Phytoremediation of 1,4-Dioxane Contaminated Aquifers: Case Studies & Lessons Learned

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What Is Phytoremediation?

"Use of plants to degrade or contain contaminants from groundwater, soil, sediments and surface water"

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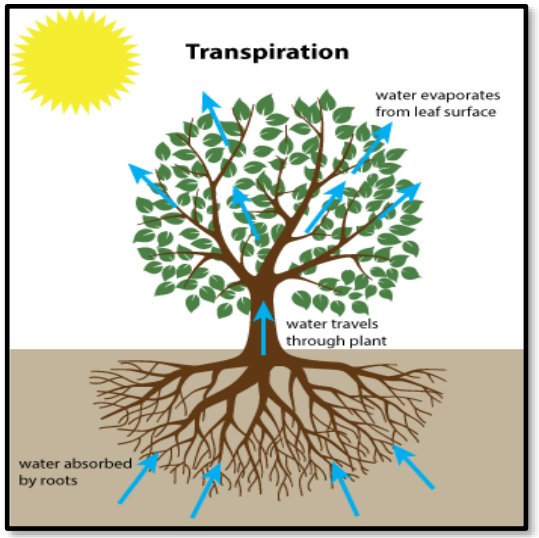
Why Phytoremediation for 1,4-Dioxane?

Conventional options **limited**

Plants **uptake** and **transpire** 1,4-dioxane contaminated groundwater – "***phytovolatilization***"

Key mechanisms include:

- **Hydraulic control** via plant uptake/transpiration
- **Degradation** via:
  - Atmospheric degradation
  - Degradation in the rhizosphere (likely)



Cost-effective alternative to Pump and Treat

Green & Sustainable remediation technology

Takeaway: *Phytoremediation can be effective, so how best do we implement the strategy?*

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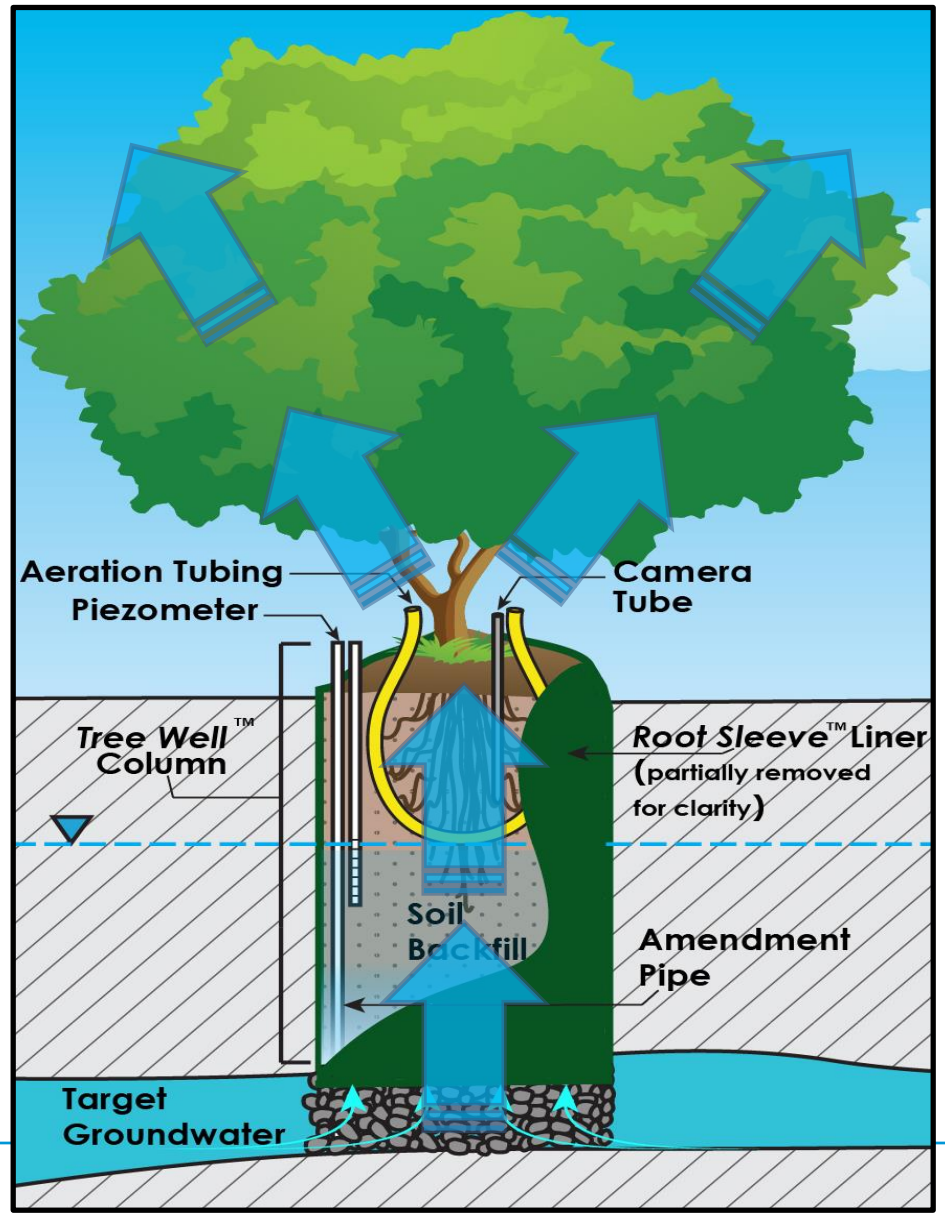
Engineered Phytotechnology: The *TreeWell*® System



- **ANS, Inc's patented system**
- **Targets *Specific* groundwater by directing root growth downward**
- **Groundwater is drawn upward through the soil column, then gets absorbed by plant roots**
- **Target deep or confined aquifers**
- **Bioreactor effect in soil column**
- **Bioaugmentation potential**
- **Optimizes growing conditions**
- **Maximizes inherent benefits of plant-based remediation**
- **Active treatment – delivered in a passive manner**

problems solved 2-clams

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System Installation

Installation Approach

- Borehole advanced to the *horizon of interest*
- Safety platform set
- Liner and aeration tubing are added
- Borehole is backfilled with topsoil and selected amendments
- Plant and above-ground completion

