One Generation Plants a Tree – Another One Gets the Shade

Update of Phytostabilization Demonstration

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PARSONS
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Acknowledgements

- AFCEE/ERT
  - Rafael Vazquez
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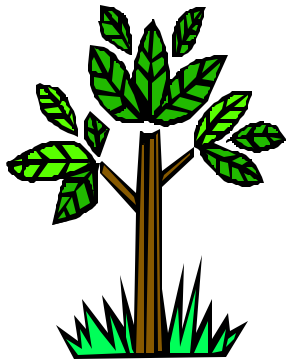
  - Victor Hauser
  - Patrick Haas
- Parsons
  - Amber Brenzikofer
  - Tom Dragoo

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)



How Does it Work?

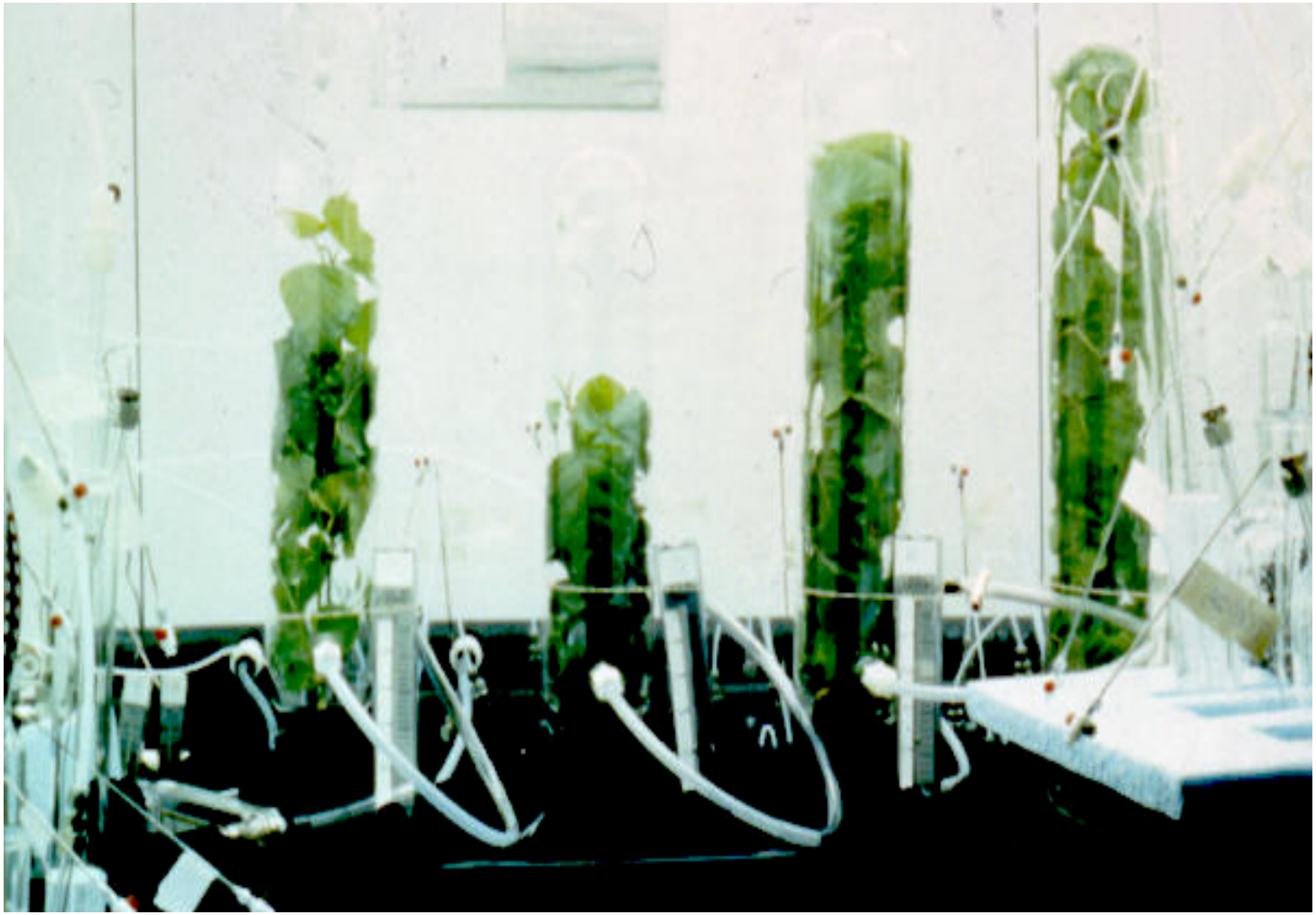
- Plants Could Act as an ***Extraction Well***
  - Removes Contaminated Groundwater Through ***Transpiration*** leading to ***Phytovolatilization***
  - Could Minimize Migration
- Plants Could Act as a ***Bioreactor***
  - Cells Within Plant Could Transform Chlorinated Solvents leading to ***Phytodegradation***
- 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

State of the Technology

- Phytovolatilization (Through the Tree to Atmosphere)
  - Lab/field trials ⇒ none to some
  - Recent research suggest diffusion through stem
- Phytodegradation (Degradation within Tree)
  - Lab/field trials ⇒ some more than others
- Reductive Dechlorination
  - Some geochemistry changes
- McCutcheon and Rock, USEPA (2001)

"While it is apparently a small amount…clear fate pathways of phytoremediation should be established."

Academic Pursuits



Mature Tree Studies

Source: Parsons ES, 1998

Actively Planting

Long-Time Frame Between Planting and Results 3 to 10 Years

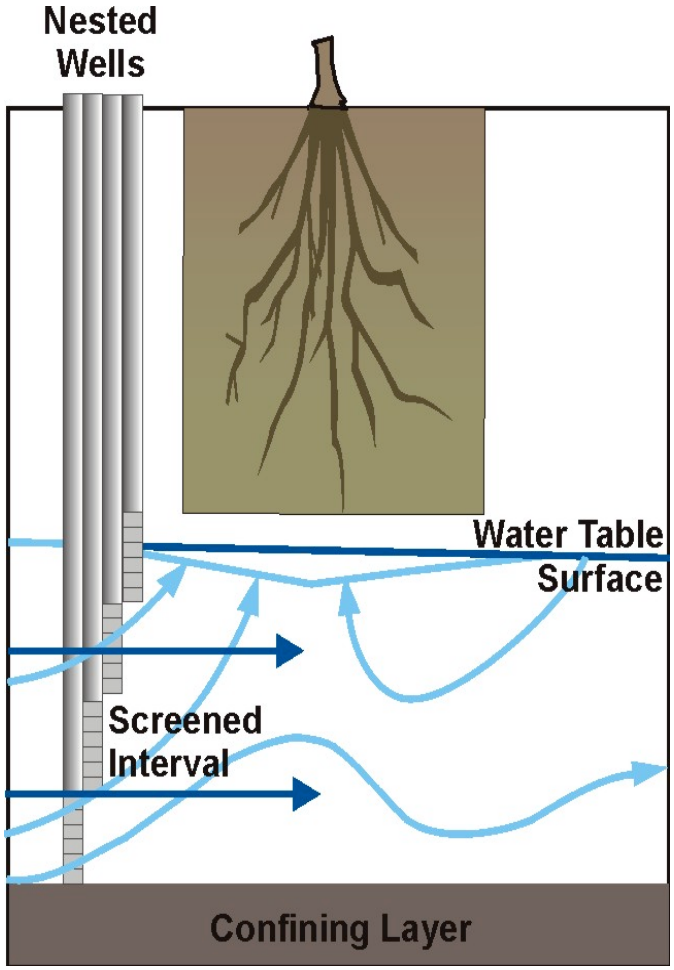
State of the Technology

- Hydraulic Control
  - Numerous field trials in progress (partial list)
    - Argonne National Laboratory, IL
    - Aberdeen Proving Ground, TX
    - USGS Site, Charleston SC
    - Superfund Site, Moore County, NC
    - Carswell Air Force Base, TX
    - Ogden, UT
    - Edward Sears Properties, NJ
    - Houston, TX
  - Planted in mid to late-1990's
  - Transpiration Ranges 0.5-10 gpd/tree

AFCEE/ERS DEMONSTRATION OVERVIEW

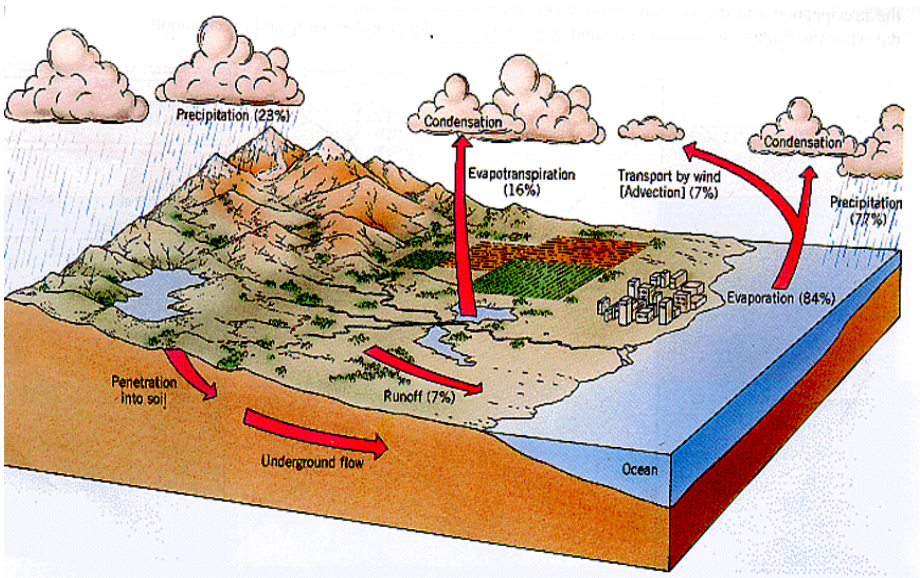
Demonstration Objectives

HYDRAULIC CONTAINMENT?



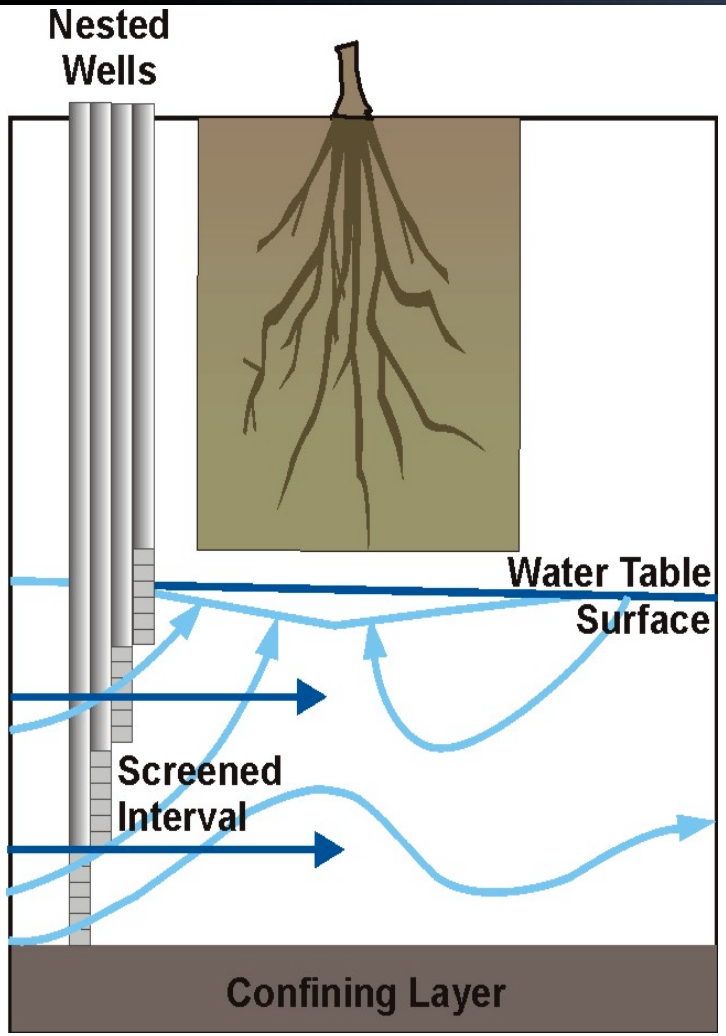
SOURCE: LANDMEYER, 2001

DEVELOP WATER BALANCE



SOURCE: GERMESHL, *et. al*., 2001

Groundwater Capture



SOURCE: LANDMEYER, 2001

Guidance Documents

- ***Protocol for Controlling Contaminated Groundwater by Phytostabilization (December 2001)***
  - **Located in AFCEE Website**
    http://www.afcee.brooks.af.mil

