A Tree-Based Remediation System for Treatment and Hydraulic Control of a Hydrocarbon Plume in a 20 Foot Deep Aquifer at a Former Refinery in Central Oklahoma

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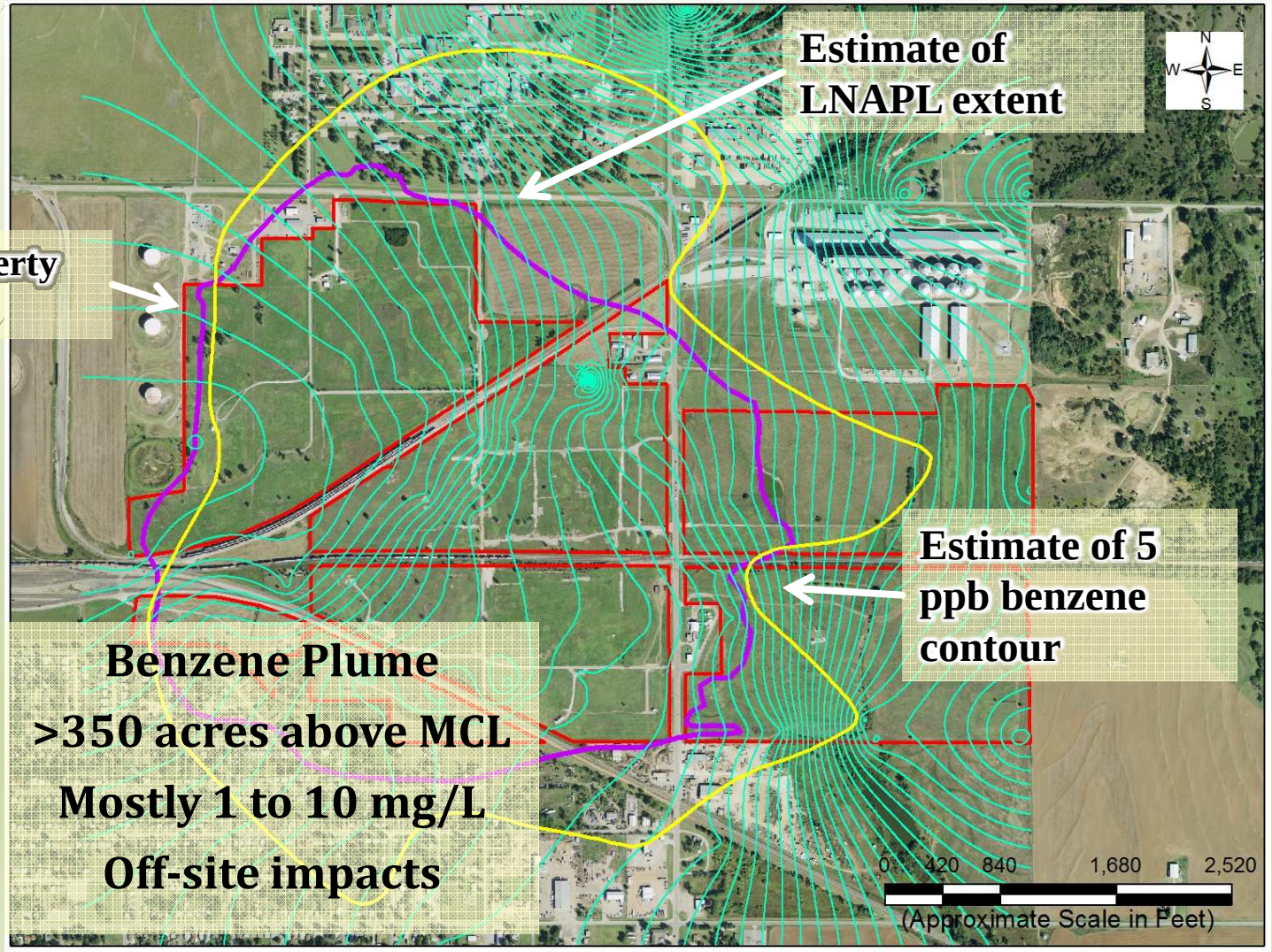
Phyto-Integrated™ Remediation System Approach

- The Problem
- Possible Solutions
- Site Conditions
- Feasibility (Pilot Study)
- Results and Lesson Learned
- Selected Solutions

The Problem

Former Refinery with Petroleum Contaminant Plume Migrating Off-Site



Possible Solution
Using Trees for Full-Scale Hydraulic Control

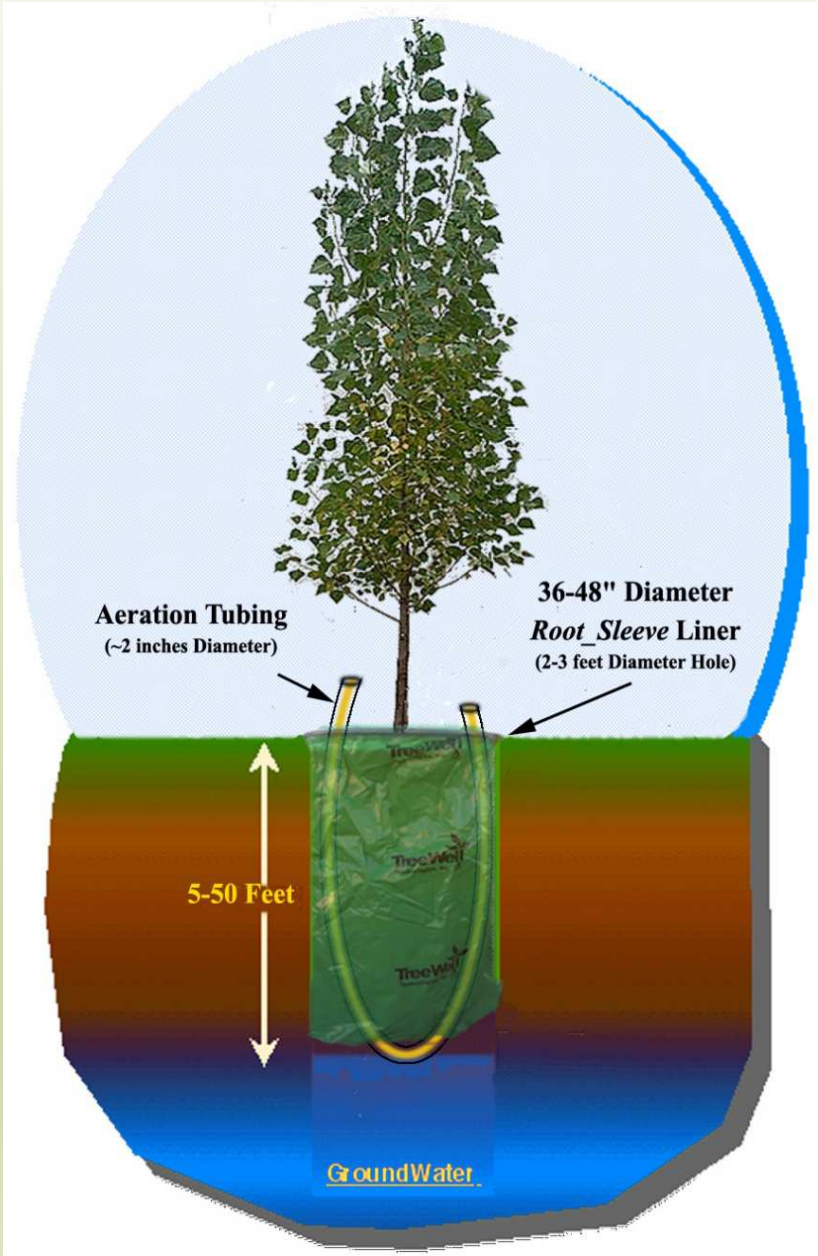
- **Minimum groundwater extraction rate**
  - **Darcy's Law for natural flow rate: function of transmissivity, hydraulic gradient, plume width**
  - **= 20,000,000 gallons/year, natural flow**
  - **= 38 gallons/minute**
- **Design basis for tree extraction rate at full canopy**
  - **36 inches/year = 1.9 gpm/acre**
  - **At 30 ft. spacing, 56 gpd/tree average over year**
  - **20 acres of trees minimum required**

