State of the Science: Surface Water Augmentation and CECs

Presentation to the CEC Science Advisory Panel for Recycled Water

Shane Trussell, Ph.D., P.E., BCEE
Trussell Technologies, Inc.
July 19, 2017
Providing Safe Drinking Water

- Treatment Technologies
- Natural Environment
Groundwater Recharge

• How do we provide safe drinking water?
Groundwater Recharge

Standard Full Advanced Treatment

- Membrane Filtration
- Reverse Osmosis
- Ultraviolet Light/Advanced Oxidation

• Treatment Technologies
Groundwater Recharge

Standard Full Advanced Treatment + Retention Time

- Treatment Technologies
- Time
- Attenuation (dilution, dispersion, degradation, adsorption, etc.)
• Diversity of removal mechanisms are used to control diversity of chemicals
• Multiple removal mechanisms also proactively mitigate next “unknown”
Natural Environment

• Treatment (degradation)
  – Soil Aquifer Treatment
  – Continuing to investigate the treatment benefits of groundwater recharge

• Time
  – Response Time
## CEC Removal by SAT

<table>
<thead>
<tr>
<th>Excellent Removal</th>
<th>Fair Removal</th>
<th>Poor Removal</th>
</tr>
</thead>
<tbody>
<tr>
<td>(&gt;90%)</td>
<td>(90 to 50%)</td>
<td>(50 to &lt;25%)</td>
</tr>
</tbody>
</table>

- Atenolol, Atorvastin, BHA, Caffeine, Dioctyl phthalate, Enalapril, Fluoxetine, Galaxolide, Nonylphenol, Norfluoxetine, Salicylic acid, Simvastatin hydroxy acid, Trimethoprim
- Carbamazepine, Primidone, TDCPP
- Benzophenone, Ibuprofen, DEET, EDTA, Iopromide, Meprobamate, Sulfamethoxazole
- Diclofenac, Naproxen, Gemfibrozil, Octylphenol, Tonalide, Triclosan
- Dilantin (Phenytoin), TCEP, TCPP

Data origin: Drewes et al., WRRF 05-04, travel time up to 2 weeks
Surface Water Augmentation

- What changes as we move from groundwater recharge to surface water augmentation?
Surface Water Augmentation

• What changes as we move from groundwater recharge to surface water augmentation?

Loss of Natural Environment Treatment

California Toxics Rule Compliance

Nutrient Limits
Surface Water Augmentation

• What changes as we move from groundwater recharge to surface water augmentation?

Loss of Natural Environment Treatment

California Toxics Rule Compliance

Nutrient Limits

But...no loss in treatment technologies
Surface Water Augmentation

• Many treatment technologies available…
Surface Water Augmentation

• But RO is by far the most important when considering chemical contaminants
Removal of Uncharged Compounds

Removal vs Molecular Weight

- Boron (62 amu)
- Ethanol (46 amu)
- NDMA (74 amu)
- Silica (128 amu)
- 1,4-dioxane (88 amu)
- Sugar (342 amu)

OCWD
SD Demo

0% 20% 40% 60% 80% 100%
Removal of Uncharged Compounds

But even RO cannot remove everything
Compounds Can Get Through Reverse Osmosis

- Acetone: $\text{H}_3\text{C} = \text{C} - \text{CH}_3$
- 1,4-dioxane
- Formaldehyde: $\text{H} - \text{C} = \text{H}$
- NDMA: $\text{H}_3\text{C} - \text{N} - \text{N} = \text{O} - \text{CH}_3$
Groundwater Recharge vs. Surface Water Augmentation

Well removed through **biodegradation** that occurs in the aquifer

San Diego Demonstration Facility Data
Groundwater Recharge vs. Surface Water Augmentation

Well removed through biodegradation that occurs in the aquifer

???
Surface Water Augmentation

How do we ensure we remove and control these compounds?
Tools for SWA

• We have tools at our disposal

Source Control → Secondary/Tertiary Treatment → Ozone → BAC → Membrane Filtration → Reverse Osmosis → Ultraviolet Light/Advanced Oxidation → Free Chlorine

Improved Treatment

Source Control

Additional Treatment

Monitoring & Diversion
Additional Challenges for SWA

- **California Toxics Rule**
  - NDMA
    - DDW Notification Level: 10 ng/L
    - CTR Limit: 0.69 ng/L

- **Nutrient Requirements**
  - Nitrogen requirement for GWR: 10 mg/L
  - **Basin Plan Objectives for Nitrogen:** ~1-2 mg/L as N
Benefits?

