Water Treatment Technology Overview

Paul Westerhoff, PhD, PE, BCEE

Vice Dean for Research & Innovation
Ira A. Fulton Schools of Engineering
Arizona State University

Deputy Direct of NSF/ERC on NanoEnabled Water Treatment

http://www.newtccenter.org
Potential Water Quality Parameters that could influence CAP Canal

• General water quality
  – Salinity
  – Consider also: pH, temperature, turbidity, hardness, total organic carbon (TOC), color

• Regulated drinking water metals
  – Arsenic (almost always occurs as As(V) rather than As(III) in Arizona)
  – Mercury
  – Chromium (Cr(VI) vs Cr(III); regulation is total)

• Regulated inorganic anions in drinking water
  – Nitrate (but also consider nitrite, ammonia, organic nitrogen)
  – Fluoride

• Volatile Organics
  – Long regulated list
  – Disinfection by-products (THM, HAA, NDMA)

• Boron impacts agriculture but not human health

• Emerging Contaminants (endocrine disrupters etc.)

• Other relevant chemicals
  – Bromide ion, iodide ion
  – Ammonia
  – CCL3 or UCMR4 lists – (e.g., PFCs)
  – Pathogens (virus, Cryptosporidium, Giardia)
<table>
<thead>
<tr>
<th>Water Quality Parameter</th>
<th>Coag-Floc-Sed-Filt (Conv WTP)</th>
<th>Activated Carbon</th>
<th>Biological treatment</th>
<th>Other Sorbent media</th>
<th>Ion Exchange</th>
<th>UF/MF</th>
<th>RO/NF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulk organics (TOC)</td>
<td>✔ ✔</td>
<td>✔ ✔ ✔</td>
<td>✔</td>
<td>✖</td>
<td>✖</td>
<td>✔ ✔ ✔</td>
<td>✔ ✔</td>
</tr>
<tr>
<td>Trace organics</td>
<td>✖</td>
<td>✔ ✔ ✔</td>
<td>✔</td>
<td>✖</td>
<td>(except PFC)</td>
<td>✖</td>
<td>✖</td>
</tr>
<tr>
<td>Tastes &amp; odors</td>
<td>✖</td>
<td>✔ ✔ ✔</td>
<td>✖</td>
<td>✖</td>
<td>✖</td>
<td>✖</td>
<td>✖</td>
</tr>
<tr>
<td>Turbidity &amp; pathogens</td>
<td>✔ ✔ ✔</td>
<td>✖</td>
<td>✔</td>
<td>✖</td>
<td>✔ ✔ ✔</td>
<td>✔ ✔</td>
<td>✖</td>
</tr>
<tr>
<td>Salinity / TDS</td>
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<td>✖</td>
<td>✖</td>
<td>✖</td>
<td>✖</td>
<td>✔ ✔</td>
<td>✖</td>
</tr>
<tr>
<td>Arsenic</td>
<td>✔ ✔ ✔</td>
<td>✖</td>
<td>✖</td>
<td>✔ ✔ ✔ (E33)</td>
<td>✔ ✔ ✔</td>
<td>✖</td>
<td>✔ ✔</td>
</tr>
<tr>
<td>Cr(VI)</td>
<td>✔ ✔</td>
<td>✖</td>
<td>✔</td>
<td>✖</td>
<td>✔ ✔ ✔</td>
<td>✔ ✔</td>
<td>✔ ✔</td>
</tr>
<tr>
<td>Nitrate</td>
<td>✖</td>
<td>✔ ✔ ✔</td>
<td>✔</td>
<td>✔ ✔ ✔</td>
<td>✖</td>
<td>✔ ✔</td>
<td>✔ ✔</td>
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<tr>
<td>Fluoride</td>
<td>✖</td>
<td>✖</td>
<td>✖</td>
<td>✔ ✔ (AA)</td>
<td>✖</td>
<td>✖</td>
<td>✖</td>
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<tr>
<td>Hardness (Ca/Mg)</td>
<td>✖</td>
<td>✔</td>
<td>✖</td>
<td>✔</td>
<td>✖</td>
<td>✔ ✔</td>
<td>✔ ✔</td>
</tr>
<tr>
<td>(Softening ✔)</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Boron</td>
<td>✖</td>
<td>?</td>
<td>✔</td>
<td>✔</td>
<td>✖</td>
<td>✔</td>
<td>✖</td>
</tr>
</tbody>
</table>

