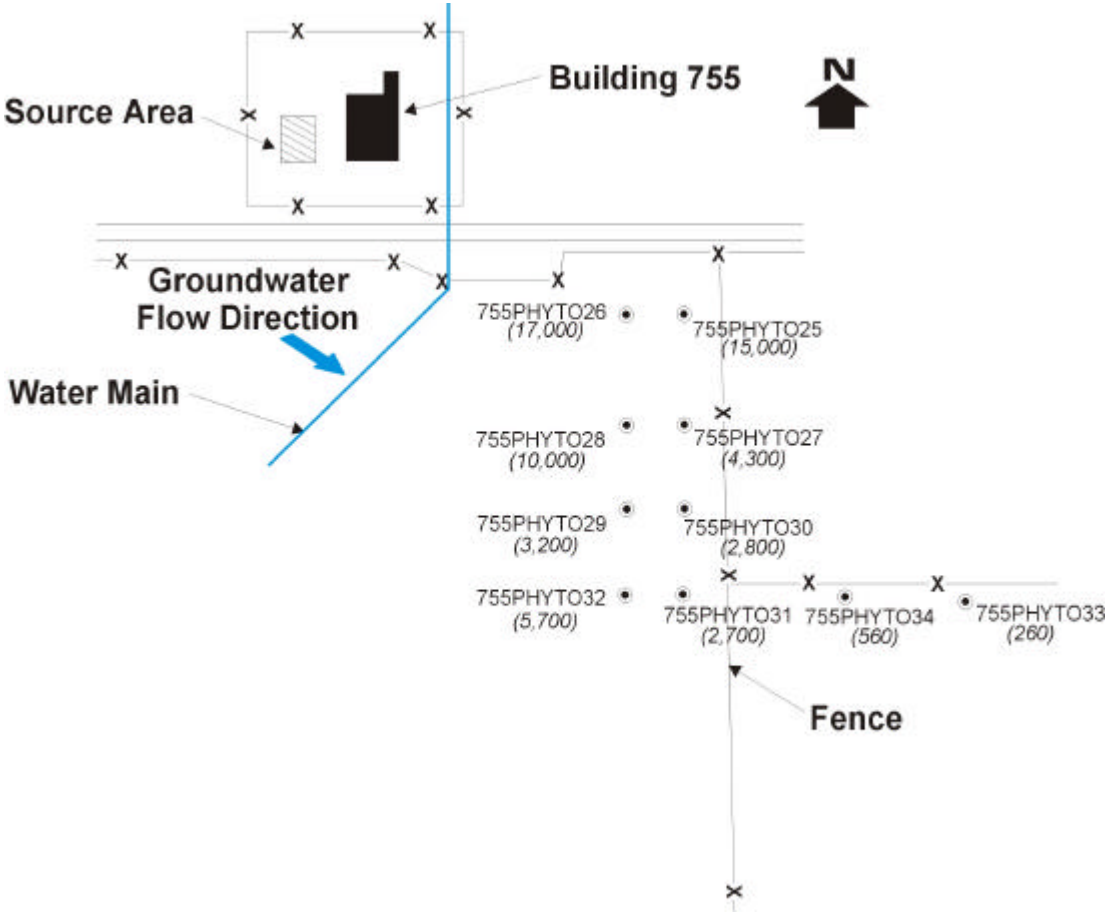
Site Map



Travis Air Force Base, CA

- **Site Conditions**
  - **Heterogeneous soil conditions from clays to silts to sands**
    - **Potential root movement issues**
  - **Groundwater approximately 10 to 20 ft bgs downgradient of source**
  - **Pan Evaporation to Precipitation Ratio » 2.7**
  - **Large area available for plantings downgradient of source**
  - **Low risk factor**

Travis Air Force Base, CA

- Plantings
  - 100 15-Gallon Eucalyptus Trees Planted in Fall 1998
    - Intensive planting pit preparation
  - 380 1-Gallon Eucalyptus Trees Planted in Spring/Summer 2000
    - Simpler plantings
  - Drip Irrigation System using Potable Water
  - Covers Approximately 2.5 Acres
  - Mature Water Use » 1-3 gpm

