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Phytoremediation Using TreeWells®: An Innovative Approach to Groundwater Remediation

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What is Phytoremediation and Why Use it?

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What is it?

- Use of plants to degrade or contain contaminants in groundwater, soil, sediments and surface water

Mechanisms:

- *Phytosequestration*
  - Sequester contaminants in root zone (containment)
- *Rhizodegradation*
  - Microbial biodegradation within root zone (remediation by destruction)
- *Phytohydraulics*
  - Capture and evaporate water (containment)
- *Phytoextraction*
  - Uptake of contaminants into plant (remediation by removal)
- *Phytodegradation*
  - Uptake and breakdown of contaminants (remediation by destruction)
- *Phytovolatilization*
  - Uptake and transpire volatile contaminants (remediation by removal)

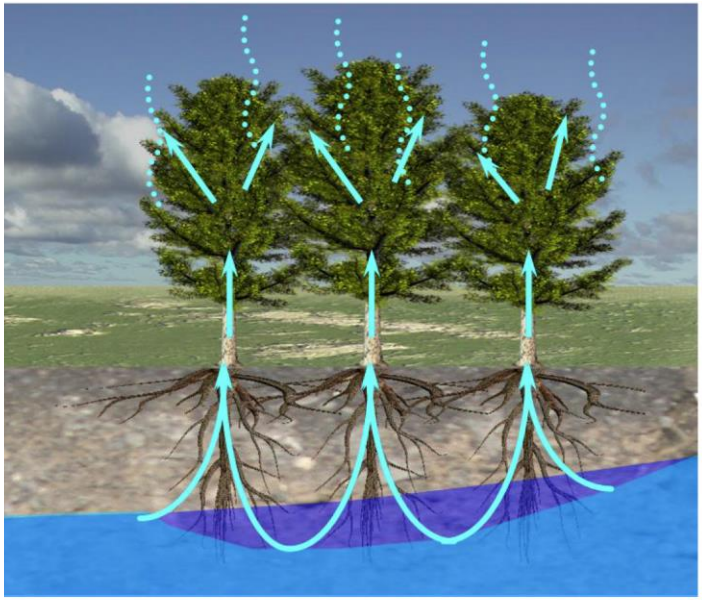

Image: ITRC Phytotechnology Guidance (2009)

What is Phytoremediation and Why Use it?

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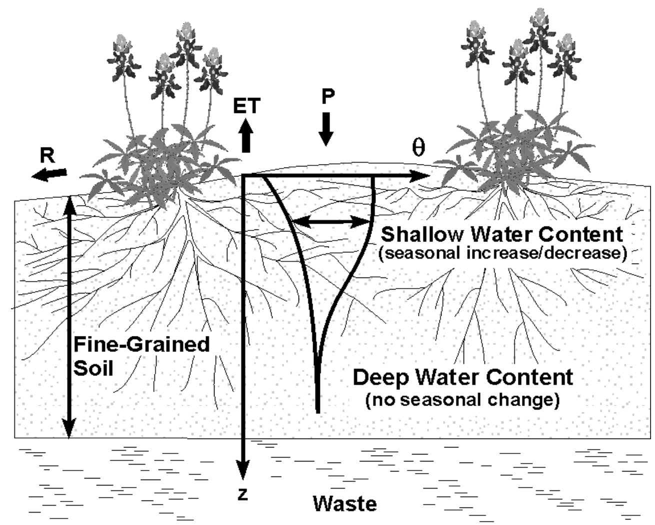
- Example contaminants – Petroleum hydrocarbons, CVOCs, Metals, MTBE, 1,4-Dioxane

Why use it?

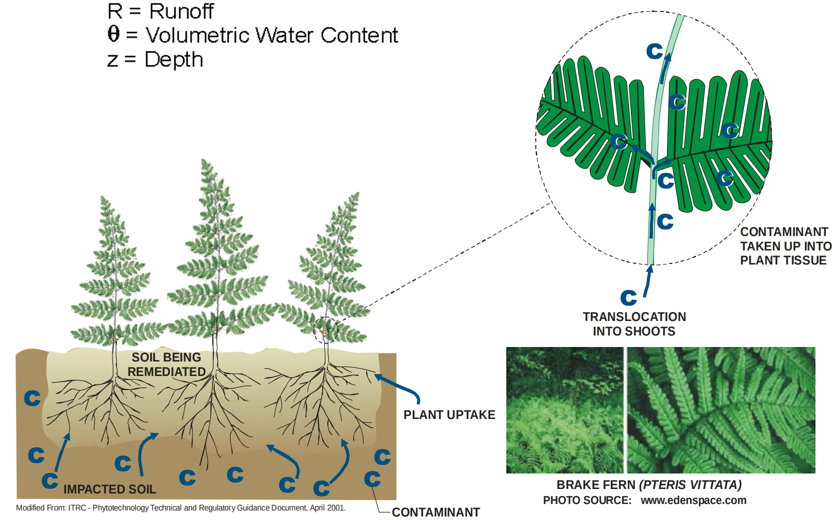
- Low carbon foot print
- Potentially much lower cost than other treatment technologies
- Proven long-term track record *when designed and implemented correctly*
- Well accepted by regulatory community
- Improves with time (trees grow larger, use more water)
- Aesthetically pleasing

Applications

- *Phyto (ET) Covers on Landfills*
  - Alternative covers to minimize percolation into waste and potentially provide waste treatment
- *Constructed Treatment Wetlands*
  - Industrial, municipal, and residential applications
- *Bioswales/Stormwater Wetlands/Green Infrastructure*
  - Storage and treatment of runoff
- *Soil Remediation*
  - Grasses, shrubs, trees
  - Relatively shallow applications (root zone)
- *Groundwater Remediation*
  - Engineered approaches can reach deeper groundwater zones



P = Precipitation
ET = Evapotranspiration
R = Runoff
θ = Volumetric Water Content
z = Depth



Why Use an Engineered Phytoremediation System?

