The Importance of NF/RO in Potable Reuse and the Role of Membrane Integrity Testing

Brent Alspach
Arcadis
The Story Begins…

Alternative Water Resources

• Saline surface water
• Saline groundwater
• Compromised groundwater
  − Arsenic
  − Nitrate
  − Perchlorate
  − …etc.
• Municipal wastewater (i.e., potable reuse)
• Seawater

All are likely to need desalination, but not every application of every case.
The Story Begins…

Alternative Water Resources

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  - …etc.
- Municipal wastewater (i.e., potable reuse)
- Seawater

Blending…?
The Story Begins…

**Alternative Water Resources**

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The Story Begins…

**Alternative Water Resources**

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  - …etc.
- Municipal wastewater (i.e., potable reuse)
- Seawater
Basic Desalination Roadmap

Is higher salinity acceptable? Yes → Done
No → Can salinity be reduced by blending? Yes → Blend

Considerations
• Availability of blend water
• Regulations
Basic Desalination Roadmap

1. Is higher salinity acceptable? [Yes/No]
   - Yes: Done
   - No: Can salinity be reduced by blending?

2. Can salinity be reduced by blending? [Yes/No]
   - Yes: Blend
   - No: Use NF/RO
Basic Desalination Roadmap

Is higher salinity acceptable?

- Yes, Done
- No, Can salinity be reduced by blending?

Can salinity be reduced by blending?

- Yes, Blend
- No, Use NF/RO

Can NF/RO still make sense in these cases?
Basic Desalination Roadmap

Is higher salinity acceptable?
- Yes → Done
- No → Can salinity be reduced by blending?
  - Yes → Blend
  - No → Use NF/RO

Can NF/RO still make sense in these cases?

How much will NF/RO cost?
Basic Desalination Roadmap

Is higher salinity acceptable?
  Yes → Done
  No → Can salinity be reduced by blending?
    Yes → Blend
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Can NF/RO still make sense in these cases?

How much will NF/RO cost?
Basic Desalination Roadmap

1. Is higher salinity acceptable?  
   - Yes: Done
   - No: Can salinity be reduced by blending?

2. Can salinity be reduced by blending?  
   - Yes: Blend
   - No: Use NF/RO

3. Can NF/RO still make sense in these cases?

How much are the additional benefits worth?
Basic Desalination Roadmap

Is higher salinity acceptable?

- Yes → Done
- No → Can salinity be reduced by blending?

- Yes → Blend
- No → Use NF/RO

Can NF/RO still make sense in these cases?

What are the additional benefits of NF/RO?
Basic Desalination Roadmap

Is higher salinity acceptable?
- Yes: Done
- No: Is higher salinity acceptable?

Can salinity be reduced by blending?
- Yes: Blend
- No: Use NF/RO

First part of this presentation

What are the additional benefits of NF/RO?
Diverse Functionality of NF/RO
Rejected Contaminants of Interest

- Dissolved Solids
- Emerging Contaminants
- Disinfection By-Products
- Pathogens
Rejected Contaminants of Interest

- Dissolved Solids
- Emerging Contaminants
- Disinfection By-Products
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## Dissolved Solids Rejection During the El Paso Water DPR Pilot

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<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
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<th>Permeate Water Quality¹</th>
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<tbody>
<tr>
<td>Chloride</td>
<td>mg/L</td>
<td>285</td>
<td>300</td>
<td>22, 6.9, 61</td>
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<td>mg/L as N</td>
<td>12.0</td>
<td>&lt; 6</td>
<td>2.2, 1.3, 5.1</td>
</tr>
<tr>
<td>Nitrite</td>
<td>mg/L as N</td>
<td>1.06</td>
<td>&lt; 0.6</td>
<td>0.04, 0.04, 0.9</td>
</tr>
<tr>
<td>Sulfate</td>
<td>mg/L</td>
<td>274</td>
<td>300</td>
<td>6.8, 0.9, 36</td>
</tr>
<tr>
<td>TDS</td>
<td>mg/L</td>
<td>1,075</td>
<td>900</td>
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1 Composite average of grab samples collected over the span of testing
### Dissolved Solids Rejection During the El Paso Water DPR Pilot

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### ESPA2-LD (RO)

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¹ Composite average of grab samples collected over the span of testing

- Rejects both TDS and specific, target component species
- Can provides significant buffer below treated water goals
## Dissolved Solids

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1 Composite average of grab samples collected over the span of testing

⚠️ Rejection varies widely among disparate NF/RO membrane products
⚠️ Higher rejection generates more challenging concentrate
Rejected Contaminants of Interest

- Dissolved Solids
- Emerging Contaminants
- Disinfection By-Products
- Pathogens
Emerging Contaminants

Key Considerations

• ECs are significantly more prevalent in treated wastewater than conventional sources of supply.

