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# Controlled Discharge Lagoon Effluent Data Study
# Bacteria & Ammonia vs. Number of Cells
# Iowa Department of Natural Resources – Wastewater Engineering

## Background

The Iowa Wastewater Facilities Design Standards (IWFDS) establish minimum criteria for controlled discharge lagoons. Chapter 18C of these standards, first adopted in 1979 and amended in 1986 and 1987 requires a minimum of three cells for all facilities with a total surface area greater than one acre. In 1995 a "Small Community Pilot Projects" program was instituted allowing, among other things, the design and construction of two cell systems as a "Value Engineering" concept for unsewered communities. Applicants proposing two cell controlled discharge lagoon (CDL) systems would still be required to apply for a variance from the design standard on a project-by-project basis. However, it was explicitly understood that such variance requests would be approved provided that "control structures are installed and the system is always operated as a controlled discharge lagoon facility" and that other applicable design standards including minimum storage volume and maximum primary cell loading rate were met.

Over 40 variance-approved 2-cell CDL systems have been constructed to-date, with an additional number currently proposed or pending construction. Historically, the IDNR has not considered or included water-quality-based effluent limits for ammonia or bacteria in NPDES permits for CDL facilities based on previous studies which concluded that water quality criteria for these parameters would not be violated by lagoon facilities with adequate design, operation and sufficient detention time. Changes in the State water quality standards as well as wasteload allocations resulting from TMDLs and concerns from EPA have prompted the department to revisit the issue. Although bacteria or ammonia effluent limits are not currently included in CDLs, monitoring for these parameters is now required.

Available engineering literature demonstrates that bacteria removal in lagoon systems is primarily dependent on actual detention time, the number of cells in series operation, and water temperature. If both 2 and 3-cell systems are provided with equal total detention times and operated in series, then theory indicates that 3-cell systems should be capable of greater bacteria removal. Perhaps the most common method of estimating bacteria removal through lagoon systems uses a 1$^{st}$ order CSTR equation which does in fact predict significantly greater removal efficiency for 3-cell facilities (see Figure 1). However, flows through a controlled discharge lagoon system may be far from an idealized CSTR flow regime and three-cell CDLs typically retain the capability and operational flexibility to operate the secondary cells in a parallel or series mode.