Low unless increase pH
SRP Water Quality Stations
(Turbidity spikes & Nitrate)
Overview of Water Treatment Plant Unit Processes Operating in metro-Phoenix

- Rarely are any 2 treatment plants the same
- Conventional treatment (dominant)
  - Alum or ferric chloride coagulants
- Direct filtration (2) – no sedimentation
- Ozone (3-4) – limited by BrO₃⁻ DBP formation
- Powder activated carbon (possible at most)
- Granular activated carbon (~50%)
- Membranes (2-3)
- All use free chlorine as a residual disinfectant
- Most struggle with compliance due to NOM, high turbidity, and THMs (some for nitrate)
- All have TDS above SMCL of 500 mg/L & all have “very hard” water (leads to many POU systems)
Conventional Water Treatment Plant

Raw Water → COAG → SED. → FILT → Basin → To Distribution System

Chemicals and Processes:
- Cl₂, O₃
- AOPs
- Cl₂, NH₂Cl, KMnO₄, ClO₂, UV
Disinfection / Oxidation Leads to Disinfection By-Product Formation

Oxidation → Organic DBPs → Disinfection
Oxidation → Inorganic DBPs
DBPs Formation

Formation of Mixed Halogen Specie:

NOM + HOCl/OCl⁻ => Chlorinated DBPs
Br⁻ + HOCl/OCl⁻ => HOBr/OBr⁻
NOM + HOBr/OBr⁻ => Brominated DBPs

Important DBP Precursors: NOM & Br⁻

NOM Measured as DOC: 1-10 mg/L
Bromide (1/300th chloride): 10-2,000 ug/L
Br/DOC ratio is important for DBP formation
Methods to Lower NOM Concentrations

1. Conventional Treatment

   Raw Water → COAG → SED. → FILT → Basin → To User

   Cl₂ → NOM → Cl₂ → NOM

2. Membrane Filtration

   Raw Water → COAG → SED. → UF/RO → Basin → To User

   Cl₂ → NOM → Cl₂ → NOM

3. Activated Carbon Adsorption

   Raw Water → COAG → SED. → FILT → GAC → Basin → To User

   Cl₂ → NOM → Cl₂ → NOM
Common Algal T&O Compounds

- Taste threshold ~ 10 ng/L
- Chlorine residual can “mask” odors
- T&O is a worldwide issue affecting the public’s “confidence” in drinking waters, but is not regulated

<table>
<thead>
<tr>
<th>Parameter</th>
<th>MIB (2-methylisoborneol)</th>
<th>Geosmin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full Name</td>
<td>(1-R-exo)-1,2,7,7-tetramethyl bicyclo[2,2,1]-heptan-2-ol</td>
<td>tran-1, 10-dimethyl-trans-9-decalol</td>
</tr>
<tr>
<td>Molecular Formula</td>
<td>C₁₁H₂₀O</td>
<td>C₁₂H₂₂O</td>
</tr>
<tr>
<td>Molecular Weight</td>
<td>168 g-mole⁻¹</td>
<td>182 g-mole⁻¹</td>
</tr>
<tr>
<td>Boiling Point</td>
<td>197 °C</td>
<td>165 °C</td>
</tr>
<tr>
<td>Aqueous Solubility</td>
<td>195 mg/L</td>
<td>150 mg/L</td>
</tr>
<tr>
<td>Kow</td>
<td>3.13</td>
<td>3.7</td>
</tr>
<tr>
<td>Henry’s Law Constant</td>
<td>5.76×10⁻⁵ atm m³-mole⁻¹</td>
<td>6.66×10⁻⁵ atm m³-mole⁻¹</td>
</tr>
</tbody>
</table>

Structure

Source: (Pirbazari et al. 1992)
WTPs with Activated Carbon

• GAC removes
  – EDC, PPCPs, PFCs, T&O and other trace organics
  – NOM that forms DBPs (TOC goal ~ 1 mg/L)
  – Requires regeneration ~ every 6 months

