Affordable Desalination Collaboration – Phase II Progress

Steve Dundorf  (Denver Technical Service Center)
Tom Seacord, John MacHarg
Outline

- Background
- Treatment System Description
- Data
- Next Steps
Desalination in the U.S.

U.S. Drought Monitor

March 20, 2007
Valid 8 a.m. EDT

Intensity:
- D0 Abnormally Dry
- D1 Drought - Moderate
- D2 Drought - Severe
- D3 Drought - Extreme
- D4 Drought - Exceptional

Drought Impact Types:
- ~ Delineates dominant impacts
- A = Agricultural (crops, pastures, grasslands)
- H = Hydrological (water)

The Drought Monitor focuses on broad-scale conditions. Local conditions may vary. See accompanying text summary for forecast statements.

http://drought.unl.edu/dm

Released Thursday, March 22, 2007
Author: Brad Rippey, U.S. Department of Agriculture

California
Texas
Florida
Goals of the ADC

• **Demonstrate** affordable desalination using off-the-shelf technology
  – 5.6-7.6 kWh/kgal
  – 1.5-2.0 kWh/m3
  – 1850-2467 kWh/acre-ft

• Create a **body of data** that can guide & benefit future SWRO designs

• **Promote** seawater desalination as an affordable, viable source of fresh water
Partners Combining Resources
Background

Desalination Energy Requirements

Specific Power (kW-hr/AF)

Desalination Energy Requirements

(kW-hr/m$^3$)

(kW-hr/kgal)

Background

<table>
<thead>
<tr>
<th>Specific Power (kW-hr/AF)</th>
<th>California State Project Water</th>
<th>Colorado Aqueduct Water</th>
<th>SWRO</th>
<th>ADC 2006 &amp; 2007 SWRO Process</th>
</tr>
</thead>
<tbody>
<tr>
<td>(kW-hr/m³)</td>
<td></td>
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<tr>
<td>(kW-hr/kgal)</td>
<td></td>
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</tr>
<tr>
<td>6.5</td>
<td>26.4</td>
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<td>4.9</td>
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<td>3.2</td>
<td>12.3</td>
<td>6.5</td>
<td>12.3</td>
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<tr>
<td>1.6</td>
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</tr>
</tbody>
</table>
Location
Location
U.S. Navy – Seawater Desalination Test Facility
Testing

Phase 1

• Construction of pilot system
• Red Tide Event
• Trouble shooting of media filter pre-treatment system
• Testing of 3 different membranes from 1 Manufacturer
• Cost analysis of a 50 MGD system for each
Testing

Phase 1
1 year

May 2005 - April 2006

Phase 2
1.5 years

May 2007 - Nov 2008

Collier County Florida Demonstration May – Feb.

Phase 2

• Identical testing with 3 other manufacturers
• Change to UF pretreatment
• Staged membranes
• Innovative flow schemes
• Cost analysis of a 50 MGD system
Outline

• Background
• Treatment System Description
• Data
• Next Steps
Intake Screen (3 mm)

Basket Strainer (3 mm)

Coagulant

Flux: 3 – 5 gpm/ft²
(1 – 1.7 lpm/m²)

Flux: 2 - 3 gpm/ft²
(0.7 – 1 lpm/m²)

Flux: 6 - 9 gfd (2 – 3 lmd)
Size: 8”

Type: Positive Displacement
Motor Efficiency: 93%
Pump Efficiency: 90%
VFD Efficiency: 97%
TDH: 600 – 1000 psig (4 – 7 MPa)

Type: Centrifugal
Motor Efficiency: 90%
Pump Efficiency: 60%
VFD Efficiency: 97%
TDH: 20 – 50 psig

Type: Pressure Exchanger
Efficiency: 96%

Membrane
(1 stage, 3 vessels)

Media Filter (~20 um)

Cartridge Filter (5 um)