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Case Studies

Three Sites with 1,4-Dioxane plumes; phytoremediation as remedy

- Central Florida
- Western North Carolina
- Western Europe

Different stages of maturity

Unique challenges to implementation at each

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Case Study 1: Central FL 1,4-Dioxane in Groundwater

Site Background

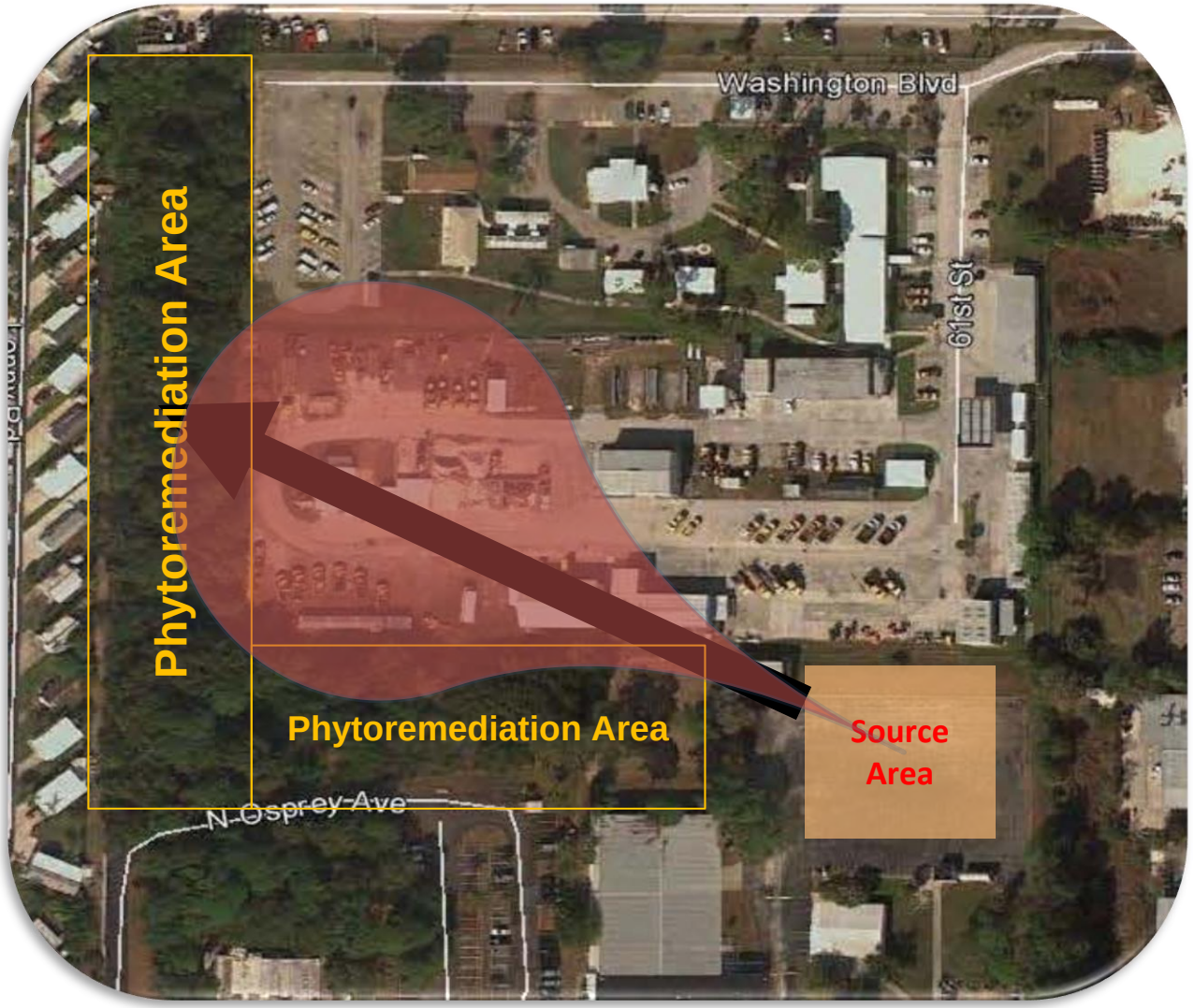
- Fractured bedrock aquifer 5'-15' bgs; contaminant mass and flow in a thin fractured zone in the 10'-15' horizon
- Initial Remedy: Long-term pump & treat system with UV/Peroxide
  - >$300K/Year O&M costs
  - >10 Years to meet Remedial Goals

Phytoremediation Implemented

- Dense forest of low-quality non-native wetland species cleared for phytoremediation system
- Expedite permitting process by promoting wetland restoration

Remedial Goals

- Hydraulic Control
- Contaminant Treatment



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Case Study 1: System Installation

2013 Installation

Summer 2015

SYSTEM INSTALLATION DETAILS

- 154 Units Installed
- 48” Borehole Drilled to 15’ bgs
- Set liner system to top of impacted zone
- Plantings set 20 feet on center
- Native trees:
  - Slash Pine (*Pinus elliottii*)
  - Sycamore (*Platanus occidentalis*)
  - Willow (*Salix caroliniana*)
  - Pond Cypress (*Taxodium ascendens*)

problems solved 2-clams

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Case Study 1: Impact on Groundwater Flow

- ***Yellow*** indicates initial GW flow at time of Phyto System installation (away from source area towards site boundary)
- ***Blue*** indicates GW flow ***18 months after*** Phyto System installed (gradient reversal/hydraulic control; flow towards the Phyto System)
- Results have been very consistently positive:
  - Groundwater flow had been historically to the west-northwest
  - Some changes in flow were seen in the first season
  - By the end of the second season, groundwater flow had reversed

Demonstration of hydraulic capture enabled shutdown of the existing pump and treat system. The system has since been dismantled and removed.

