# Lessons Learned in the Remediation of Herbicides Contaminated Groundwater Using *Engineered_Phytoremediation*$^{SM}$

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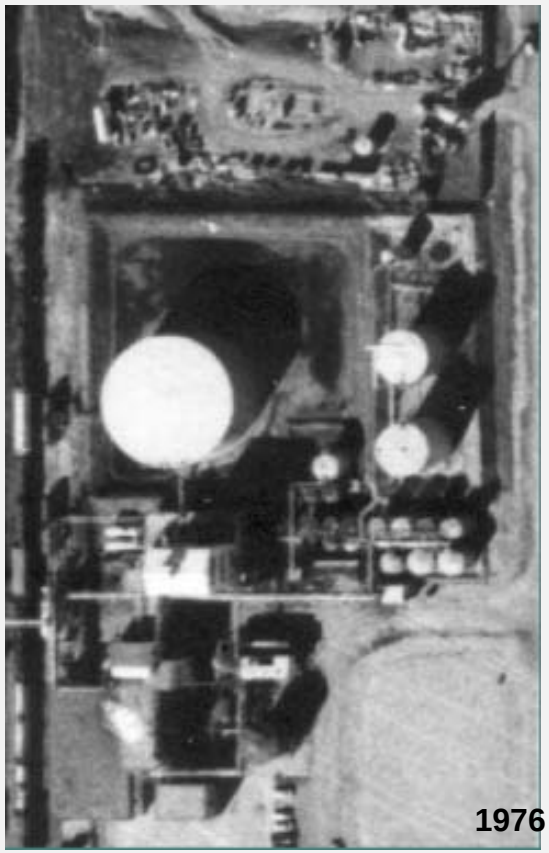
TEA Inc. | Environmental Solutions

# Types of Phytoremediation

- Traditional phytoremediation

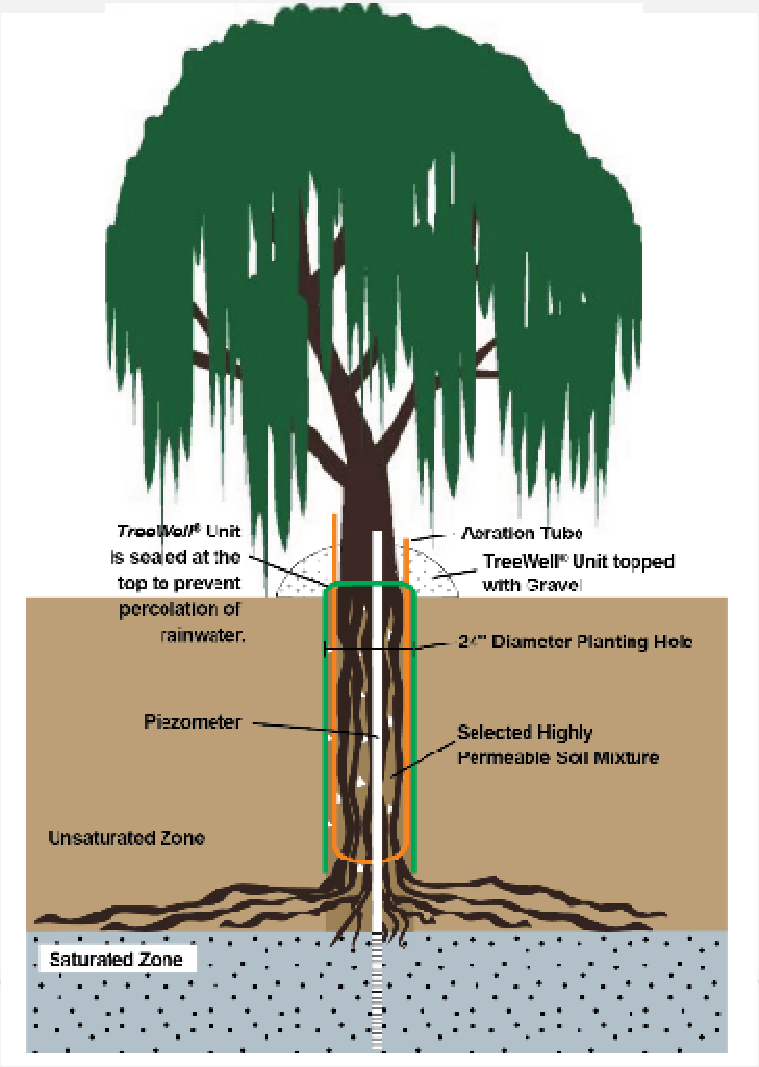
- *Engineered_Phytoremediation*[SM]
  - **Utilizes patented technology**
  - **Promotes vertical root growth**
  - **Focuses the hydraulic influence of trees on targeted groundwater zones**
  - **Enhances tree viability in phytotoxic environments**

# Site Background


1976

- Herbicide production facility from 1961-1980
- Asphalt cap installed in 1988 over the former manufacturing area
- 2,4-Dichlorophenoxyacetic acid (2,4-D). 2001 Max Conc. = 3,800 ppm
- 0.3m-2m fill and surficial sand overlying 10m thick lacustrine, 20m thick clay till, 5m thick empress formation, and bedrock

