Potential for Accumulation of Recycled Water Contaminants

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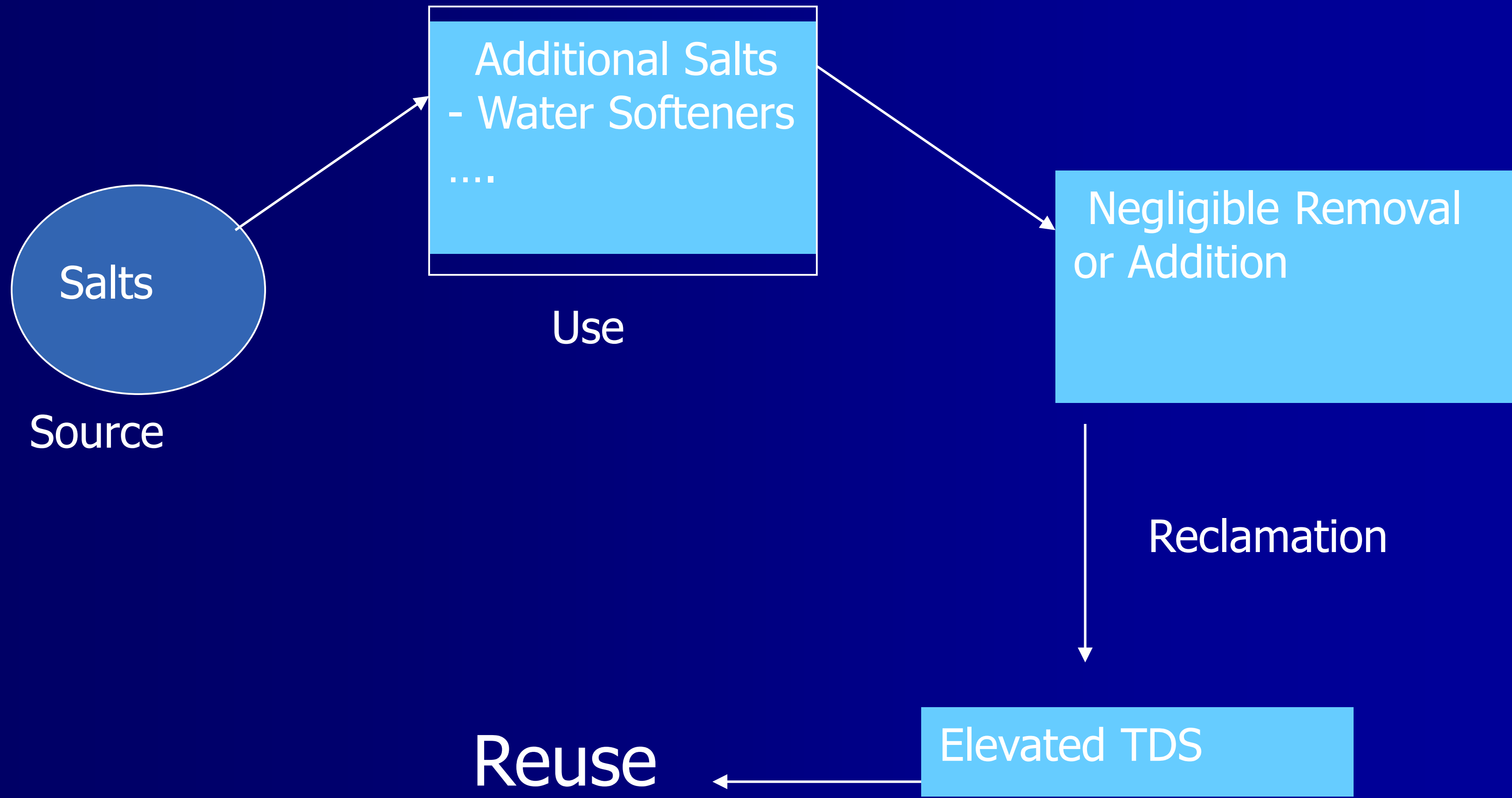
National Roadmap for Desalination and Water Purification

- Report requested by Congress and Completed in 2003
- National Research Council Review in 2003
- Why include Water Reuse?
- Roadmap adopted by Australia

Total Dissolved Solids (TDS)



