Bureau of Reclamation

- Water supply and management: potential to create “new water” sources
  - brackish surface and groundwater
  - seawater
  - reclaimed wastewater
  - produced water
- Identify location, quantity, quality, and accessibility of water supply and demand
- Determine risk of water shortages and potential conflict

Reclamation (2011), Conventional Oil and Gas
Produced Water Resources in the western United States

- Over 80% of oil and gas production occurs in the western US
- O&G industry water generation and water demand:
  - National produced water volumes > 2 billion gal/day
  - Hydraulic fracturing uses 500,000 gal to >10,000,000 gal of water per well fracturing event

API (2012), US Gas Shale Plays
Water Management Reports

Presentation Outline

• Define sourcing and disposal
  – Alternative water sourcing
  – Industrial water reuse
• Independent water user
• Produced water management
  – Range of options
  – Economical, technical, social, and environmental considerations
• Treatment for beneficial use
  – Technology evaluation
  – Beneficial use opportunities
Water Requirements

- Drilling water needed and used during well completion
- Hydraulic fracturing for formation stimulation
- Fracturing fluids can be up to 99% water
- Volume of water needed varies by site and type of formation
- It is projected that shale gas will comprise > 20% of the total U.S. gas supply by 2020

Clark et al., Hydraulic Fracturing and Gas Shale Development

RECLAMATION
Water Sourcing and Supplies

**Primary Water Sources for Hydraulic Fracturing**
- Surface water
- Groundwater
- Municipal water suppliers
- Treated wastewater from municipal and industrial treatment facilities
- Power plant cooling water
- Recycled produced water and/or flow back water

**Source Water Restrictions**
- Limited existing water infrastructure
- Drought risk
- Competition with urban growth
- Seasonal variations and reliability of water supply
Water Disposal

• Need for management
  – Flowback water
  – Deteriorated quality
  – Produced water

• Management Options
  – Disposal
  – On-site reuse
  – Offsite treatment
  – Beneficial Use

Reclamation (2011), Beneficial Use of Hydraulic Fracturing Flowback Water
Supply and Demand Balance

• Direct reuse of hydraulic fracturing flowback and produced water
  – Compatible with the producing formation
  – Available on-site (reduces transport cost)
  – Reduces disposal wells
• Brackish groundwater or municipal wastewater
• Water independence through industry reuse

Qualifying Water Demand and Production over a Well Lifetime
Produced Water Management

Water Sourcing

Transportation
Natural Conveyance
Alternate Sources

Onsite Reuse

Centralized Treatment

Disposal
Beneficial Use
Technical Considerations

• Treatment Options
  – Water treatment technologies
  – Evaluating technology capability
  – Commercial applications for the industry
  – Emerging technologies

• Resources
  – USGS produced water quality database (updating currently)
  – Produced water treatment primer

Define produced water quality and quantity to assess treatment potential

Determine treated quality requirements for reuse or alternative use

Select appropriate water treatment technologies
Produced Water Characterization

Table 13. Common inorganic constituents in conventional produced water

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Units</th>
<th>Low</th>
<th>High</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>TDS</td>
<td>mg/L</td>
<td>100</td>
<td>400,000</td>
<td>USGS produced water database</td>
</tr>
<tr>
<td>Sodium</td>
<td>mg/L</td>
<td>0</td>
<td>150,000</td>
<td>USGS produced water database</td>
</tr>
<tr>
<td>Chloride</td>
<td>mg/L</td>
<td>0</td>
<td>250,000</td>
<td>USGS produced water database</td>
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<tr>
<td>Barium</td>
<td>mg/L</td>
<td>0</td>
<td>850</td>
<td>Fillo 1992</td>
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<tr>
<td>Strontium</td>
<td>mg/L</td>
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<td>6,250</td>
<td>Fillo 1992</td>
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<tr>
<td>Sulfate</td>
<td>mg/L</td>
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<td>15,000</td>
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<tr>
<td>Bicarbonate</td>
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<td>0</td>
<td>15,000</td>
<td>USGS produced water database</td>
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<tr>
<td>Calcium</td>
<td>mg/L</td>
<td>0</td>
<td>74,000</td>
<td>USGS produced water database</td>
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</tbody>
</table>

