# Introductions & Experience


**Edward Gatliff, Ph.D.**
Agronomy/Soil Chemistry

**Paul Thomas, B.S.**
Geology/Hydrogeology


**First applied phytoremediation remedy in 1988 and have continued phytoremediation activities to the present**


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# Phytoremediation Applications

- Soil Remediation
- Groundwater Remediation
- Groundwater
  - Hydraulic Control/Mitigation
  - Plume Control/Mitigation

# Traditional Approach to Phytoremediation

## Conventional, or non-engineered

- Conventional planting to treat affected soil and groundwater via:
  - Rhizodegradation, Phytodegradation (in-plant), enhanced microbial degradation
- Applications typically limited to shallow soil & groundwater, low contaminant concentrations via:
  - Restricted root development (plant/lithology), precipitation, phytotoxicity

# ANS' Trademark & Patented Approach to Phytoremediation

## Constructed, or engineered

- *TreeMediation*® Program
  - designed and constructed system to control plant growth, manage site conditions and target the zone for remedial effect
- *TreeWell*® Technology
  - Expanded opportunities: deep groundwater, targeted horizons, high contaminant concentrations
- *Phyto-Integrated*™ Remediation Systems
  - Combining phytoremediation with other technologies

# Keys to Assured Results

- Understand the site conditions as they relate to Phytoremediation
- Conduct phyto-feasibility study
- Apply agronomic & engineering principles to control conditions
- Perform proper implementation, operation and monitoring

# *TreeWell* Technology - Basic Approach

**Borehole excavated to the horizon of interest**

***Root_Sleeve*™ liner installed on safety platform**

**Hole is backfilled with topsoil & selected amendments**

**aeration & other tubing are added after platform is placed over the hole**

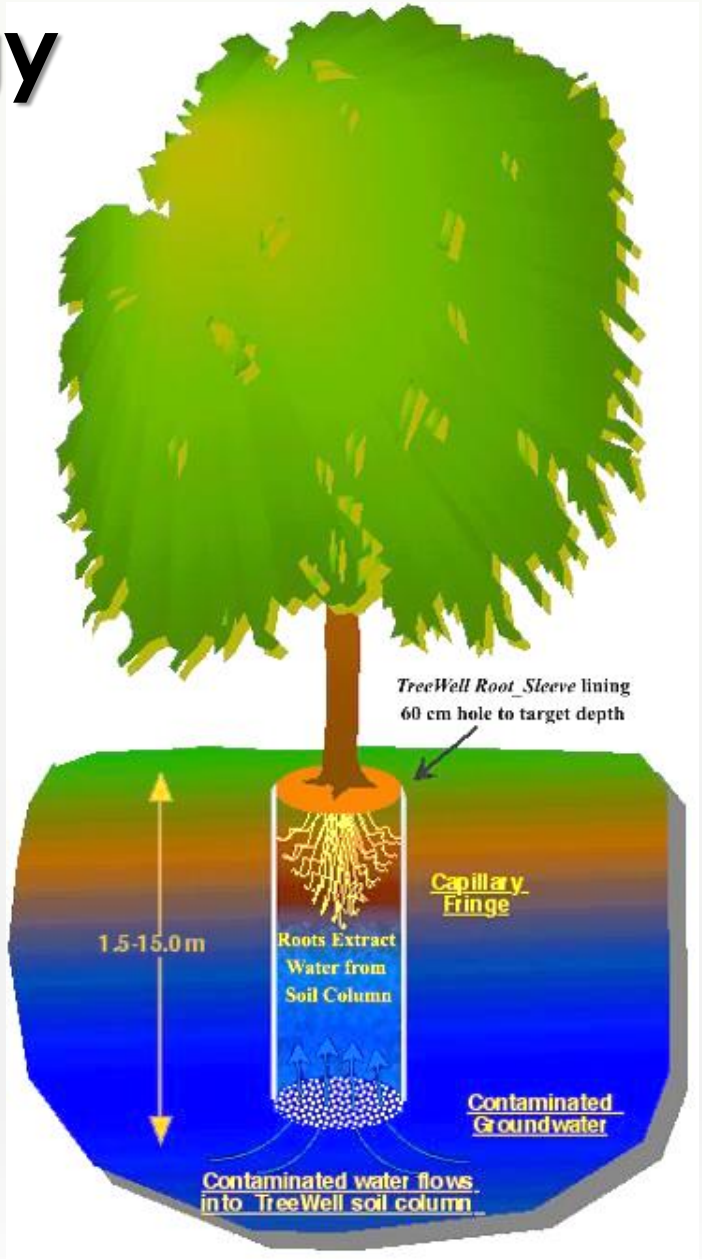
**Trees are planted**

# *TreeMediation Program*

- Enables access to groundwater up to 100 feet bgs (and more…)
- Ability to remediate and affect the hydraulics of specific horizons
- Ability to address normally phytotoxic levels of contaminants
- Limits/Eliminates irrigation requirements
- Excludes surface/rain water – no confounding

# *TreeWell* Technology

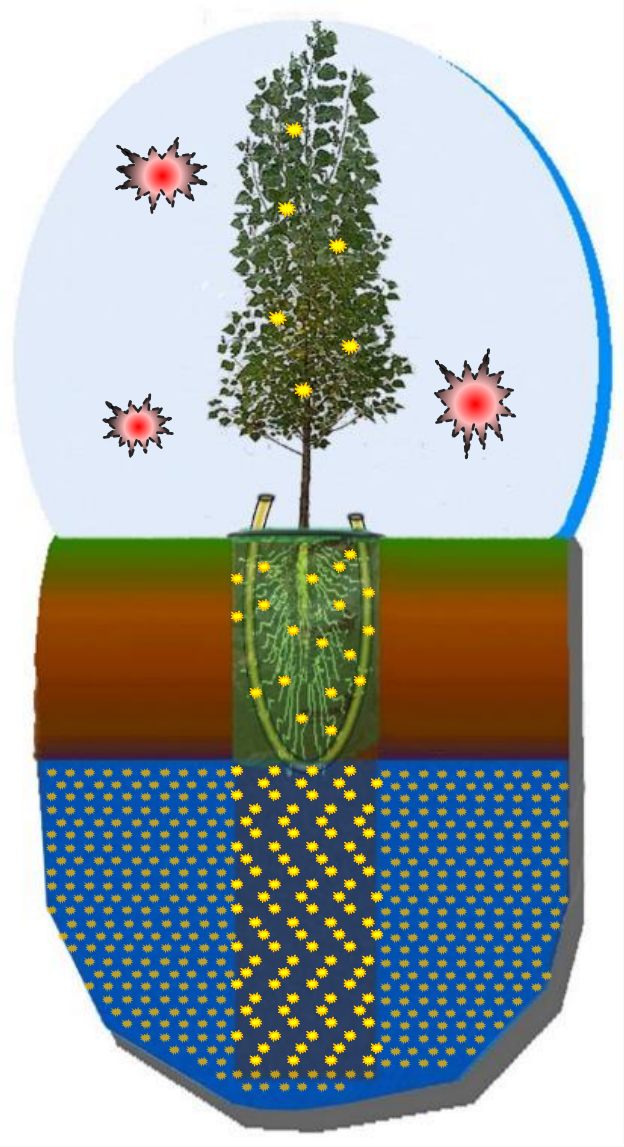
- Tree acts as solar pump
- Groundwater is drawn upward through soil column
- **Bioreactor Effect** - biodegradation occurs prior to root uptake; thereby mitigating phytotoxic effects



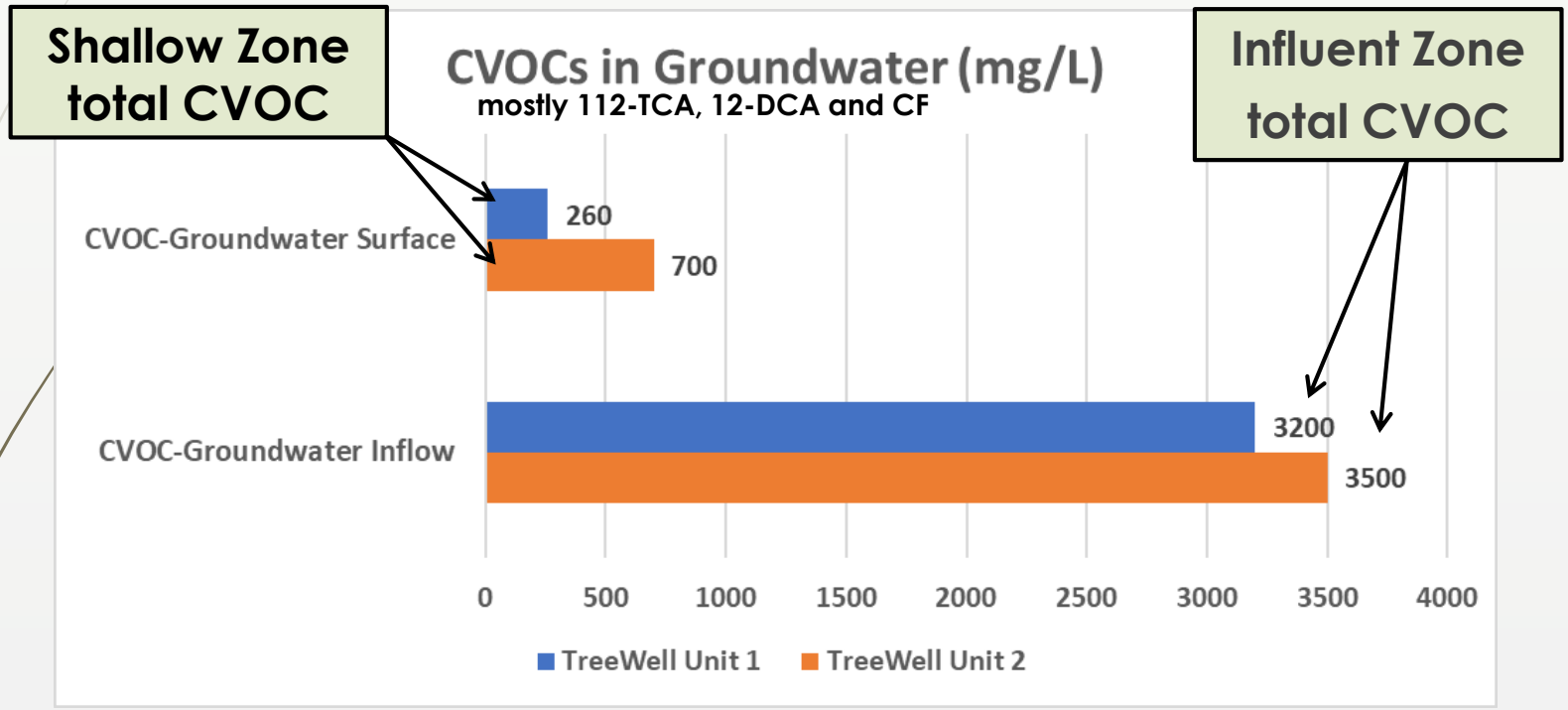
# *TreeWell* Technology for VOCs

**Tree is the Pump & the *TreeWell* unit is the Bioreactor Treatment System**

- Tree pumping draws contaminants into *TreeWell* Treatment Column
- Untreated contaminants from the Treatment Column are drawn to the rhizosphere and treated by a number of potential processes
- Residual contaminants may be taken up by the plant and treated within the plant
- Remaining molecules may pass through the plant and may be emitted into the atmosphere in the transpiration stream
- ….and then Photo-oxidized
  (Ex: 1,4-Dioxane, MTBE, Organo-Chlorine Pesticides, etc…)



# *TreeWell* Technology
# Bioreactor Effect

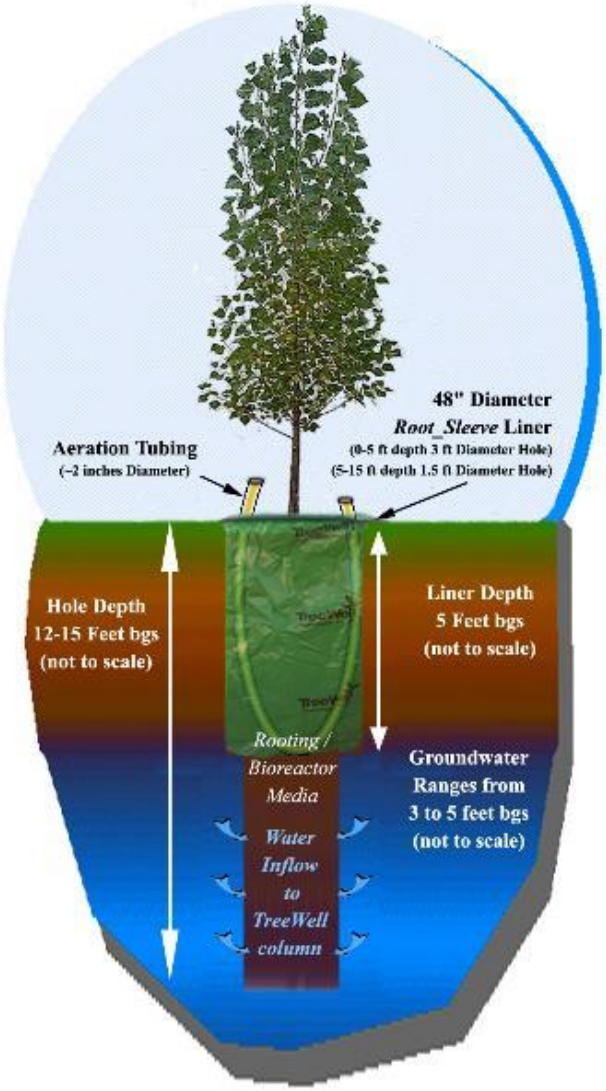



**Contaminated groundwater inflows into the bottom of the *TreeWell* column and as the water rises through the column, the bioreactor effect reduces contaminant concentrations by 80-90%.**

# *Phyto-Integrated* Remediation Systems - Advanced Techniques

## *TreeWell* Technology Bio-Barrier

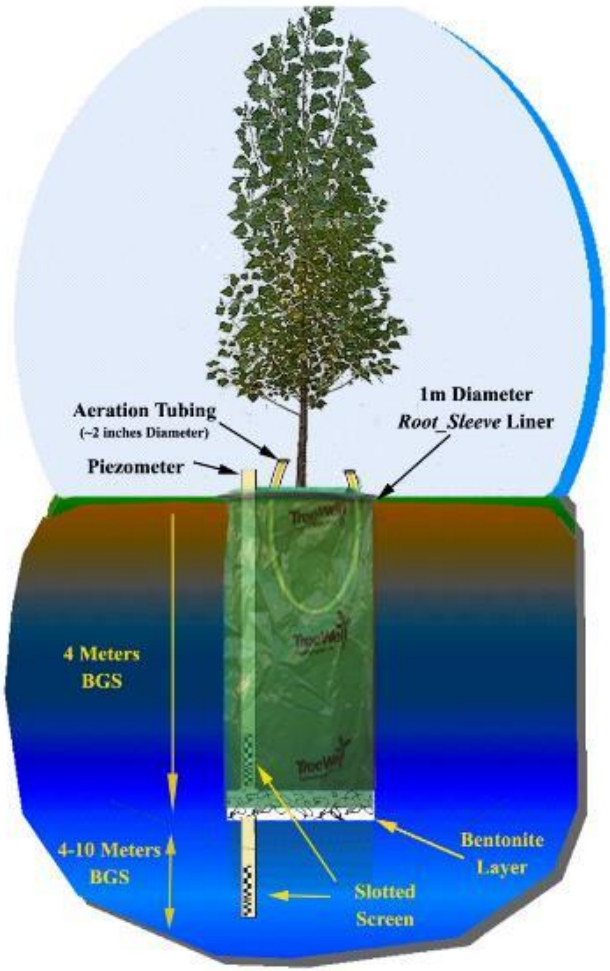
- intercepting the contaminant plume in the target horizon of the aquifer