# Site Phytoremediation Concept




- Target shallow lacustrine groundwater using *TreeWell*® units
- Groundwater flows upward through media within *TreeWell*® *Root_Sleeve*™
- Biodegradation prior to groundwater uptake
- Aeration tubing enhances dissolved oxygen levels

# Pilot Study Objectives

- Determine viability as a long-term remedial strategy
- Reduce 2,4-D concentrations
- Obtain hydraulic control of groundwater

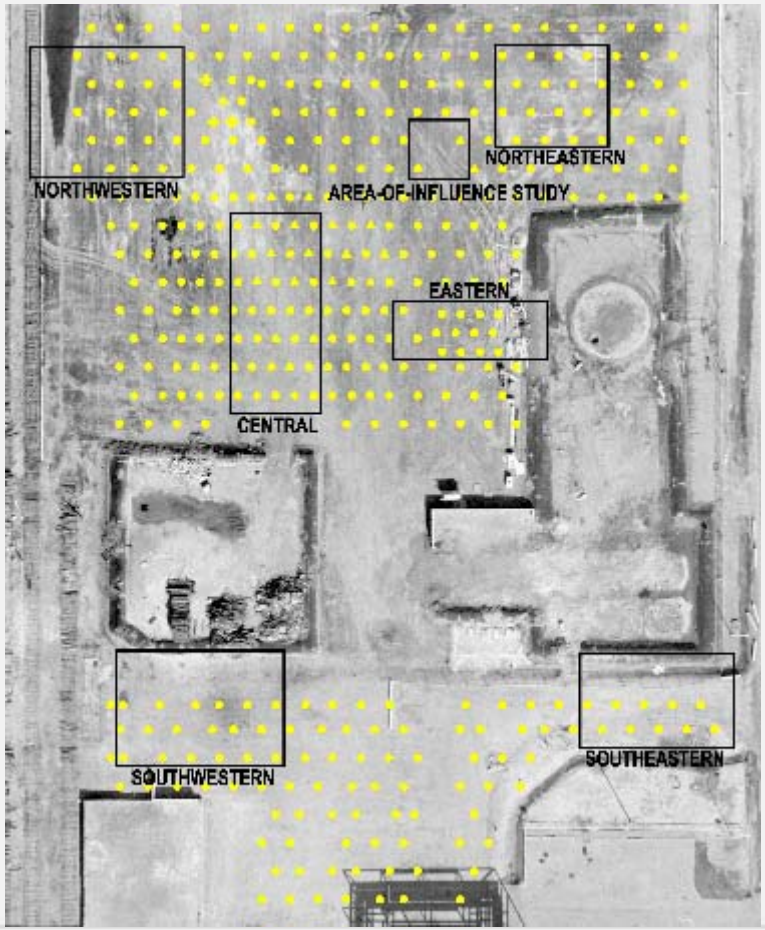
# Challenges for Phytoremediation

- Presence of residual material
- Fluctuating groundwater levels resulting in temporary concentration increases
- Short growing seasons resulting in limited biodegradation
- Shallow water-table depth
- Nutrient deficient soils
- Unknown mortality rates during the early stages of the phytoremediation system

# *Engineered_Phytoremediation*$^{SM}$ Implementation Timeline

- **Focused pilot study (2002)**
  - **6 species, 20 locations with 16 trees and 4 grasses**
- **Large scale pilot study (2005)**
  - **6 species, 400 locations with trees 458 trees**
  - **Monitoring program (tree health and measurements, groundwater elevation, chemical analysis)**
- **Tree replanting (2007 and 2011)**