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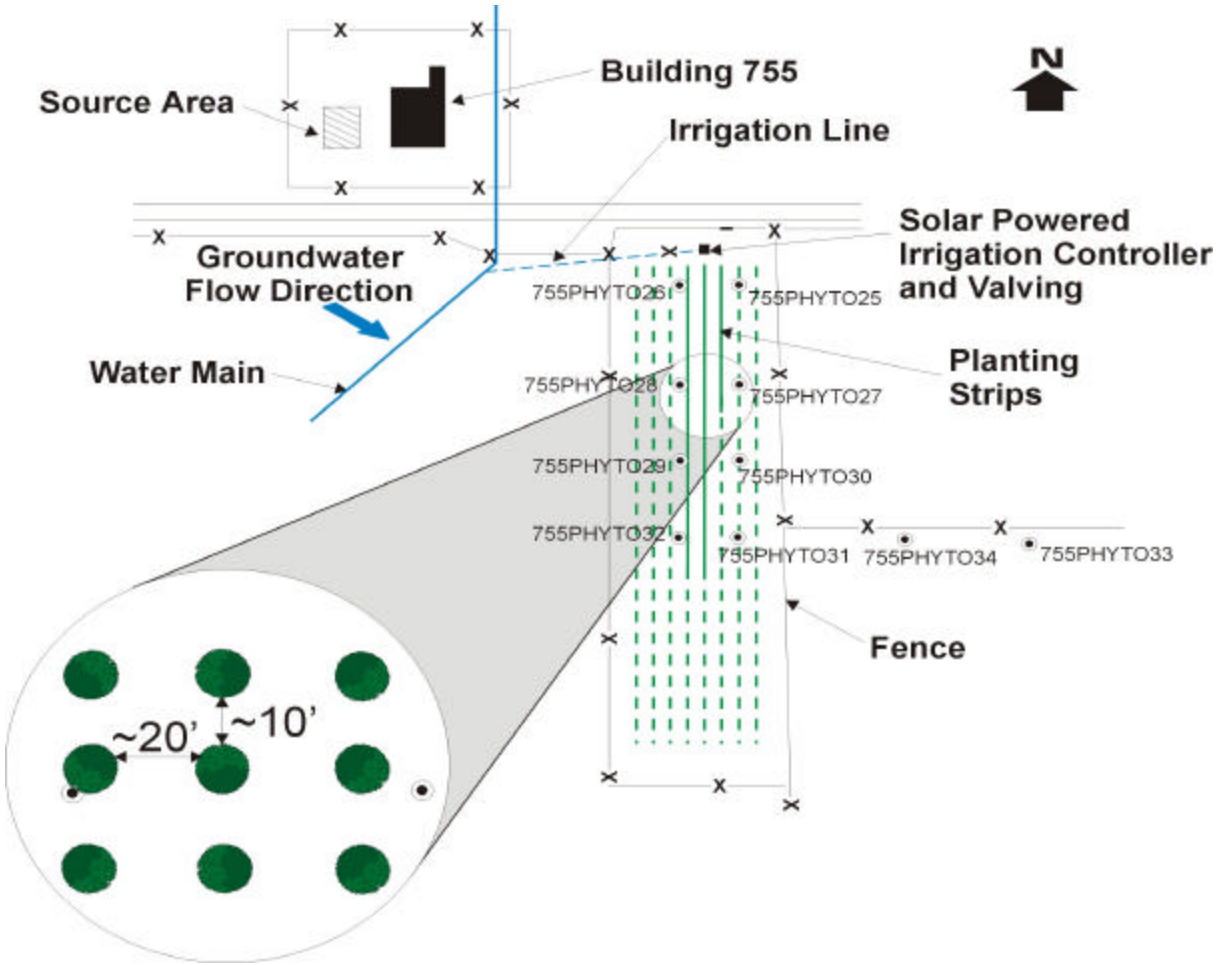
Planting Layout



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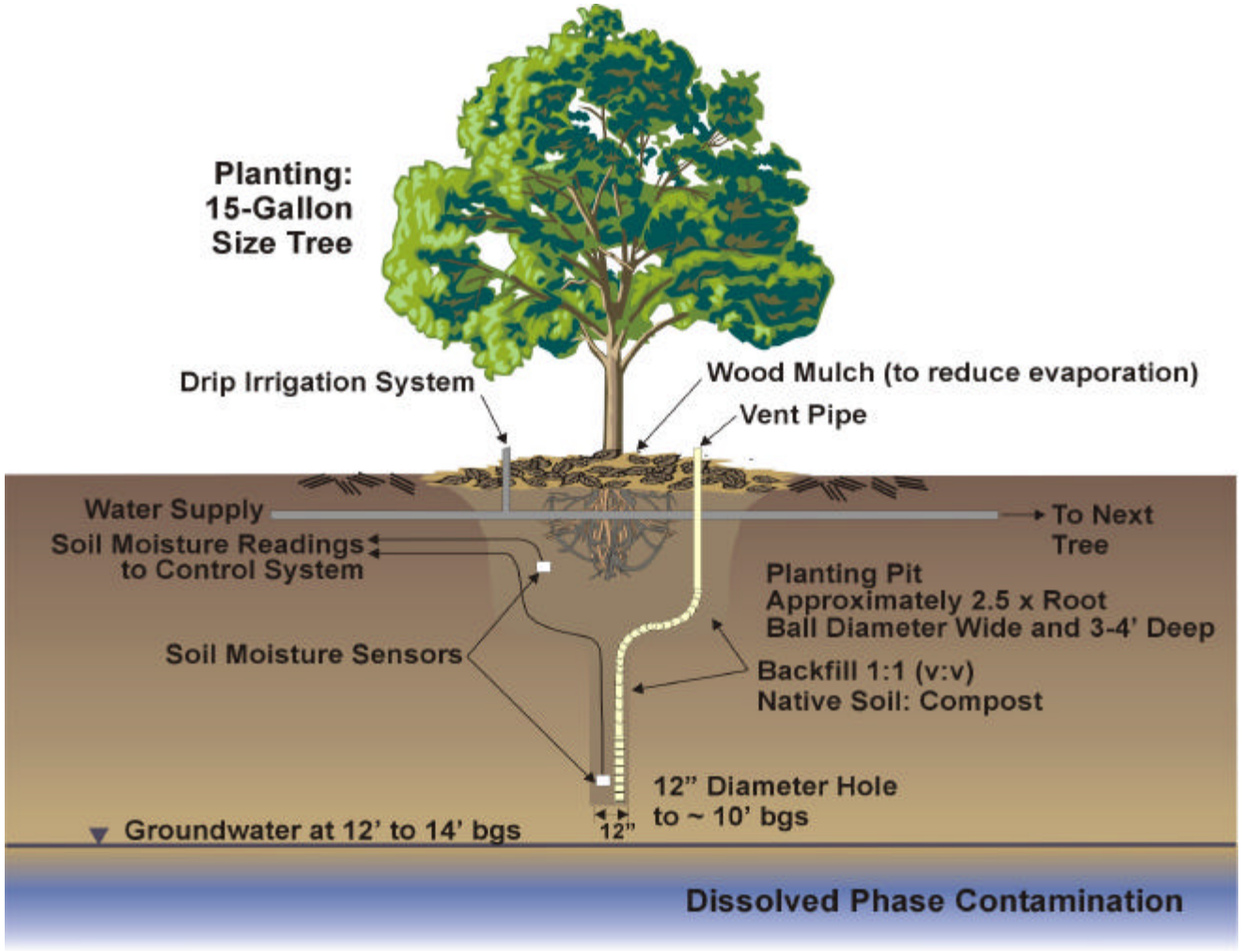
Initial Planting Pit