• Wastewater quality, including speciation and concentration of ECs, varies widely.

• As with most contaminants, rejection of ECs varies with:
  - Membrane product
  - Membrane age
  - Degree of fouling
  - Chemical characteristics
  - Water quality
  - System operational settings

Rejection of ECs can vary substantially among different potable reuse applications.
Emerging Contaminants

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Rough (!) Rejection Rule

70 - 90%
Emerging Contaminants

EC Rejection During the El Paso Water DPR Pilot

Key Points
- 96 different ECs tracked
- ~1/3 were present in wastewater effluent
- Only 7 ECs detected in NF/RO permeate
- Minimum 95% rejection of all ECs detected
Emerging Contaminants

EC Rejection During the El Paso Water DPR Pilot

Consider the concentrate!

Example: PFCs

- Secondary Clarifier Effluent
- Membrane Filtrate
- ESPA2-LD (RO) Permeate
- NF50 (NF) Permeate
- UV-AOP Effluent
- GAC-1 Effluent
- GAC-2 Effluent
- GAC-3 Effluent

Sample Location
Rejected Contaminants of Interest

- Dissolved Solids
- Emerging Contaminants
- **Disinfection By-Products**
- Pathogens
Disinfection By-Products

**NF/RO Removes (to varying degrees):**

- **Regulated DBPs:**
  - Trihalomethanes (THMs)
  - Haloacetic acids (HAAs)
  - N-nitrosodimethylamine (NDMA)
  - Bromate

- **Unregulated / emerging DBPs:**
  - Halonitromethanes (HNMs)
  - Haloacetonitriles (HANs)
  - Total organic halides (TOX)

- **DBP Precursors:**
  - Total organic carbon (TOC)
  - Bromide
  - Ammonia (pH dependent)
Disinfection By-Products

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Particularly important if ozone is used upstream for membrane pretreatment.
Disinfection By-Products

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NF/RO can be an important barrier for minimizing DBPs.
Rejected Contaminants of Interest

- Dissolved Solids
- Emerging Contaminants
- Disinfection By-Products
- Pathogens
Pathogens

Key Points

• Numerous studies have demonstrated the ability of NF/RO to reject pathogens to varying degrees.

• Pathogen rejection cannot be readily verified by a direct integrity test (DIT) on an ongoing basis during operation…yet?

→ Most states do not award any significant pathogen removal credit to NF/RO processes.

However…!

The ability of NF/RO to reject pathogens is not predicated on the award of removal credit.
Pathogens

Key Points

• Numerous studies have demonstrated the ability of NF/RO to reject pathogens to varying degrees.

• Pathogen rejection cannot be readily verified by a direct integrity test (DIT) on an ongoing basis during operation...yet?

→ Most states do not award any significant pathogen removal credit to NF/RO processes.

Thus...

NF/RO remains a potentially important pathogen barrier in potable reuse treatment.
NF/RO Integrity Testing
Why is direct integrity testing (DIT) the appropriate standard of care for granting pathogen removal credits?
First, some context...
Regulatory Guidance

Membrane Filtration Guidance Manual (MFGM) Definitions

**Direct Integrity Test**: (LT2ESWTR)
a physical test applied to a membrane unit in order to identify and/or isolate integrity breaches

**Indirect Integrity Monitoring**: (LT2ESWTR)
monitoring some aspect of filtrate water quality that is indicative of the removal of particulate matter
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Examples:
- Pressure decay test

Directly challenges the membrane barrier, **but** generally cannot be conducted continuously during operation.
Regulatory Guidance

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**Examples:**
- Turbidity
- Particle counts
- Conductivity

