Demonstrating Redundancy and Monitoring to Achieve Reliable Potable Reuse

Shane Trussell, Ph.D., P.E., BCEE

Direct Potable Reuse in California: Specialty Seminar
September 23rd, 2015
**Surface Water Augmentation**

- Full Advanced Treatment
- Large Reservoir
- Potable Water Treatment Plant
- Water Consumers

**Source Water Augmentation**

- Full Advanced Treatment
- Small Reservoir
- Potable Water Treatment Plant
- Water Consumers

**Groundwater Recharge**

- (T22) Tertiary Treatment
- Full Advanced Treatment
- Large Groundwater Aquifer
- Chlorination
- Water Consumers

**AWT as approved water supply**

- Full Advanced Treatment
- Water Consumers
Groundwater Recharge

Surface Water Augmentation
- Full Advanced Treatment
- Large Reservoir
- Potable Water Treatment Plant
- Water Consumers

Source Water Augmentation
- Full Advanced Treatment
- Small Reservoir
- Potable Water Treatment Plant
- Water Consumers

AWT as approved water supply
- Full Advanced Treatment
- Water Consumers

Dilution and Response
- Chlorination
- Time
Regulations passed in 2014

Regulations in development

Feasibility being assessed for CA
What are the paths to reliability?

Public Health Protection

Dilution  OR  Treatment & Monitoring
Does Dilution Work?

Typical Conditions

Raw

FAT Effluent

Post-Dilution

Safe?

No

Yes

Yes
Does Dilution Work?

<table>
<thead>
<tr>
<th>Failure Conditions</th>
<th>Raw</th>
<th>FAT Effluent</th>
<th>Post-Dilution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safe?</td>
<td>✖️</td>
<td>✖️</td>
<td>✅</td>
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</table>

*Process Failure*
Enhanced treatment provides same benefit

<table>
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<tr>
<th>Typical Conditions</th>
<th>Raw</th>
<th>Enhanced Treatment</th>
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<td>👎</td>
<td>⬆️</td>
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Enhanced treatment provides same benefit

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<th>Raw</th>
<th>Enhanced Treatment</th>
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<tbody>
<tr>
<td>Process Failure</td>
<td></td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Safe?</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>✋</td>
<td>✌️</td>
</tr>
</tbody>
</table>
What Else Does the AWPF Concept Consider?
New treatment challenges for reuse

Pathogens

Secondary Effluent → Membrane Filtration → Reverse Osmosis → Ultraviolet Light/Advanced Oxidation → Aquifer
New treatment challenges for reuse

Pathogens

Secondary Effluent → Membrane Filtration → Reverse Osmosis → Ultraviolet Light/Advanced Oxidation → Aquifer
New treatment challenges for reuse

Pathogens
- Secondary Effluent
- Membrane Filtration
- Reverse Osmosis
- Ultraviolet Light/Advanced Oxidation
- Aquifer

Toxic Chemicals
- Reverse Osmosis (RO)
New treatment challenges for reuse

**Pathogens**
- Secondary Effluent
- Membrane Filtration
- Reverse Osmosis
- Ultraviolet Light/Advanced Oxidation
- Aquifer

**Toxic Chemicals**
- 1,4-dioxane
- NDMA
- Acetone
New treatment challenges for reuse

Pathogens
- Secondary Effluent
- Membrane Filtration
- Reverse Osmosis
- Ultraviolet Light/Advanced Oxidation
- Aquifer

Toxic Chemicals
- 1,4-dioxane
- NDMA
- Acetone

Taste and Odor
Performance monitoring is crucial
Performance monitoring is crucial

Performance must be demonstrated
Title: Demonstrating Redundancy and Monitoring to Achieve Reliable Potable Reuse
Project Goal

To leverage industry “state of the art” to demonstrate how a combination of treatment redundancy and enhanced monitoring techniques can reliably achieve potable reuse treatment objectives.
AWPF Concept Built on Reliability

- Reliability
- Resilience
- Redundancy
- Robustness
AWPF Concept Built on Reliability

- Redundancy: additional log removals and monitoring for acute contaminants to reduce impact of treatment anomalies
# Treatment Redundancy

