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*Managing Water in the West*

# Water Management Planning Guidelines

**May 21st, 2013**
**EUCI: Produced Water Management in the West**

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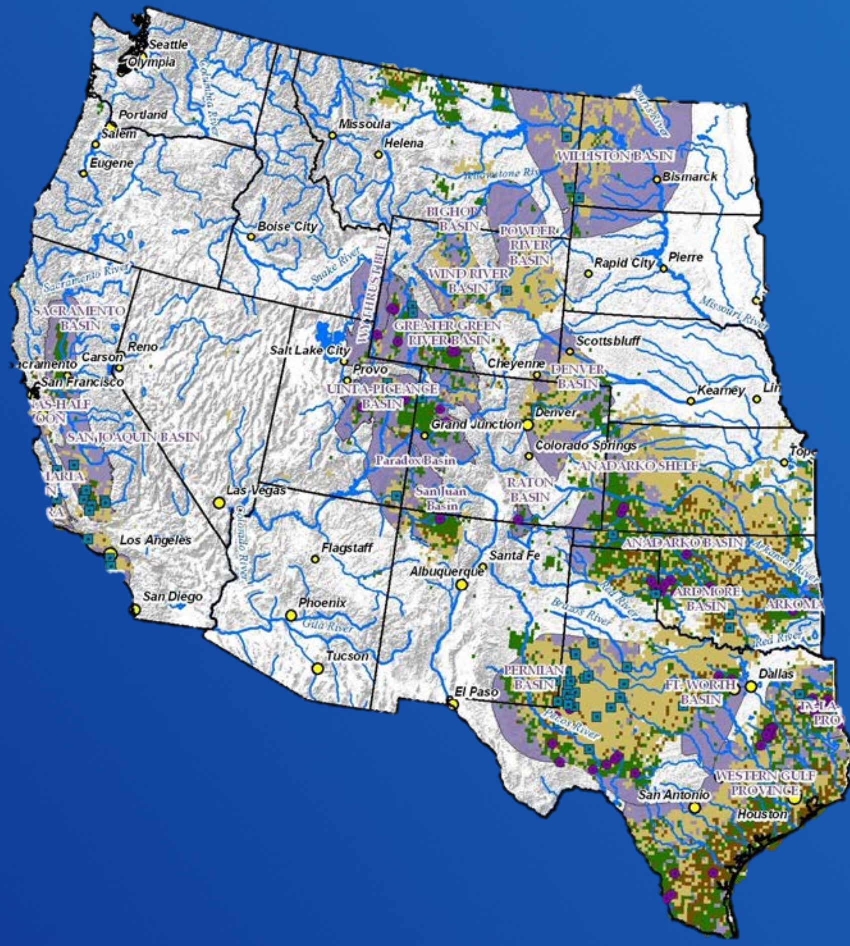
U.S. Department of the Interior
Bureau of Reclamation

# 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

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# 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

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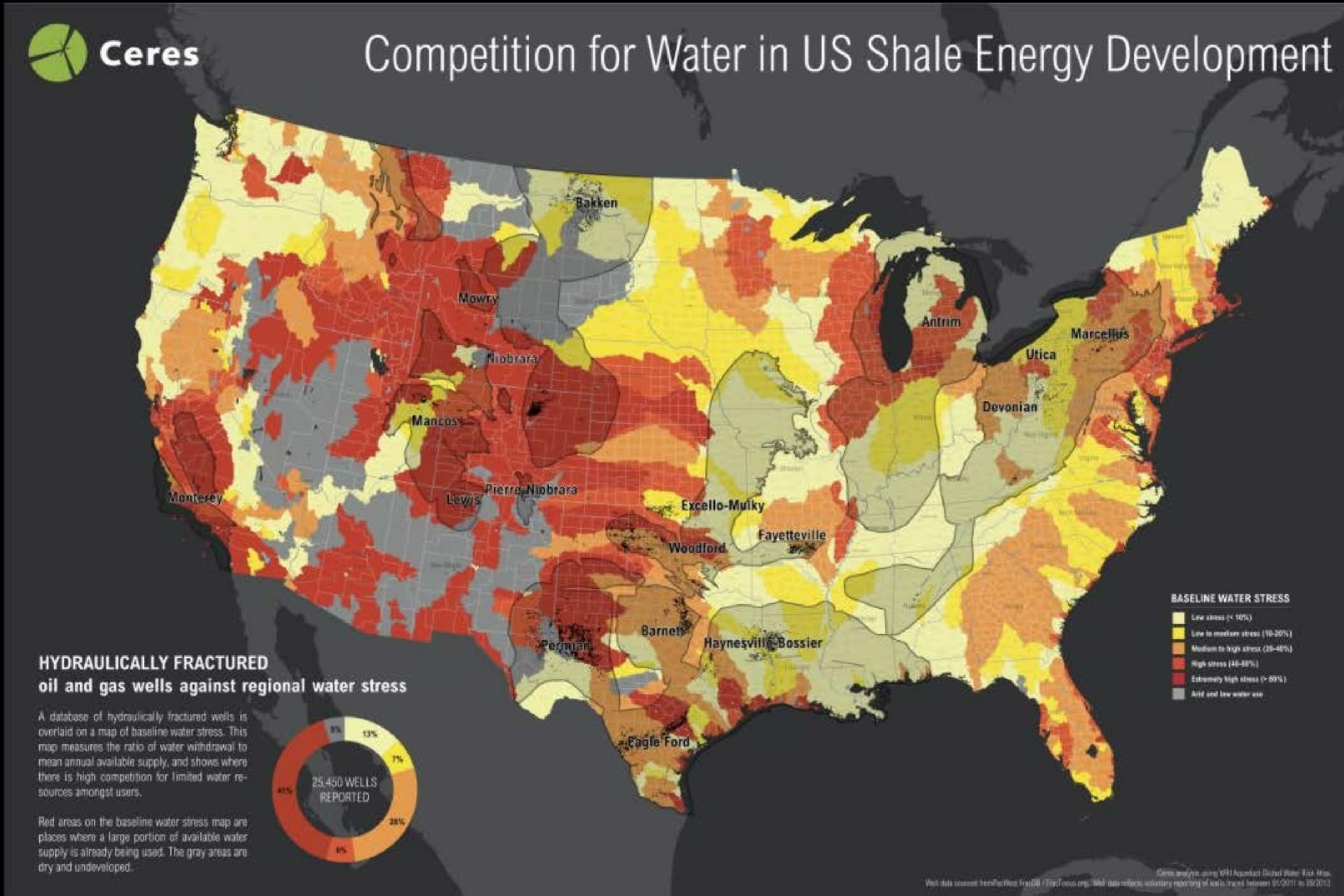


http://www.ceres.org/issues/water/hydraulic-fracturing-water-stress/hydraulic-fracturing-water-stress