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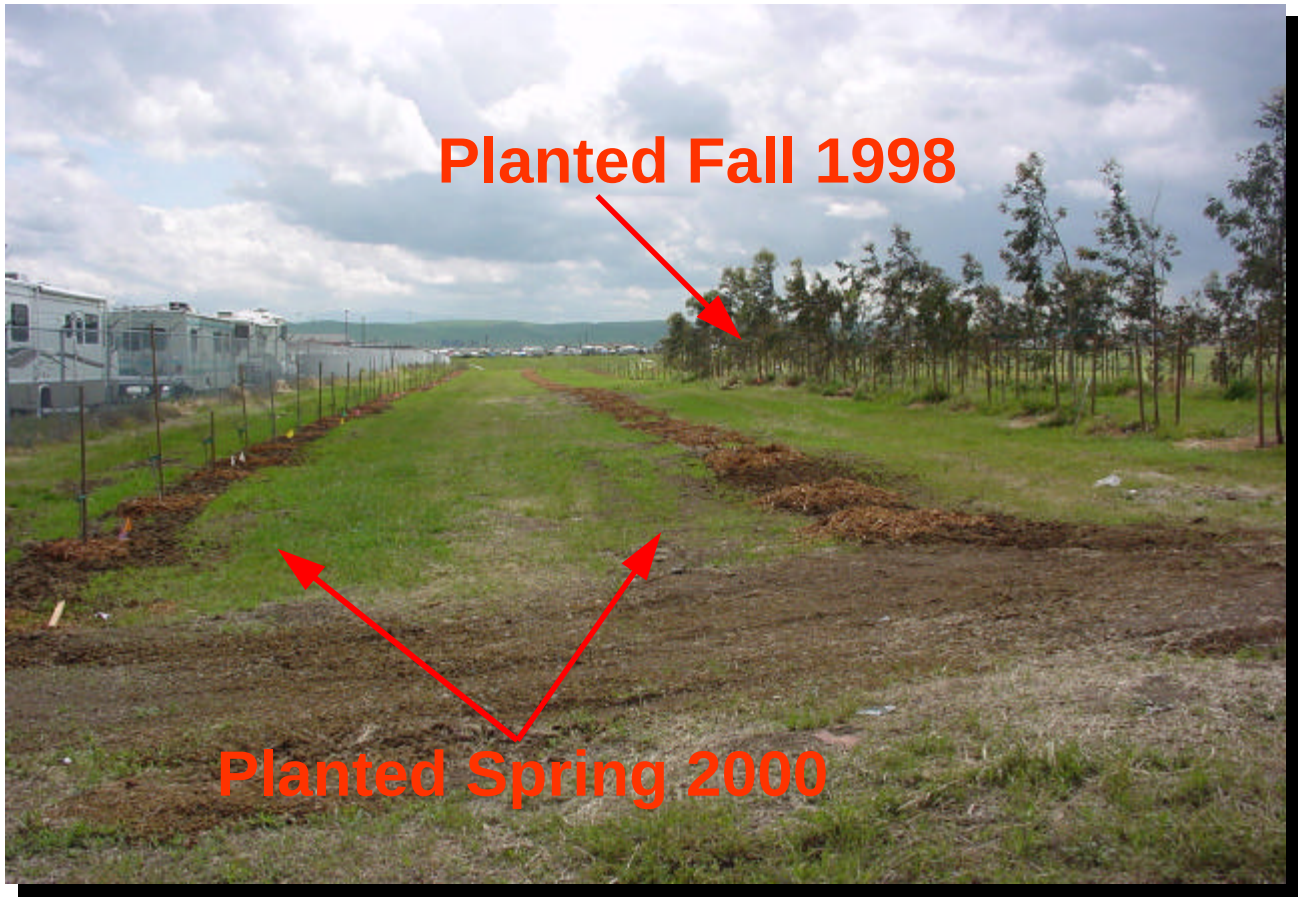
Travis AFB Plantings



Altus Air Force Base, OK

- Site 2
  - AGE Washrack Pond
  - TCE Contamination in Groundwater
- Site Conditions
  - Silty to Sandy Clay
    - Cobbles/boulders in planting area revealed during installation
  - Groundwater approximately 5 to 10 ft bgs
  - Pan Evaporation to Precipitation Ratio » 2.5