Evaluation of Integrated-Phyto Approach

- **Conduct Pilot Study to determine the feasibility of using a *TreeWell®* system - *a Tree-Based Pump and Treat system***

Patented *TreeWell*® Approach

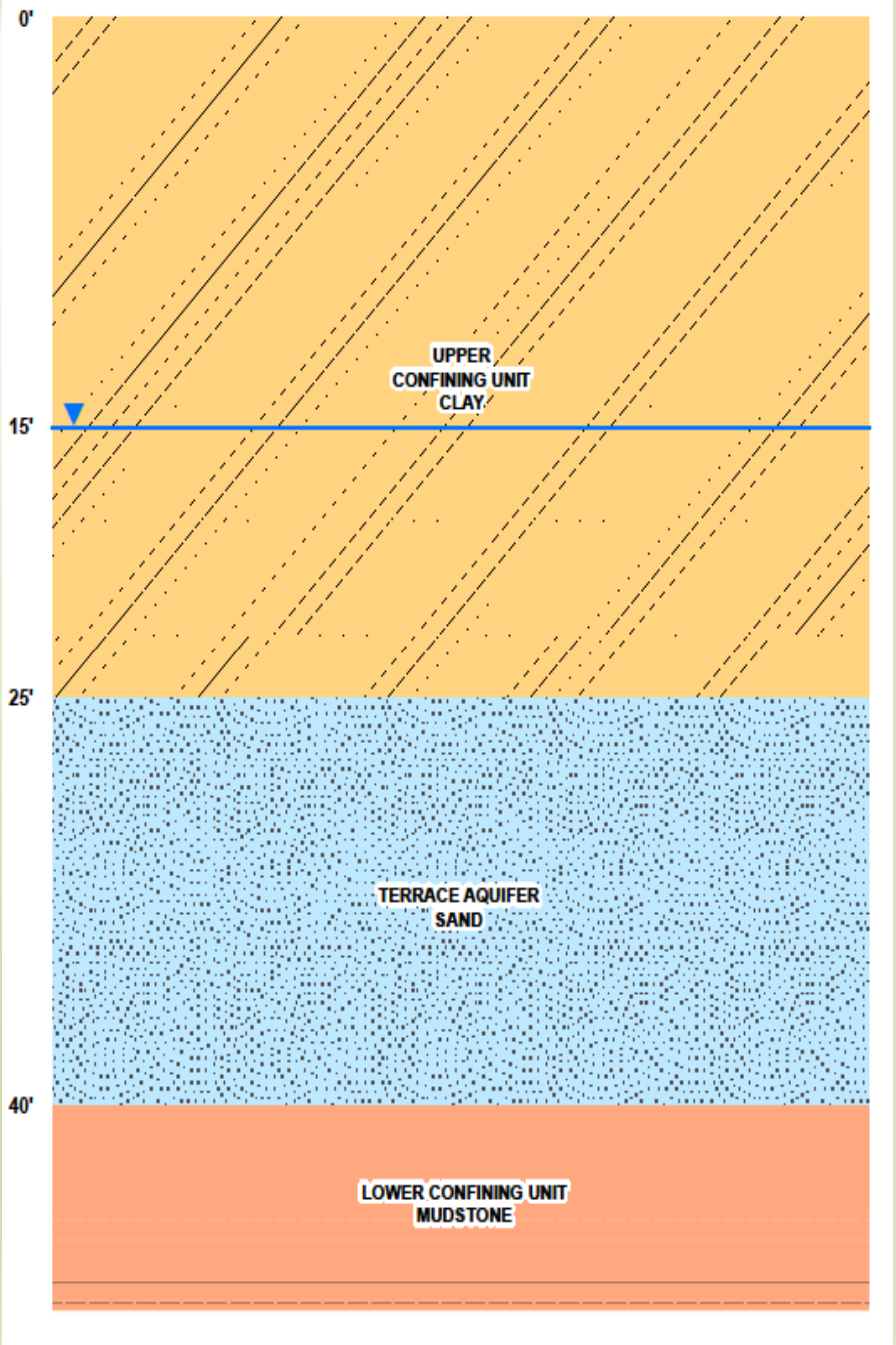
- Alternative to Traditional Pump and Treat System
- Tree acts as solar pump
- Capillary groundwater moves upward through soil column & rhizosphere as the tree transpires
- Significant biodegradation occurs in the soil column (bioreactor effect and reduced phytotoxicity)



