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

Brent Alspach
Arcadis

America's Authority in Membrane Treatment
AMTA
American Membrane Technology Association
Improving America's Waters Through Membrane Treatment and Desalting

American Water Works Association
Dedicated to the World's Most Important Resource™

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

- **Saline surface water**
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Blending…?

The Story Begins…

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Ion exchange…?

The Story Begins…

Alternative Water Resources

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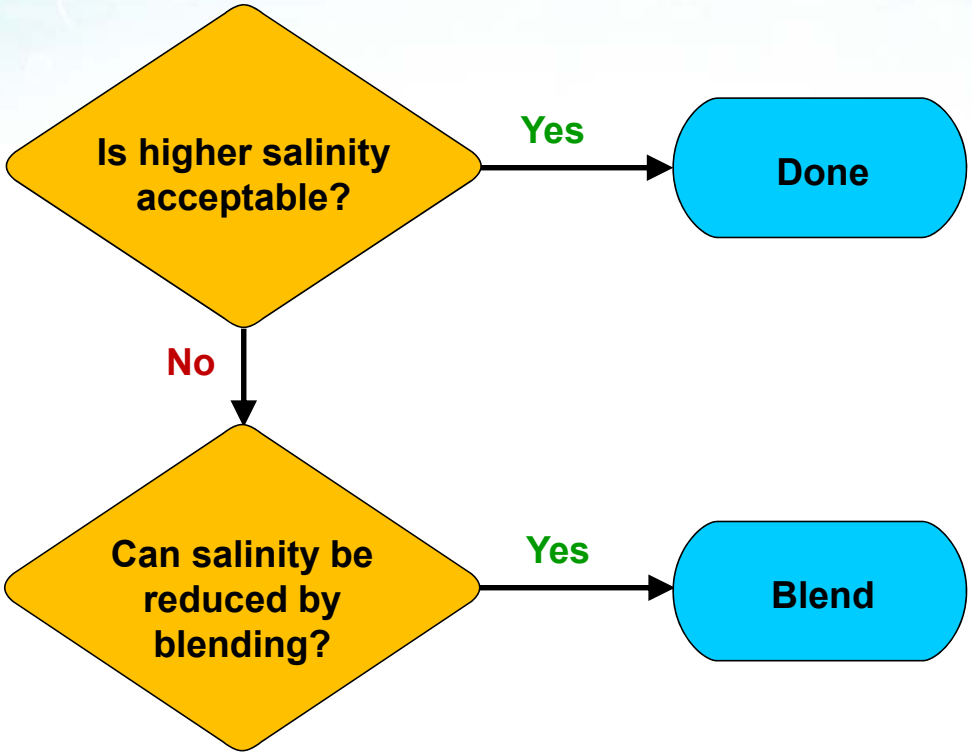
- Seawater

Among the most likely alternative sources to not require desalination.

