Lessons Learned in the Remediation of Herbicides Contaminated Groundwater Using *Engineered_Phytoremediation*\textsuperscript{SM}

William Campbell PE  
TEA, Inc.  
Baton Rouge, LA, USA
Types of Phytoremediation

- Traditional phytoremediation

**Engineered_Phytoremediation**

- 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

- 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<sup>SM</sup>
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\textsuperscript{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\textsuperscript{SM}
Installation June 2005
Phytoplantation Over Time

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

June 2007
Phytoplanetation Over Time

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

June 2011

June 2015
Evidence of Remediation

05MW029-150
(Area-of-Influence-Study)

- 2,4-D
- 2,4-Dichlorophenol
- 3 & 4 Chlorophenol

○ - Concentration is non-detect for sampling event, graphed as 1/2 detection limit.
Evidence of Remediation

05MW036-150
(Southwest Area)

- 2,4-D
- 2,4-Dichlorophenol
- 3 & 4 Chlorophenol

Contaminant Concentration (mg/L)

Time
Evidence of Remediation

05MW051-150 (Central Area)

- **2,4-D**
- **2,4-Dichlorophenol**
- **3 & 4 Chlorophenol**

- Concentration is non-detect for sampling event, graphed as 1/2 detection limit.
Evidence of Remediation

05MW060-150 (Northwest Area)

Contaminant Concentration (mg/L)

Time

2,4-D
2,4-Dichlorophenol
3 & 4 Chlorophenol
Effects of Residual Material

Residual material can cause significant fluctuations in groundwater concentrations

![Graph showing concentration changes over time for 2,4-D](image-url)
Effects of Dissolved Oxygen

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

○ – Concentration is non-detect for sampling event, graphed as 1/2 detection limit.
Effects of Dissolved Oxygen

2,4-D Remediation affected when DO levels drop near to or below 1 mg/L
## Changes in Dissolved Oxygen with Time

<table>
<thead>
<tr>
<th>Aerobic Conditions</th>
<th>Baseline Groundwater Monitoring Event (Fall 2005)</th>
<th>Most Recent Groundwater Monitoring Event (Fall 2014)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Aerobic Conditions</strong> (DO ≥1 mg/L)</td>
<td>85% of Wells</td>
<td>47% of Wells</td>
</tr>
<tr>
<td><strong>Limited Aerobic Conditions</strong> (DO ≥0.5 mg/L but &lt; 1 mg/L)</td>
<td>10% of Wells</td>
<td>6% of Wells</td>
</tr>
<tr>
<td><strong>Anaerobic Conditions</strong> (DO &lt;0.5 mg/L)</td>
<td>5% of Well</td>
<td>47% of Wells</td>
</tr>
</tbody>
</table>
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

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

<table>
<thead>
<tr>
<th>Tree Specie</th>
<th>Year Planted</th>
<th>Jun-06</th>
<th>Aug-06</th>
<th>Jun-07</th>
<th>Sep-07</th>
<th>Jun-08</th>
<th>Sep-08</th>
<th>Sep-10</th>
<th>Sep-11</th>
<th>Sep-12</th>
<th>Aug-14</th>
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<tr>
<td>Green Ash</td>
<td>2005</td>
<td>2.9</td>
<td>3.1</td>
<td>3.3</td>
<td>3.1</td>
<td>3.3</td>
<td>3.5</td>
<td>3.8</td>
<td>3.5</td>
<td>4.0</td>
<td>3.9</td>
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<tr>
<td>Russian Olive</td>
<td>2011</td>
<td>NP</td>
<td>NP</td>
<td>NP</td>
<td>NP</td>
<td>2.9</td>
<td>4.0</td>
<td>3.6</td>
<td></td>
<td>4.0</td>
<td>3.6</td>
</tr>
<tr>
<td>Russian Olive</td>
<td>2007</td>
<td>NP</td>
<td>NP</td>
<td>NP</td>
<td>2.8</td>
<td>3.1</td>
<td>3.7</td>
<td>4.3</td>
<td>3.7</td>
<td>4.3</td>
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<tr>
<td>Buckthorn</td>
<td>2007</td>
<td>NP</td>
<td>NP</td>
<td>NP</td>
<td>2.9</td>
<td>3.8</td>
<td>4.0</td>
<td>4.2</td>
<td>4.5</td>
<td>4.7</td>
<td>3.8</td>
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<tr>
<td>Green Ash</td>
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<td>NP</td>
<td>NP</td>
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<td>1.8</td>
<td>2.5</td>
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<td>1.8</td>
<td>2.3</td>
<td>2.4</td>
<td>2.5</td>
<td>2.6</td>
<td>2.3</td>
<td>2.5</td>
<td>1.9</td>
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<td>Willow</td>
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<td>2.8</td>
<td>3.1</td>
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<td>3.3</td>
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<td>2005</td>
<td>2.3</td>
<td>3.0</td>
<td>2.7</td>
<td>2.5</td>
<td>2.8</td>
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<td>3.8</td>
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<td>4.0</td>
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<td>2005</td>
<td>2.6</td>
<td>3.5</td>
<td>2.2</td>
<td>2.7</td>
<td>2.3</td>
<td>3.3</td>
<td>1.5</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

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

- Elevations not measured in 2009
- 10% of Typ. Precip
- 170% of Typ. Precip

Spring (green diamonds) and Fall (orange squares) data points are shown.
Lessons Learned at this Site

- Engineered_Phytoremediation℠ 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

**TEA, Inc.**

Christopher Akudo, PhD  
(Baton Rouge, Louisiana)

William Campbell, PE  
(Baton Rouge, Louisiana)

Russ Copeland, PE  
(Baton Rouge, Louisiana)

Scott Courtright, Consulting Arborist  
(Baton Rouge, Louisiana)

Dave Wandor  
(Midland, MI)

**Partners**

Edward Gatliff, PhD  
(Applied Natural Sciences, Inc., Hamilton, Ohio)

Audrey Sidebottom  
(Dow Chemical Canada ULC, Fort Saskatchewan, Alberta)

Joanne West, PEng  
(Dow Chemical Canada ULC, Nanaimo, British Columbia)
Thank You! Questions?