Controlled Discharge Lagoons
2 Cell vs. 3 Cell Bacteria & Ammonia Performance
Some History - CDL Design in Iowa

• Pre-1979
  – 2 cells
  – Facultative lagoon sizing based on surface area loading

• Post 1979
  – 3 cells required by design standards for CDLs > 1 acre total surface area
  – 180 days of storage

• 1995 Pilot Program
  – 2 cells allowed by variance for a group of unsewered communities (pilot project) as a value engineering concept

• 1995 to recent
  – 2-cell variances granted on a regular basis for unsewered communities
  – Justification: Equivalent performance and cost savings
Some More History - CDL Effluent Limits

• No water quality based effluent limits in NPDES permits
  – “Properly operated CDLs with 180-days of storage pose no risk of violating applicable water quality criteria.”

• 2006 - Revised water quality standards
  – Designation of all perennial streams
  – Removal of protected flow concept

• Mid 2000’s – Present
  – Multiple TMDLs assigning waste load allocations to point sources (including CDLs)

• Spring 2009
  – Ammonia and bacteria monitoring required for all CDLs
Number of Cells vs. Performance

• Question: Are three cells better than two...
  ...for treatment of bacteria & ammonia by CDLs?
• Old concept (“Reactor Theory 101”)  
• Not considered in previous variances
• Applicable to CDLs?
  – Long holding times
  – Batch discharge
  – Not always operated in series
The equation can be rearranged to determine the optimum number of cells (typically 3) required for a particular level of pathogen removal. In general, a 3 or 4 cell system (in series) with a total actual detention time of about 20 days will remove fecal coliforms to desired levels and all parasites. It can also be shown with the design equation that the use of additional cells beyond 3 provides minimal benefits. The removal of

![Graph showing fecal coliform numbers in undisinfected facultative pond effluent.](image)

**Figure 1.** Fecal Coliform Numbers in Undisinfected Facultative Pond Effluent.

work elsewhere that the number of cells in the pond system is a critical factor in achieving high removal of pathogens and other contaminants. Multiple cells significantly reduce short circuiting; and as the number of cells increases, the hydraulic regime approaches the ideal plug flow conditions. A multiple cell system will consistently outperform a single large cell with an equivalent detention time.
Predicted Removal Efficiencies and Effluent Concentrations

- Series Operation
- $k = 2.6$
- 180 days total holding time
- HRT = 100% of storage time
- 2/3 of total volume in primary cells
- mean water temperature = 10 degrees C

Effluent Concentration (#/100 mL) vs. # of Cells

- Ci = 630,000
- Ci = 6,300,000

% Removal Efficiency
- 100.00%
- 99.75%
- 99.50%
- 99.25%
- 99.00%
- 98.75%
- 98.50%
Effluent Data (so far)

• 2006 - special sampling effort (DNR/UHL)
  – Support assumptions behind no water quality based effluent limits
  – 1, 2, 3 & 4 cell systems sampled
  – Majority 3 cells
  – No variance approved 2-cell systems

• 2009/2010 - special sampling effort (DNR/UHL)
  – Investigate variance-approved 2-cell performance
  – Samples from variance-approved 2-cell CDLs only

• NPDES Monitoring (2009 - present)
  – NPDES permits issued with new monitoring requirements
  – Larger data set than previous special sampling efforts
  – Will continue to grow
## Effluent Data (so far)

<table>
<thead>
<tr>
<th></th>
<th>Sample Data Points (Post-1979)</th>
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<tbody>
<tr>
<td></td>
<td>2-Cell</td>
</tr>
<tr>
<td>Bacteria</td>
<td>159 (113)</td>
</tr>
<tr>
<td>Ammonia</td>
<td>146 (102)</td>
</tr>
<tr>
<td># of Facilities</td>
<td>50 (41)</td>
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Example Data Set

- Five Sample Values:
  
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<tr>
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<tbody>
<tr>
<td>1</td>
<td>10</td>
<td>100</td>
<td>1,000</td>
<td>10,000</td>
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- Sample Value as Percent Rank (Percentile)
  - 1 sample smaller than 10, 3 values larger than 10, percent rank of 10 = 1/4 (25\textsuperscript{th} percentile)
  
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<tbody>
<tr>
<td>0</td>
<td>25</td>
<td>50</td>
<td>75</td>
<td>100</td>
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- Percent Exceedance (NOT exceedance probability)
  - 3 out of 4 (75\%) of the remaining samples exceed (or equal) 10
  
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</thead>
<tbody>
<tr>
<td>100</td>
<td>75</td>
<td>50</td>
<td>25</td>
<td>0</td>
</tr>
</tbody>
</table>
3 out of 4 (75%) of the other samples in the data set equal or exceed the sample value of 10.
E. coli - Percent Exceedance
All Data - 2 vs. 3 Cells
E. coli - Percent Exceedance
Post 1979 - 2 vs. 3 Cells