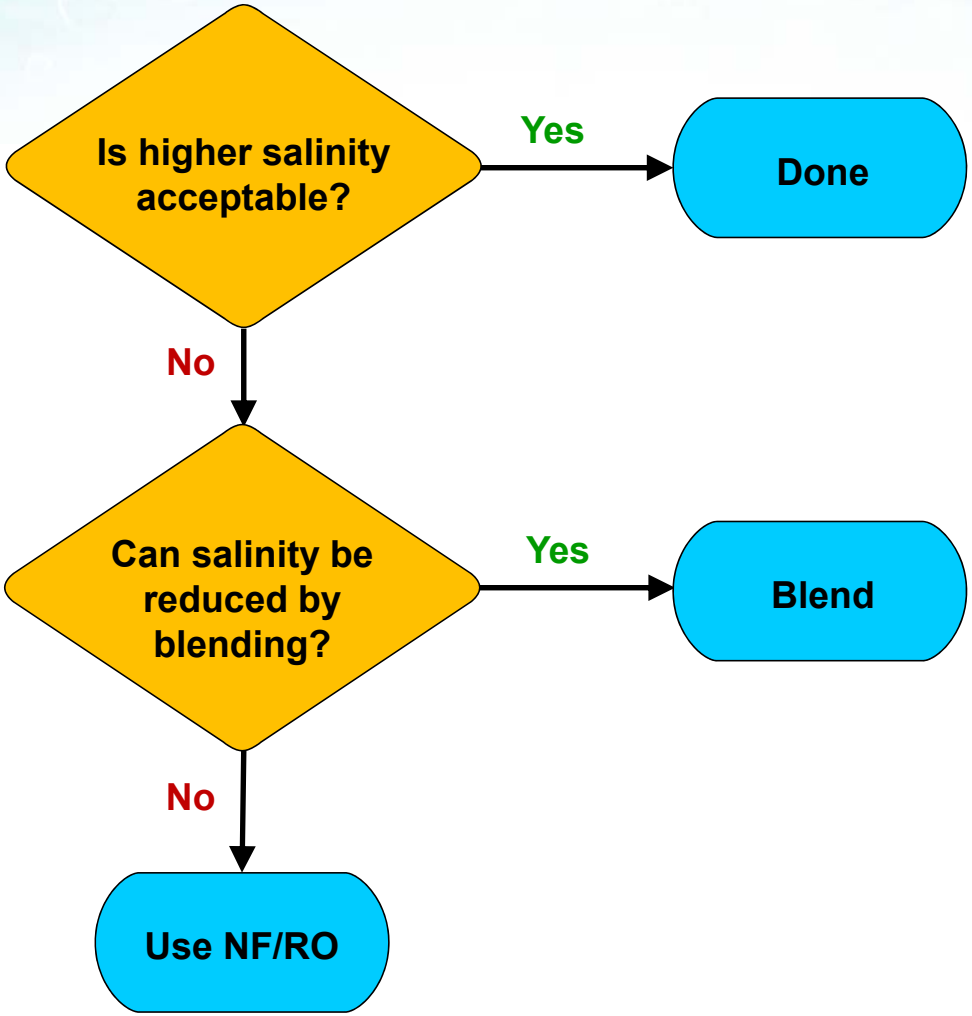
Basic Desalination Roadmap



Considerations

- Availability of blend water
- Regulations

Basic Desalination Roadmap



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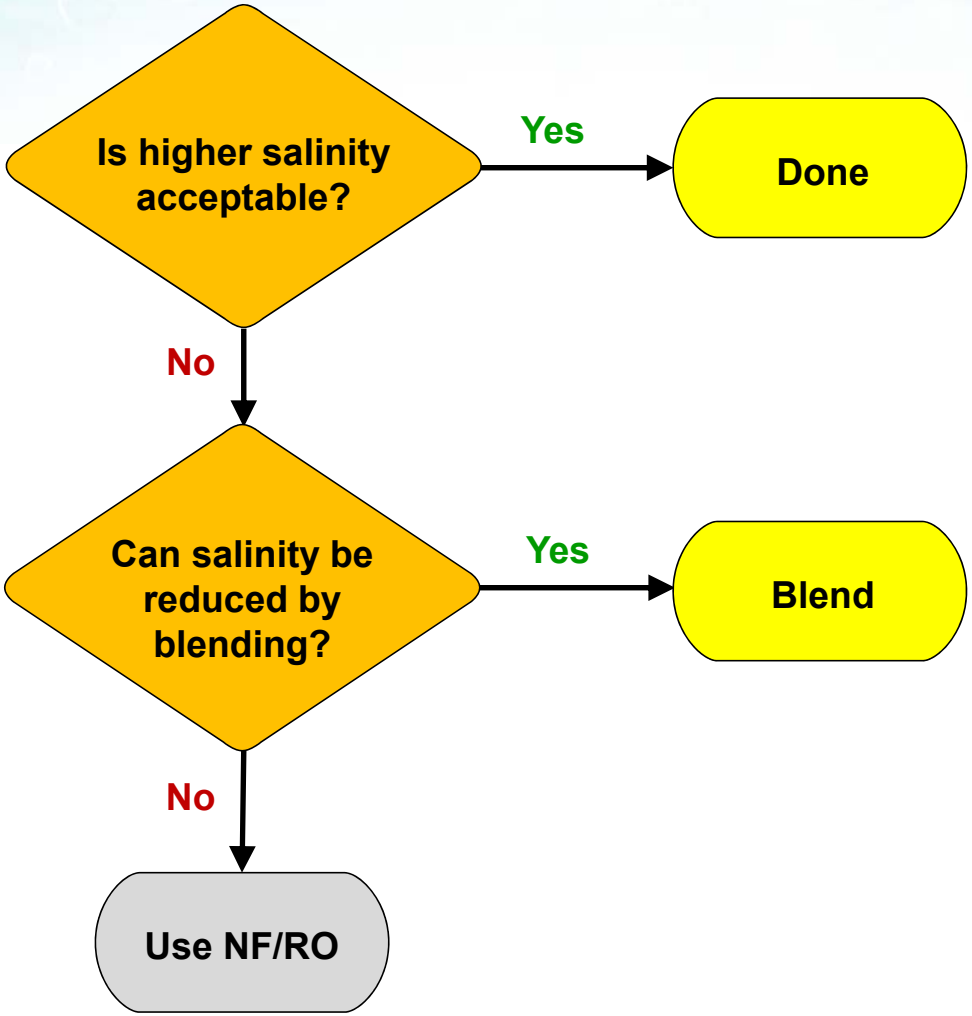
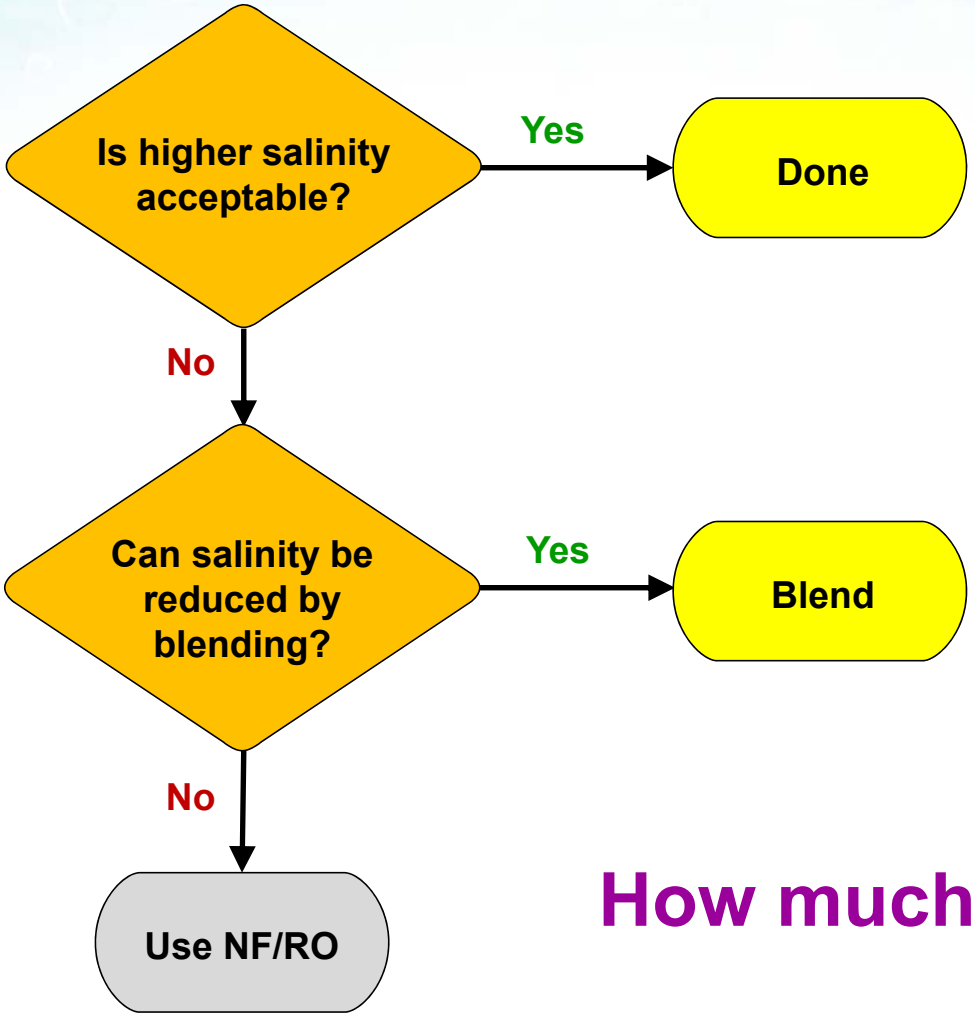


