Phytoremediation of Nitrogen-Impacted Sites: Adapting a Natural System for Site Cleanup

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Presented by:

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Phytoremediation: What Is it And Why Use It?

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What is it?

- Use of plants to degrade or contain contaminants from groundwater, soil, sediments and surface water
- Example contaminants – Petroleum Hydrocarbons, CVOCs, Metals/Metalloids, MTBE, 1,4-Dioxane, Nutrients ***and especially Nitrogen!***

Why use it?

- *"Green & Sustainable"* vs other more traditional technologies
- Typically much lower cost than other treatment technologies
- Proven long-term track record *when designed and implemented correctly*
- Aesthetically pleasing
- Well accepted by regulatory community
- An effective risk-management strategy for addressing contaminated sites
  - Reduce contaminant mass (treatment)
  - Prevent migration of contaminants (containment)

Why Phytoremediation for Nitrogen Impacted Sites?

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- Traditional treatment options typically expensive to install and maintain (e.g., P&T, in-situ bio, PRBs)
- Conversely, plants must have N, and obtain it *passively*. N is the single nutrient needed most by plants
  - Example: corn fields may receive > 150kg/acre of N several times per growing season
  - Fast-growing, deep-rooting trees have as much or more demand for N (e.g., Poplars, Willows, Eucalypts)
- *Utilize the multiple N-removing mechanisms that plants bring to bear…*

Five Key Phytoremediation Mechanisms for Nitrogen Treatment

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1. Root uptake of soil- or groundwater-borne nitrate and/or ammonium for plant growth (***Mass Removal)***
2. Dewater surficial soils by transpiration and containment of N to groundwater (***Containment***)
3. Hydraulic control of N by transpiration uptake of groundwater i.e., transpiration (*Containment*)
4. Promote denitrification ($NO_3 \rightarrow N_2$) due to root exudates (*e-donor*) - creates anoxic conditions under trees (***Treatment)***
5. Promote anammox process ($NH_4 + NO_3 \rightarrow N_2$) due to root exudates - creates anoxic conditions under trees ***(Treatment)***

Typically a combination of these mechanisms provides the desired phyto-remedial outcome

Phytoremediation Approaches

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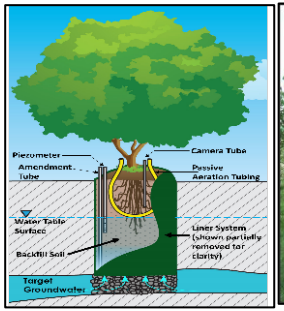
- **Traditional or Non-Engineered**
  - Conventional planting to treat affected soil and/or groundwater
  - For sites where impacts are near surface and accessible to roots (within ~3m bgs)

- **Engineered/Constructed**
  - Exclusively for groundwater impacts (not soil)
  - Designed and constructed systems to control plant growth, manage site conditions and target the zone of remedial effect
  - E.g., *Root-Directed Phytoremediation* system



Case Studies: Three N-Impacted Phytoremediation Sites

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- U.S. Sites: *Delaware, N. Carolina and N. California*
- What about colder climates? And how do we overcome wintertime dormancy issues? *Particularly for groundwater phytoremediation systems*…
- Phyto system design ***must*** account for dormancy
- Layout of phyto system must account for wintertime plume migration, to prevent off-site migration
- Determine the plume's velocity
- In milder climates (e.g., BC) utilize conifers or evergreens in the phyto system for year-round transpiration
- Must be understood that ***colder climates = longer time to meet remedial goals***

Northern California Phytoremediation Project

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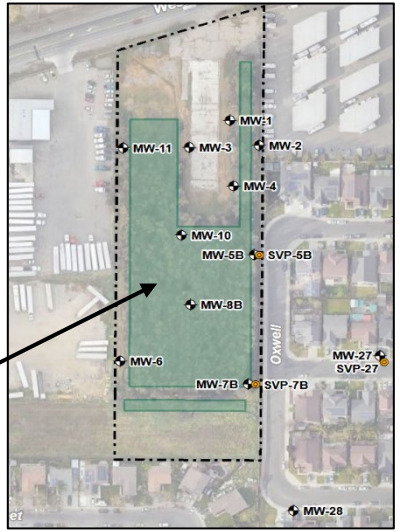
Site Background