Additional Challenges for SWA

• California Toxics Rule
  – NDMA
    • DDW Notification Level: 10 ng/L
    • CTR Limit: 0.69 ng/L

• Nutrient Requirements
  – Nitrogen requirement for GWR: 10 mg/L
  – Basin Plan Objectives for Nitrogen: ~1-2 mg/L as N

Requires improved secondary treatment to reduce nitrogen levels
Evolution of Biological Treatment

5-stage Bardenpho

Ca 1980

1970

1973

Trickling Filter

Activated Sludge

HPOAS

Modified Ludzack-Ettinger Process
Importance of Solids Retention Time

Dissolved Organic Carbon, mg/L

Solids Retention Time, days

Non-nitrifying
Importance of Solids Retention Time

Dissolved Organic Carbon, mg/L vs. Solids Retention Time, days

Partial nitrification

- Dissolved Organic Carbon, mg/L
- Solids Retention Time, days
Importance of Solids Retention Time

Reliable Nitrification
Importance of Solids Retention Time

- SRT is also important to CEC removal
Robust Treatment is Critical for Chemical Control

- No single process effectively controls the wide diversity of chemical contaminants

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Secondary/Tertiary Treatment</th>
<th>Ozone</th>
<th>BAC</th>
<th>Membrane Filtration</th>
<th>Reverse Osmosis</th>
<th>Ultraviolet Light/Advanced Oxidation</th>
<th>Free Chlorine</th>
</tr>
</thead>
<tbody>
<tr>
<td>17β-estradiol</td>
<td>Excellent</td>
<td>Excellent</td>
<td>Poor</td>
<td>Excellent</td>
<td>Excellent</td>
<td>Excellent</td>
<td>Excellent</td>
</tr>
<tr>
<td>Carbamazepine</td>
<td>Poor</td>
<td>Excellent</td>
<td>Poor</td>
<td>Excellent</td>
<td>Excellent</td>
<td>Excellent</td>
<td>Poor</td>
</tr>
<tr>
<td>NDMA</td>
<td>Fair</td>
<td>Good</td>
<td>Poor</td>
<td>Fair</td>
<td>Excellent</td>
<td>Excellent</td>
<td>Poor</td>
</tr>
<tr>
<td>1,4-dioxane</td>
<td>Poor</td>
<td>Good</td>
<td>Poor</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Poor</td>
</tr>
</tbody>
</table>

17β-estradiol, Carbamazepine, NDMA, 1,4-dioxane are shown with their molecular structures.
CEC Control at Demonstration Facilities