Site Conditions

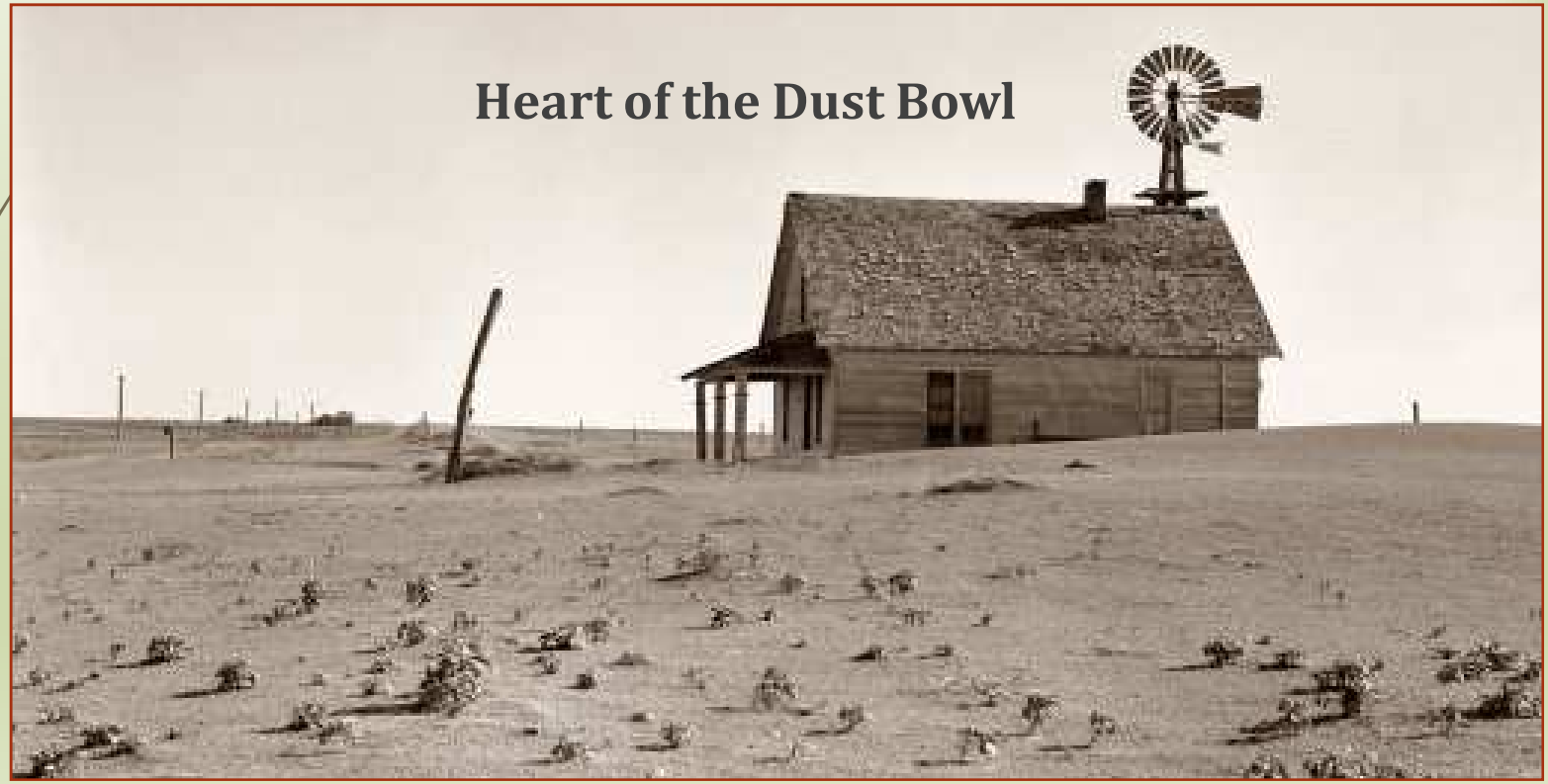
Alluvial Terrace Deposits

- Water table 15-20 Ft BGS
- ~0-25 Feet
  Upper confining clay
- ~25-40 Feet
  Sand unit
  - $K_{avg} = 2 \times 10^{-2}$ cm/sec
  - Confined aquifer – water levels rise into overlying clay
- Lower confining red bed mudstone



Climate also a challenge for Trees

- **High Temperatures Common**
  - **Often Weeks of 100F+ Temperatures**
- **Drought conditions common**
- **Impractical to irrigate**



Pilot Study

Feasibility of Utilizing *TreeWell* System

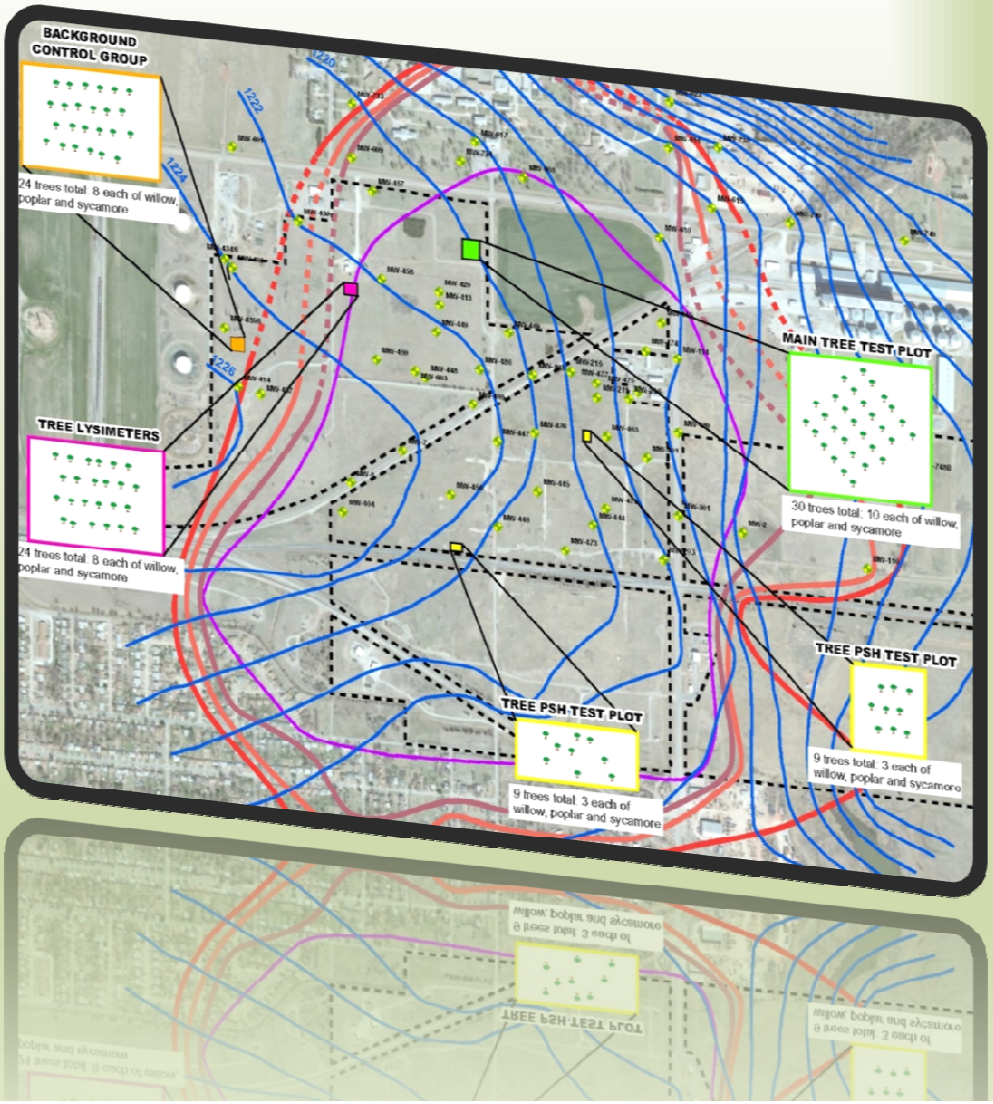
- **Determine ability to establish trees**
  - **without irrigation**
  - **in the presence of LNAPL (phytotoxicity)**
  - **have roots draw water from 20 foot deep**
- **Evaluate tree species for viability**
  - **Weeping Willow**
  - **Hybrid Poplar**
  - **London Plane (Hybrid Sycamore)**