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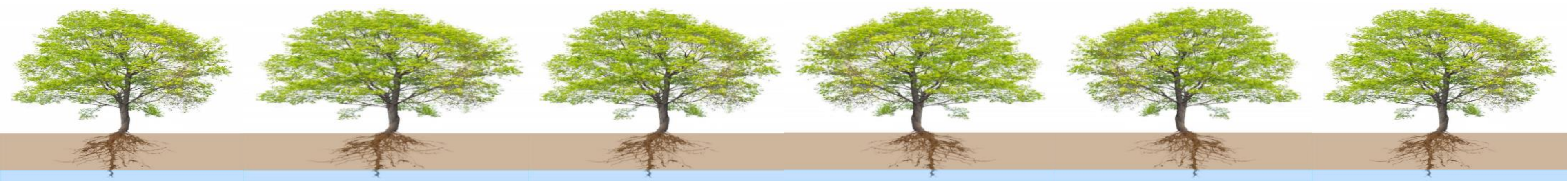
Limitations of Conventional Phytoremediation

- Target groundwater too deep
- Site soils too poor, too compacted
- Concentrations too high

Benefits of Engineered Phytoremediation using the *TreeWell*® System

- Control plant growth, manage site conditions and target the zone of remedial effect
- Target groundwater as deep as 50’ bgs (or more)
- Treat high contaminant concentrations
- Can reduce the time to meet remedial goals vs. conventional phytoremediation
- Example contaminants – CVOCs, Petroleum hydrocarbons, Metals/Metalloids, Sulfolane, MTBE, 1,4-Dioxane, Pesticides
- Enables plants to THRIVE



Engineered Phytoremediation: The *TreeWell* System

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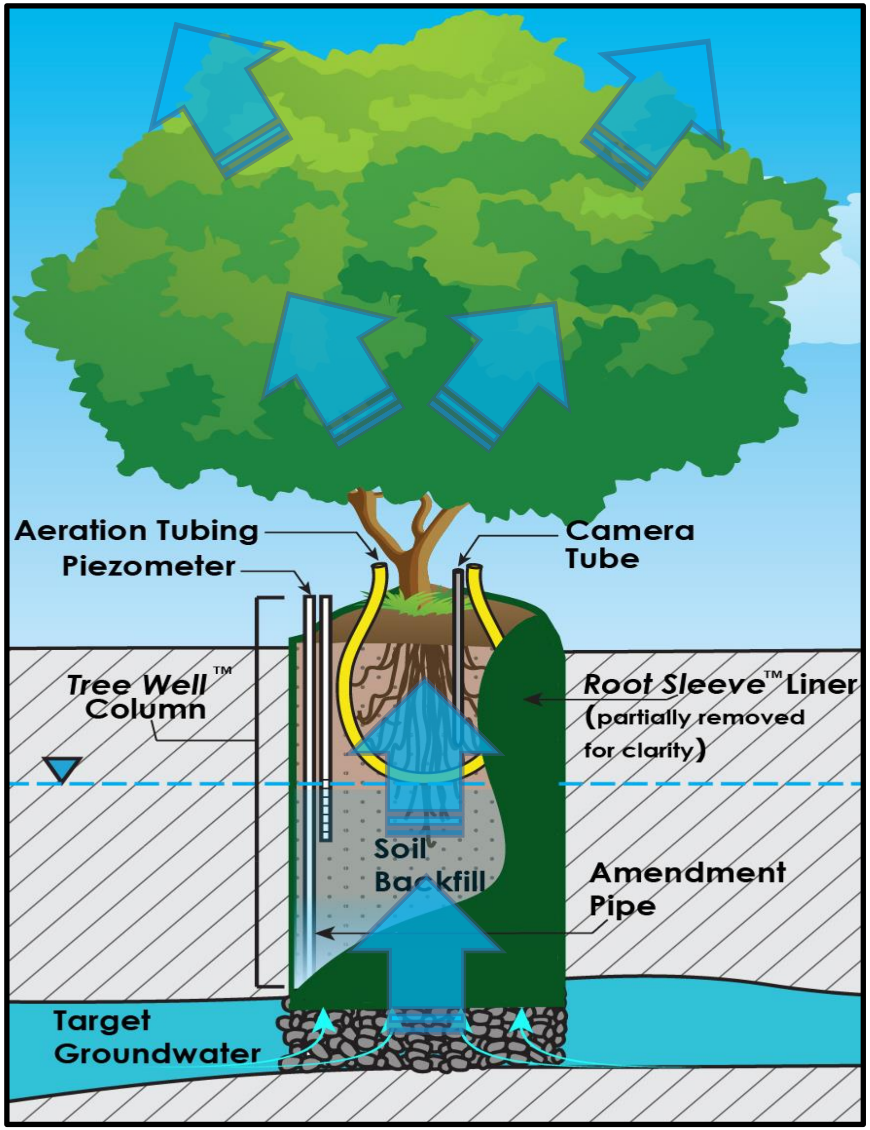

- Patented by Geosyntec's partner firm Applied Natural Sciences, Inc. (ANS)
- Targets <u>specific</u> groundwater by directing root growth downward to capillary fringe
- Groundwater is drawn upward through the soil column, then absorbed by plant roots
- Highly adaptable – can be tailored to specific site conditions
- Effectively target deep or confined aquifers
- Optimizes growing conditions for trees
- Bioreactor effect – both oxidizing and reducing zones in each unit
- Increases soil temps – enhances biodegradation rates in vadose zone
- Pre-treatment option (reactive treatment media)
- Active treatment – in a passive manner
- Maximizes inherent benefits of plant-based remediation by optimizing the key phytodegradation mechanisms…