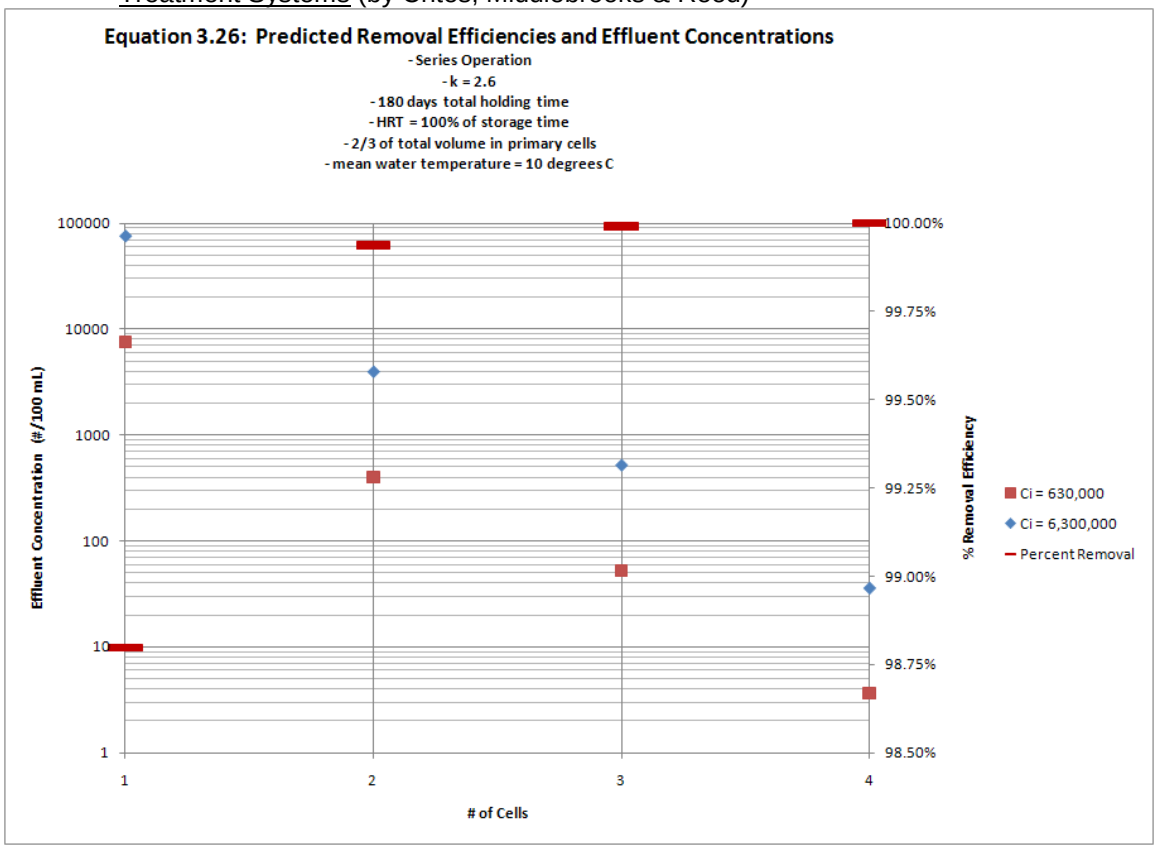
## Purpose

567 IAC 64.2(9) "c" states:

> Variances from the design standards and siting criteria which provide in the judgment of the department for **substantially equivalent or improved effectiveness** may be requested when there are unique circumstances not found in most projects. The director may issue variances when circumstances are appropriate.

The purpose of this paper is to evaluate observed bacteria and ammonia removal performance of CDLs as a function of the number of cells, with particular attention to relative performance of 2-cell variance approved systems vs. 3-cell systems constructed in accordance with current provisions of the IWFDS. This and other information will be used to evaluate and consider whether or not the department should continue to grant variances for 2-cell CDL configurations while weighing the water quality impact.

Figure 1: Theoretical Bacteria Removal Efficiencies Using Equation 3.26 of Natural Wastewater Treatment Systems (by Crites, Middlebrooks & Reed)




## Previous Efforts and Data Sources

The DNR established a Controlled Discharge Lagoon Committee in 2005 to examine the performance of a number of controlled discharge lagoon systems. Special sampling was conducted at 29 lagoon facilities in the fall of 2005 and spring 2006. The facilities were classified by construction date (i.e. constructed to current design standards), whether they were considered hydraulically overloaded and by whether they were considered to be properly operated. In general, the results of this study indicated that 3-cell systems constructed in accordance with current design standards that provide approximately 180-days of detention and are properly operated would not violate bacteria or ammonia water quality criteria. However, no samples were taken from variance-approved 2-cell CDLs as part of this study.

In 2009 and 2010 another set of special sampling was conducted focused solely on variance-approved 2-cell CDLs. A total of 62 samples from Fall 2009 and Spring 2010 discharge periods were taken from 36 individual facilities statewide and analyzed for E. coli and ammonia. This data indicated a significant difference in performance between the 2-cell systems and previous results for 3-cell facilities observed in the 2005-2006 sampling. The data from both the 2005-2006 and 2009-2010 sampling efforts is summarized in Figures 2 through 5.