# *Engineered_Phytoremediation*[SM] Planting Locations




## 2005 Implementation

- Birch
- Green Ash
- Hackberry
- Laurel Leaf Willow
- Poplar
- Quaking Aspen

## Replanting

- Green Ash
- Russian Olive
- Sea Buckthorn
- Tamarack

# *Engineered_Phytoremediation*[SM]
# Installation June 2005

# Phytoplantation Over Time

**Trees can do more than just survive in the presence of 2,4-D**

**June 2007**

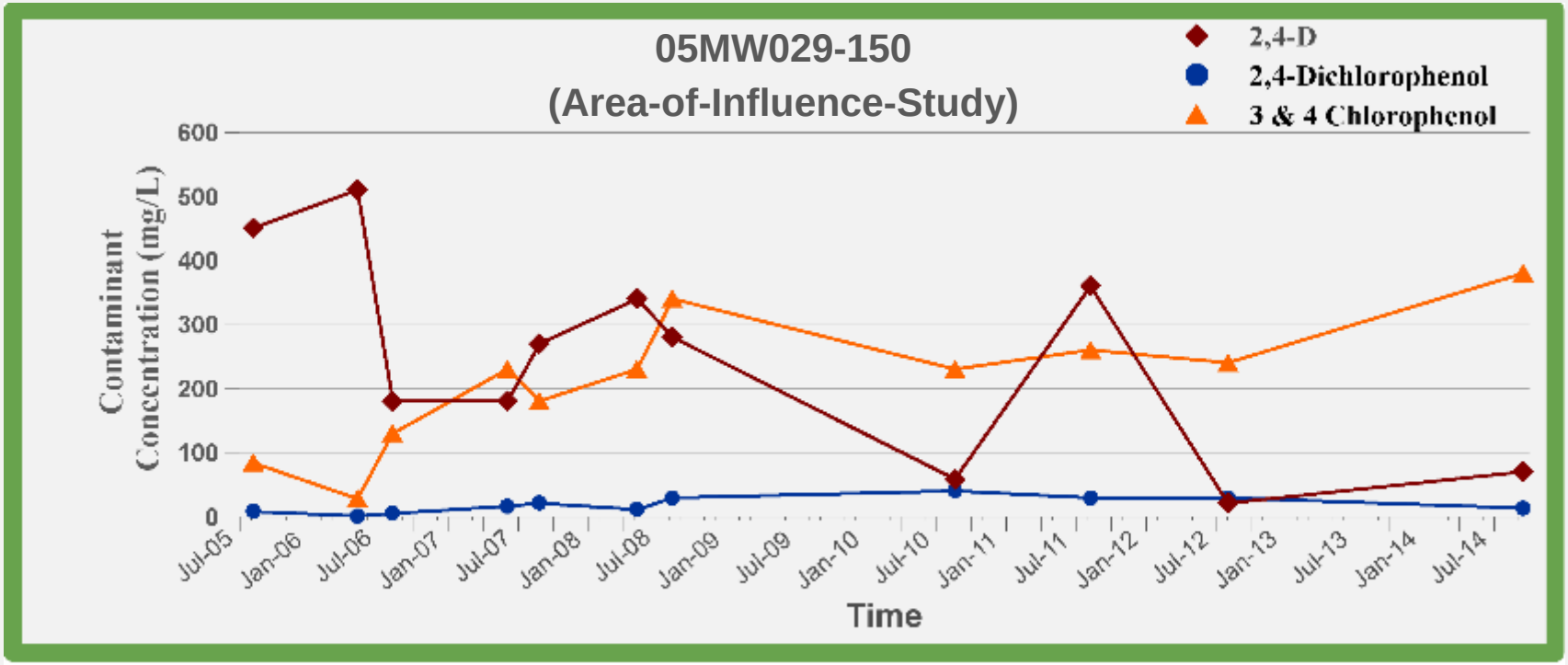
# Phytoplantation Over Time

**Trees can do more than just survive in the presence of 2,4-D**

June 2011

June 2015

# Evidence of Remediation




○ – *Concentration is non-detect for sampling event, graphed as 1/2 detection limit.*

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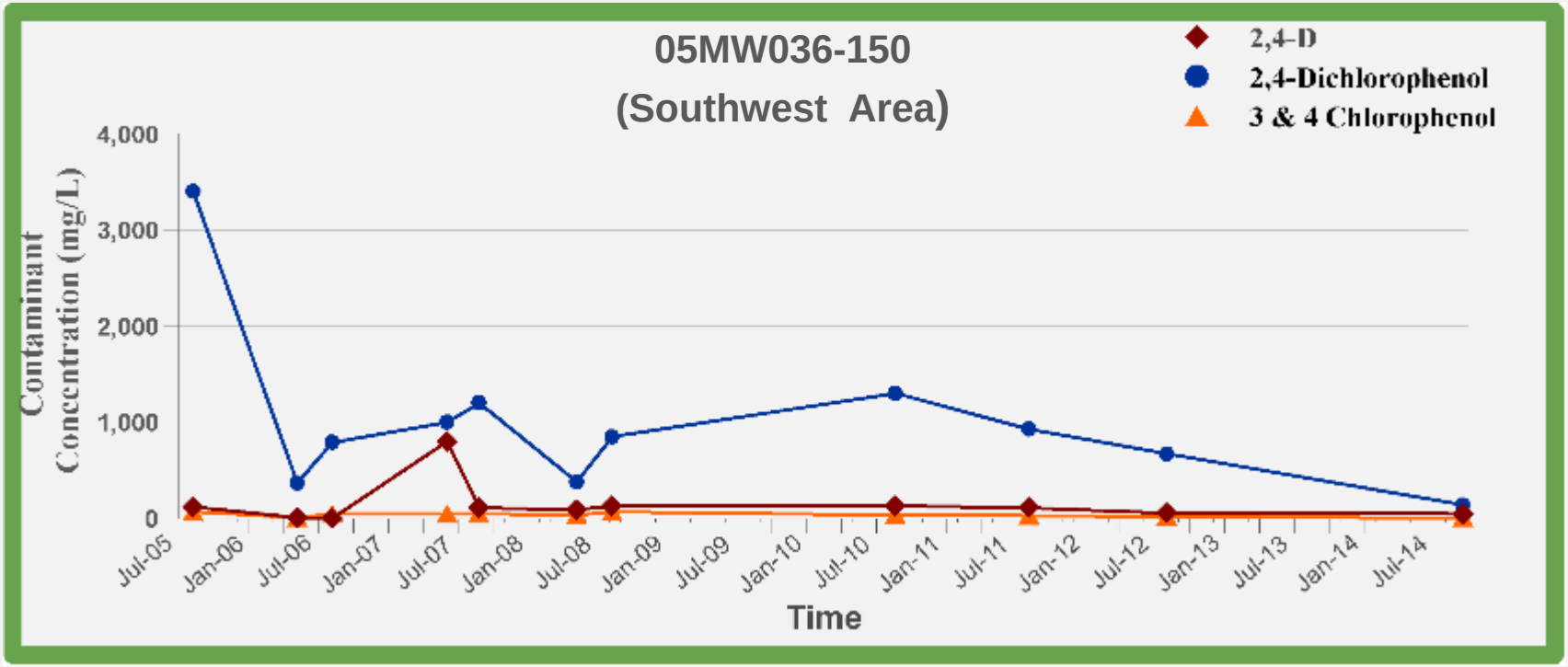