<table>
<thead>
<tr>
<th></th>
<th>3ry</th>
<th>O₃</th>
<th>BAC</th>
<th>MF</th>
<th>RO</th>
<th>UV/AOP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Virus</td>
<td>2</td>
<td>6</td>
<td>-</td>
<td>-</td>
<td>1-2</td>
<td>6</td>
</tr>
<tr>
<td>Crypto</td>
<td>1</td>
<td>2-4</td>
<td>-</td>
<td>4</td>
<td>1-2</td>
<td>6</td>
</tr>
<tr>
<td>Giardia</td>
<td>2</td>
<td>6</td>
<td>-</td>
<td>4</td>
<td>1-2</td>
<td>6</td>
</tr>
</tbody>
</table>
Failure to achieve 5-log?

- 6-log: 2.3%
- 7-log: 0.003%
- 8-log: 0.0000001%
Robustness: increased diversity of treatment process types improves chances of attenuating an unknown contaminant
Robustness: Incorporating more strength

Pretreatment

- 3\textsuperscript{ry}
- O\textsubscript{3}
- BAC

Full advanced treatment

- MF
- RO
- UV/AOP

- Biological Adsorption
- Oxidation
- Physical removal

- Chemical Inactivation

- Biological Adsorption
- Physical removal

- Physical removal

- Physical removal

- Physical degradation
- Oxidation
- Inactivation UV light
Robustness: Proactively mitigates next “unknown”

Organics treatment

3 ry

O₃  BAC  MF  RO  UV/AOP

Biological Adsorption
Physical removal

Oxidation
Chemical Inactivation

Physical removal

Physical removal

Physical degradation
Oxidation
Inactivation UV light
MEASURING RELIABILITY
### Measuring Reliability

<table>
<thead>
<tr>
<th>Process</th>
<th>Image</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ozone</td>
<td>![Ozone Image]</td>
</tr>
<tr>
<td>BAC</td>
<td>![BAC Image]</td>
</tr>
<tr>
<td>MF</td>
<td>![MF Image]</td>
</tr>
<tr>
<td>RO</td>
<td>![RO Image]</td>
</tr>
<tr>
<td>UV/AOP</td>
<td>![UV/AOP Image]</td>
</tr>
<tr>
<td></td>
<td>Measuring Reliability</td>
</tr>
<tr>
<td>---</td>
<td>-----------------------</td>
</tr>
<tr>
<td>Ozone</td>
<td>![Ozone Image]</td>
</tr>
<tr>
<td>BAC</td>
<td>![BAC Image]</td>
</tr>
<tr>
<td>MF</td>
<td>![MF Image]</td>
</tr>
<tr>
<td>RO</td>
<td>![RO Image]</td>
</tr>
<tr>
<td>UV/AOP</td>
<td>![UV/AOP Image]</td>
</tr>
</tbody>
</table>

**DATA**
Measuring Reliability

- Ozone
- BAC
- MF
- RO
- UV/AOP

DATA DATA DATA DATA DATA

Actual performance
Measuring Reliability

Ozone  BAC  MF  RO  UV/AOP

DATA  DATA  DATA  DATA  DATA

Target performance

Actual performance
## Performance Monitoring Data

<table>
<thead>
<tr>
<th>Critical Control Points</th>
<th>Ozone</th>
<th>BAC</th>
<th>MF</th>
<th>RO</th>
<th>UV/AOP</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DO₃ (x3)</strong></td>
<td>--</td>
<td>Turb. (Eff) PDT</td>
<td>Δ TOC</td>
<td>Δ Cond.</td>
<td>UV Intensity Power UVT</td>
</tr>
</tbody>
</table>

### Equipment Images

- [Hach](#)
- [Rosemount Analytical](#)
- [Kuntze Instruments](#)
- [GE Power & Water](#)
Data Management

- Meters
- Local Storage And Control
- SCADA/Central Storage
- Performance Analysis
Data Analysis

System On (Flow?)