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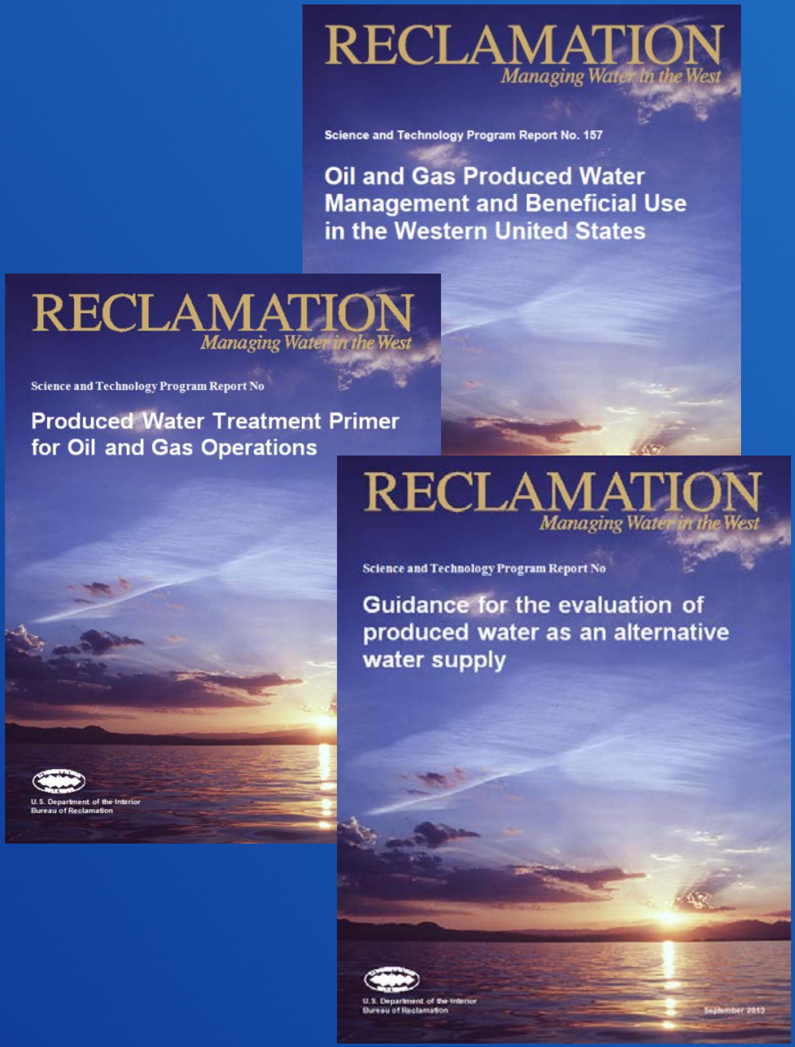
# Water Management Reports

## 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

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# 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

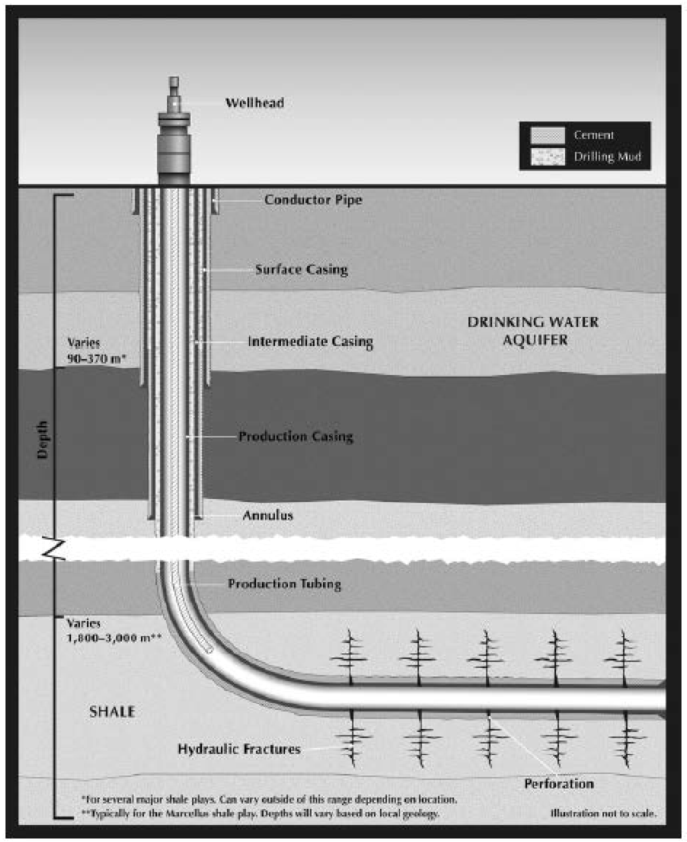


**Figure 2.** Typical configuration for a horizontally drilled, hydraulically fractured shale gas well.

Clark et al., Hydraulic Fracturing and Gas Shale Development

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# Water Sourcing and Supplies

