

Function and Performance of *PHYTO-INTEGRATED*TM Remediation Systems on Deep Groundwater and/or Targeted Horizons – Hydraulics and Treatment

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What is *PHYTO-INTEGRATED*TM Remediation

**Traditional
phytoremediation
effectiveness is limited
by natural conditions**

- **GW too deep**
- **Contaminants too high - toxic**
- **Incompatible soil conditions**
- **Etc....**



What is *PHYTO-INTEGRATED*TM Remediation

Phytoremediation + Traditional Technologies

*PHYTO-INTEGRATED*TM
Remediation
employs vegetation
as a component of a
designed and
constructed system
that:

- controls plant growth,
- manages site conditions and
- targets the zone of remedial effect

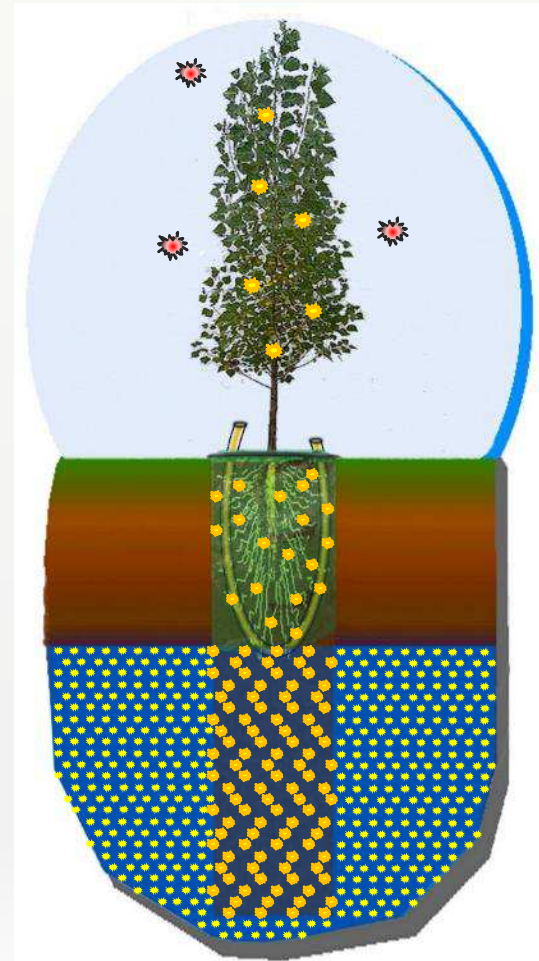


TreeWell System

– Patented *PHYTO-INTEGRATED* Pump & Treat System

Tree is the Pump & the *TreeWell* unit is the 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
- A few remaining molecules may pass through the plant and may be emitted into the **atmosphere** in the transpiration stream
-and then **Photo-oxidized**



Sites and Conditions

- Source Areas & Groundwater Plumes

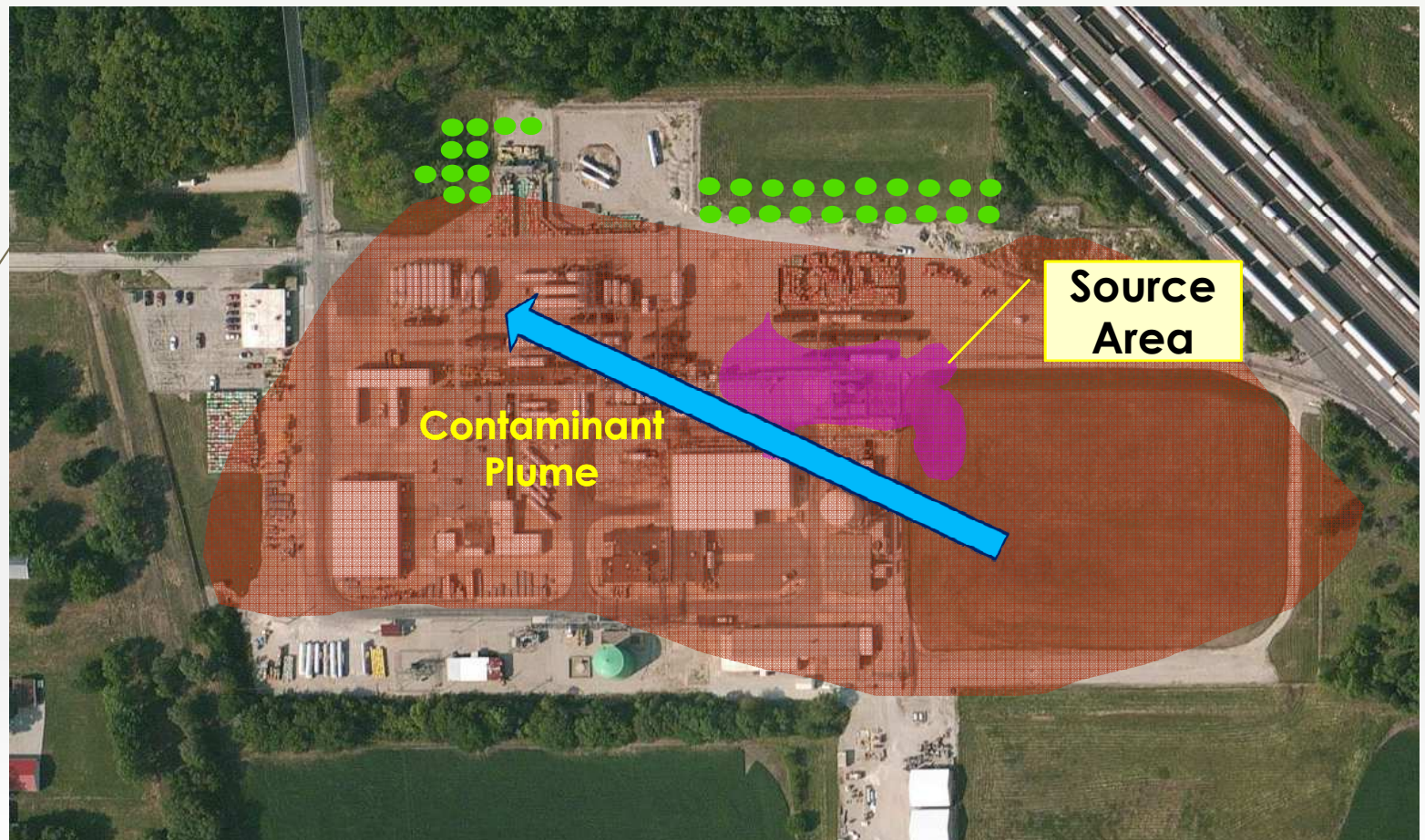
- **Eastern Illinois** –
 CCl_4 with plume in Silty Clay
(Target Horizon (TH): 15-25 ft)
- **Western Pennsylvania** –
TCE/TCA with plume in Soil
(TH: 5-15 ft) & Fractured Bedrock
(TH: 15-35 ft)
- **Near Sarasota Florida** –
1,4 Dioxane with plume in
Fractured Bedrock - TH: 7-15 ft