TreeWell System
Successfully Applied Elsewhere

Pilot Study 2012-2014

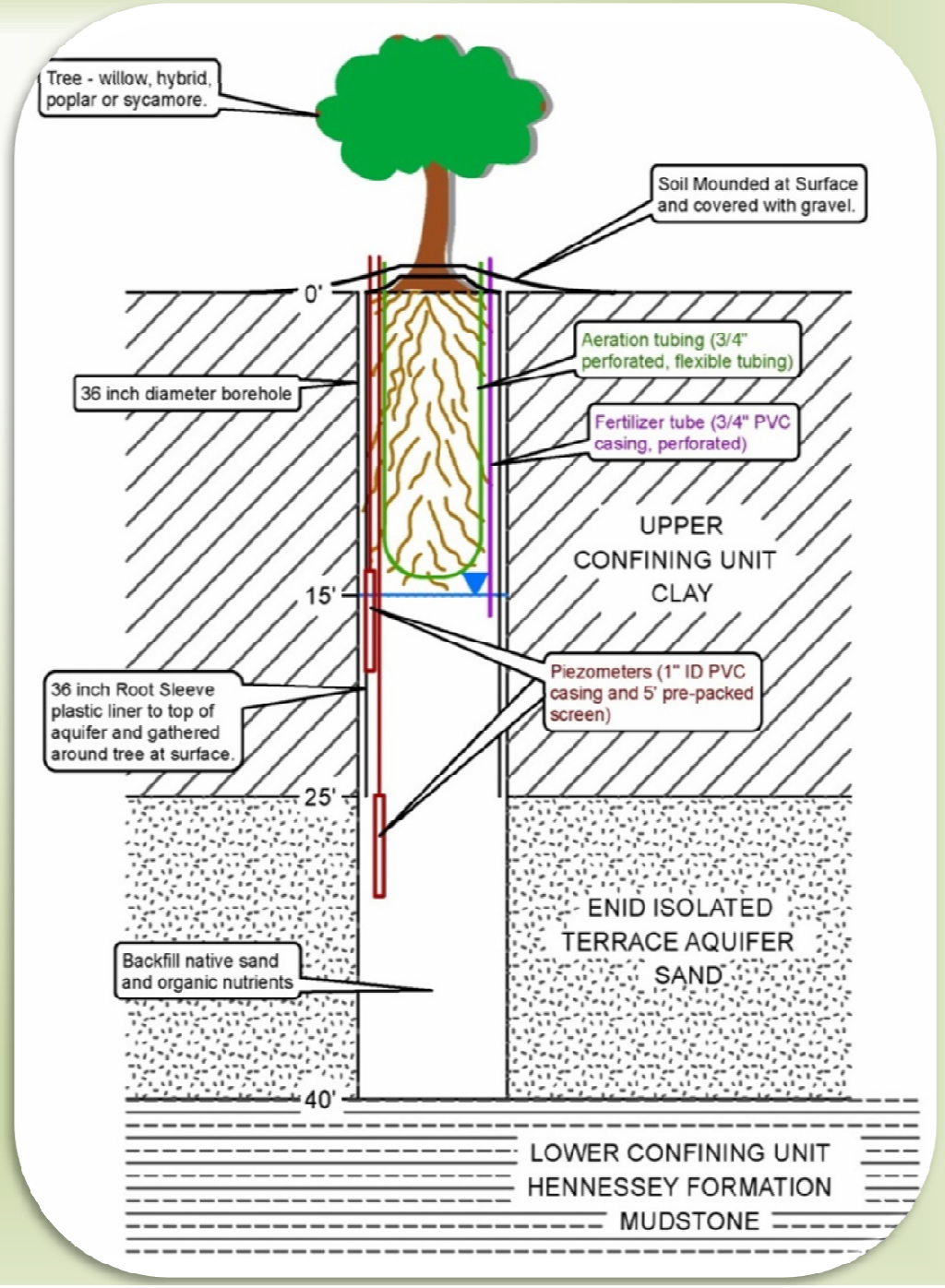
Five Study Areas

- One Background (no VOCs)
- One Main – hydraulic effect
- Two LNAPL (3 ultimately) – toxicity effects
- One Lysimeter – water use



Site *TreeWell* Unit Design

- 40 inch hole bored to 25-35 feet into Sand Aquifer
- Liner placed to 15 ft bgs (near top of GW in 2012 & 2015)
- Aeration tubing looped to 15 ft bgs
- Entire column filled with clean rooting media



Pilot Study – June 2013

Pilot Study - Results

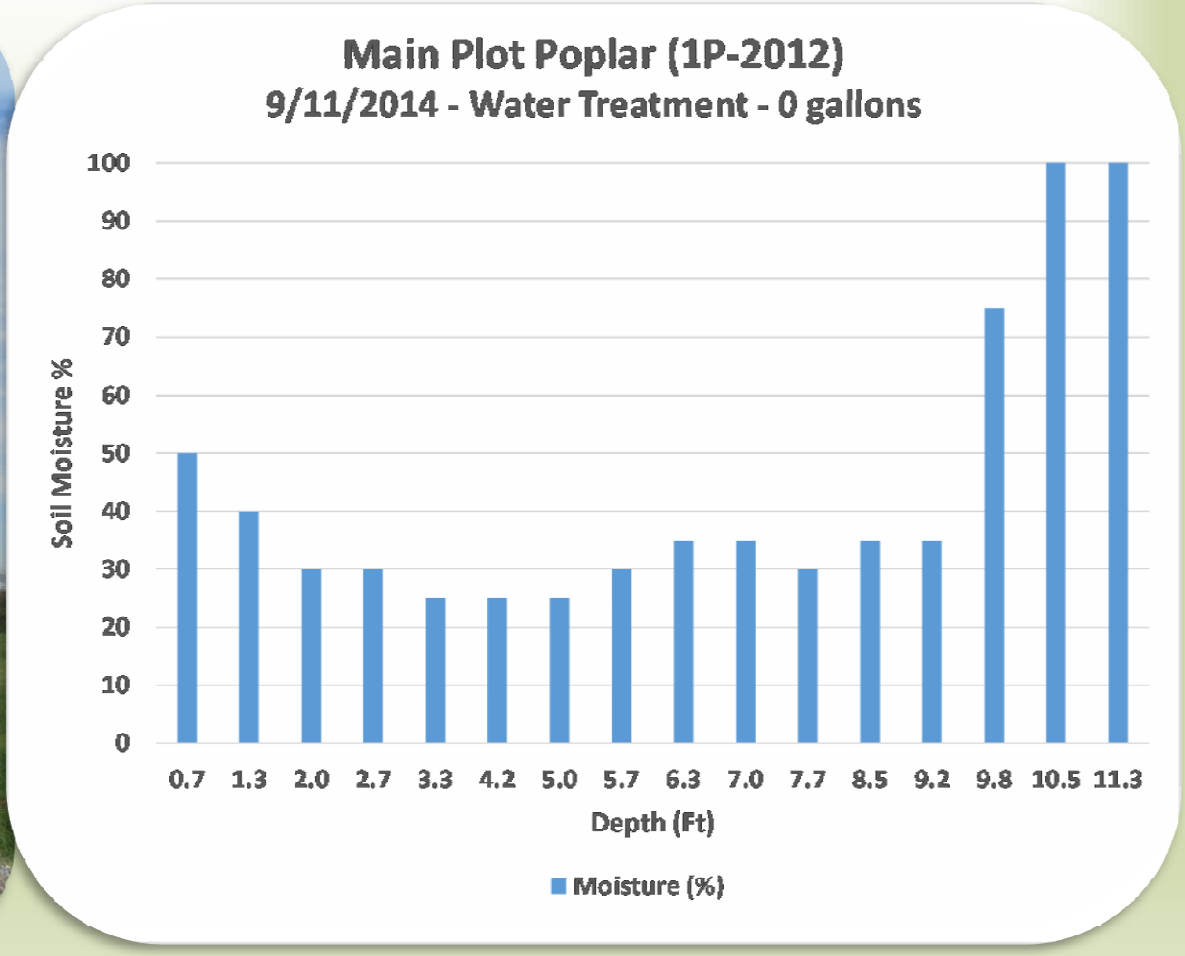
- **Trees can be grown in *TreeWell* system without irrigation (even in very harsh climatic conditions)**
  - **London Plane proved most hearty**
  - **With pesticide management, Hybrid Poplar also viable**
  - **Golden weeping willow replaced with Black Willow**
- **Roots readily develop to top of capillary fringe (which was found to rise 10-14 feet above water table creating a significant bioreactor column)**
- **Significant soil gas venting likely reduces potential phytotoxic effects**