Primary Water Sources for Hydraulic Fracturing

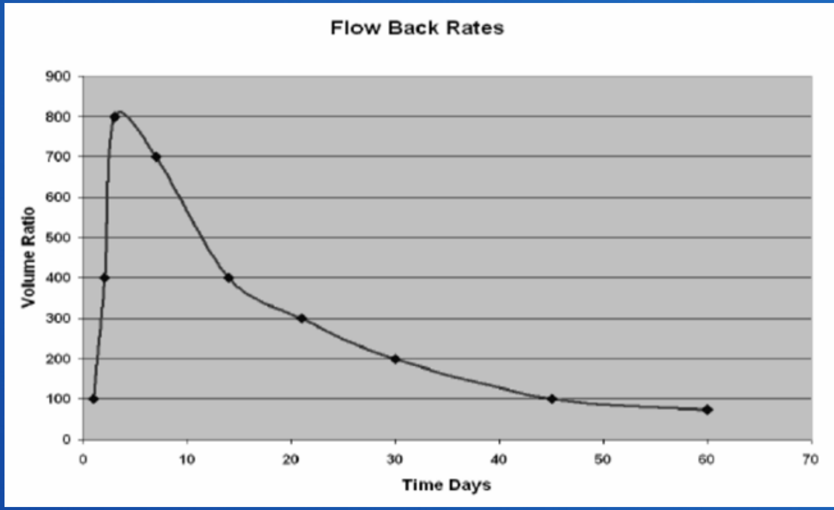
- Surface water
- Groundwater
- Municipal water suppliers
- Treated wastewater from municipal and industrial treatment facilities
- Power plant cooling water
- Recycled produced water and/or flow back water

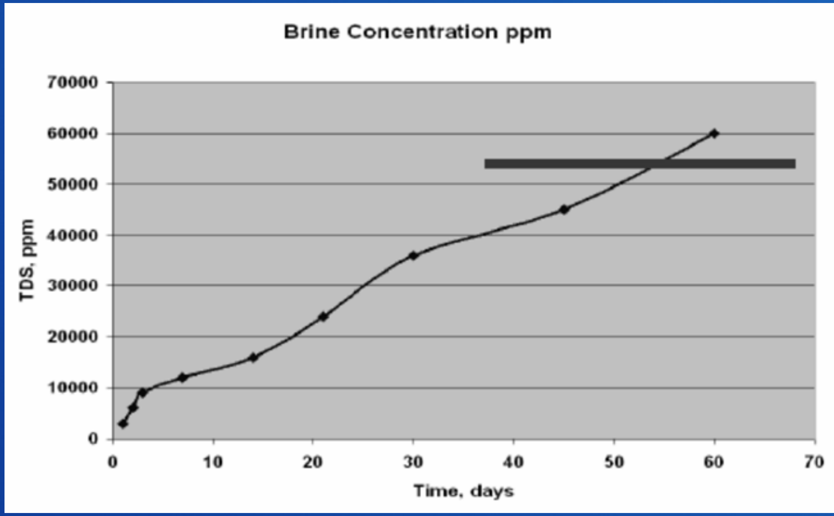
Source Water Restrictions

- 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

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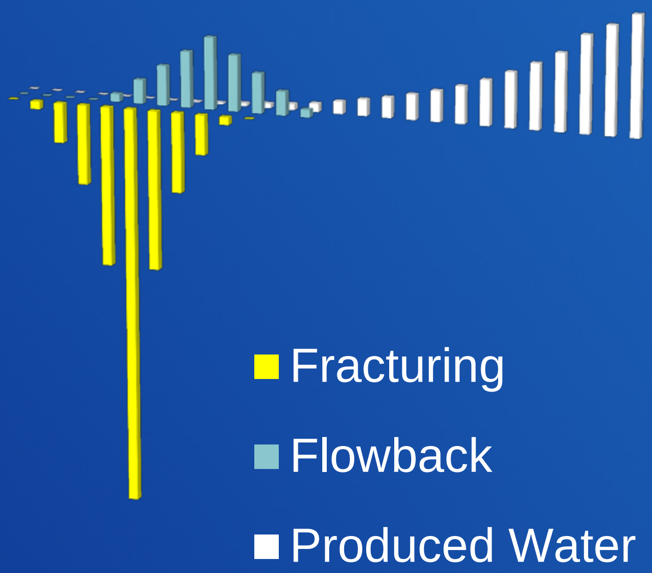
# Supply and Demand Balance

- 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

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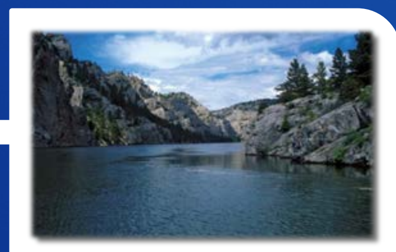
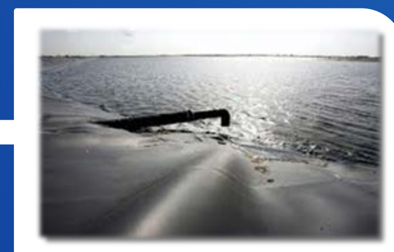
# Produced Water Management