Key Remediation Mechanisms Involved in the *TreeWell* System

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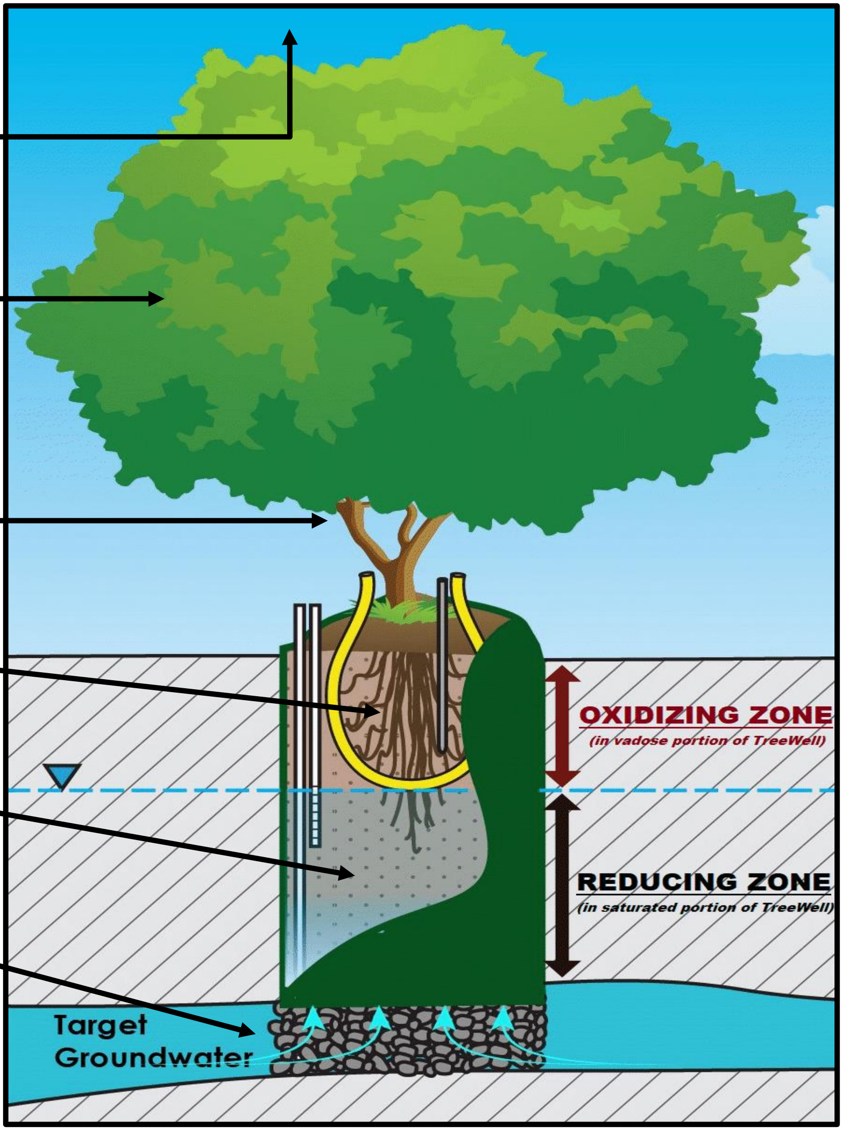
Mechanism	***Description***
Phytovolatilization	Volatile contaminants are absorbed by roots, enter transpiration stream and volatilize off leaf surfaces.
Phytodegradation	*In Planta* degradation of contaminants through uptake into transpiration stream. "Green Liver" concept.
Phytoextraction	Contaminant removal from soil (to lesser degree groundwater) and accumulation *In Planta*.
Rhizodegradation (Oxidizing Zone)	Microbial degradation in the area around plant roots (rhizosphere). Enhanced by root exudates.
Chemical Reduction (Reducing Zone)	"Bioreactor" effect created by *TreeWell* system: strongly reducing conditions can be created in the saturated zone of unit (ISCR)
Phytohydraulics	Containment of impacted groundwater via plant root uptake and evapotranspiration. Often coincides with contaminant degradation. "*Pump & Treat*" mediated by plants.