Roots Develop to Capillary Fringe

Root Development & Soil Moisture by Depth

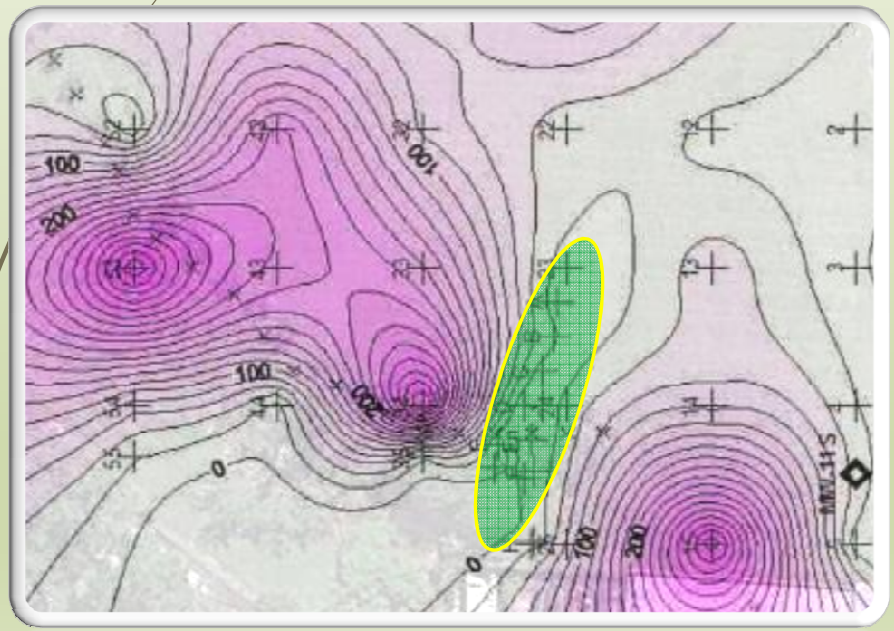
Roots to 11 feet (Capillary Fringe)

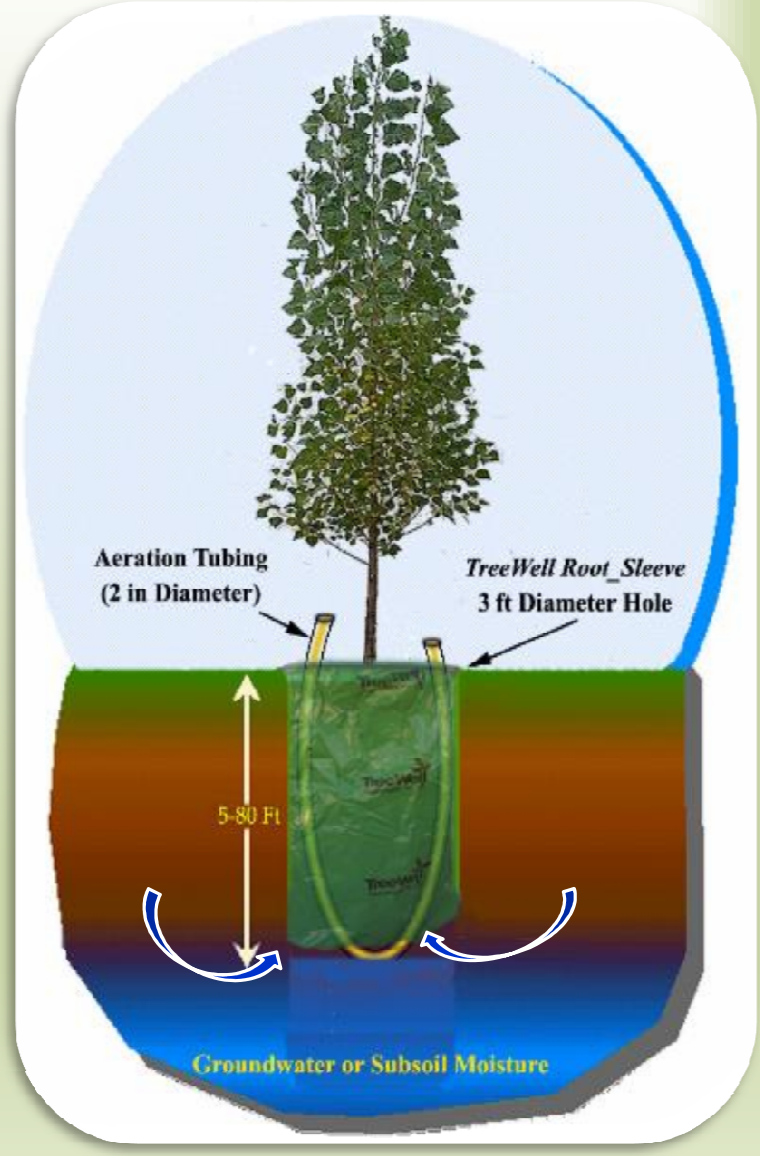
Water Table @ ~22 Feet BGS



Soil Gas Venting by *TreeWell* Units

- A recent soil gas study at another *TreeWell* system location yielded results that showed the *TreeWell* units acting as vents for soil gases
- **Soil VOC gases were not present in sample ports near *TreeWell* units**