Eastern Illinois – Operating Facility

CCl_4 in Groundwater in Glacial Till Soils

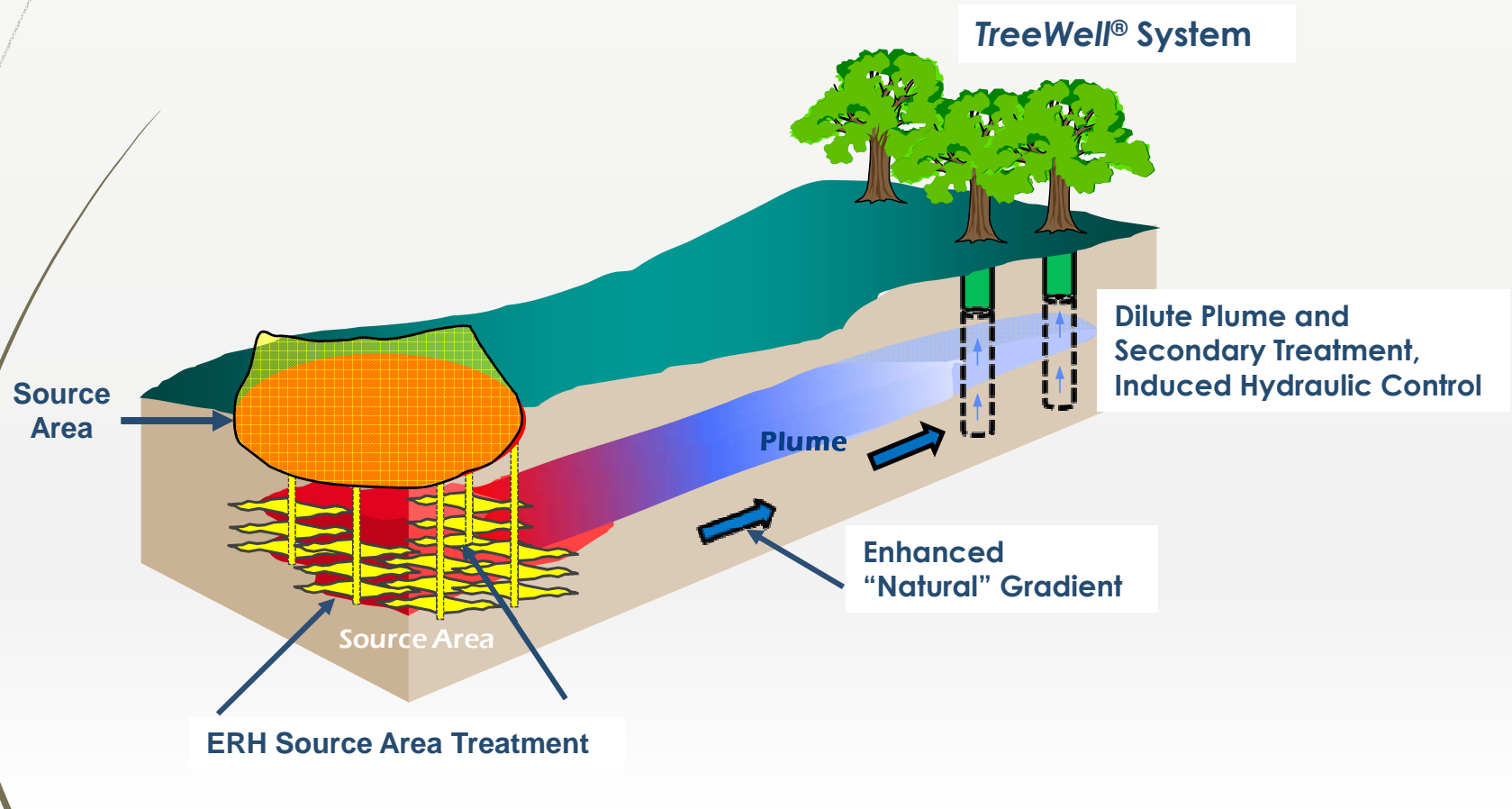
- 15-25 ft (silty clay with thin sand and silt seams)
- *TreeWell* System Pilot Study to control plume migration (Trees: Willows & Poplars)



Eastern Illinois

Combining Technologies

- Source area reduction with ERH
- Groundwater Plume Control with Expanded TreeWell system



Eastern Illinois

Plume Control & Groundwater Remediation

- Groundwater modeling indicated that 28 additional *TreeWell* units would insure plume control – completed Fall, 2016