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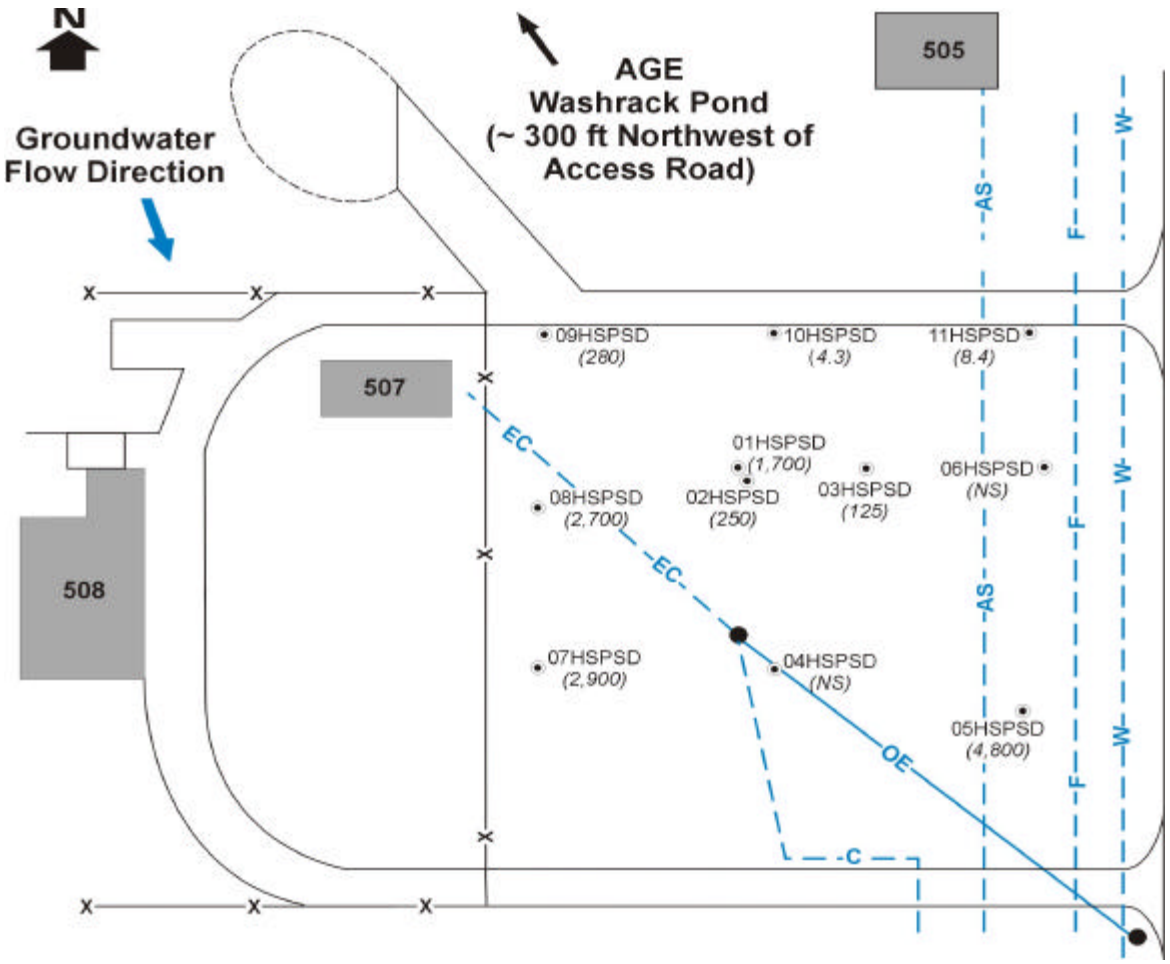
Site Map



Altus Air Force Base, OK

- **Plantings**
  - **108 5-Gallon Cottonwood Trees Planted in Spring 1999**
    - **Mixed planting pit preparation**
  - **High Mortality Rate During First Growing Season**
  - **Drip Irrigation System using Potable Water**
  - **Covers Approximately 0.5 Acres**
  - **Mature Water Use » 0.5 gpm**