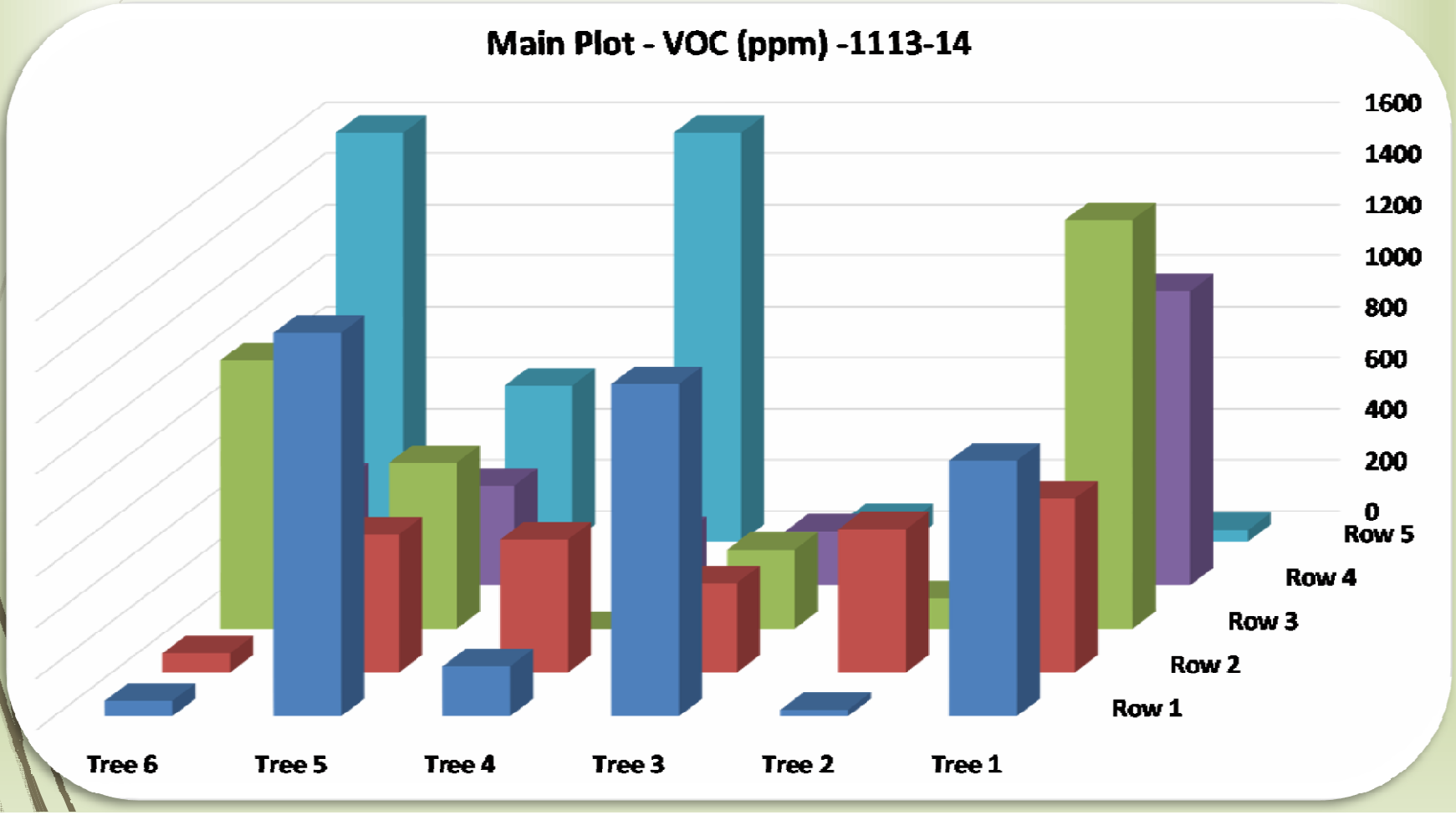
Soil gas Venting by Site *TreeWell* Units

A Thermo Scientific TVA-1000 FID unit was used to measure VOC concentration of soil gases emerging from the *TreeWell* aeration tubing.

- **To enhance air exchange in the looped aeration tube one side is placed at a higher elevation than the other - creating a venturi effect**
- **Both the "intake" and "outflow" vents were tested**
  Note: intake vents typically zero