• PAC
  – Removes same trace organics
  – Does not remove NOM well
  – Typical dosages are 10-25 mg/L
  – Requires sedimentation / filtration & sludge processing
  – Usually applied seasonally
Ozone or UV/H2O2

• Disinfection
  – Ozone or UV light
  – ClO2 also used as an alternative disinfectant
  – Free chlorine is used after water treatment

• Oxidation of trace organics
  – Powerful oxidants that can generate HO radicals
Membranes

• Micro/ultrafiltration
  – used at a few plants instead of coagulation-floc-settling – sand filters
  – Removes particulates (Turbidity, Giardia, Crypto, Bacteria, Some virus)
  – Does not remove trace organics or salts
  – Can remove arsenic and other pollutants if iron salts are added (> 1 MGD)
  – Achieves ~98% water recovery

• Nanofiltration
  – Not used in Valley currently
  – Removes divalent ions (Ca/Mg/SO$_4^{2-}$)
  – Newer NF membranes remove trace organics
  – Operates at lower pressure and higher water recovery than RO

• Reverse osmosis membranes
  – Used for wastewater reuse at some locations
  – Requires pretreatment to prevent fouling
  – Typically achieves 85% recovery (15% is concentrated brine)
  – Adoption of energy recovery devices significantly lowered operating costs
  – Membranes replaced ~ every 5 years
  – Removes almost everything
Nitrate (NO$_3^-$)

- **Drinking water**
  - Ion exchange is the typical removal mechanism
    - Requires 5-20% NaCl brine to clean resin frequently
    - Advances in chemical or biological brine regeneration are on the horizon
  - Blending is commonly used to manage NO$_3^-$ in SRP canal and wells entering distribution systems
  - Nitrite is a concern
  - Ammonia is concern for water utilities

- **Wastewater**
  - Has high levels of ammonia, nitrate and/or nitrite
  - Requires biological denitrification
Arsenate ($\text{H}_2\text{AsO}_4^-$)

- Naturally occurring in Arizona
  - Groundwaters
  - Verde River water
- Groundwater wellhead treatment options
  - Ion exchange
  - Iron oxide packed bed media (E33, GFH, etc)
  - Ferric chloride + MF or filtration
- Surface water
  - Alum/Ferric at conventional WTPs
Hexavalent Chromium vs Cr(III)

- Cr(VI) regulation pending (CA is 10 ppb) vs EPA MCL for chromium of 100 ppb
- Metal (Hydr)Oxide Based Resins
  - Bayoxide E33
  - Granular Ferric Hydroxide
  - Adsorbsia GTO
- Weak Base Anion Exchange Resins
  - ResinTech SIR700 – 2.7 eq/L
  - Purolite S106 – 2.0 eq/L
- Hybrid Media
  - Layne RT – nanoscale iron hydroxide impregnated anion exchange
- Cr(VI) removal processes
  - Selective ion exchange
  - Ferrous reduction, coagulation, filtration
- Reverse osmosis
- Reductive coagulation/separation (Fe$^{2+}$, Sn$^{2+}$)
Flouride ($F^-$) & other halides

• Complicated regulation
  – Regulation has a low & high end concentration range (0.5-1.5 mg/L)
  – Most water utilities add fluoride to water

• Fluoride removal
  – Sorption onto activated alumina (used by some GW facilities in AZ) in packed bed designs with frequent acid regeneration

• Bromide and iodide are difficult to treat

• RO remove $Cl^-$, $I^-$, $Br^-$, $F^-$
Boron removal

- Boron regulation for plants is more strictive than for human health
- Generally < 1 mg/L target (CA ~ 0.5 mg/L for citrus in some areas)
- Ion Exchange
  - Some boron-selective ion-exchange resin does not require pH adjustment
  - Most of commercial resins are modified by N-methyl-D-glucamine (NMDG) functional group such as Diaion WA30, Diaion CRB 02, Purolite S108, Dowex2x8, Dowex XUS 43594.00, Amberlite IRA 743, XSC-700
- RO/NF processes can remove boron if you increase pH

