Agricultural Reuse of Treated Produced Water

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Energy Water Solutions
Purpose of Project

Use locally produced oilfield-generated produced water for agricultural beneficial reuse purposes.
Objectives

1. Evaluate cotton growth and yield response to irrigating with treated produced water blended with groundwater (1:4 ratio).

2. Determine the effect of treated produced water on soil chemical properties by measuring soil elemental concentrations and pH and electrical conductivity (EC) at varying soil depths.
Why Cotton?

– Non-food crop
– Texas’ most valuable crop

2014 Yield

– U.S.: 15.8 million bales
– Texas: 6.2 million bales
  • 86% of Texas cotton produced in West Texas
Cotton Production

• Cotton is considered a drought and salt tolerant crop
  – Requires 510 – 610 mm water (20” – 24”)
    for maximum yield
  – ~50% of cotton in Texas High Plains is irrigated

• Threat to maintaining production

WATER QUANTITY and QUALITY
Project Details

• Location
  – Texas A&M AgriLife Research Station, Pecos, TX
  – 12.1” average rainfall (1981-2010)

Permian Basin Oil Production

2008
710,480 barrels/day

2015
1,339,412 barrels/day
Project Details

• **Produced water**
  – Anadarko provided locally produced oilfield-generated produced water
  – Transported the water to the test site for treatment and land-application

• **Treatment of produced water**
  – Energy Water Solutions (the Woodlands, TX)
  – Developed a process train for the treatment of produced water from both oil and gas production fields
Public Policy Initiatives

Improved Legislation & Permitting

- Wellington Water Works
  - Colorado Water Court Approval 2007

- HB and Senate Bill in Colorado enabling ground discharge
  - Over 7.5 M Barrels of recycled water released in aquifer

- United States Patents for design and processes
  - 6,348,154 - Methods to remove heavy metals from water
  - 8,097,163 - Purification of oil field water for beneficial use
  - 12/421,462 - Beneficial use of produced water (pending)

- Texas Railroad Commission mobile permit
  - Five additional bills proposed in Texas in 2013 Session
    - SWD tariff, recycling mandate, discharge of fresh..
Mobilizing Recycling planning for lowered costs

- Movable in field
- Central field depot
- Optimum placement
- Close to wells
- Limit trucking
- Lower risk & opex

Consistent water quality via plant control systems

Modular units scale: 1,250 to over 50,000 BPD
EWS Optimized Process

Modular On Site Energy Water Solution

Fresh Water and Products

US Patent Protection

8,097,163 - Purification of oilfield Water for beneficial use (1-5)

6,348,154 - Methods to remove heavy metals from water - rare earth minerals harvesting (4)
Project Details

Irrigation Treatments (3 reps)
1. 100% groundwater (GW)
2. Blended water (4:1 ratio, GW:treated produced)

Irrigation volumes (June 6th to September 4th)
Groundwater: 13.9 acre-inches
Blended water: 10.7 acre-inches
Project Details

• **Cotton variety: DP 1359**
  - Planted on 2 June 2015
  - Harvested on 24 November 2015
    • Lint yield
    • Fiber quality

• **Soil and Water Monitoring:**
  - Soil samples collected at depth prior to initiating research and after the final irrigation event
    • 0-15 cm, 15-30 cm, and 30-60 cm
  - Water samples (groundwater, treated produced, and blended) were collected every four weeks
RESULTS
**Water samples collected on 6 June 2015**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Units</th>
<th>Groundwater</th>
<th>Treated Produced</th>
<th>Blended</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium (Na)</td>
<td>ppm</td>
<td>999</td>
<td>42</td>
<td>766</td>
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<tr>
<td>Calcium (Ca)</td>
<td>ppm</td>
<td>167</td>
<td>4</td>
<td>127</td>
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<tr>
<td>Magnesium (Mg)</td>
<td>ppm</td>
<td>50</td>
<td>1</td>
<td>40</td>
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<tr>
<td>Carbonate (CO₃)</td>
<td>ppm</td>
<td>&lt; 1</td>
<td>&lt; 1</td>
<td>&lt; 1</td>
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<tr>
<td>Bicarbonate (HCO₃)</td>
<td>ppm</td>
<td>122</td>
<td>37</td>
<td>122</td>
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<tr>
<td>Chloride (Cl)</td>
<td>ppm</td>
<td>1900</td>
<td>20</td>
<td>1450</td>
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<tr>
<td>Conductivity</td>
<td>µS/cm</td>
<td>4950</td>
<td>150</td>
<td>3800</td>
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<tr>
<td>pH</td>
<td></td>
<td>7.6</td>
<td>7.8</td>
<td>7.4</td>
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<tr>
<td>Phosphorus (P)</td>
<td>ppm</td>
<td>&lt; 0.01</td>
<td>&lt; 0.01</td>
<td>&lt; 0.01</td>
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<tr>
<td>Potassium (K)</td>
<td>ppm</td>
<td>18</td>
<td>5</td>
<td>14</td>
</tr>
<tr>
<td>Nitrate (NO₃)</td>
<td>ppm</td>
<td>5</td>
<td>6</td>
<td>4</td>
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<tr>
<td>Sulfate (SO₄)</td>
<td>ppm</td>
<td>1204</td>
<td>31</td>
<td>1362</td>
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<tr>
<td>Boron (B)</td>
<td>ppm</td>
<td>0.5</td>
<td>4.1</td>
<td>0.8</td>
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<tr>
<td>TDS</td>
<td>ppm</td>
<td>3218</td>
<td>98</td>
<td>2470</td>
</tr>
<tr>
<td>SAR</td>
<td></td>
<td>17.4</td>
<td>4.9</td>
<td>15.2</td>
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</table>
Soil Characteristics
Hoban silty clay loam