Typically a combination of these mechanisms are at work

Engineered Phytoremediation: The "Straw" *TreeWell* Unit

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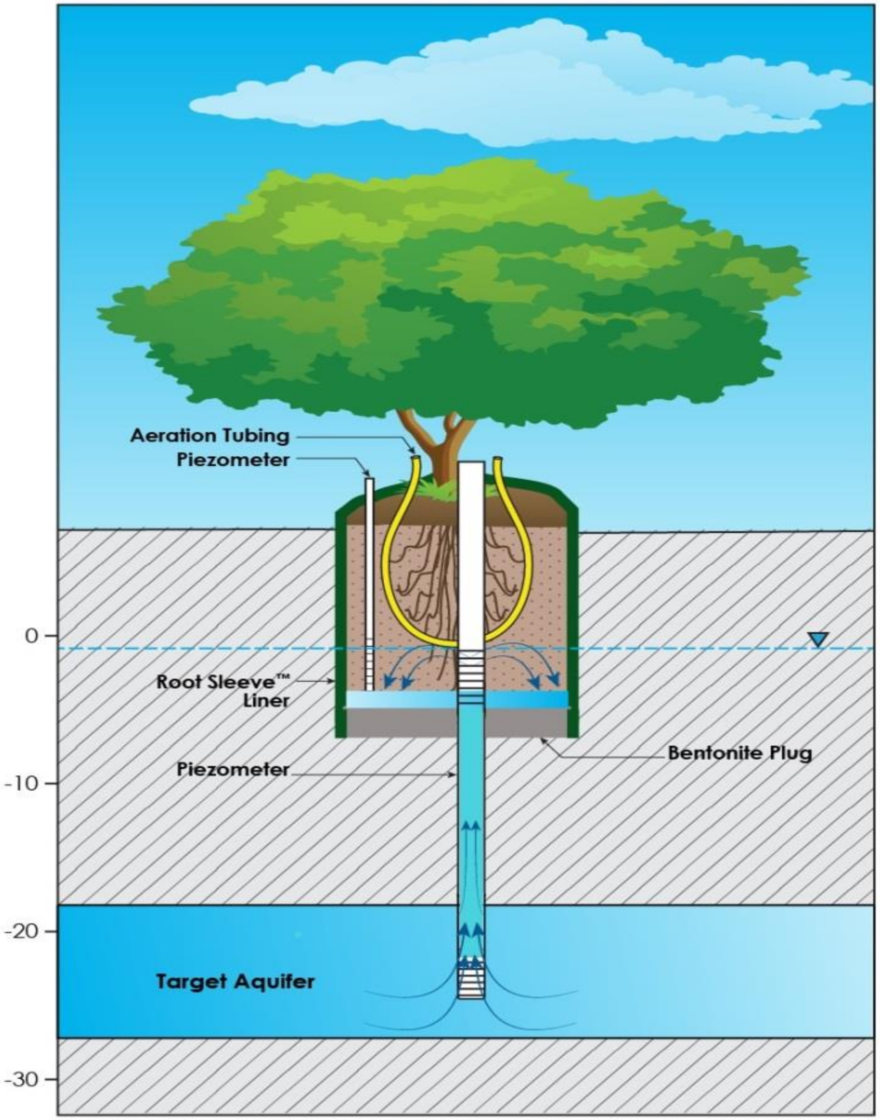

"Straw" *TreeWell* Design

- Targets deep confined aquifers
- Overcomes constructability challenges of shallower water-bearing zones above the aquifer of interest
- Hydraulic head drives target groundwater into the TreeWell unit through the double-screened "straw" piezometer

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

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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 species cleared for phytoremediation system
- Expedite permitting process by promoting wetland restoration

Remedial Goals

- Hydraulic Control
- Contaminant Treatment

Case Study 1: System Installation

2013 Installation

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*)