Can NF/RO still make sense in these cases?

Basic Desalination Roadmap



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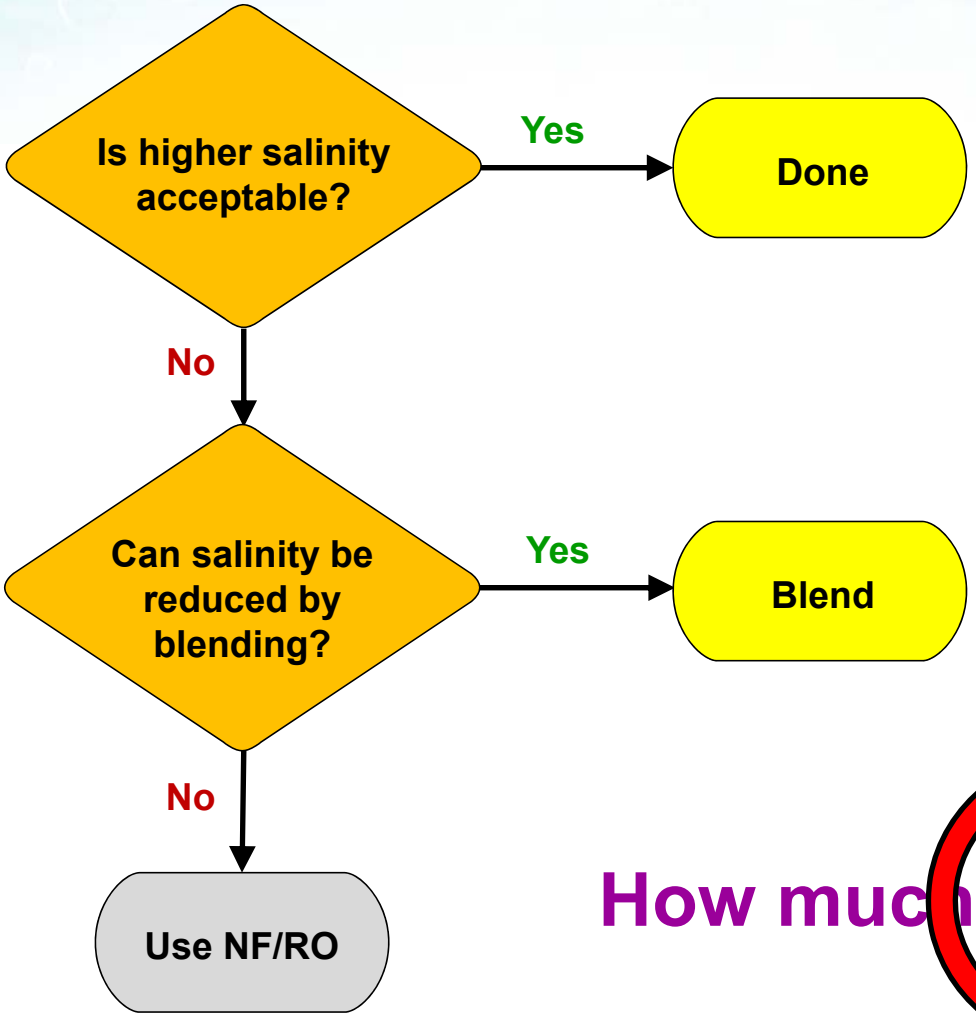
How much will NF/RO cost?

