Introducing Desalinated Seawater into Existing Distribution Systems

Hélène Baribeau, Ph.D., P.E.

AWWA CA-NV 2014 Fall Conference
October 22, 2014 – Reno, Nevada
• Blending desalinated seawater with other water sources in existing distribution systems

• Introduction:
  – Existing water supply system (Otay Water District)
  – Desalination facilities (Carlsbad, Rosarito)

• Blending issues:
  – Disinfectant residual stability
  – Disinfection by-products (DBPs)
  – Corrosion
  – Boron
  – Biological stability

• Concluding remarks
Introduction – Otay

San Diego Region
FUTURE RESIDENTIAL AND INDUSTRIAL LAND

New Residential and Industrial Lands (2050)
- New Residential (Densities higher than 4 du/ac)
- New Industrial
- Otay Water District
- Otay Water District within City of San Diego
- Other Water Districts

New Residential and Industrial Lands by Water District

<table>
<thead>
<tr>
<th>District</th>
<th>Industrial Acres</th>
<th>Rank</th>
<th>Residential Acres</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Otay Water District</td>
<td>3,862.9</td>
<td>1</td>
<td>1,302.7</td>
<td>2</td>
</tr>
<tr>
<td>City Of San Diego</td>
<td>869.8</td>
<td>2</td>
<td>2,998.6</td>
<td>1</td>
</tr>
<tr>
<td>Vallecitos County Water District</td>
<td>622.9</td>
<td>3</td>
<td>320.9</td>
<td>8</td>
</tr>
<tr>
<td>Padre Dam Mun. Water District</td>
<td>495.3</td>
<td>4</td>
<td>366.4</td>
<td>5</td>
</tr>
<tr>
<td>Carlsbad Mun. Water District</td>
<td>471.8</td>
<td>5</td>
<td>383.1</td>
<td>4</td>
</tr>
<tr>
<td>City Of Oceanside</td>
<td>326.1</td>
<td>6</td>
<td>518.8</td>
<td>3</td>
</tr>
<tr>
<td>Vista Irrigation District</td>
<td>140.2</td>
<td>11</td>
<td>336.0</td>
<td>7</td>
</tr>
<tr>
<td>Helix Water District</td>
<td>10.6</td>
<td>18</td>
<td>348.3</td>
<td>6</td>
</tr>
</tbody>
</table>

Source: SANDAG Series 12 Planned Land Use Inventory
• Otay Water District’s current water sources: Pipeline fed by several water treatment plants:
  – Metropolitan Water District of Southern California’s (MWD) Robert A. Skinner Treatment Plant
  – San Diego County Water Authority’s (SDCWA) Twin Oaks Valley Water Treatment Plant (TOVWTP)
  – City of San Diego’s Miramar WTP, and Alvarado WTP (and Otay WTP for emergencies)
  – Helix Water District
• Potential additional, future water sources:
  – SDCWA’s Carlsbad Desalinated Seawater Facility
  – NSC Agua’s Rosarito Beach desalination facility
• Proportions vary seasonally
• SDCWA’s Twin Oaks Valley Water Treatment Plant (TOVWTP):
  – 100 MGD plant
  – Submerged ultrafiltration membranes, ozonation with hydrogen peroxide, and biological filtration on granular activated carbon (GAC)
  – Chlorine and ammonia
  – No corrosion inhibitor
City of San Diego’s Miramar Water Treatment Plant:

- 144 MGD plant
- Conventional treatment processes: coagulation, flocculation, sedimentation, and multi-media filtration
- Ozone as primary disinfectant, chlorine as secondary disinfectant, and monochloramine as distribution disinfection
- Corrosion control by pH adjustment
Introduction – Future Supplies

• SDCWA’s Carlsbad Desalinated Seawater Facility:
  – Public-private partnership with Poseidon Resources Corp.
• 50-MGD located at the Encina Power Station
• Pre-treatment: gravity-media filtration
• Single-pass high-rejection RO membranes
• Water conditioning by lime, and disinfection with chlorine and ammonia
• Blending at the effluent of TOVWTP, then introduced in the distribution system
Rosarito Beach (Baja California, Mexico):

- Pretreatment: Pre-screening, intermittent dissolved air flotation (DAF), rapid sand filtration (dual media), and cartridge filters

- RO membranes, with a full or partial second-pass for additional removal of boron, bromide and chloride

- Post-treatment conditioning with calcium carbonate (CaCO$_3$)

- Free chlorine (0.5-1.0 mg/L Cl$_2$)
Rosarito Beach (Baja California, Mexico):
  - Excess desalinated water will be conveyed by pipeline through the international border
  - 25-mile pipeline

In Otay:
  - Possibly UV
  - Additional chlorine
  - Ammonia
### Introduction – Future Supplies