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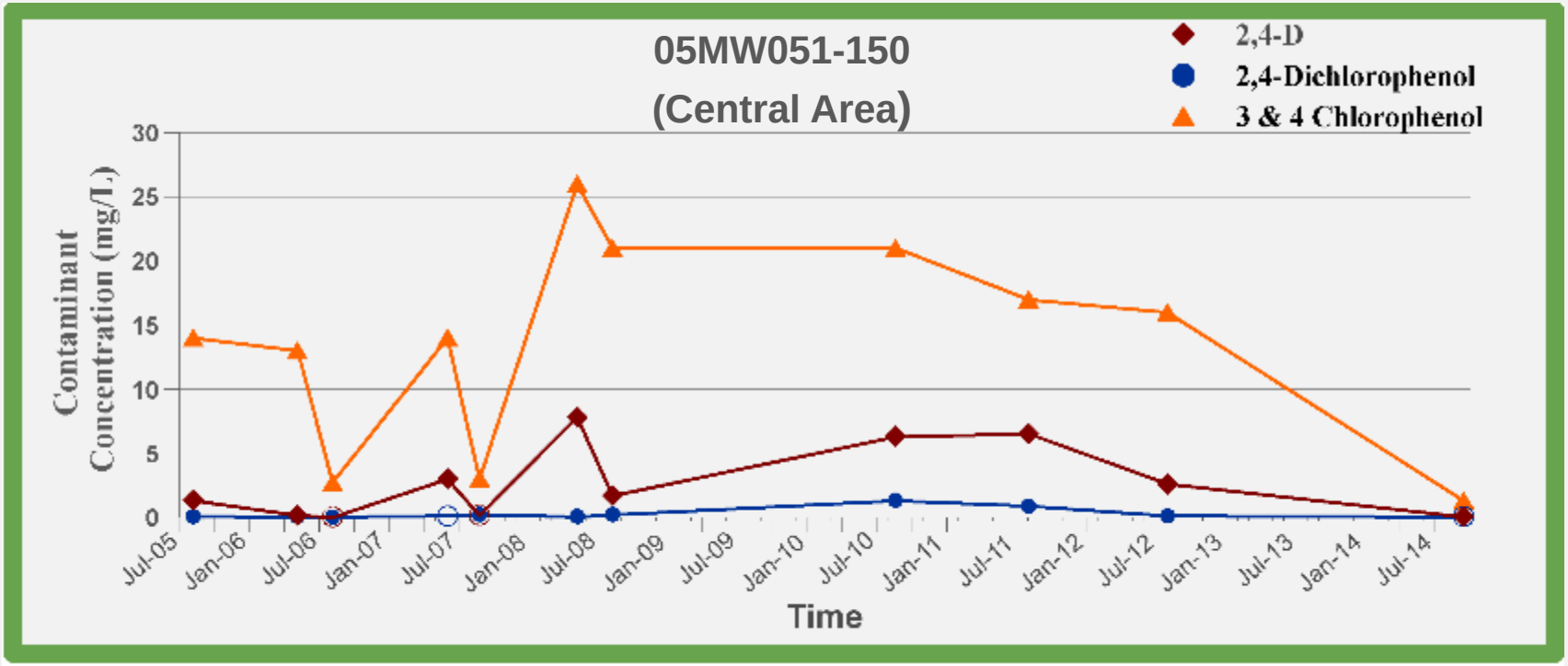


