Phytoremediation of Landfill Leachate

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Landfill facts and figures

- Americans generate approximately 250 million tons of trash annually, and approximately 57% of the waste is landfilled

- Over 2,500 landfills are currently in operation in the United States
- EPA estimates 10,000 old and abandoned municipal landfills exist
What is landfill leachate?

• Liquid that moves through or drains from a landfill

• Generated by…
  o Excess rainwater percolation through waste
  o Inherent water content of wastes
Leachate composition

• Physical, chemical, and microbial processes occurring in the waste release pollutants from the waste into percolating water.

• 4 major groups of pollutants:
  - **Dissolved organic matter** (e.g., COD, TOC)
  - **Inorganic macro components** (e.g., calcium, sodium, chloride, iron)
  - **Heavy metals** (e.g., cadmium, copper, zinc, chromium)
  - **Xenobiotic compounds** (e.g., pesticides, aromatic hydrocarbons)
Leachate composition

<table>
<thead>
<tr>
<th></th>
<th>Leachate source 1</th>
<th>Leachate source 2</th>
<th>River water</th>
<th>Rainwater</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>NH₄⁺</strong></td>
<td>877</td>
<td>80</td>
<td>0.1</td>
<td>0.3</td>
</tr>
<tr>
<td><strong>NO₃⁻</strong></td>
<td>0.2</td>
<td>9</td>
<td>10</td>
<td>0.2</td>
</tr>
<tr>
<td><strong>P</strong></td>
<td>1.6</td>
<td>0.7</td>
<td>0.04</td>
<td>0.004</td>
</tr>
<tr>
<td><strong>SO₄²⁻</strong></td>
<td>29</td>
<td>66</td>
<td>17</td>
<td>1.98</td>
</tr>
<tr>
<td><strong>Cl</strong></td>
<td>2080</td>
<td>65</td>
<td>8.2</td>
<td>4.4</td>
</tr>
<tr>
<td><strong>K</strong></td>
<td>1031</td>
<td>60</td>
<td>0.2</td>
<td>0.1</td>
</tr>
<tr>
<td><strong>Ca</strong></td>
<td>23</td>
<td>125</td>
<td>2.5</td>
<td>0.2</td>
</tr>
<tr>
<td><strong>Mg</strong></td>
<td>335</td>
<td>61</td>
<td>1.2</td>
<td>0.3</td>
</tr>
<tr>
<td><strong>Na</strong></td>
<td>2421</td>
<td>50</td>
<td>4.8</td>
<td>2.2</td>
</tr>
<tr>
<td><strong>Fe</strong></td>
<td>0.48</td>
<td>1.9</td>
<td>0.047</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td><strong>Mn</strong></td>
<td>2.5</td>
<td>2.3</td>
<td>0.018</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td><strong>Al</strong></td>
<td>0.03</td>
<td>&lt;0.01</td>
<td>0.042</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td><strong>Zn</strong></td>
<td>0.2</td>
<td>0.1</td>
<td>0.007</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td><strong>DOC</strong></td>
<td>522</td>
<td>34</td>
<td>1.9</td>
<td>1.2</td>
</tr>
<tr>
<td><strong>pH</strong></td>
<td>7.5</td>
<td>6.5</td>
<td>6.29</td>
<td>4.88</td>
</tr>
<tr>
<td><strong>EC (mS cm⁻¹)</strong></td>
<td>27.7</td>
<td>2.3</td>
<td>0.49</td>
<td>0.022</td>
</tr>
<tr>
<td><strong>COD</strong></td>
<td>1400</td>
<td>250</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td><strong>BOD₅</strong></td>
<td>128</td>
<td>20</td>
<td>ND</td>
<td>ND</td>
</tr>
</tbody>
</table>
The problem

• Leachate has the potential to contaminate groundwater
  o Historically, landfills were built without engineered liners
  o Recently, a study estimated that 82% of landfill cells had leaks in the liners

• Leachate run-off may pollute surface water
  o Surface water pollution less common than groundwater pollution

http://www.soilenvironmentservices.co.uk/soil_survey_project_examples.htm

Landfills may generate leachate for hundreds of years after closure
Question 1

• Name one environmental issue associated with landfill leachate.
Conventional leachate treatments

• Leachate transfer
  o Recycling
  o Combined treatment with domestic sewage

• Biodegradation
  o Aerobic processes (lagoons, activated sludge)
  o Anaerobic processes (anaerobic digestion)

• Chemical and physical methods
  o Chemical oxidation
  o Chemical precipitation
  o Coagulation/flocculation
  o Sedimentation

Phytoremediation of leachate

Fig. 1. Schematic representation of the soil–plant bioreactor for the plant–soil based treatment of landfill leachate.