- Former ag-chem distribution facility; closed in 90's
  - N-fertilizer and other ag products
- NO_3 and NH_4 are primary COCs by mass (~99%)
- Soil: NO_3 = 6 to 696 mg/kg; NH_4 = ND to 67 mg/kg
- GW: NO_3 = ND to 140 mg/L; NH_4 = ND to 246 mg/L
- GW at ~ 2 to 4m bgs
- Phytoremediation system implemented in 2003 over 2.3-acres
  - Red Gum Eucalyptus (Evergreen trees)
- Key Remedial Goals
  - *Contaminant treatment of soils & GW*
  - *Hydraulic Containment of plume*
- Long-term success
  - *Year-round hydraulic control of plume*
  - *Significant reduction in COC mass (>99% for some COCs)*
  - *1,000s of kgs of N-NO3 removal*



Northern California Phytoremediation Project: Hydraulic Gradient Effects

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- *Summertime potentiometric surface measurements indicate **strong inward gradient,** due to the "phyto-pumping" by trees in the phytoremediation plantation*
- *Protects residences located immediately downgradient of the site from VOCs in groundwater*

- *Wintertime potentiometric surface measurements **still** indicate **inward gradient** due to the "phyto-pumping" by trees by the plantation*
- *Still protective for residences located immediately downgradient of the site*
- *Evergreens and mild wintertime temps*

Central California Phytoremediation Project: Total-N Trends in Soil

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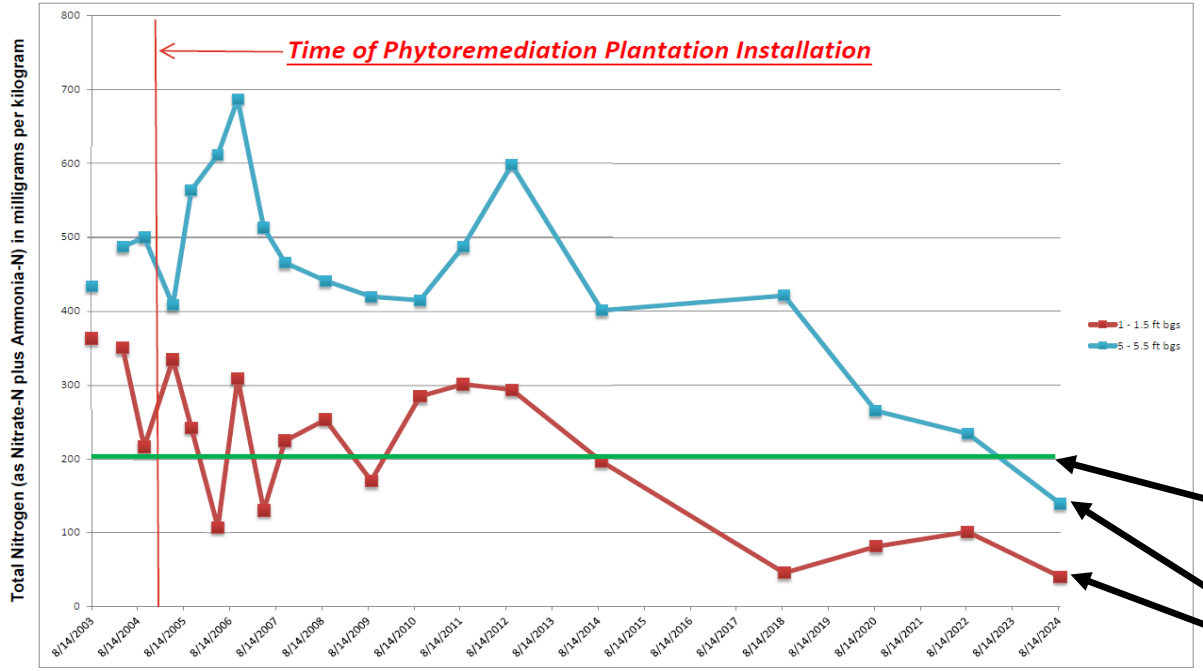