Water Sourcing ⟷ Water Disposal

Transportation



Natural Conveyance



Disposal

Beneficial Use

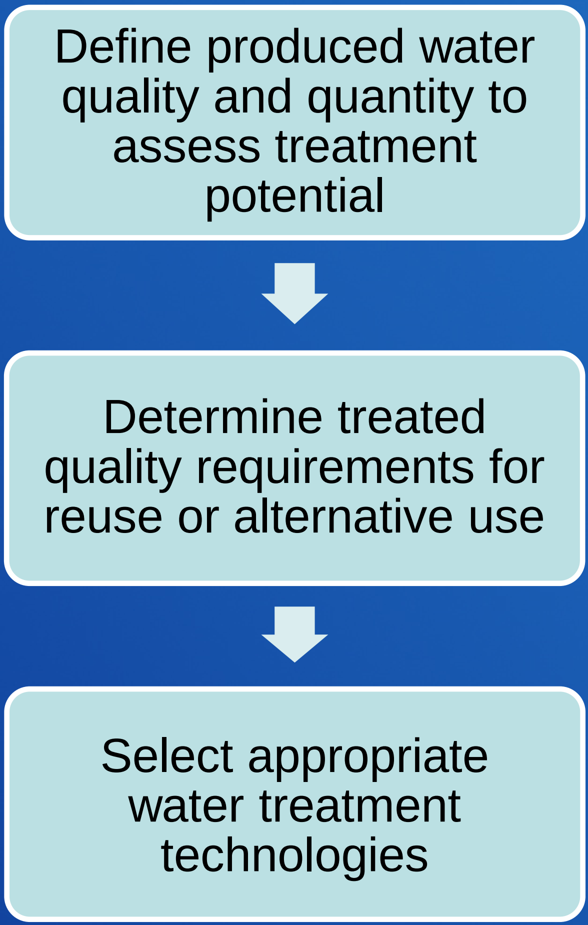
Alternate Sources

Onsite Reuse

Centralized Treatment

# 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

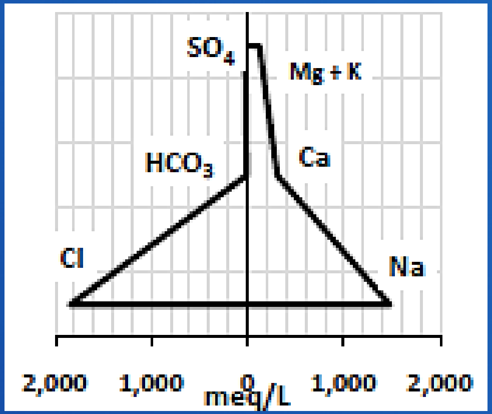


# Produced Water Characterization

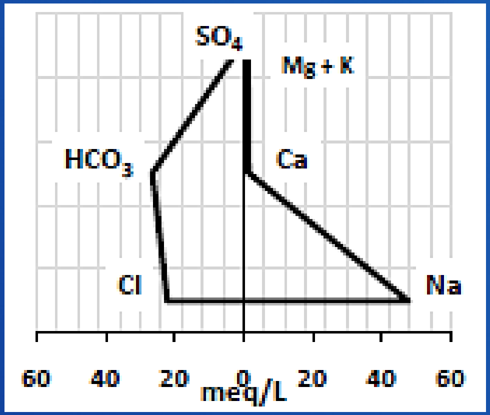
**Table 13. Common inorganic constituents in conventional produced water**

| Constituent | Units | Low | High | Reference |
|---|---|---|---|---|
| TDS | mg/L | 100 | 400,000 | USGS produced water database |
| Sodium | mg/L | 0 | 150,000 | USGS produced water database |
| Chloride | mg/L | 0 | 250,000 | USGS produced water database |
| Barium | mg/L | 0 | 850 | Fillo 1992 |
| Strontium | mg/L | 0 | 6,250 | Fillo 1992 |
| Sulfate | mg/L | 0 | 15,000 | USGS produced water database |
| Bicarbonate | mg/L | 0 | 15,000 | USGS produced water database |
| Calcium | mg/L | 0 | 74,000 | USGS produced water database |

**Conventional Oil and Gas**




**Coalbed Natural Gas**

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# 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

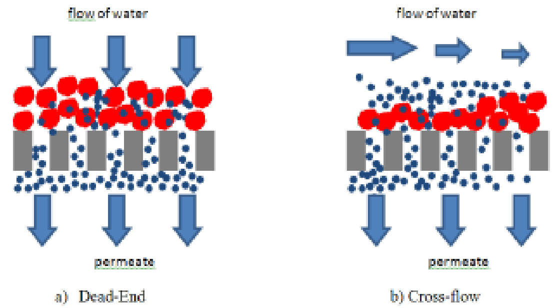


Figure 23. Dead-end versus cross flow filtration.

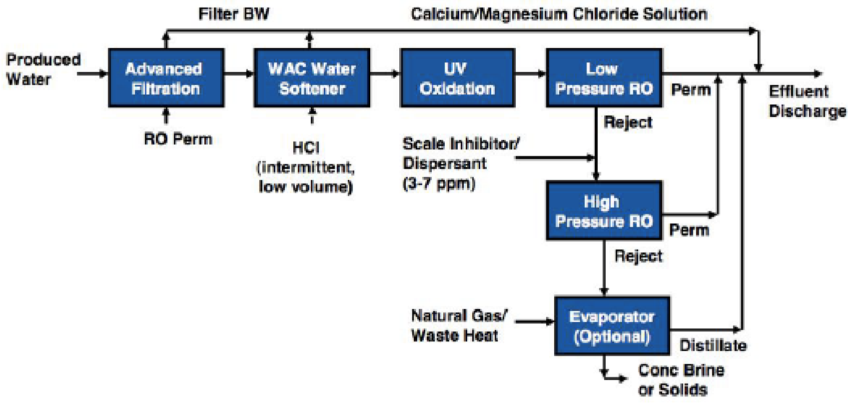


Figure 24. Schematic diagram of CDM produced water treatment process.

Reclamation (2011), Produced Water Treatment Technology Schematics

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# Categorizing Water Treatment Capabilities and Performance

Reclamation (2011), Technology Capabilities

| Technology | Emerging Technology | Previously Employed for Produced Water | Application Range | Overall TDS Rejection (%) | Overall Process Recovery (%) |
|---|---|---|---|---|---|
| ***Membrane*** | | | | | |
| NF | No | Yes | 1,000 to 35,000 | > 99 | 60 to 80 |
| RO | No | Yes | 1,000 to 35,000 | > 99 | 30 to 60 |
| ED/EDR | No | Yes | 500 to 1,500 | 55 to 75 | 80 to 90 |

| Technology | Robustness[1] | Reliability[2] | Flexibility[3] | Mobility[4] | Modularity[5] | Residual Disposal/ Manage-ment |
|---|---|---|---|---|---|---|
| ***Membrane*** | | | | | | |
| NF | ++ | +++ | ++ | ++ | Yes | + |
| RO | ++ | +++ | ++ | ++ | Yes | + |
| ED/EDR | + | +++ | + | ++ | Yes | + |