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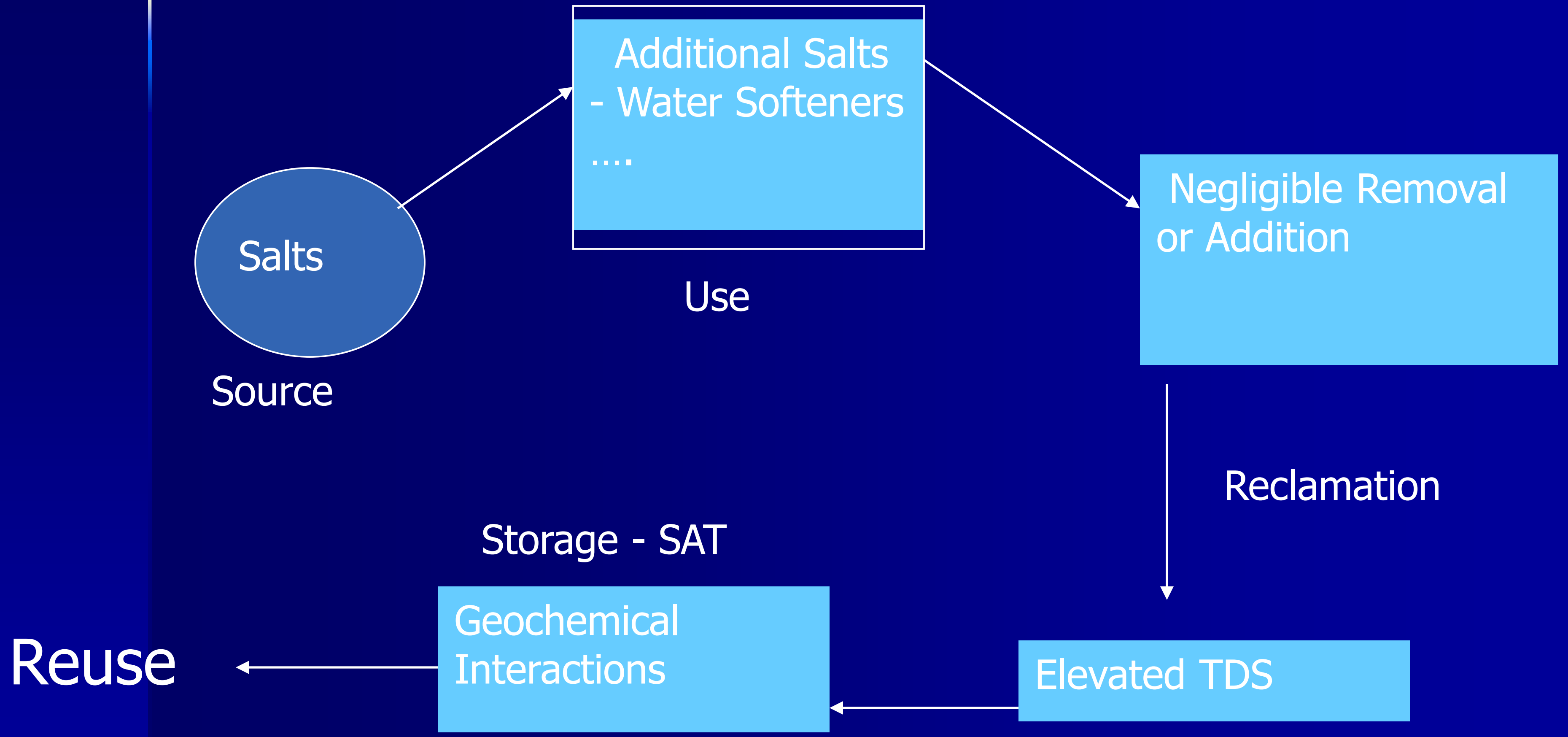
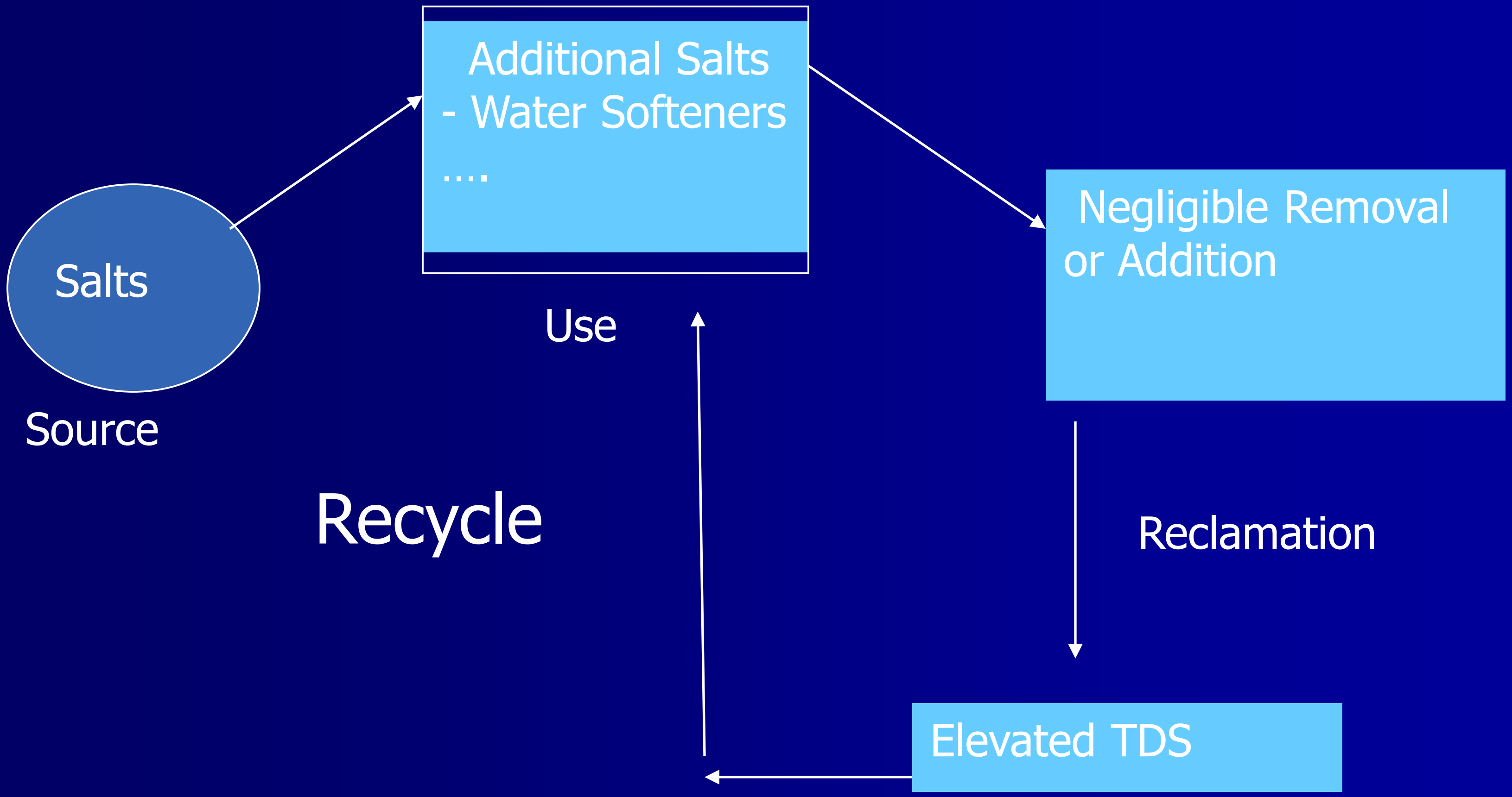


