CFD and Tracer Testing Definitions

- Computational Fluid Dynamics (CFD)
- Theoretical Detention Time (T or $T_D$)
- Disinfection Contact Time ($T_{10}$)
- Hydraulic Efficiency (Detention Efficiency)
- Baffle Factor
- Disinfection Credit (CT)
- Tracer Test
Typical Clearwell Design Approach is based on Empirical Data
Research Has Demonstrated the Impact of L:W Ratio on Baffle Factor

Figure ES.2: Impact of L/W on $T_w/T$ ratio

\[ y = 0.2163 \ln(x) - 0.0827 \]

$R^2 = 0.8733$
Case Study 1: Tracer Study of a Clearwell Baffle Retrofit
New Clearwell Baffles Improve Efficiency

Baffle Factor = 0.64

$T_m = 109$ minutes
Case Study 2: Tracer Test of Well-Baffled Circular Clearwells
Tracer Application Details are Critical for Valid Test Results

Clearwell Inlet Tracer Concentration
Tracer Application Details are Critical for Valid Test Results

Initial Tracer Application Point

Ultimate Tracer Application Point

Tracer Concentration

Time (hr)

BF > 0.85

BF = 0.67
CFD Modeling and Tracer Testing Can Reveal Unexpected Issues

Joints Not Tightly Sealed
Sealed Baffle Wall Joint Achieved Clearwell Efficiency Objective

BF > 0.7
Case Study 3: Baffled Clearwell Tanks
Tracer Tests Consistently Demonstrate Poor Clearwell Efficiency

- Tracer reaches influent sampling location 20 minutes after start of tracer feed.
- Total influent piping detention time = 32 minutes.
- Tank 1 T<sub>10</sub> Value:
  175 minutes - 32 minutes = 143 minutes
- Series T<sub>10</sub> Value:
  380 minutes - 32 minutes = 348 minutes
- Tracer concentration in Tank 1 effluent reaches 10% of influent concentration 175 minutes after the start of tracer feed.

Tracer concentration in Tank 2 effluent reaches 10% of influent concentration 380 minutes after the start of tracer feed.

- Influent
- Tank 1 Effluent
- Tank 2 Effluent
Consistently Poor Tracer Test Results – Now What?

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Parallel Flow</th>
<th>Series Flow</th>
<th>Tank 1 Series Flow</th>
<th>Tank 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Water Depth, (ft)</td>
<td>6.23</td>
<td>6.56</td>
<td>8.92</td>
<td>6.38</td>
</tr>
<tr>
<td>System Volume during test (gal)</td>
<td>480,000</td>
<td>505,000</td>
<td>344,000</td>
<td>246,000</td>
</tr>
<tr>
<td>WTP influent to Tank(s) (gpm)</td>
<td>556</td>
<td>556</td>
<td>556</td>
<td>556</td>
</tr>
<tr>
<td>Effluent flow from Tank(s), avg. (gpm)</td>
<td>590</td>
<td>580</td>
<td>556</td>
<td>610</td>
</tr>
<tr>
<td>Theoretical Detention Time (min)</td>
<td>839</td>
<td>892</td>
<td>619</td>
<td>422</td>
</tr>
<tr>
<td>Observed influent tracer conductivity (µS/cm)</td>
<td>120</td>
<td>101</td>
<td>101</td>
<td>110</td>
</tr>
<tr>
<td>Observed T_{10} in Tank(s) (min)</td>
<td>173</td>
<td>350</td>
<td>143</td>
<td>128</td>
</tr>
<tr>
<td>Calculated Baffle Factor</td>
<td>0.21</td>
<td>0.39</td>
<td>0.23</td>
<td>0.30</td>
</tr>
</tbody>
</table>
CFD Modeling Required to Understand Poor Tracer Test Results
CFD Model Confirms Performance Inefficiency
Computer Modeling Facilitates Evaluation of Improvement Alternatives
Corrective Actions Selected Based on Owner-Defined Criteria
CFD Accurately Modeled Improved Clearwell Efficiency
Case Study 4: Well-Baffled Rectangular Concrete Clearwell

Tracer Testing BF = 0.3
Original Design Conditions Model Reveals Sources of Inefficiency
Model of Original Design Conditions Reveals Sources of Inefficiency
CFD Modeled Clearwell Performance Matches Tracer Results

<table>
<thead>
<tr>
<th>Flow Condition (gpm)</th>
<th>Tracer Test</th>
<th>Model Output</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$T_{10}$ (min)</td>
<td>BF (unitless)</td>
</tr>
<tr>
<td>350</td>
<td>238</td>
<td>0.30</td>
</tr>
</tbody>
</table>
Simple Inlet Modifications Significantly Improve Flow Patterns
Lesson-Learned: Inlet and Outlet Flow Distribution are Critical
Low-Cost Modifications Significantly Improved Clearwell Efficiency

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<td>238</td>
<td><strong>0.30</strong></td>
</tr>
</tbody>
</table>

0.73 with Inlet Improvement
Case Study 5: Over-Designed Clearwells Can Still Under-Perform

Ported Baffle Wall (typ.)

\[ T_{10} = 133 \text{ minutes} \]

Model-predicted BF = 0.54
Complete Tracer Concentration Gradient Shows Poor Efficiency
Minor Changes Can Have Major Clearwell Efficiency Impacts
Lesson-Learned: Minor Changes Can Have Major Efficiency Impacts

Original Design at 133 Minutes

Model-predicted BF = 0.54

BEFORE

Modified Design at 133 Minutes

Model-predicted BF > 0.8

AFTER
Summary of Lessons Learned

• Tracer tests
  – Setup (feed points, sample locations) are critical to accurate test results
  – Consult with an experienced tester about protocol and data analyses

• Utilize CFD technology to design and execute projects more efficiently
  – Achieve performance efficiency objectives
  – Cost efficiency - proactive investment pays dividends

• Improve clearwell design with or without CFD
  – L:W is a good start, but it is not the only efficiency consideration
    • Vertical and horizontal distribution
      – At Inlet and Outlet
    • Control short circuiting at turns
Other Opportunities to Utilize CFD Models to Improve Hydraulic Performance

- Dam spillways
- Pump sumps
- Distribution system tanks
- Process Basins
  - Flocculation basins
  - Orifice walls
  - Flow distribution
Thank you

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