# *Phyto-Integrated* Remediation Systems - Advanced Techniques

## "Straw" *TreeWell* Technology

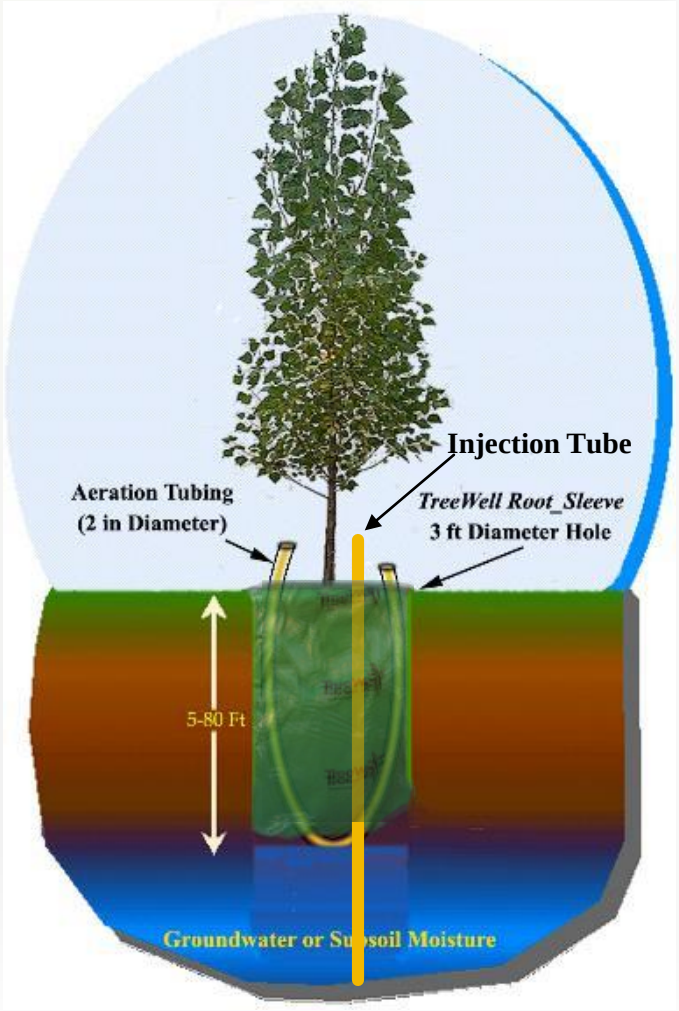
- extracting groundwater from extreme depths (110 feet bgs to-date)
- addressing bedrock aquifers
- or, in-situ treatment by recirculation of groundwater within the *TreeWell* column



# *Phyto-Integrated* Remediation Systems - Advanced Techniques

## Treatment Injections

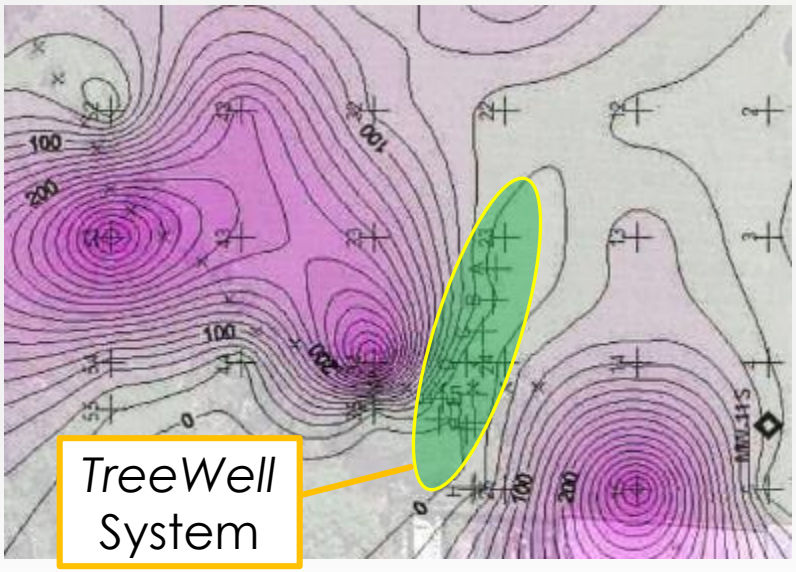
- Treating sinker/ DNAPL contaminants with EZVI, etc…

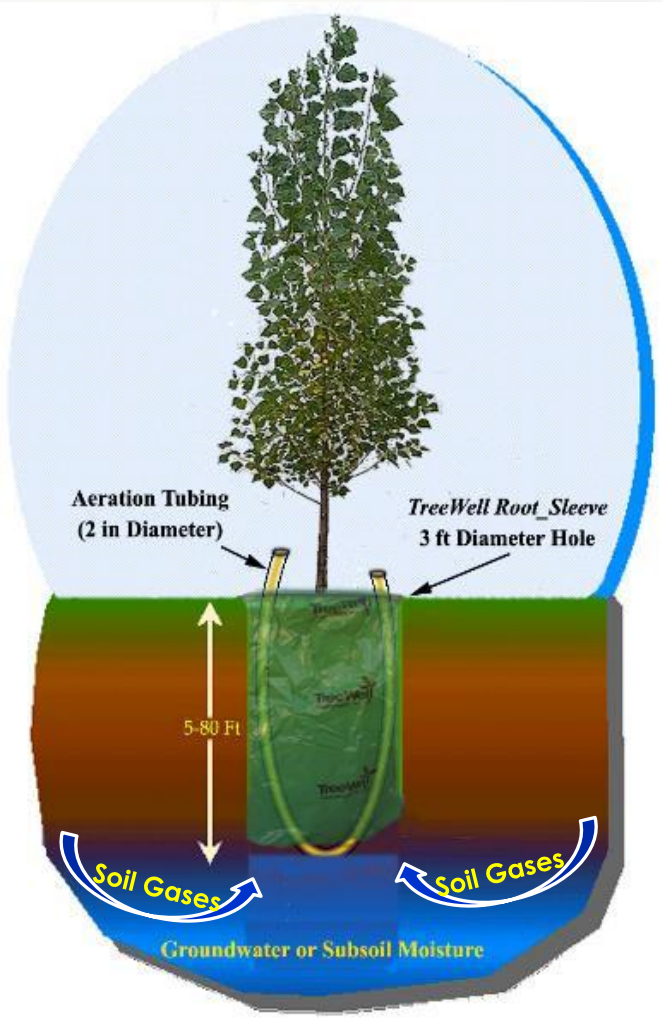


# *Phyto-Integrated* Remediation Systems - Advanced Techniques

## Passive Air Sparging

- Soil Gases evacuated in area of *TreeWell* units



# *Phyto-Integrated* Remediation Systems - Advanced Techniques

**Seasonally Shallow Groundwater**

# Projects & Results

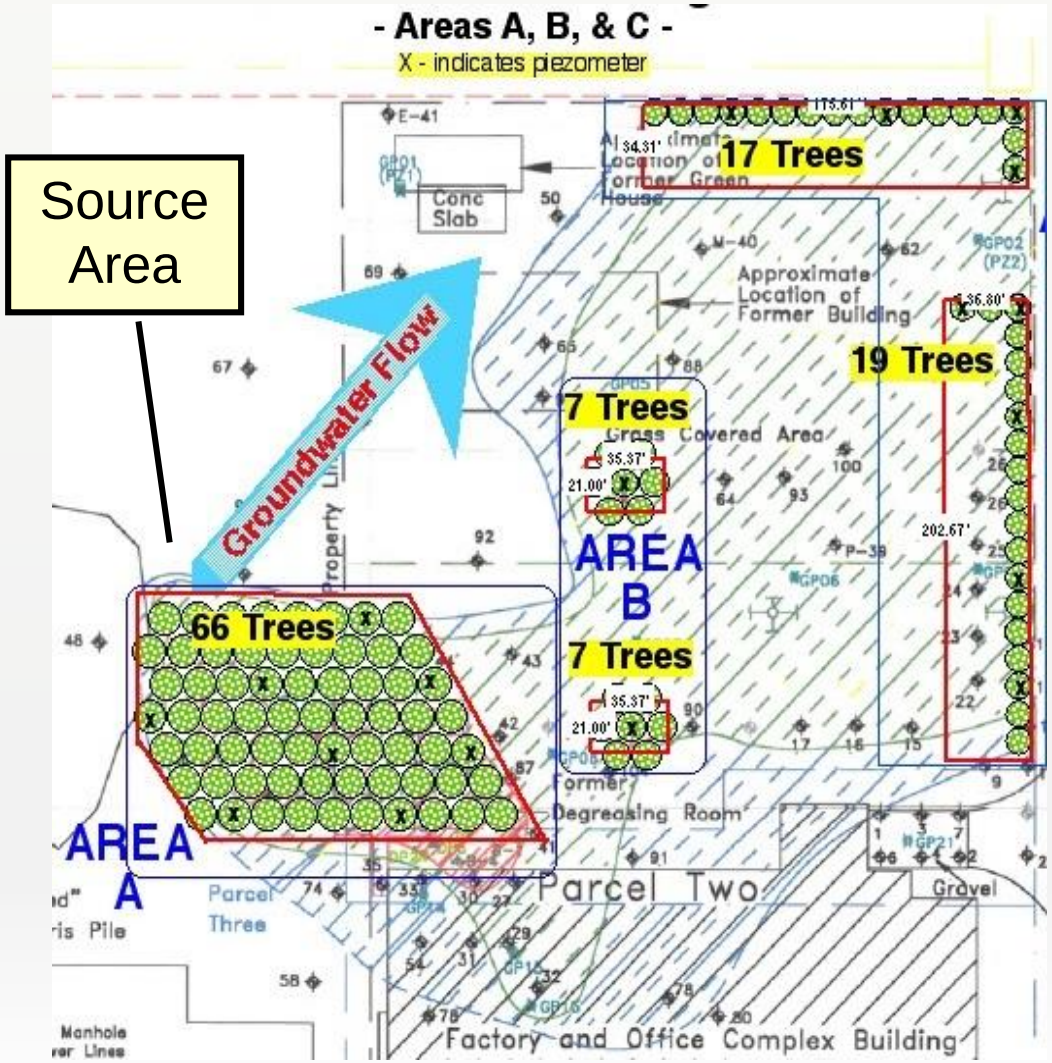
## - for TCE, 2,4-D, Benzene & Chlorobenzene contaminated groundwater


# Aurora, Illinois - 2000

## TCE Remediation of Groundwater 12+ ft deep

### TCE in Groundwater

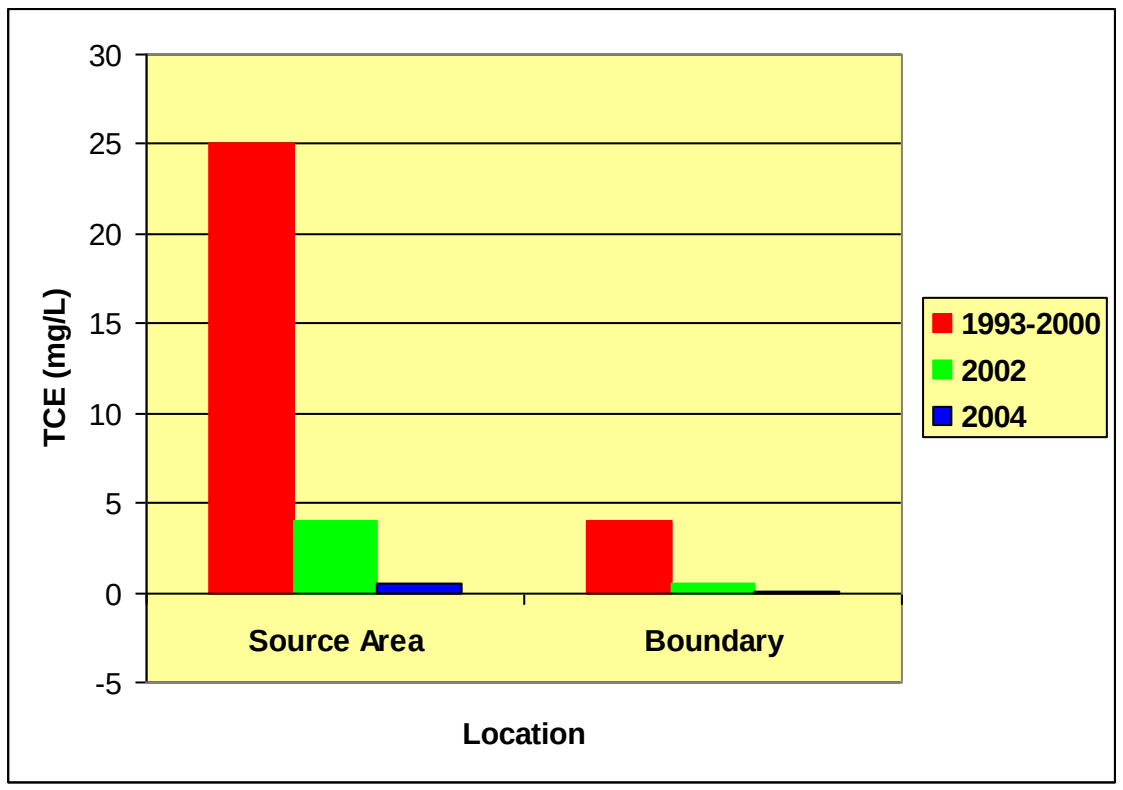
- High concentrations in the source area (source removed)
- Lower concentrations at the downgradient boundary
- Plume moving off-site