| Excellent | Good | Fair | Poor |
|---|---|---|---|
| +++ | ++ | + | - |

**Table 20. Comparison of organic contaminant and particulate removal technologies for treatment of produced water**

| Technology | Emerging Technology | Previously Employed for Produced Water | Overall Process Recovery (%) | Contaminants removed | Organic Matter Removal | Particulate Removal (min size removed) | Heavy Metals | Low Chemical Demand | Low Energy Demand | Minimal Maintenance | Ease of Operation | Minimal Posttreatment Requirement | Low Cost | Robustness[1] | Reliability[2] | Flexibility[3] | Mobility[4] | Modularity[5] | Waste Disposal Requirements | Small Footprint |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Biological aerated filters | No | Yes | 100% | oil, nitrogen, COD, BOD | ++ | ++ | + | +++ | +++ | +++ | +++ | + | +++ | +++ | +++ | +++ | - | + | ++ | - |
| Hydroclone | No | Yes | 98% | particulates | NA | 5-15 um | - | +++ | + | +++ | +++ | +++ | + | +++ | +++ | + | + | - | ++ | ++ |
| Centrifuge | No | Yes | 98% | particulates | NA | 2 um | - | +++ | + | +++ | +++ | +++ | + | +++ | +++ | + | + | - | ++ | ++ |
| API gravity separator | No | Yes | 98% | particulates | NA | 150 um | - | +++ | + | +++ | +++ | +++ | + | +++ | +++ | + | + | - | ++ | ++ |
| Corrugated plate separator | No | Yes | 98% | particulates | NA | 40 um | - | +++ | + | +++ | +++ | +++ | + | +++ | +++ | + | + | - | ++ | ++ |
| Dissolved air/gas flotation | No | Yes | 100% | TOC, oil and grease, particulates, hydrogen sulfide | +++ | 3-25 um | - | +++ | ++ | ++ | +++ | +++ | ++ | ++ | +++ | + | + | - | ++ | ++ |
| Adsorption/media filtration | No | Yes | 98% | particulates, BTEX, oil, TOC, iron, manganese, heavy metals | +++ | 5 um | ++ | +++ | +++ | ++ | +++ | +++ | ++ | +++ | +++ | +++ | +++ | +++ | ++ | ++ |
| Oxidation | No | Yes | 100% | manganese, iron, sulfur, color, odor, synthetic organic compounds | ++ | NA | ++ | ++ | ++ | ++ | ++ | +++ | ++ | +++ | +++ | +++ | +++ | +++ | +++ | +++ |
| Settling pond | No | Yes | 100% | particulates, iron, manganese | NA | +++ | ++ | +++ | +++ | +++ | +++ | +++ | +++ | +++ | +++ | ++ | - | - | +++ | - |
| Air stripping | No | Yes | 100% | TOC, volatile organics | +++ | NA | - | +++ | ++ | ++ | ++ | +++ | ++ | +++ | +++ | + | ++ | + | +++ | ++ |
| Surfactant modified zeolite vapor phase bioreactor | Yes | Yes | 95% | TOC, volatile organics | +++ | | ++ | ++ | +++ | +++ | +++ | +++ | ND | ND | ND | ND | ND | +++ | ++ | ++ |
| Constructed wetlands | No | Yes | 100% | TOC, dissolved organic compounds (increased calcium and slightly increased TDS) | +++ | +++ | ++ | +++ | +++ | +++ | +++ | +++ | +++ | +++ | +++ | ++ | - | - | +++ | - |
| Granular activated carbon fluidized bed reactor | No | Yes | 100% | TOC, volatile organics | +++ | ++ | +++ | +++ | +++ | ++ | +++ | +++ | + | +++ | +++ | +++ | +++ | +++ | + | +++ |
| UV disinfection | No | Yes | 100% | inactivation of microbial contaminants | NA | NA | NA | +++ | + | + | +++ | +++ | + | + | +++ | +++ | +++ | +++ | +++ | +++ |
| Ceramic MF/UF membrane | Yes | Yes | 85 to 95% | particulates, dissolved (with coagulation) and suspended organics, biological contaminants | ++ | 0.01 um | - | ++ | ++ | ++ | ++ | +++ | ++ | +++ | ++ | ++ | +++ | +++ | ++ | ++ |
| Polymeric MF/UF membrane | No | Yes | 85 to 95% | particulates, dissolved (with coagulation) and suspended organics, biological contaminants | ++ | 0.01 um | - | ++ | ++ | ++ | ++ | +++ | ++ | + | ++ | ++ | +++ | +++ | ++ | ++ |

Legend: Excellent | Good | Fair | Poor

**Table 21. Comparison of desalination technologies for treatment of produced water**

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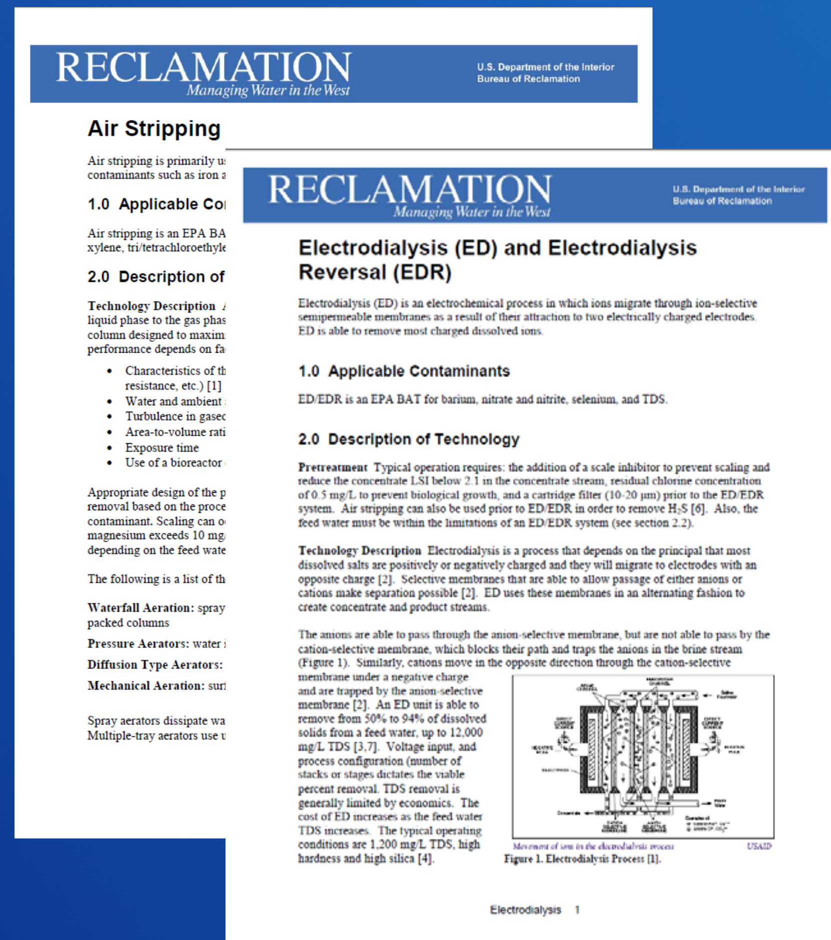
# Catalog of Commercial Treatment Technologies