Eastern Illinois

Plume Control & Groundwater Remediation

- Model at 20 GPD/tree
- Source Area Recovery Wells Shutdown



Western Pennsylvania

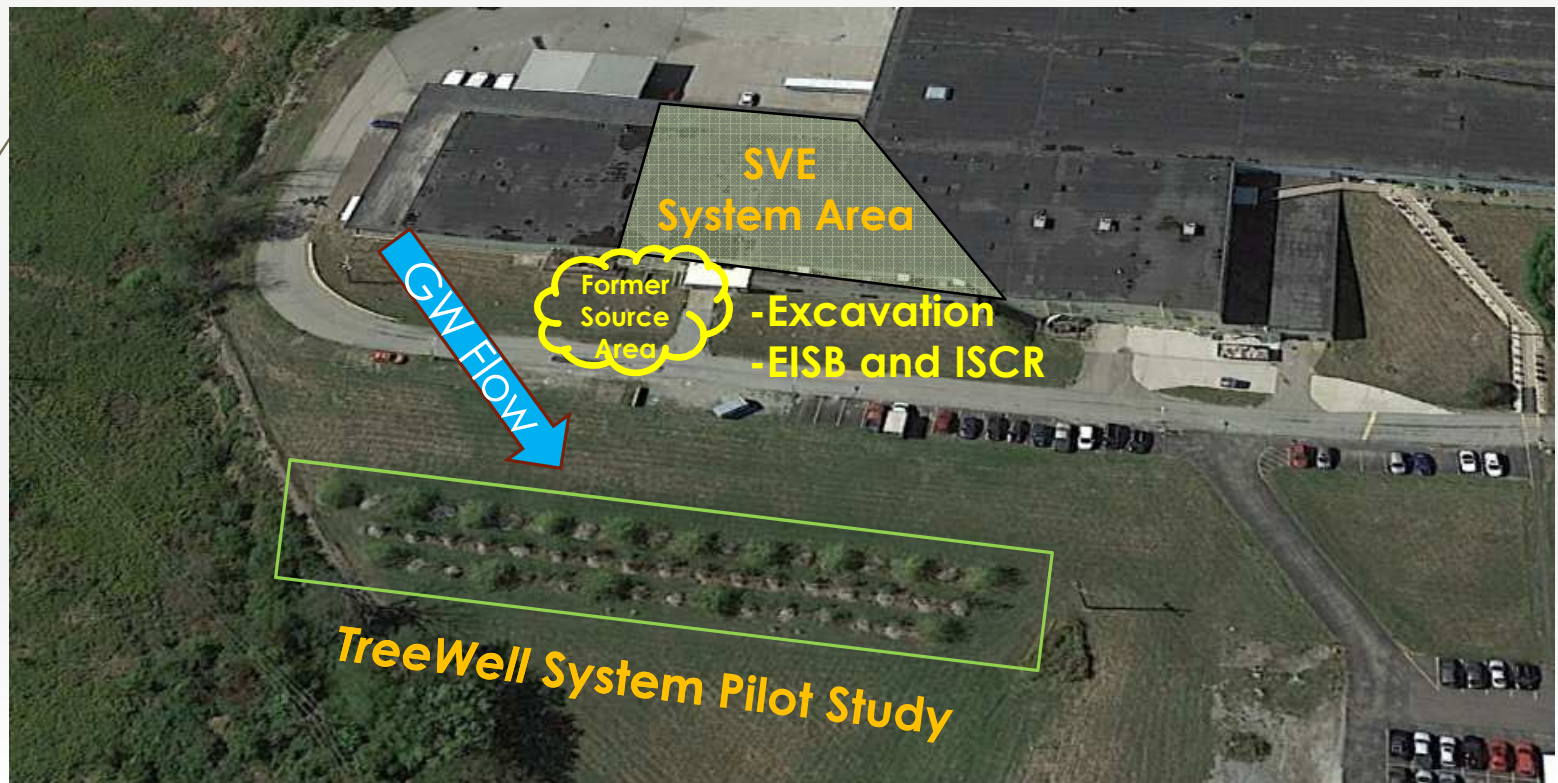
Combined Technologies Approach

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 System** to address both aquifer horizons



Western Pennsylvania TreeWell System Pilot Study

Three rows of *TreeWell* units to address two groundwater horizons

- Shallow Soil (5-15 ft)
- Deep Fractured Bedrock (15-35 ft)

Tree Species - willows & poplars



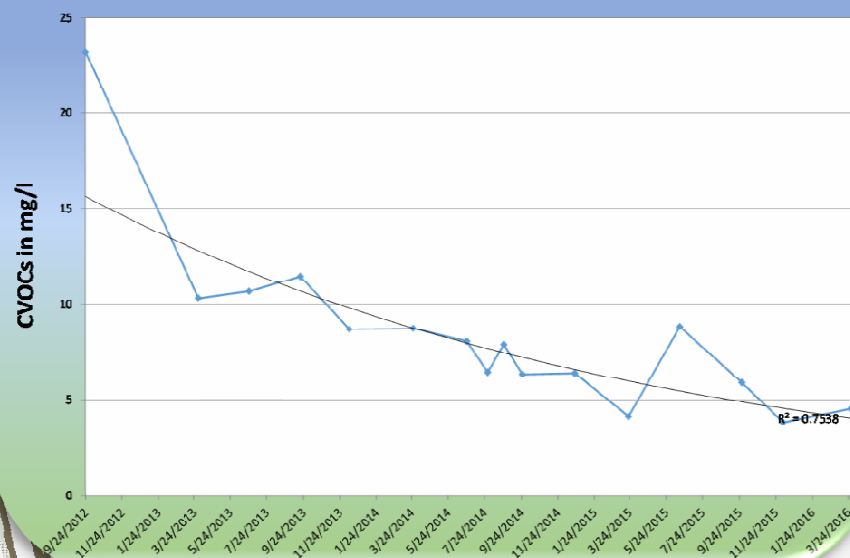
Western Pennsylvania

Source Area Total CVOCs - 262 mg/l

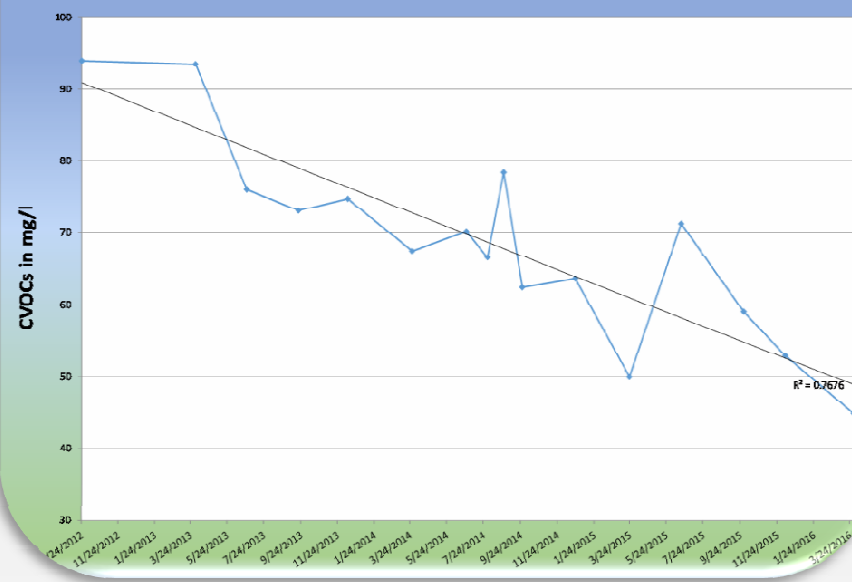
Downgradient Wells - From Sept.,2012 to Mar.,2016

Shallow dropped from 25 to 5 mg/L Deep dropped from 95 to 45 mg/L

Tree Well® System Performance
Inception to Spring 2016
15 feet Depth in Saprolite
MW-26SL