Basic Desalination Roadmap



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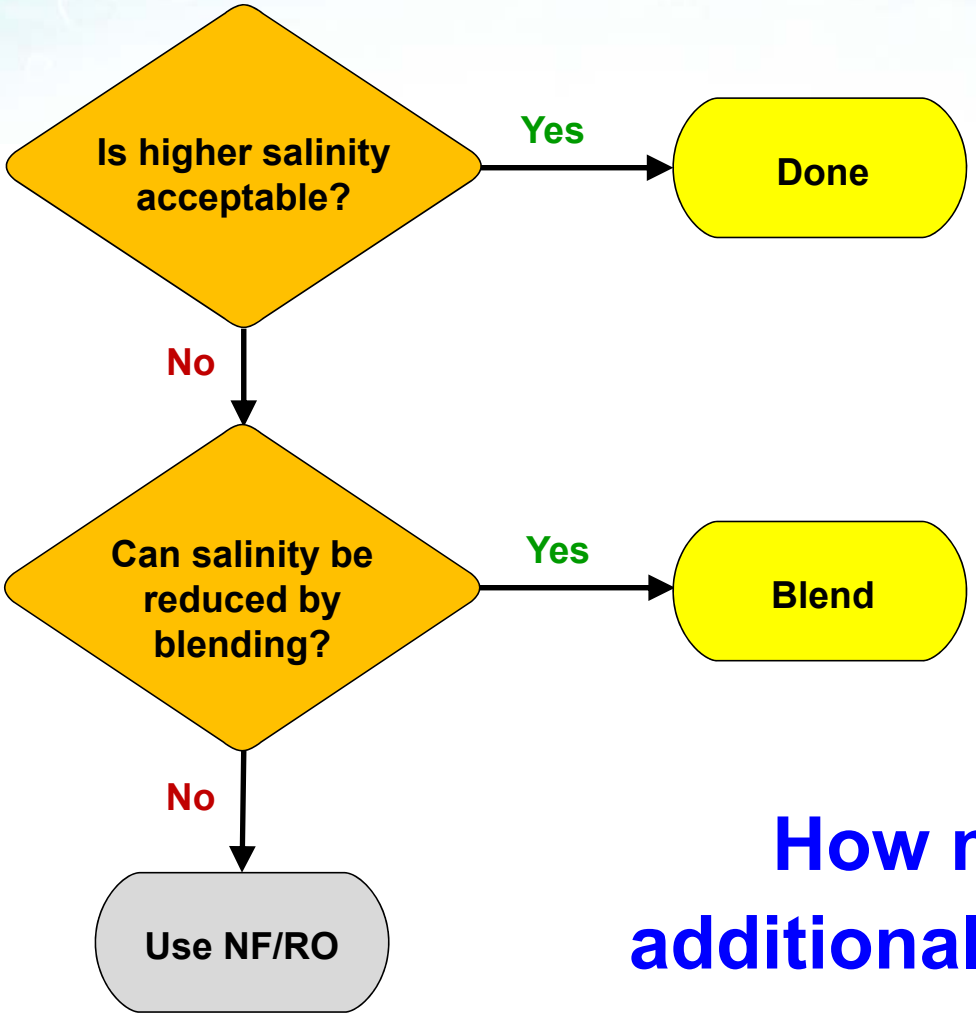
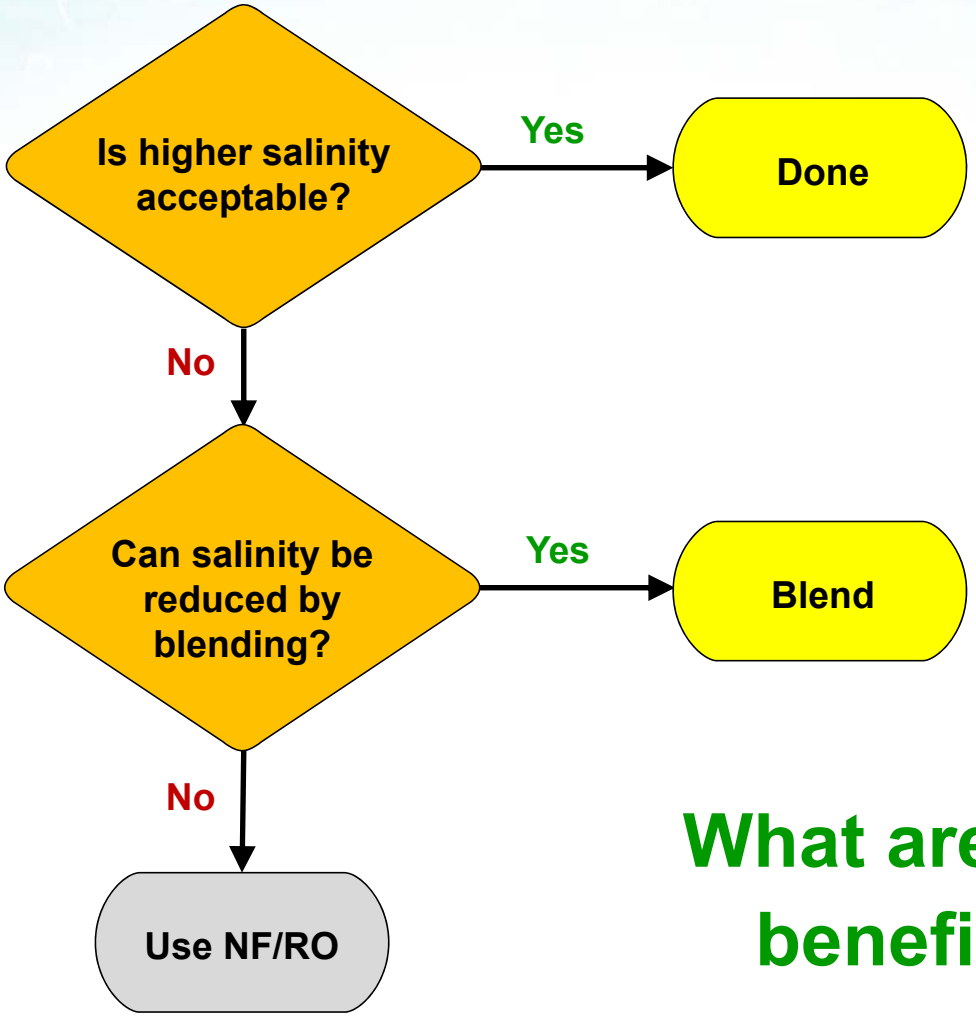


Can NF/RO still make sense in these cases?