- 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**



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## Air Stripping

Air stripping is primarily us
contaminants such as iron a

### 1.0 Applicable Co

Air stripping is an EPA BA
xylene, tri/tetrachloroethyle

### 2.0 Description of

**Technology Description** A
liquid phase to the gas phas
column designed to maxim
performance depends on fa

- Characteristics of th resistance, etc.) [1]
- Water and ambient
- Turbulence in gasec
- Area-to-volume rati
- Exposure time
- Use of a bioreactor

Appropriate design of the p
removal based on the proce
contaminant. Scaling can o
magnesium exceeds 10 mg
depending on the feed wate

The following is a list of th

**Waterfall Aeration:** spray
packed columns

**Pressure Aerators:** water i

**Diffusion Type Aerators:**

**Mechanical Aeration:** surf

Spray aerators dissipate wa
Multiple-tray aerators use u

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## Electrodialysis (ED) and Electrodialysis Reversal (EDR)

Electrodialysis (ED) is an electrochemical process in which ions migrate through ion-selective semipermeable membranes as a result of their attraction to two electrically charged electrodes. ED is able to remove most charged dissolved ions.

### 1.0 Applicable Contaminants

ED/EDR is an EPA BAT for barium, nitrate and nitrite, selenium, and TDS.

### 2.0 Description of Technology

**Pretreatment** Typical operation requires: the addition of a scale inhibitor to prevent scaling and reduce the concentrate LSI below 2.1 in the concentrate stream, residual chlorine concentration of 0.5 mg/L to prevent biological growth, and a cartridge filter (10-20 μm) prior to the ED/EDR system. Air stripping can also be used prior to ED/EDR in order to remove $H_2S$ [6]. Also, the feed water must be within the limitations of an ED/EDR system (see section 2.2).

**Technology Description** Electrodialysis is a process that depends on the principal that most dissolved salts are positively or negatively charged and they will migrate to electrodes with an opposite charge [2]. Selective membranes that are able to allow passage of either anions or cations make separation possible [2]. ED uses these membranes in an alternating fashion to create concentrate and product streams.

The anions are able to pass through the anion-selective membrane, but are not able to pass by the cation-selective membrane, which blocks their path and traps the anions in the brine stream (Figure 1). Similarly, cations move in the opposite direction through the cation-selective membrane under a negative charge and are trapped by the anion-selective membrane [2]. An ED unit is able to remove from 50% to 94% of dissolved solids from a feed water, up to 12,000 mg/L TDS [3,7]. Voltage input, and process configuration (number of stacks or stages dictates the viable percent removal. TDS removal is generally limited by economics. The cost of ED increases as the feed water TDS increases. The typical operating conditions are 1,200 mg/L TDS, high hardness and high silica [4].

*Movement of ions in the electrodialysis process* USAID

Figure 1. Electrodialysis Process [1].

Electrodialysis 1

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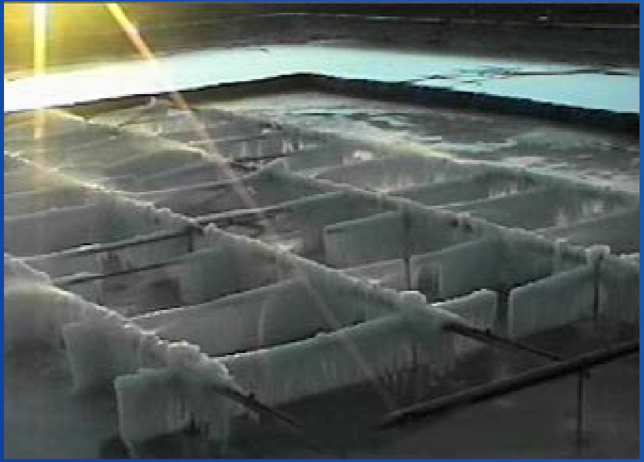
# Reclamation Funding of Produced Water Treatment Technologies

- 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



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# 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