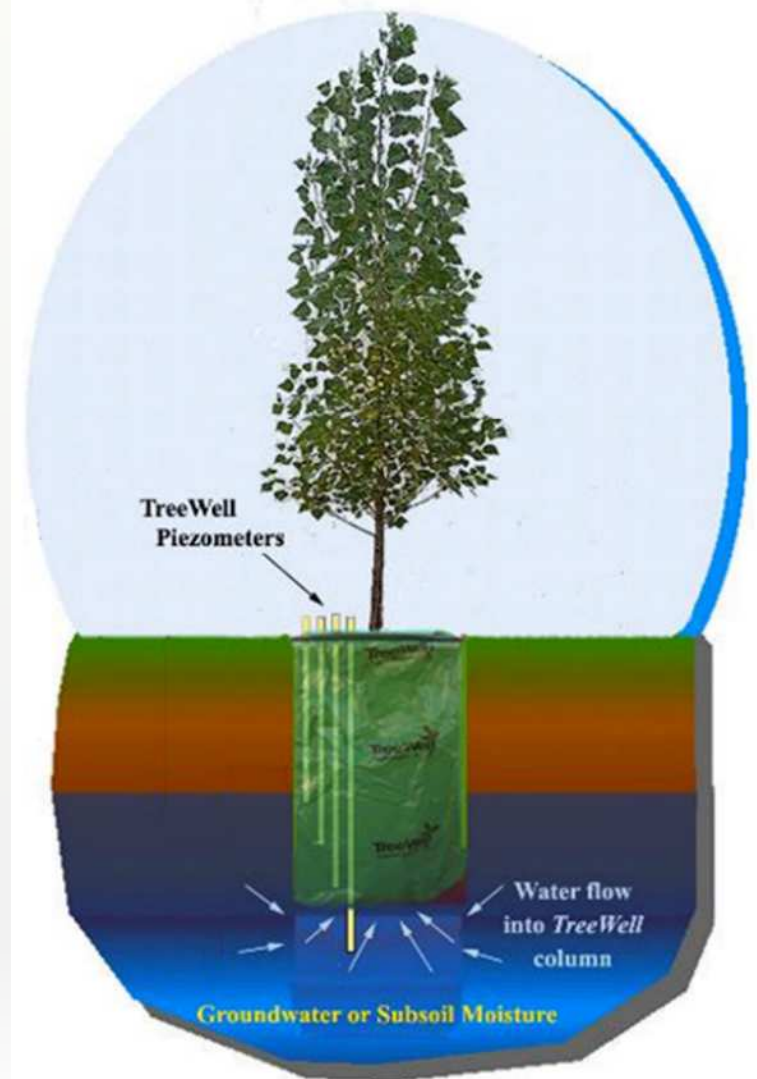


Tree Well® System Performance
Inception to Spring 2016
35 feet Depth in Rock
MW-26WR

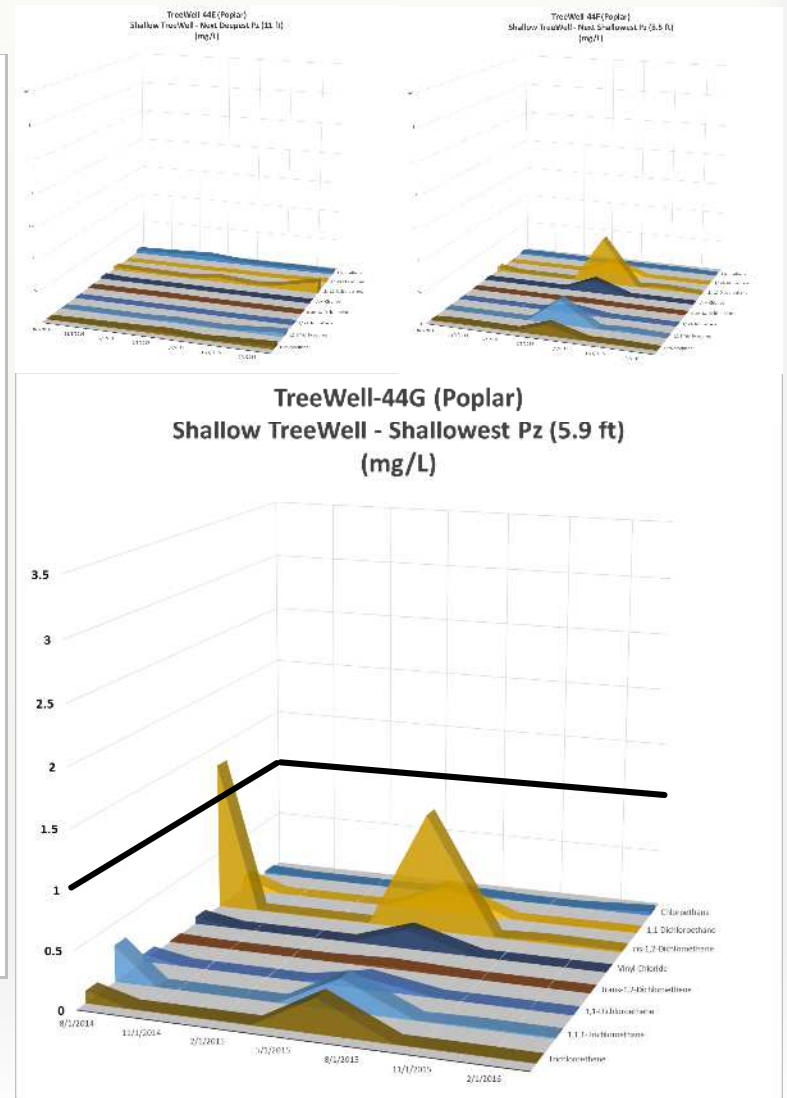
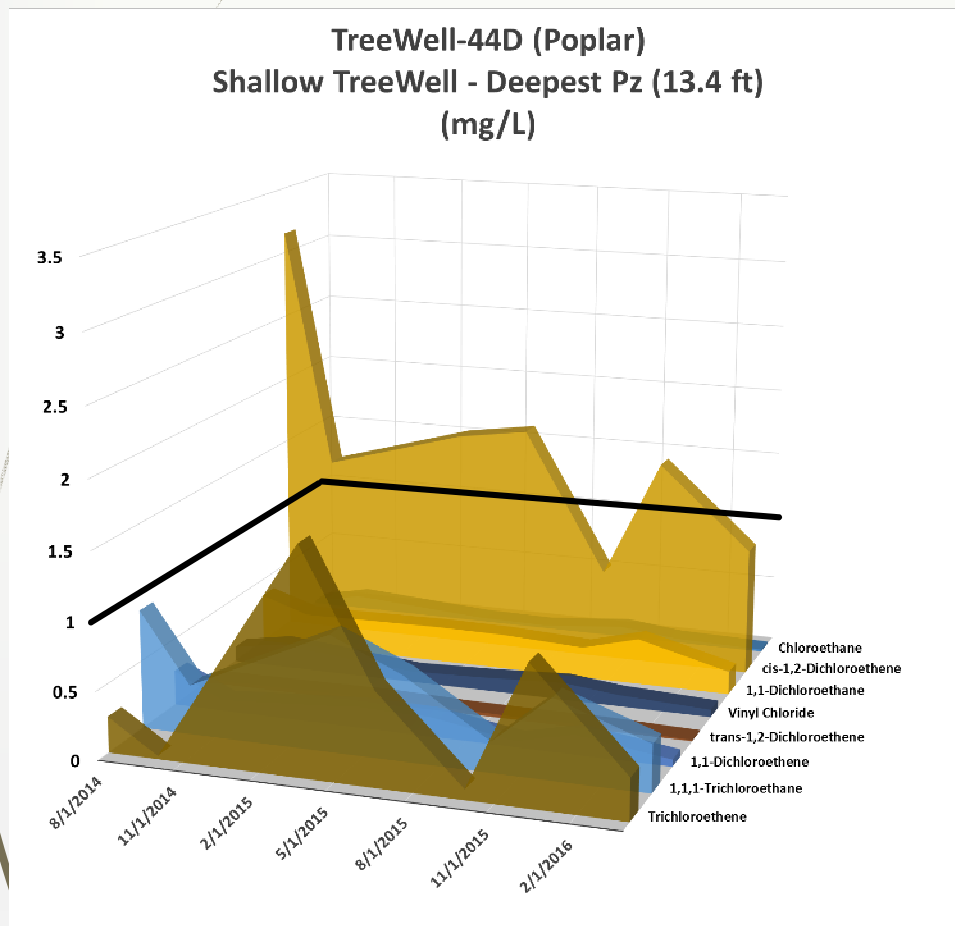