# Aurora, Illinois

## Results

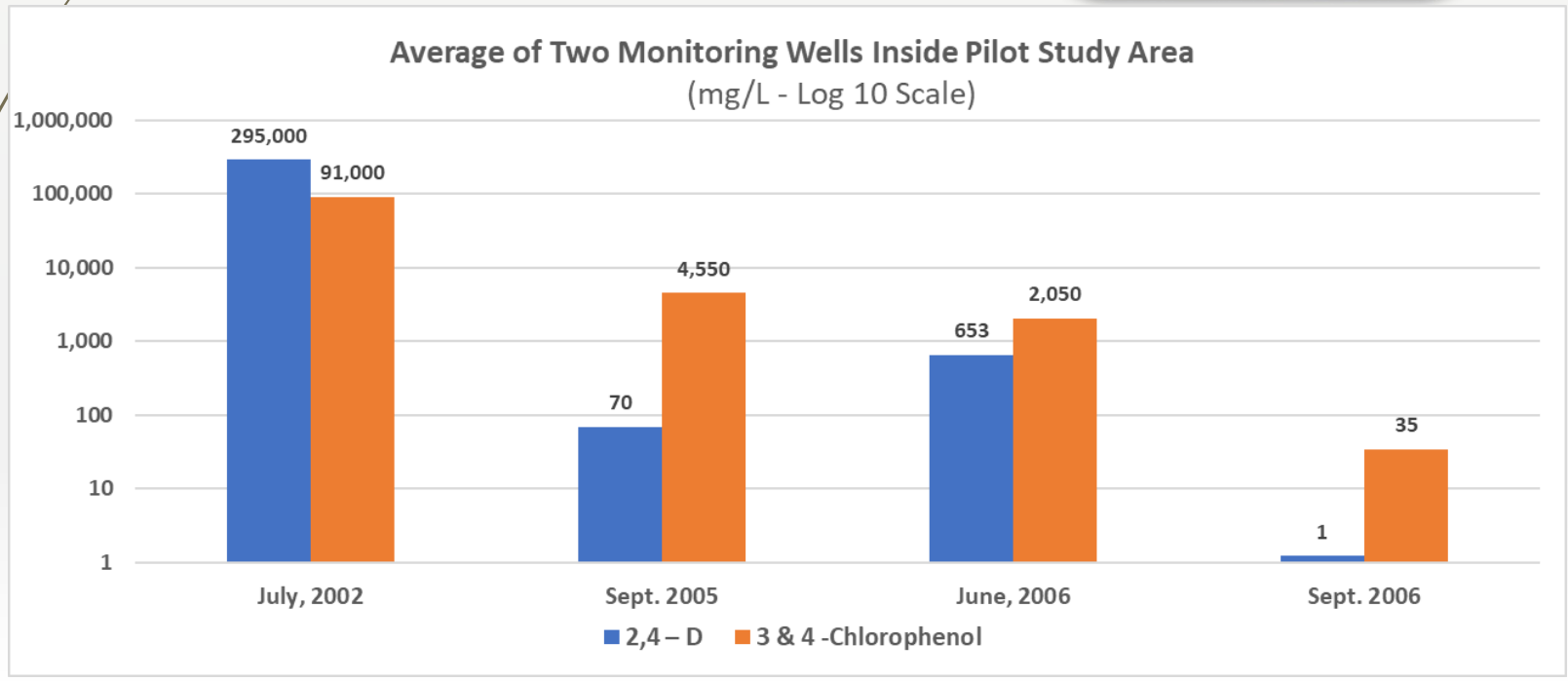
- TCE concentrations drop in the source and boundary areas
- State allowed site closure after 4 years



# Edmonton, AB - 2002

## Cold Region and Highly Contaminated with Herbicide 2,4-D

### 2002 Pilot Study Groundwater Data Results



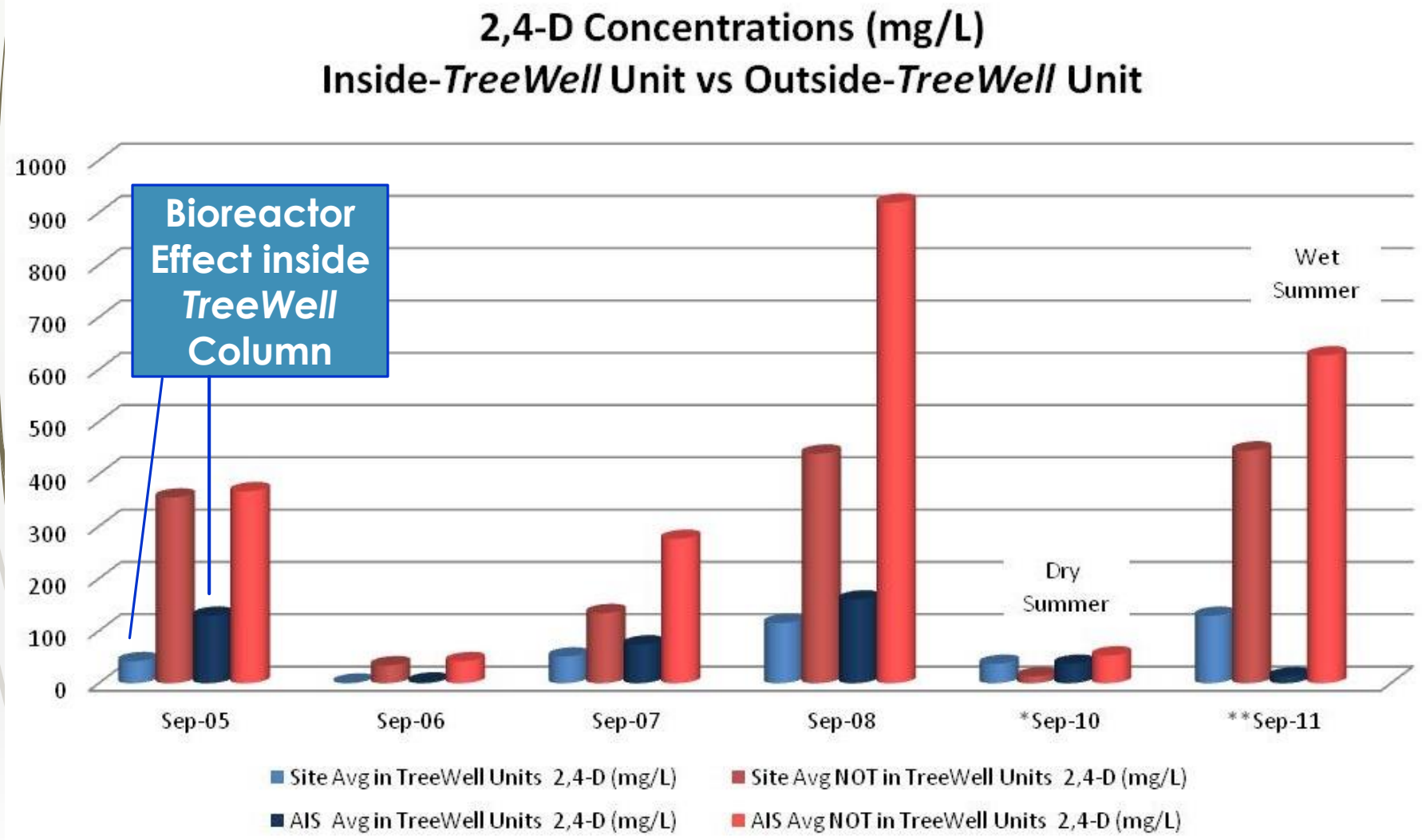
# Edmonton, AB – 2005

## Full Scale Implementation

June 17, 2005
Asphalt was jack hammered

# Edmonton, AB – 2005

## First documentation of bioreactor effect

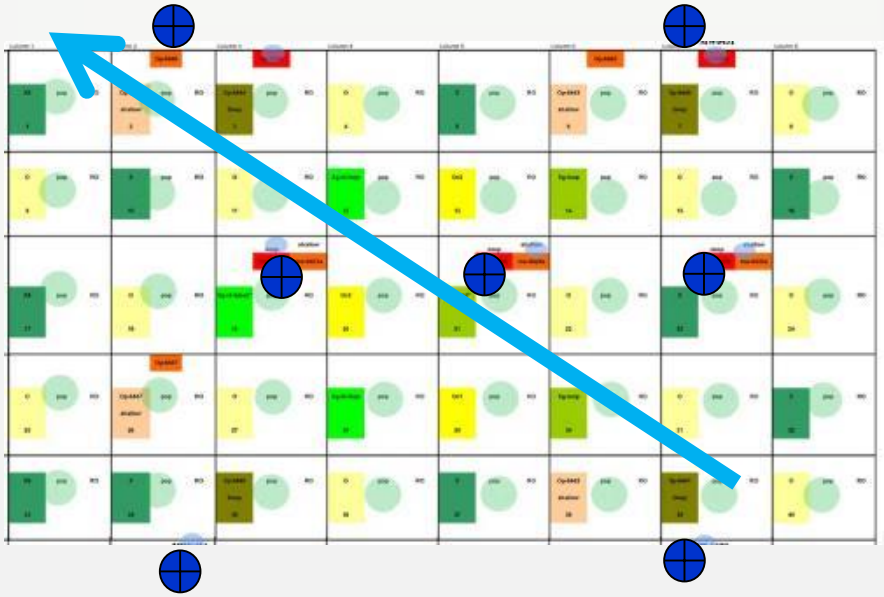


# Central Michigan - 2007
## - Highly Contaminated Groundwater

**Phytotoxic Environment**

- Elevated concentrations of :
  - **Chlorobenzene** (140 mg/L),
  - **Benzene** (900 mg/L)
  - and other VOCs

**Monitoring Wells**

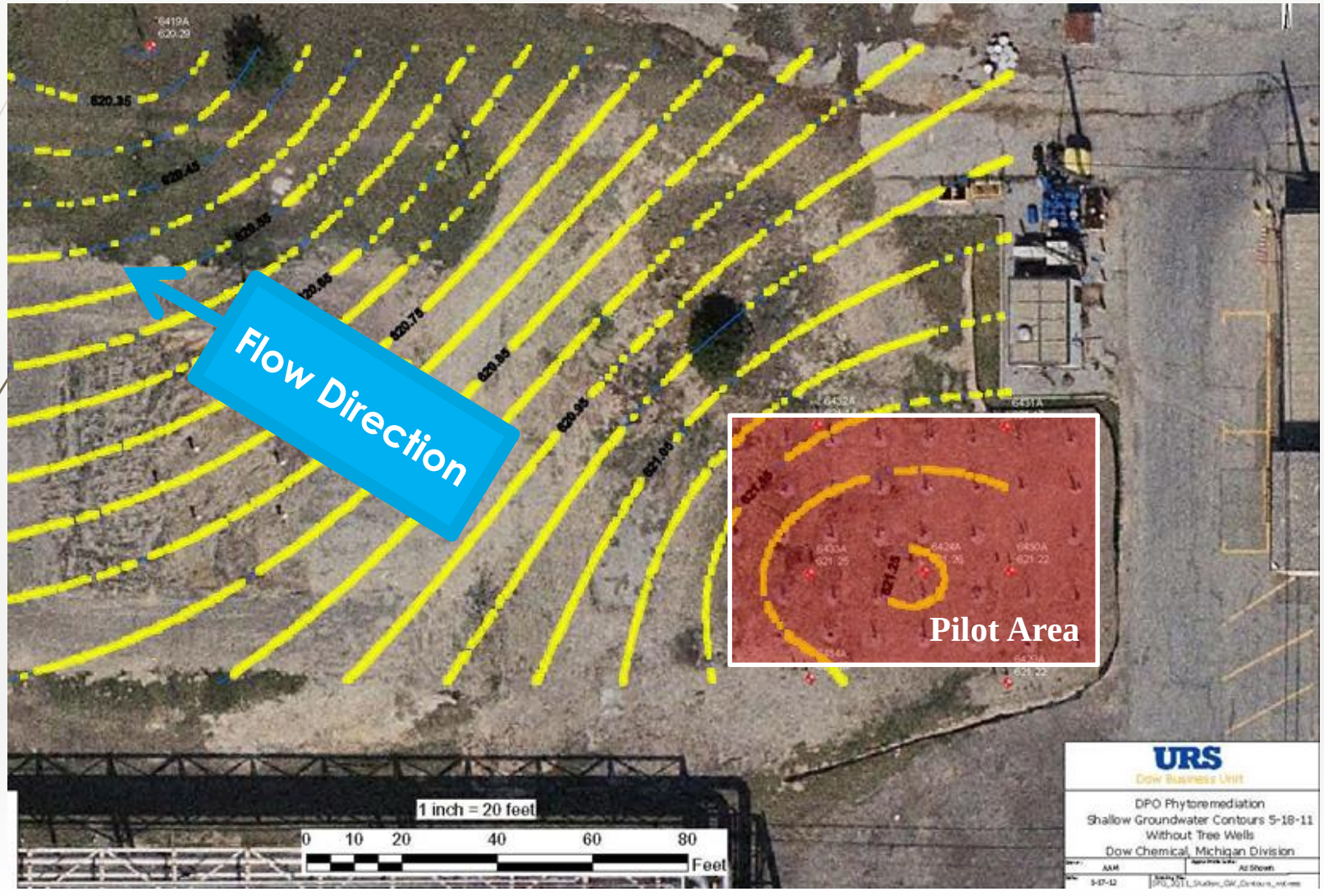


**Groundwater Flow**

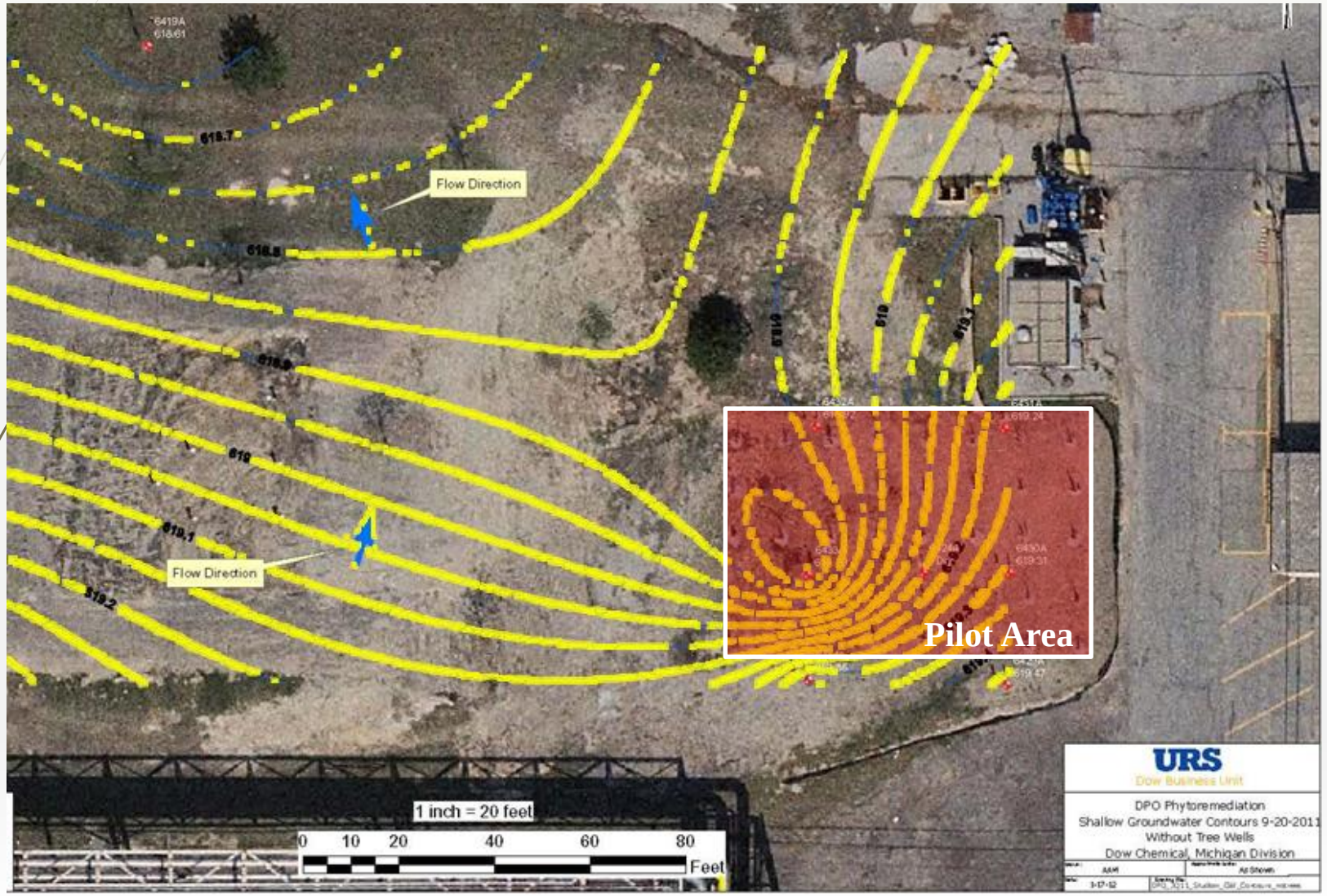
# Central Michigan
## Pilot Results:

### Tree Performance
- Good Healthy Growth
- Limited Phytotoxicity


# Central Michigan Pilot Results:
## Hydraulic Influence – Shallow May, 2011



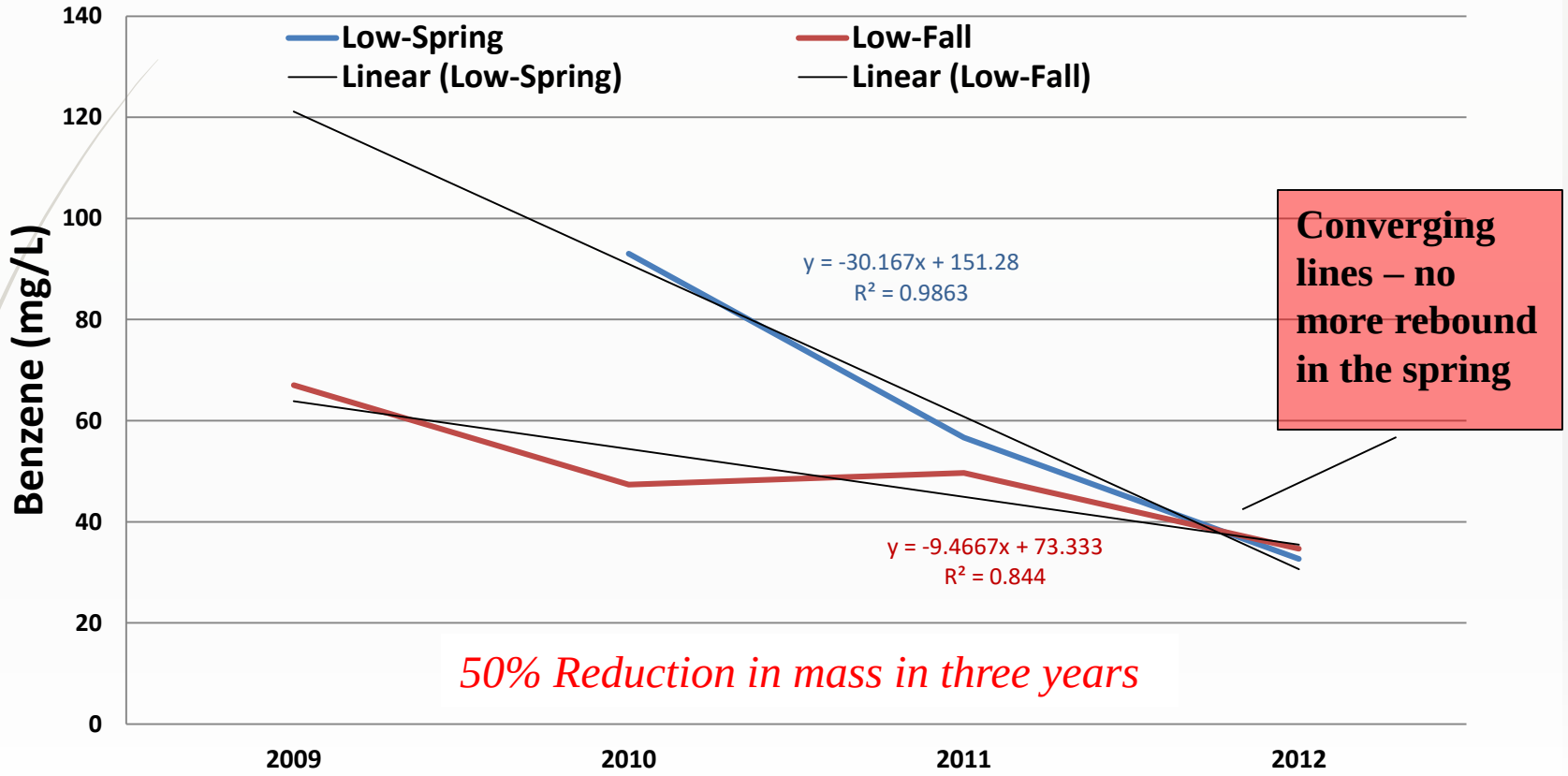
# Central Michigan Pilot Results:
## Hydraulic Influence – Shallow - Sept., 2011



# Central Michigan Pilot Results:
## Benzene Reduction

**Average of:**

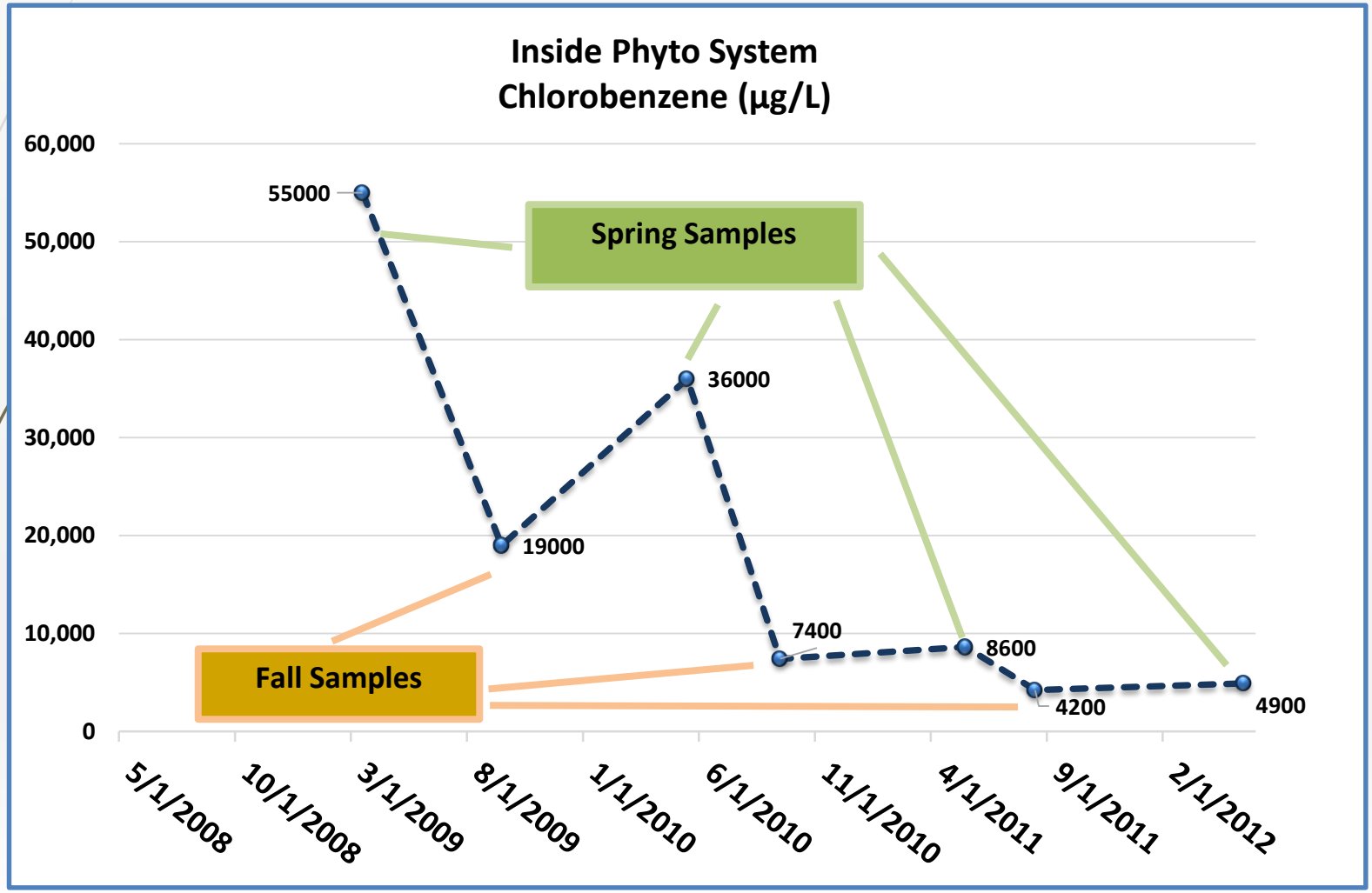
- Low Concentration (downgradient) Wells
- Fall vs Spring – Plotted after 2nd growing season



# Central Michigan Pilot Results:

## Chlorobenzene Reduction – Fall vs Spring

### Monitoring Well – 6430A – *Shallow* Aquifer



# Recent Projects & Results

## - for $CCl_4$, TCE and/or 1,4-Dioxane Contaminated Groundwater

Illinois – Installed, 2015

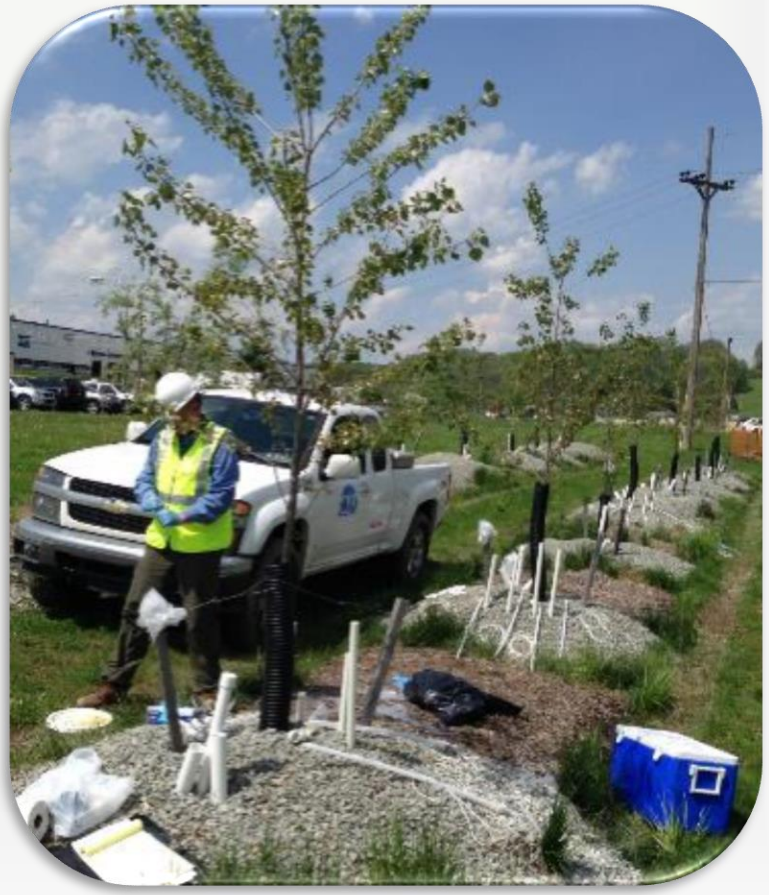
Netherlands – Installed, 2013

Pennsylvania – Installed, 2013

Florida – Installed, 2013

# Site Conditions
## - Source Areas & Groundwater Plumes

- **Near Sarasota Florida –**
  1,4 Dioxane with plume in Fractured Bedrock - Target Horizon (TH): 7-15 ft
- **Netherlands –**
  1,4 Dioxane with plume in Silty Clay (TH:3-8 ft) & Sand (TH:20-30 ft)
- **Western Pennsylvania –**
  TCE/TCA with plume in Soil (TH: 5-15 ft) & Fractured Bedrock (TH: 15-35 ft)
- **Eastern Illinois –**
  $CCl_4$ with plume in Silty Clay (TH:15-25 ft)



# Near Sarasota,Florida

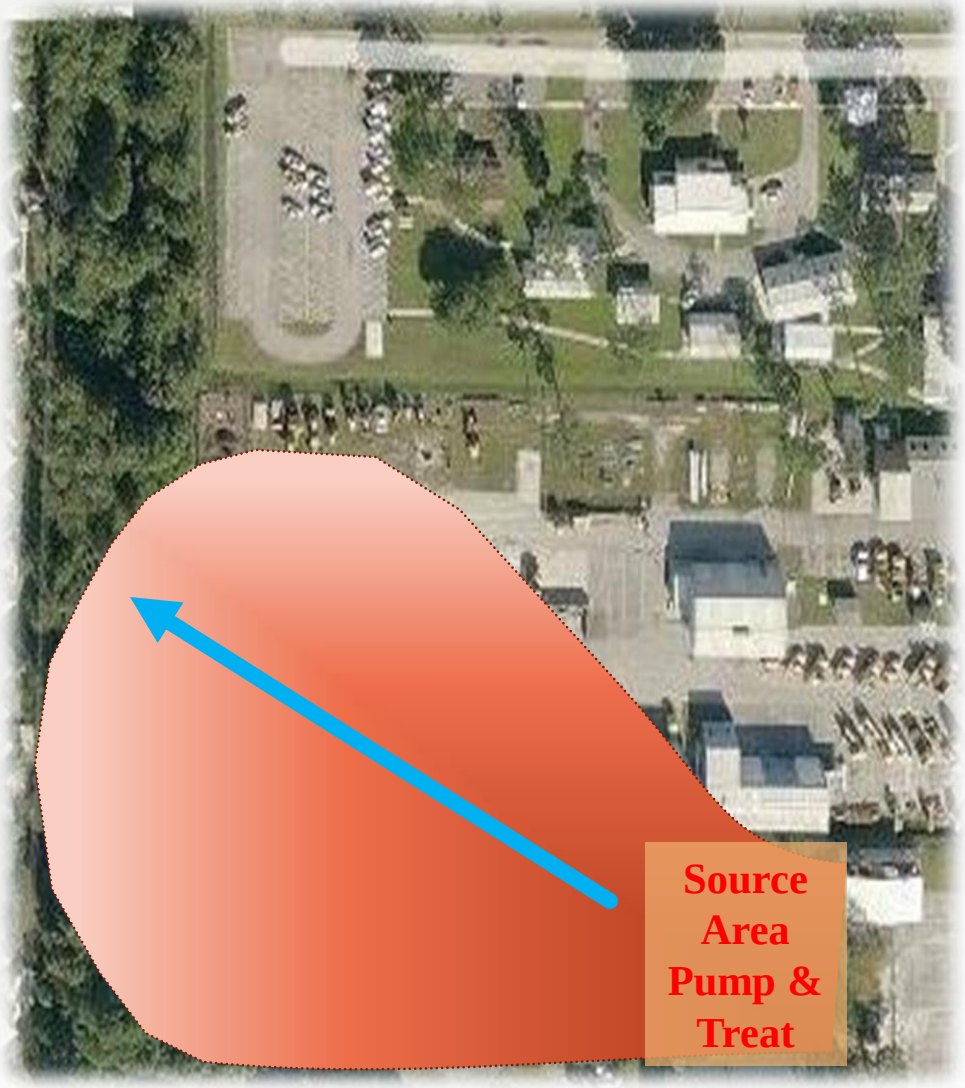
## 2.5 Acre – mature, full vegetative canopy required removal