How much are the additional benefits worth?

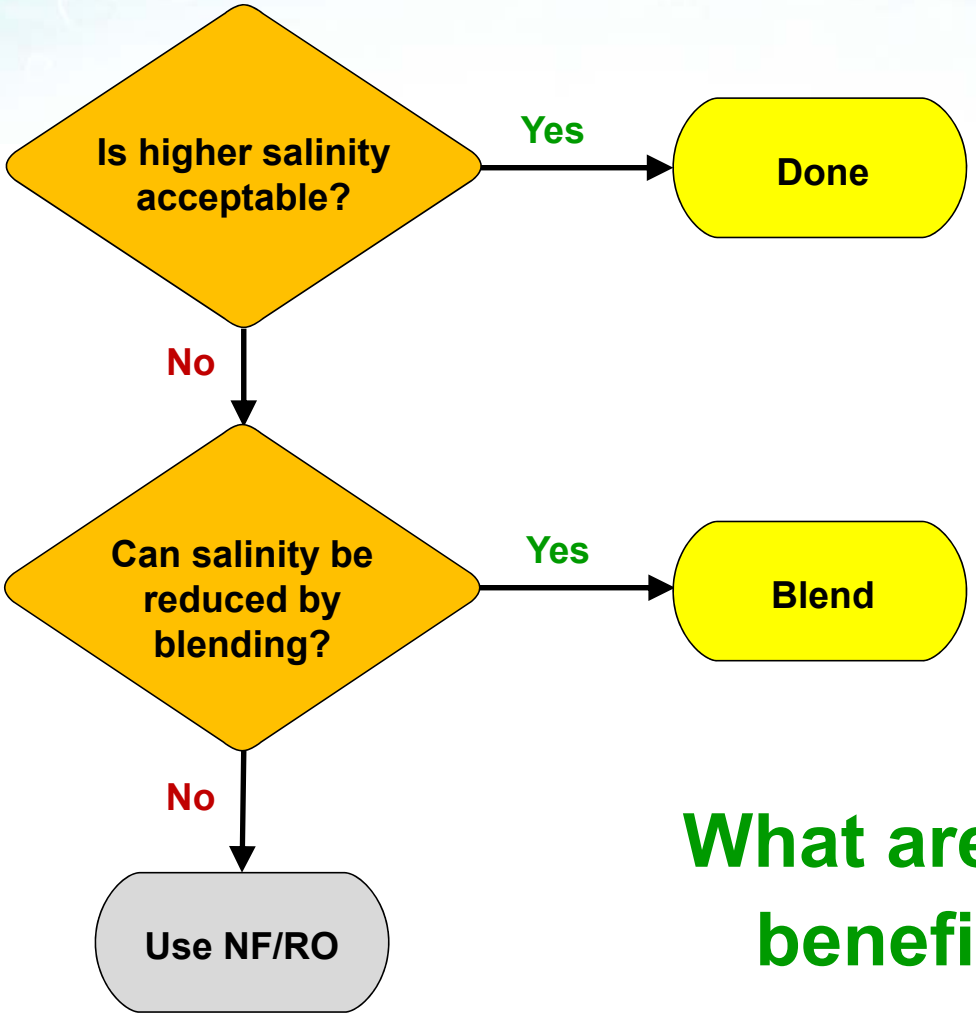
Basic Desalination Roadmap



Can NF/RO still make sense in these cases?

What are the additional benefits of NF/RO?

Basic Desalination Roadmap



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

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Dissolved Solids

Dissolved Solids Rejection During the El Paso Water DPR Pilot

Parameter	Units	NF/RO Feed	Treated Water Goal	Permeate Water Quality[1]		
				ESPA2-LD (RO)	NF90 (NF)	ESNA1 (NF)
Chloride	mg/L	285	300	22	6.9	61
Nitrate	mg/L as N	12.0	< 6	2.2	1.3	5.1
Nitrite	mg/L as N	1.06	< 0.6	0.04	0.04	0.9
Sulfate	mg/L	274	300	6.8	0.9	36
TDS	mg/L	1,075	900	78	0.4	0.4