Seawater (SW) systems to remove boron to < 1 ppm (Lenntech)
<table>
<thead>
<tr>
<th>Source</th>
<th>&lt; 2 ng/L &amp; ≤ Blank</th>
<th>2 to 10 ng/L</th>
<th>10 to 20 ng/L</th>
<th>20 ng/L to 1 ug/L</th>
<th>&gt; 1 ug/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ground water at recharge site</td>
<td>Steroids and others</td>
<td>Acetaminophen, caffeine, DEET, erythromycin, meprobamate, oxybenzone, pentoxifylline</td>
<td>None</td>
<td>Sulfamethoxazole, sucralose (from one site)</td>
<td>None</td>
</tr>
<tr>
<td>SRP waters (Verde River &amp; Salt River)</td>
<td>Steroids and others</td>
<td>Sucralose, sulfamethoxazole, acetaminophen, cotinine, dilantin,</td>
<td>Caffeine, DEET</td>
<td>Oxybenzone</td>
<td>None</td>
</tr>
<tr>
<td>CAP Canal from Colorado River</td>
<td>Steroids and others</td>
<td>Sulfamethoxazole, oxybenzone, meprobamate, DEET, cotinine, dilantin, carbamazepine, acetaminophen, primidone, estradiol</td>
<td>Caffeine, triclosan</td>
<td>Sucralose</td>
<td>None</td>
</tr>
<tr>
<td>Activated sludge WWTP with nitrification</td>
<td>Steroids</td>
<td>Acetaminophen, ibuprofen, diazepam, pentoxifylline</td>
<td>Cotinine</td>
<td>Caffeine, naproxen, oxybenzone, TBBA, carbamazepine, hydrocodone, meprobamate, sulfamethoxazole, DEET, erythromycin, trimethoprim, primidone, dilantin, triclosan, diclofenac, sucralose, fluoxetine</td>
<td>None</td>
</tr>
<tr>
<td>Raw wastewater</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>Ibuprofen, naproxen, triclosan, sucralose, acetaminophen, caffeine, cotinine, oxybenzone, DEET, meprobamate, TBBA, sulfamethoxazole</td>
<td></td>
</tr>
</tbody>
</table>
Recharge / Soil Aquifer Treatment

- Organics Removal
  - Reduces NOM / TOC
  - Taste and odor removed
  - Many trace organics (but not all)
- No removal of salts
- Can mobilize local pollutants
- Denitrified wastewater recharged or RO treated is common in Arizona
Backup slides
Example Constituents

Constituents

- Dissolved Specie
  - Metals & Ligands
  - Organics
    - Important Properties
      - Charge
      - Hydrophobicity
      - Solubility, volatility

- Particles
  - Inorganic: clay (Turbity)
  - Organic: bacteria, protozoa, virus
    - Important Properties
      - Size, shape
      - density
      - surface charge

- Gases
  - Oxygen
  - Carbon Dioxide
  - Ammonia, chlorine, ozone, etc.
    - Important Properties
      - Solubility
      - Volatility
      - Interface (G/L)
Treatment of these systems is largely governed by regulatory mandates for human and ecological health. Processes include:

<table>
<thead>
<tr>
<th>Processes</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coag/floc</td>
<td>(P)</td>
</tr>
<tr>
<td>Sedimentation</td>
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<tr>
<td>Filtration</td>
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<tr>
<td>Flotation</td>
<td></td>
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<tr>
<td>Membranes</td>
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<tr>
<td>Aeration</td>
<td>(G)</td>
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<tr>
<td>Stripping</td>
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<table>
<thead>
<tr>
<th>Processes</th>
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<tbody>
<tr>
<td>Oxidation/reduction</td>
<td>(D)</td>
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<tr>
<td>Precipitation</td>
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<tr>
<td>Ion Exchange</td>
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<tr>
<td>RO membranes</td>
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<tr>
<td>Biological Treatment</td>
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<tr>
<td>Softening</td>
<td></td>
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<tr>
<td>Adsorption</td>
<td></td>
</tr>
</tbody>
</table>
Hydrology Affects Water Quality
(conductance can affect algal dominance)
Up-stream reservoirs attenuate DOC
Current Levels

Total Chromium (ppb)

- CAP (AF): 1.1
- Tempe: 7.1
- Peoria: 7.2
- Glendale: 10.5
- Chandler: 11
- Epcor (PV): 34
- Phoenix: 38
- Epcor (AF): 66