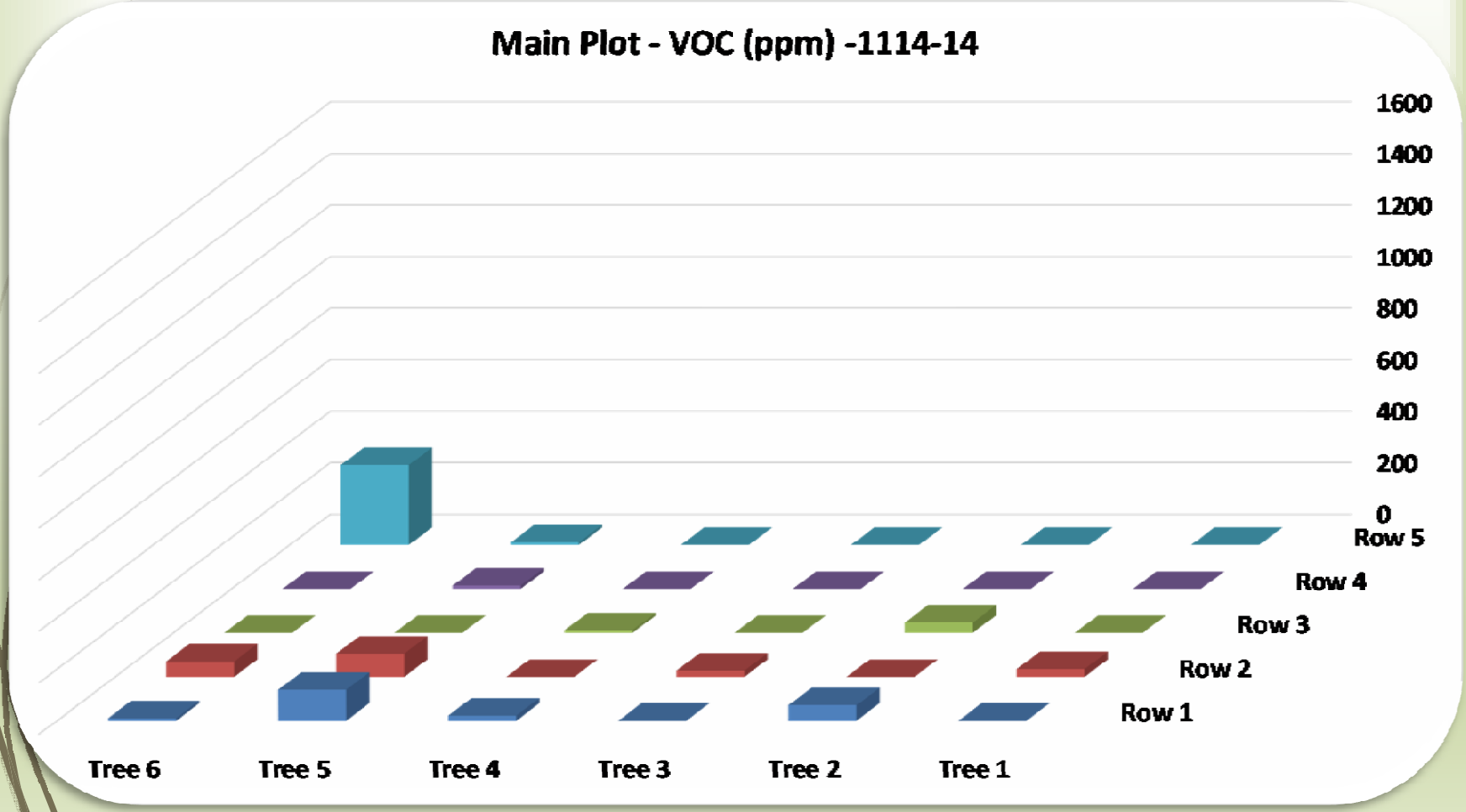
Soil Gas Venting - Wind @ 6.0 mph

Each *TreeWell* unit was tested on a daily basis from 11/4-15, 2014



Soil Gas Venting - Wind @ 0.0 mph

Soil gas emissions subside with no wind to enhance venturi effect



Pilot Study
Lessons Learned

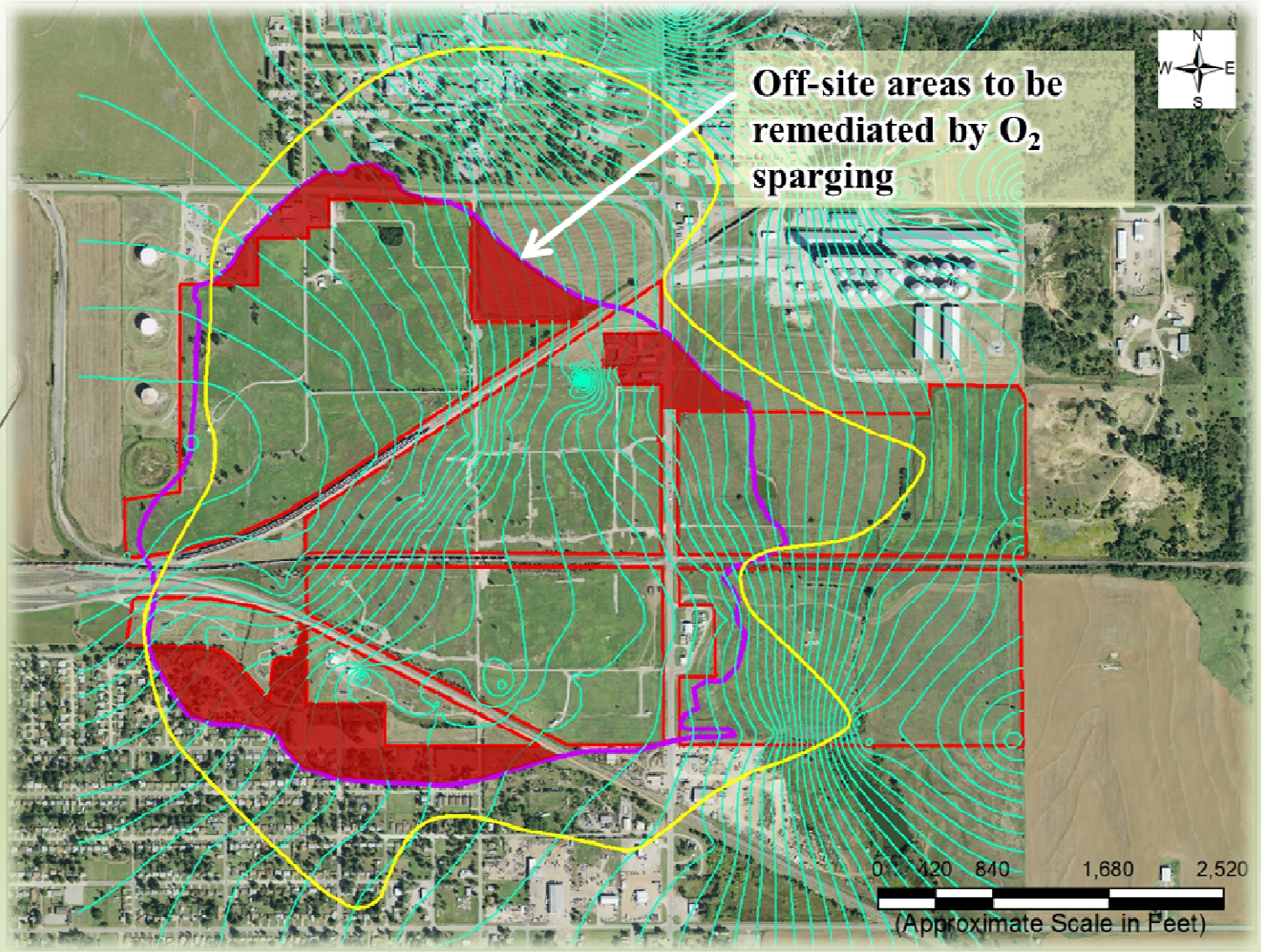
- **How to install 40 inch diameter, 30-40 feet deep *TreeWell* units more safely & efficiently**