- ***Phytotechnology Technical and Regulatory Guidance Document (April 2001)***
  - **Located at ITRC Website**
    http://www.itrcweb.org

Protocol for Controlling Contaminated Groundwater by Phytostabilization

December 2001

Prepared for:

Air Force Center for Environmental Excellence

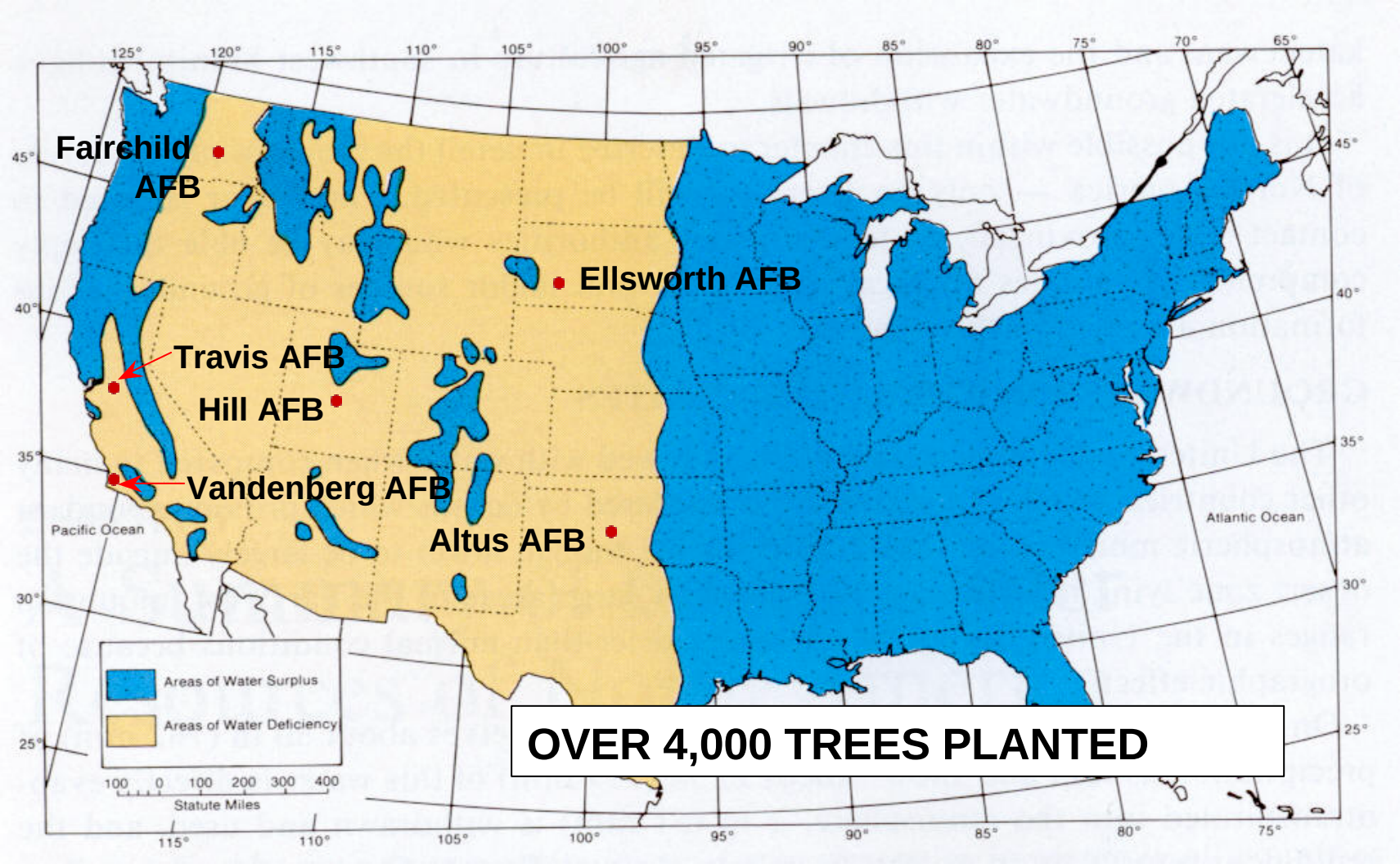
Technology Transfer Division

(AFCEE/ERT)