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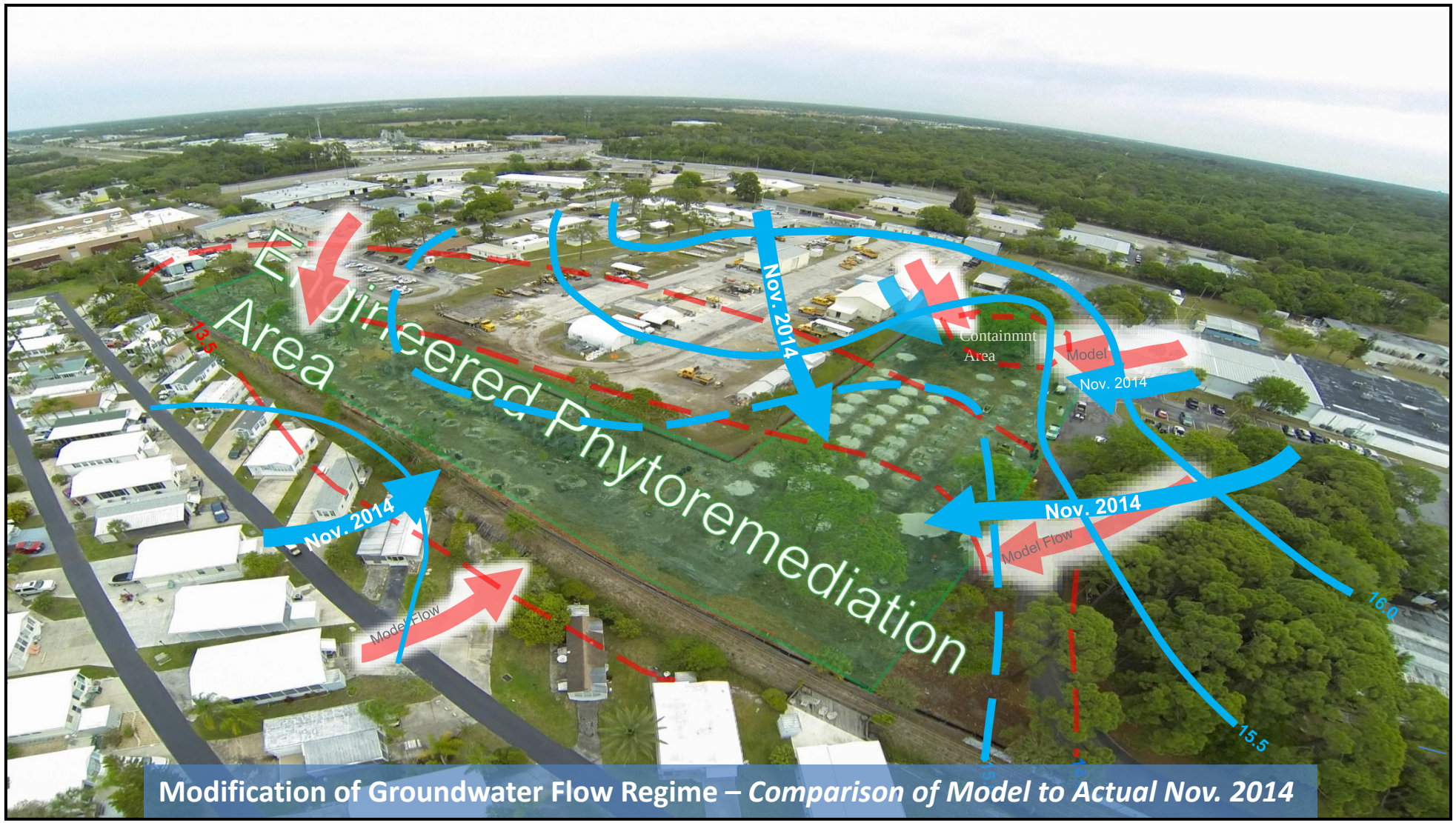
Case Study 1: Modeled vs Actual Groundwater Flow



Modification of Groundwater Flow Regime – *Comparison of Model to Actual Nov. 2014*