HISTORICAL AVERAGE SOIL TOTAL NITROGEN CONCENTRATIONS

Northern California Phytoremediation Site

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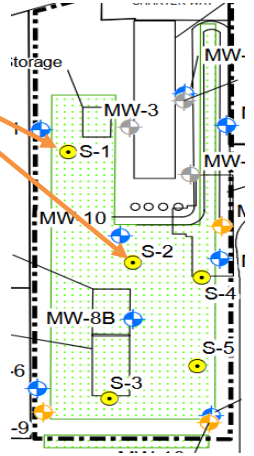
Five Biennial Soil Sampling Locations



- **Total-N** = ***NO_3-N + NH_4-N***
- **200 mg/kg** Total-N = ***Cleanup Goal***
- Total-N in AUG-2024 **< 200 mg/kg** in both sampled depth intervals for first time

Delaware Poultry Processor

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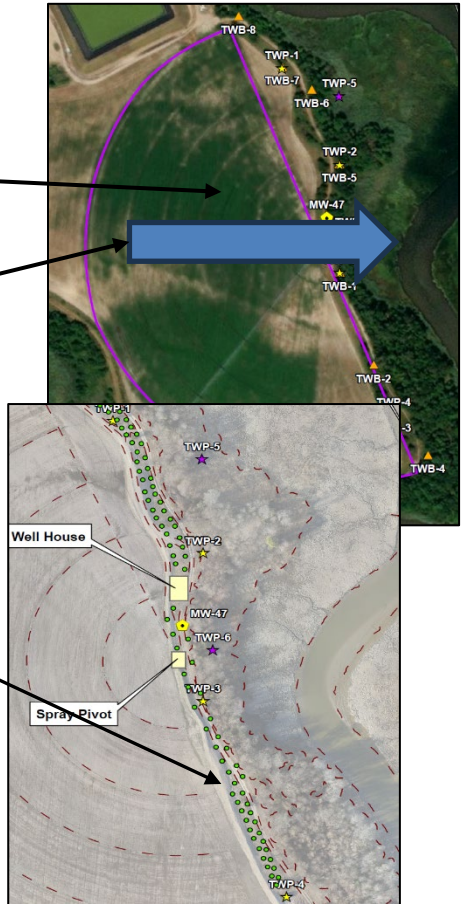
Site Background

- Active poultry processing facility
  - Process WW applied to ag fields (pivot "fertigation")
  - Led to NO_3 impacts to shallow groundwater
- GW: NO_3 = 10 to 45 mg/L
- GW at ~ 3 to 6m bgs
- GW flows toward sensitive surface water body
- Potential NO_3 migration to creek triggered remediation reqmt.
- Phytoremediation system implemented in spring 2023
  - 80 Engineered Phytoremediation Units
  - Arrayed along a ~ 1,000-ft transect, perp. to GW flow
  - Intercept & treat plume
- Key Remedial Goals
  - *Hydraulic Containment of plume*
  - *Contaminant treatment of GW*



Delaware Phytoremediation System

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Phytoremediation Implementation

- Units constructed in fall 2022
- Targeting GW at depths between 3 to 6 m bgs
- *Poplars & Willows* planted in spring 2023; fast-growing and deep-rooting phreatophytes
- “Nitrogen-hungry” trees

Delaware Phytoremediation System

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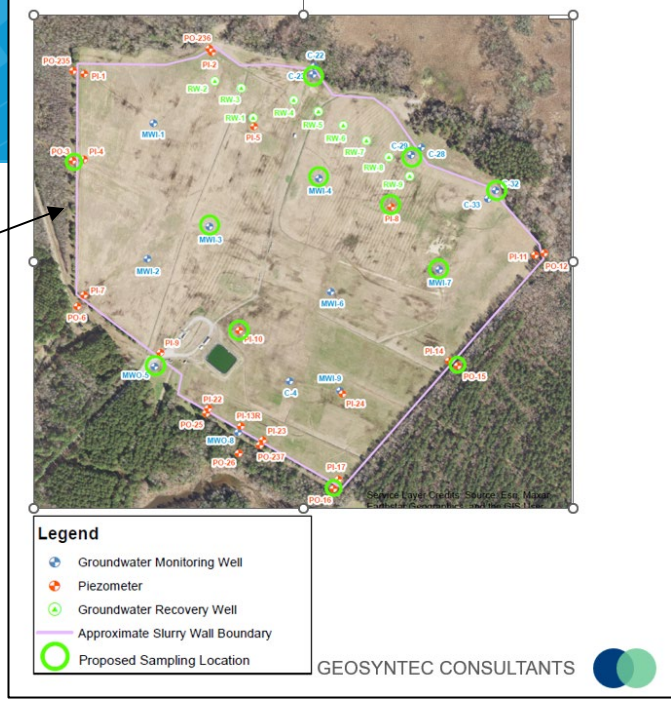
Phytoremediation System Status