Conducted continuously during operation, but do not directly challenge the membrane barrier.
Regulatory Guidance

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The two processes are complementary, and both are required.
Direct Integrity Test: (LT2ESWTR)
a physical test applied to a membrane unit in order to identify and/or isolate integrity breaches

Indirect Integrity Monitoring: (LT2ESWTR)
monitoring some aspect of filtrate water quality that is indicative of the removal of particulate matter

Except...
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a physical test applied to a membrane unit in order to identify
and/or isolate integrity breaches

Indirect Integrity Monitoring: (LT2ESWTR)
monitoring some aspect of filtrate water quality that is
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A continuous DIT would preclude indirect monitoring.
Regulatory Guidance

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**Possible example:**
Nalco’s 3D TRASAR® Technology…?
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No state has approved this technology as a DIT yet.
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and/or isolate integrity breaches

Indirect Integrity Monitoring: (LT2ESWTR)
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Limited applicability!
Regulatory Guidance

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USEPA mandate applicable **only** to utilities using membrane filtration (including NF/RO) for compliance with LT2ESWTR Cryptosporidium requirements.
Regulatory Guidance

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Many states have more broadly adopted the LT2ESWTR membrane regulatory framework.
Why are water quality surrogates insufficient for awarding NF/RO pathogen log removal credit?
Insufficiency of Surrogates

1. Contaminant rejection properties vary widely among different NF/RO products.

- NF vs. RO elements
- “Loose” vs. “tight” NF
- Brackish groundwater RO vs. seawater RO elements
- Etc.
Insufficiency of Surrogates

1. Contaminant rejection properties vary widely among different NF/RO products.

- NF vs. RO elements
- “Loose” vs. “tight” NF
- Brackish groundwater RO vs. seawater RO elements
- Etc.

Bad terminology, but it conveys the point.
Insufficiency of Surrogates

1. Contaminant rejection properties vary widely among different NF/RO products.

- NF vs. RO elements
- “Loose” vs. “tight” NF
- Brackish groundwater RO vs. seawater RO elements
- Etc.

Need to demonstrate pathogen removal creates impetus for high-rejection RO, even if not otherwise necessary.
Insufficiency of Surrogates

2. Removal mechanisms for dissolved and particulate contaminants are fundamentally different.

• Dissolved phase contaminants:
  - Rejection occurs by hindered diffusion.
  - Some salt passage will always occur.
  - Small seal leaks may impact permeate quality only minimally.

• Particulate contaminants (pathogens):
  - Rejection occurs by size exclusion / physical sieving.
  - A perfectly sealed system should achieve 100% rejection.
  - Small seal leaks may allow passage of potentially dangerous pathogen quantities.
Insufficiency of Surrogates

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• Dissolved phase contaminants:
  - Rejection occurs by hindered diffusion.
  - Some salt passage will always occur.
  - Small seal leaks may impact permeate quality only minimally.

  A proper surrogate should be rejected via an analogous mechanism.

• Particulate contaminants (pathogens):
  - Rejection occurs by size exclusion / physical sieving.
  - A perfectly sealed system should achieve 100% rejection.
  - Small seal leaks may allow passage of potentially dangerous pathogen quantities.
3. Rejection of dissolved phase surrogates is subject to variables that do not exert similar influence on pathogen rejection.

Variables include:

- pH
- Temperature
- Membrane age
- Operating flux
- Oxidant damage (if any)
- Fouling

Impact may be small, but not insignificant
Insufficiency of Surrogates

3. Rejection of dissolved phase surrogates is subject to variables that do not exert similar influence on pathogen rejection.