Anthracite
Diam.: 0.85 – 0.95 mm
U.Coef: <1.4

Sand
Diam.: 0.45 – 0.55 mm
U.Coef: <1.4

Gravel
Diam.: 0.3 mm
U.Coef: <1.4

Main High Pressure Pump

Booster Pump

Concentrate

Permeate

Energy Recovery

45 cm
25 cm
15 cm
18”
10”
6”

Flux: 3 – 5 gpm/ft²
(1 – 1.7 lpm/m²)

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(0.7 – 1 lpm/m²)

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Type: Pressure Exchanger
Efficiency: 96%
Pilot Layout

- Cartridge Filter
- Media Filters
- High Pressure Pump
- Strainer
- Energy Recovery
- 8” RO Membrane Vessels
Pilot System
Process Schematic

Pressure (psi)

Membrane Feed: 112 gpm
42.5% Recovery
7.5 gfd
1.93 kWh/m³
Boron: 0.9 mg/L
Total Dissolved Solids (mg/L)

Membrane Feed: 112 gpm
42.5% Recovery
7.5 gfd
1.93 kWh/m³
Boron: 0.9 mg/L
Energy Recording

High Pressure Pump (Positive Displacement)

Booster Pump (Centrifugal)

Power Monitored Individually

Total Power
Outline

• Background
• Treatment System Description
• Data (Preliminary)
• Next Steps
Raw Water Quality

- **Temperature:**
  12 – 20 °C

- **TDS:**
  30,000 – 33,000 mg/L
Raw Water Quality

- Turbidity: 0.3 – 12 NTU
- pH: 7.2 – 8.8 mg/L
Pretreatment

- Turbidity
  (Goal: < 0.1) Not exceeded 88%
Pretreatment

- SDI
  (Goal: < 5) Not exceeded 86%
# RO Performance Tests

## Multiple Membrane Manufacturer Testing

<table>
<thead>
<tr>
<th>Phase 1</th>
<th>Phase 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturer 1</td>
<td>Manufacturer 2</td>
</tr>
<tr>
<td>Manufacturer 2</td>
<td>Manufacturer 3</td>
</tr>
<tr>
<td>Manufacturer 3</td>
<td>Manufacturer 4</td>
</tr>
</tbody>
</table>

**Phase 1:**
- Manufacturer 1: \(\uparrow\) Rejection, \(\uparrow\) Energy
- Manufacturer 2: \(\checkmark\)
- Manufacturer 3: \(\checkmark\)
- Manufacturer 4: \(\checkmark\)

**Phase 2:**
- Manufacturer 2: \(\checkmark\)
- Manufacturer 3: \(\checkmark\)
- Manufacturer 4: \(\checkmark\)

\(\checkmark\) indicates successful performance.
## RO Performance Tests

### Phase II Flux & Recovery Matrix

<table>
<thead>
<tr>
<th>Flux (gfd)</th>
<th>Recovery</th>
<th>42.5%</th>
<th>46%</th>
<th>50%</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Phase 1: Recovery was 35%, 42.5%, 50%

Longer Term Testing @ Optimum Cost Point (2 weeks)
Specific Power Consumption

- Manufacturer 2

- Specific Power Consumption for different recovery rates and flow rates:
  - 6 gfd
  - 7.5 gfd
  - 9 gfd
  - 10 gfd

- Specific Power (kW-hr/m³) vs. Recovery (%):
  - Total Energy
  - RO Energy

- Specific Power (kW-hr/1,000 gallons) vs. Recovery (%):
Specific Power Consumption