Figure 2: E. coli Statistics from 2005, 2006, 2009 and 2010 Sampling

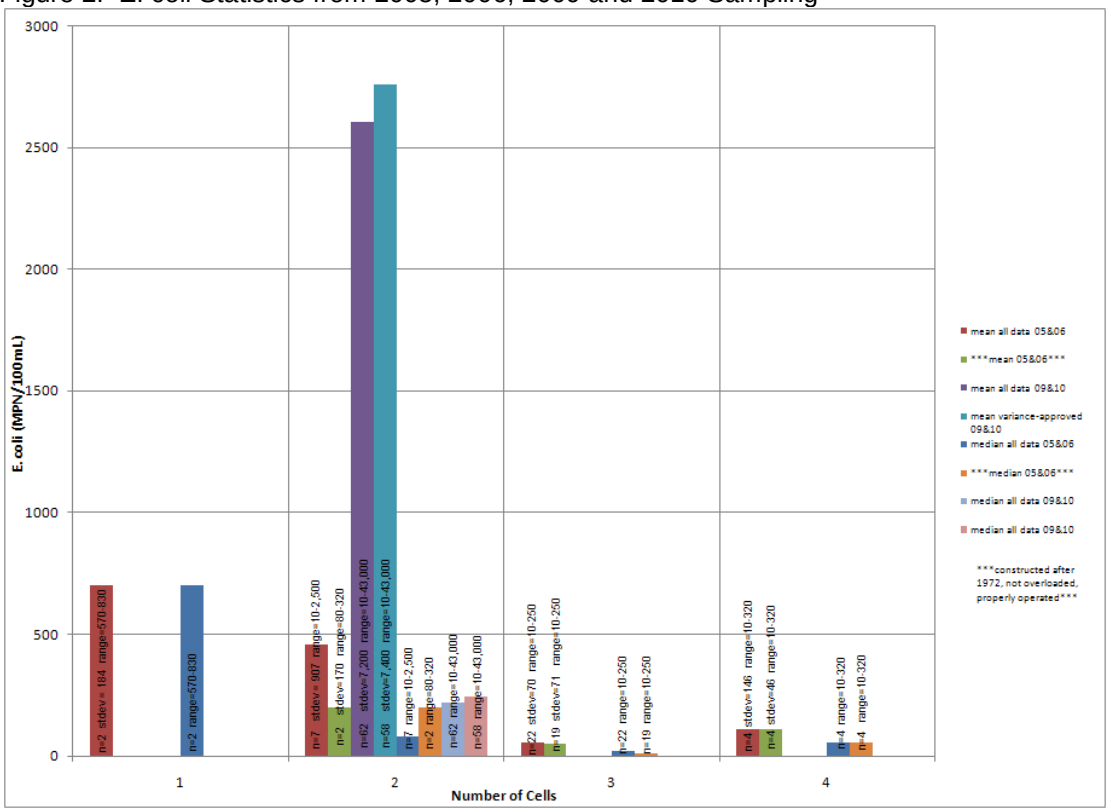



Figure 3: Ammonia Statistics from 2005, 2006, 2009 and 2010 Sampling