Western Pennsylvania *TreeWell* System Bioreactor Study

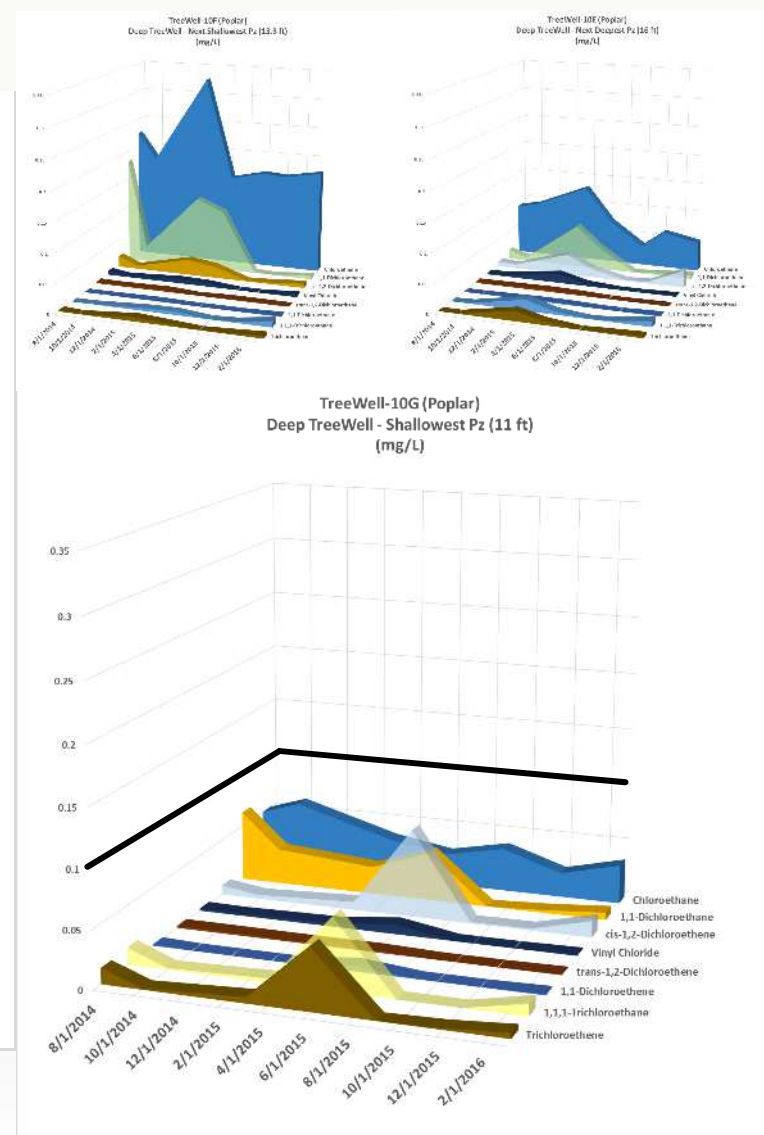
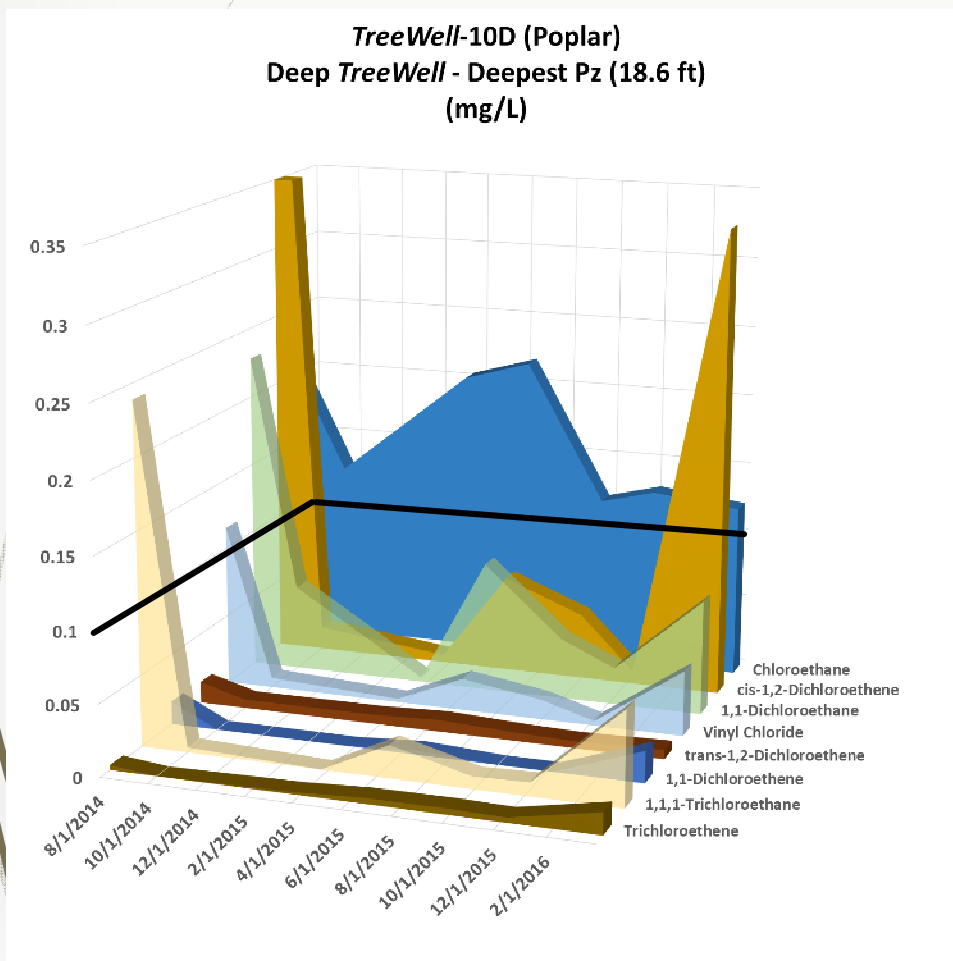
- Four piezometers with 1 ft screens were installed at progressive depths inside shallow & deep *TreeWell* Units
- GW samples were collected periodically from Aug., 2014 to present (Mar., 2016)