problems solved 2-clams

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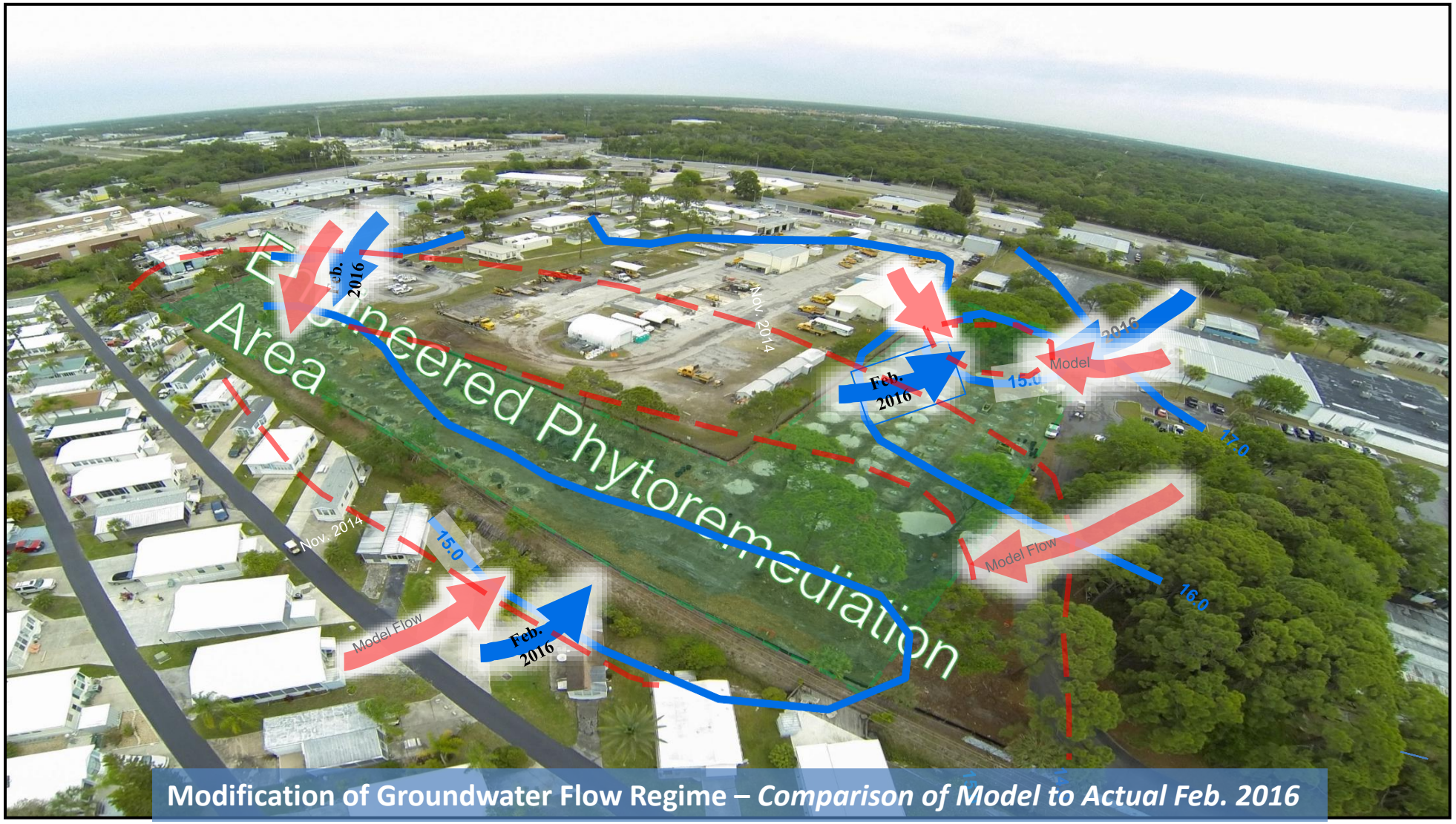
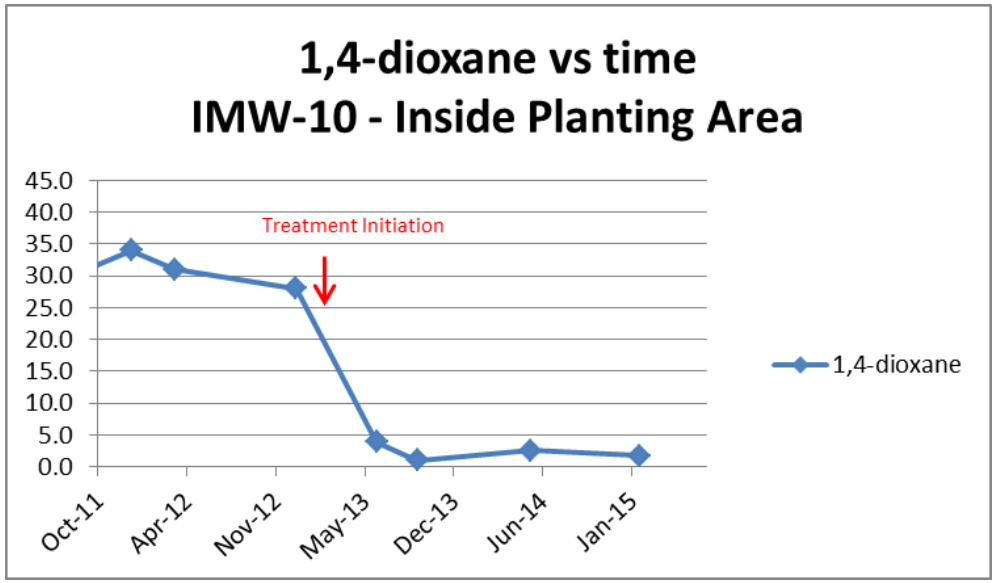
Case Study 1: Modeled vs Actual Groundwater Flow

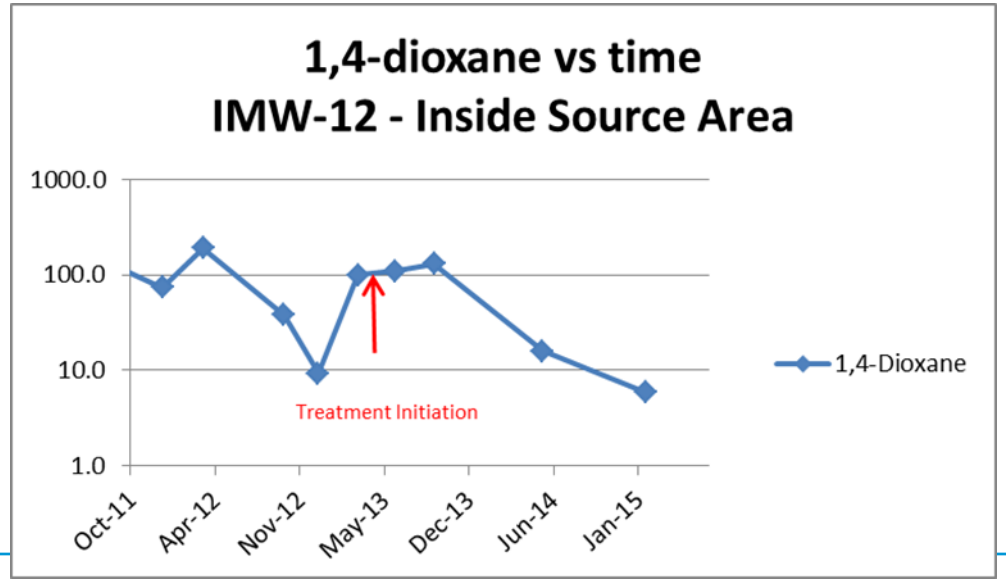


Modification of Groundwater Flow Regime – *Comparison of Model to Actual Feb. 2016*

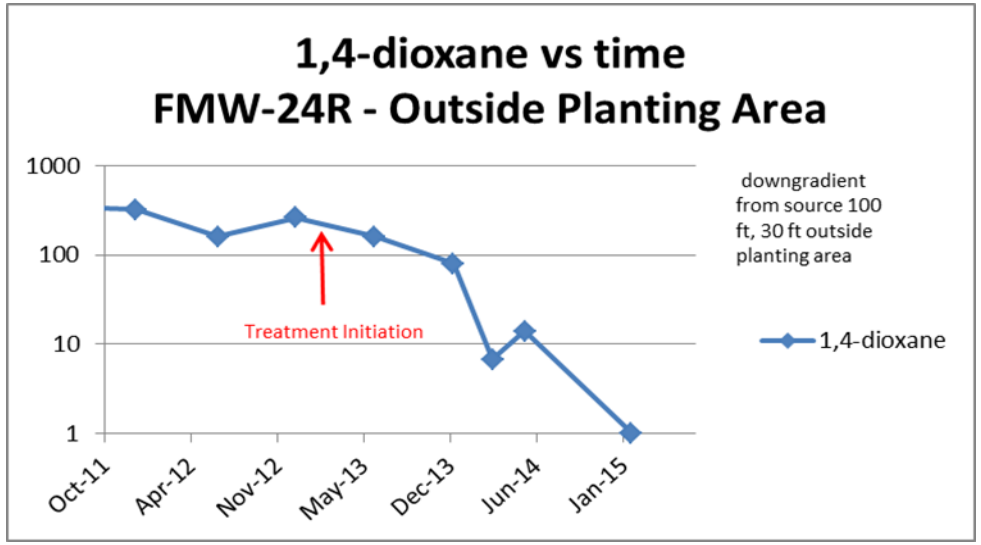
problems solved 2-clams

Case Study 1: Monitoring Data





- Additionally, dissolved-phase concentrations have decreased significantly and rapidly since implementation
- ***No Further Action*** – January 2017