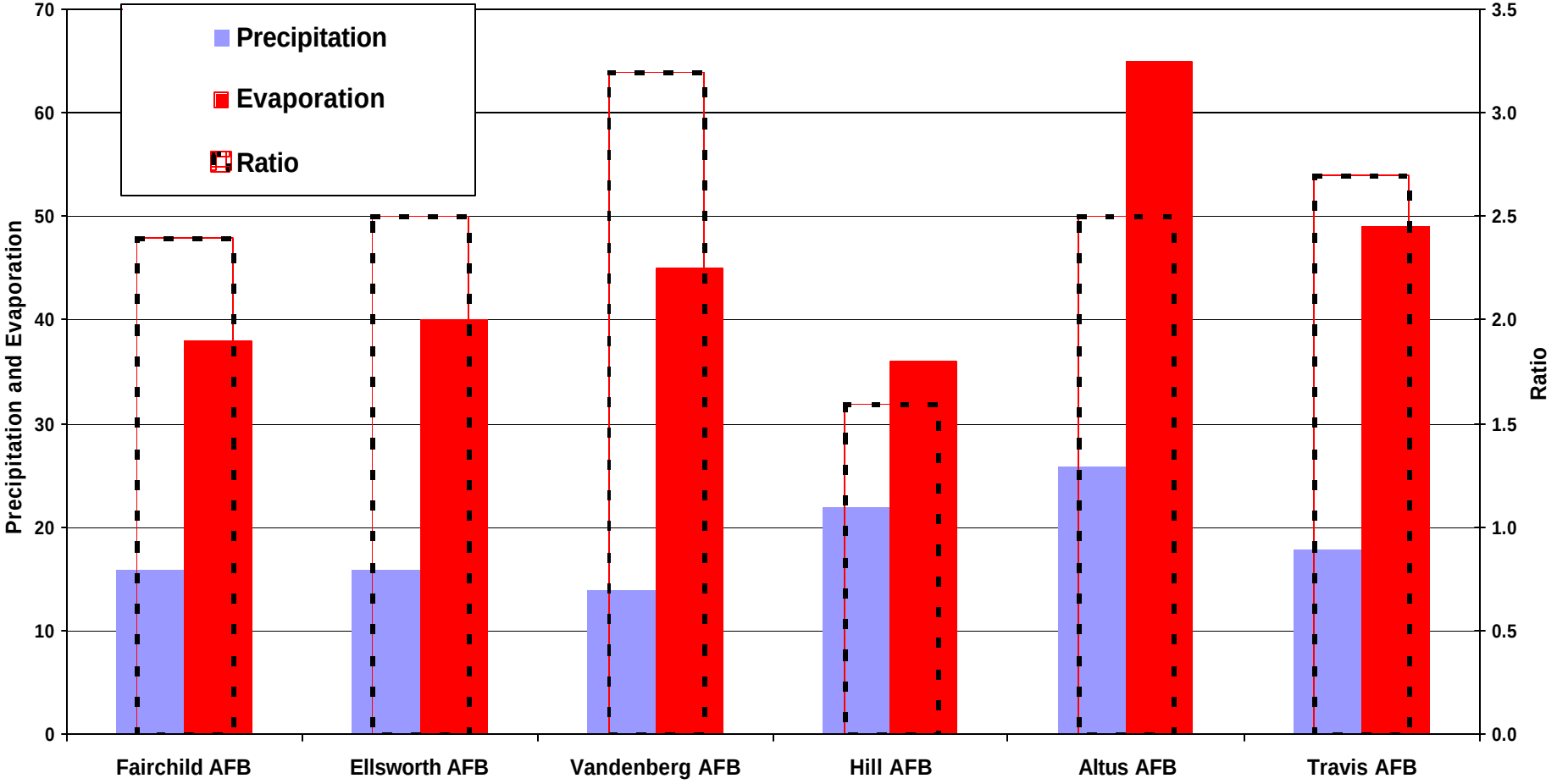
3207 North Road

Brooks AFB, TX 78235-5363

Demonstration Locations

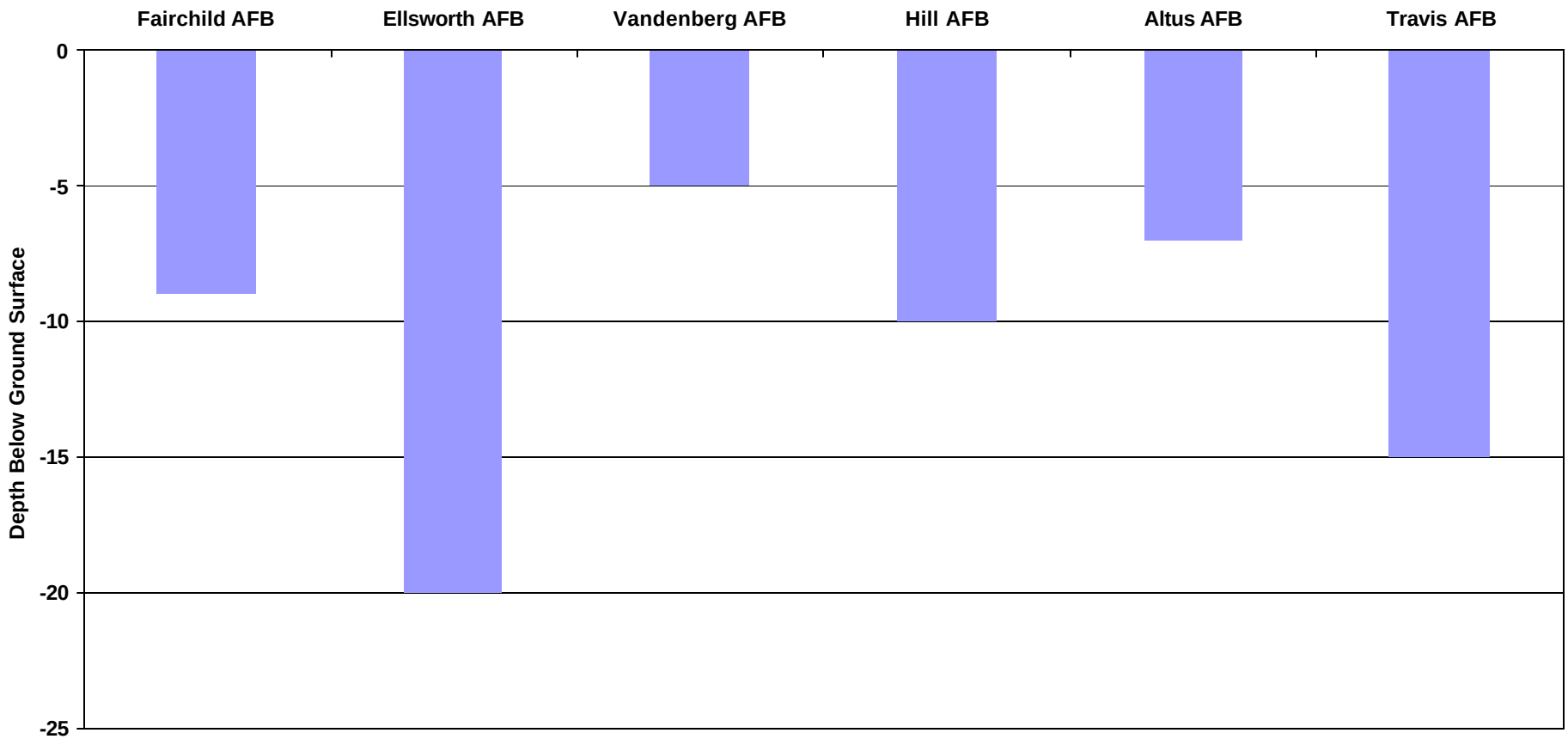


Climate

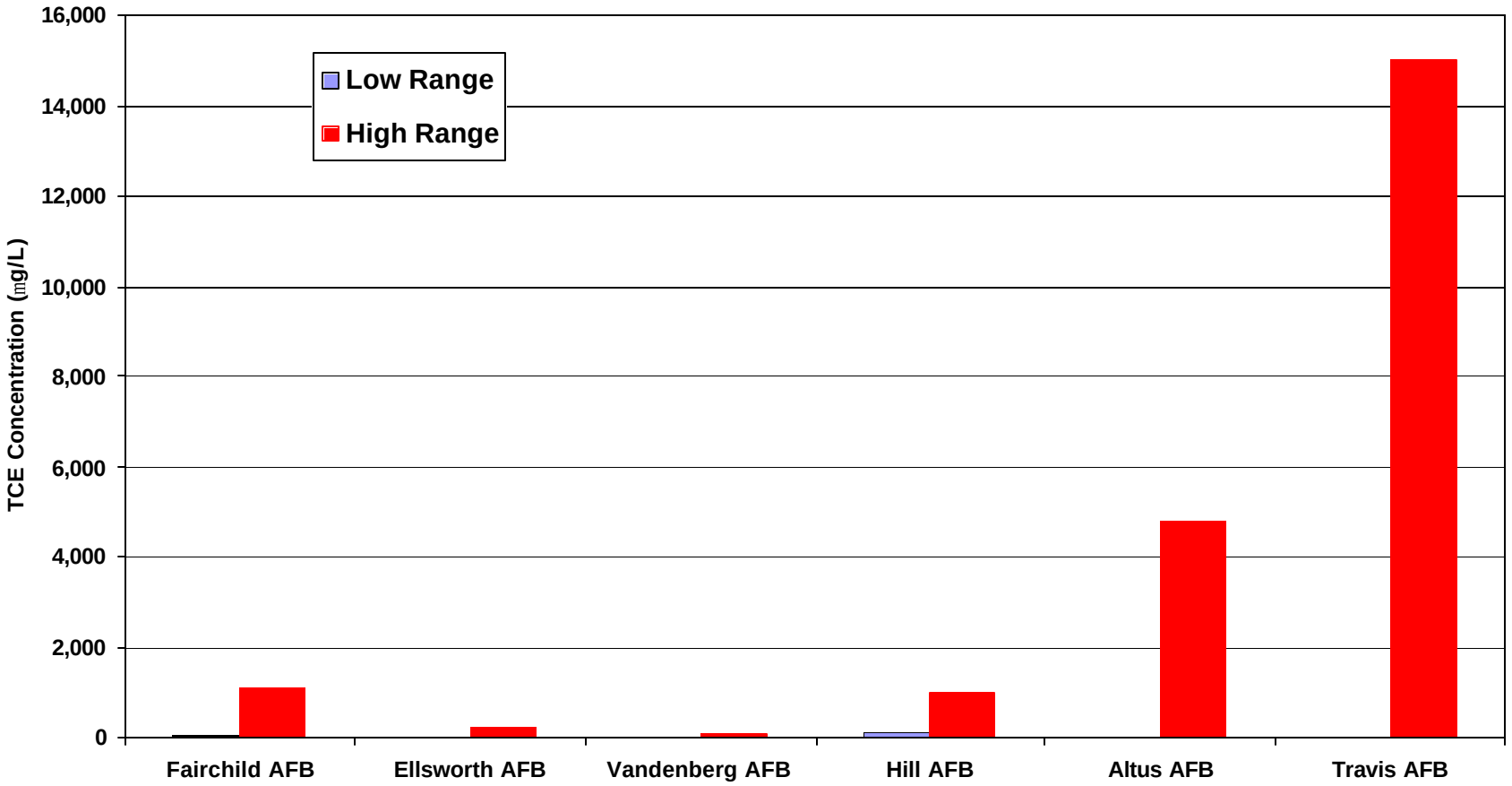


Source: AFCEE, 2001.

Depth to Groundwater



Range of TCE Concentrations



General Design

- What is the objective?
- Perform water balance using literature values, etc.
- Potentially some groundwater modeling involved
- Evaluate actual space available, etc.
- Take into account dormant conditions, time periods

Tree Types and Planting Methods

LOCATION	TREES	ACERAGE	Type	Planting Method-Year
Fairchild AFB	1,130	1	184-411, OP-367, Evidano	A-2001
Ellsworth AFB	1,027	1	NM6, DN182, DN17	A-2001
Vandenberg AFB	1,260	1	184-411, OP-367, Evidano	A-2001
Hill AFB	143	0.25	184-411, OP-367, 52-225	A, B-2001
Altus AFB	109	0.5	Noreaster	C-1999
Travis AFB	380	2.2	Eucalyptus sideroxylon 'Rosea'	C-1998/2000

Planting Method Key:

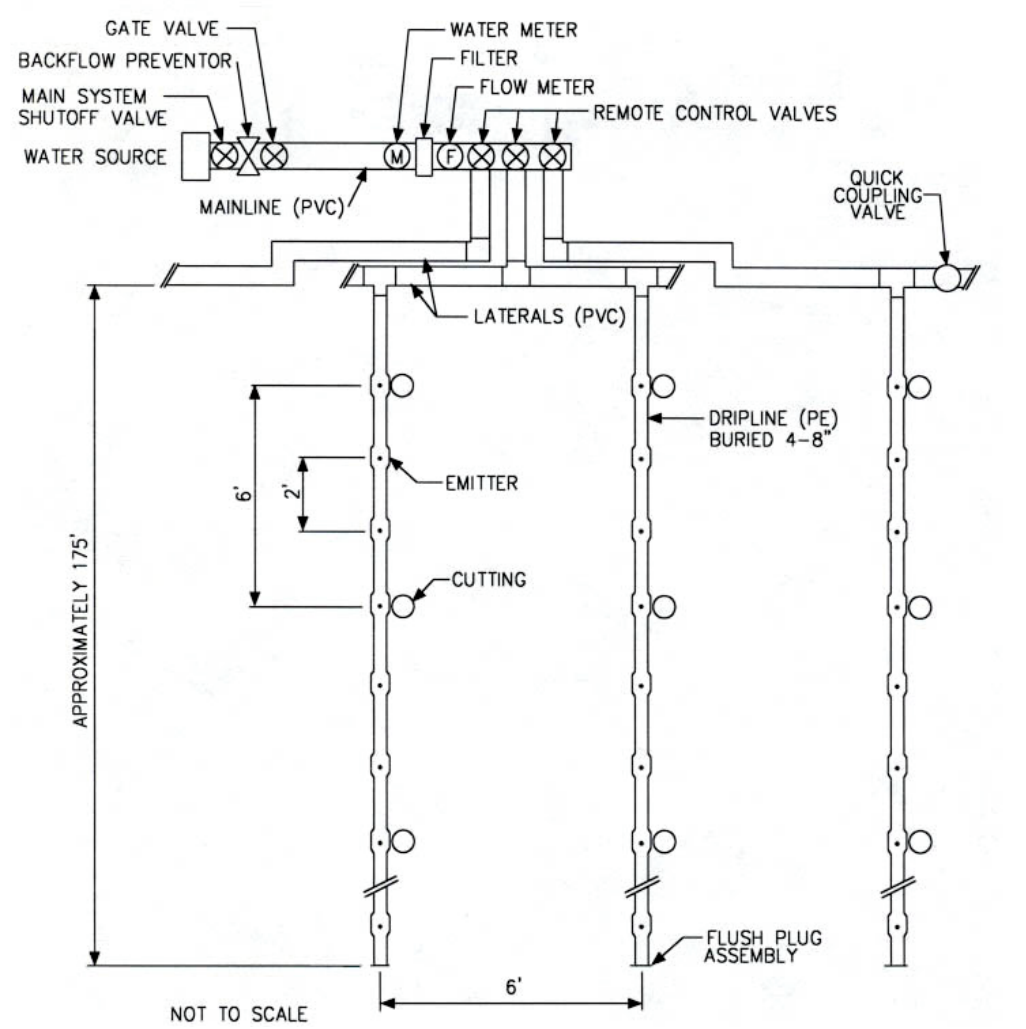
A – 9 inch cuttings pushed directly into ground

B – 10 foot cuttings with augured hole

C – 1 to 15 gallon root ball with planting pit; some with augured holes to groundwater

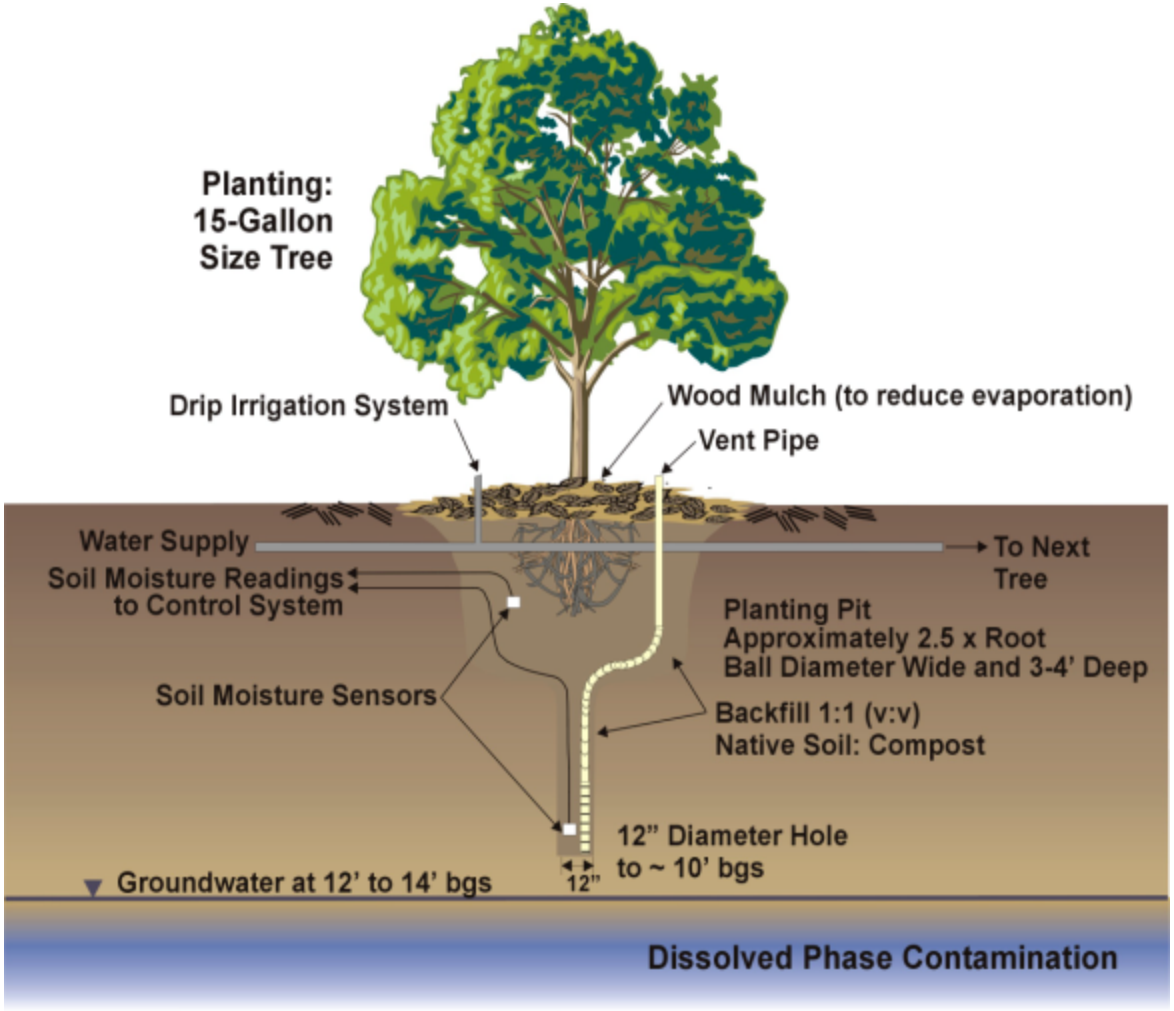
Site Preparation

Irrigation?