Safety Platform placed over the hole

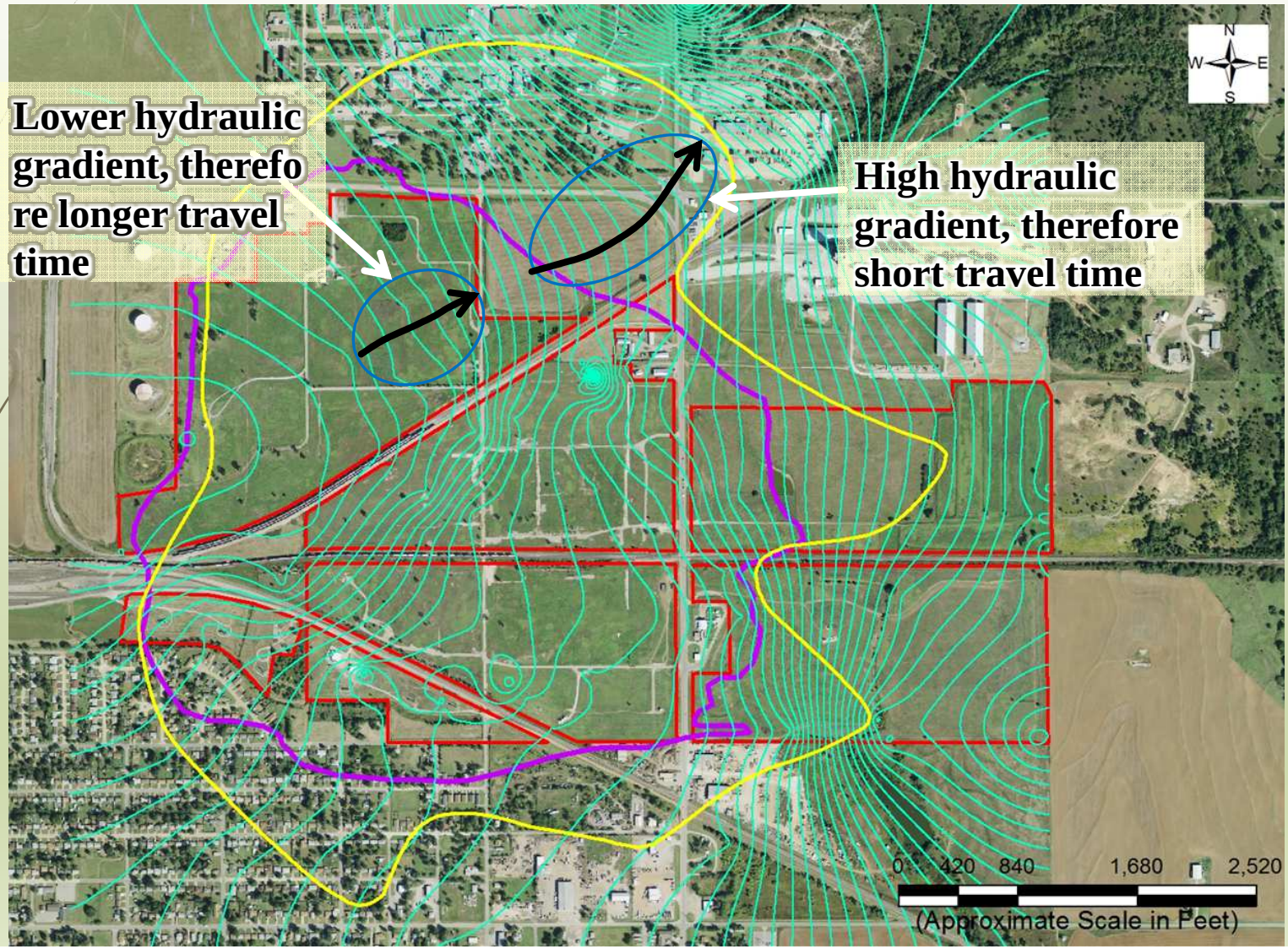
Selected Solutions

- **Treat LNAPL Pockets with Oxygen Sparging**
- **Reduce hydraulic gradient with Pump & Treat system creating opportunity for Monitored Natural Attenuation to control off-site migration of contaminant plume**
- **Use *TreeWell*® system as a Tree-Based Pump and Treat system to reduce hydraulic gradient**

Treat off-site LNAPL pockets with oxygen sparging

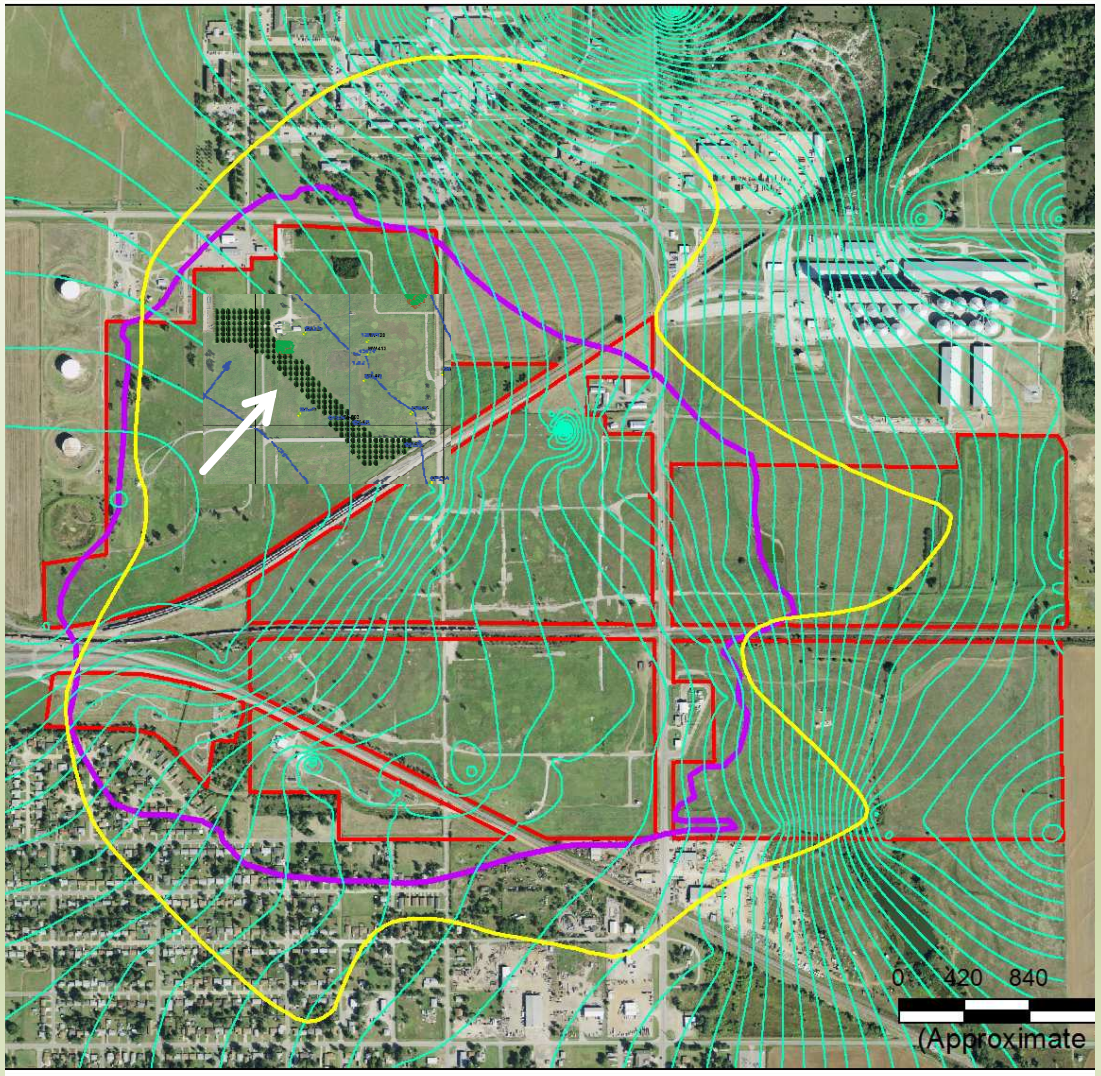


Natural Attenuation is dependent on travel time



Install 400 Trees Reduce On-Site Gradient to Achieve Hydraulic Effect in 2022

400 trees extracting an average of 50 gallons per day could achieve the necessary reduction in the hydraulic gradient and thus the travel time of the contaminant plume through the area of most concern



Benefits

- **Integrated-Phyto Approach offers significant cost savings over traditional Pump and Treat.**
  - **Overcomes significant problems encountered with Pump & Treat system (clogged pipes, wells, iron precipitates, etc…)**
  - **Low O&M**
  - **Savings - Conservative Estimate of over $2 million over a 30 year period**

Questions?