All indicated concentrations in µg/L

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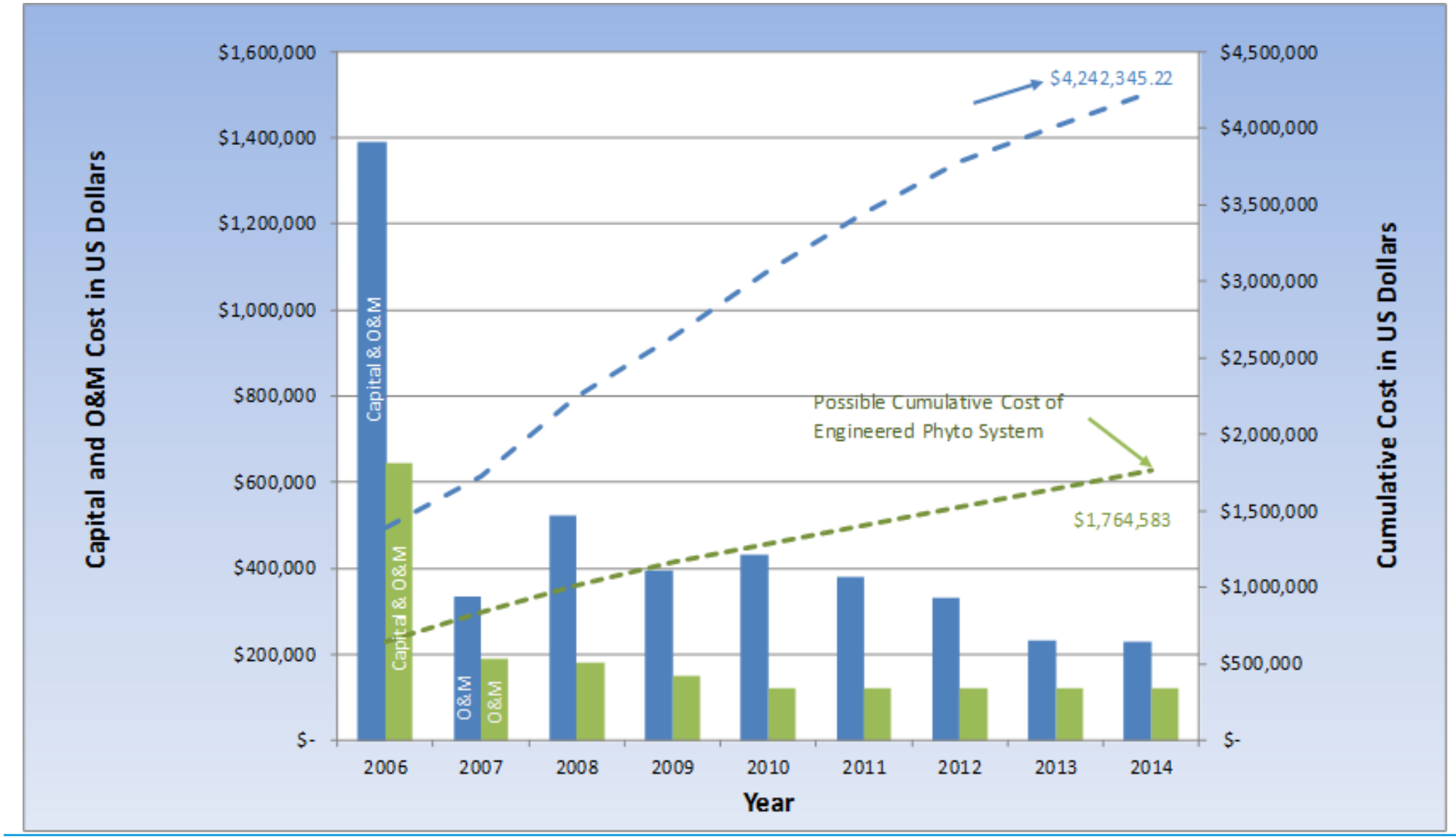
Case Study 1: Cost Savings of Phytoremediation vs. P&T