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

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EXAMPLE

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- ✓ 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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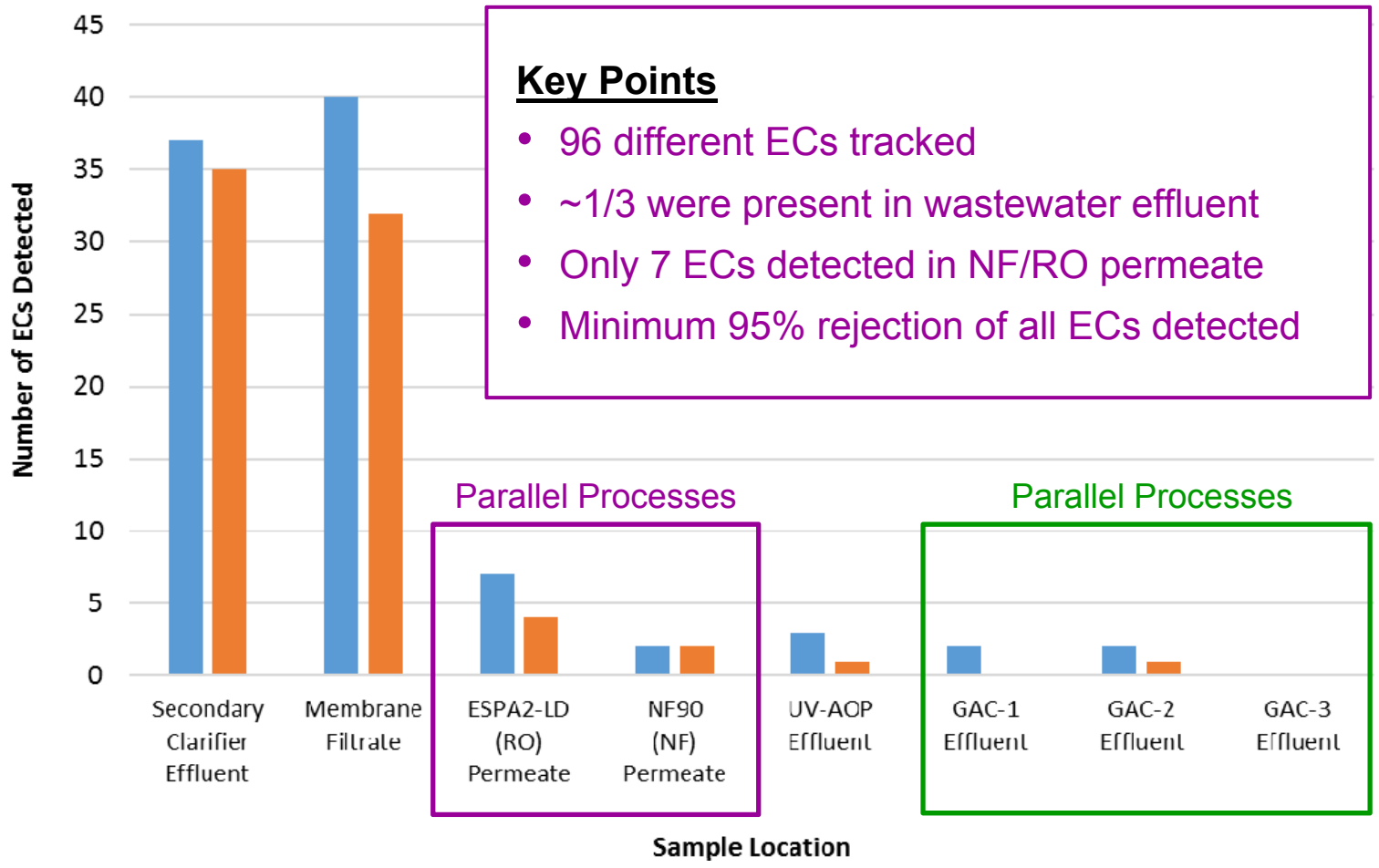
Rough (!) Rejection Rule