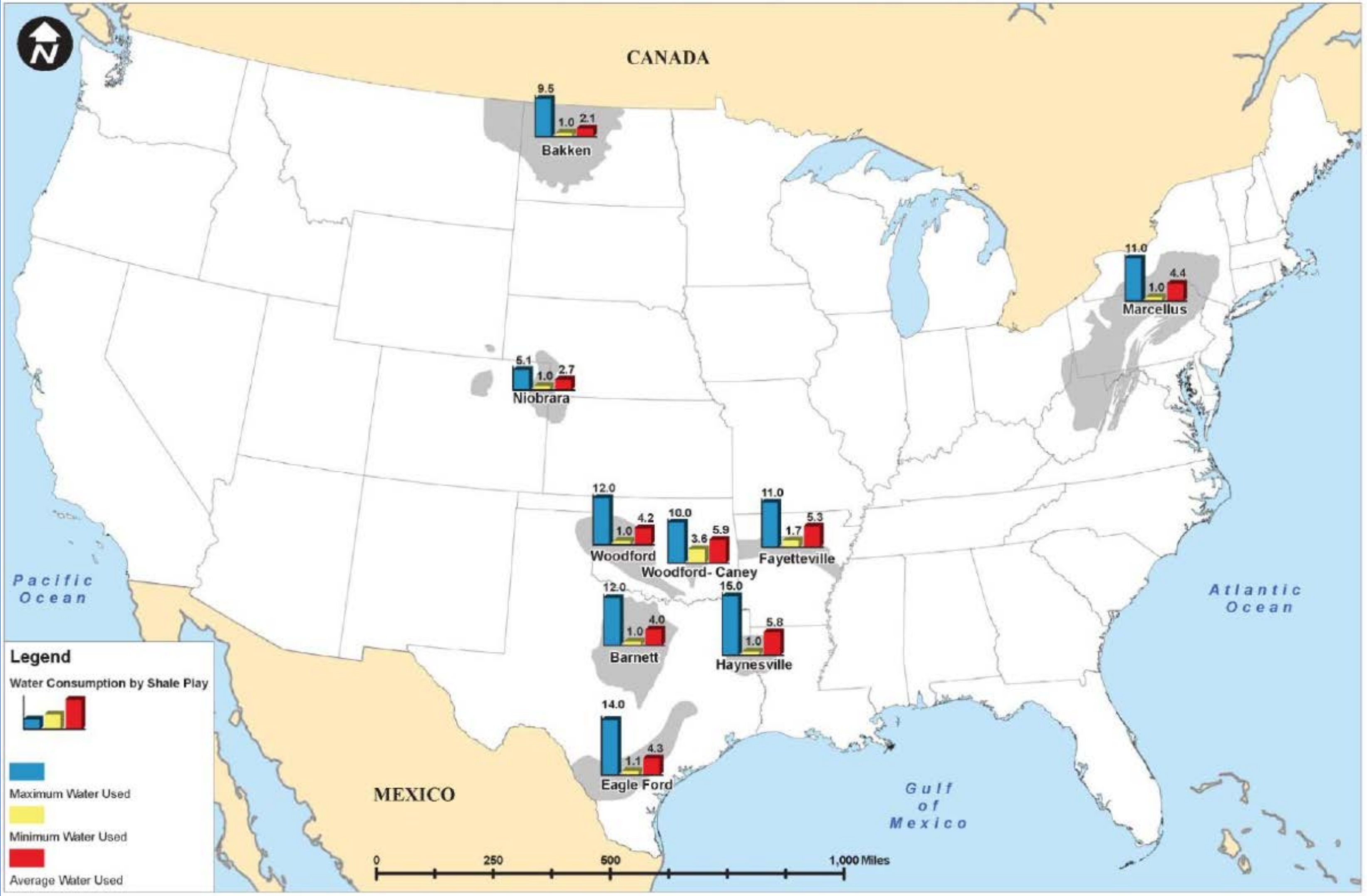
↓

Assess internal saving available through onsite reuse during operations

↓

Evaluate the value of external entities to handle water disposal

# Water Consumption




Source: ALL Consulting

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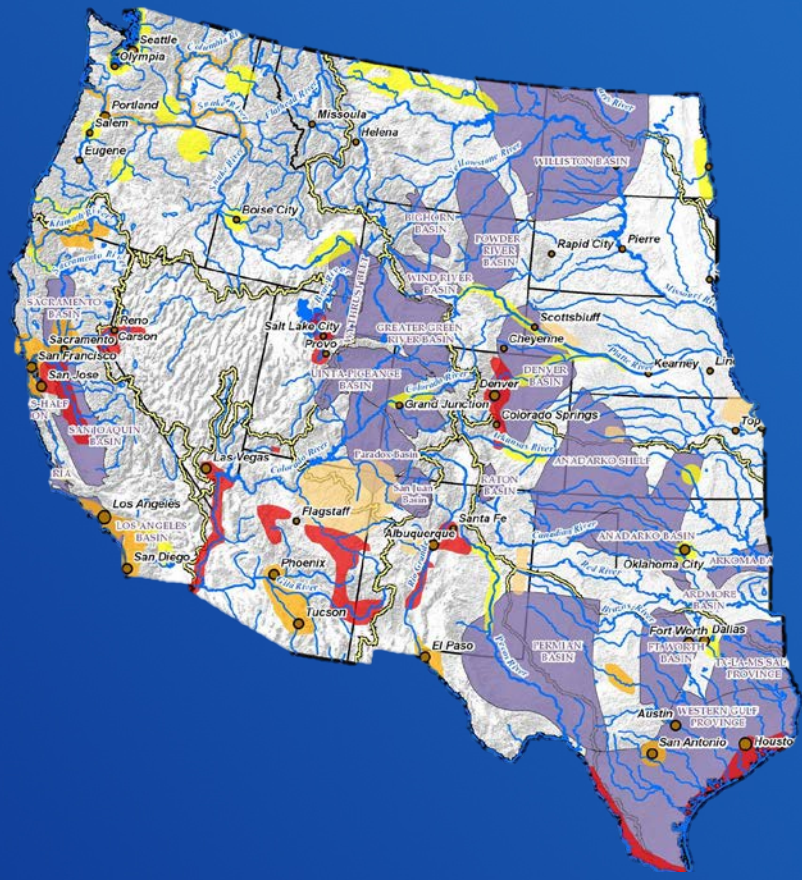
# Locations of Opportunity

- 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

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# Disposal and Source Costs

| TABLE 1— BAKKEN FIELD WATER-HANDLING COSTS | |
|---|---|
| **Acquisition Costs** | **Cost, USD/bbl** |
| Raw Water | 0.25–1.75 |
| Transportation | 0.63–5.00 |
| **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

Companies Profiled in: "The North American Market for Produced Water Treatment Equipment" report

| | |
|---|---|
| 212 Resources | Ge Water & Process Technologies |
| Agv Technologies, Inc. | Geo-Processors Pty. Ltd. |
| Aker Solutions | Geopure Hydrotechnologies |
| Altela, 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) |
| Eprocess Technologies Pty. Ltd. | Prosep Inc. |
| Exterran | Saipem |
| Flsmidth | 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

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# Water availability and environmental concerns in petroleum production