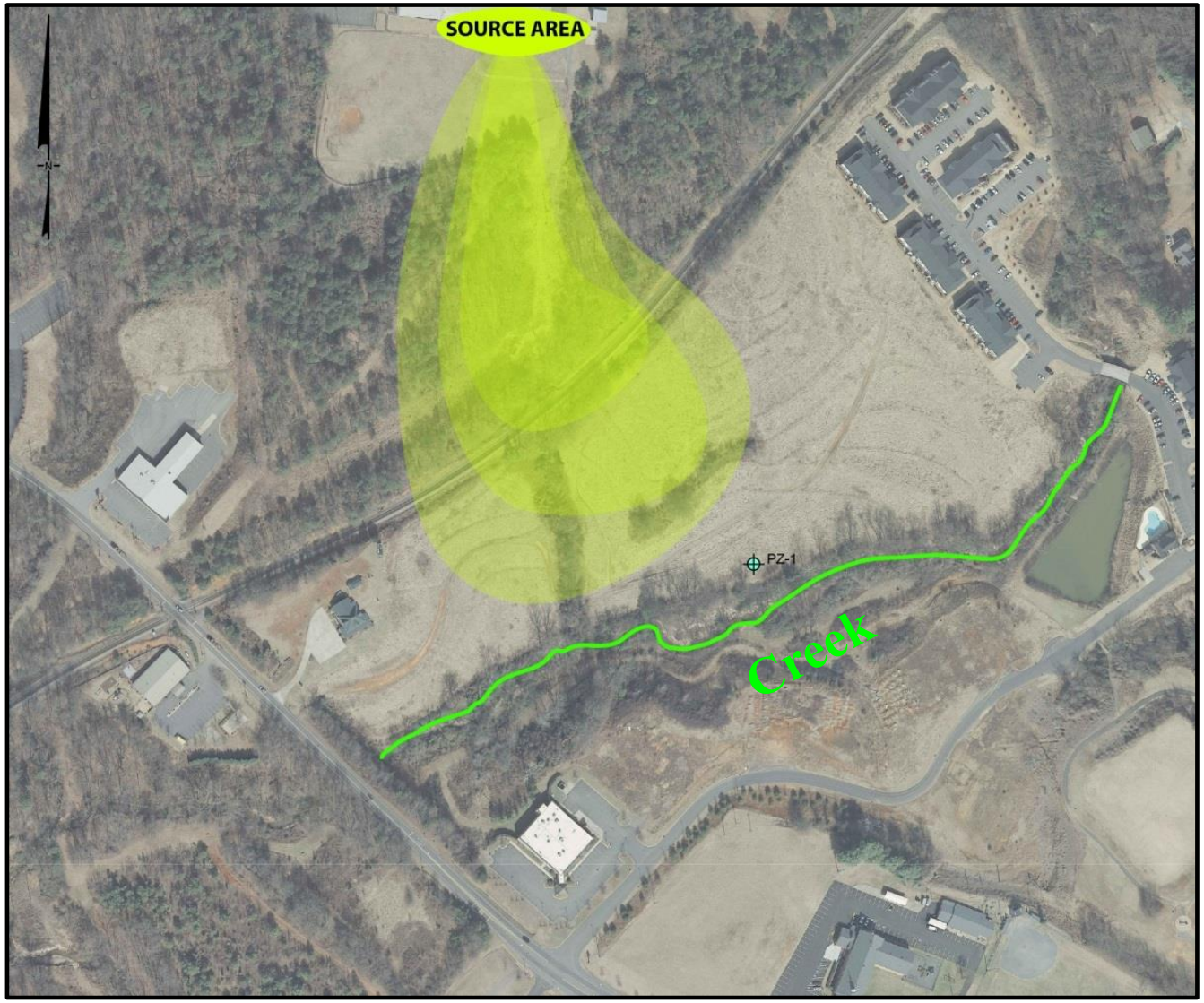
Case Study 2: 1,4-Dioxane in a Saprolite and Fractured Bedrock – North Carolina

Site Background

- Former auto parts manufacturing facility
- 1,4-Dioxane Plume
- Regulatory driver is discharge to creek
- Saprolite over fractured bedrock
- Variable saprolite thickness (5’ to 80’)
- Contaminant flow at base of saprolite
- Surface water standards for creek

Initial Remedy

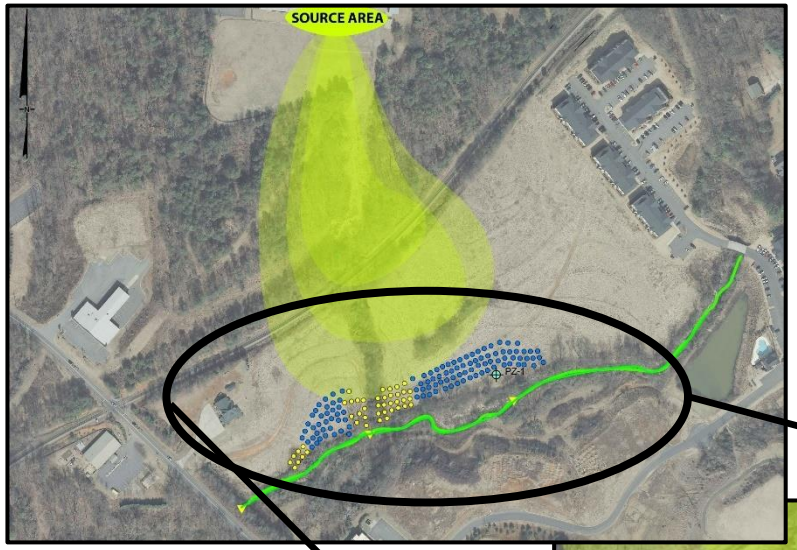
- Extensive ART® well system including in-well UV/Ozone in operation since 2006
- High O&M Costs
- Effectiveness asymptotic – concentrations still relatively high



Case Study 2: Concept Development of Phyto-Barrier

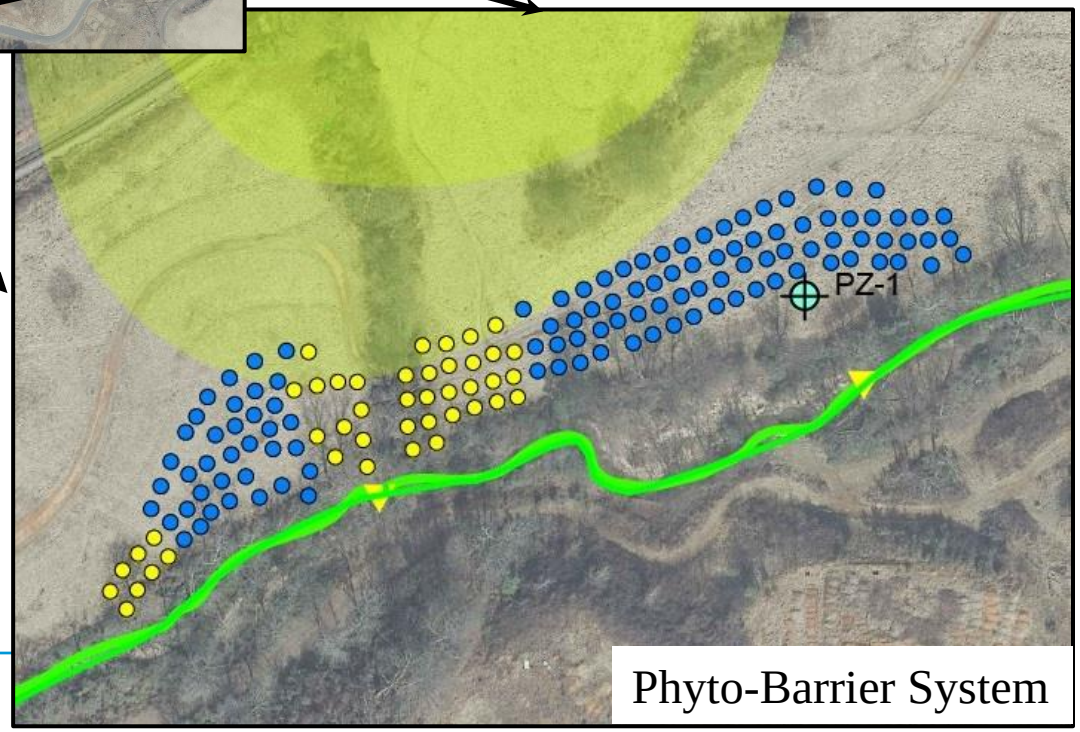
FOCUSED FEASIBILITY STUDY

- Rebound study
- Aquifer performance testing
- Vertical Profile Sampling
- Groundwater modeling to determine capture requirements
- Results indicated phytoremediation would be effective