Summer 2015

Case Study 1: Impact on Groundwater Flow

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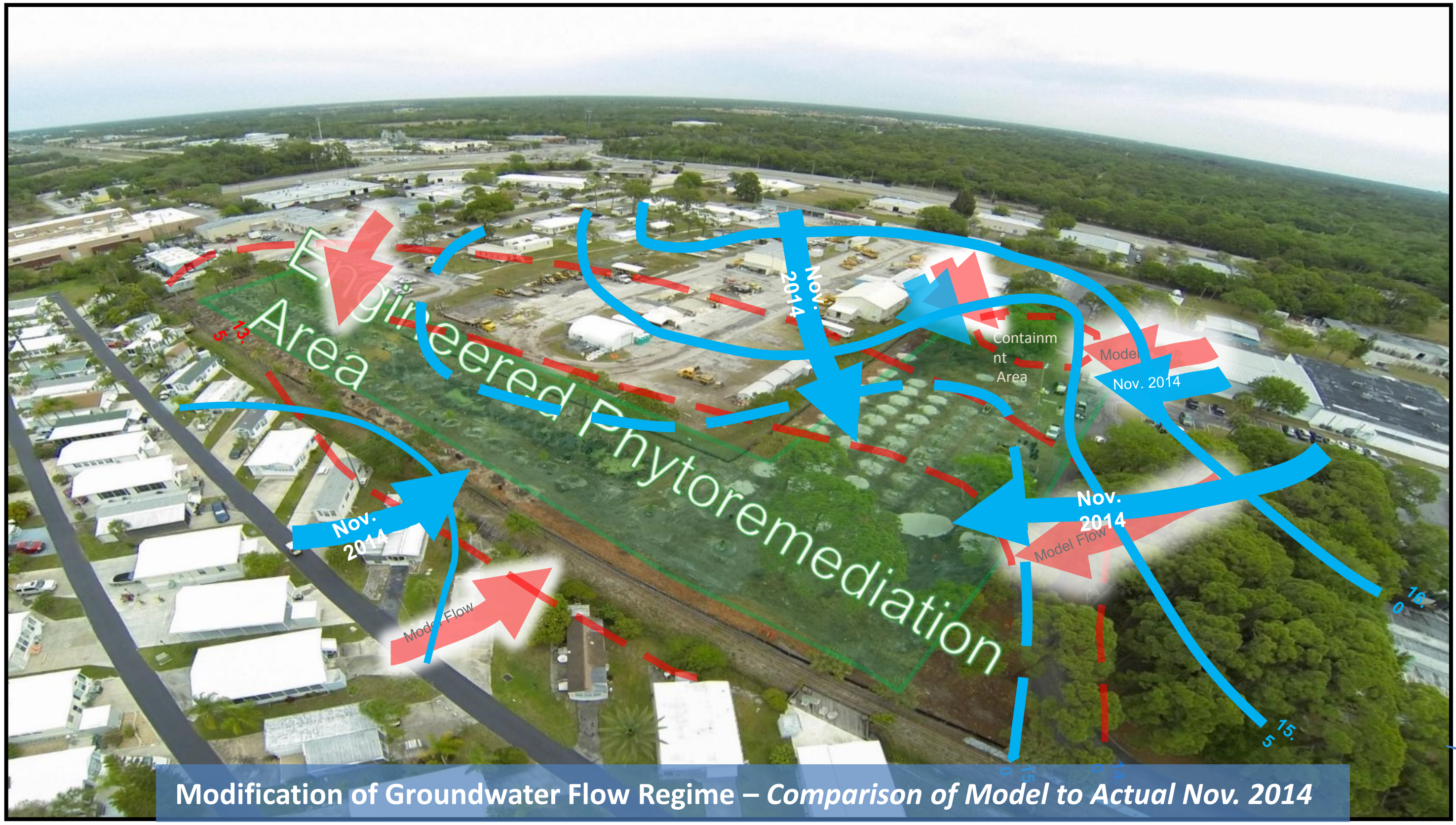
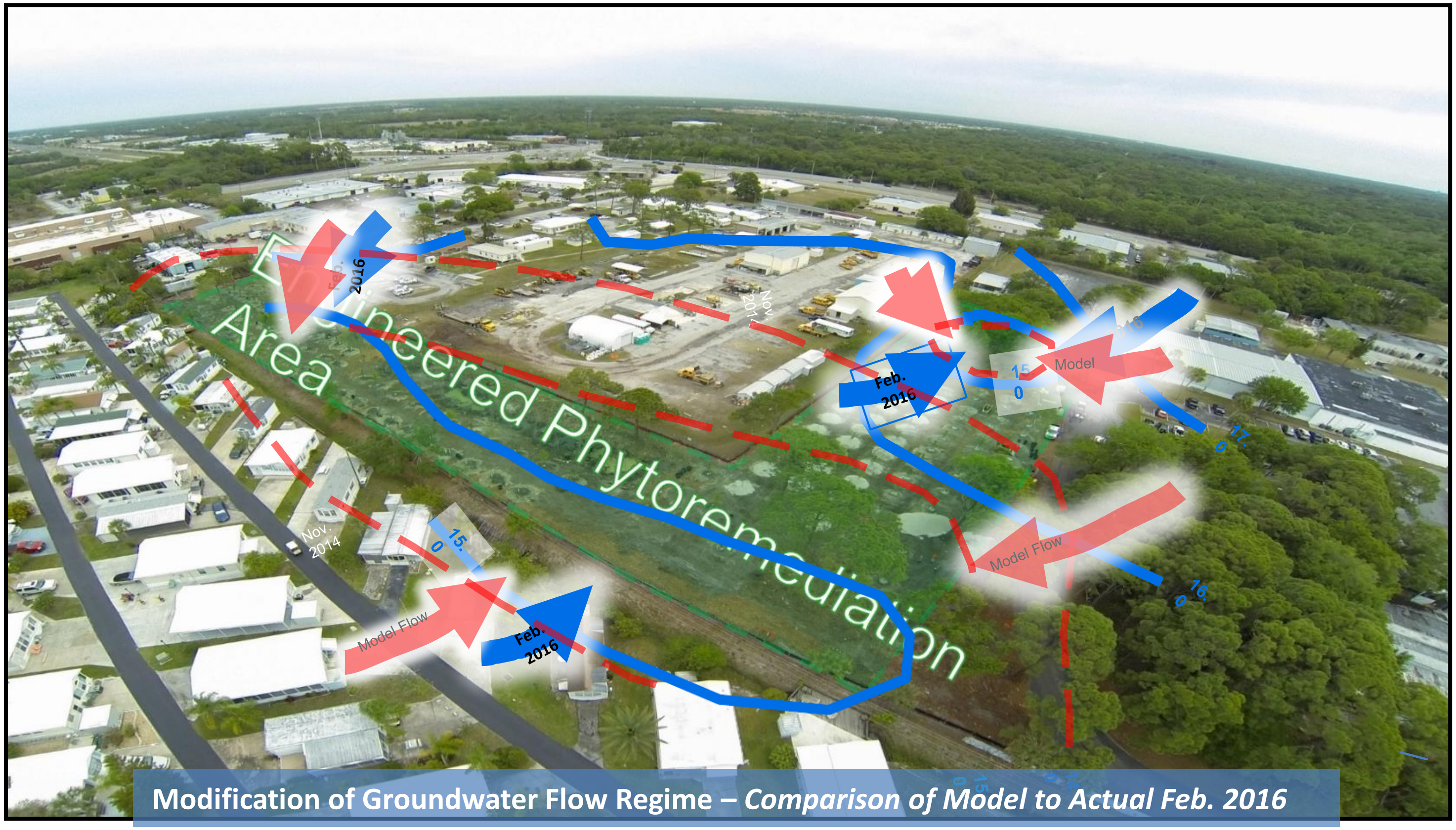
- ***Yellow*** indicates initial GW flow at time of Phyto System installation (away from source area towards site boundary)
- ***Blue*** indicates GW flow ***18 months after*** Phyto System installed (gradient reversal/hydraulic control; flow towards the Phyto System)
- Results have been very consistently 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.