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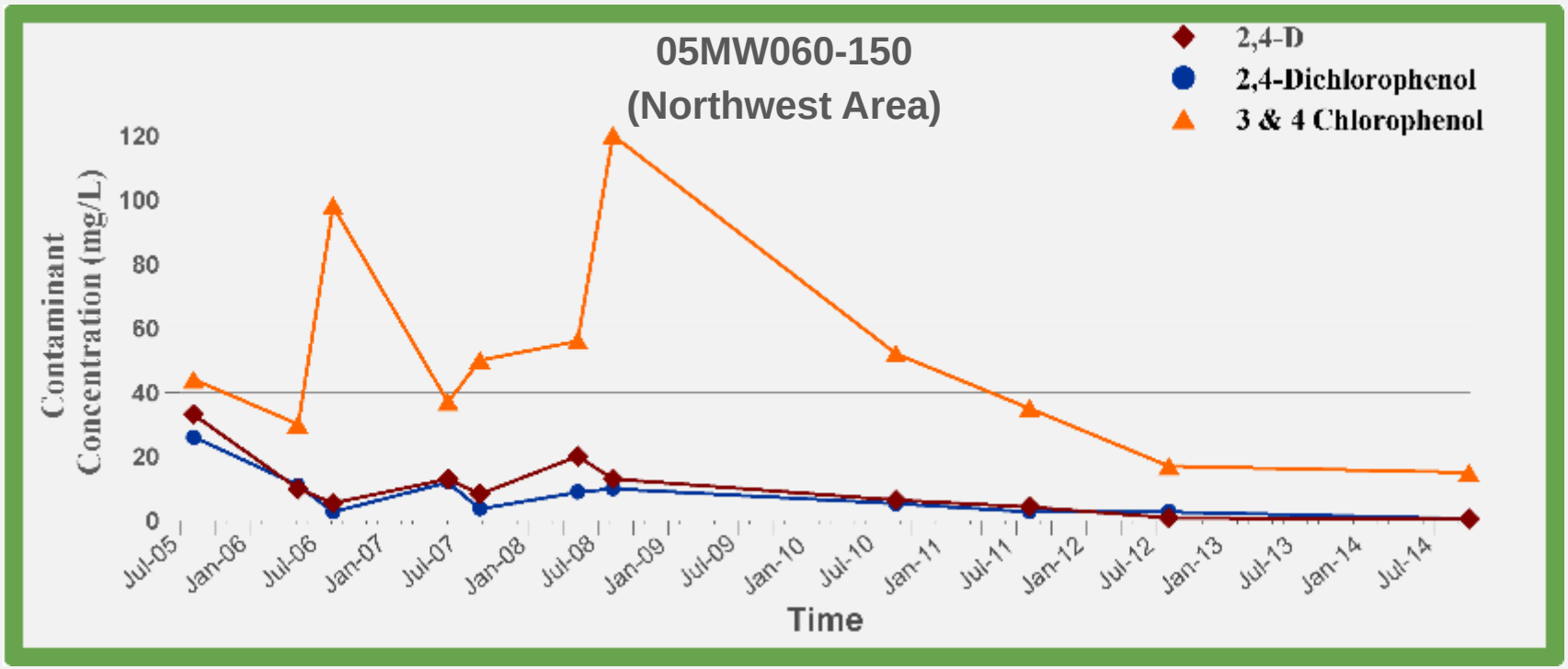
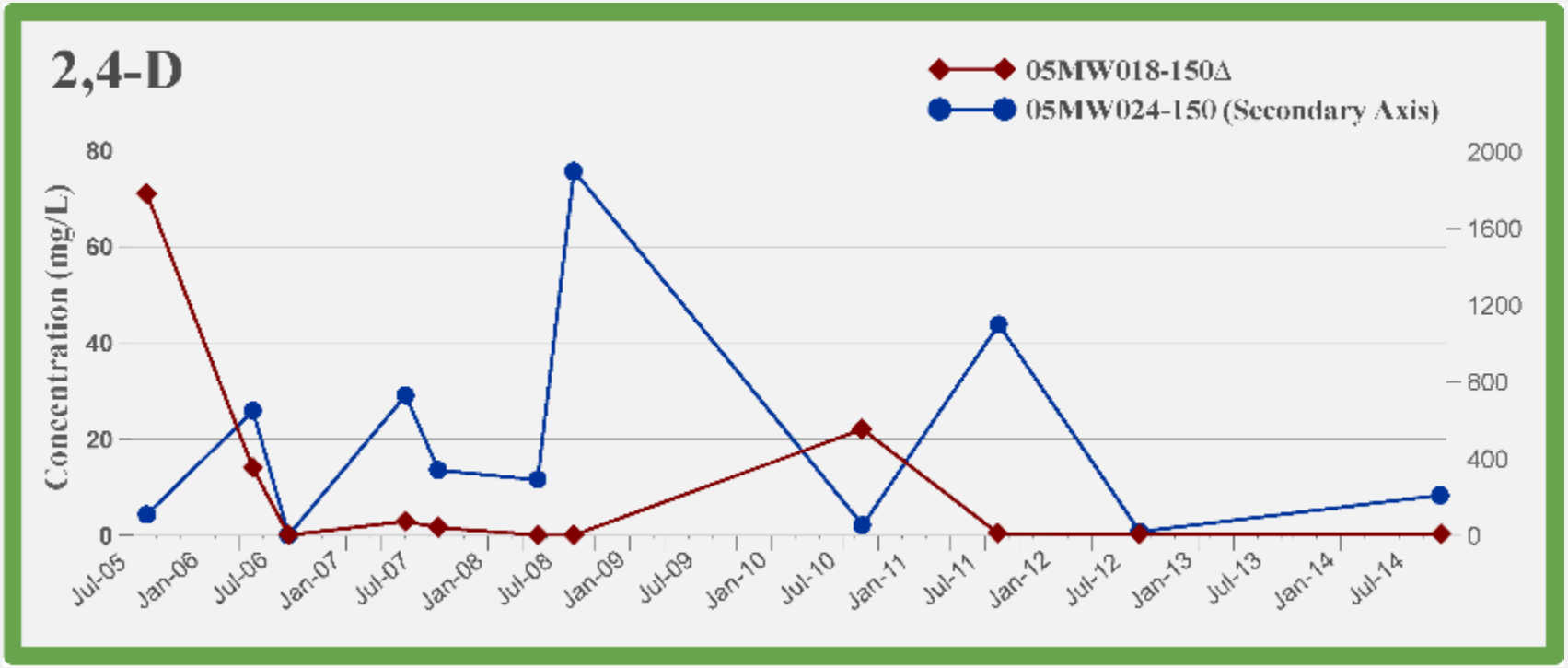