Recycling Requires Desalination



Results

- National Research Council was Convinced – Combining Water Reuse and Desalination is Inevitable
- Scottsdale currently removes salts for irrigation
- More water could be reused if salinity was not an issue

Direct Potable – Full Advanced Treatment

→ MF/UF → RO → Advanced Oxidation →

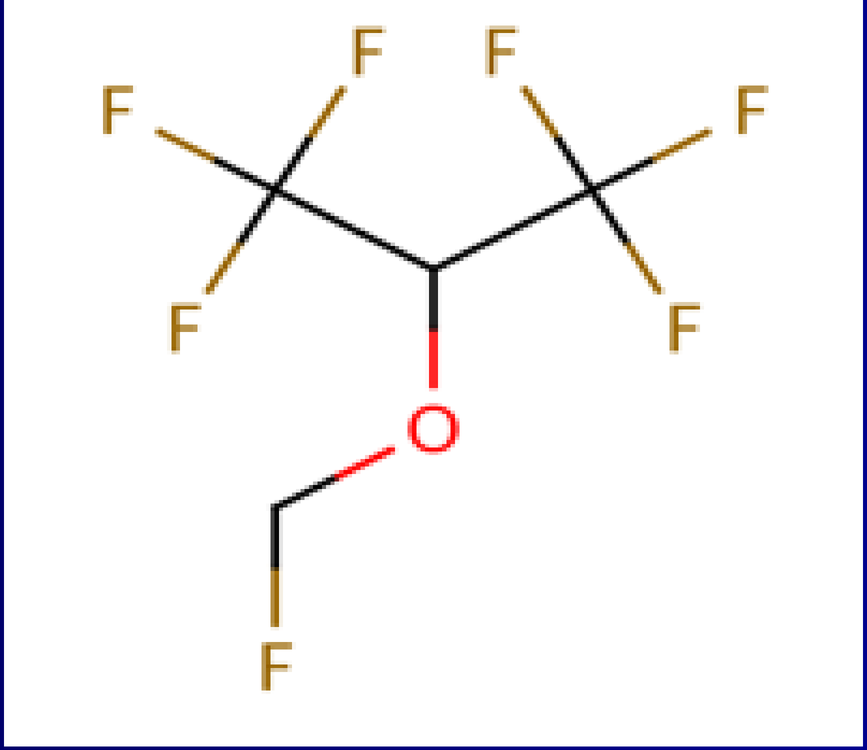
Primary Barriers – Reverse Osmosis

- Rejects salts and most organics
- Small non-ionic molecules are not efficiently removed
- N-Nitrosodimethylamine (NDMA) is most infamous
- Borate is not completely removed – well known problem for seawater desalination

Primary Barrier – Advanced Oxidation

- Readily oxidizes many organic compounds
- Highly oxidized compounds can resist oxidation
- Chlorinated Trihalomethanes can pass through RO and not be impacted by advanced oxidation
- Worst case scenario – low MW fluorinated compound

Ultane – PBT Profiler – ½ life of 180 days



Primary Barriers

- Highly oxidized low MW organics might not be efficiently removed
- Small non-ionic inorganics might be efficiently removed (Boron)

Boron Chemistry

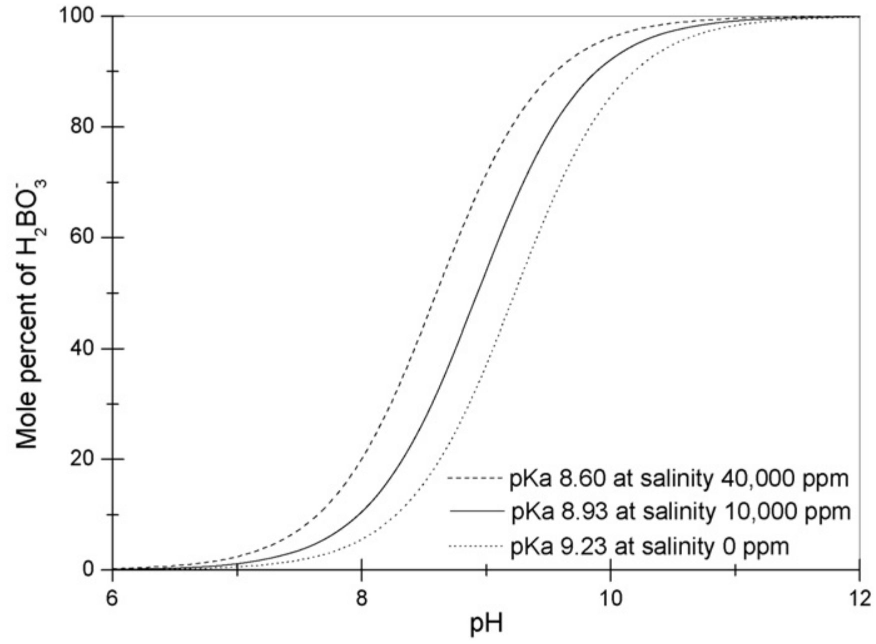


Fig. 2. Molar fraction of borate ion in solution at different salinity. (Reproduced with permission from ref [12]. Copyright 1979 American Chemical Society.)