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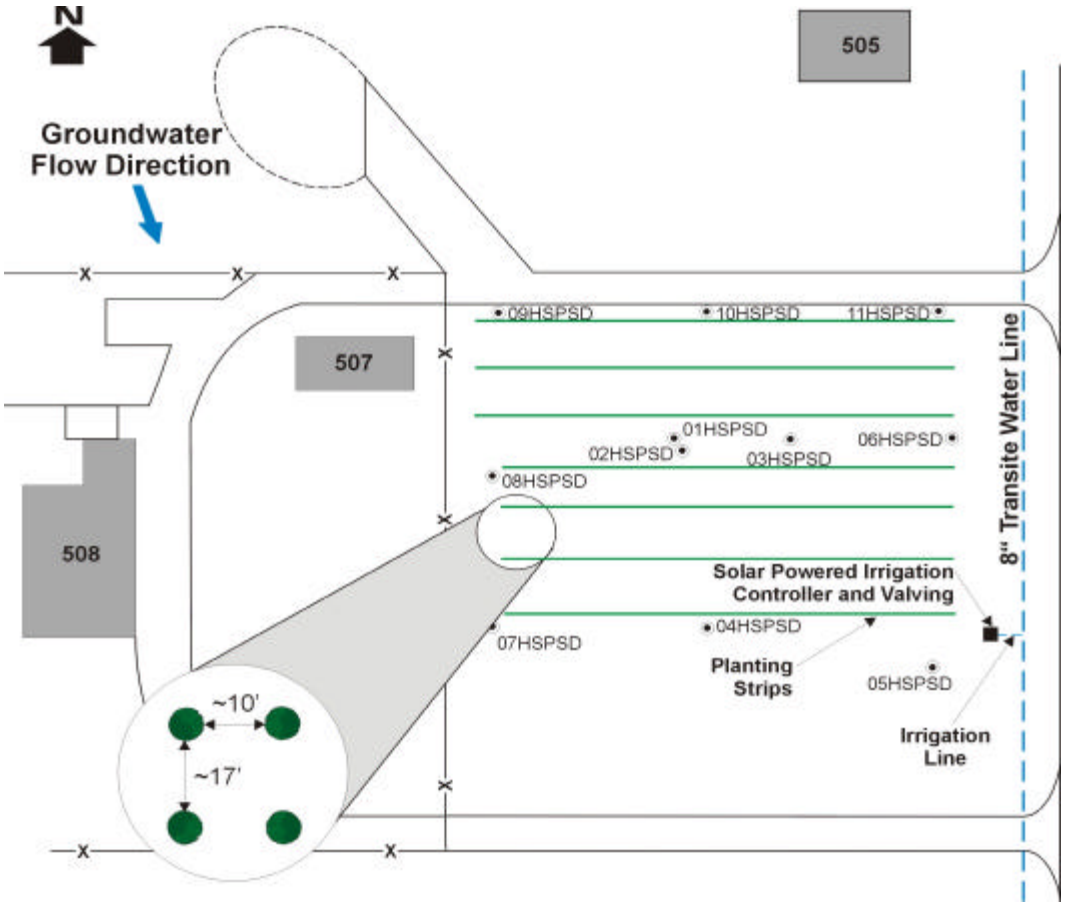
Planting Layout



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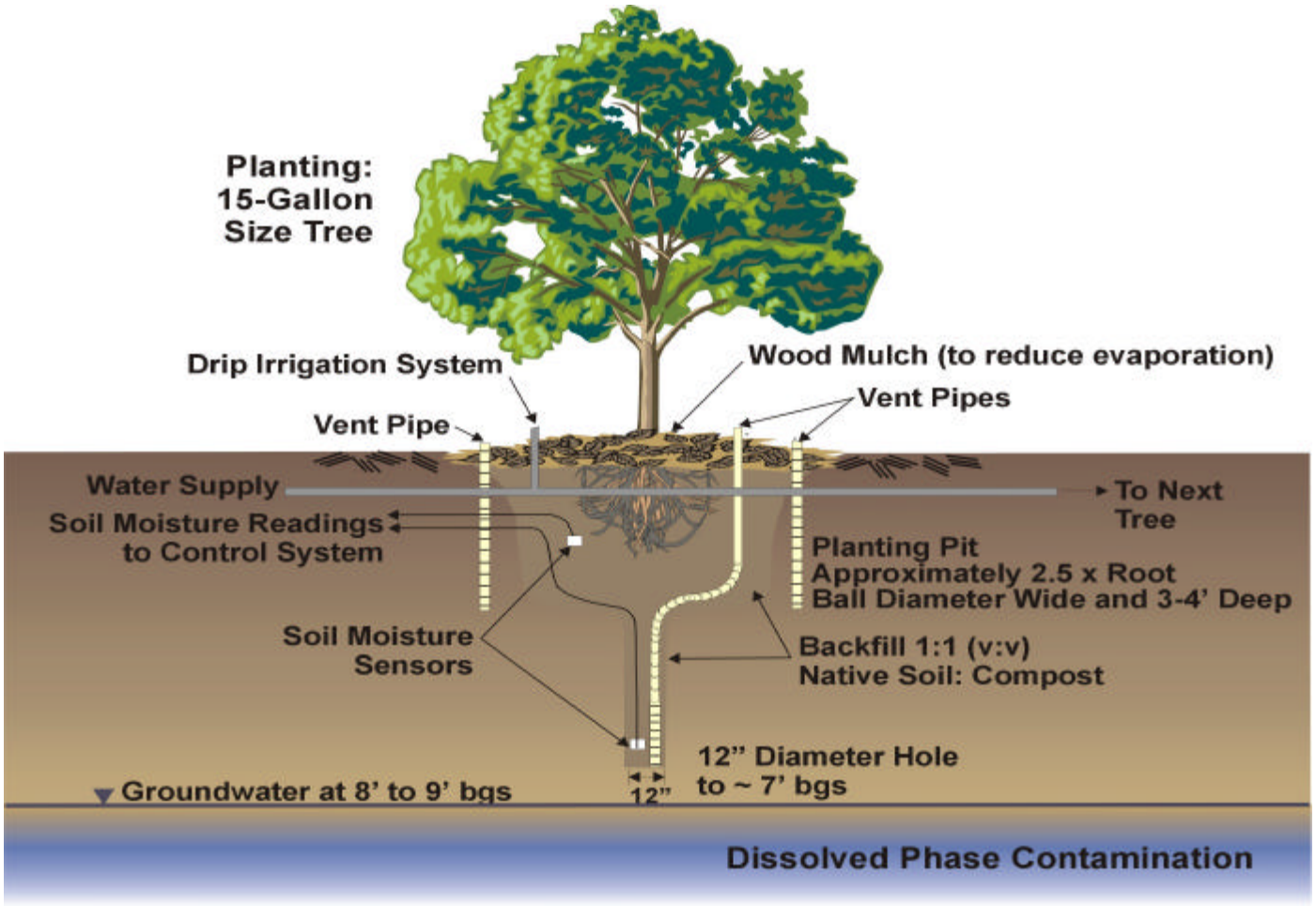
Planting Pit