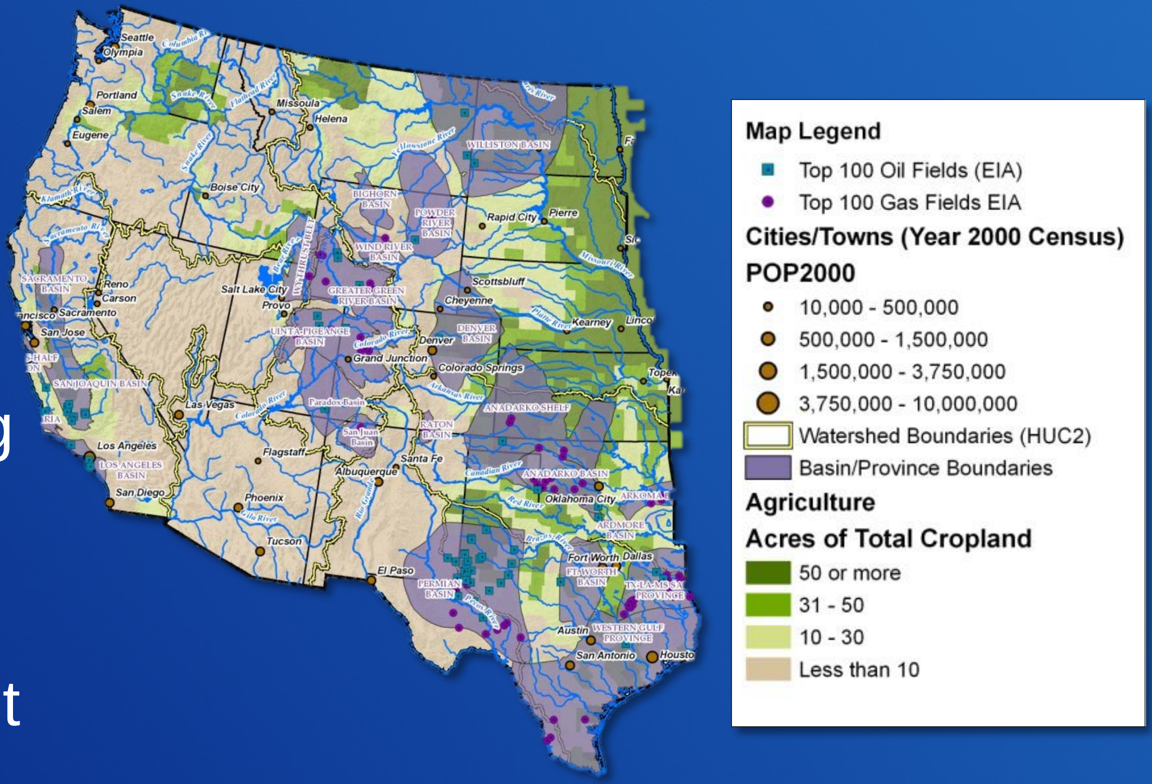
- **Water sourcing**
  - Water use prioritization/availability
  - Impact of water withdrawal on quality
  - Transportation
- **Chemical addition**
  - Release to surface or groundwater
- **Injection**
  - Contamination of surrounding surface or groundwater
- **Flowback/ produced water**
  - Contamination of surrounding water supplies
- **Treatment and disposal**
  - Environmental impacts from saline water discharges
  - Downstream impacts
  - Transportation

# 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



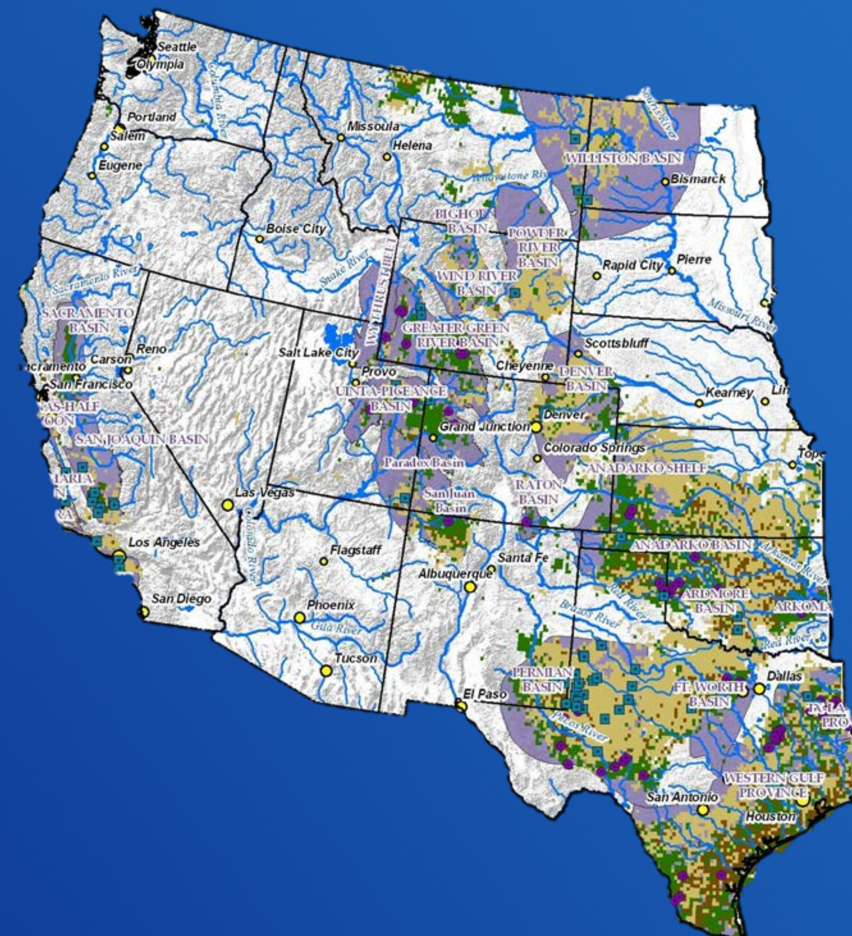

Reclamation (2011), Agricultural areas overlaid with O&G basins

# 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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