### Problem:

- Remaining Source
- Pump & Treat not working
- 1,4-Dioxane plume migrating off-site via bedrock aquifer

### Aquifer media:

- Shallow (0-7 feet)
  - Sand (clean)
- Deeper (7-15 feet)
  - Fractured Bedrock (contaminated)



# Near Sarasota, FL
## Initial Groundwater Flow Conditions – March 2013

- 154 Unit *TreeWell* System for Plume Control & Treatment – (Trees: Slash Pine, Willow, Sycamore, Cypress, Laurel Oak)

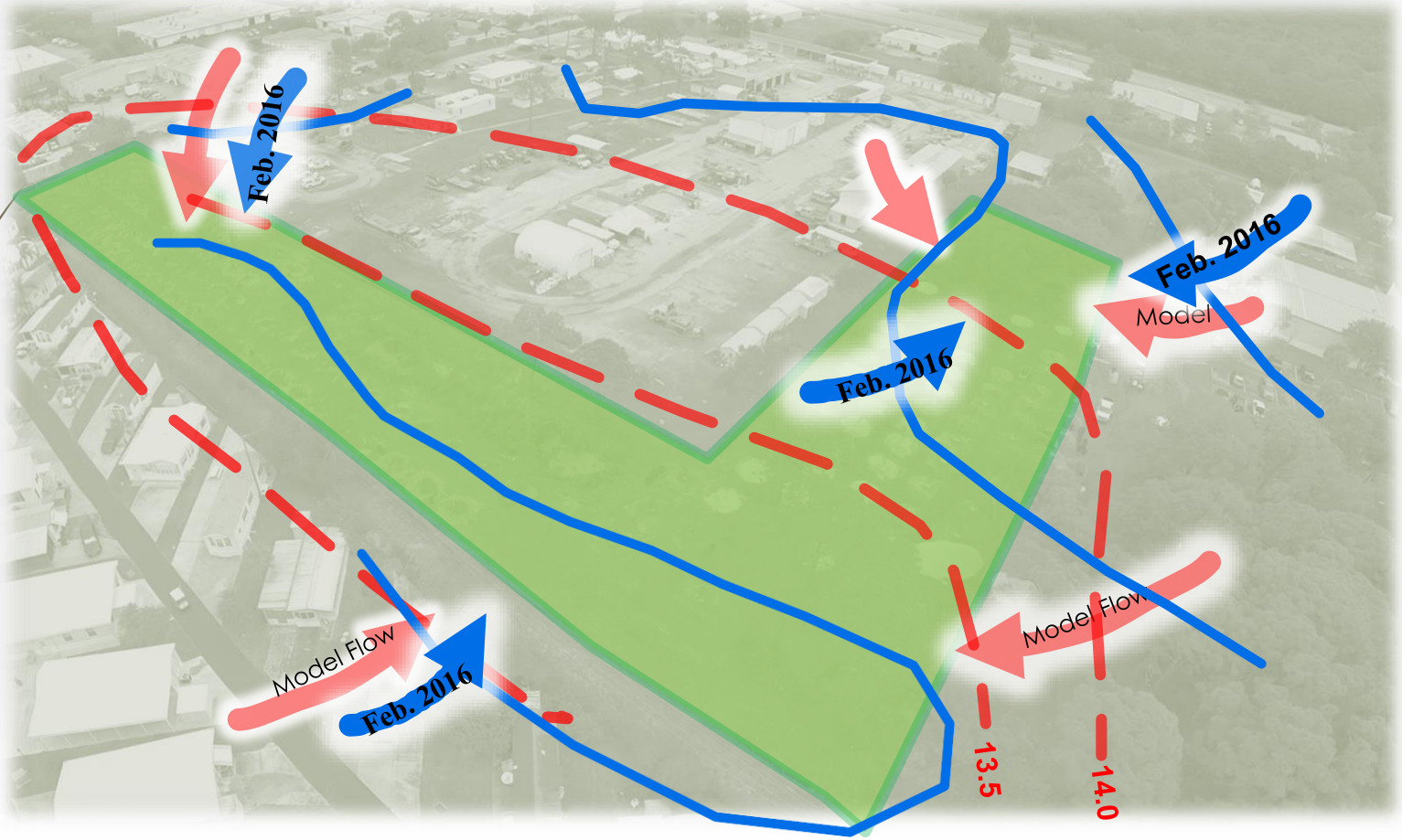
# Near Sarasota, FL
## Groundwater Flow Results

- Model predicted groundwater flow conditions at 20 gpd/tree
- Compared to Actual Conditions in Nov., 2014

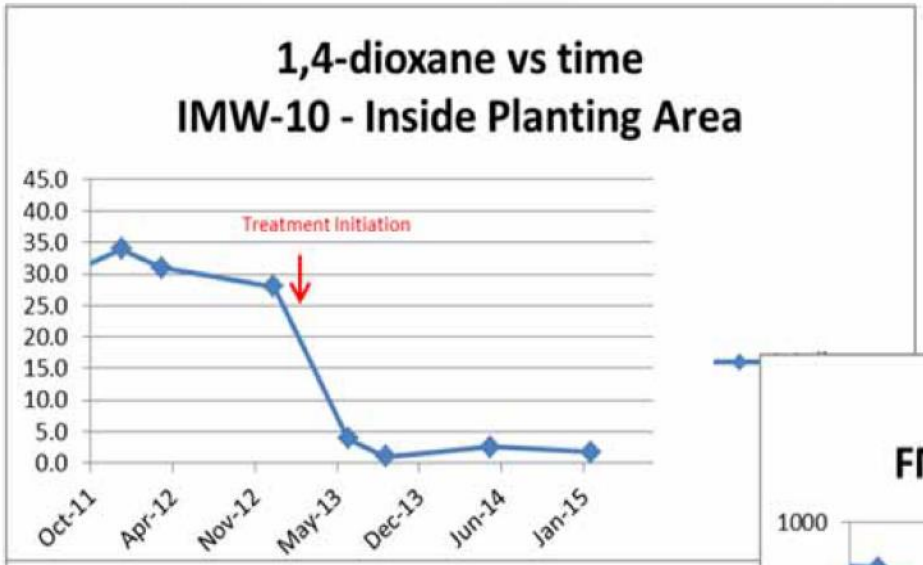
# Near Sarasota, FL
## Groundwater Flow Results

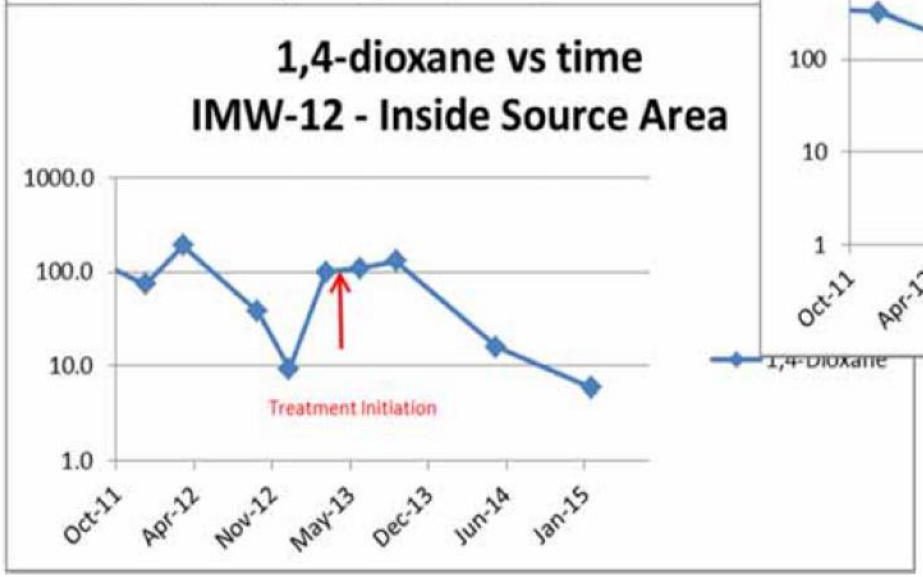
**Hydraulic conditions in February, 2016**

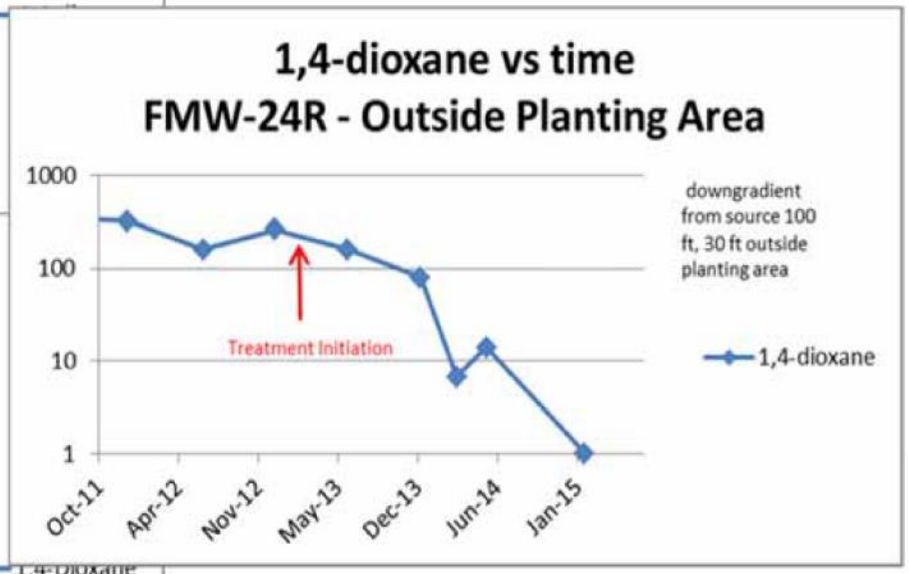
- **Comparison with the model continues to improve despite above-average precipitation during winter of 2015-2016**



# Near Sarasota Florida
## - Remediation Results (1,4-Dioxane µg/L)



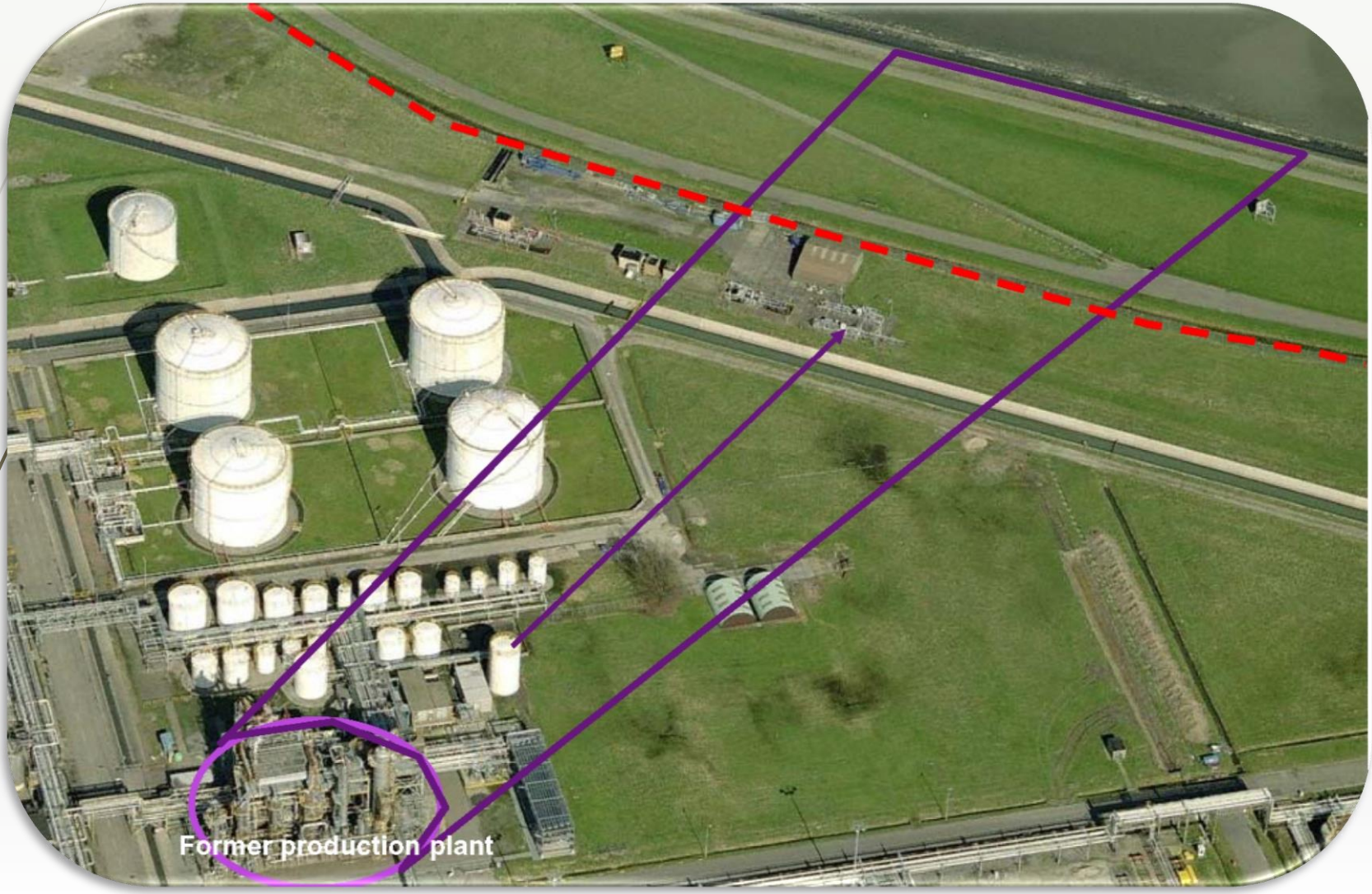
# Near Sarasota Florida
## Primary Benefits

- Shutdown of the Source Area Pump and Treat system ($300k/year savings)
- Demonstrated "Active" remediation and hydraulic control with relatively low O&M costs
- Anticipate reduction of plume and cleanup to target levels within 5-7 years
- NFA in 4 years, December, 2016