San Diego Demonstration

Padre Dam Demonstration
## CEC Control at Demonstration Facilities

### San Diego Demonstration

<table>
<thead>
<tr>
<th>CEC:</th>
<th>Median Concentration (ng/L)</th>
<th>Tertiary Effluent</th>
<th>MF/UF Filtrate</th>
<th>UV Effluent</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-Nonylphenol</td>
<td>750</td>
<td>&lt;100</td>
<td>&lt;100</td>
<td></td>
</tr>
<tr>
<td>4-tert-Octylphenol</td>
<td>470</td>
<td>&lt;50</td>
<td>&lt;50</td>
<td></td>
</tr>
<tr>
<td>Estrone</td>
<td>5.2</td>
<td>&lt;5</td>
<td>&lt;5</td>
<td></td>
</tr>
<tr>
<td>Triclosan</td>
<td>14</td>
<td>&lt;10</td>
<td>&lt;10</td>
<td></td>
</tr>
<tr>
<td>2,4-D</td>
<td>34</td>
<td>&lt;5</td>
<td>&lt;5</td>
<td></td>
</tr>
<tr>
<td>Albuterol</td>
<td>7.4</td>
<td>&lt;5</td>
<td>&lt;5</td>
<td></td>
</tr>
<tr>
<td>Amoxicillin</td>
<td>3300</td>
<td>&lt;20</td>
<td>&lt;20</td>
<td></td>
</tr>
<tr>
<td>Butalbital</td>
<td>5.9</td>
<td>&lt;5</td>
<td>&lt;5</td>
<td></td>
</tr>
<tr>
<td>Diuron</td>
<td>12</td>
<td>&lt;5</td>
<td>&lt;5</td>
<td></td>
</tr>
<tr>
<td>Sulfamethoxazole</td>
<td>18</td>
<td>&lt;5</td>
<td>&lt;5</td>
<td></td>
</tr>
<tr>
<td>Carbamazepine</td>
<td>71</td>
<td>&lt;10</td>
<td>&lt;10</td>
<td></td>
</tr>
<tr>
<td>Cotinine</td>
<td>13</td>
<td>&lt;10</td>
<td>&lt;10</td>
<td></td>
</tr>
<tr>
<td>Atenolol</td>
<td>59</td>
<td>&lt;5</td>
<td>&lt;5</td>
<td></td>
</tr>
<tr>
<td>Cimetidine</td>
<td>22</td>
<td>&lt;5</td>
<td>&lt;5</td>
<td></td>
</tr>
<tr>
<td>Diclofenac</td>
<td>110</td>
<td>&lt;5</td>
<td>&lt;5</td>
<td></td>
</tr>
<tr>
<td>Lidocaine</td>
<td>140</td>
<td>&lt;5</td>
<td>&lt;5</td>
<td></td>
</tr>
<tr>
<td>Lopressor</td>
<td>99</td>
<td>&lt;20</td>
<td>&lt;20</td>
<td></td>
</tr>
<tr>
<td>Thiabendazole</td>
<td>6.35</td>
<td>&lt;5</td>
<td>&lt;5</td>
<td></td>
</tr>
<tr>
<td>Trimethoprim</td>
<td>16</td>
<td>&lt;5</td>
<td>&lt;5</td>
<td></td>
</tr>
<tr>
<td>Acesulfame-K</td>
<td>340</td>
<td>57</td>
<td>&lt;20</td>
<td></td>
</tr>
<tr>
<td>Diltiazem</td>
<td>42</td>
<td>&lt;5</td>
<td>&lt;5</td>
<td></td>
</tr>
<tr>
<td>Gemfibrozil</td>
<td>19</td>
<td>&lt;5</td>
<td>&lt;5</td>
<td></td>
</tr>
<tr>
<td>DEET</td>
<td>19</td>
<td>&lt;10</td>
<td>&lt;10</td>
<td></td>
</tr>
<tr>
<td>Dilantin</td>
<td>35</td>
<td>&lt;20</td>
<td>&lt;20</td>
<td></td>
</tr>
<tr>
<td>Carisoprolol</td>
<td>42</td>
<td>&lt;5</td>
<td>&lt;5</td>
<td></td>
</tr>
<tr>
<td>Erythromycin</td>
<td>35</td>
<td>&lt;10</td>
<td>&lt;10</td>
<td></td>
</tr>
<tr>
<td>Iohexal</td>
<td>3300</td>
<td>470</td>
<td>&lt;10</td>
<td></td>
</tr>
<tr>
<td>Meprobamate</td>
<td>30</td>
<td>&lt;5</td>
<td>&lt;5</td>
<td></td>
</tr>
<tr>
<td>Sucralose</td>
<td>16000</td>
<td>4000</td>
<td>&lt;100</td>
<td></td>
</tr>
<tr>
<td>TCEP</td>
<td>170</td>
<td>15</td>
<td>&lt;10</td>
<td></td>
</tr>
<tr>
<td>TCPF</td>
<td>1100</td>
<td>100</td>
<td>&lt;100</td>
<td></td>
</tr>
<tr>
<td>TDCPP</td>
<td>310</td>
<td>&lt;100</td>
<td>&lt;100</td>
<td></td>
</tr>
</tbody>
</table>