GATE VALVE
BACKFLOW PREVENTOR
MAIN SYSTEM SHUTOFF VALVE
WATER SOURCE
WATER METER
FILTER
FLOW METER
REMOTE CONTROL VALVES
M
F
MAINLINE (PVC)
QUICK COUPLING VALVE
LATERALS (PVC)
DRIPLINE (PE) BURIED 4-8"
EMITTER
CUTTING
6'
2'
APPROXIMATELY 175'
FLUSH PLUG ASSEMBLY
6'
NOT TO SCALE

Planting – Root Ball

Elaborate Planting Pits



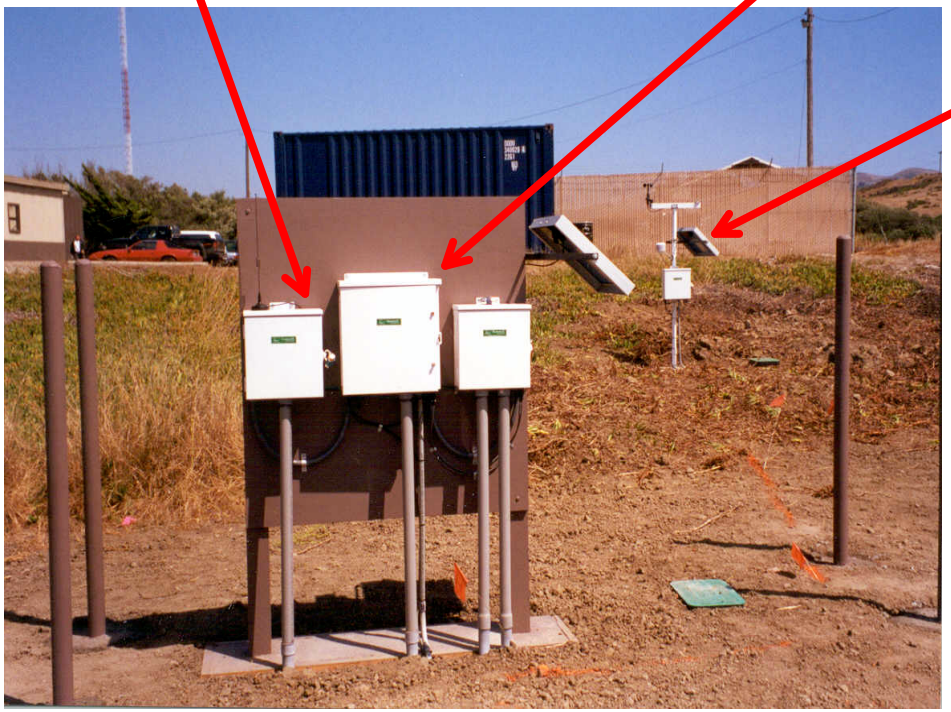
Planting - Cuttings

- Weed Control
- 200 to 1,500 Trees Per Acre
- Wide Range of Spacing

Planting – Deep Techniques

On-Site Data Collection Systems

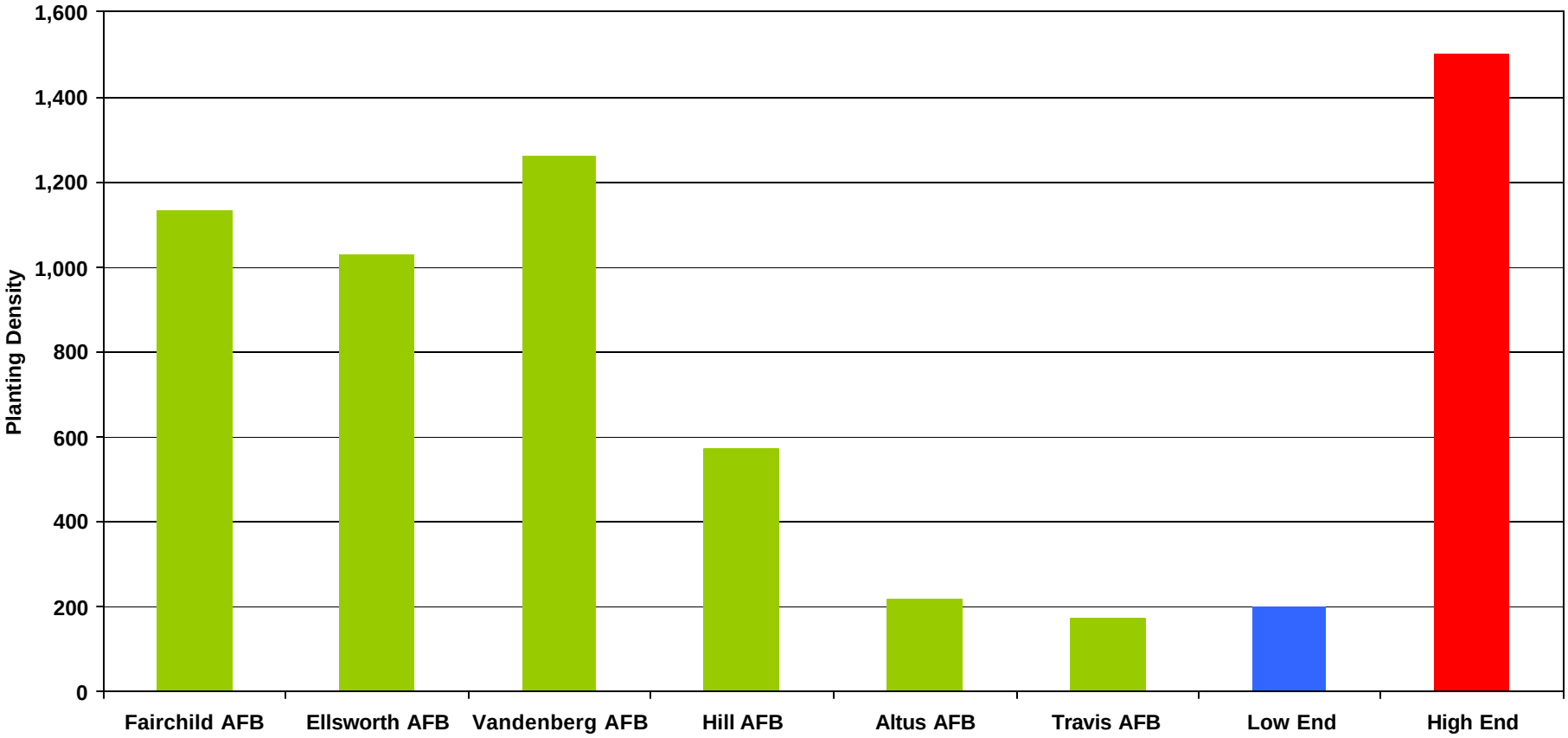
Irrigation Controller/System
- Remotely controlled
- Drip Irrigation



Data Acquisition System
- Groundwater Levels
- Soil Moisture
- Sap Flow
- Solar powered

Weather Station
- Temperature
- Precipitation
- Evapotranspiration
- Solar powered

Planting Densities



Construction Cost

LOCATION	TREES	ACERAGE	$/TREE	$/ACRE
Fairchild AFB	1,130	1	$21	$23,200
Ellsworth AFB	1,027	1	$23	$23,600
Vandenberg AFB	1,260	1	$31	$39,300
Hill AFB	143	0.25	$184	$106,000
Altus AFB	109	0.5	$201	$43,800
Travis AFB (Phase I)	100	0.5	$231	$46,120
Travis AFB (Phase II)	380	2	$54	$10,230
EPA (2000)	*-*	*-*	*-*	*$80,000*

DEMONSTRATION RESULTS TO DATE

Plant Mortality

Location	Trees	1st Season	2nd Season	3rd Season
Fairchild AFB	1,130	18%	1.5%	NA
Ellsworth AFB	1,027	10%	10%	NA
Vandenberg AFB	1,260	5%	<1%	NA
Hill AFB	143	45%	9%	NA
Altus AFB	109	83%	11%	NA
Travis AFB	380	6%	5%	4%

“The Enemy”

Plant Growth

9-Inch Cuttings

4-Day Old Cuttings

4-Week Old Cuttings

Travis AFB

February 1999 – Initial Planting

January 2001

December 2002

April 2000 – Secondary Planting

January 2001

December 2002

Altus AFB

1999

2000

2002

Fairchild AFB

April 2001

November 2001

September 2002

Fairchild AFB (cont)

November 2001

September 2002

Ellsworth AFB

June 2001

October 2002

Hill AFB

July 2001 – Site A

August 2002 – Site A

Hill AFB (cont)

