Remediation of Sodium Contaminated Sites

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Mark Landress P.G.
Project Navigator, Ltd.
10497 Town & Country Way Suite 830
Houston, TX 77024
713-468-5005
www.ProjectNavigator.com
Salt and Sodium Contamination Overview

- 98% of oil production waste is high TDS produced water.
- Oilfield produced water (PW) brine is the major source of salt and sodium contamination to soil and groundwater.
- Thousands of sites across the US are affected.
- There are 18 billion bbl of produced water generated onshore from oil production, less from gas. New sources include coal bed methane, desalination and R/O systems.
- Many states are only now becoming vigilant about the problem given the threat to groundwater in oil producing states.
- Because of visual impact and loss of vegetation, landowner action is driving remediation of production sites which would previously be abandoned with minimal action.
- Sodium impacts from produced water brines pose particular challenges and require specific understanding of the soils and chemistry to treat effectively.
Produced Water Problem Areas

Production location with brine discharges and residual oil from leaky well head packing.

Leaks and discharges from injection wells.

Surface discharge of salt water from historical brine discharge area.

Pipeline and flowline leaks.

Soil damaged due to sodium impacts.

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How Salt Causes Damage

- **Saline Conditions** - High total dissolved solids (TDS)
  - High TDS = high salinity: Interferes with plant growth limiting the uptake of water. Dissolved salts directly toxic to plants. Plants are sensitive at early growth stage. High TDS measured by electrical conductivity (EC).

- **Sodic Conditions** - Low EC but high Na.
  - Excess sodium: Damages the soil structure, clogs soil pores, prevents water infiltration. Clay soils most affected.

- **Saline - Sodic Conditions** - High EC and high Na.
  - Have chemical characteristics of both saline and sodic soils. Plant growth affected by both excess salt and excess sodium.

- **Other Components** - Oil, Metals
  - Metals including boron, zinc, barium, also can interfere with plant growth.
  - Contributions from drilling mud components

- All conditions kill or stress vegetation with stunted growth, tip burn, bronzing and defoliation.

- Because of the high sodium and salinity conditions of produced water, damaged areas are commonly both saline and sodic.
Classification of Salt Impacted Soils

- Average levels of salt and sodium in produced water are so high that any discharge will have significant effects on soil and plants.

Ref: USGS API 4758

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Factors Affecting Salt Damage

• **Soil Type**
  – Clay rich soils have higher cation exchange capacity (CEC) and surface area. Can absorb greater amounts of soluble salts. Sandy soils are easier to manage. Exchangeable sodium (ESP) tends to be higher in fine soils.

• **Organic Matter and pH**

• **Climatic Conditions and Drainage, Geology**
  – Higher rainfall tends to promote leaching of salts. Soils generally easier to reclaim under moist conditions. Soils already high in salts harder to reclaim.

• **Available Water Quality**
  – High quality irrigation water with low dissolved salts is better for reclamation.

• **Duration, Volume and Composition of PW**
  – Small volumes and short contact time obviously favorable.
  – Pits, seeps, historical discharges that affect deeper subsurface harder to treat.
How Sodium Affects Soil

Forces holding clay together are weakened when sodium clay and water are in contact. Packs tightly when wet. When Ca replaces Na, soil is flocculated and stable aggregates are formed. Soil structure and drainage is maintained.
Managing Strategies into Tactical Action

Sodium Remediation Mechanism

- Calcium amendment added with water.
- With bulking and saturation - Ca replaces Na.
- Na displaced into soil with lower ESP.
- Calcium eventually binds to remediate surface soil.
- Chloride is flushed out and soil eventually regains its structure.
- Sodium content of subsurface soil will increase as sodium is displaced from the impacted zone.
- Objective is to displace enough sodium in the surface soil to sustain vegetation.
- Site specific soil conditions, groundwater and and geologic factors influence how the amendments are applied.
Assessment and Management

• **Step 1**
  – Identify the problem, source and magnitude.
  – Sample soil and water for EC, ESP, SAR and pH. CEC, organics, lime, metals, (ie 29b parameters).
  – Geophysics, TDS/Conductivity, in-field also useable as a supplement to sampling.

• **Step 2**
  – Devise the management plan which takes into account the short and long term surface soil management, land use and potential groundwater issues.

• **Step 3**
  – Implement reclamation based upon the management plan.