- **Water quality expected by Otay:**

<table>
<thead>
<tr>
<th></th>
<th>Rosarito</th>
<th>Carlsbad</th>
<th>TOVWTP</th>
<th>Miramar</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Alkalinity (mg/L CaCO₃)</strong></td>
<td>≥45</td>
<td>≥45</td>
<td>92</td>
<td>100</td>
</tr>
<tr>
<td><strong>Boron (mg/L)</strong></td>
<td>0.75</td>
<td>0.75</td>
<td>0.14</td>
<td>0.12</td>
</tr>
<tr>
<td><strong>Bromide (mg/L)</strong></td>
<td>0.2</td>
<td>0.4</td>
<td>(ND)</td>
<td>ND</td>
</tr>
<tr>
<td><strong>Calcium (mg/L Ca²⁺)</strong></td>
<td>≥16</td>
<td>≥16</td>
<td>37</td>
<td>51</td>
</tr>
<tr>
<td><strong>Chloride (mg/L)</strong></td>
<td>180</td>
<td>120</td>
<td>78</td>
<td>86</td>
</tr>
<tr>
<td><strong>TDS (mg/L)</strong></td>
<td>320</td>
<td>320</td>
<td>370</td>
<td>460</td>
</tr>
<tr>
<td><strong>pH</strong></td>
<td>8.5</td>
<td>8.5</td>
<td>7.8</td>
<td>8.2</td>
</tr>
</tbody>
</table>
Introduction – Future Supplies

• 50-100% will be desalinated seawater from Rosarito and Helix Water District, depending on seasons
• Remaining will be treated water from SDCWA:

<table>
<thead>
<tr>
<th></th>
<th>Winter</th>
<th>Spring and Fall</th>
<th>Summer</th>
</tr>
</thead>
<tbody>
<tr>
<td>100% desalinated seawater from Carlsbad</td>
<td>67% desalinated seawater from Carlsbad</td>
<td>33% desalinated seawater from Carlsbad</td>
<td></td>
</tr>
<tr>
<td>0% from TOVWTP</td>
<td>33% from TOVWTP and/or Miramar</td>
<td>67% from TOVWTP and/or Miramar</td>
<td></td>
</tr>
</tbody>
</table>
Using existing literature and studies, evaluate the potential effects of introducing desalinated seawater in an existing distribution system and blending with other water sources.
Outline

• Blending issues:
  – Disinfectant residual stability
  – Disinfection by-products (DBPs)
  – Corrosion
  – Boron
  – Biological stability
• Chloramine stability is influenced by:
  – Chlorine dose
  – Chlorine-to-ammonia ratio
  – pH
  – Temperature
  – Organic material
  – Alkalinity
  – Bromide
  – Contact time
  – *etc.*
Disinfectant Stability – Bromide

• With free chlorine, bromide forms hypobromous acid (HOBr) and hypobromite ion (OBr⁻):

\[ \text{HOCl} + \text{Br}^- \leftrightarrow \text{Cl}^- + \text{HOBr} \]

– HOBr/OBr⁻ are weaker oxidants than HOCl/OCl⁻

• Chloramines: Bromide forms bromine-substituted haloamines (e.g., bromamines):

\[ \text{HOBr} + \text{NH}_3 \leftrightarrow \text{NH}_2\text{Br} + \text{H}_2\text{O} \]

– Chloramine decays faster in the presence of bromide

“Formation and Control of Disinfection By-Products in Drinking Water”, AWWA 1999
Disinfectant Stability

• Other factors affect disinfectant stability:
  – Order of chemical addition:
    • HOBr and ammonia >> Chloramines and bromide
    • Pre-formed chloramine (before bromide is added) are more stable than when bromide is introduced before ammonia
  – Contact time between chemical addition (chlorine, ammonia, bromide)
  – pH: Chloramines are more stable at higher pH
  – Chlorine-to-ammonia ratio: Chloramines are more stable at the lower ratios
  – Alkalinity: Effect is not straightforward
  – Temperature: Chloramines are more stable at low temp.
Disinfection By-Products (DBPs)

• DBP formation is influenced by:
  – Disinfectant type, dose and residual
  – Concentration and nature of precursors (NOM)
  – Bromide concentration
  – Temperature
  – pH
  – Contact time (e.g., between chlorine and ammonia addition)
  – etc.
• HOBr/OBr$^-$ are more efficient halogen substitution agents (can attack more sites) than HOCl/OCl$^-$:  
  – Greater concentrations of DBPs  
  – More brominated species  
  – Faster rates of formation

“Formation and Control of Disinfection By-Products in Drinking Water”, AWWA 1999
Disinfection By-Products (DBPs)

- Upon blending of desalinated seawater with treated surface water:
  - Higher NOM concentrations → Greater DBP levels
  - Lower pH → Lower THM concentrations
  - Seasonal changes in blends → Seasonal changes in DBP concentrations
  - Sampling locations for compliance with Stage 2 DBPR may need to be reviewed
  - Formation of toxic non-regulated DBPs:
    - E.g., haloacetonitriles (HANs), mutagen X compounds (MX), halonitromethanes (HNMs), cyanogen bromide (CNBr)
Disinfectant Stability and DBPs