Case Study 1:
Modeled vs Actual Groundwater Flow



Case Study 1:
Modeled vs Actual Groundwater



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

Case Study 1: Monitoring Data

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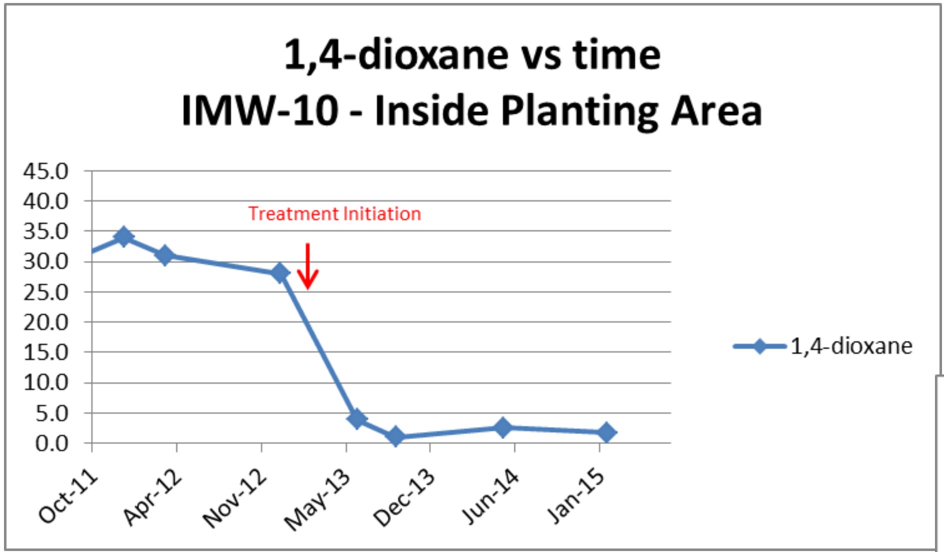
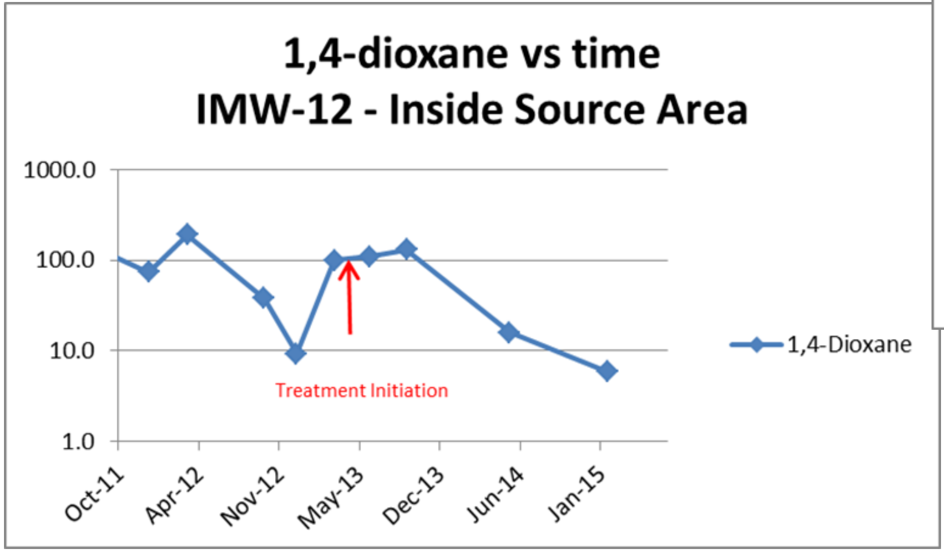
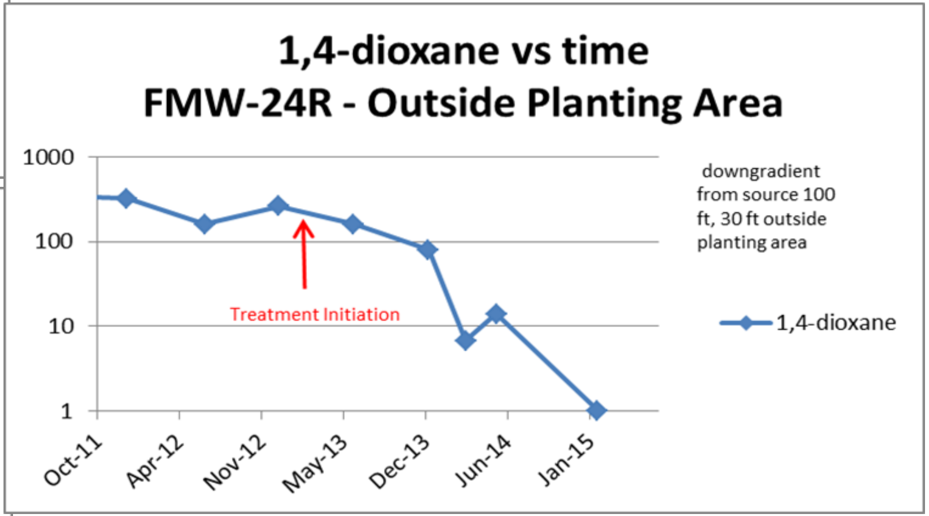


- **Additionally, dissolved-phase concentrations have decreased significantly and rapidly since implementation**
- ***No Further Action* – January 2017**