### Padre Dam Dam Demonstration

<table>
<thead>
<tr>
<th>CEC:</th>
<th>Maximum Concentration (ng/L)</th>
<th>Secondary Effluent</th>
<th>RO Effluent</th>
<th>UV/AOP Effluent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atenolol</td>
<td>540</td>
<td>7.8</td>
<td>ND</td>
<td></td>
</tr>
<tr>
<td>Carbamazepine</td>
<td>280</td>
<td>&lt;5</td>
<td>ND</td>
<td></td>
</tr>
<tr>
<td>Dilantin (phenytoin)</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td></td>
</tr>
<tr>
<td>Meprobamate</td>
<td>290</td>
<td>&lt;5</td>
<td>ND</td>
<td></td>
</tr>
<tr>
<td>Primidone</td>
<td>190</td>
<td>ND</td>
<td>ND</td>
<td></td>
</tr>
<tr>
<td>Perchlorate</td>
<td>400</td>
<td>&lt;50</td>
<td>230</td>
<td></td>
</tr>
<tr>
<td>PFOA</td>
<td>7.2</td>
<td>ND</td>
<td>&lt; 2.5</td>
<td></td>
</tr>
<tr>
<td>PFOS</td>
<td>4.6</td>
<td>ND</td>
<td>ND</td>
<td></td>
</tr>
<tr>
<td>17α-Ethinyl estradiol</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td></td>
</tr>
<tr>
<td>17β-estradiol</td>
<td>0.58</td>
<td>&lt; 0.4</td>
<td>ND</td>
<td></td>
</tr>
<tr>
<td>Equilin</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td></td>
</tr>
<tr>
<td>Estradiol</td>
<td>ND</td>
<td>ND</td>
<td>&lt; 8</td>
<td></td>
</tr>
<tr>
<td>Estrone</td>
<td>5.8</td>
<td>ND</td>
<td>ND</td>
<td></td>
</tr>
<tr>
<td>NDMA</td>
<td>16</td>
<td>17</td>
<td>ND</td>
<td></td>
</tr>
<tr>
<td>Caffeine</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td></td>
</tr>
<tr>
<td>Cotinine</td>
<td>48</td>
<td>19</td>
<td>ND</td>
<td></td>
</tr>
<tr>
<td>DEET</td>
<td>510</td>
<td>&lt;100</td>
<td>ND</td>
<td></td>
</tr>
<tr>
<td>Sucralose</td>
<td>48000</td>
<td>&lt;100</td>
<td>180</td>
<td></td>
</tr>
<tr>
<td>TCEP</td>
<td>540</td>
<td>&lt;10</td>
<td>ND</td>
<td></td>
</tr>
<tr>
<td>Triclosan</td>
<td>40</td>
<td>ND</td>
<td>ND</td>
<td></td>
</tr>
</tbody>
</table>
Robust Treatment is Critical for Chemical Control

- No single process effectively controls the wide diversity of chemical contaminants

<table>
<thead>
<tr>
<th></th>
<th>17β-estradiol</th>
<th>Carbamazepine</th>
<th>NDMA</th>
<th>1,4-dioxane</th>
</tr>
</thead>
<tbody>
<tr>
<td>Secondary/Tertiary Treatment</td>
<td>Excellent</td>
<td>Poor</td>
<td>Fair</td>
<td>Poor</td>
</tr>
<tr>
<td>Ozone</td>
<td>Excellent</td>
<td>Excellent</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>BAC</td>
<td>Poor</td>
<td>Poor</td>
<td>Poor</td>
<td>Poor</td>
</tr>
<tr>
<td>Membrane Filtration</td>
<td>Poor</td>
<td>Excellent</td>
<td>Fair</td>
<td>Good</td>
</tr>
<tr>
<td>Reverse Osmosis</td>
<td>Excellent</td>
<td>Excellent</td>
<td>Excellent</td>
<td>Good</td>
</tr>
<tr>
<td>Ultraviolet Light/Advanced Oxidation</td>
<td>Excellent</td>
<td>Excellent</td>
<td>Poor</td>
<td>Poor</td>
</tr>
<tr>
<td>Free Chlorine</td>
<td>Excellent</td>
<td>Poor</td>
<td>Poor</td>
<td>Poor</td>
</tr>
</tbody>
</table>

Should not rely solely on treatment technologies…
Additional Monitoring

Five year record of TOC in Final Product Water at OCWD Groundwater Replenishment System

Additional Monitoring

Standard Operating Procedure for TOC Spikes

TOC Excursions

SOP for TOC Spikes

Appendix D: TOC Decision Chart
Source Control

Tougher penalties for dumping of waste water: PUB

SINGAPORE — Fines for the dumping of waste water containing chemicals into public sewers will be tripled to S$15,000, while offenders could also be jailed for up to three months.