70 - 90%

Emerging Contaminants

EXAMPLE

EC Rejection During the El Paso Water DPR Pilot



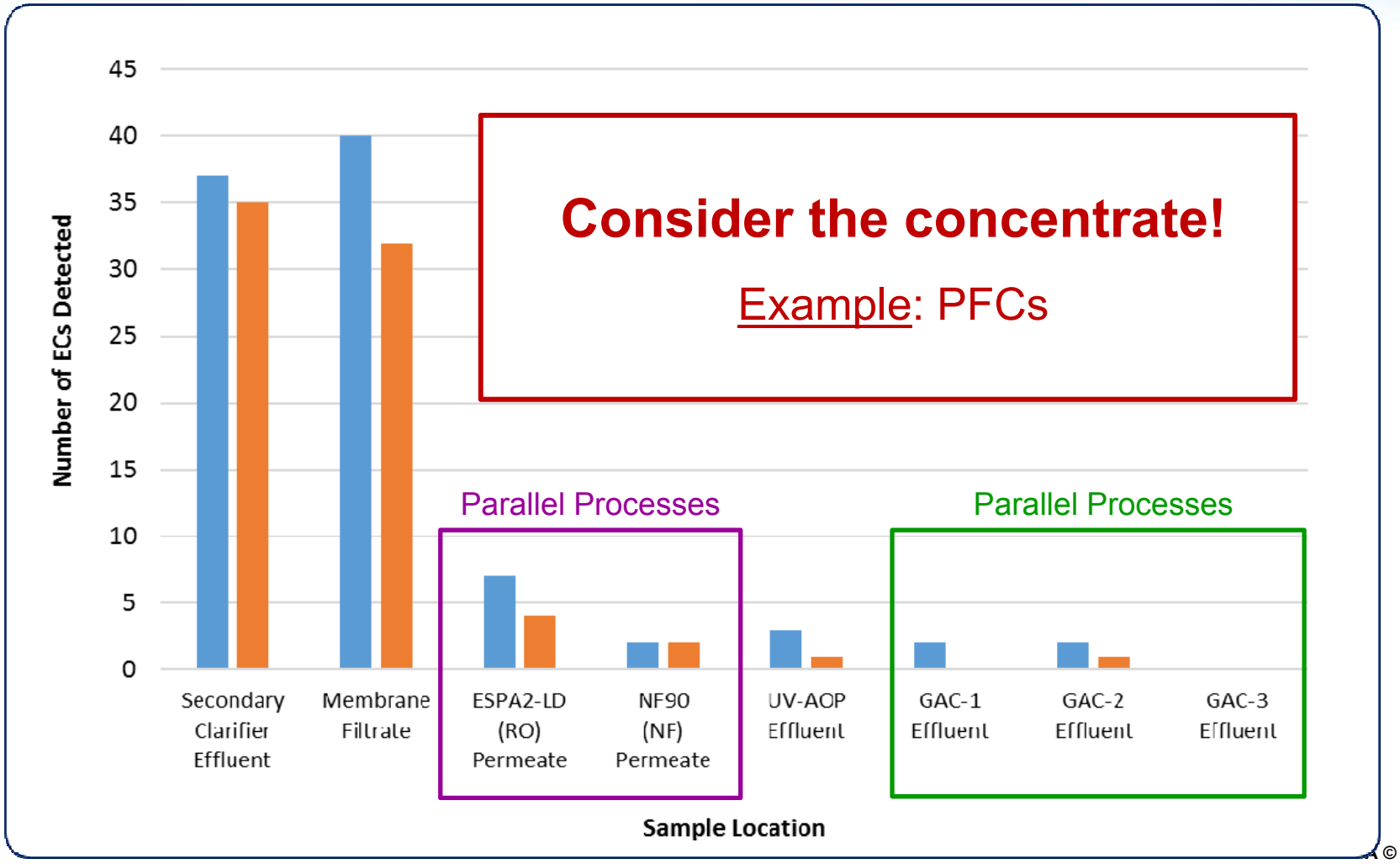
Key Points

- 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

EXAMPLE

EC Rejection During the El Paso Water DPR Pilot



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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  - Ammonia (pH dependent)

NF/RO can be an important barrier for minimizing DBPs.

Rejected Contaminants of Interest

Dissolved Solids

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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.

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Examples:

- Turbidity
- Particle counts
- Conductivity

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

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The two processes are complementary, and both are required.

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Except…

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A continuous DIT would preclude indirect monitoring.

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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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Limited applicability!

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

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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

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Bad terminology,
but it conveys the point.

Insufficiency of Surrogates

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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.

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A proper surrogate should be rejected via an analogous mechanism.

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

Insufficiency of Surrogates

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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.

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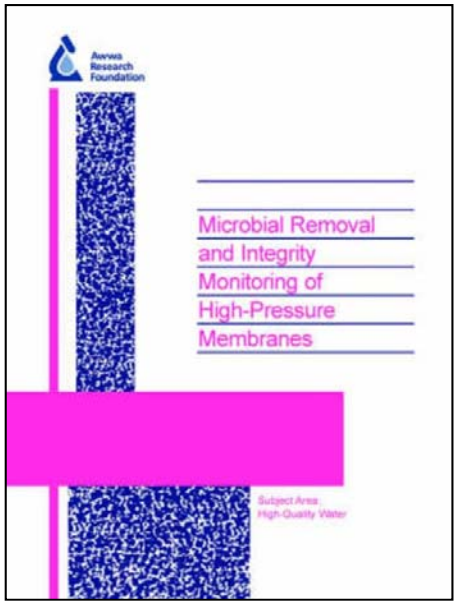
Dissolved solids cannot be used to verify log removal values (LRVs) as high as 3.0.

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."

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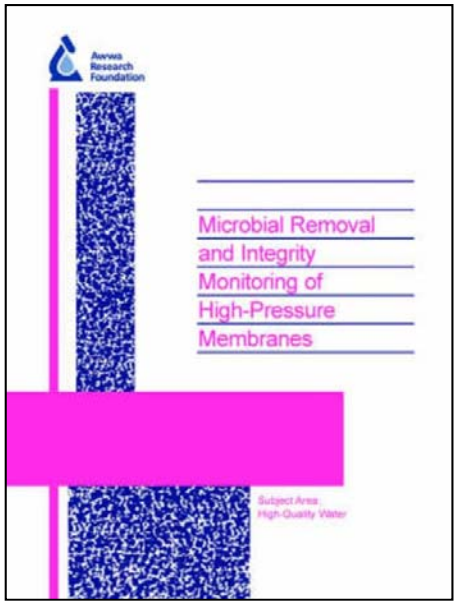


Microbial Removal and Integrity Monitoring of High-Pressure Membranes

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

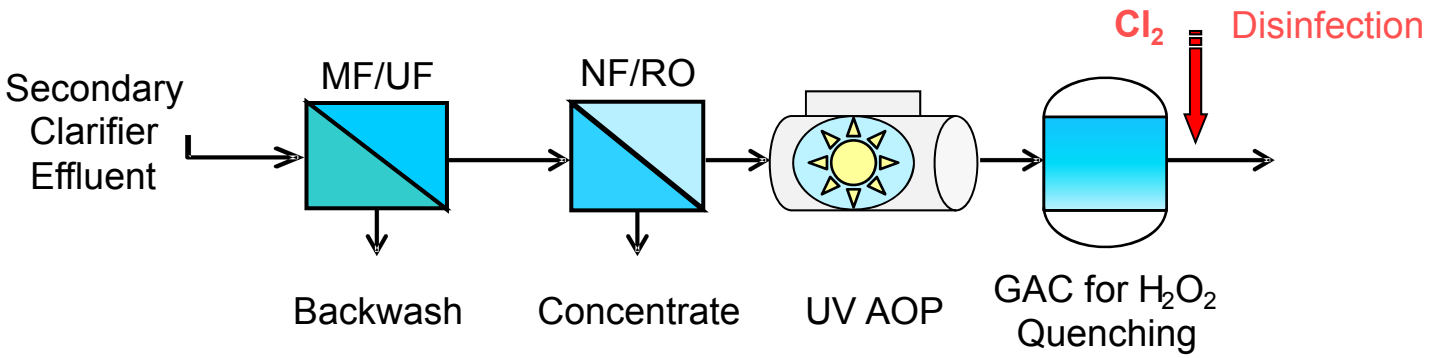
✘ Unreliable

And not currently permittable

NF/RO Pathogen Credit:
Awarded vs. Achieved

Example: El Paso DPR Pilot

Advanced Water Purification Facility (AWPF) Pilot



"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)

Unit Process	Prospective Log Removal / Inactivation Credits		
	Crypto	*Giardia*	Viruses
MF/UF	4	4	0
NF/RO	0	0	0
UV AOP	4-6	4-6	4-6
GAC	0	0	0
Cl_2	0	3	4
Total Awarded	8-10	11-13	8-10
Potential Requirement[1]	5	7	8