July 2001 – Site B

August 2002 – Site B

Vandenberg AFB

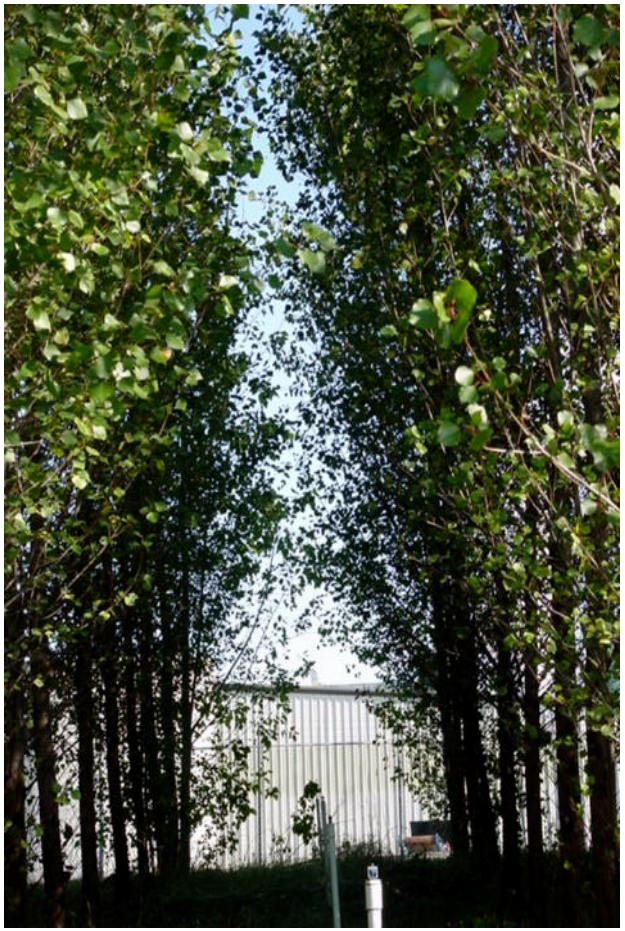
August 2001

February 2002

November 2002

Large Leaf Areas

4-Year Old Poplar Stand



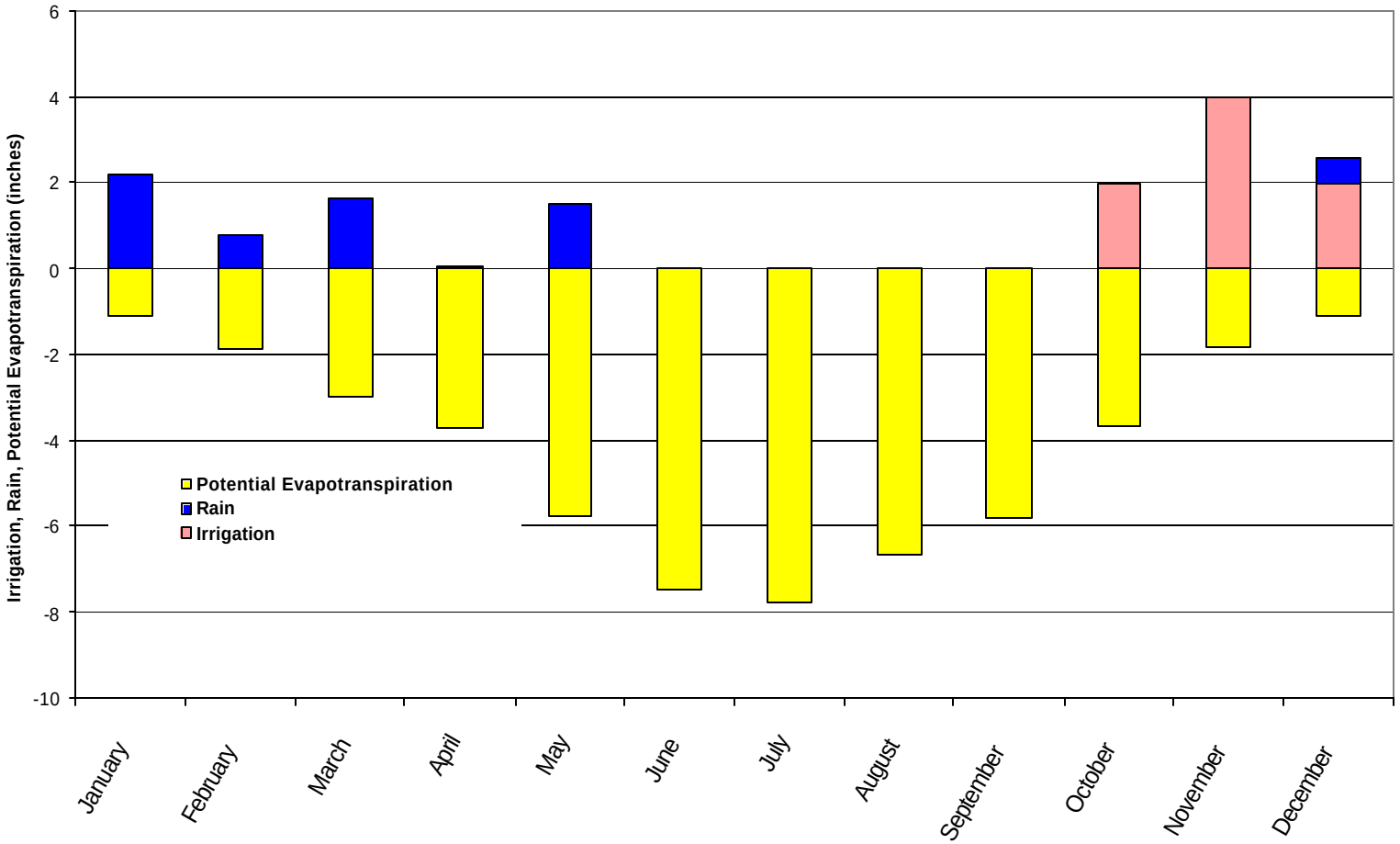
Water Balance

$$\textit{Inflow} = \textit{Outflow} \pm \textit{Change in Storage}$$

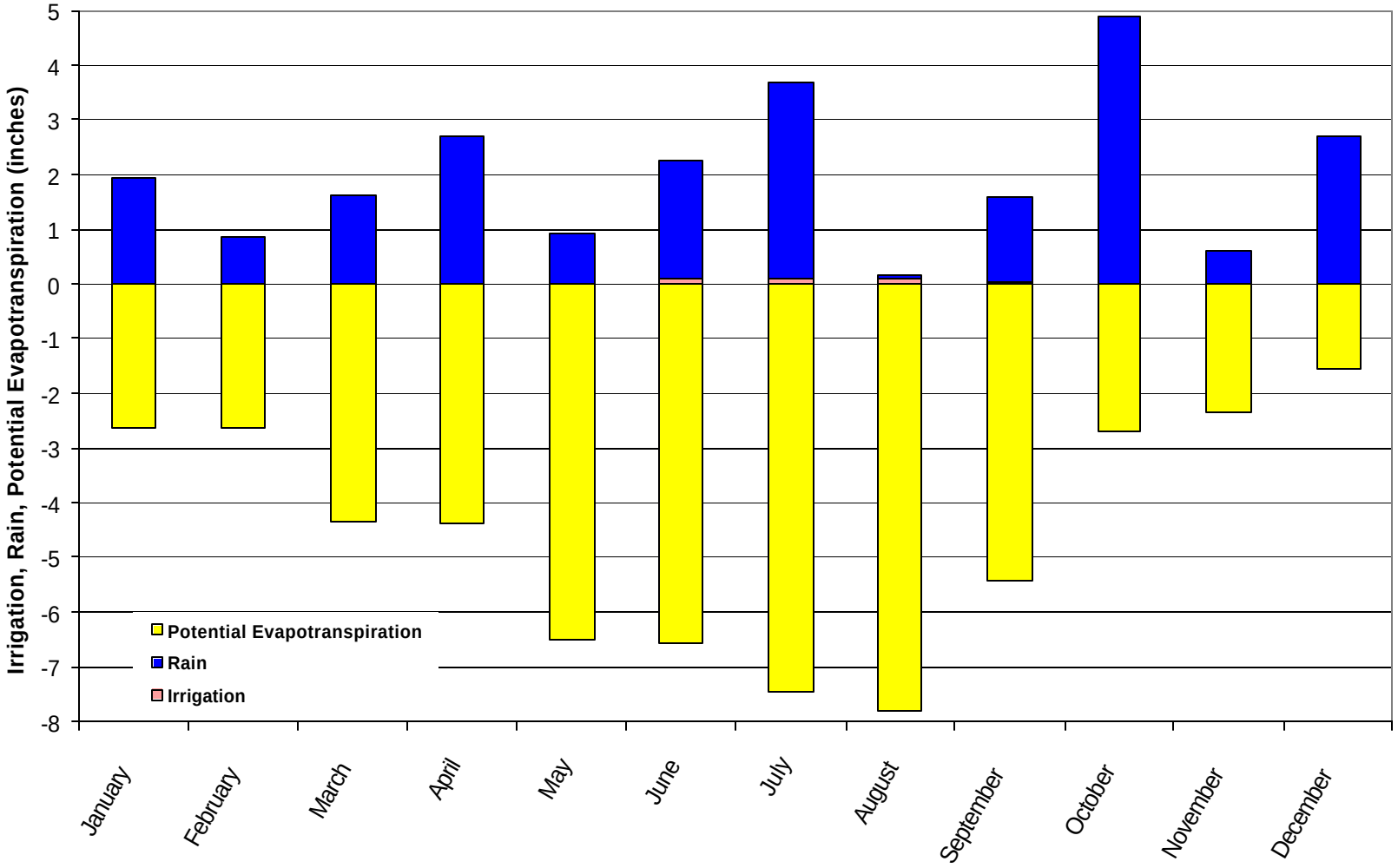
$$P + GW_{in} = R_o + E + T + GW_{out} + \Delta S$$

- Where:
  - P = Precipitation
  - GW_{in} = Groundwater Flow In
  - R_o = Total Runoff/Runon
  - E = Evaporation
  - T = Transpiration
  - GW_{out} = Groundwater Flow Out
  - ΔS = Change in Storage (soil water and aquifer)

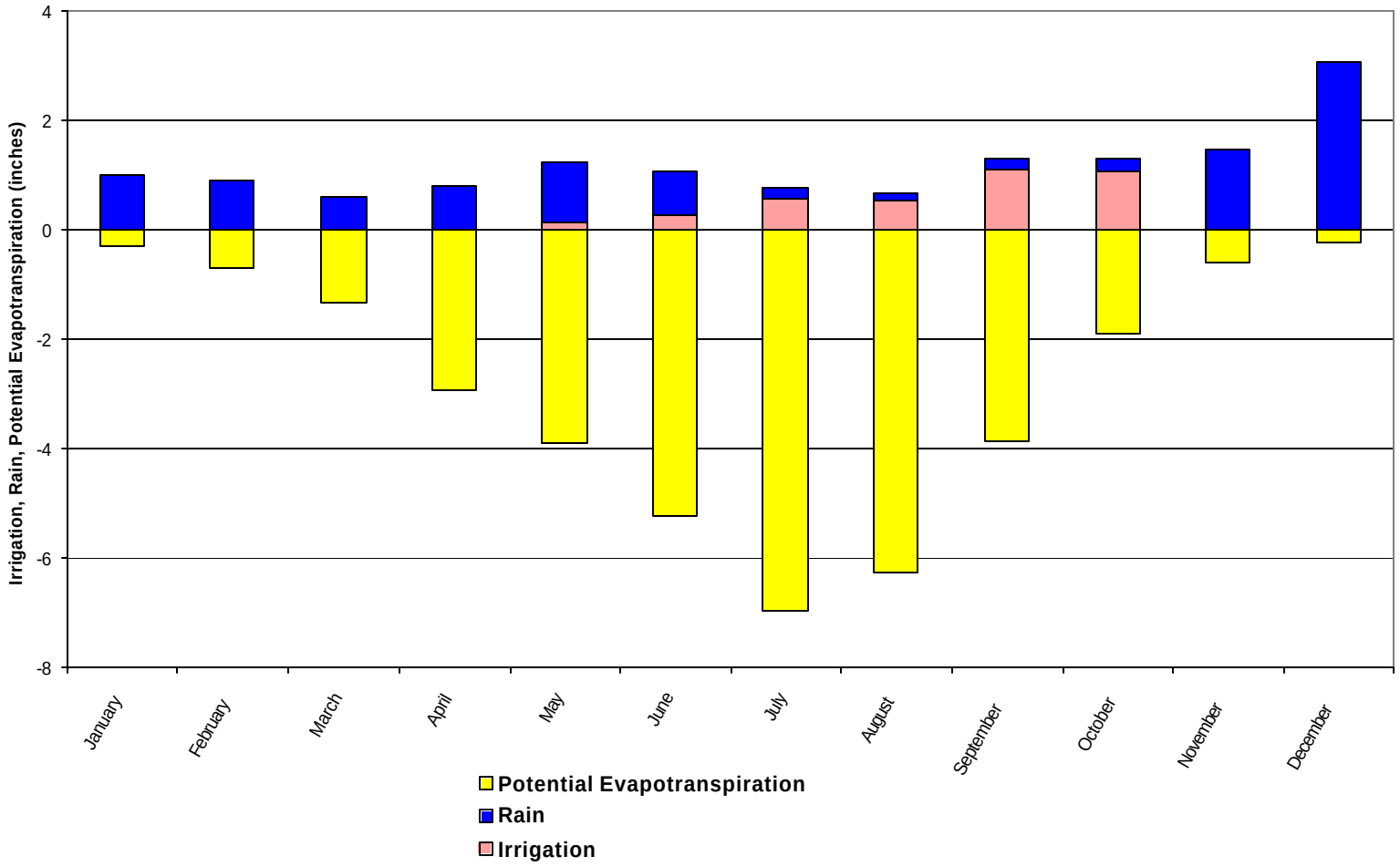
Travis AFB


Irrigation, Rain, Potential Evapotranspiration (inches)
6
4
2
0
-2
-4
-6
-8
-10
Potential Evapotranspiration
Rain
Irrigation
January
February
March
April
May
June
July
August
September
October
November
December