Jones et al, 2006
Case study 1: Introduction

• Goal
  o Complete rehabilitation of municipal solid waste landfill site

• Design
  o Leachate treated by constructed wetlands and then pumped back to irrigate vegetated landfill cover

• Plants
  o *Phragmites australis* (wetlands)
  o willow and grasses (soil cover)

http://en.wikipedia.org/wiki/Phragmites
Case study 1: CW results

Average 60% removal of major pollutants achieved desired efficiency as leachate pre-treatment

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Inflow</th>
<th>Outflow</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Average</td>
<td>(Range)</td>
</tr>
<tr>
<td>T</td>
<td>ºC</td>
<td>18.07</td>
<td>(12.3–25)</td>
</tr>
<tr>
<td>pH</td>
<td></td>
<td>8.03</td>
<td>(7.2–9.73)</td>
</tr>
<tr>
<td>SS</td>
<td>mg/L</td>
<td>180</td>
<td>(6–1160)</td>
</tr>
<tr>
<td>EC</td>
<td>mS/cm</td>
<td>8.9</td>
<td>(1.4–16.2)</td>
</tr>
<tr>
<td>DOC</td>
<td>mg/L</td>
<td>429</td>
<td>(183–1047)</td>
</tr>
<tr>
<td>COD</td>
<td>mg/L</td>
<td>1508</td>
<td>(200–4040)</td>
</tr>
<tr>
<td>BOD₅</td>
<td>mg/L</td>
<td>193</td>
<td>(34–490)</td>
</tr>
<tr>
<td>NO₂⁻</td>
<td>mg/L</td>
<td>9.7</td>
<td>(&lt;0.5–30)</td>
</tr>
<tr>
<td>NO₃⁻</td>
<td>mg/L</td>
<td>159</td>
<td>(&lt;0.1–540)</td>
</tr>
<tr>
<td>CN⁻</td>
<td>mg/L</td>
<td>(&lt;0.1–&lt;0.1)</td>
<td>(&lt;0.1–&lt;0.1)</td>
</tr>
<tr>
<td>F⁻</td>
<td>mg/L</td>
<td>(&lt;0.1–&lt;0.1)</td>
<td>(&lt;0.1–&lt;0.1)</td>
</tr>
<tr>
<td>Cl⁻</td>
<td>mg/L</td>
<td>961</td>
<td>(132–1994)</td>
</tr>
<tr>
<td>Br⁻</td>
<td>mg/L</td>
<td>2.6</td>
<td>(&lt;0.1–5)</td>
</tr>
<tr>
<td>SO₄²⁻</td>
<td>mg/L</td>
<td>170</td>
<td>(&lt;0.1–340)</td>
</tr>
<tr>
<td>S²⁻</td>
<td>mg/L</td>
<td>(&lt;0.1–0.25)</td>
<td>(&lt;0.1–0.25)</td>
</tr>
<tr>
<td>SO₃²⁻</td>
<td>mg/L</td>
<td>(&lt;0.1–&lt;0.1)</td>
<td>(&lt;0.1–&lt;0.1)</td>
</tr>
<tr>
<td>HPO₄²⁻</td>
<td>mg/L</td>
<td>5.8</td>
<td>(&lt;0.5–11.0)</td>
</tr>
</tbody>
</table>
Case study 1: Plant cover results

• Beneficial effect of leachate application on landfill vegetation was observed
  o Trees started to leaf earlier compared to surrounding vegetation
  o Vegetation indices were higher throughout whole vegetation season

• Comparison of irrigated vs. non-irrigated plants
  o In irrigated plants, nitrogen, sodium, and cadmium levels were higher in plant leaves
  o Nitrogen, sodium, cadmium, zinc, and manganese levels were higher in plant wood
Case study 1: Conclusions

- Irrigation did not show excess accumulation of salts, heavy metals, or nutrients that could negatively affect soil properties and plant growth.
- Further monitoring is required to determine long-term effects of irrigation.
- Under controlled conditions, leachate acts as good fertilizer.
- To achieve higher nutrient removal, tree species with higher biomass production should be used.
Additional literature and findings

• Irrigated trees on landfill caps promoted favorable environment for methane oxidizing bacterial populations\(^8\)
• Spray irrigation of leachate resulted in the death of native trees and shrubs in Australia, with no regrowth\(^9\)
• Poplars and willows have been shown to have high evapotranspiration rates when irrigated with leachate

Question 2

• Name one plant previously mentioned that could be used to remediate landfill leachate
Human health considerations

- Received little attention
- Few quantitative reports on microbiological composition of leachate\textsuperscript{10}
- General perception:
  - Due to high temperatures during waste decomposition, low pH, and antibiotic characteristics, it is generally thought that most bacterial, protozoal, and viral populations are deactivated\textsuperscript{11, 12, 13}
  - If pathogens do persist, they are unlikely to survive for long periods\textsuperscript{14, 15}
References

• Cover slide photo: http://mikedavidsonent.com/newsite/?p=226


• (12) Donnelly et al., 1981. Recovery of faecal indicator and pathogenic microbes from landfill leachate. Land disposal: municipal solid waste, EPA.


Answers to quiz questions

1. Contamination of groundwater or surface water
2. Reeds, willow, poplar, grasses, shrubs