# Netherlands

## 1,4-Dioxane Plume

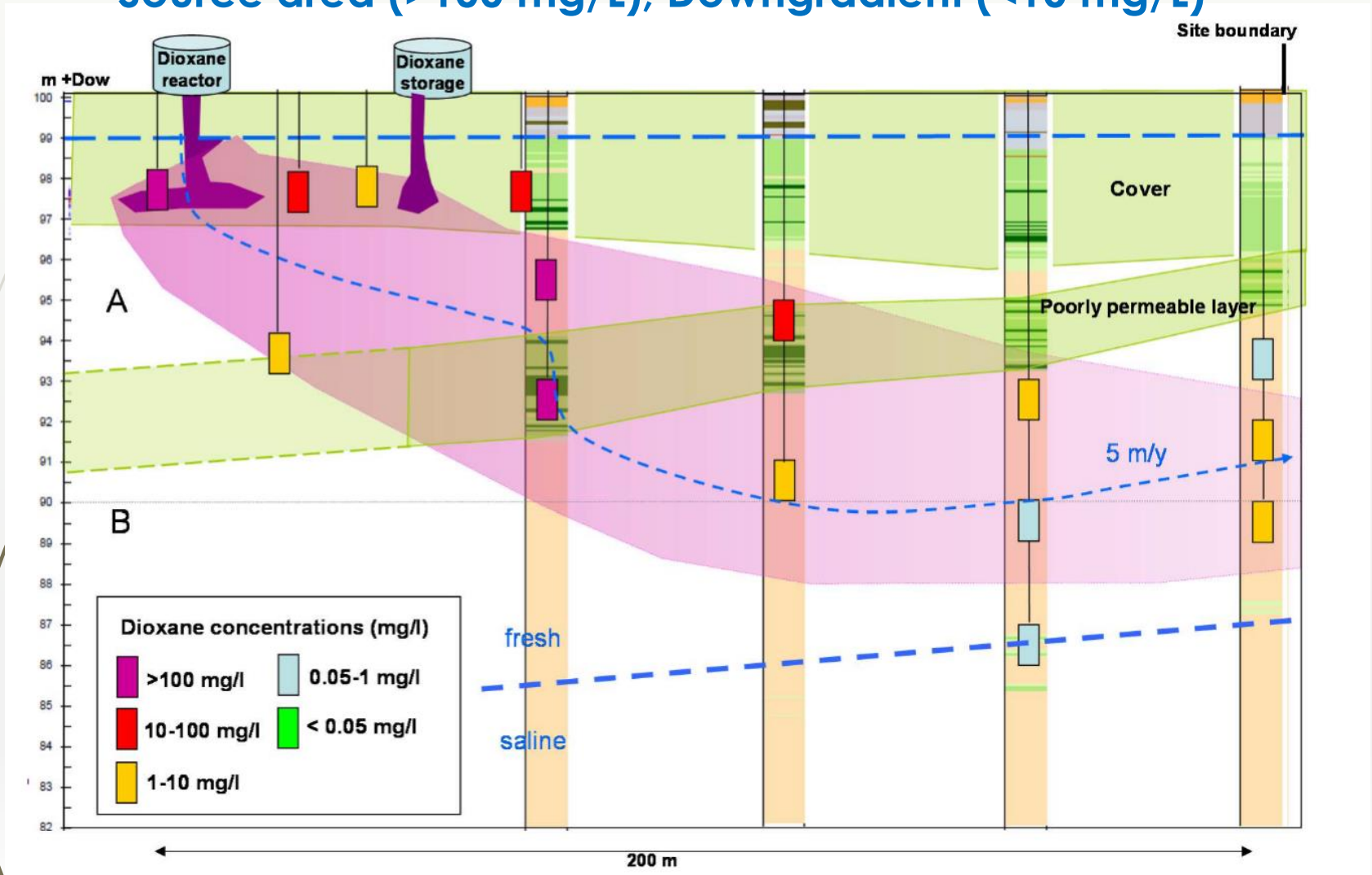
– Source area (>100 mg/L), Downgradient (<10 mg/L)



# Netherlands

## 1,4-Dioxane Plume – 2-12m bgs

### – Source area (>100 mg/L), Downgradient (<10 mg/L)

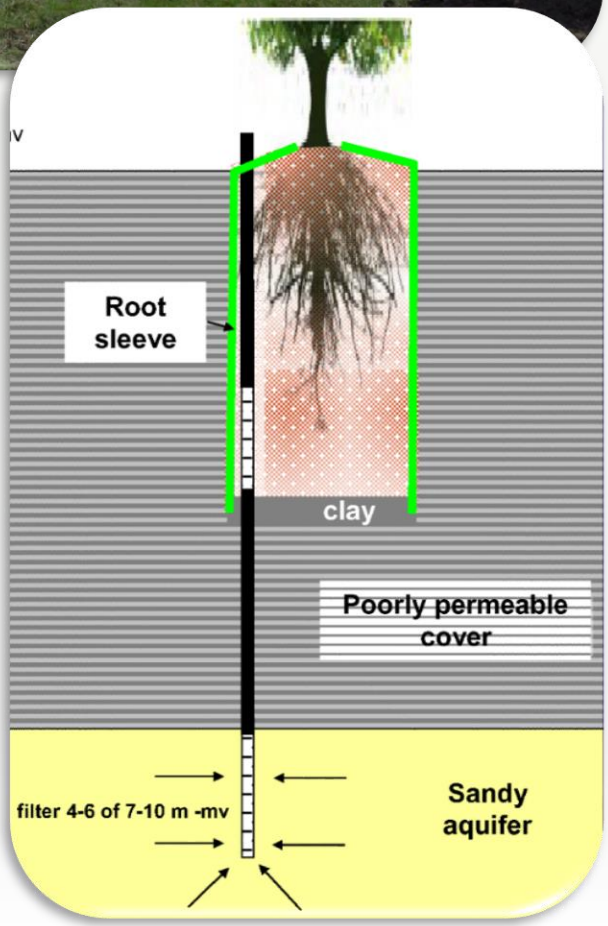


# Netherlands

## Installation – Feb, 2013

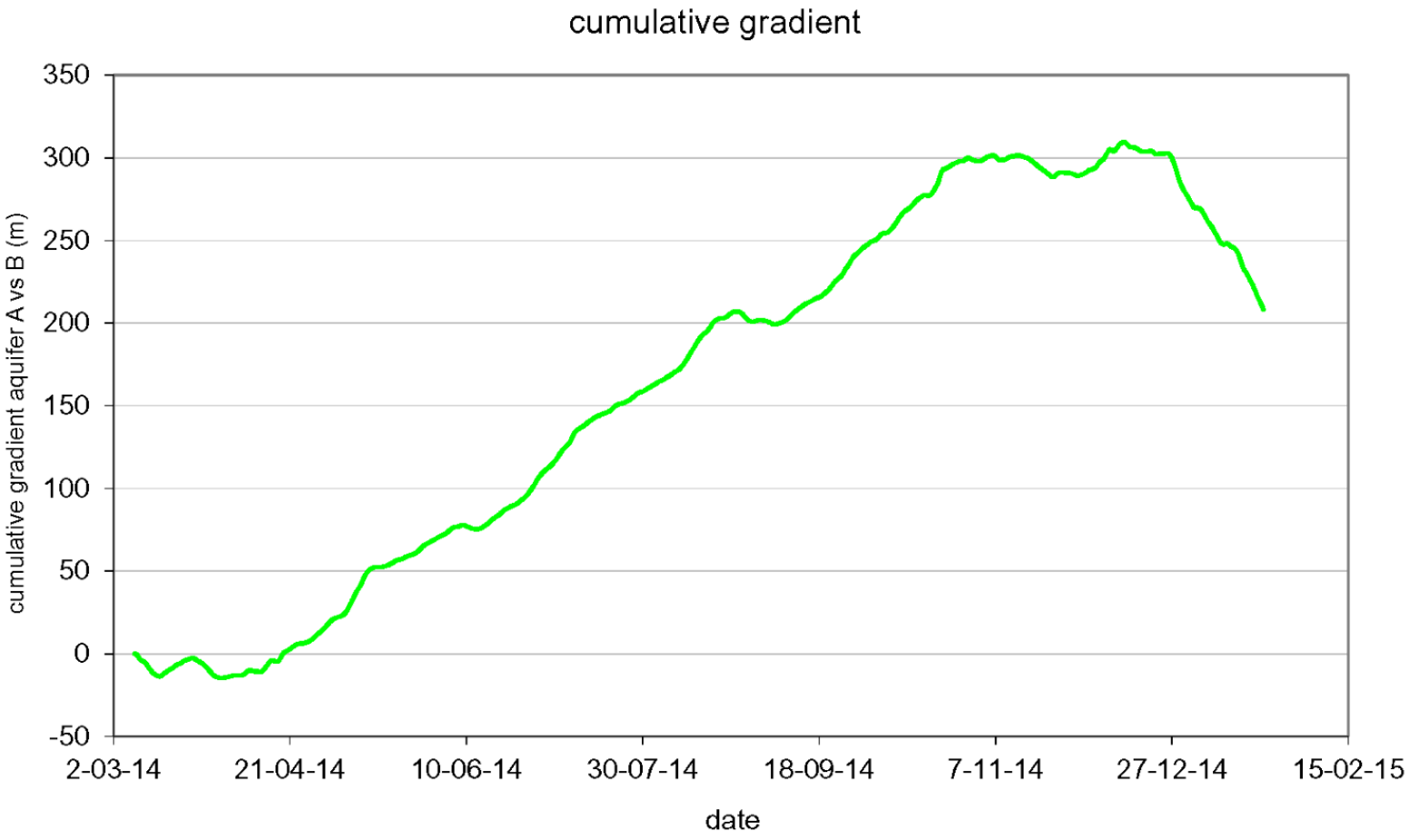
**Shallow *TreeWell* units – plume 3-8 ft bgs**