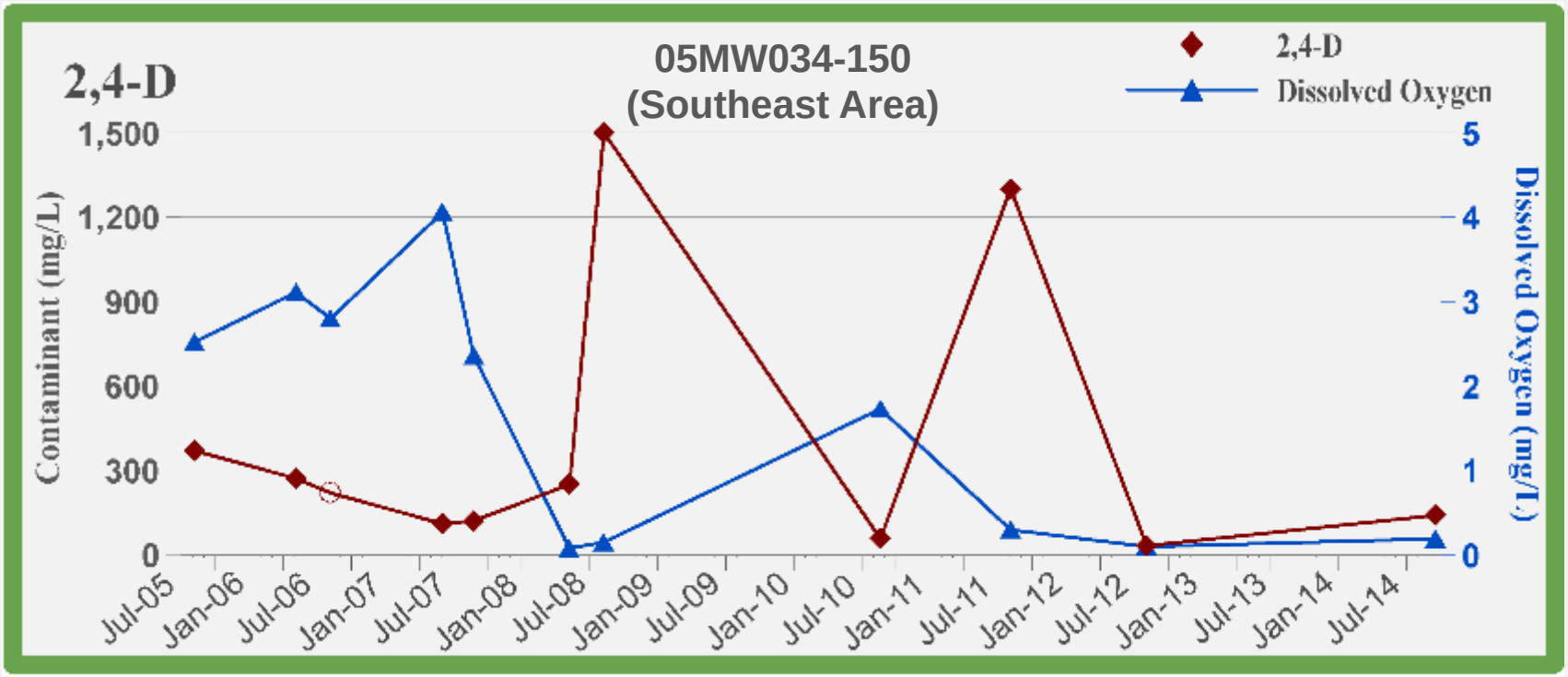
# Effects of Residual Material

**Residual material can cause significant fluctuations in groundwater concentrations**



# Effects of Dissolved Oxygen

**2,4-D Remediation affected when DO levels drop near to or below 1 mg/L**

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# Effects of Dissolved Oxygen