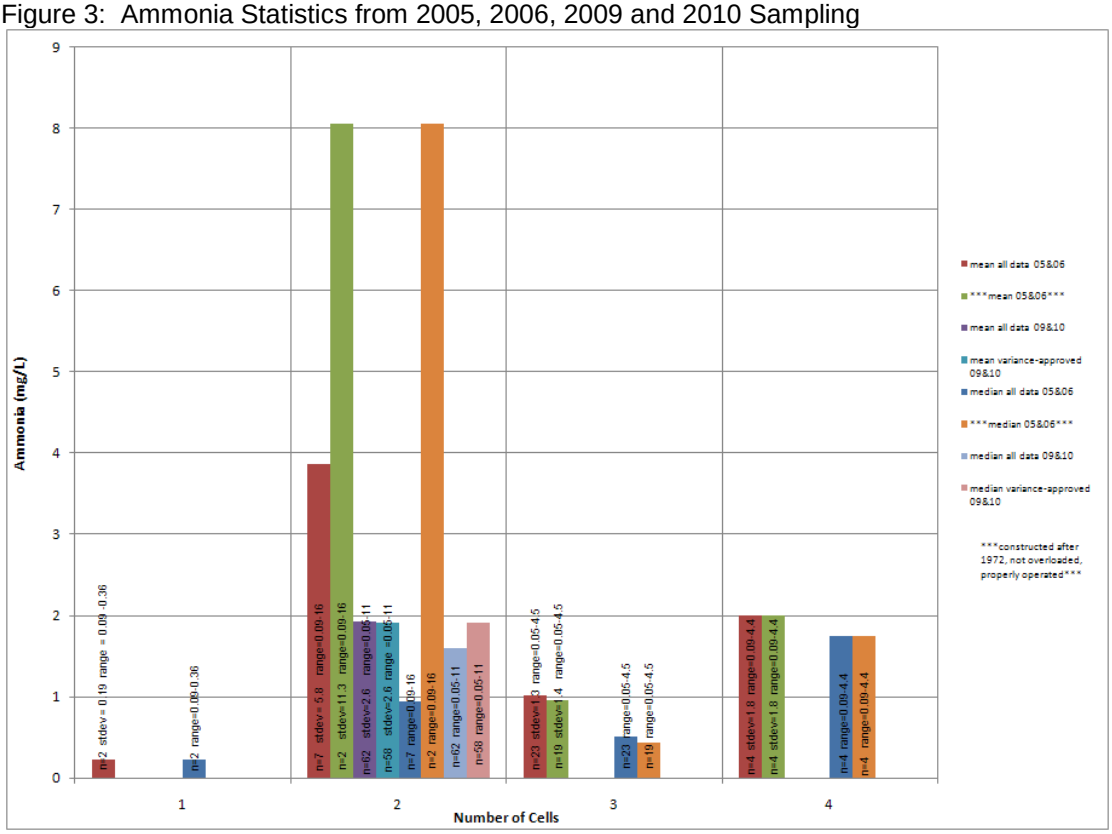


Figure 4: Individual E. coli Sample Results from 2005, 2006, 2009 and 2010 Sampling

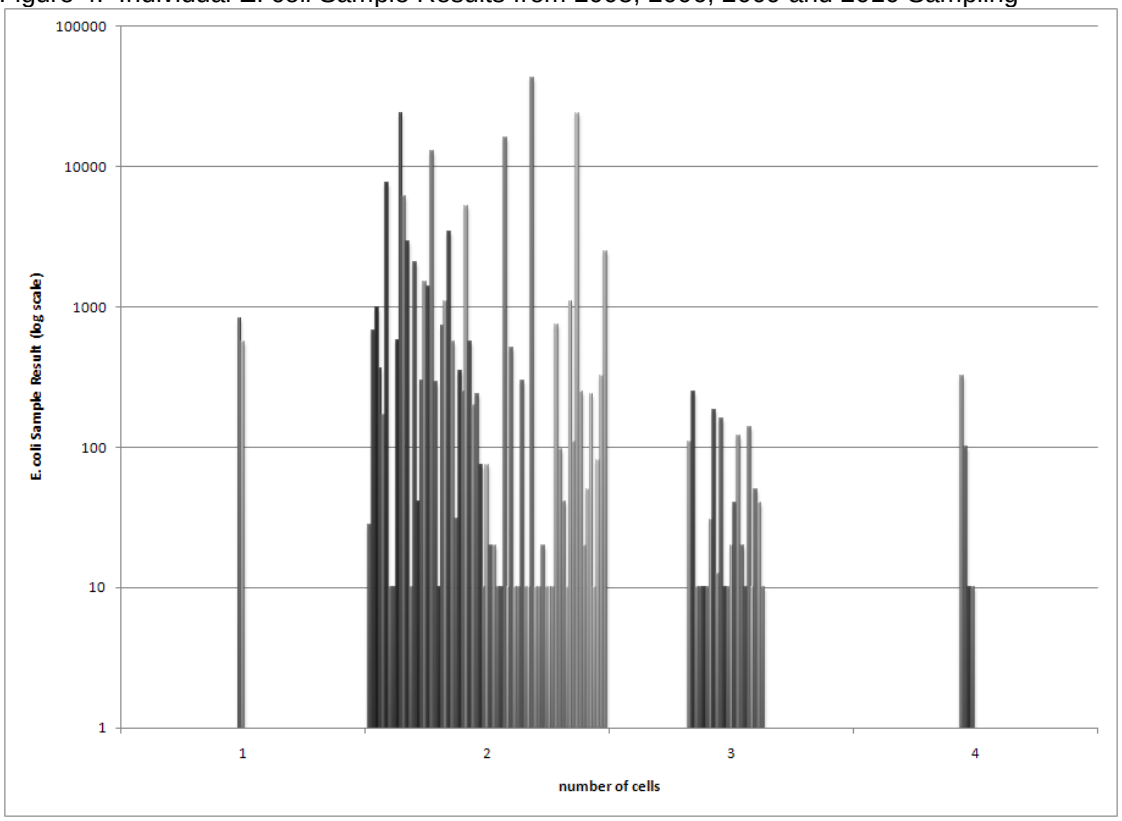
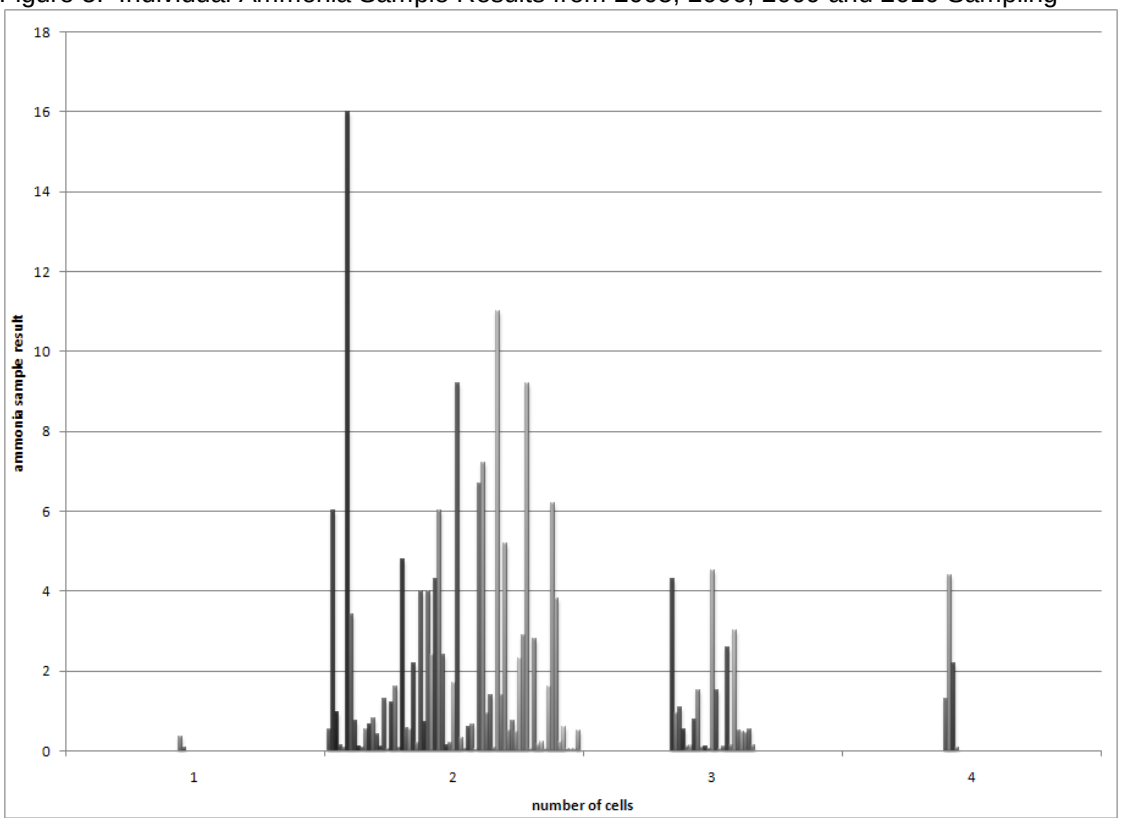