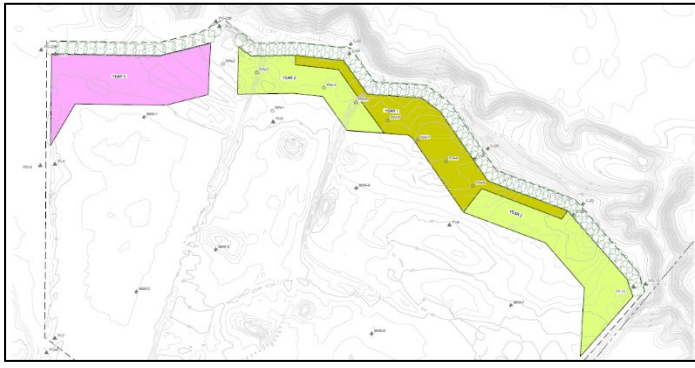
- Within 3 growing seasons, most trees between 5 to 8 m tall, with substantial canopies
- Roots confirmed to 3-m bgs by camera inspection
  - *Hydraulic connection with target GW now being established*
  - *Increasing positive effects on N-impacted plume with next growing seasons*
  - *Downgradient performance MWs will indicate effectiveness*

N. Carolina Phytoremediation System

Site Background

- **Former N-fertilizer manufacturing facility; closed in 90's**
  - **Significant N impacts to GW over its ~ 100 acres**
- **GW: Avg. NO_3 = 213 mg/L; Avg. NH_4 = 200 mg/L**
- **GW at ~ 3m bgs**
- **Present remedy = large slurry wall containment with P&T**
  - **Pumped GW (~53 M litres/yr) stored in pond; used for fertigation**
  - **Truck-based transport; *high $ and high GHG***
- **Beginning in 2025: large-scale traditional phytoremediation**
  - **2025: First 5 of 20 acres planted**
  - **APR-26: Add'l 10 acres to be planted**
  - **APR-27: Final 5 acres to be planted**
- **Key Remedial Goals**
  - *Hydraulic Containment of plume*
  - *Contaminant treatment of GW*
  - ***Shut down current remedy & save $$$***





N. Carolina Phytoremediation System

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Spring 2025: First 5-Acres Planted

- **High-density tree plantings**
- **Poplar, Willow, Sycamore and other trees**
- **Raised bed plantings**
  - ***Drip-line irrigation using the on-site storage pond as source***
  - ***Reduces weed competition***
  - ***Begin reducing trucking reqmts.***
- **Learnings from 2025 being applied to 2026/2027 implementations**

Phytoremediation for N-Impacted Sites
Summary & Takeaways

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Whether Traditional or Engineered, Phytoremediation Can be *Highly Effective* for N-Impacted Soil and/or GW

- NO_3 and NH_4 impacts can be effectively managed/treated by phytoremediation
- Proper assessment of site will allow for optimal system design & long-term effectiveness
  - **Properly characterize site from a phytoremediation perspective**
  - **Confirm impacted media are accessible to plant roots (may require engineered approach)**
  - **Expectations are reasonable**
    - *Time frame for cleanup*
    - *Site prep requirements*
    - *Maintenance requirements (irrigation, fertilization and/or weeding)*
  - **Phytoremediation can be effective in cold-weather climates**
    - *Colder climates = longer time to meet cleanup goals*

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Thank You

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