Phytoremediation as a Technology for Both Risk Management and Remediation at a Former Herbicides Production Site

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History of Herbicide Production Area

- Start-up of herbicide operations in 1961
  - 2,4-D
  - chlorophenols

- Shut-down of herbicide operations in 1980

- Demolition of equipment
  - early 1980s
  - asphalt cover
Former Herbicides Plant
Post equipment demolition
Key Issues

- Soil contamination
- Groundwater contamination
- Asphalt cover

- 2,4-D
- Phenols
- Chlorinated Organics
<table>
<thead>
<tr>
<th>ppm</th>
<th>400 to 1,900</th>
<th>40 to 400</th>
<th>8 to 40</th>
<th>4 to 8</th>
<th>&lt;4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Color</td>
<td>Red</td>
<td>Brown</td>
<td>Yellow</td>
<td>Green</td>
<td></td>
</tr>
</tbody>
</table>

**Groundwater Analytical Data - 2,4-D**

The image shows an aerial view with points marked in various colors indicating different concentration ranges of 2,4-D in groundwater.
Soil and Groundwater Management Strategy

- Understand Risks
  - Characterization
  - Fate and Transport
  - Risk Assessment
- Apply Risk Management Systems
  - Mitigate contaminated groundwater movement
  - Manage exposure to personnel
- Remediation (cleanup) of contaminants in groundwater and soil
Phytoremediation - Risk Management and Remediation

- Cost effective and efficient control of groundwater movement
- Biodegradation by plants and their associated root-zone microbial populations
- Addition of oxygen to degrade site contaminants
- Manage contamination in-situ
  - no waste generation
  - no energy use
  - sustainable
Phytoremediation Pilot Study

- Hydraulic Control
- Contaminant Reduction
- Phytoremediation Technology Research
Phytoremediation Pilot Chronology

- Initial Plant Viability Test (2002)
  - Two plots with a total of 16 trees and grasses
  - 6 species of trees, 4 of grasses

- Phyto Pilot Study (June 2005)
  - 475 trees, 6 species
  - 100+ monitoring installations
  - designed research studies
  - monitoring program
    - analytes, tree health, water level data
Phytoremediation Pilot Design Parameters

- Sufficient quantity of trees to create drawdown
- Direct trees to deeper groundwater extraction
- Protect Tree roots from high herbicide concentrations
  - TreeMediation® System
- Mixed tree variety to evaluate viability
- Three experimental designs
Specific Planting Technology

- Patented phytoremediation technology Treemediation ®
- Water flows upward through media in TreeWell® Root_Sleeve
- Biodegradation prior to tree root uptake
- Targets deeper groundwater
Tree Planting Locations

- Strategic grid system
- Higher concentrations
- 4.5 meter centres
June 17, 2005
Asphalt was jack hammerd and soil augered.
All tree locations & in-well monitoring installed
Planting process underway.
Phytoremediation Research Plots

- **Species Study**
  - 4 plots, 6 species with 4 replicates of each type

- **Area of Influence Study**
  - 4 willows, 4 monitoring wells with each willow

- **Treatment Effectiveness Study**
  - varying soil mixture, w or w/o air tube, w or w/o sleeve
Phytoremediation Research Plots

- Treatment Effectiveness Study
- Species Study
- Area of Influence Study
Phytoremediation Research Results

- **Species Study – Tree Viability, overall mortality 34%**
  - Green ash – zero mortality, good viability results/lower water use
  - Aspen – acceptable viability results/medium water use
  - Willow and poplar – low to moderate viability results/robust water use
    - High water levels confound results for willow & poplar
    - Evidence of high concentration effects for willow
  - Birch & hackberry – low vigor rating, low survival rate
  - Russian olive (2002) – promising species
Tree viability

Bivariate Fit of Health Rating - Aug 06 By 2,4-D - June 06

Higher health ratings at lower 2,4-D concentrations

Monitoring well not in TreeWell

Mortalities due to other reasons: water levels, winter, seasonal stress, poor roots

Premature to be drawing conclusions
Phytoremediation Research Results

- Area of Influence Study
  - Willow mortality - 100%
    - Likely due to high 2,4-D concentrations
  - No conclusions - artificially high water table is confounding results
Phytoremediation Pilot
Hydraulic Control Study

- Hydraulic drawdown due to tree uptake - no conclusions yet
- Artificially high water table confounding results
  - Average depth to groundwater in 2002 = 2 m±
  - Actual encountered in 2005 & 2006 = 0.5 m±
- Tree establishment and viability is inhibited
2002 Phyto Demonstration

- Limited planting to show if plants viable in these site conditions
- Water table levels low in 2002
- Mortality high, but a few are thriving
2002 Plantation Areas

Between-Tree Monitoring Well #1

Between-Tree Monitoring Well #2
### Phytoremediation Results

#### Groundwater Data

<table>
<thead>
<tr>
<th></th>
<th>Between Trees Monitoring Well # 1 mg/L</th>
<th>Between Trees Monitoring Well #2 Mg/L</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>07/24/2002</td>
<td>09/14/2005</td>
</tr>
<tr>
<td>2,4 – D</td>
<td>300</td>
<td>0.009</td>
</tr>
<tr>
<td>3 &amp; 4 - Chlorophenol</td>
<td>130</td>
<td>1.5</td>
</tr>
</tbody>
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2005 Phyto Pilot
Paired Piezometers locations
2,4-D Comparison of Paired Piezometers
TreeWell Piezometer vs. Adjacent Piezometer

2m spacing (0.5m for Pairs 9-11)

Piezometer Pairs

2,4-D (ppm)

TreeWell - Sept '05
TreeWell - June '06
Adjacent - Sept '05
Adjacent - June '06
Monitoring Plan

- Tree health assessment
  - 3 times/year

- Groundwater levels
  - 8 times/year

- Groundwater sample collection and analysis
  - 2 times/year
    - VOC’s, chlorophenols, herbicides
    - Field parameters (pH, temp, ORP, conductivity, D.O.)
Next Steps in Pilot Study

1. Collect soil data to compare with 2002 data
2. Collect representative leaf and stem samples for nutrients and herbicides analysis
3. Replant dead areas in spring 2007 (perhaps 2 tree varieties/hole)
4. Plant control area for species evaluation (spring 2007)
5. Harvest representative number of trees in fall 2007 to evaluate root growth
Expectations

- Phytoremediation can be an effective risk management system
- Phytoremediation is a remediation technology
- Site conditions are a challenge but not insurmountable
Contributors to Project

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The Dow Chemical Company

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Dow Chemical Canada, Inc.
Questions?

Phytoremediation Pilot Project

Work in Progress

Trees have been planted here to study the long-term improvement of the soil and groundwater through the use of this innovative remedial technique.

WEST WOODS ESTATES