Figure 5: Individual Ammonia Sample Results from 2005, 2006, 2009 and 2010 Sampling



Recent Data

Beginning in April 2009 following rule changes to 567 IAC Chapter 63 – Monitoring, Analytical and Reporting Requirements, the department began reissuance of NPDES discharge permits to controlled discharge facilities with new monitoring requirements for bacteria and ammonia. Monitoring records for CDL facilities with bacteria and ammonia monitoring included in their discharge permits were retrieved from the DNR's NPDS database up to January 2011 for this evaluation. Industrial and semi-public lagoon facilities were excluded and the data was sorted according to the number of lagoon cells, and whether the lagoons were constructed after the effective date of current design standards (1979). A summary of the data set is given in the table below.

Table 1: Reported CDL Ammonia and Bacteria Monitoring (to 1/27/11)

| | All Data by Number of Cells | | | | Total | Post 1979 Construction by Number of Cells | | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | | 1 | 2 | 3 | 4 | |
| Facilities | 3 | 16 | 33 | 2 | 54 | 0 | 10 | 27 | 2 | 39 |
| Facilities with Reported E. coli Results | 3 | 15 | 30 | 2 | 50 | 0 | 10 | 24 | 2 | 36 |
| Facilities with Reported Ammonia Results | 3 | 12 | 31 | 2 | 48 | 0 | 7 | 25 | 2 | 34 |
| Number of E. coli Samples | 5 | 55 | 98 | 9 | 167 | 0 | 34 | 83 | 9 | 126 |
| Number of Ammonia Samples[1] | 6 | 36 | 91 | 6 | 139 | 0 | 20 | 77 | 6 | 103 |

[1] "Ammonia Samples" are monthly average ammonia results for the individual facilities. In some instances, more than one sample was taken to derive the monthly average.