These are the tougher penalties national water agency PUB will introduce, as 11 factories were caught illegally dumping waste water containing high levels of Volatile Organic Compounds (VOCs) into the sewage system. Seven offenders were brought to court, while the remaining four had their offences compounded with a fine.

The number of offenders caught this year has surpassed the total number of illegal dumping cases in the last two years. There were seven cases last year, up from two in 2010.

VOCs such as paints, methylene chloride are commonly present in waste discharges, known as trade effluent, from electroplating, pharmaceutical, printing and food businesses, trades and industries.

Mr Idaly Mamat, Senior Engineer of PUB’s Water Reclamation (Network) Department, said: “As some VOCs are toxic and flammable, the discharge of trade effluent containing high concentration of such VOCs into the public sewer poses fire and safety hazards to workers or operators working in the public sewerage system.

“IT can also affect the treatment process at water reclamation plants, and subsequently, impact the production of Newater or industrial water.”

Waste water containing levels of these compounds should be collected by licensed toxic industrial waste collectors for off-site treatment and disposal.

The PUB will be amending the Sewerage and Drainage (Trade Effluent Regulations) to effect the stricter penalties. The amendment will kick in by next year.

To further monitor the quality of waste water, the PUB installed 40 VOC sensors last month in industrial sites such as Tuas, Pioneer Sector and Woodlands to monitor the concentration levels of chemicals discharges into the sewerage system.

An SMS alert will be sent to PUB if any illegal discharge is detected, and officers will be deployed on site to trace the discharge.

The sensors also enable PUB to closely monitor 1,783 factories identified as “concerns”, out of 4,800 listed in its records.

Since the deployment of the sensors, 20 more cases of waste water with high VOC levels discharged into the public sewerage system were detected, with 16 offenders identified by the PUB. Investigations are ongoing to identify the rest of the culprits.

To further ensure public sewers are free from obstruction — which might lead to overflows and the subsequent pollution of waterways and reservoirs — the PUB has progressively installed some 1,000 sensors since 2010 in manholes island-wide to monitor used water levels.

“Before we had these water-level sensors, we had to depend on public feedback to notify us on water overflowing from manholes into the surroundings,” said Mr Idaly.

“With the sensors, we are able to detect this before it happens, so we can stop a blockage before the water overflows into our canals and waterways. This prevents water pollution and prevents public nuisance as well.”

• Singapore example – VOC monitoring in sewers

• Develop source control programs
Surface Water Augmentation

• What does the reservoir offer us?
Surface Water Augmentation

- What does the reservoir offer us?

Dilution  Response Time
Surface Water Augmentation

• What does the reservoir offer us?

Dilution  
Response Time

As we move toward direct potable reuse…
Moving to Direct Potable Reuse

- Loss of natural environment
  - Time
  - Treatment
Moving to Direct Potable Reuse

- Loss of natural environment
  - Time
  - Treatment

Diagram showing the processes of groundwater augmentation, reservoir augmentation, source water augmentation, and direct distribution, with notes on additional treatment and monitoring controls.
Summary

Groundwater Recharge

• Challenges
  – CECs
• Solution
  – Retention time + treatment in ground

Surface Water Augmentation (and Direct Potable Reuse)

• Challenges
  – CECs
  – VOCs
  – California Toxics Rule
  – Nutrient Limits
  – Reduced retention time
  – Loss of natural environmental treatment
Summary

Groundwater Recharge

- **Treatment**
  - Full advanced treatment (injection)
  - Disinfected tertiary (spreading)

- **Time**
  - Retention time in aquifer

Surface Water Augmentation (and Direct Potable Reuse)

- **Treatment**
  - Full advanced treatment + additional treatment technologies

- **Time**
  - Improve source control
  - Improve monitoring
Thank you!

shanet@trusselltech.com