Manufacturer 3

Lowest Energy Membrane

<table>
<thead>
<tr>
<th>Recovery</th>
<th>Total SWRO Energy</th>
<th>Specific Power (kW-hr/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30%</td>
<td>6 gfd</td>
<td>5.3</td>
</tr>
<tr>
<td></td>
<td>7.5 gfd</td>
<td>4.8</td>
</tr>
<tr>
<td></td>
<td>9 gfd</td>
<td>4.2</td>
</tr>
<tr>
<td>35%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>6 gfd</td>
<td>4.8</td>
</tr>
<tr>
<td></td>
<td>7.5 gfd</td>
<td>4.2</td>
</tr>
<tr>
<td></td>
<td>9 gfd</td>
<td>4.0</td>
</tr>
<tr>
<td>40%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>6 gfd</td>
<td>4.3</td>
</tr>
<tr>
<td></td>
<td>7.5 gfd</td>
<td>3.9</td>
</tr>
<tr>
<td></td>
<td>9 gfd</td>
<td>3.7</td>
</tr>
<tr>
<td>45%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>6 gfd</td>
<td>4.2</td>
</tr>
<tr>
<td></td>
<td>7.5 gfd</td>
<td>3.8</td>
</tr>
<tr>
<td></td>
<td>9 gfd</td>
<td>3.6</td>
</tr>
<tr>
<td>50%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>6 gfd</td>
<td>4.1</td>
</tr>
<tr>
<td></td>
<td>7.5 gfd</td>
<td>3.7</td>
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<tr>
<td></td>
<td>9 gfd</td>
<td>3.5</td>
</tr>
<tr>
<td>55%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>6 gfd</td>
<td>4.0</td>
</tr>
<tr>
<td></td>
<td>7.5 gfd</td>
<td>3.6</td>
</tr>
<tr>
<td></td>
<td>9 gfd</td>
<td>3.4</td>
</tr>
</tbody>
</table>
Permeate TDS

Includes membrane ripening data
Permeate TDS

- Flux $\uparrow = \text{TDS} \downarrow$
- Recovery $\uparrow = \text{TDS} \uparrow$
Permeate TDS

- Low energy membrane produced highest TDS

↑ Rejection ↑ Energy
- 80 to 175 mg/L
- 95 to 295 mg/L
- 190 to 350 mg/L

↓ Rejection ↓ Energy
50 MGD Product, 2006 USD, 25 year life
190,000 m³/day

Intake
Pumping (Feed)
Pretreatment
RO Membranes
Conditioning & Disinfection
Pumping (Permeate)
Storage
Distribution

- Maintenance
- Labor
- Replacement

CIP
Sludge Disposal
Brine Discharge

RECLAMATION
50 MGD Cost Model Results

Manufacturer 2

- Capital Costs ($/gpd)
- O&M Costs
- Total Costs

Recovery

O&M & Total Costs $/m³

6 gfd
7.5 gfd
9 gfd
10 gfd
50 MGD Cost Model Results

Manufacturer 3

<table>
<thead>
<tr>
<th>Recovery (%)</th>
<th>Capital Costs ($/gpd)</th>
<th>O&amp;M &amp; Total Costs $/kgal</th>
<th>O&amp;M Costs $/kgal</th>
<th>Total Costs $/kgal</th>
</tr>
</thead>
<tbody>
<tr>
<td>40%</td>
<td>6 gfd</td>
<td>$0.40</td>
<td>$1.30</td>
<td>$1.70</td>
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<tr>
<td>42%</td>
<td>7.5 gfd</td>
<td>$0.43</td>
<td>$1.35</td>
<td>$1.78</td>
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<tr>
<td>44%</td>
<td>9 gfd</td>
<td>$0.46</td>
<td>$1.40</td>
<td>$1.86</td>
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<tr>
<td>46%</td>
<td>10 gfd</td>
<td>$0.49</td>
<td>$1.45</td>
<td>$1.94</td>
</tr>
<tr>
<td>48%</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>50%</td>
<td></td>
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</tr>
<tr>
<td>52%</td>
<td></td>
<td></td>
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<tr>
<td>54%</td>
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</tr>
</tbody>
</table>
50 MGD Cost Model Results

Slightly decreasing cost with increasing recovery

- 42.5% Recovery
- 46% Recovery
- 50% Recovery
Major Accomplishments

5.98 kW-hr/kgal (1.58 kW-hr/m³)
  demonstrated at: 6 GFD, 42.5% Recovery

6.81 to 8.90 kW-hr/kgal (1.80 to 2.00 kW-hr/m³)
  at most affordable operating points - 50% recovery
Outline