Yes
- Ozone Production?
  Yes
  - Import data. Meter function?
    Yes
  No
  Process failure LRV = 0

No
- Remove data

System Operation

Process Function
Data Analysis

System Operation
- System On (Flow?)
  - Yes: Ozone Production?
    - Yes: Import data. Meter function?
      - Yes: Calculate LRV
      - No: Process failure. LRV = 0
    - No: Remove data
  - No: Remove data

Process Function
- Import data. Meter function?
  - Yes: Calculate LRV
  - No: Meter failure

Meter Function

Data Analysis

ALL DATA

- System Up?
  - Normal operations
  - Process failure
  - Meter Failure
- System down?
  - Planned failure
  - Unplanned failure

System Operation

Process Function

Meter Function

Calculate LRV

System On (Flow?)

Yes

No

Meter failure

Yes

No
OZONE

BAC

MF

RO

UV/AOP
Forms of Reliability

**Mechanical Reliability**
How frequently system is running as designed

**Inherent Reliability**
Quality of water produced when system is running properly

- System Up
- System Down
- System Performance
Mechanical Reliability

Unplanned Downtime: 9%
Planned Downtime: 1%
Total Uptime: 90%
1.2 Days downtime
154 Days

Demo plant not designed with standby
Ozone Performance Calculation

**Inputs**
- Temperature
- Dissolved O$_3$ Meters (x3)
- Contact Time

**Calculations**
- Determine total CT value

**Assign LRV**
- Use info from SWTRs to assign Crypto LRV
- If Crypto LRV $> 1$, Giardia and virus = 6
Ozone Performance Data

Cryptosporidium Inactivation (Log)

Date

Crypto LRV (Kuntze)
Crypto LRV (Indigo)

Target LRV
Ozone Performance Curve

- Crypto LRV-Kuntze
- Crypto LRV-Indigo

Y-axis: Cryptosporidium LRV (log)
X-axis: Percent of Time Less Than Y-Value
Mechanical Reliability

- **Uptime**: 98%
  - 154 Days
- **Planned Downtime**: 1.6%
  - 2.7 Days
- **Unplanned Downtime**: 0.6%
  - 0.99 Days
BAC Performance Data

<table>
<thead>
<tr>
<th>Date</th>
<th>Flow (GPM)</th>
</tr>
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<tbody>
<tr>
<td>07/11</td>
<td></td>
</tr>
<tr>
<td>07/13</td>
<td></td>
</tr>
<tr>
<td>07/15</td>
<td></td>
</tr>
<tr>
<td>07/17</td>
<td></td>
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<tr>
<td>07/19</td>
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</tr>
<tr>
<td>07/21</td>
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<td>07/23</td>
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<td>07/25</td>
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<td>07/27</td>
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<td>07/29</td>
<td></td>
</tr>
<tr>
<td>07/31</td>
<td></td>
</tr>
</tbody>
</table>
BAC Performance Data

Graph showing fluctuations in TOC (Total Organic Carbon) levels over a period from July 11 to July 31. The graph includes lines for influent, effluent, and TOC removal percentages.
Transformation of Organic Matter by Ozone

- Ozone oxidizes EfOM
- Quantifiable decrease in:
  - UVT
  - Fluorescence
  - Color
- Breaks down large MW and produces smaller MW, more polar, and more hydrophilic type organics
What does ozone do to TOC?
Oxidation Byproducts Are Yummy!

<table>
<thead>
<tr>
<th>Location</th>
<th>Acetate</th>
<th>Formate</th>
<th>Formaldehyde</th>
<th>Glyoxal</th>
<th>Acetone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ozone</td>
<td>200</td>
<td>50</td>
<td>100</td>
<td>25</td>
<td>0</td>
</tr>
<tr>
<td>BAC</td>
<td>150</td>
<td>150</td>
<td>150</td>
<td>150</td>
<td>150</td>
</tr>
<tr>
<td>RO</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>UV</td>
<td>50</td>
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<td>50</td>
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<tr>
<td>AOP</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Process Monitoring by UVT Meters

![Graph showing process monitoring data for O3 Influent, O3 Effluent, and BAC Effluent over dates from 7/16/14 to 12/13/14.]
RO concentrate shows less fluorescence than the feed water (tertiary effluent) and contains **40% less TOC**.
Reduction in Feed TOC Benefits Product Water Quality