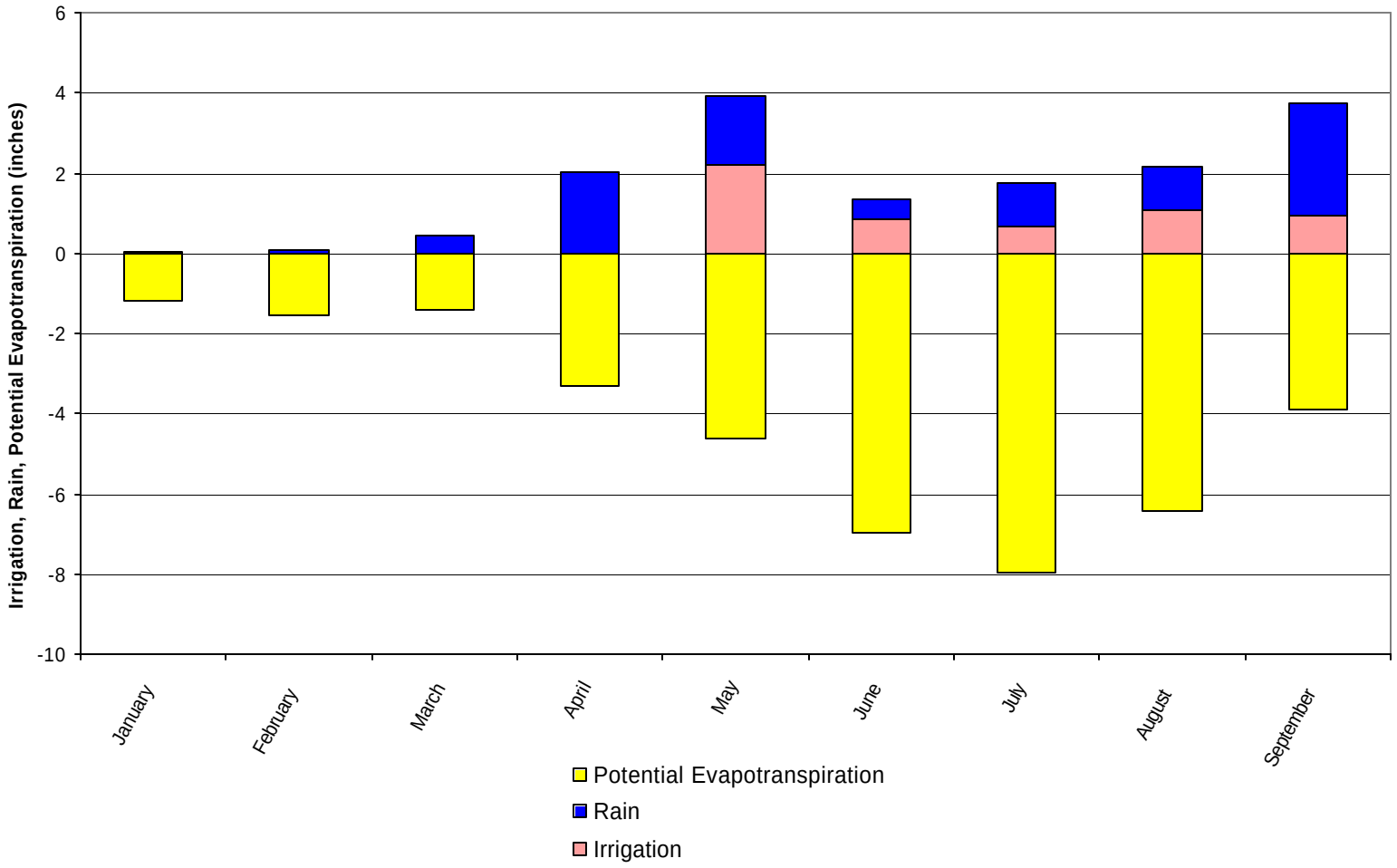
Altus AFB


Irrigation, Rain, Potential Evapotranspiration (inches)
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
Potential Evapotranspiration
Rain
Irrigation
January
February
March
April
May
June
July
August
September
October
November
December

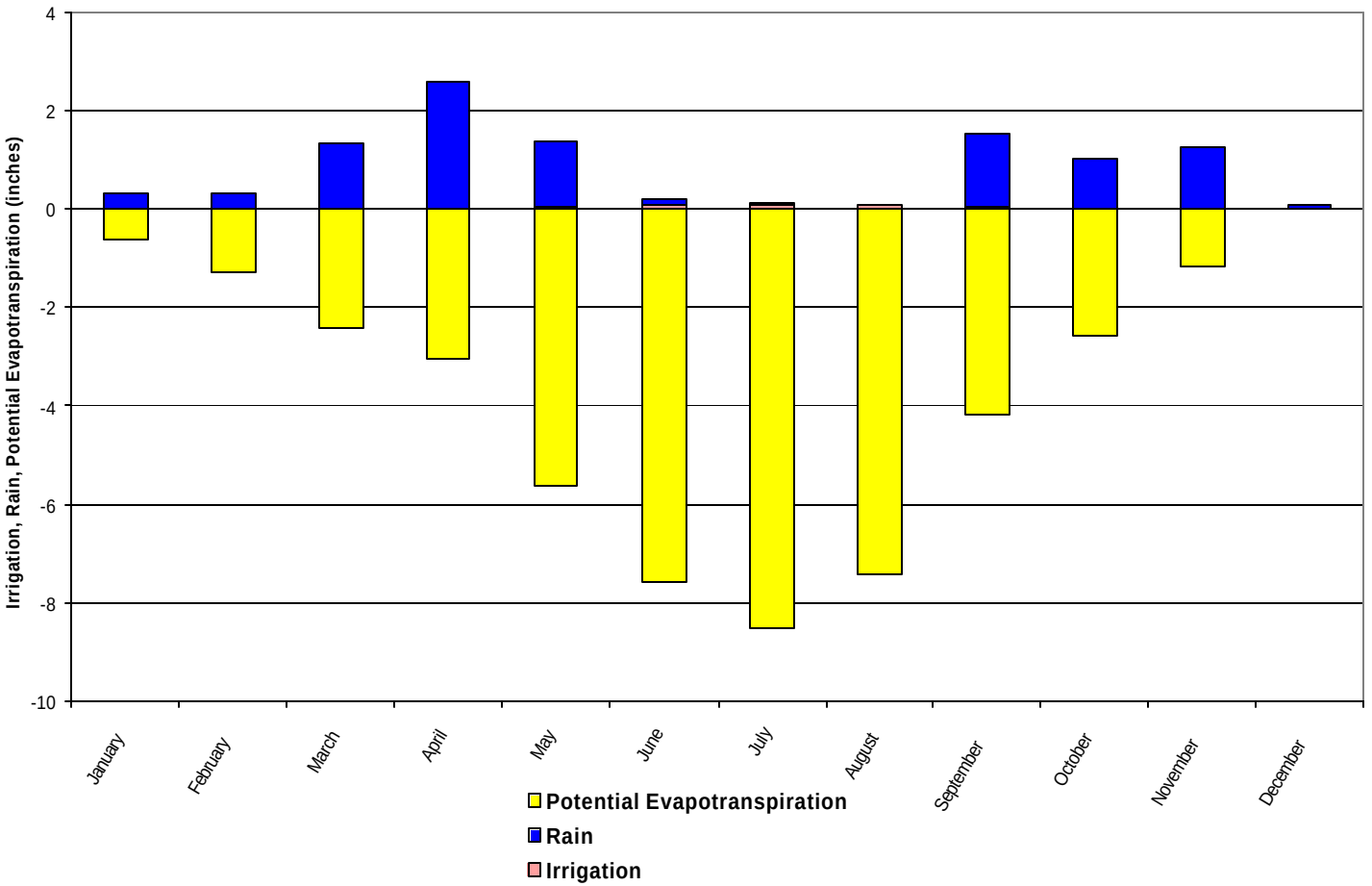
Fairchild AFB



Ellsworth AFB

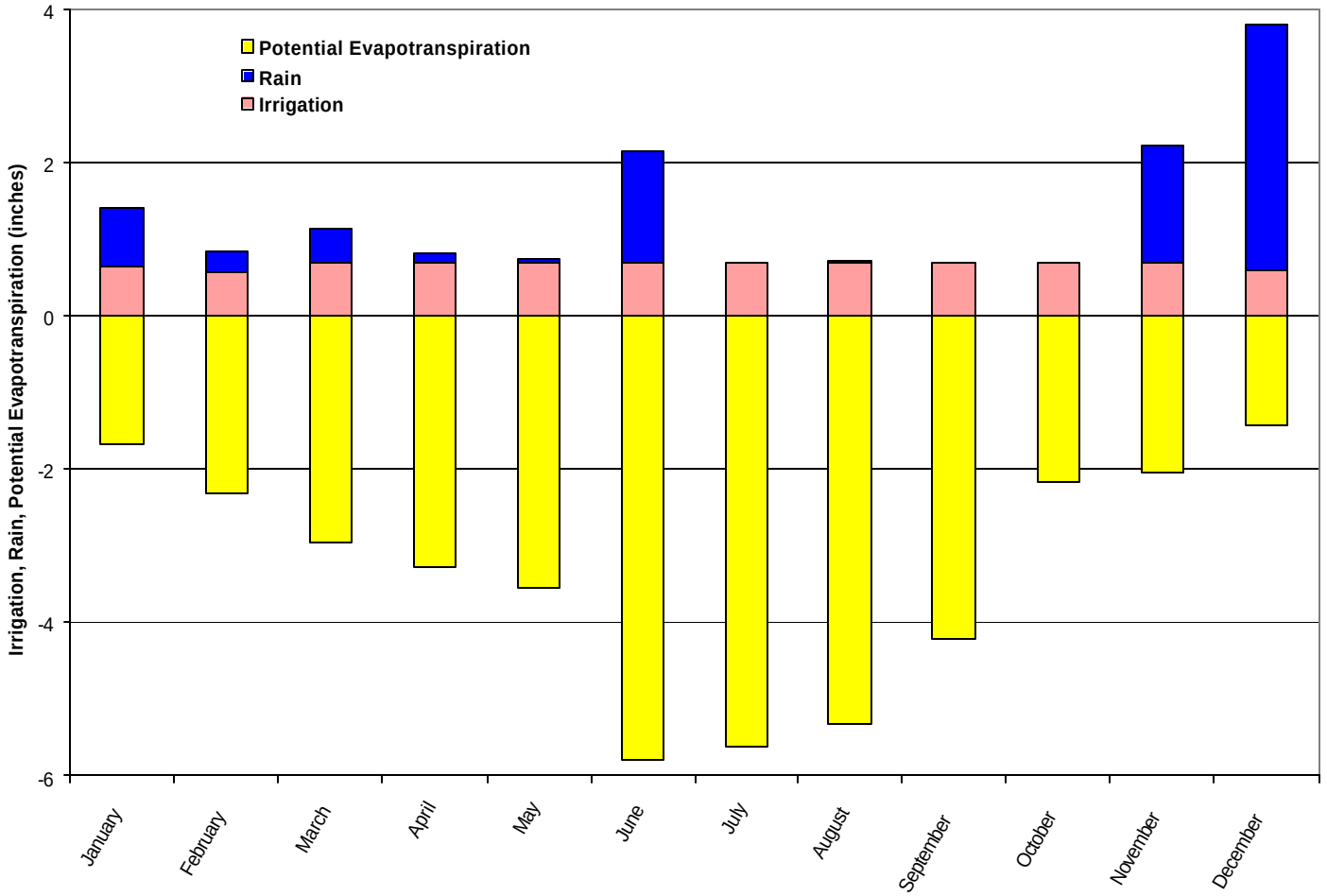


Hill AFB



Some manual irrigation (equates to approximately 0.6 inch).