**Deep (Straw) *TreeWell* units – plume 20-30 ft bgs**



# Netherlands

## Hydrological Situation

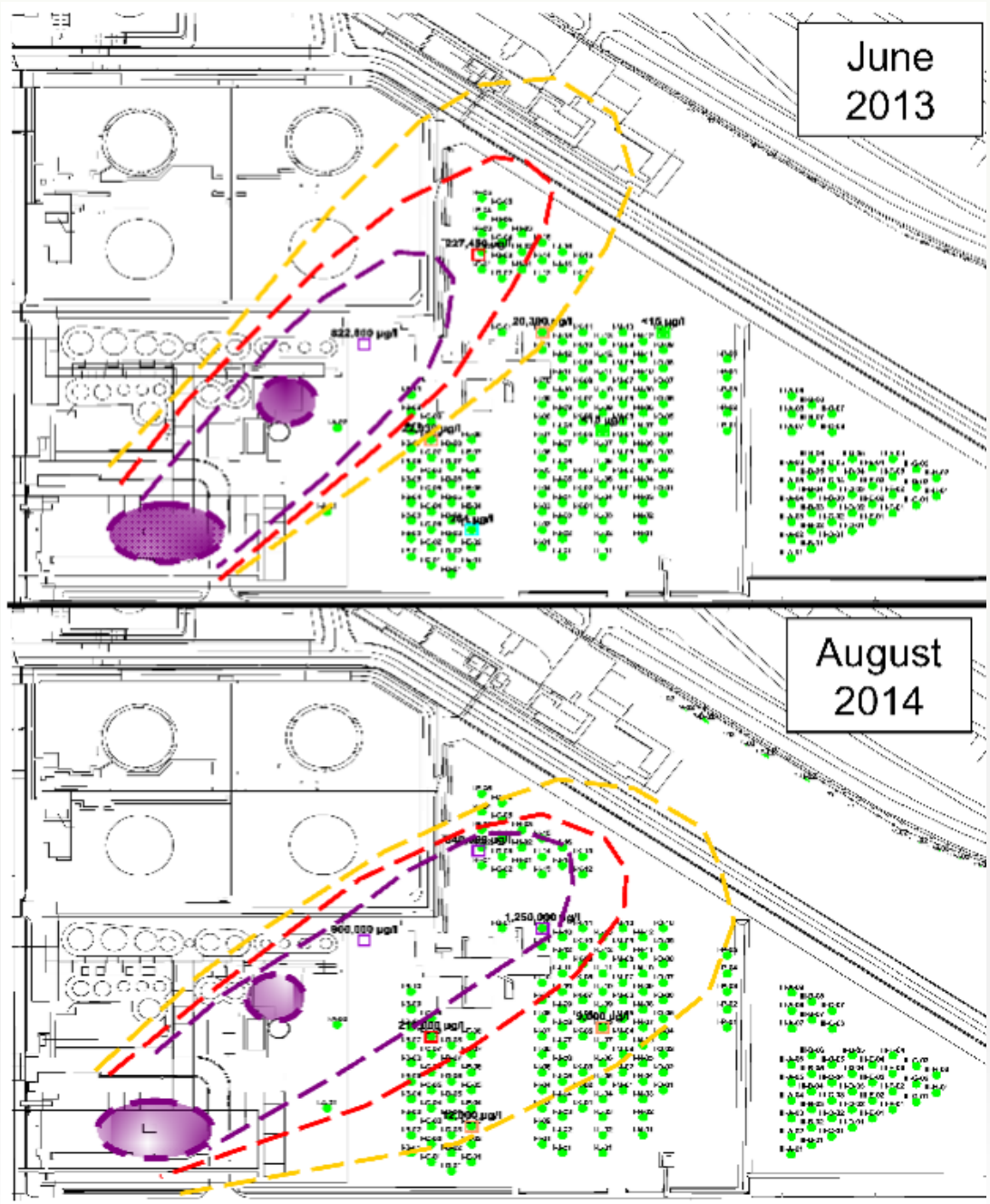



Positive gradient = containment

# Netherlands

## Effect on Plume

Dioxane plume in aquifer A is drawn toward phyto-containment area



# Western Pennsylvania

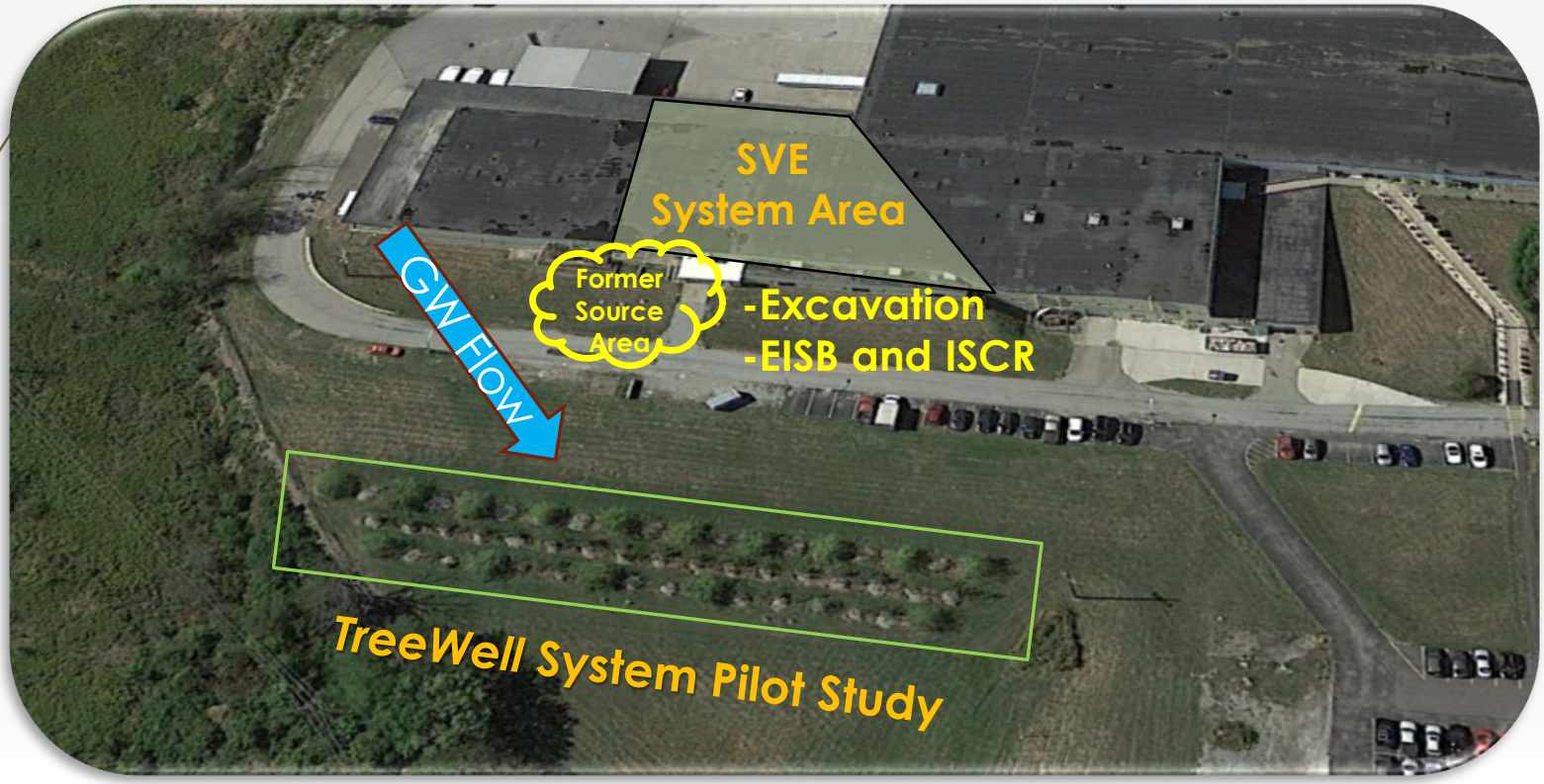
## Combined Technologies Approach

### Source area treatment

- **Excavation** of 1500 tons of highly impacted soil
- **EISB & ISCR**

### *TCE/TCA* in Two Groundwater Formations (5-15 & 15-35 ft)

- ***TreeWell* units** to address both aquifer horizons

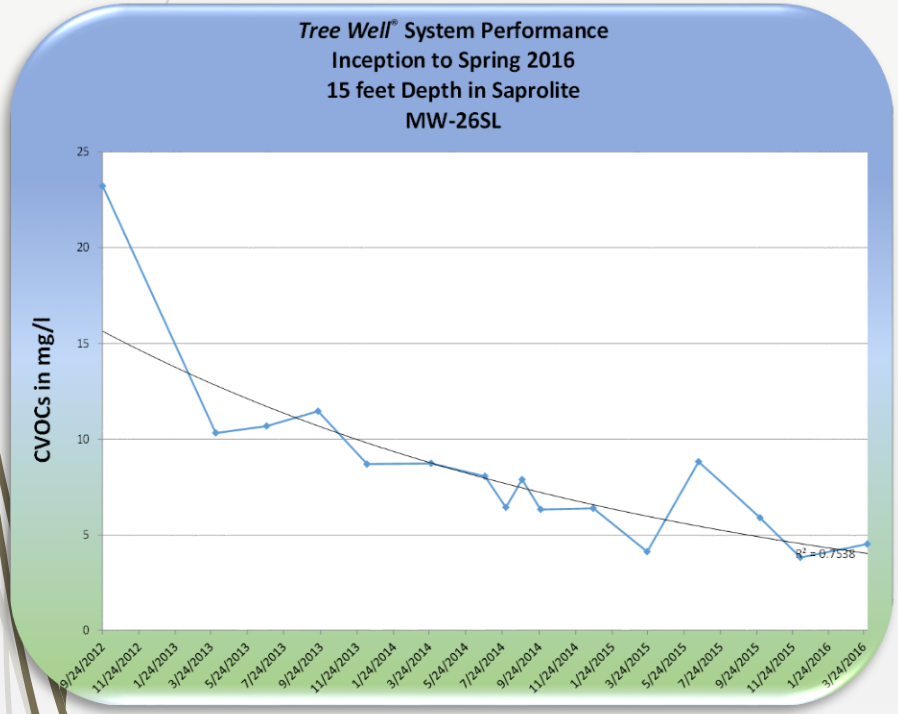


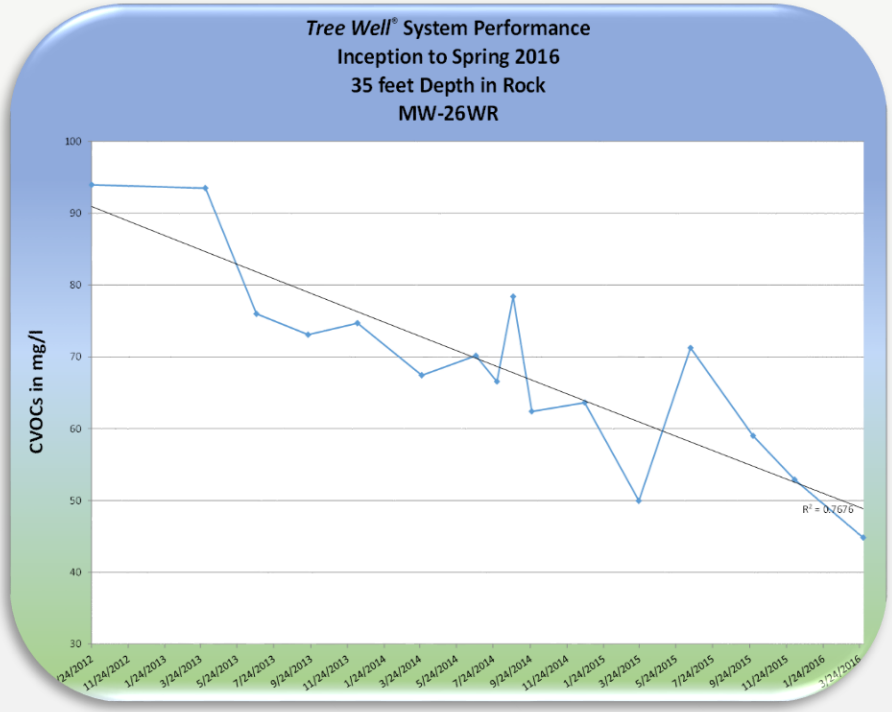
# Western Pennsylvania
## Source Area Total CVOCs - 262 mg/l

Downgradient Wells - From Sept.,2012 to Mar.,2016

Shallow dropped from 25 to 5 mg/L

Deep dropped from 95 to 45 mg/L



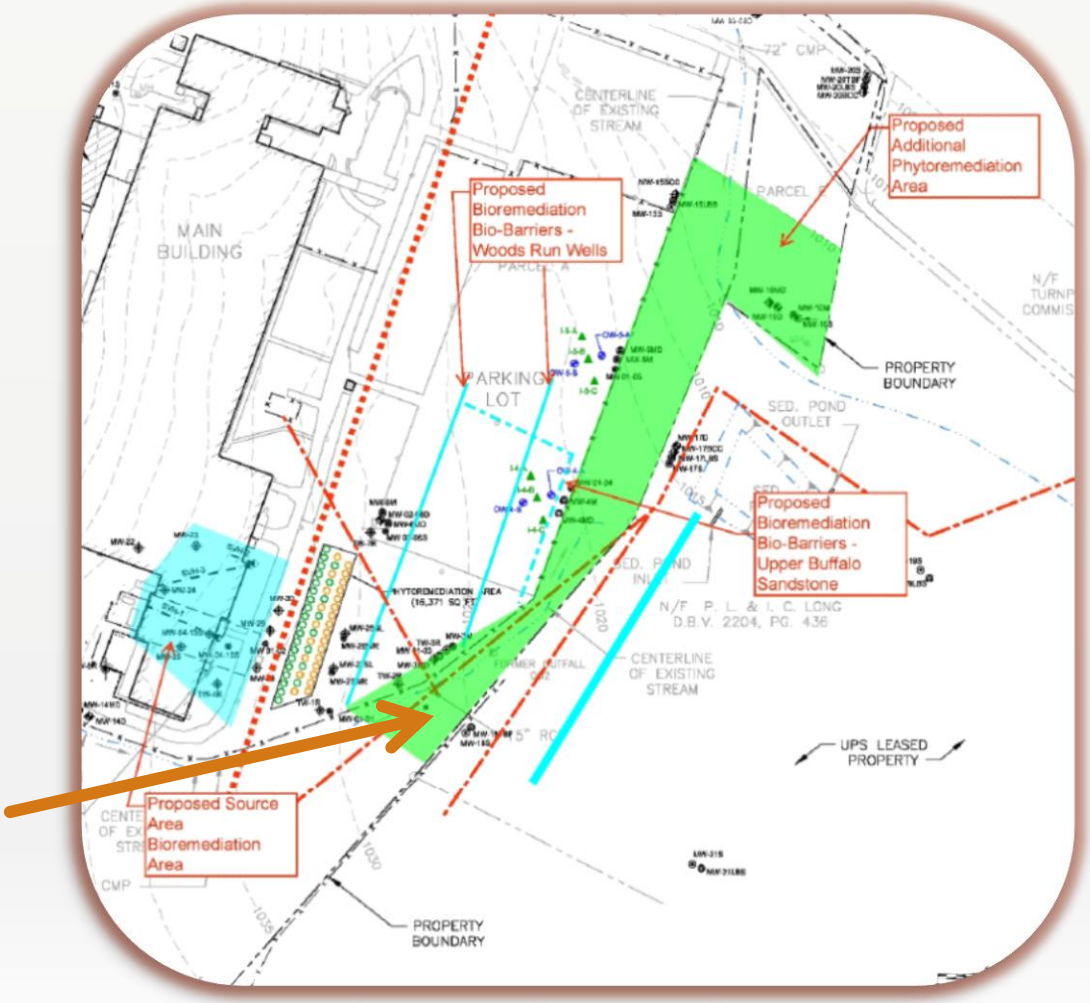



# Western Pennsylvania

## Successful Pilot Study

### > System Enlargement

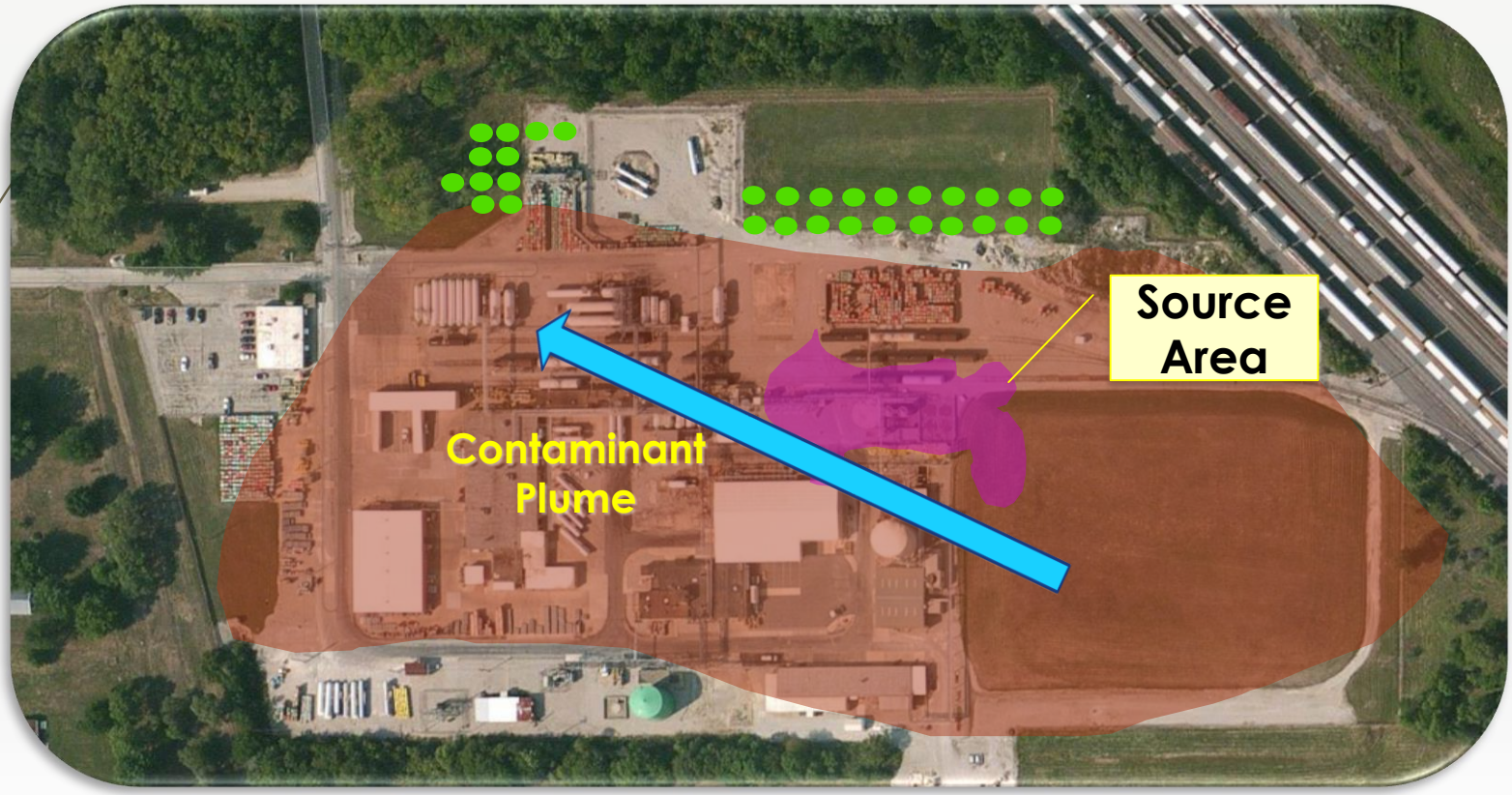
- Additional 166 *TreeWell* units along eastern boundary