• **Step 4**
  – Monitor progress to ensure remediation is effective
## Salt Management Options

<table>
<thead>
<tr>
<th>Natural Attenuation</th>
<th>Onsite Treatment</th>
<th>Excavation</th>
</tr>
</thead>
<tbody>
<tr>
<td>NA applicable for:</td>
<td>Onsite treatment applicable for:</td>
<td>Excavation applicable for:</td>
</tr>
<tr>
<td>SAR &lt; 12 ESP &lt; 12</td>
<td>Shallow depth.</td>
<td>Small sites or in combination with remediation for oil or other impacts.</td>
</tr>
<tr>
<td>EC &lt; 10</td>
<td>Impact &gt; 3 feet requires special management.</td>
<td>Excavation which includes in-situ treatment good in conjunction with pit closures and LDNR 29b remediation.</td>
</tr>
<tr>
<td>Adequate rainfall.</td>
<td>In-situ treatment with gypsum (slow).</td>
<td></td>
</tr>
<tr>
<td>Adequate drainage.</td>
<td>Ca-exchanging chemical amendments (fast).</td>
<td></td>
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<tr>
<td>Some tolerant plants will grow.</td>
<td>Clean soil addition.</td>
<td></td>
</tr>
<tr>
<td>Soil damage shallow.</td>
<td>Vertical mixing.</td>
<td></td>
</tr>
</tbody>
</table>

In the absence of a strict cleanup criteria, planting of salt tolerant vegetation is an effective alternative where treatment is not feasible or economic.
Case Study

- Large commercial recovery facility with historical salt water discharge.
- Multiple pits and lagoons with tanks and injection wells operated over 50 year period.
- Multiple impacts from TPH, salt and metals.
- High chloride and sodium in shallow groundwater.
- Deep depth of impact due to historical waste application.
- Remedial objective: Meet (Louisiana) 29b parameters. (SAR 12, EC 10, ESP 15)
Case Study Area

Impacted area is historical brine disposal pit. Silty clay soil. Excess salt crusts at surface. Saline-sodic conditions with poor soil structure and defoliated conditions.

Metrics

Overall Area 80 Acres
Study Area - 8 acres
SAR - 25-35
ESP - 20-25
Pit depth 5 feet
Impact depth - 18 feet
Target treatment depth - 3ft

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Sampling & Evaluation Program

- An extensive sampling program was devised to address all historical compliance issues in addition to salt.
- At least 2 samples per acre are collected for assessment.
- Single composite is made for each 6.5 acre area.
- Spot samples collected in high salt areas.
- Chemical amendment and in-situ treatment selected as appropriate remedy.

Sample Layout

Composite Preparation

Computer Modeling

Constituents by Depth

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Managing Strategies into Tactical Action

Remedy Phase - Excavation

- Soil excavated soil through impacted zone.
- Clean soil mix depth calculated to reduce salt, metals and TPH to compliance limits.
- Blended stockpile compacted lightly with bulking material and amendment.
- Sample collected for QA check.
Remedy Phase - Treatment

- Bulking material is added and mixed in soil.
- Prepared area is treated with surfactant and water to wet soil for amendment application.
- Calcium amendment is added using spray trailers in concentrations calculated from ESP.

Sugar cane pulp added as bulking agent.

Liquid amendment from SOS Environmental
Post Treatment Progress

- Treated areas are planted with Bermuda grass which is relatively salt tolerant.
- Test plots of salt-tolerant crops including grasses, barley, wheat, and others are planted to reduce runoff and enrich the soil.
Periodic Maintenance

- Impacted area is periodically checked for soil development and vegetative growth.
- Compost (sugar cane pulp, hay, rice hulls, wood chips) is applied yearly.
- Soil is ripped and disked with heavy agricultural equipment.
- Bermuda grass re-seeded as needed.
- Area is irrigated naturally by rainfall. No additional water is added.
Assessing the Results

- Pre and post-remedial results are compared and progress monitored within 6 months of treatment.
- Overall reduction in SAR shows good initial results.
- Costs:
  - Initial cost for chemical treatment: $0.33 to $0.45/sf
  - Total treatment cost including excavation and mixing: $0.89/sf
Lessons Learned

- Smaller areas with well-defined boundaries are less complex and easier to manage. Multiple affected areas, different composition, make assessment difficult and add complexity to assessment.
- Subsurface soils need low ESP and good drainage to carry away salts displaced by the calcium amendments.
- Large amounts of bulking material are needed to maintain percolation in soil. More is better.
- Good quality organic material is needed at the surface to sustain plants.
- Application of phosphate fertilizers needs to be carefully managed or free calcium needed for sodium displacement becomes unavailable for reaction.
- A combination of methods including short and long term management is usually needed for sustainable growth in heavily impacted areas.
Useful References

API Publication 4758 - Recent publication on strategies for managing produced water contamination.

Deuel & Holiday. Very good reference with example calculations and detailed descriptions.

USDA Handbook 60. Complete reference from US Salinity Laboratory.