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Altus AFB Plantings

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Performance Measures

- Monitoring Program
  - Growth of trees
  - Soil moisture
    - Potential and volumetric
  - Groundwater levels
  - Sap Flow
  - Precip/Evapotranspiration
  - Contaminant concentrations
  - Groundwater/Precip Water use
  - Phytovolatilization
  - Phytodegradation
- Bottom Line Þ Need to Show Migration Has Stopped and Decreasing Contaminant Concentrations

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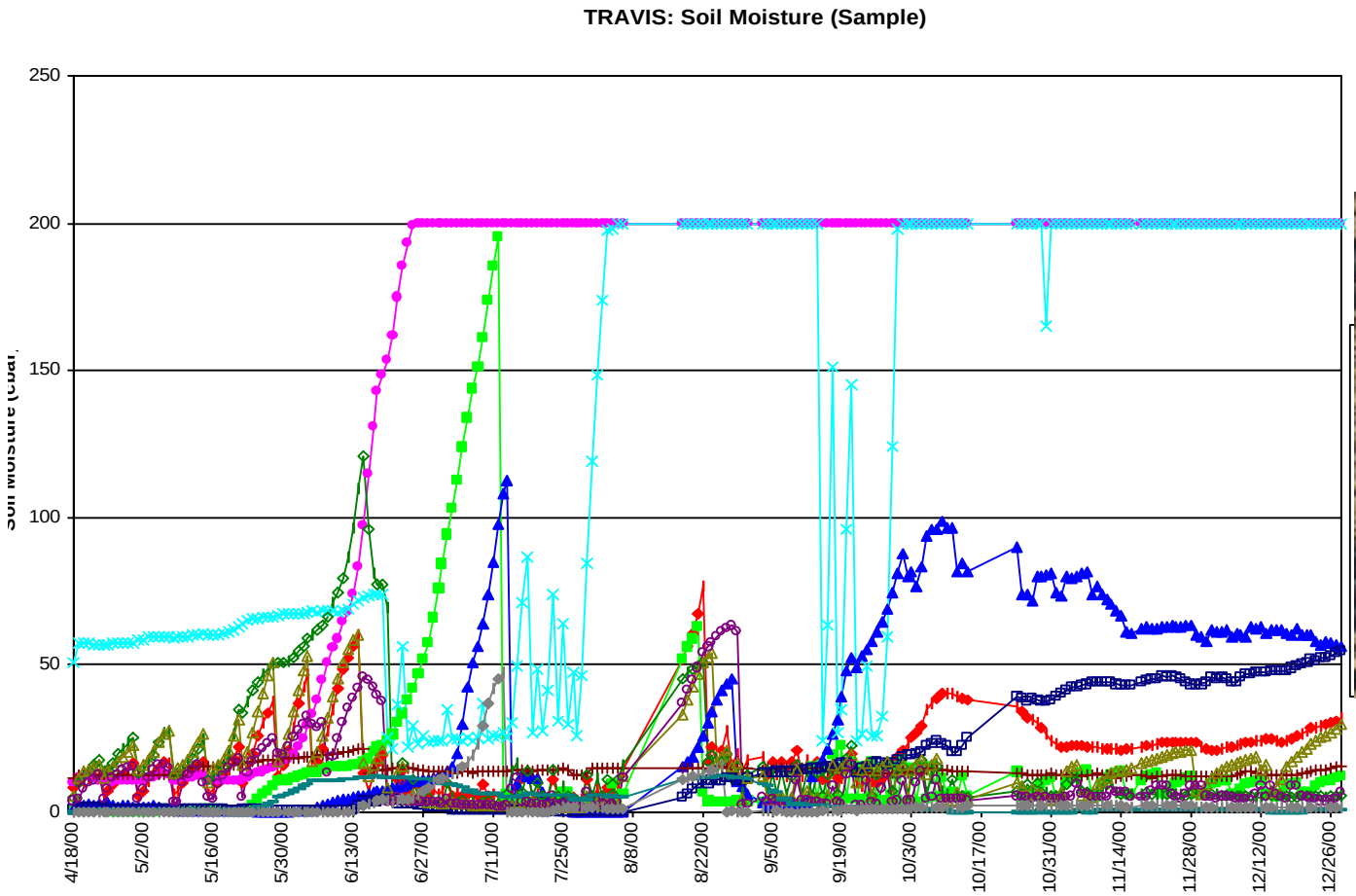
Example Soil Moisture Measurements



