Potential for Accumulation of Recycled Water Contaminants

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Peter Fox, PhD
School of Sustainable Engineering and the Built Environment
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)

Source

Salts

Additional Salts
- Water Softeners
  ....

Use

Negligible Removal or Addition

Reclamation

Reuse

Elevated TDS
Total Dissolved Solids (TDS)

Salts

Additional Salts - Water Softeners

Use

Negligible Removal or Addition

Reclamation

Elevated TDS

Geochemical Interactions

Storage - SAT

Reuse

Source
Recycling Requires Desalination

Salts

Source

Additional Salts - Water Softeners

Use

Negligible Removal or Addition

Recycle

Elevated TDS

Reclamation
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 – $1/2$
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.)

\[ \text{B(OH)}_3 + 2\text{H}_2\text{O} \Leftrightarrow \text{B(OH)}_4^- + \text{H}_3\text{O}^+; \ pK_a = 9.23 \]
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]).

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What are the Limits for Direct Potable?

- **Make-up Water**: 0.15 MGD
- **Recycled Water – 85% Recovery**: 1 MGD
- **Reject Water**: 0.15 MGD

**Anthropogenic Contributions**
Mass Balance

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

Qm MGD
Make-up Water

Recycled Water – 85% Recovery
1 MGD

Reject Water
0.15 MGD

(Qm-0.15) MGD
Water Consumption

Anthropogenic Contributions
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.

- **Make-up Water**: $Q_m + Q_e \text{ MGD}$
- **Recycled Water**: $0.15 \text{ MGD}$
- **Reject Water**: $0.15 \text{ MGD}$
- **Discharge**: $Q_e \text{ MGD}$
- **Water Consumption**: $(Q_m - 0.15) \text{ MGD}$

**Recycling Process**:

1. **Anthropogenic Contributions**: $(Q_m - 0.15) \text{ MGD}$
2. **Recovery**: $1 \text{ MGD}$
3. **Recycled Water**: $0.15 \text{ MGD}$
4. **Reject Water**: $0.15 \text{ MGD}$

**Equation**:

$$1 \text{ MGD} = (Q_m - 0.15) \text{ MGD} + Q_e \text{ MGD}$$
What if Qe is 1 MGD?

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

What do worms eat?