**Introduction**

- Fly ash is a byproduct of coal combustion
- It is kept in slurry ponds (ash + water), or stores of dry coal ash
- 19+ billion gallons of coal ash in North Carolina
- 2008 spill in Kingston, TN, jeopardized wildlife and drinking water
- 2014 spill in Eden, NC polluted the Dan River, biggest of its kind in US history
- Cause of major and costly litigation and settlement cases
- Efforts to capitalize on the abundance of this material through construction
- Use in construction recently approved by Environmental Protection Agency (EPA)
- Interest in a lower density highway embankment
- Rain events could transport leachate from ash containing heavy metals such as arsenic, mercury and selenium to surface water and groundwater sources

**Project Objectives**

- Characterize the geotechnical properties of this particular fly ash (from Western North Carolina)
- Determine the efficacy of bioremediation methods on reducing concentrations of heavy metals in fly ash leachate
- Determine the optimal treatment specifications that are field-applicable and realistic
- Determine if the levels of nitrogen produced by the system are a threat to surface water

**Bio-Cementation**

- Microbial induced calcite precipitation (MICP); a biogeochemical process that stimulates calcium carbonate precipitation within the soil matrix
- Bacterium *Sporosarcina pasteurii* converts urea into ammonia (NH₃) and carbon dioxide (CO₂)
- Net increase in pH due to hydroxyl ions (OH⁻) generated from the production of NH₃, which exceeds the available Ca²⁺ for calcite precipitation
- This provides the alkaline environment and carbonate required for the precipitation of calcite (CaCO₃)

**Materials and Methods**

**Geotechnical Characteristics**

- Particle size analysis was implemented using a 152 hydrometer and ASTM (American Society of Testing and Materials) standards
- Compaction done with a 4" diameter mold and by ASTM standards. Sample was compacted at different moisture contents. Each of three lifts was compacted using a 5.5lb standard compaction hammer.

**Effluent Testing:**

- To establish a baseline, fly ash at 25% water was compacted manually with a tamper in an acrylic mold. 10 pore volumes of water were added incrementally and flushed through over ~8 days. Samples were collected incrementally directly from the spout for testing.
- Next, *Sporosarcina pasteurii* and urea were added to dry fly ash following the recipe below. The sample was compacted, and the same amount of water was flushed through. More bacteria was added after 6 pore volumes of water. Samples were collected the same way as above.

**ICP-MS**

- Inductively Coupled Plasma – Mass Spectrometry
- Capable of detecting metals and some non-metals at concentrations as low as one part per quadrillion
- Sample is ionized with ICP and then a mass spec is used to separate and quantify ions

**Results**

<table>
<thead>
<tr>
<th>Sample</th>
<th>Volume (mL)</th>
<th>Conc of Ca (mg/L)</th>
<th>Conc of Cr (mg/L)</th>
<th>Conc of Cu (mg/L)</th>
<th>Conc of Pb (mg/L)</th>
<th>Conc of Hg (mg/L)</th>
<th>Conc of Se (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>75</td>
<td>701</td>
<td>195</td>
<td>52.6</td>
<td>2611</td>
<td>53.2</td>
<td>1633</td>
</tr>
<tr>
<td>Slurry</td>
<td>2580</td>
<td>257</td>
<td>114</td>
<td>&lt;0.1</td>
<td>130</td>
<td>9.06</td>
<td>504</td>
</tr>
<tr>
<td>Treated</td>
<td>100</td>
<td>782</td>
<td>288</td>
<td>5.64</td>
<td>319</td>
<td>19.9</td>
<td>746</td>
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<tr>
<td>Treated</td>
<td>905</td>
<td>36.7</td>
<td>832</td>
<td>&lt;0.1</td>
<td>31.5</td>
<td>1.29</td>
<td>187</td>
</tr>
<tr>
<td>Treated</td>
<td>500</td>
<td>966</td>
<td>214</td>
<td>813.6</td>
<td>2344</td>
<td>132</td>
<td>155</td>
</tr>
</tbody>
</table>

- Slurry had a lower concentration of all heavy metals tested except arsenic
- Concentrations of heavy metals decreased as more water was passed through the sample
- Selenium levels in the treated sample were lower than those of the baseline at all points

**Discussion**

- Data indicates that dry fly ash contains higher concentrations of heavy metals than slurry, indicating need for mitigation for construction
- Treated samples showed an initial spike in concentration, then a decline; cumulative graphs show how much has been leached out
- Selenium levels in the treated sample were lower than those of the baseline at all points

**Future Work**

- Total Nitrogen testing to assess the threat to surface waters via eutrophication
- Optimize for urea, pH
- Investigate fly ash materials from other sources, specific watersheds

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