# Eastern Illinois – Operating Facility

## $CCL_4$ in Groundwater in Glacial Till Soils

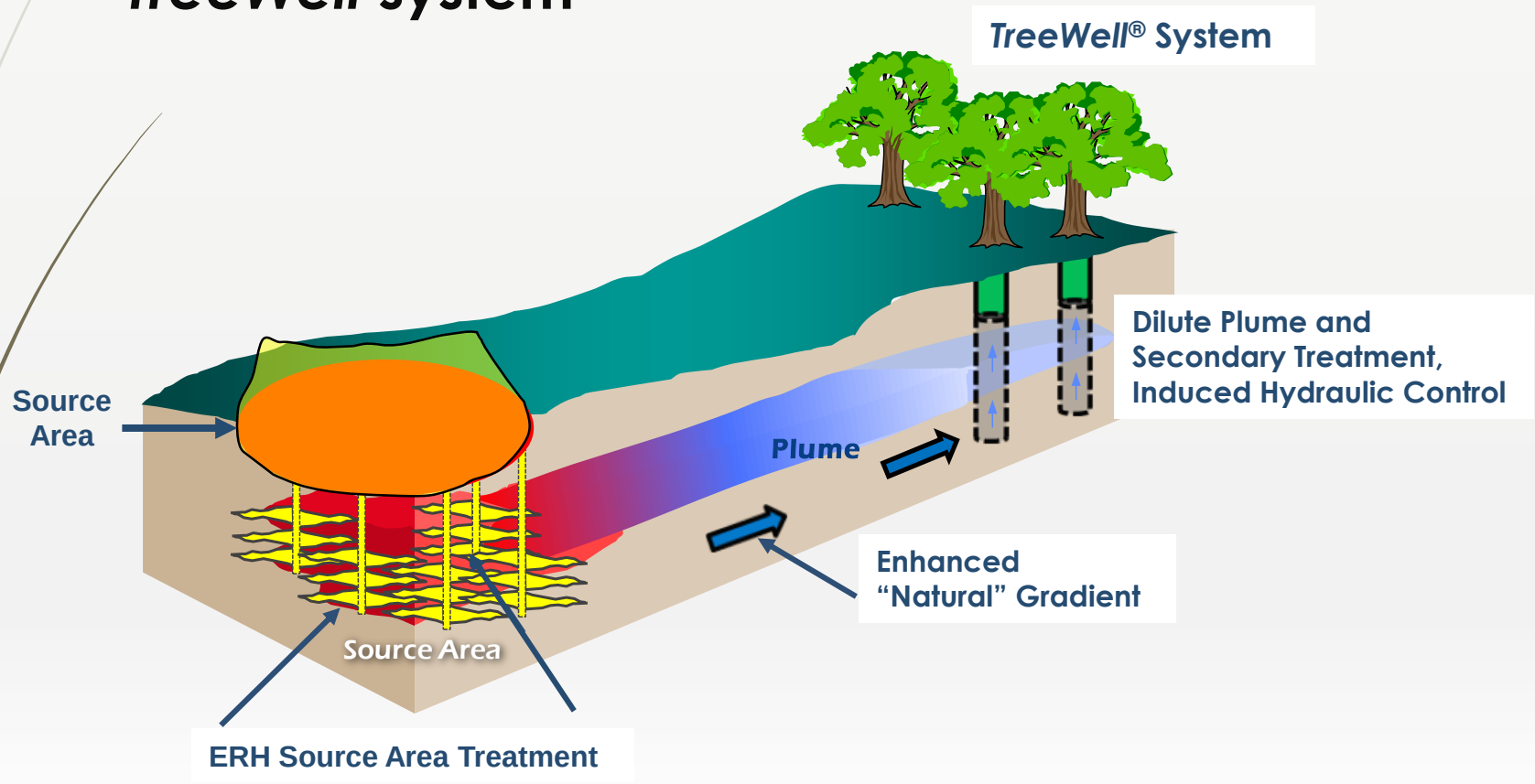
- 15-25 ft (silty clay with thin sand and silt seams)
- *TreeWell* System Pilot Study to control plume migration
- Pilot Study Success - Source Area Recovery Wells Shutdown



# Eastern Illinois

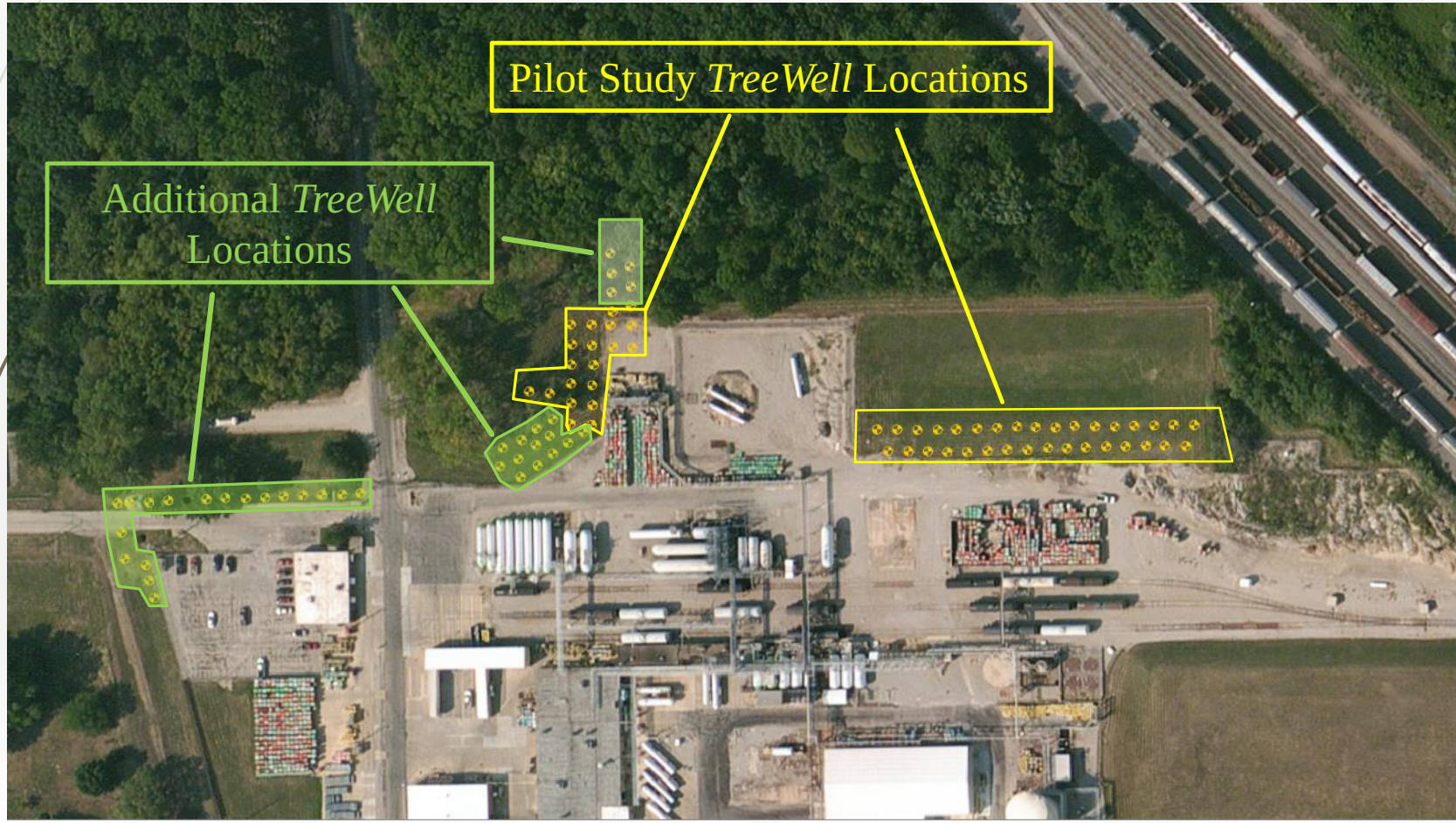
## Combining Technologies

- Source area reduction with Electrical Resistance Heating (ERH)
- Groundwater Plume Control with Expanded *TreeWell* system



# Eastern Illinois
## Plume Control & Groundwater Remediation

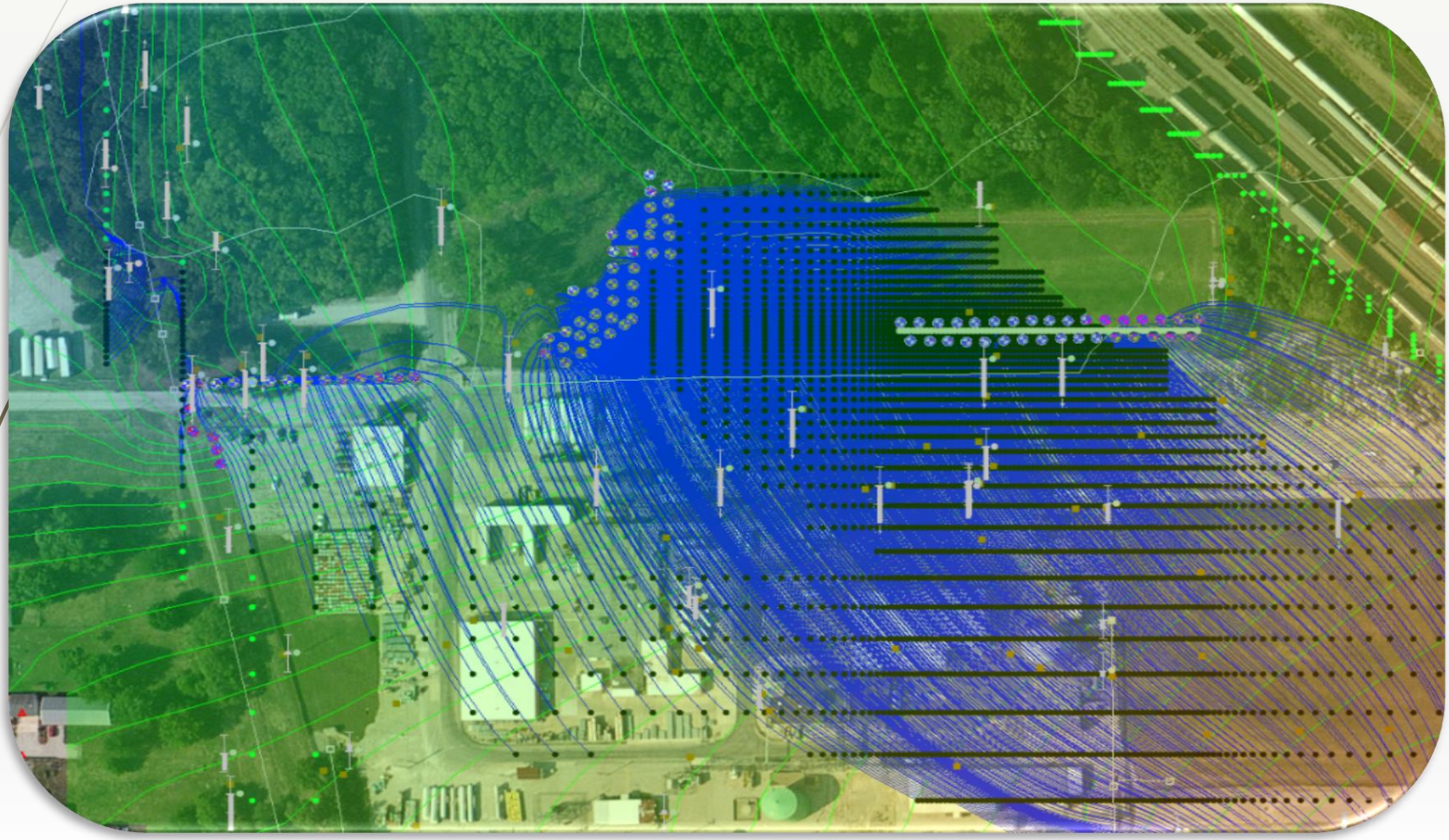
- **Groundwater modeling indicated that 28 additional *TreeWell* units required to insure plume control**



# Eastern Illinois

## Plume Control & Groundwater Remediation

- Model at 20 GPD/tree



# Western North Carolina

## 1,4-Dioxane in Saprolite and Fractured Bedrock
## Combining Technologies

**INITIAL REMEDY – Source Area**

**Air Sparge SVE System (1995-2005)**

**Extensive ART® well system**

- **In-Well UV/Ozone (since 2006)**

**CURRENTLY – Remaining Source/Plume**

**Remaining Hotspot Remediation**

- **Small Pumping System (<1gpm) to POTW**

**Plume Control – Model Design**

- ***TreeWell* unit barrier along creek boundary to meet Regulatory Guidelines**


**Contaminant flow at top of fractured bedrock (10-25' bgs at creek)**

# Western North Carolina
## Current Status

- 2015 was the establishment season for the *TreeWell* system (Trees: Sycamore and Willow)
- On the basis of the rebound study, and strength of the model, operation of the ART well system has been abandoned
- Remaining Hotspot treated by pumping less than 1 gpm to POTW

Willow

Sycamore

June, 2017

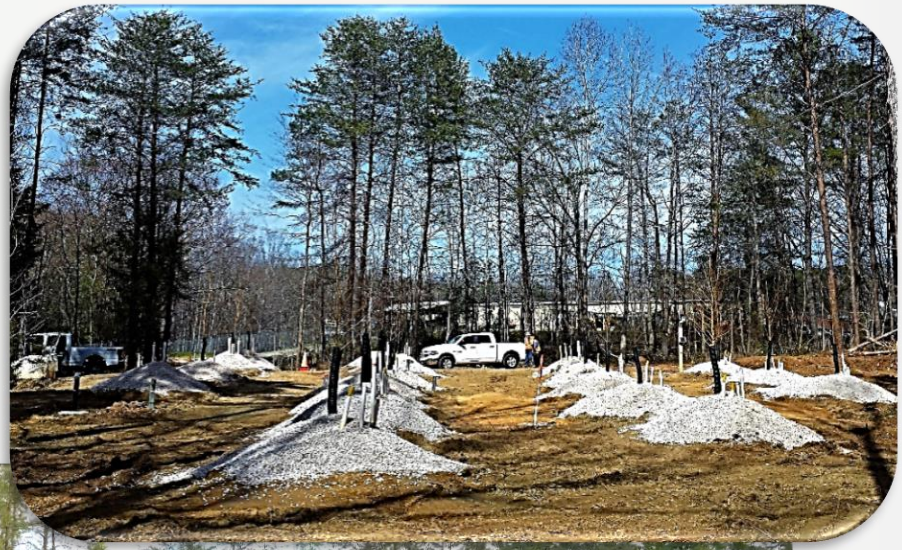
# Northwestern SC

## Chlorobenzene Plume (<1-46 mg/L)

### in Saprolite and Partially Weathered Rock – GW 25-40' bgs

February 2017

March 2017



June 2017

# *Phyto-Integrated* Remediation Systems - General Benefits

- Lower installation costs vs many other engineered systems
- Lower maintenance costs vs other engineered systems and traditional phyto
- Effectiveness improves with time
- Aesthetically pleasing
- Adaptable to a large range of settings, contaminants and contaminant levels

# *Phyto-Integrated* Remediation Systems
## Site locations – 1988 to 2016