Conventional Oil and Gas

Coalbed Natural Gas

RECLAMATION
Water Treatment Technologies

- **Pretreatment Technologies**
  - Bioreactors and Membranes
  - Filtration and Floatation
  - Adsorption and Oxidation

- **Desalination Technologies**
  - Membrane Filtration**
  - Electrodialysis**
  - Thermal Processes

- **Commercial Process Combinations**
  - Veolia OPUS™
  - Higgins Loop™

**Commonly require pretreatment
Categorizing Water Treatment Capabilities and Performance

Reclamation (2011), Technology Capabilities

<table>
<thead>
<tr>
<th>Technology</th>
<th>Emerging Technology</th>
<th>Previously Employed for Produced Water</th>
<th>Application Range</th>
<th>Overall TDS Rejection (%)</th>
<th>Overall Process Recovery (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Membrane</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NF</td>
<td>No</td>
<td>Yes</td>
<td>1,000 to 35,000</td>
<td>&gt; 99</td>
<td>60 to 80</td>
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<tr>
<td>RO</td>
<td>No</td>
<td>Yes</td>
<td>1,000 to 35,000</td>
<td>&gt; 99</td>
<td>30 to 60</td>
</tr>
<tr>
<td>ED/EDR</td>
<td>No</td>
<td>Yes</td>
<td>500 to 1,500</td>
<td>55 to 75</td>
<td>60 to 80</td>
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</table>

<table>
<thead>
<tr>
<th>Technology</th>
<th>Robustness</th>
<th>Reliability</th>
<th>Flexibility</th>
<th>Mobility</th>
<th>Modularity</th>
<th>Residual Disposal/Management</th>
</tr>
</thead>
<tbody>
<tr>
<td>Membrane</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>NF</td>
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<td>+++</td>
<td>++</td>
<td>++</td>
<td>Yes</td>
<td>+</td>
</tr>
<tr>
<td>ED/EDR</td>
<td>+</td>
<td>+++</td>
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<td>++</td>
<td>Yes</td>
<td>+</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Excellent</th>
<th>Good</th>
<th>Fair</th>
<th>Poor</th>
</tr>
</thead>
<tbody>
<tr>
<td>+++</td>
<td>++</td>
<td>+</td>
<td>-</td>
</tr>
</tbody>
</table>
Catalog of Commercial Treatment Technologies

- Categorical technology classification
- Applicable contaminants removed
- Description of technology
- Example treatment train
- Examples of commercial technology manufactures
  - Technology surveys
  - Pilot and full scale applications of technology
- Emerging technologies**
Reclamation Funding of Produced Water Treatment Technologies

- R&D efforts with commercialized technologies used in O&G
  - Altela Rain™ (Upper picture)
  - Freeze-thaw (Lower picture)

- Research areas of interest to O&G
  - Concentrate management
  - Zero liquid discharge
  - Mineral recovery
  - Membrane distillation
  - Forward osmosis
Economic Considerations

Costs of management

- Disposal costs (transportation, injection, evaporation, etc.)
- Internal costs for water sourcing and opportunity to offset through water treatment and reuse
- Treatment costs for reuse or beneficial use of water
- Third party water treatment options for disposal/treatment
- Value of water in the region

Determine disposal costs and options as a baseline estimate
Assess internal saving available through onsite reuse during operations
Evaluate the value of external entities to handle water disposal
Water Consumption

Source: ALL Consulting
Locations of Opportunity

- Production locations
- Produced volumes
- General water quality
- Potential water management opportunities:
  - Beneficial use
  - Conveyance systems
  - Disposal options
  - Facility co-location

Reclamation (2011), 2025 Water Conflict and Basin Overlay
# Disposal and Source Costs

<table>
<thead>
<tr>
<th>TABLE 1—BAKKEN FIELD WATER-HANDLING COSTS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Acquisition Costs</strong></td>
</tr>
<tr>
<td>Raw Water</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Transportation</td>
</tr>
</tbody>
</table>

| **Disposal Costs**                         |
| Transportation                             | 0.63–9.00     |
| Deep-well Injection                        | 0.50–1.75     |

| **Average Total Costs**                    |
|                                           | 2.00–16.80    |