<table>
<thead>
<tr>
<th>Process Type</th>
<th>Median TOC (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tertiary Effluent</td>
<td>0.01</td>
</tr>
<tr>
<td>Ozone Effluent</td>
<td>0.1</td>
</tr>
<tr>
<td>BAC Effluent</td>
<td>1</td>
</tr>
<tr>
<td>MF/UF Filtrate</td>
<td>10</td>
</tr>
<tr>
<td>RO Permeate</td>
<td>0.01</td>
</tr>
<tr>
<td>UV Effluent</td>
<td>0.1</td>
</tr>
<tr>
<td>RO Concentrate</td>
<td>10</td>
</tr>
</tbody>
</table>

Legend:
- Blue: with O3/BAC
- Red: Without O3/BAC Not Sampled
NDMA Formation and Removal

Median Concentration (ng/L)

- Tertiary Effluent
- Ozone Effluent
- BAC Effluent
- MF/UF Filtrate
- RO Permeate
- UV Effluent

With O3/BAC
without O3/BAC

Without O3-BAC Not Sampled
Without O3-BAC Not Sampled

MRL: 2 ng/L
<table>
<thead>
<tr>
<th>OZONE</th>
<th>BAC</th>
<th>MF</th>
<th>RO</th>
<th>UV/AOP</th>
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<tbody>
<tr>
<td><img src="OzoneIcon.png" alt="Ozone Icon" /></td>
<td><img src="BACIcon.png" alt="BAC Icon" /></td>
<td><img src="MFIcon.png" alt="MF Icon" /></td>
<td><img src="ROIcon.png" alt="RO Icon" /></td>
<td><img src="UV/AOPIcon.png" alt="UV/AOP Icon" /></td>
</tr>
</tbody>
</table>
Mechanical Reliability

MF

Unplanned Downtime
0.15%
0.2 Days

Planned Downtime
2.24%
3.5 Days

Total Uptime
97.6%
153 Days

UF

Unplanned Downtime
0.4%
0.6 Days

Planned Downtime
0.7%
1.2 Days

Total Uptime
99%
153 Days
MF/UF Performance Calculation

**Performance Criteria**
- If filtrate Turbidity < 0.15 NTU over 24-h period
- Use daily membrane integrity test to determine LRV

**Assign LRVs**
- Crypto: determine LRV based on EPA calculations
  \[
  LRV = \log \left( \frac{Q_p \cdot ALCR \cdot P_{am}}{\Delta P_{test} \cdot V_{sys} \cdot VCF} \right)
  \]
- Giardia: assume equivalent to Crypto LRV
- Virus: assign LRV = 0 (or do study)
MF Performance Data

![Graph showing MF Performance Data with LRV parameters]
UF Performance Data
UF Performance Data
MF/UF Performance Curves

MF LRV Distribution

UF LRV Distribution
Mechanical Reliability

Total Uptime: 99%
153 Days

Unplanned Downtime:
- 0.2%
- 0.34 hours

Planned Downtime:
- 0.7%
- 1.1 days
RO Performance Calculation

Performance Criteria
• RO Permeate TOC < 500 ppb
• Measure TOC reduction
• Measure conductivity reduction

Assign LRVs
• All pathogens: LRV equals log removal of TOC or conductivity (greater)
RO Performance Data

**RO Train A Conductivity**
Influent (Black) & Effluent (Red) Conductivity (uS/cm)

**RO Train B Conductivity**
Influent (Black) & Effluent (Red) Conductivity (uS/cm)
RO Performance Data

The chart illustrates the Total Organic Carbon (TOC) concentration over time from '07/10 to '07/31. The data is represented by a line graph with TOC concentration in mg/L on the y-axis and dates on the x-axis. The range of TOC concentration is from 0 to 10 mg/L. The chart also shows percent removal (%), indicating the effectiveness of the RO (Reverse Osmosis) system over the specified period.
RO Performance Data

RO Pathogen Removal

![Graph showing RO Pathogen Removal from 07/11 to 07/31]
RO Performance Curve
<table>
<thead>
<tr>
<th>OZONE</th>
<th>BAC</th>
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<th>RO</th>
<th>UV/AOP</th>
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</thead>
<tbody>
<tr>
<td>![Ozone Icon]</td>
<td>![BAC Icon]</td>
<td>![MF Icon]</td>
<td>![RO Icon]</td>
<td>![UV/AOP Icon]</td>
</tr>
</tbody>
</table>
Mechanical Reliability