Bacteria Results

Summary statistics including the median, mean, maximum (error bar) and upper and lower quartiles for all E. coli samples sorted by the number of lagoon cells are shown in Figure 6. Reported "non-detects" were assigned a value of 1 for the purposes of statistical evaluation. The same statistics for a subset of this data including only facilities constructed after 1979 are shown in Figure 7. Note that all 2-cell CDLs constructed after 1979 are variance-approved configurations.

Exceedance percentages for 2 and 3-cell CDLs from the same data set are shown in Figures 8 and 9.

Observations/Notes:

- The results from NPDES monitoring data show a distinct difference in effluent bacteria concentrations between 2-cell and 3-cell systems, consistent with the previous 2005-2006 and 2009-2010 data.

- The magnitude of performance difference (approximately one order of magnitude) for observed values between 2 and 3-cell systems is close to that predicted by theory for both median values and the exceedance values. For example, the median values for post-1979 2 and 3-cell systems are 534 and 35 #/100 mL, respectively. At an influent concentration of 1.343E6 #/100 mL the predicted effluent for a 2-cell configuration under the conditions stated in Figure 1 is 534 #/100 mL while that predicted for a 3-cell system is 70 #/100 mL.

As another example, for post-1979 facility samples a calculated exceedance value of 30% (70$^{th}$ percentile) corresponds with 2 and 3-cell sample values of 1,670 and 110 #/100 mL, respectively.

- Very few samples for either 2 or 3-cell systems exceeded a value 10,000 #/100 mL irrespective of when they were constructed. However, at lower threshold values the relative performance gap increases. An approximate 20% difference in sample exceedance is shown for 1,000 #/100 mL and a 35 - 40% gap is present at 100 #/100 mL.

- Sample ranges for all cell configurations exceeded those found in the previous data. No attempt was made to discern whether the facilities included in the NPDES data set are hydraulically or organically overloaded, or what their modes of operation or discharge were during the time preceding or during discharges.