Sample Value (# / 100 mL)

Percent Exceedance

3-cells 2006  2-cells UHL 09/10  2-cells NPDES  3-cells NPDES
E. coli - Percent Exceedance
Combined Data Sets (2006 to 2011)
E. coli - Percent Exceedance

NPDES Data by Discharge Season

- 2-cells Fall 2009
- 3-cells Fall 2009
- 2-cells Spring 2010
- 3-cells Spring 2010
- 2-cells Fall 2010
- 3-cells Fall 2010
- 2-cells Spring 2011
- 3-cells Spring 2011
- 3-cells Fall 2011
E. coli - Percent Exceedance
NPDES Data (Fall 2009 - Fall 2011)
Ammonia - Percent Exceedance
All Data - 2 vs. 3 Cells
Ammonia - Percent Exceedance
Post 1979 - 2 vs. 3 Cells

Sample Value (mg/L)

Percent Exceedance

3-cell 2006  ▲  2-cell UHL 09/10  ■  2-cell NPDES  ●  3-cell NPDES
Ammonia - Percent Exceedance
Combined Data Sets (2006 - 2011)
Ammonia - Percent Exceedance
NPDES Data by Discharge Season

<table>
<thead>
<tr>
<th>Sample Value (mg/L)</th>
<th>Percent Exceedance</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>2-cells Fall 2009</td>
</tr>
<tr>
<td>3</td>
<td>3-cells Fall 2009</td>
</tr>
<tr>
<td>2</td>
<td>3-cells Spring 2010</td>
</tr>
<tr>
<td>3</td>
<td>2-cells Spring 2010</td>
</tr>
<tr>
<td>2</td>
<td>2-cells Fall 2010</td>
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<tr>
<td>3</td>
<td>3-cells Fall 2011</td>
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<tr>
<td>2</td>
<td>2-cells Spring 2011</td>
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<tr>
<td>3</td>
<td>3-cells Spring 2011</td>
</tr>
<tr>
<td>2</td>
<td>2-cells Fall 2011</td>
</tr>
<tr>
<td>3</td>
<td>3-cells Fall 2011</td>
</tr>
</tbody>
</table>
Ammonia - Percent Exceedance
NPDES Data by Discharge Season (Post 79)
Ammonia - Percent Exceedance
NPDES Data (Fall 2009 - Fall 2011)
Observations

• Unknows
  – Future bacteria limits for CDLs
  – Future ammonia limits for CDLs
  – Operational characteristics at the time of sampling (series, parallel, etc.)
  – Specific hydraulic/loading variability

• Knowns
  – Significant seasonal variability
  – In general, the data shows better bacteria & ammonia performance for 3-cell systems
    • Exception = ammonia data from Spring 2011
  – Better bacteria results from Spring discharges?

• Result
  – Variance approvals for new 2-cell systems based on “equivalent effectiveness” are no longer being recommended by DNR Engineering staff
Observations (cont.)

- Hypothetical Criteria vs. Observed NPDES Performance

<table>
<thead>
<tr>
<th>Comparison Criterion</th>
<th>Percent Exceedance (Post 1979)</th>
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<tbody>
<tr>
<td></td>
<td>2-Cell</td>
</tr>
<tr>
<td>Bacteria</td>
<td></td>
</tr>
<tr>
<td>1073 #/100 mL</td>
<td>18.3 (22.6)</td>
</tr>
<tr>
<td>Ammonia</td>
<td>36.4 (37.3)</td>
</tr>
<tr>
<td>1 mg/L</td>
<td>36.1 (36.2)</td>
</tr>
<tr>
<td>2 mg/L</td>
<td>28.6 (28.0)</td>
</tr>
<tr>
<td>3 mg/L</td>
<td>22.4 (19.1)</td>
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<tr>
<td>4 mg/L</td>
<td>19.5 (17.4)</td>
</tr>
<tr>
<td>5 mg/L</td>
<td>11.0 (7.8)</td>
</tr>
<tr>
<td></td>
<td>3-Cell</td>
</tr>
<tr>
<td></td>
<td>8.1 (7.4)</td>
</tr>
<tr>
<td></td>
<td>13.2 (12.3)</td>
</tr>
<tr>
<td></td>
<td>9.3 (9.1)</td>
</tr>
<tr>
<td></td>
<td>4.8 (5.7)</td>
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<tr>
<td></td>
<td>4.1 (4.9)</td>
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Questions?

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LEADING IOWANS IN CARING FOR OUR NATURAL RESOURCES