*Source: University of North Dakota’s Energy and Environmental Research Center*
Water Treatment Market

- **Total market:**
  - ~ $1.2 billion in 2017

- **North America:**
  - $760 million in 2011
  - $825 million in 2012

- **Oil field-produced water:**
  - $627 million in 2012
  - $929 million in 2017

- **Gas field-produced water:**
  - $198 million in 2012
  - $267 million in 2017


| 212 Resources                    | Ge Water & Process Technologies |
| Agv Technologies, Inc.          | Geo-Processors Pty. Ltd.        |
| Aker Solutions                  | Geopure Hydrotechnologies       |
| Altelka, Inc.                   | Global Process Systems          |
| Amcol International Corp.       | Gradek Energy, Inc.             |
| Aqua Ewp                        | Halliburton                     |
| Aqua-Pure Ventures              | Hamworthy                       |
| Aquatech                        | Hydration Technology Innovation (Hti) |
| Auxsol, Inc.                    | Layne Christensen               |
| Cameron International Corp.     | Mycelx Technologies Corp.       |
| Dps Global                      | Nov Mission Products            |
| Drake Water Technologies, Inc.  | New Logic Research              |
| Ecosphere Technologies          | Ovivo                           |
| Eco-Tec                        | Process Group International (Pgi) |
| Eproces Technology Pte. Ltd.    | Prosep Inc.                     |
| Extarren                        | Saipem                          |
| Fsmidth                         | Schlumberger                    |
| Fmc Technologies (Cds)          | Set Corp.                       |
| Filterboxx Packaged Water Solutions, Inc. | Severn Trent                   |
Social and Environmental Considerations

• Public perception of the energy industry
  – Arid regions in the west
  – Drought restrictions

• Water cycle considerations for the environment
  – Fracturing water that does not return is considered consumed
  – Environmental stewardship of safe management practices
  – Opportunity to sustain habitat by supplying water
Water availability and environmental concerns in petroleum production

- **Water sourcing**
  - Water use prioritization/availability
  - Impact of water withdrawal on quality
  - Transportation

- **Chemical addition**
  - Release to surface or groundwater

- **Injection**
  - Contamination of surrounding surface or groundwater

- **Flowback/produced water**
  - Contamination of surrounding water supplies

- **Treatment and disposal**
  - Environmental impacts from saline water discharges
  - Downstream impacts
  - Transportation

**RECLAMATION**
Produced Water as a Water Supply

- Drought-proof option during emergencies
- Non-tributary water not subject to water rights limitations
- Potential for variation in flow over time
- Oil and gas development for future years
- Water resource can be mined up to 300 years
Beneficial Use Opportunities in the western US

- Irrigation
- Livestock watering
- Stream flow augmentation
- Hydraulic fracturing
- De-icing fluids
- Industrial uses
- Emergency drought supplies

Reclamation (2011), Agricultural areas overlaid with O&G basins
On-going Research Efforts

- **Published Studies** (Department of Energy, US Geological Survey, Argonne National Labs, National Energy Technology Laboratory, A&E)

- **Regulatory Guidelines** (Environmental Protection Agency Centralized Waste Treatment Facilities for Oil and Gas)

- **Reclamation Experience** (Missouri River Bakken Shale Fracturing Water Supply Agreements)

- **Commercial Treatment** (Commercial Technology Survey, Technology Evaluation at Reclamation Facilities)

- **Industry Collaboration** (Industry Water Management Expertise Survey, Produced Water Treatment Community of Practice)
General Conclusions

• Water demand for drilling and fracturing, also potential supply

• Industry independence

• Produced water management
  – Range of options
  – Economical, technical, social, and environmental considerations

• Treatment for beneficial use
  – Technologies are available
  – Beneficial use opportunities
  – Alternative users may offset treatment costs

Reclamation (2011), Conventional Oil and Gas
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