$$B(OH)_3 + 2H_2O \Leftrightarrow B(OH)_4^- + H_3O^+;\ pK_a = 9.23$$

Boron Removal

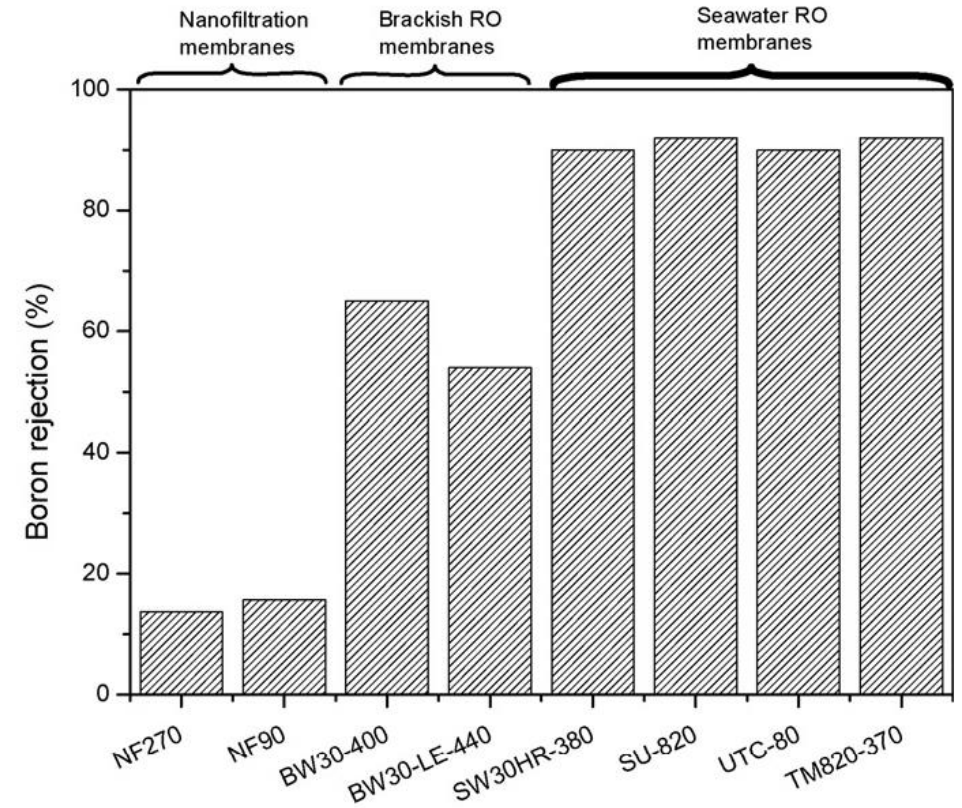


Fig. 5. Boron rejection efficiencies of some commercial membranes at standard test conditions. (Reproduced with permission from ref [40,42,43]. Copyright 2008 Elsevier; and from ref [41].) Seawater RO membranes: applied pressure 55 bar; pH 8; TDS 32,000 mg/L; temperature 25 °C. Brackish water RO membranes: applied pressure 10–16 bar; pH 8; TDS 2000 mg/L; temperature 25 °C. NF membranes: applied pressure 4 bar; pH 8; TDS 800 mg/L; temperature 20 °C.