Western Pennsylvania Bioreactor Study – Shallow Groundwater



Western Pennsylvania Bioreactor Study – Deep Groundwater



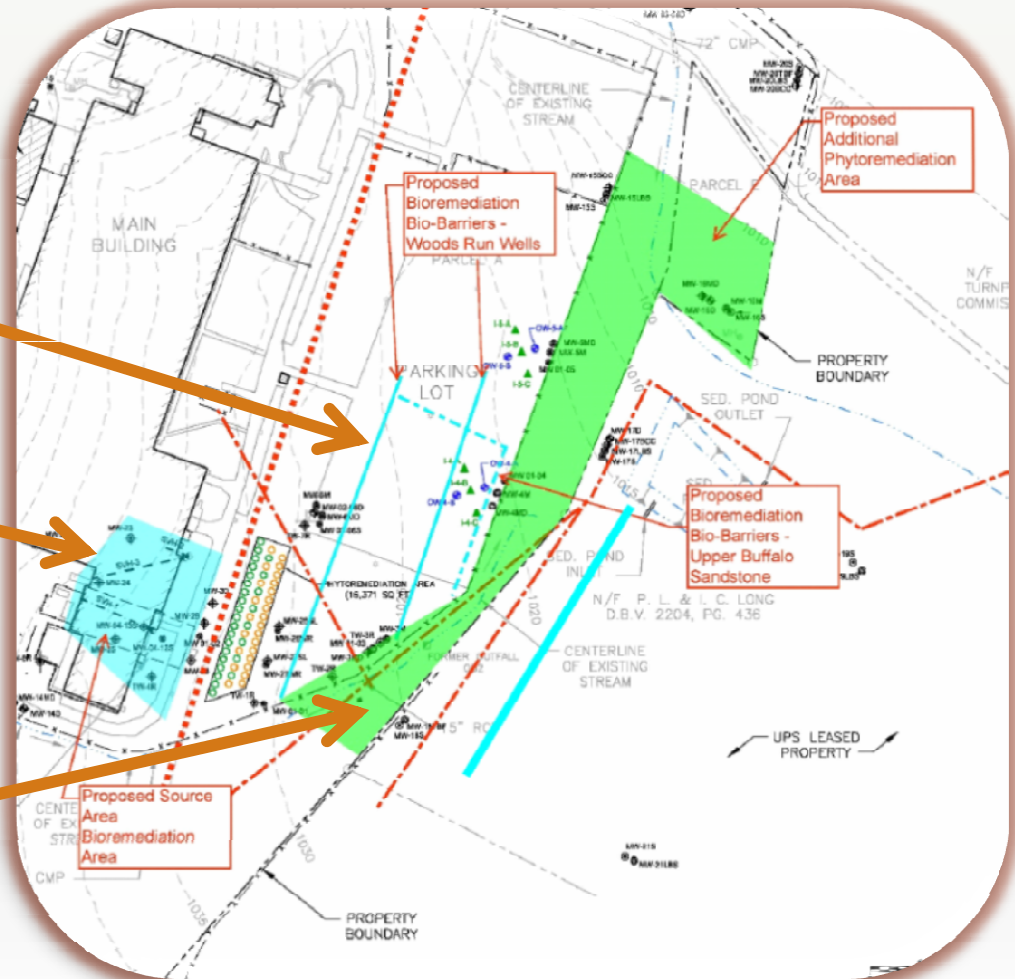
Western Pennsylvania

Successful Pilot Study

> Additional Treatment Systems

Multiple Technologies to be employed

- Bioremediation – Surface Soil, Woods Run Formation (shale) and Buffalo Formation (Sandstone)
- SVE with Bioremediation beneath the floor slab
- Additional 200 unit *TreeWell* System along eastern boundary (soil and Woods Run, possibly Buffalo)



Near Sarasota, Florida

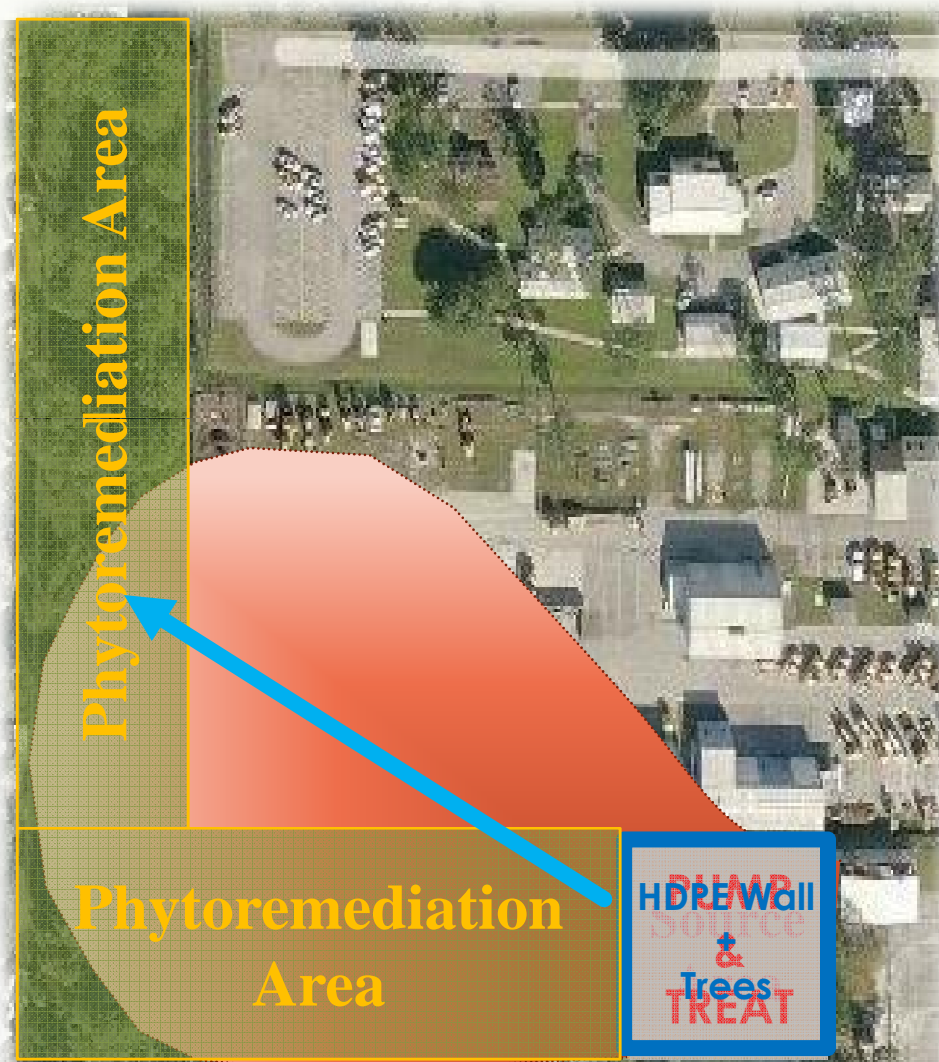
2.5 Acre – mature, full vegetative canopy