CONCEPTUAL DESIGN

- A phyto-barrier to reduce overall flow to creek
- Install planting units along creek boundary - adequate to meet RGs
- Groundwater modeling revisited

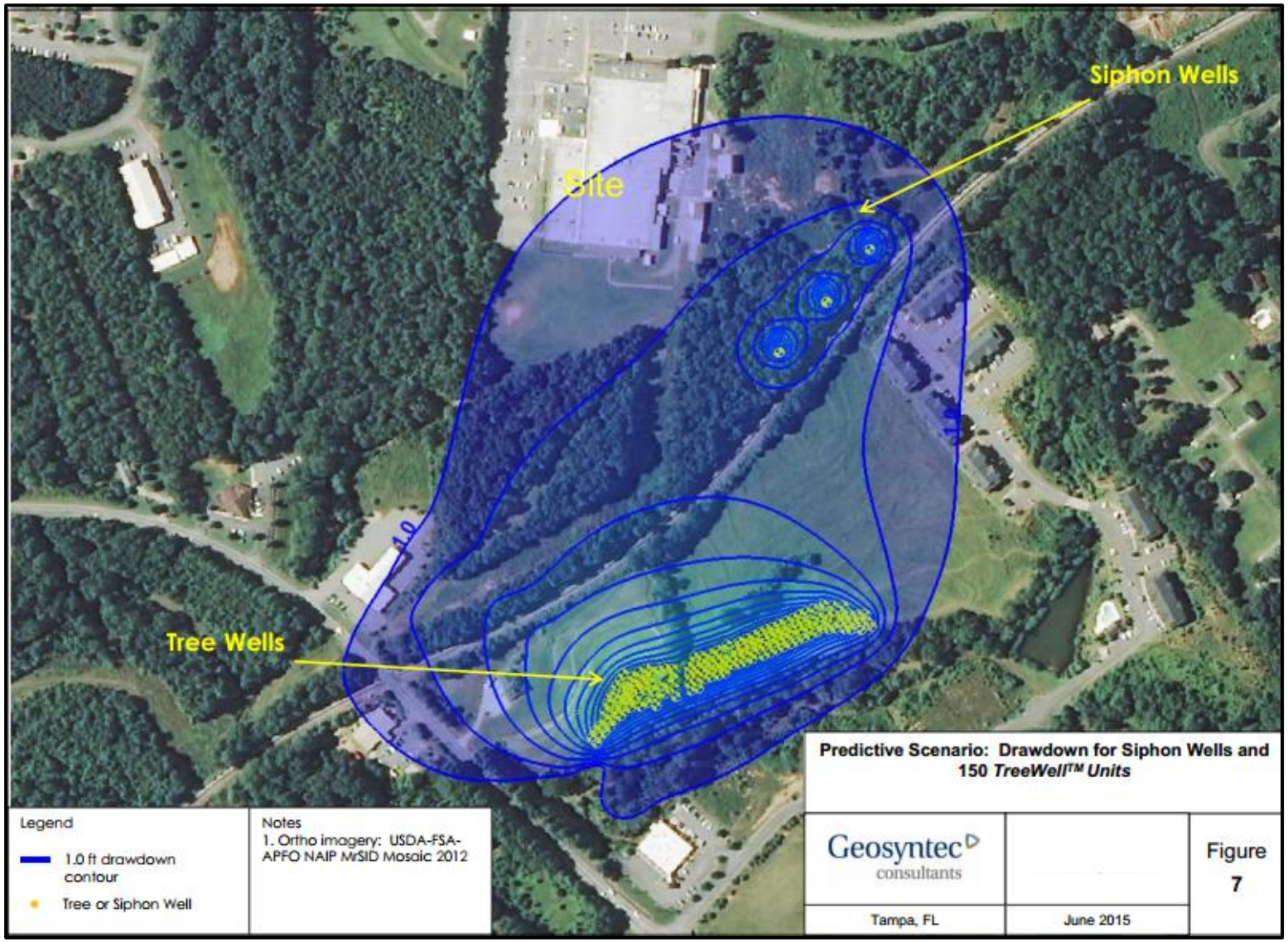


Phyto-Barrier System

Case Study 2: Groundwater Modeling Predictions

Groundwater Modeling

- Establish that phytoremediation system will be protective of surface waters
- Fine-tune the final design
  - Number of plantings
  - Placement of plantings



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Case Study 2: Phytoremediation System Installation – Spring 2015

Drilling Operations

Tree Planting

Completed System

Spring 2015 Installation of 150 units adjacent to creek

- 48” Units drilled to 15’ to 20’ depth
- Three native species:
  - Golden Willow (*Salix alba*)
  - Tulip Poplar (*Liriodendron tulipifera*)
  - London Plane (*Platanus acerifolia*)

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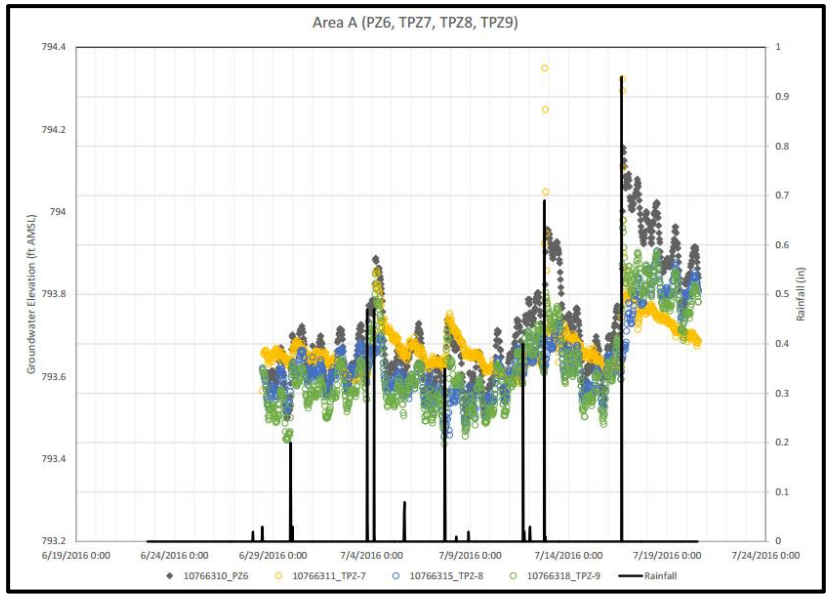
Case Study 2: System Progress