- Bench-scale tests under the conditions encountered:
  - Disinfectant dose
  - Chlorine-to-ammonia ratio
  - Bromide concentration
  - DOC concentration
  - Bromide-to-DOC ratio
  - Bromide-to-chlorine ratio
  - Temperature
  - pH
  - Alkalinity
  - Contact time
• Main challenges of water providers introducing desalinated seawater into existing distribution systems

• Low alkalinity and hardness of desalinated seawater, near neutral pH, and higher chloride-to-sulfate ratio
  → Need conditioning (stabilization) of desalinated seawater before distribution

• Even after stabilization, zinc and lead releases can remain a problem

• Disruption of corrosion scales present inside existing distribution systems
Corrosion

• Two phenomena:
  – Aggressiveness, or erosion of internal surfaces, which affects cement-mortar lined and asbestos-cement pipes
  – Corrosion of metallic pipes

• Influenced by numerous water quality parameters:
  – Temperature, pH, alkalinity, dissolved inorganic carbon (DIC), oxidants, TDS, calcium, chloride, sulfate, ammonia, fluoride, NOM, etc.

• Aggressiveness/corrosiveness trends may be driven in opposite directions

• And microbiologically-induced corrosion (MIC)
• Consider water quality AND distribution system materials to determine suitable corrosion control practice(s):
  
  – Desktop studies using corrosion indices:

    • Aggressiveness: Precipitation or dissolution of CaCO₃ (Langelier Saturation Index, LSI; Ryznar Saturation Index, RSI; calcium carbonate precipitation potential, CCPP; Aggressiveness Index, AI)

    • Corrosiveness: Chloride, sulfate and alkalinity (Larson Ratio or Larson Index, LI; chloride-to-sulfate mass ratio, CSMR; Buffer Intensity)

  – Pilot testing (e.g., pipe racks or pipe loops with metal coupons)
• Corrosion control practice(s):
  – Precipitation of a thin layer of CaCO$_3$:
    • By increasing pH, alkalinity, calcium concentration, and/or DIC concentration
  – Passivation of the material:
    • Formation of less soluble metal compounds (e.g., carbonates, silicates, phosphates, zinc)
Boron

- Essential nutrient for humans, but also adverse health effects
- Affects some vegetation → Limit in recycled water (Notification Level of 1 mg/L in California)
- Present in high concentrations in seawater
- Removal:
  - Specific membranes
  - 2nd pass RO
- Some of Otay’s requirements:
  - Maximum boron concentration of 0.75 mg/L
  - Maximum bromide concentration of 0.2 mg/L
Factors influencing microbial regrowth:

- Disinfectant residual (nature and concentration)
- Temperature
- Nutrients (carbon : nitrogen : phosphorus for heterotrophs)
- Turbidity, sediments
- pH
- Alkalinity
- Distribution system materials, corrosion control practice(s)
- Hydraulic conditions, water age
- etc.
Biological Stability

• In desalinated seawater:
  – Low carbon content → Less microbial regrowth
  – Low alkalinity, low pH, and corrosion control practices → May promote nitrification

• Water quality monitoring before and after introducing desalinated seawater in an existing distribution system is important
• In desalinated seawater:
  – Target a low bromide residual (0.2 mg/L) to limit monochloramine decay and DBP formation
  – Numerous other parameters affect chloramine decay and DBP formation:
    • Disinfectant dose, chlorine-to-ammonia ratio, bromide and DOC concentrations, bromide-to-DOC and bromide-to-chlorine ratios, temperature, pH, alkalinity, contact time
  – May need to increase calcium concentration and alkalinity
  – Select adequate corrosion control practice(s)
  – Blending location (e.g., in the distribution system vs. storage reservoir) greatly influence the impact on the overall system
Recommendations

• Bench-scale tests under the specific conditions encountered (disinfectant dose, chlorine-to-ammonia ratio, bromide and DOC concentrations, bromide-to-DOC and bromide-to-chlorine ratios, temperature, pH, alkalinity, and contact time) to assess chloramine decay and DBP formation

• Desktop studies and pilot testing to determine suitable corrosion control practice(s) (e.g., pipe racks or pipe loops with metal coupons)

• Water quality monitoring, before and after introducing the new water source
Acknowledgements

• Otay Water District:
  – Rod Posada, P.E., Chief of Engineering
  – Bob Kennedy, P.E., Engineering Manager
  – Jeff Marchioro, P.E. Senior Civil Engineer

• AECOM:
  – Jason Caprio, P.E.

• DLM Engineering:
  – Don MacFarlane, P.E.
Thank you!

Hélène Baribeau, Ph.D., P.E.
Baribeau Environmental Engineering
714-488-0496, HBaribeau@BaribeauEnvironmental.com