Variables include:

- pH
- Temperature
- Membrane age
- Operating flux
- Oxidant damage (if any)
- Fouling

Impact may be small, but not insignificant

Could increase salt passage while improving pathogen rejection.
Insufficiency of Surrogates

4. Only minimal credit can be verified.

Best-case assumptions for NF/RO:
- Membrane elements specific for desalinated seawater
- Standard solution of sodium chloride
- Standard test conditions (temperature, pressure, pH, etc.)
- Controlled laboratory environment
- Ideal performance

→ Rated for 99.8% rejection

Actual field conditions do not represent best-case assumptions.
Insufficiency of Surrogates

4. Only minimal credit can be verified.

Best-case assumptions for NF/RO:
- Membrane elements specific for desalinated seawater
- Standard solution of sodium chloride
- Standard test conditions (temperature, pressure, pH, etc.)
- Controlled laboratory environment
- Ideal performance

→ Rated for 99.8% rejection

Dissolved solids cannot be used to verify log removal values (LRVs) as high as 3.0.
Insufficiency of Surrogates

5. Dissolved solids and pathogen rejection are not reliably well-correlated.

• Some research has shown rejection of >6-log for viruses…

• …however, LRVs are inconsistent in the literature

“Conductivity and/or TDS rejection cannot be used as an accurate predictor of viral passage.”
Insufficiency of Surrogates

5. Dissolved solids and pathogen rejection are not reliably well-correlated.

• Some research has shown rejection of >6-log for viruses…

• …however, LRVs are inconsistent in the literature

*Microbial Removal and Integrity Monitoring of High-Pressure Membranes*
Lozier et al., 2003
Why are water quality surrogates insufficient for awarding NF/RO pathogen log removal credit?
Why are water quality surrogates insufficient for awarding NF/RO pathogen log removal credit?

- Undesirable
- Unreliable

And not currently permissible
NF/RO Pathogen Credit:
Awarded vs. Achieved
Example: El Paso DPR Pilot

Advanced Water Purification Facility (AWPF) Pilot

- Secondary Clarifier Effluent
- MF/UF
- NF/RO
- Backwash
- Concentrate
- UV AOP
- GAC for $\text{H}_2\text{O}_2$
- Quenching
- $\text{Cl}_2$
- Disinfection

“Full Advanced Treatment” (FAT) with the addition of GAC

Note: Chlorine disinfection not tested during the pilot
### Example: Awarded Credit

**Potential El Paso Water DPR Facility (Preliminary)**

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<td>MF/UF</td>
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\(^1\) Estimated potential during piloting
### Example: Awarded Credit

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*Requirement achieved without NF/RO credit*

| Cl₂          | 0      | 3       | 4       |

| Total Awarded | 8-10   | 11-13   | 8-10    |

| Potential Requirement¹ | 5      | 7       | 8       |

¹ Estimated potential during piloting
**Example: Awarded Credit**

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**Same treatment train; same performance**

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1. Estimated potential during piloting
**Example: Achieved Reduction**

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**Total Achieved**

|                  | 12-14 | 15-17 | 12-14 |

**Potential Requirement\(^1\)**

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### Example: Achieved Reduction

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**Assume the successful implementation of a DIT for NF/RO systems:**

**Awarded Credit = Achieved Credit**

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# Example: Achieved Reduction

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1. Estimated potential during piloting

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**Does the use of FAT result in facility overdesign?**
Example: Achieved Reduction

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<td>If so, what are the implications?</td>
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### Example: Awarded = Achieved

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Example: Awarded = Achieved

Advantages

✓ “Right-sized”

✓ Cost-effective
Example: Awarded = Achieved

**Disadvantages**

- Eliminates buffer for virus reduction
- Removes an entire pathogen barrier, lessening the degree of public health protection
- Creates disparity in pathogen control with FAT facilities
- Represents a technological progression (i.e., DIT for NF/RO) that reduces, not enhances, public health protection
- Asks the public to accept a lesser standard of care for the treatment of source waters that carry the highest microbial risk
Summary
Summary

NF/RO in Potable Reuse:

- Evaluate the need for NF/RO based on its value for achieving specific water quality goals
- Consider the benefits of additional contaminant removal:
  - Emerging contaminants
  - DBPs and DBP precursors
  - Pathogens
- Achieves pathogen reduction independent of a DIT or awarded credit...
- ...but a DIT would increase awarded credit and enhance consumer confidence.
Summary

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- Evaluate the need for NF/RO based on its value for achieving specific water quality goals
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  - Pathogens

NF/RO is an important multi-purpose barrier for potable reuse treatment.

- Achieves pathogen reduction independent of a DIT or awarded credit...
- ...but a DIT would increase awarded credit and enhance consumer confidence.
Questions?

Brent Alspach
Arcadis
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