1 Estimated potential during piloting

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[illegible]	[illegible]	[illegible]	0
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Requirement achieved without NF/RO credit

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UV AOP	4-6	4-6	4-6
GAC	0	0	0
Cl_2	0	3	4
Total Achieved			
Potential Requirement[1]	5	7	8

1 Estimated potential during piloting

Example: Achieved Reduction

Potential El Paso Water DPR Facility (Preliminary)

Unit Process	Prospective Log Removal / Inactivation		
	Crypto	*Giardia*	Viruses
MF/UF	4	4	0
NF/RO	**4**	**4**	**4**
UV AOP	4-6	4-6	4-6
GAC	0	0	0
Cl_2	0	3	4
Total Achieved	**12-14**	**15-17**	**12-14**
Potential Requirement[1]	5	7	8

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	Crypto	*Giardia*	Viruses
MF/UF	4	4	0
NF/RO	**4**	**4**	**4**
UV AOP	4-6	4-6	4-6
[illegible]	[illegible]	[illegible]	0
Cl_2	0	3	4
Total Achieved	**12-14**	**15-17**	**12-14**
Potential Requirement[1]	**5**	**7**	**8**

Same treatment train; same performance

1 Estimated potential during piloting

Example: Achieved Reduction

Potential El Paso Water DPR Facility (Preliminary)

Unit Process	Prospective Log Removal / Inactivation		
	Crypto	*Giardia*	Viruses
MF/UF	4	4	0
NF/RO	**4**	**4**	**4**
UV AOP	4-6	4-6	4-6
[illegible]	[illegible]	[illegible]	0
Cl_2	0	3	4
Total Achieved	**12-14**	**15-17**	**12-14**
Potential Requirement[1]	**5**	**7**	**8**

Reduction achieved independent of award!

1 Estimated potential during piloting

Example: Achieved Reduction

Potential El Paso Water DPR Facility (Preliminary)

Unit Process	Prospective Log Removal / Inactivation		
	Crypto	*Giardia*	Viruses
MF/UF	4	4	0
NF/RO	[illegible]	[illegible]	4
UV AOP	4-6	4-6	4-6
GAC	0	0	0
Cl_2	0	3	4
Total Achieved	**12-14**	**15-17**	**12-14**
Potential Requirement[1]	**5**	**7**	**8**

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

Awarded Credit = Achieved Credit

1 Estimated potential during piloting

Example: Achieved Reduction

Potential El Paso Water DPR Facility (Preliminary)

Unit Process	Prospective Log Removal / Inactivation		
	Crypto	*Giardia*	Viruses
MF/UF	4	4	0
NF/RO	4	4	4
UV AOP	4-6	4-6	4-6
GAC	0	0	0
Cl_2	0	3	4
Total Achieved	**12-14**	**15-17**	**12-14**
Potential Requirement[1]	**5**	**7**	**8**

Does the use of FAT result in facility overdesign?

1 Estimated potential during piloting

Example: Achieved Reduction

Potential El Paso Water DPR Facility (Preliminary)

Unit Process	Prospective Log Removal / Inactivation		
	Crypto	*Giardia*	Viruses
MF/UF	4	4	0
NF/RO	4	4	4
UV AOP	4-6	4-6	4-6
GAC	0	0	0
Cl_2	0	3	4
Total Achieved	**12-14**	**15-17**	**12-14**
Potential Requirement[1]	**5**	**7**	**8**

If so, what are the implications?

1 Estimated potential during piloting

Example: Awarded = Achieved

Potential El Paso Water DPR Facility (Preliminary)

Unit Process	Prospective Log Removal / Inactivation Credits		
	Crypto	*Giardia*	Viruses
MF/UF	4	4	0
NF/RO	4	4	4
UV AOP	4-6	4-6	4-6
GAC	0	0	0
Cl_2	0	3	4
Total Awarded/Achieved	12-14	15-17	12-14
Potential Requirement[1]	5	7	8

1 Estimated potential during piloting

Example: Awarded = Achieved

Potential El Paso Water DPR Facility (Preliminary)

Unit Process	Prospective Log Removal / Inactivation Credits		
	Crypto	*Giardia*	Viruses
MF/UF	4	4	0
NF/RO	4	4	4
UV AOP	4-6	4-6	4-6
GAC	0	0	0
Cl_2	0	3	4
Total Awarded/Achieved			
Potential Requirement[1]	5	7	8

1 Estimated potential during piloting

Example: Awarded = Achieved

Potential El Paso Water DPR Facility (Preliminary)

Unit Process	Prospective Log Removal / Inactivation Credits		
	Crypto	*Giardia*	Viruses
MF/UF	4	4	0
NF/RO	4	4	4
~~UV AOP~~	~~4-6~~	~~4-6~~	~~4-6~~
GAC	0	0	0
Cl_2	0	3	4
Total Awarded/Achieved			
Potential Requirement[1]	5	7	8

1 Estimated potential during piloting

Example: Awarded = Achieved

Potential El Paso Water DPR Facility (Preliminary)

Unit Process	Prospective Log Removal / Inactivation Credits		
	Crypto	*Giardia*	Viruses
MF/UF	4	4	0
NF/RO	4	4	4
~~UV AOP~~	~~4-6~~	~~4-6~~	~~4-6~~
GAC	0	0	0
Cl_2	0	3	4
Total Awarded/Achieved	**8**	**11**	**8**
Potential Requirement[1]	5	7	8

1 Estimated potential during piloting

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

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
  - 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.

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