All indicated concentrations in µg/L

Case Study 1:
Cost Savings of Phytoremediation

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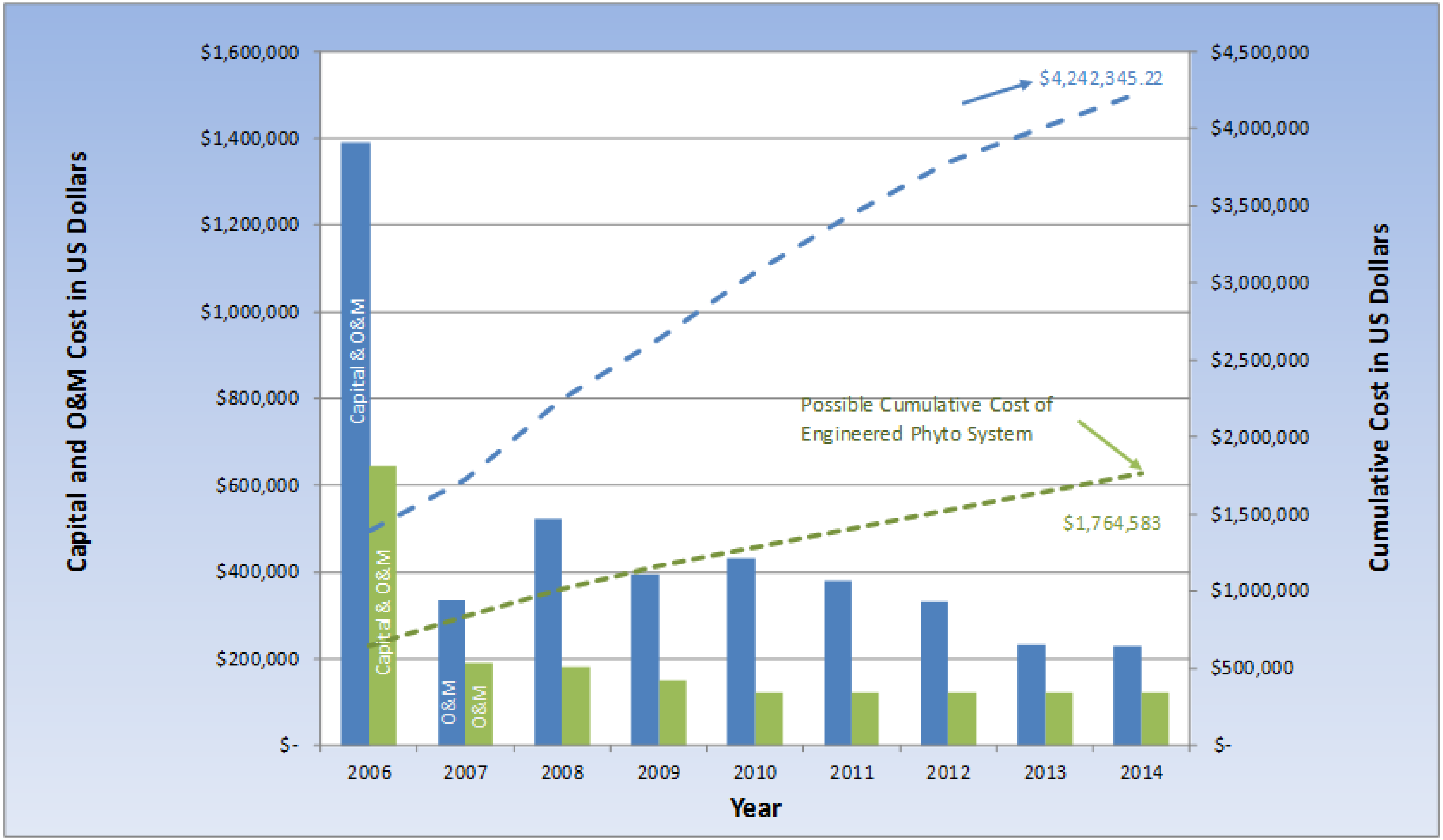

Case Study 2: 1,4-Dioxane in a Saprolite and Fractured Bedrock – North Carolina

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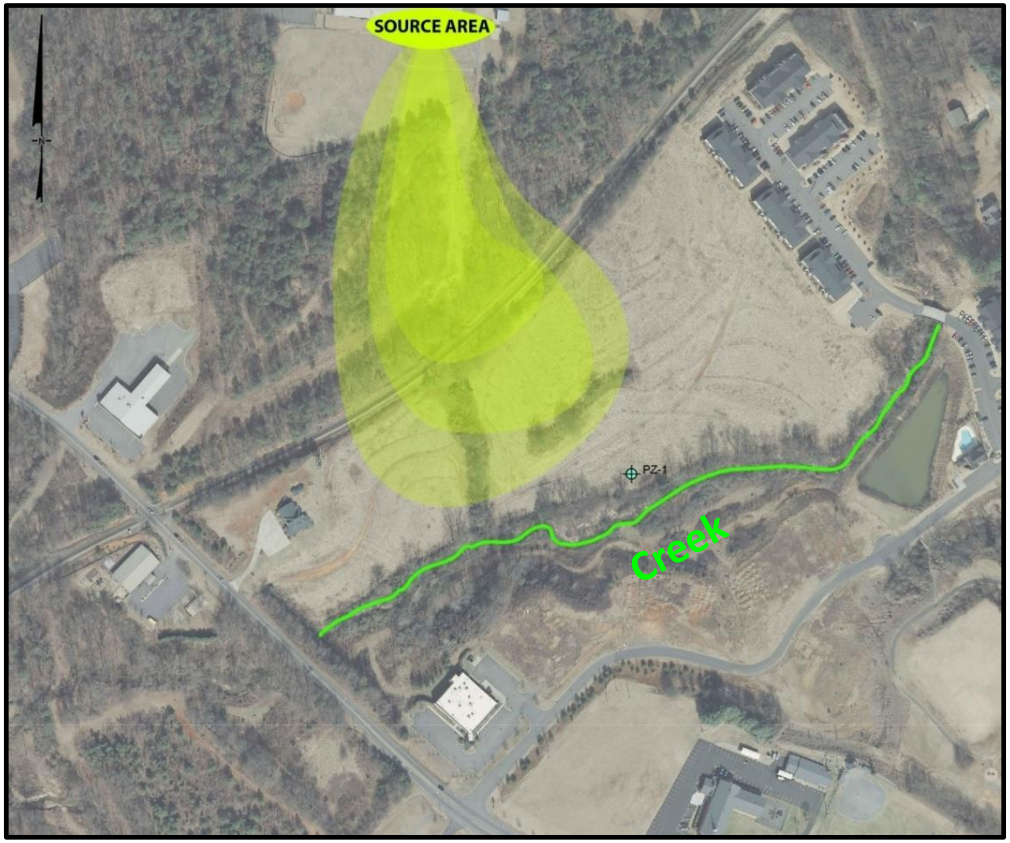
Site Background