Spring 2017

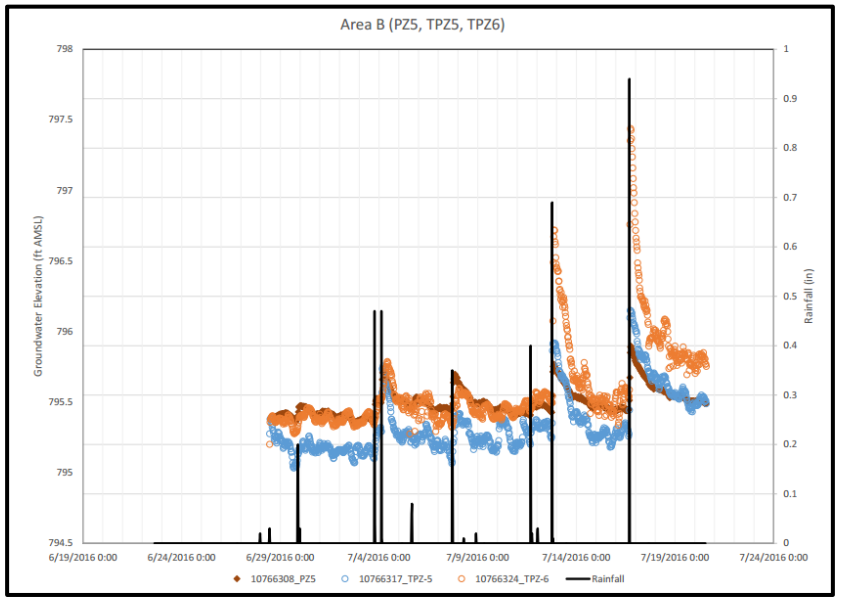
- Vigorous plant growth in all three species
- Roots now relying on groundwater for irrigation needs
- In general, all plants have more than doubled in size

problems solved
2-clams

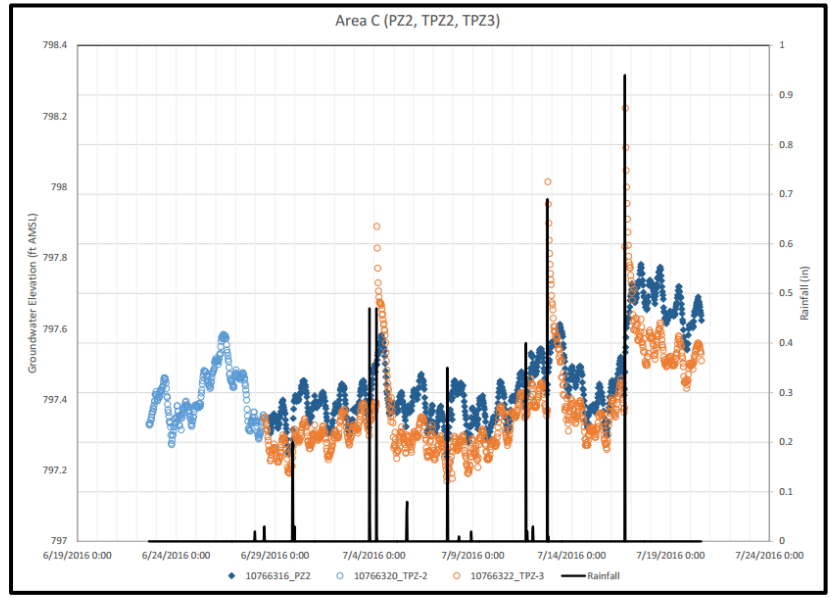
Case Study 2: Indications of Hydraulic Control



Western Zone



Central Zone



Eastern Zone

Summer 2016 Transducer Data

- PZs Inside Units vs. PZs Outside Units
  - Consistently lower GW heads inside vs. outside
  - Inward gradient established

Case Study 2: Summary of Results To Date

- On the basis of the rebound study and the groundwater modeling results, operation of the ART well system has been discontinued
    - Cost savings to client – no more O&M
- Observing early indications of hydraulic capture by Summer 2016
- Down-gradient MWs: Data too date indicate that target concentrations are being met the surface water interface (do not exceed surface water standards - 3 ug/L)
- 2016 – Regulatory approval of Risk-Based Closure with phyto planting as engineering control
- Predicted groundwater uptake by Phyto System: ~6000 to 7000 GPD by 2020

Case Study 3: 1,4-Dioxane Plume in Western Europe

Background

- Former 1,4-Dioxane production facility
- Associated plume: [1,4-Dioxane] near source zone ~ 300 mg/L
- Is phyto feasible? Phytotoxicity??
  - Bench-scale study indicated plants could tolerate >1,000 mg/L 1,4-Dioxane concentrations in groundwater

Phytoremediation Implemented in 2013

- 230 Planting Units – primarily near source zone
- Hybrid Poplars
- RGs: Hydraulic Control & Treatment
- Impacts observed by end of 2014

Mass Balance Evaluation

- Can't account for all 1,4-Dioxane
- Strong indirect evidence of rhizodegradation

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Summary: Phytoremediation of 1,4-Dioxane Impacted Aquifers

Key Takeaways for Remediation Practitioners

- Can be highly effective when applied with ***proper design and implementation***
- Significant ***cost-savings*** over conventional treatment options
- Low O&M
- Stand-alone, ***Green & Sustainable remediation*** technology
- Well-accepted by regulatory community
- Numerous secondary benefits
- Potential for ***enhanced rhizosphere degradation*** (*P. dioxanivorans*, others)

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Thank You

Questions?

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