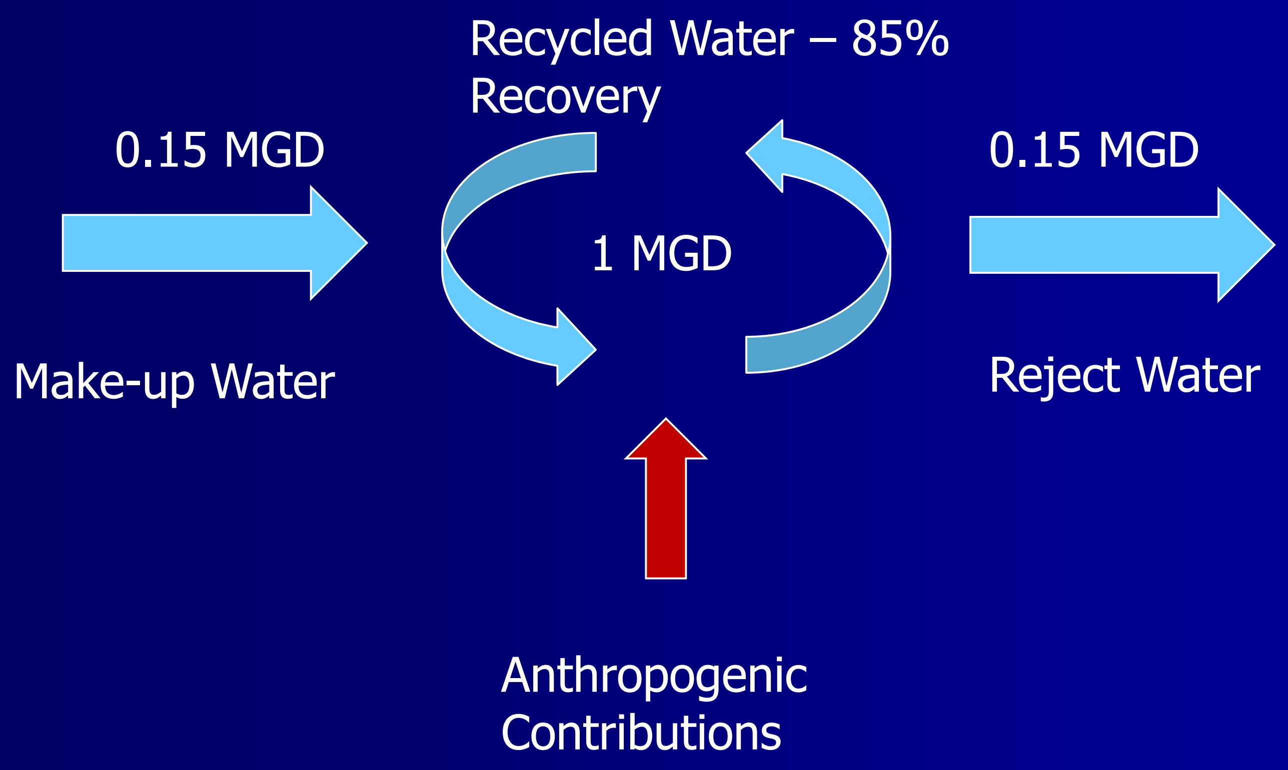
Boron Regulations

Table 2
Regulations and guidelines for boron in drinking water (adapted from [25–33]).

	Time of issuing	1990	1997	1998	2000	2001	2003	2004	2005	2006	2007	2009
Regulations and guidelines (mg/L)	WHO	0.3		0.5								
	European Union (EU)			1.0								
	Canada						5.0					
	New Zealand				1.4							
	Australia							4.0				
	Israel							0.3				
	Singapore					1.0						
	Abu Dhabi					1.5						
	U.S. (California)					1.5						
	Japan (Fukuoka)				1.5							
Targeted boron level (mg/L)	Ashkelon (Israel)								≤0.4			
	Palmahim (Israel)										≤0.4	
	Dhekelia (Cyprus)		<1									
	Larnaca (Cyprus)					<1						
	Sydney (Australia)											<1
	Perth (Australia)									≤2		

- -→: Not regulated or data unavailable.

What are the Limits for Direct Potable?



Mass Balance

- If there is no removal of an anthropogenic constituent – classic cycles of concentration will apply
- Let M = mass rate of anthropogenic constituent
- C = M/(Qm) where Qm = make up flow
- Effectively a concentration factor will be Qr/Qm

Worst Case Scenario

- If Boron addition results in a 0.5 mg/l increase in reclaimed water
- Recycling can increase the concentration by a factor of 6.66 with 85% recovery
- Boron in recycled water would be 3.33 mg/l