Problem:

- Remaining Source
- 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)



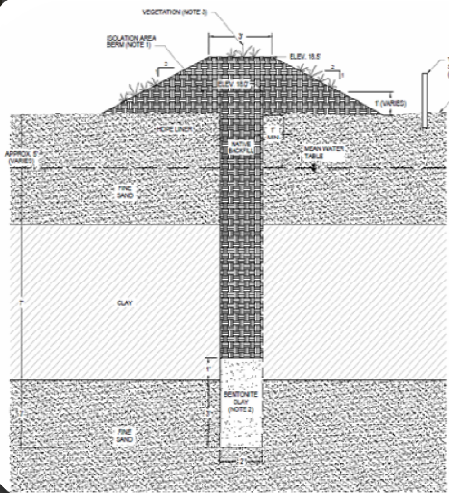
Near Sarasota, FL

Initial Groundwater Flow Conditions – March 2013

- 154 Unit **TreeWell System** for Plume Control & Treatment – (Trees: **Slash Pine, Willow, Sycamore, Cypress, Laurel Oak**)
- HDPE Containment Wall** for Source Area Control - Including **TreeWell Units** and Existing Trees for Remediation and Hydraulic Control



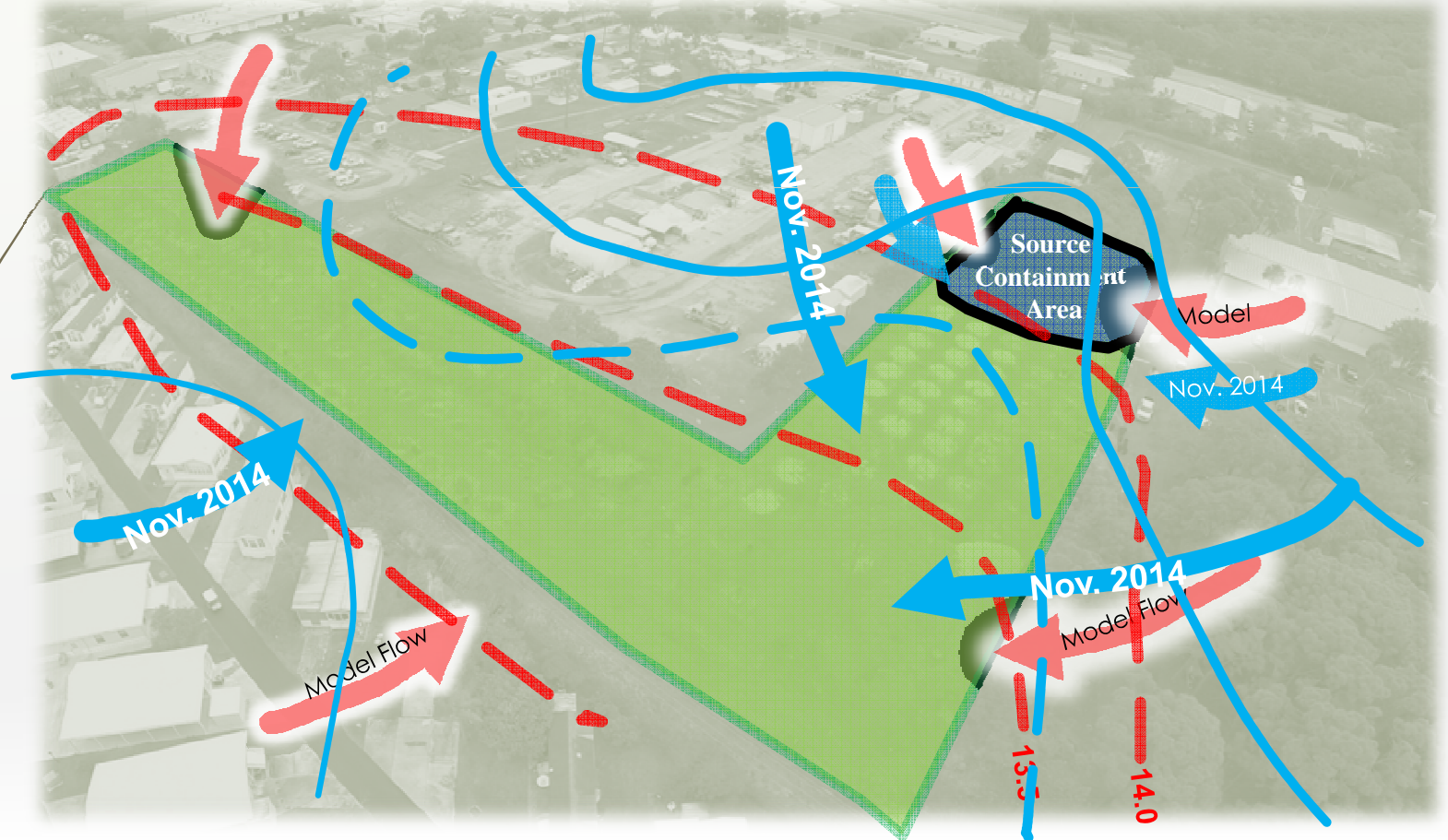
HDPE barrier wall design section



Near Sarasota, FL

Groundwater Flow Results

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

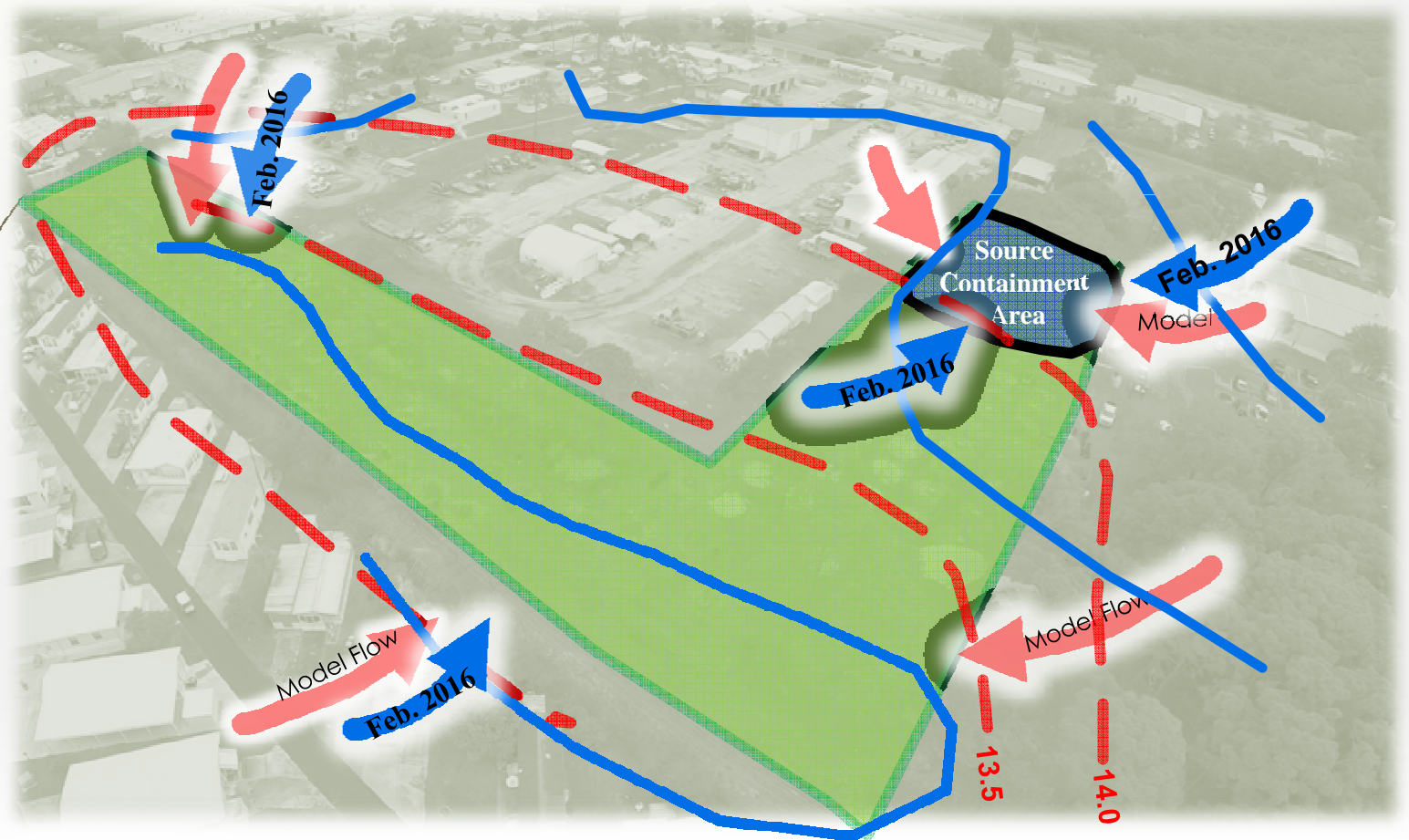


Near Sarasota, FL

Groundwater Flow Results

Hydraulic conditions in February, 2016

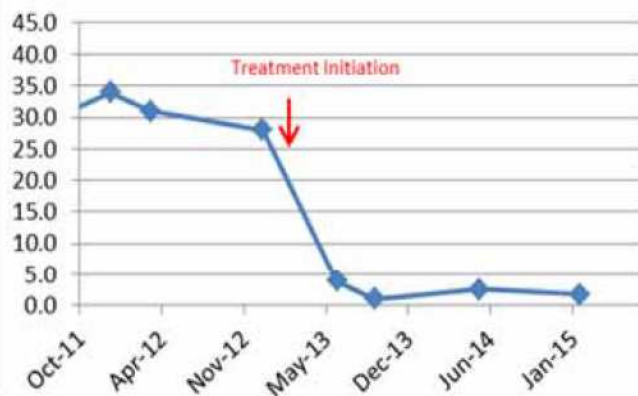
- Comparison with the model continues to improve despite above-average precipitation during winter of 2015-2016



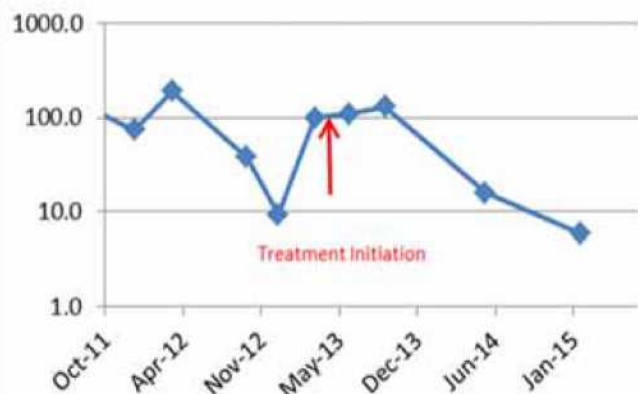
Near Sarasota Florida

- Remediation Results (1,4-Dioxane $\mu\text{g/L}$)

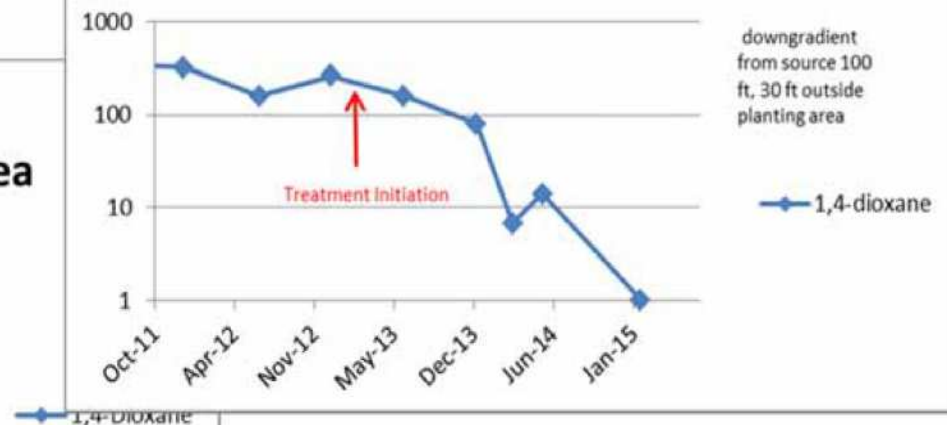
1,4-dioxane vs time
IMW-10 - Inside Planting Area



1,4-dioxane vs time
IMW-12 - Inside Source Area



1,4-dioxane vs time
FMW-24R - Outside Planting Area



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**





Summary

Combining *PHYTO-INTEGRATED™* Remediation with other Technologies for Source Area Treatment and Plume Control

Source Area

- **Eastern Illinois** –
Electrical Resistance Heating (ERH)
- **Western Pennsylvania** –
Soil Vapor Extraction (SVE), Enhanced In-Situ Bio (EISB) & In-Situ Chemical Reduction (ISCR), Limited Excavation
- **Near Sarasota Florida** –
Pump & Treat, HDPE Containment Wall + Trees + *TreeWell®* Units

Plume

- **All Sites** - *TreeWell®* Pump & Treat System

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General Benefits

Combining *PHYTO-INTEGRATED*TM Remediation with other Technologies for Source Area Treatment and Plume Control

- Adaptable to a large range of settings, contaminants and contaminant levels
- Multiple technology combinations possible
- Lower capital costs vs many other traditional technologies and even when comparable – lower O&M costs are usually significant
- Lower maintenance costs vs other traditional technologies and traditional phyto
- Effectiveness improves with time
- Aesthetically pleasing

PHYTO-INTEGRATED™ Remediation Systems

Site locations – 1988 to 2016