Unplanned Downtime
2.5%
3.9 Days

Planned Downtime
0.8%
1.2 Days

Total Uptime
97%
152 Days
UV Performance Calculation

Performance monitoring
- Measure power level
- Measure UV intensity
- Measure UV transmittance

Calculate LRV
- IF:
  - Power $\geq$ 60%
  - UV intensity $> 5$ mW/cm$^2$
  - UVT $> 95$
- LRV = 6 for all pathogens
UV/AOP Performance Curve
System Performance Curve

Ozone Crypto/Giardia/Virus LRV

MF or UF Crypto/Giardia/Virus LRV

RO Crypto/Giardia/Virus LRV

UV Crypto/Giardia/Virus LRV

Total Train Crypto/Giardia/Virus LRV
System Performance Curve

Coming soon!
CHALLENGE TESTS
Expanding O$_3$ credit for Crypto

Ozone credit maxes out at 3-logs for drinking water

---

**Exhibit 11.1  CT Values for Cryptosporidium Inactivation by Ozone**

(40 CFR 141.730)

<table>
<thead>
<tr>
<th>Log credit</th>
<th>Water Temperature, °C$^1$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;=0.5</td>
</tr>
<tr>
<td>0.25</td>
<td>6.0</td>
</tr>
<tr>
<td>0.5</td>
<td>12</td>
</tr>
<tr>
<td>1.0</td>
<td>24</td>
</tr>
<tr>
<td>1.5</td>
<td>36</td>
</tr>
<tr>
<td>2.0</td>
<td>48</td>
</tr>
<tr>
<td>2.5</td>
<td>60</td>
</tr>
<tr>
<td>3.0</td>
<td>72</td>
</tr>
</tbody>
</table>

$^1$CT values between the indicated temperatures may be determined by linear interpolation.
Expanding O₃ credit for Crypto

- Experimental plan reviewed by IAP/PAC
- Comparing ozone inactivation of Crypto in surface water and 3ry effluent
- Assessing up to 5-log inactivation in 3ry water
- Two rounds of testing began in Sept 2015
- Biovir Labs providing safety oversight
Chemical Challenge Test

- 1,4-dioxane
- NDMA
- Acetone
- Formaldehyde
Chemical Challenge Test

1,4-dioxane
NDMA
Acetone
Formaldehyde
Chemical Challenge Test

Testing at Demonstration Facility on September 18, 2015
REGULATORY INTERACTIONS
Moving Crediting Schemes into Potable Reuse

- Ozone crediting from Surface Water Treatment Rules
- MF/UF crediting from EPA Guidance
- Expanding ozone credit for Crypto
LESSONS LEARNED
Data management is a big deal
Data management is a big deal

- 1 meter
- One reading
- > 250,000 data points
- > 3,000,000 data points

Uncommon to mine this much data...
Data filtering takes time

Strategies to deal with meter noise

Correct filtering of data for analysis

(Power > 60% is not equal to Power ≥ 60%)

Learning some logged data are unnecessary – while some unlogged data are!
More is not necessarily better . . .
Strategies for Future Implementation

• Connect all monitors to a single data storage system
• Ensure data is easily accessible for analysis
• Develop data processing logic prior to start-up can save time
• Provide adequate time for meter commissioning
Next Steps

• Continue data collection and data mining (April 2015 – April 2016)

• Adapt monitoring strategies based on findings

• Build performance curves to assess reliability

• Report on challenge test results
Acknowledgements

- **WateReuse Research Foundation**'s financial, technical, and administrative assistance in funding and managing the project through which this information was discovered, developed, and presented.
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- Project funding under the Safe Drinking Water, Water Quality and Supply, Flood Control, River and Coastal Protection Bond Act of 2006, administered by the State of California, **Department of Water Resources**.
Supporting Utilities

City of San Diego
PUBLIC UTILITIES
Water & Wastewater

PADRE DAM
Municipal Water District

Helix Water District
Questions?

Direct Potable Reuse in California: Specialty Seminar
September 23rd, 2015