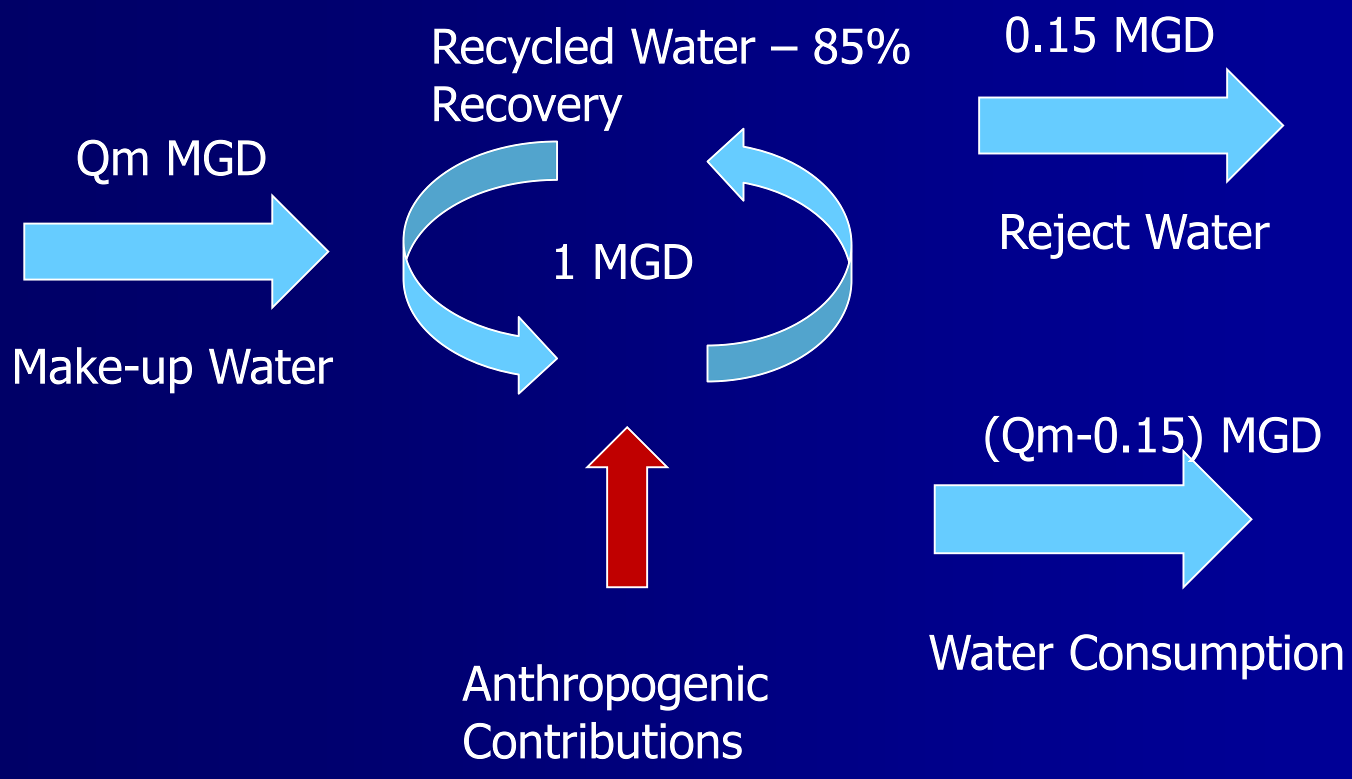
Different Percentage Removals

- Nanofiltration – 20% Removal would result in Boron = 2.66 mg/l
- Brackish Water RO – 55% removal would result in Boron = 1.4985 mg/l
- Seawater RO – 90% removal would result in Boron = 0.33 mg/l
- A removal percentage equal to the percent recovery will result in no concentration i.e. 85% - 0.5 mg/l

What about Contaminants of Emerging Concern

- Toxicologists analyze contaminants of emerging concern such as pharmaceuticals with known data
- They report Drinking Water Equivalent Levels (DWELs) as safe levels to drink
- Most DWELs are orders of magnitude greater than measured concentrations