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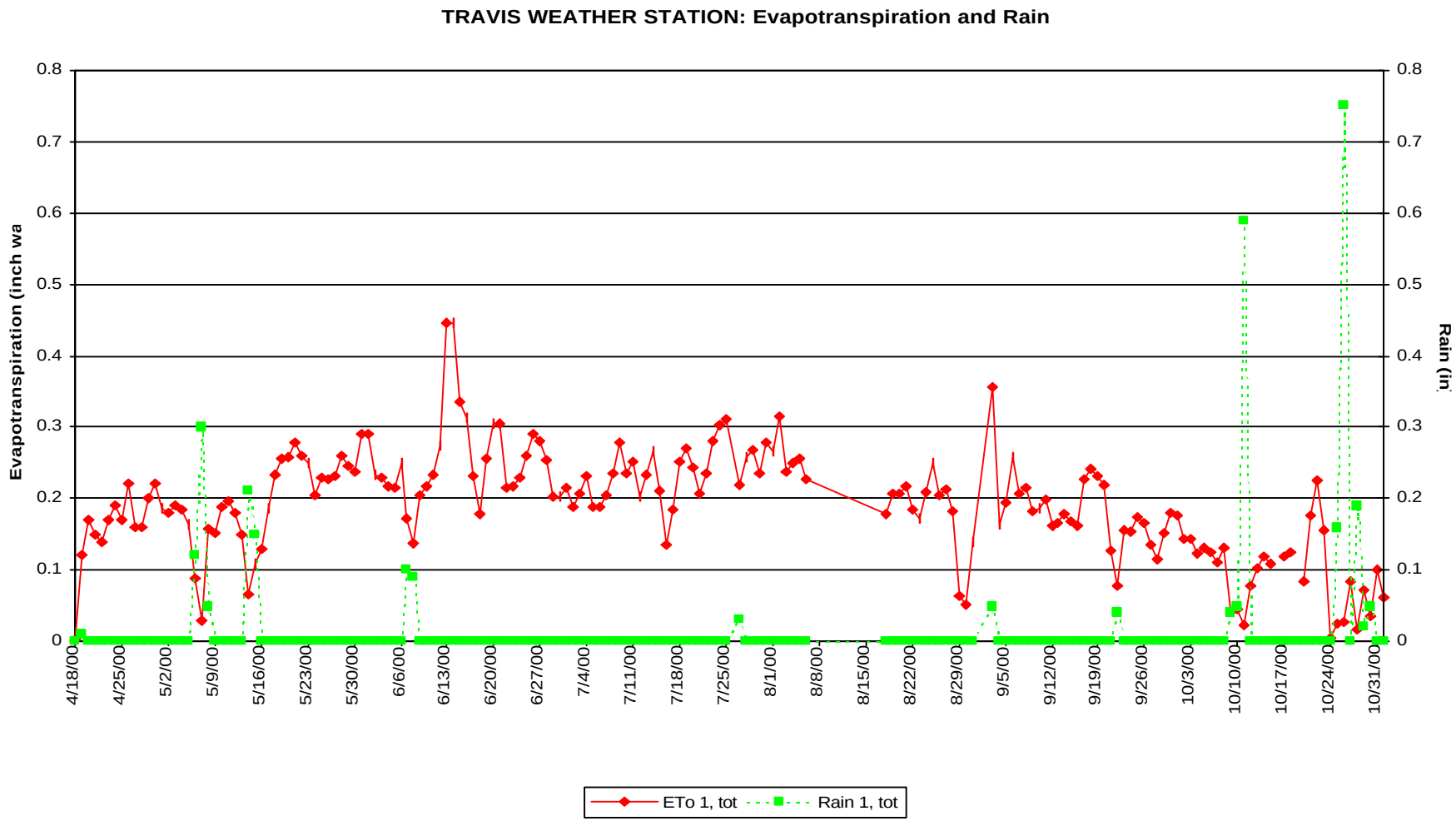
ET versus Precip