<table>
<thead>
<tr>
<th>pH</th>
<th>Conductivity mmhos/cm</th>
<th>NO$_3$-N</th>
<th>P</th>
<th>K</th>
<th>Ca ppm</th>
<th>Mg</th>
<th>S</th>
<th>Na</th>
<th>SAR*</th>
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<tbody>
<tr>
<td>8.7</td>
<td>1.8</td>
<td>22.1</td>
<td>30</td>
<td>450</td>
<td>17634</td>
<td>516</td>
<td>482</td>
<td>1373</td>
<td>16.7</td>
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</tbody>
</table>

17% CaCO$_3$ and 31% gypsum (NRCS)
# Soil Characteristics (post harvest)

<table>
<thead>
<tr>
<th>Irrigation Source</th>
<th>Sample Depth</th>
<th>pH</th>
<th>Conductivity mmhos/cm</th>
<th>NO₃-N</th>
<th>P</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
<th>S</th>
<th>Na</th>
<th>B</th>
<th>Cl</th>
<th>SAR*</th>
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</thead>
<tbody>
<tr>
<td>Blended</td>
<td>0-6&quot;</td>
<td>9.0</td>
<td>1.5</td>
<td>9</td>
<td>35</td>
<td>531</td>
<td>14915</td>
<td>575</td>
<td>654</td>
<td>1230</td>
<td>1.6</td>
<td>1018</td>
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<tr>
<td></td>
<td>6-12&quot;</td>
<td>9.1</td>
<td>1.2</td>
<td>12</td>
<td>26</td>
<td>474</td>
<td>16896</td>
<td>513</td>
<td>476</td>
<td>1347</td>
<td>1.2</td>
<td>896</td>
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<tr>
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<td>12-24&quot;</td>
<td>8.8</td>
<td>1.7</td>
<td>19</td>
<td>19</td>
<td>425</td>
<td>24243</td>
<td>485</td>
<td>528</td>
<td>1349</td>
<td>1.2</td>
<td>1256</td>
<td>15.3</td>
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<tr>
<td>Groundwater</td>
<td>0-6&quot;</td>
<td>8.9</td>
<td>2.2</td>
<td>36</td>
<td>35</td>
<td>528</td>
<td>15054</td>
<td>596</td>
<td>835</td>
<td>1751</td>
<td>1.6</td>
<td>1637</td>
<td>17.5</td>
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<tr>
<td></td>
<td>6-12&quot;</td>
<td>9.0</td>
<td>2.1</td>
<td>18</td>
<td>26</td>
<td>471</td>
<td>16352</td>
<td>514</td>
<td>503</td>
<td>1496</td>
<td>1.1</td>
<td>979</td>
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<td>12-24&quot;</td>
<td>8.8</td>
<td>1.8</td>
<td>26</td>
<td>16</td>
<td>409</td>
<td>25706</td>
<td>485</td>
<td>504</td>
<td>1487</td>
<td>1.2</td>
<td>1609</td>
<td>16.9</td>
</tr>
</tbody>
</table>

*Source Depth -- mmhos/cm --

**Blended**

- **Groundwater**
  - 0-6": 9.0, 2.2, 36, 35, 528, 15054, 596, 835, 1751, 1.6, 1637, 17.5
  - 6-12": 9.0, 2.1, 18, 26, 471, 16352, 514, 503, 1496, 1.1, 979, 17.3
  - 12-24": 8.8, 1.8, 26, 16, 409, 25706, 485, 504, 1487, 1.2, 1609, 16.9
# Cotton Yield

<table>
<thead>
<tr>
<th>Irrigation Source</th>
<th>Lint Yield (lb/acre)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Groundwater</td>
<td>587</td>
<td>0.834</td>
</tr>
<tr>
<td>Blended</td>
<td>568</td>
<td></td>
</tr>
</tbody>
</table>
Summary

Irrigating with treated produced water blended with groundwater

– Did not reduce cotton yield or lint quality
– Reduced soil salinity parameters
Future Research

• Identify and quantify boron in treated water
  – Fate in soil?
  – Plant uptake?

• Blending greater volumes of desalinated produced water with less well water may:
  – Improve soil chemical and physical properties
    • As result of decreasing salt load
  – Conserve fresh water sources
  – Enhance the longevity of agricultural production

• However, other ratios of blended water (and possibly other crops) must be examined…
Future Research

Treatments
1. Groundwater (100%)
2. Blend 1 (1:1 GW:TPW)
3. Blend 2 (2:1 GW:TPW)
4. Blend 3 (3:1 GW:TPW)
5. TPW (100%)