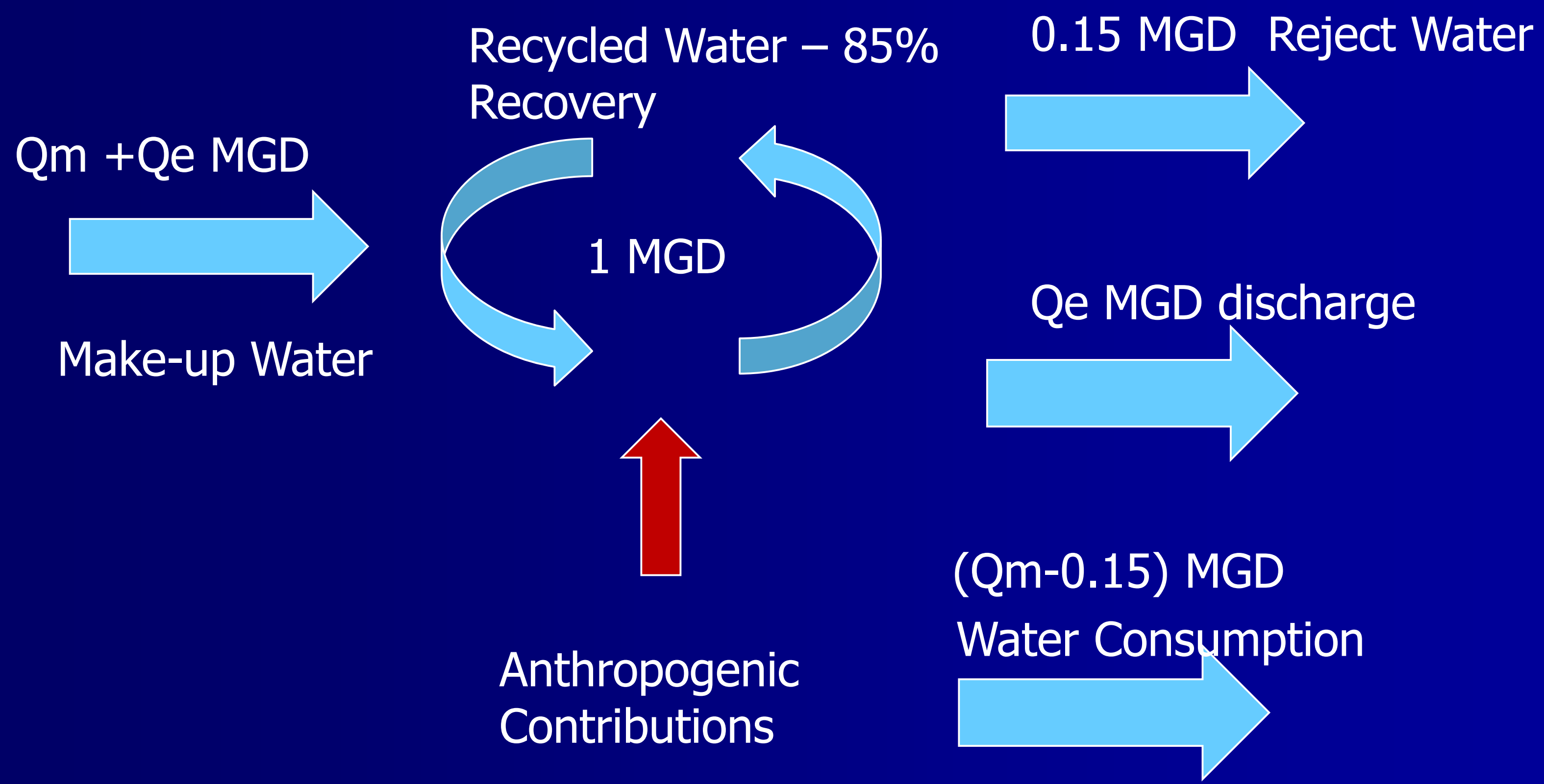
Reality Check -Q make-up must be larger to account for water consumption



What if Qm is 1 MGD?

- Depends on the presence of anthropogenic constituents of concern in consumed water
- Consumed water tends to seasonal and can be a small percentage in winter months
- If constituents are only added to recycled water then the previous analysis applies

Concentration Factor is reduced if there is discharge or non-potable reuse



What if Qe is 1 MGD?

- Essentially 50% of the anthropogenic constituents will be discharged
- The concentration factor will be reduced by $Qr/(Qr+Qe) = 0.5$
- A percent removal of 42.5% will be sufficient to prevent concentration of anthropogenic consituents

Conclusions

- Even under the worse case scenario recycling water is unlikely to result in concentrating contaminants
- Discharge or non-potable reuse make will help reduce any risk of concentrating contaminants
- The analysis did not consider potential removals at water treatment plants

Questions??