- 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

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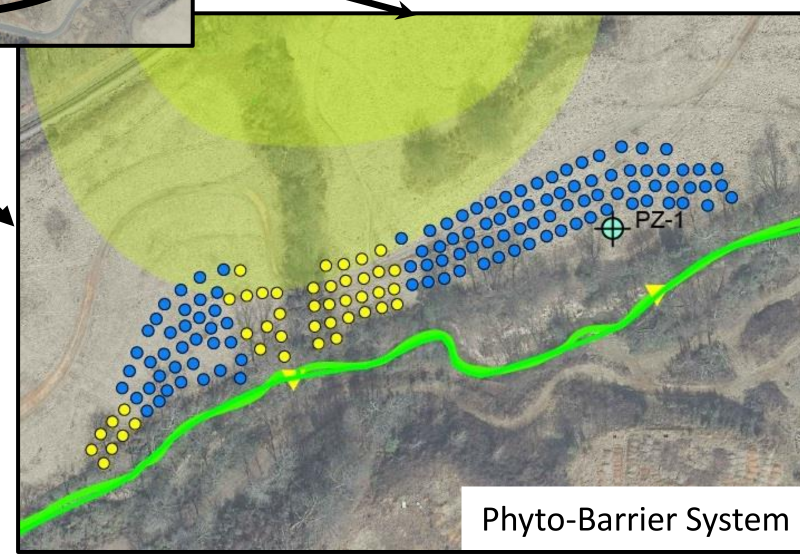
FOCUSED FEASIBILITY STUDY

- 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



Case Study 2: Groundwater Modeling Predictions

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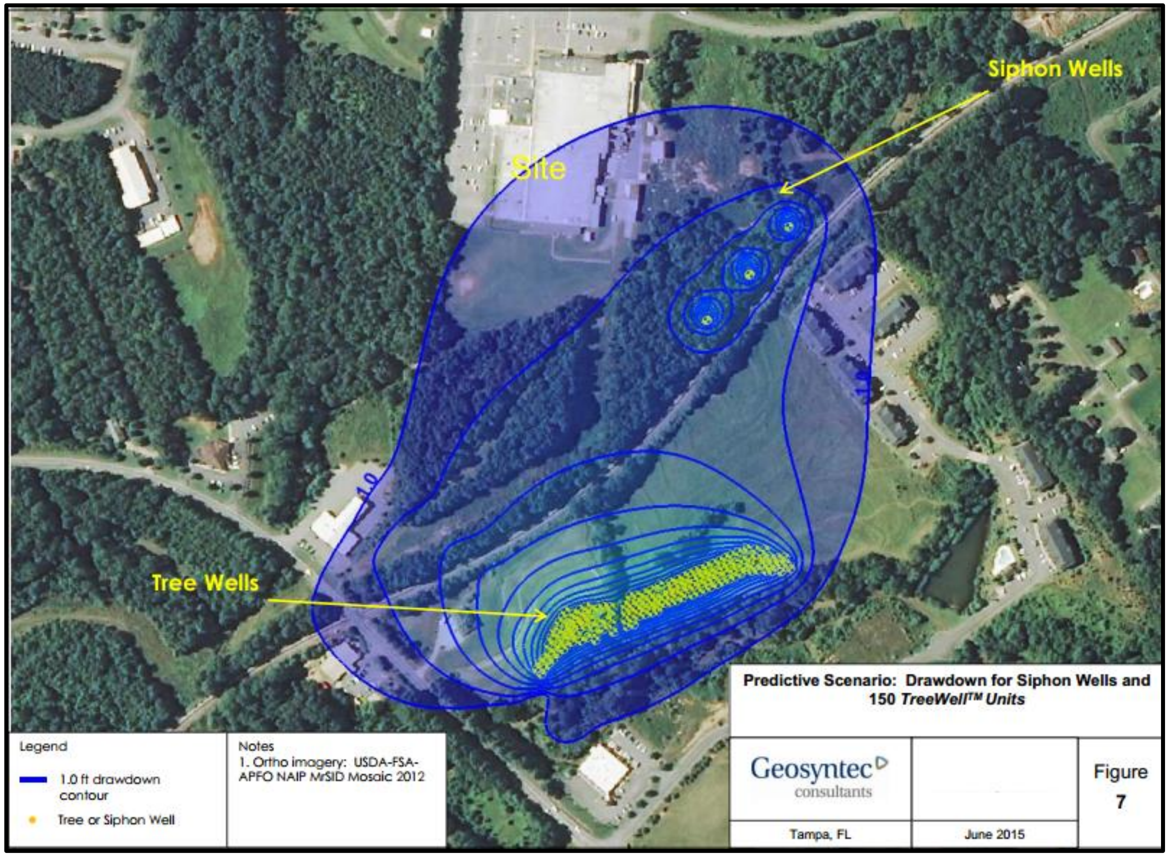
Groundwater Modeling

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



Case Study 2: Phytoremediation System Installation – Spring 2015

Drilling Operations

Tree Planting

Completed System

<u>Spring 2015 Installation of 150 units adjacent to creek</u>

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

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

Case Study 2: Summary of Results To Date

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- On the basis of the rebound study and the groundwater modeling results, operation of the ART well system has been discontinued, and has since been dismantled
    - Cost savings to client – no more O&M
- Observing early indications of hydraulic capture by Summer 2016
    - Transducer data show consistently lower heads inside plantation versus outside
    - Inward gradient established
- Down-gradient MWs: Data to date indicate that target concentrations are being met at the surface water interface (do not exceed surface water standards - 3 µg/L)
- 2016 – Proposed possible Risk-Based Closure with phyto planting as engineering control under new North Carolina RBCA rule.
    - Outcome pending.
- Predicted groundwater uptake by phyto system: ~6,000 to 7,000 GPD by 2020

Summary of Key Phytoremediation Benefits

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- Can be very effective when applied with proper design and implementation
- Highly adaptable to specific site conditions and contaminants
- Applicable to many contaminants – even at high concentrations
- Applicable to many sites – even in cold climates
- Great alternative to P&T systems
- Potential of significant cost-savings over conventional treatment options
- Stand-alone technology
- Well-accepted by regulatory community
- Numerous secondary benefits

Thank You

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