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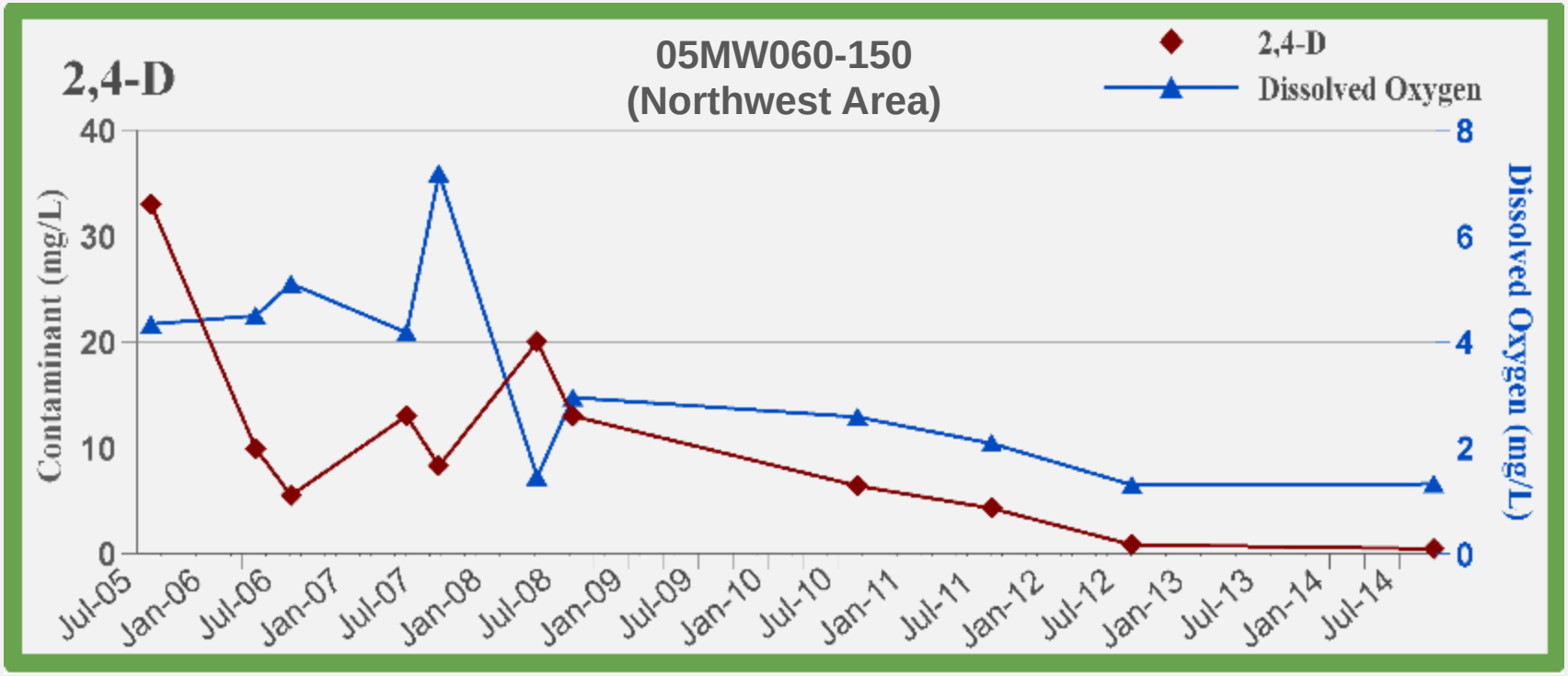


# Changes in Dissolved Oxygen with Time

| Aerobic Conditions | Baseline Groundwater Monitoring Event (Fall 2005) | Most Recent Groundwater Monitoring Event (Fall 2014) |
|---|---|---|
| Aerobic Conditions (DO ≥1 mg/L) | 85% of Wells | 47% of Wells |
| Limited Aerobic Conditions (DO ≥0.5 mg/L but < 1 mg/L) | 10% of Wells | 6% of Wells |
| Anaerobic Conditions (DO <0.5 mg/L) | 5% of Well | 47% of Wells |

# Growing Season Observations

**Increased signs of stress during growing seasons**

- Change in leaf color
- Droopy, curled, or cupped leaves
- Burnt leaf tips
- Early leaf drop

# Tree Viability by Species

| Tree Specie (Common Name) | Year Planted | Trees Remaining | % Remaining |
|---|---|---|---|
| Green Ash | 2005 | 35 of 40 | 88% |
| Russian Olive | 2011 | 113 of 140 | 81% |
| Russian Olive | 2007 | 73 of 95 | 77% |
| Sea Buckthorn | 2007 | 3 of 4 | 75% |
| Green Ash | 2007 | 57 of 85 | 67% |
| Tamarack | 2007 | 2 of 4 | 50% |
| Hackberry | 2005 | 15 of 40 | 38% |
| Laurel Leaf Willow | 2005 | 60 of 188 | 32% |
| Quaking Aspen | 2005 | 13 of 84 | 15% |
| Paper Birch | 2005 | 2 of 20 | 10% |
| Theves Poplar | 2005 | 0 of 82 | 0% |

# Tree Vigor Ratings

| Tree Specie | Year Planted | Jun-06 | Aug-06 | Jun-07 | Sep-07 | Jun-08 | Sep-08 | Sep-10 | Sep-11 | Sep-12 | Aug-14 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Green Ash | 2005 | 2.9 | 3.1 | 3.3 | 3.1 | 3.3 | 3.5 | 3.8 | 3.5 | 4.0 | 3.9 |
| Russian Olive | 2011 | NP | NP | NP | NP | NP | NP | NP | 2.9 | 4.0 | 3.6 |
| Russian Olive | 2007 | NP | NP | NP | 2.8 | 3.1 | 3.7 | 4.3 | 3.7 | 4.3 | 2.3 |
| Buckthorn | 2007 | NP | NP | NP | 2.9 | 3.8 | 4.0 | 4.2 | 4.5 | 4.7 | 3.8 |
| Green Ash | 2007 | NP | NP | NP | 1.8 | 2.5 | 1.8 | 2.3 | 3.5 | 2.6 | 3.7 |
| Tamarack | 2007 | NP | NP | NP | 2.1 | 3.3 | 2.8 | 4.0 | 4.0 | 4.0 | 2.9 |
| Hackberry | 2005 | 1.8 | 2.3 | 2.4 | 2.5 | 2.8 | 2.6 | 2.3 | 2.5 | 1.9 | 3.2 |
| Willow | 2005 | 2.5 | 3.3 | 2.8 | 2.8 | 3.1 | 3.2 | 3.3 | 3.3 | 3.3 | 3.4 |
| Quaking Aspen | 2005 | 2.3 | 3.0 | 2.7 | 2.5 | 2.8 | 2.8 | 3.8 | 3.4 | 3.8 | 3.8 |
| Paper Birch | 2005 | 1.8 | 2.9 | 3.3 | 2.9 | 3.6 | 4.0 | 3.7 | 3.2 | 3.8 | 4.0 |
| Theves Poplar | 2005 | 2.6 | 3.5 | 2.2 | 2.7 | 2.3 | 3.3 | 1.5 | N/A | N/A | N/A |