Vandenberg AFB



Water Extraction

$$P + GW_{in} = R_o + E + T + GW_{out} + DS$$

Extraction Well

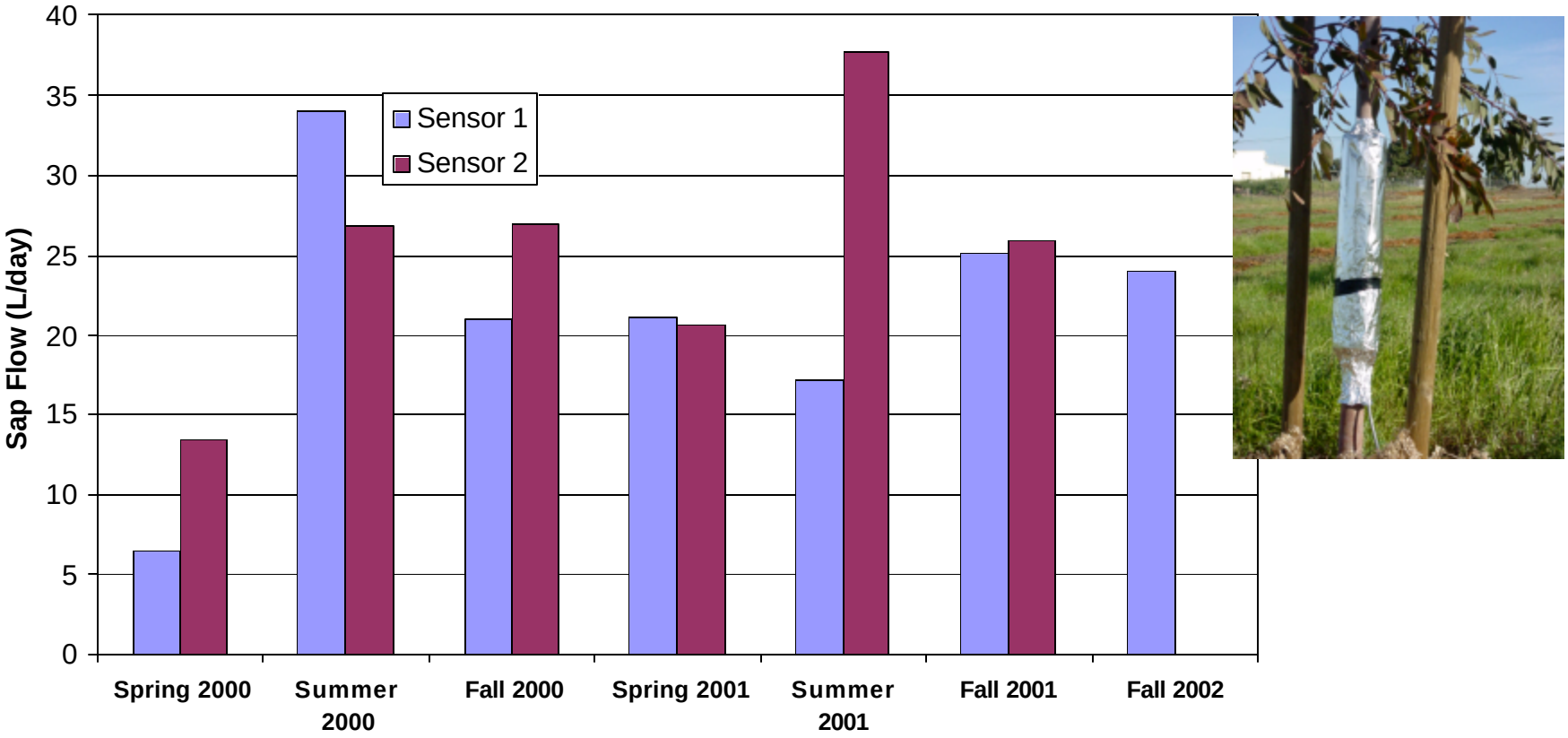
$$Q \quad (similar\ to\ T) \quad = \frac{K(H^2 - h^2)}{1{,}055 \log R / r}$$

Source: Driscoll, 1986

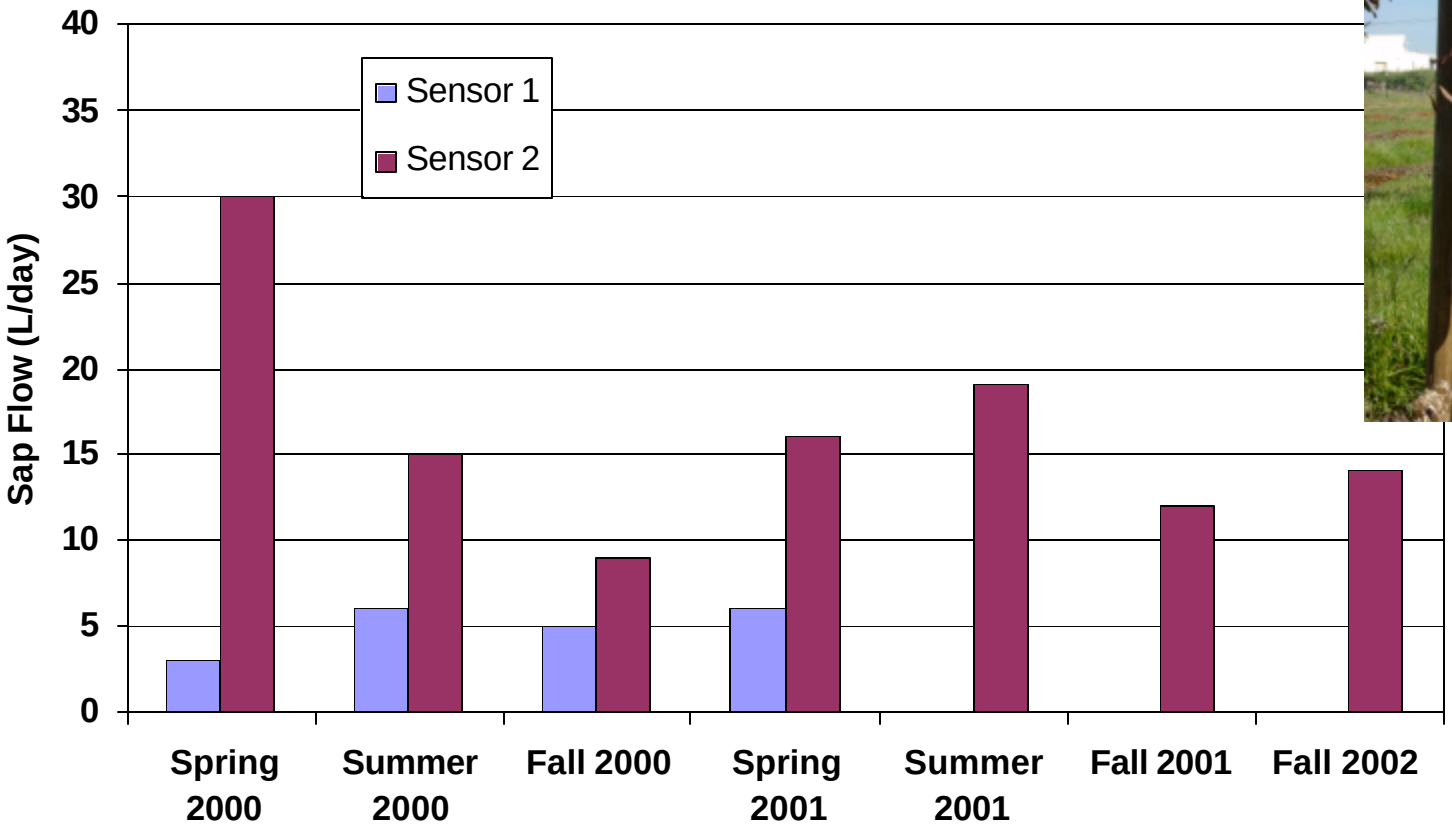
Plants (some estimate of variable "T")

$$T = PET \times K_c \times LAI \times A$$

Travis AFB Sap Flow



Altus AFB Sap Flow



Groundwater Use

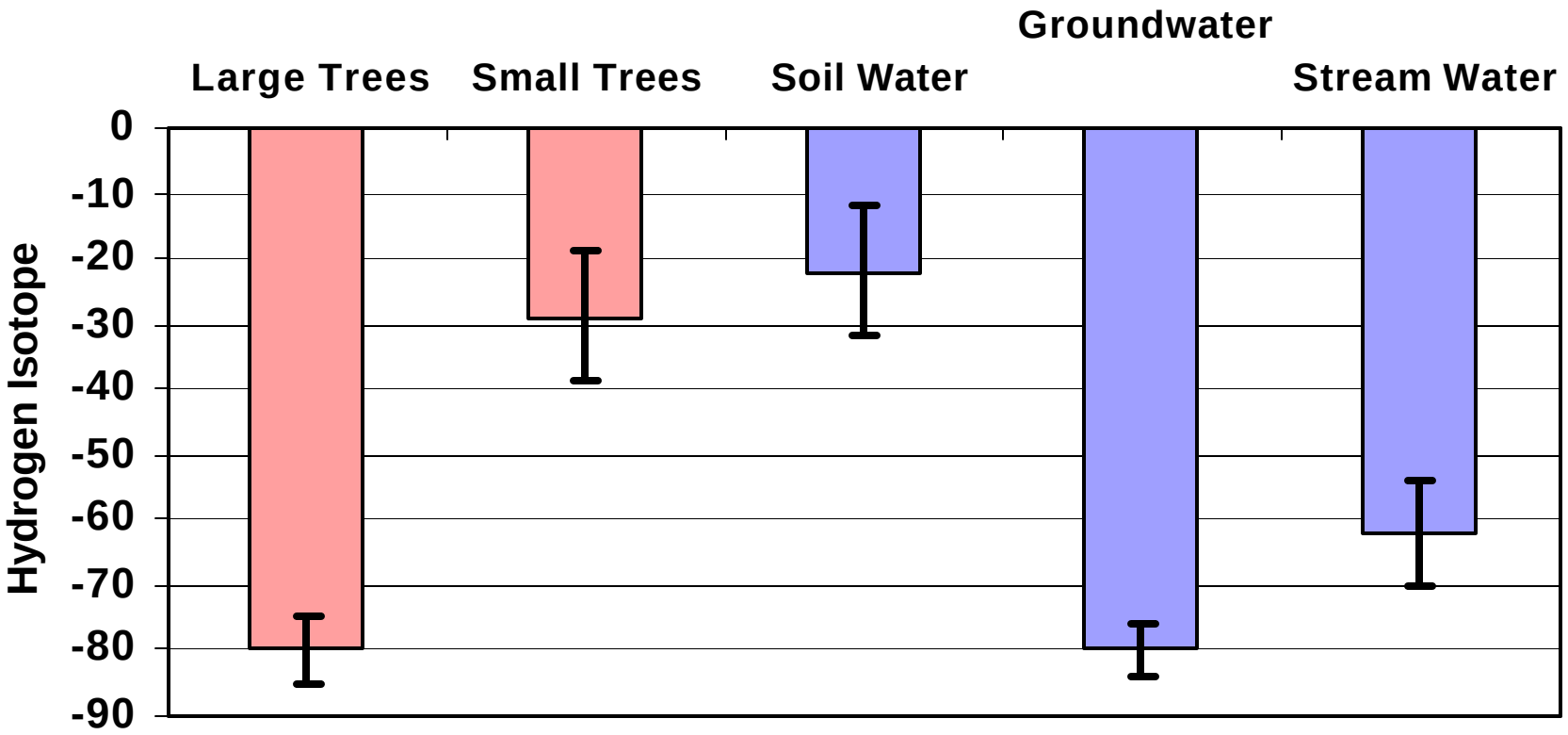
$$T_{gw} = PET \times K_c \times LAI \times A \times f_{gw}$$

- Some Estimate of Water Source (f_{gw})
  - Stable Isotope Analysis
  - Deuterium δ^2H
  - Oxygen $\delta^{18}O$
  - Evaluate surface water (precip), groundwater, irrigation water, and sap flow

$$T_{TREE}\,\delta_{TREE} = f_{GW}\,T_{TREE}\,\delta_{GW} + (1-f_{GW})\,T_{TREE}\,\delta_{SW}$$

Source: Doucette, 2003.

Example Water Source



Source: Dawson, 1996.

Were waiting on data for 2002.