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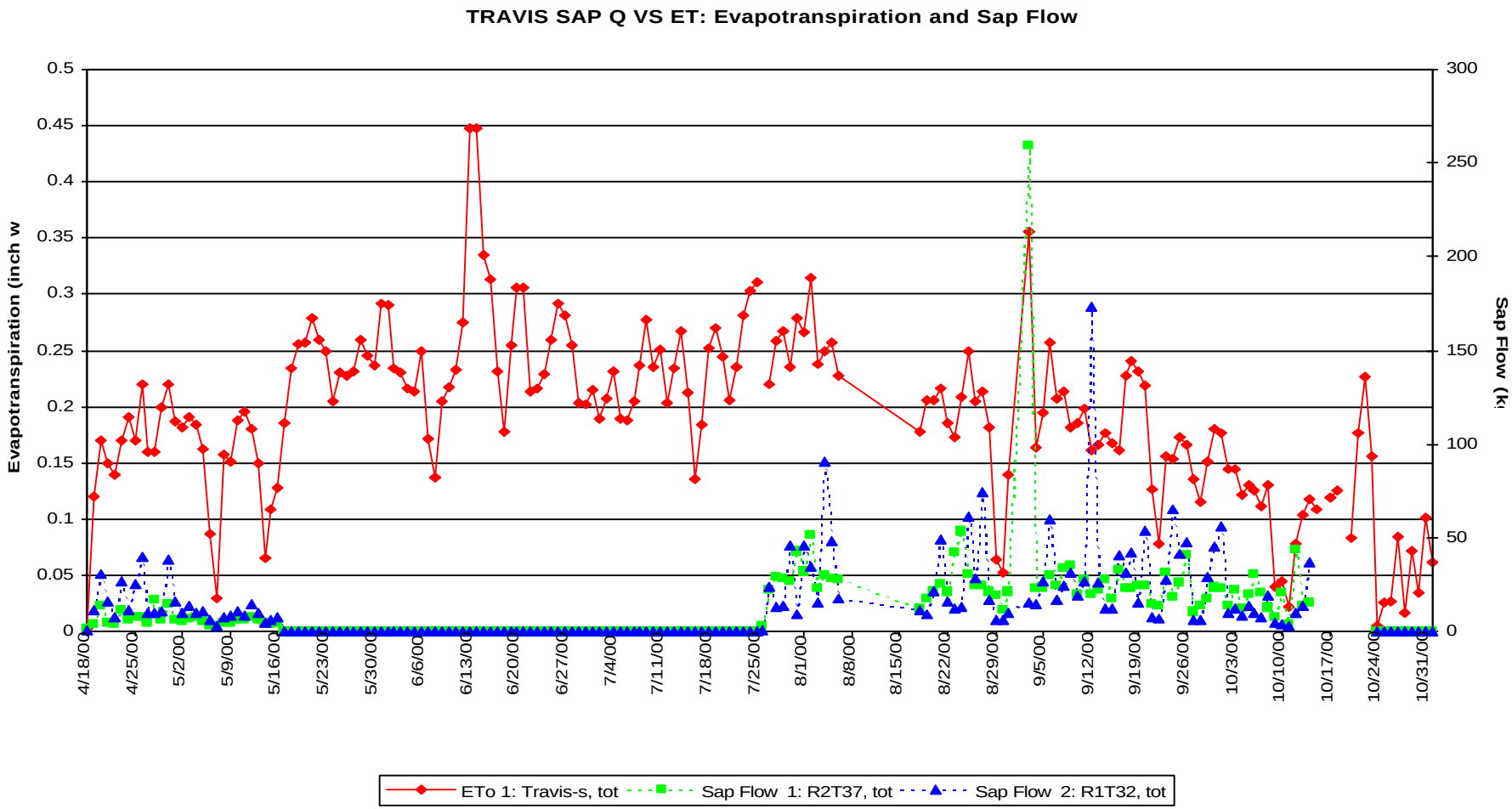
ET versus Sap Flow



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Future Demonstration Work

- **Continued Monitoring of Travis and Altus Air Force Bases**
- **Plantings at Five New Bases Using "Short Rotation Woody Crop" Planting Methodologies**
  - **Fairchild AFB**
  - **Hill AFB**
  - **Ellsworth AFB**
  - **Offutt AFB**
  - **Whiteman AFB**
- **Monitoring of the New Plantings**
- **Complete Cost and Performance Documentation**

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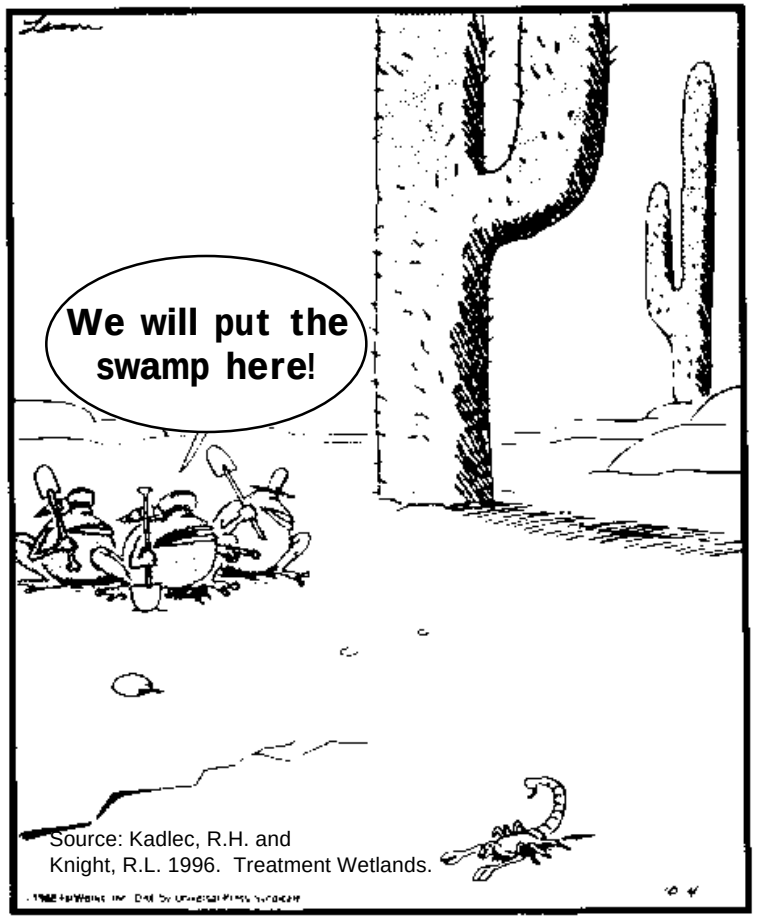
Phytoremediation Pioneers

- The Technologies Future
  - Additional Data Will Become Available
  - Protocols Will Be Completed
  - Better Design Criteria Will Be Available
  - Multiple Disciplines Will Need to Work Together
  - Ecological Impacts Will Be Answered
  - “Carbon Off-Sets” May Become More Practical
  - In the End Þ Another Tool for the “Tool Box”



Source: Kadlec, R.H. and Knight, R.L. 1996. Treatment Wetlands.

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Questions

THANK-YOU