1-Very Poor 2-Poor 3-Good 4-Very Good 5-Excellent

# Complicated Growth Monitoring

- Tree Heights (40% of monitored trees affected by pruned tree tops)
- Canopy Development

# Exposure Effects

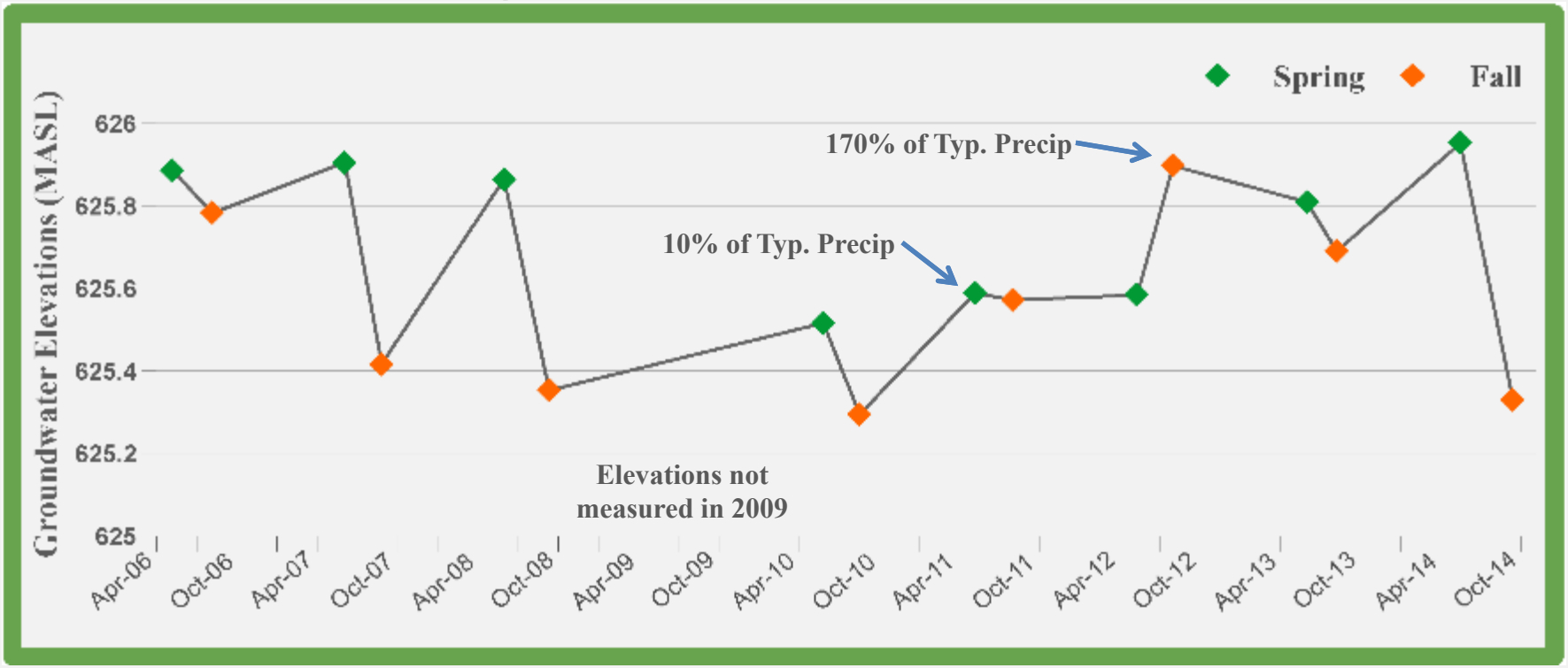
- Exposure to 2,4-D expressed through leaf or canopy appearance
- Exposure to chlorides expressed through leafs (e.g., burnt leaf tips)

# Tree Replanting

- **Root Placement within *TreeWell*® unit**
- **Species Selection**

# Water Level Observations

## Average Early and Late Growing Season Groundwater Elevations



# Lessons Learned at this Site

- ***Engineered_Phytoremediation*$^{SM}$ has increased tree viability and established positive 2,4-D remediation results**
- **Diverse and carefully considered tree selection will increase system performance in the presence of numerous challenges**
- **Dissolved oxygen levels and residual materials significantly impact remediation**
- **Be flexible with conventional monitoring metrics**
- **Occasional replanting will be necessary**

# Contributors to the Project

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# Thank You!  Questions?