- Background
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## Next Steps

### Completion of Multiple Membrane Manufacturer Testing

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</tr>
<tr>
<td>Manufacturer 3</td>
<td>Manufacturer 4</td>
</tr>
</tbody>
</table>

- Manufacturer 1: Complete
- Manufacturer 2: Complete
- Manufacturer 3: Complete
- Manufacturer 4: Complete
Next Steps

Internally Staged Membranes

- **Same flux, same recovery**
  - Lower feed pressure (lower operating costs)
  - Lower fouling potential (lower operating costs)

- **Higher flux, same recovery**
  - Smaller array (lower capital costs)

- **Same flux, high recovery**
  - Smaller pretreatment (lower capital costs)
  - Less feed water (lower operating costs)
## Next Steps

### Internally Staged Membranes

#### Standard SWRO Element Loading

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<tr>
<th></th>
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</table>

#### Internally Staged Options

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<th>11,000</th>
<th>11,000</th>
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<td>7500</td>
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<td>7500</td>
<td>11,000</td>
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<td>11,000</td>
<td>11,000</td>
<td>11,000</td>
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</tbody>
</table>

Values above are Permeate Flow (gpd)

<table>
<thead>
<tr>
<th></th>
<th>22.7</th>
<th>28.4</th>
<th>41.6</th>
</tr>
</thead>
</table>

(m³/day)
Next Steps

Internally Staged Membranes

Design Chosen

| 6000 | 6000 | 6000 | 11,000 | 11,000 | 11,000 | 11,000 |

Chosen to Optimize:
- Boron Rejection
- TDS Removal
- Energy
In the cold Pacific temperatures

Element Characteristics

<table>
<thead>
<tr>
<th>6000</th>
<th>22.7</th>
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</thead>
<tbody>
<tr>
<td>Flow: 6000 gpd (22.7 m³/day)</td>
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</tr>
<tr>
<td>Salt Rejection: 99.8%</td>
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<tr>
<td>Membrane Area: 400 ft² (11.3 m²)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>11,000</th>
<th>41.6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow: 11,000 gpd (41.6 m³/day)</td>
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<tr>
<td>Salt Rejection: 99.7%</td>
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<tr>
<td>Membrane Area: 400 ft² (11.3 m²)</td>
<td></td>
</tr>
</tbody>
</table>

(Test conditions: 32,000 mg/l NaCl, 800 psi (5.5 MPa), 25°C, pH 8, 8% recovery)
Next Steps

Innovative Flow Regimes

Unbalanced Flow around PX

Balanced
Unbalanced (gpm)

HP Pump

88

44

88

45

99

81

Unbalanced Flow around PX

Membrane Recovery
49%
44%

System Recovery
49%
54%

Booster Pump

44

54

44

55

44

44

Permeate

Concentrate

44

44

36

37

44

44

44

44
Next Steps

Innovative Flow Regimes

Unbalanced Flow around PX

Balanced
Unbalanced
(mg/L)

31,900
31,900

HP Pump

32,600
38,500

33,800
43,900

31,900
31,900

Booster Pump

31,900
31,900

63,700
67,400

Power:
2.02 kWh/m³
2.12 kWh/m³

Permeate

Concentrate

RECLAMATION
Next Steps

Innovative Flow Regimes - Unbalanced Flow around PX

44/54 Data points

Overall System Recovery

- Treatment Costs $/kgal
- RO Energy kWh/m3
- Capital Costs $/gpd
- Total Energy kWh/m3
- Quality mg/L TDS

RECLAMATION
Next Steps

Innovative Flow Regimes

Interstage Booster Pump

HP Pump

Booster Pump

Booster Pump

PX

Concentrate

Permeate
Gracias

Colorado - USA

Affordable Desalination Collaboration – Phase II Progress

www.AffordableDesal.com

Steve Dundorf

U.S. Department of Interior – Bureau of Reclamation

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Thursday - 10/25/07
Session 06 9:00 AM – 12:30
**Presentation Length:** 30 minutes (6th presentation)