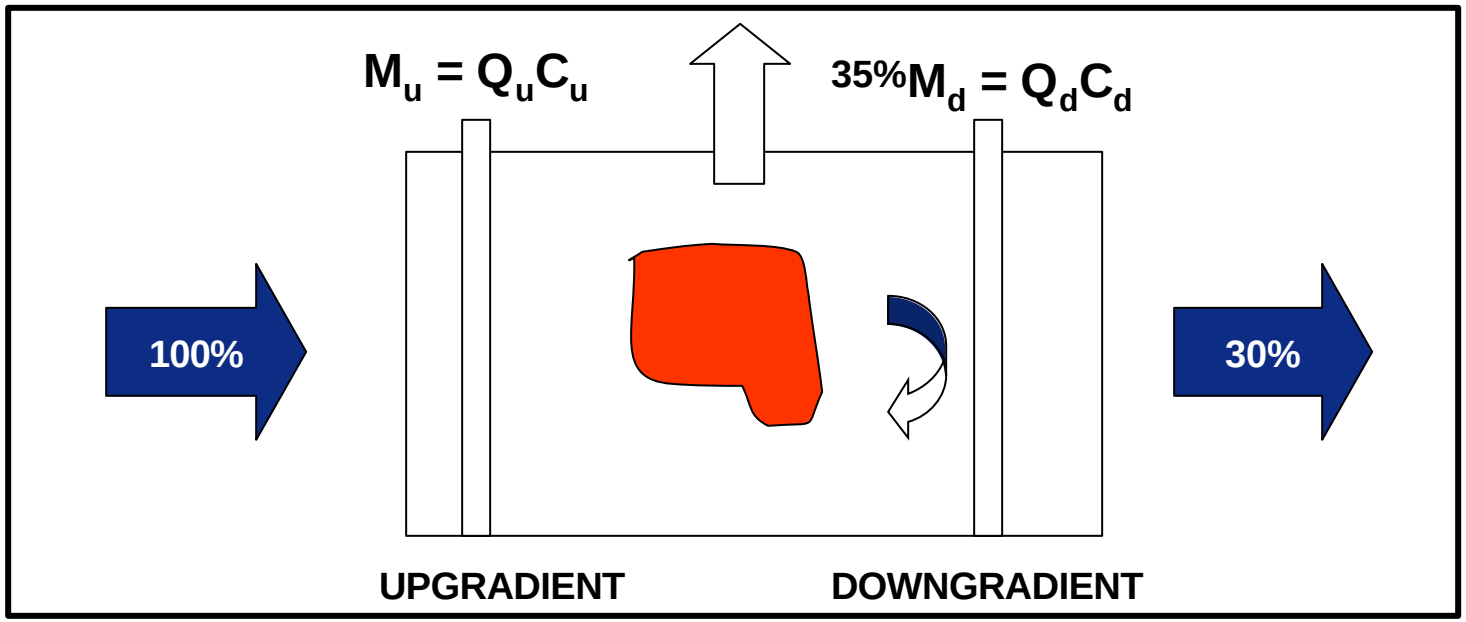
Impact on Groundwater Quality

- Travis AFB
  - No significant changes to TCE concentrations from 2001 to 2002; it appears that the “hot spot” (17,000 ppb TCE) in the planting area has not moved.
- Altus AFB
  - VOC concentrations in the middle and upgradient of the plant stand have typically remained unchanged. However, all three down gradient wells generally show slight decreases in VOC concentrations from 2001 to 2002.
- Fairchild AFB
  - The “hot spot” upgradient of the planting area appears to have moved into the planting area and the TCE concentrations decreased from 1,100 ppb to 230 ppb.

Impact on Groundwater Quality

- Ellsworth AFB
  - No significant VOC concentration changes from 2001 to 2002.
- Hill AFB
  - During the 2002 sampling event, every sampled location showed decreases in DCE and TCE concentrations, on average 20 to 40 percent, respectively.
- Vandenberg AFB
  - PCE decreased in all wells sampled in 2002; maximum PCE concentration was 380 ppb in 2001 and decreased to 100 ppb in 2002. Maximum TCE concentration decreased from 67 ppb to 10 ppb. Groundwater plume appears to have moved 100 feet downstream.

Mass Flux Changes



SOURCE: Adapted from Landmeyer, 2001

Uptake

- What is the mass flux (M_p) of contaminants through the plants?

$$M_p = TSCF * T * f_{GW} * C_{GW}$$

where:

TSCF = Transpiration Stream Concentration Factor

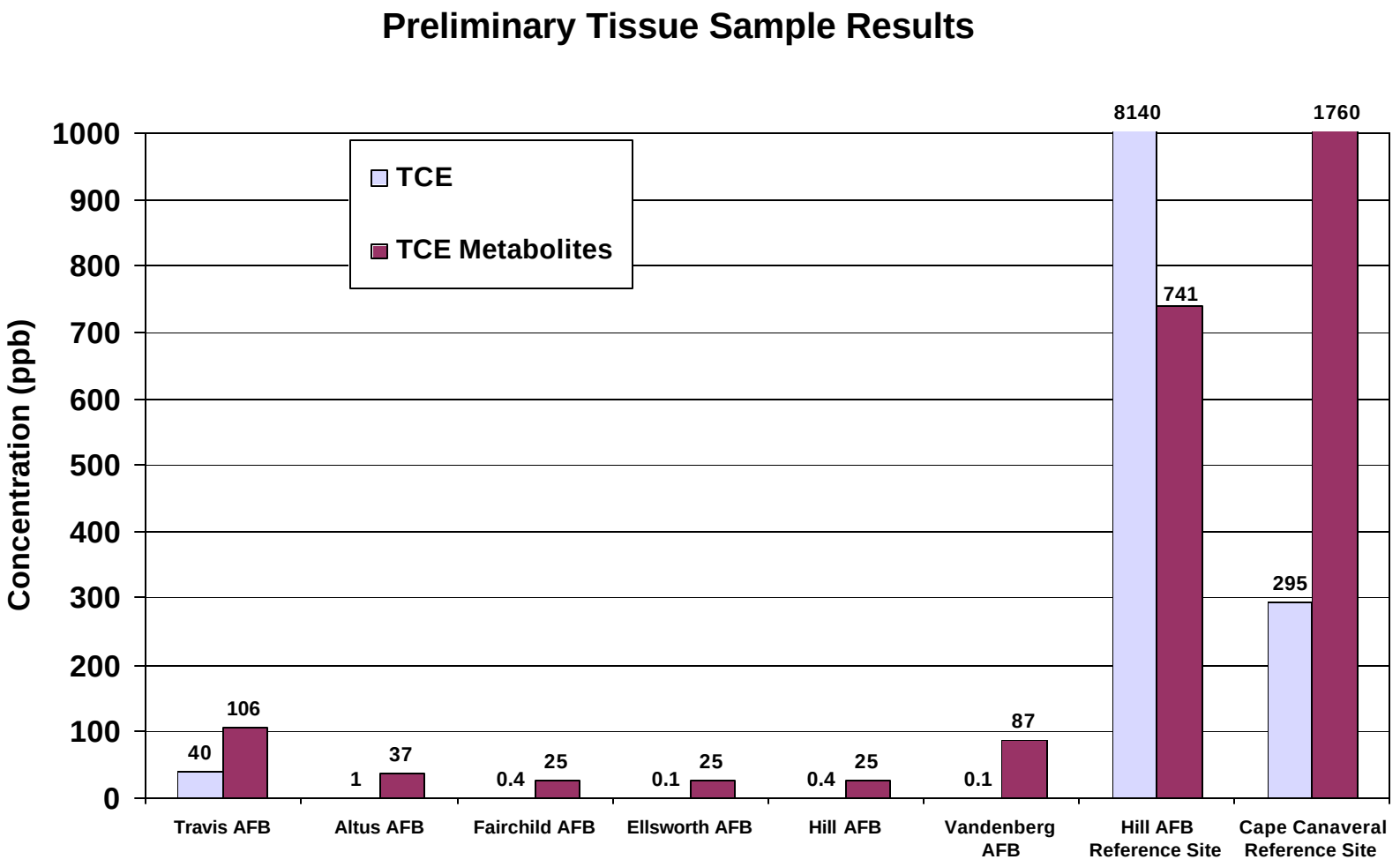
T = Water Removal Rate

f_{GW} = Fraction of Q_{TREE} as Groundwater

C_{GW} = Average Concentration of the Groundwater

- Source: Doucette, 2003.

Tissue Samples



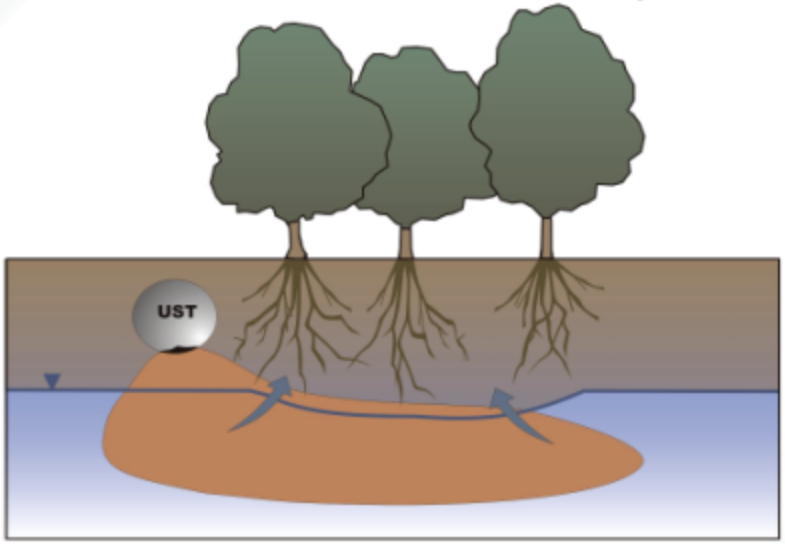
Annual Costs

LOCATION	Actual/Estimated 5 Year Range
Fairchild AFB	$32,500 - $41,200
Ellsworth AFB	$32,500 - $41,200
Vandenberg AFB	$32,500 - $41,200
Hill AFB	$32,500 - $41,200
Altus AFB	$19,000 – $39,700
Travis AFB (Phase I)	$20,700 - $39,700

Note: Highly dependent on level of monitoring required.

Phytostabilization of Shallow Contaminated Groundwater Using Tree Plantings at Multiple Air Force Demonstration Sites

Technology Demonstration
Interim Technical Reports
Interim Cost and Performance Reports



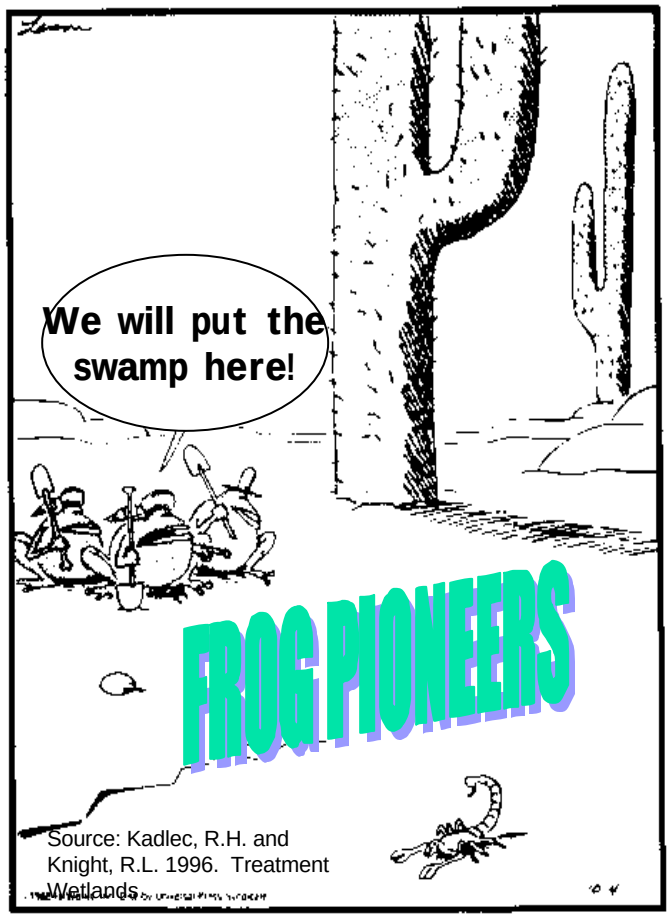
Final
January 2003

Volume I

Air Force Center
for Environmental Excellence

Path Forward

- First Few Years = Establish Healthy Plant Stand
- Continue Monitoring for 2 to 5 Years
- Annual Progress and Cost Updates
- Potential Migration to Irrigated Plantings



Questions

THANK-YOU