Figure 6: Box Plot of All E. coli Data by Number of Lagoon Cells

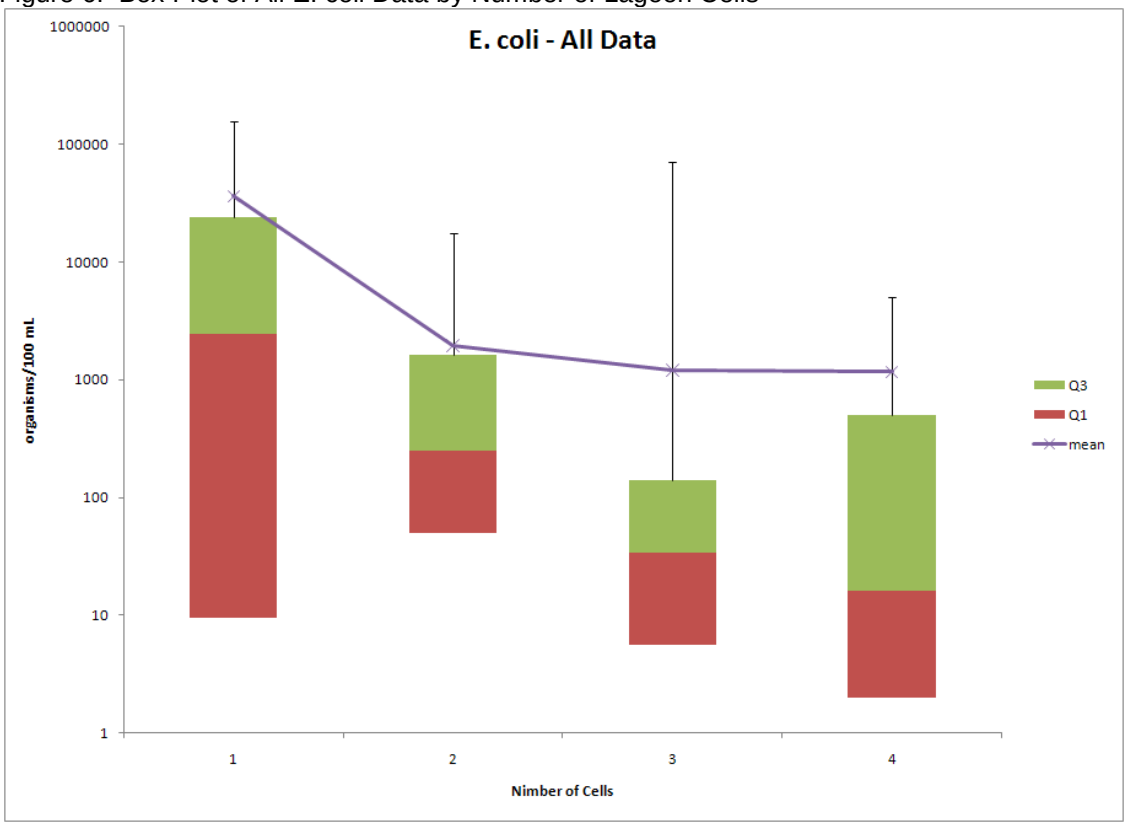


Figure 7: Box Plot of E. coli Data by Number of Lagoon Cells - Constructed After 1979

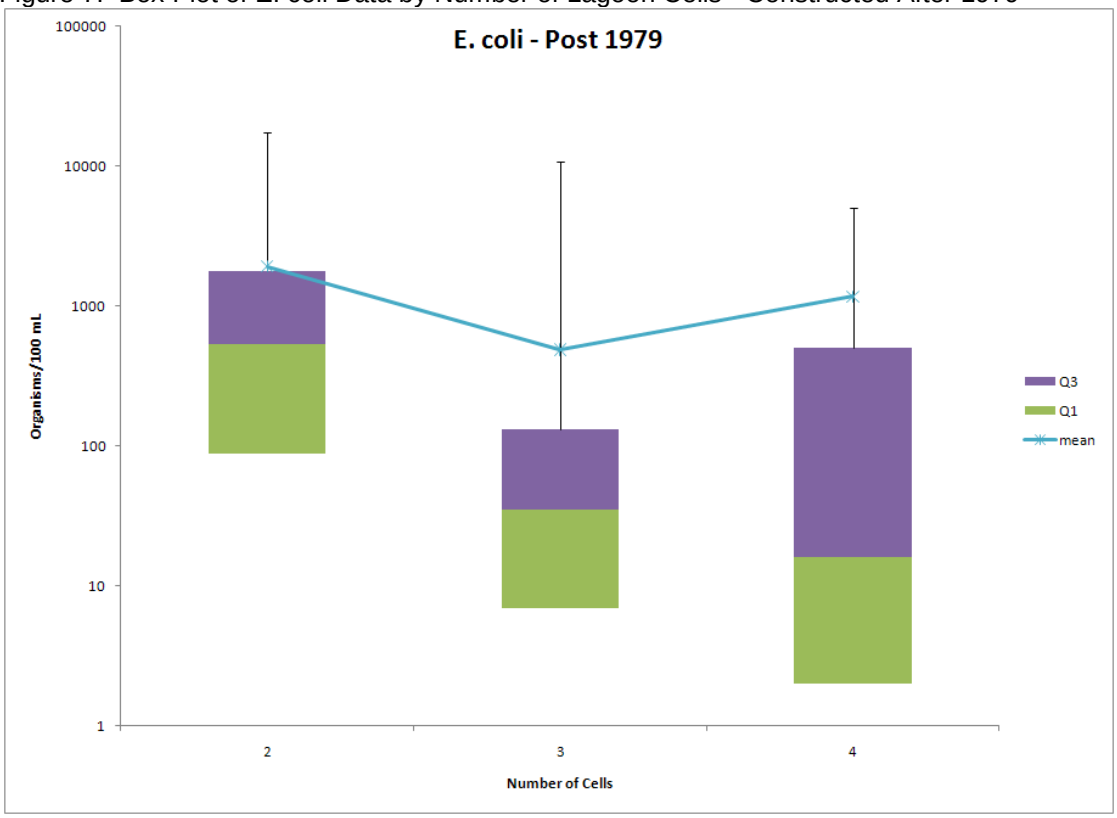



Figure 8: Exceedance Percentages for All 2 and 3-Cell Sample Values

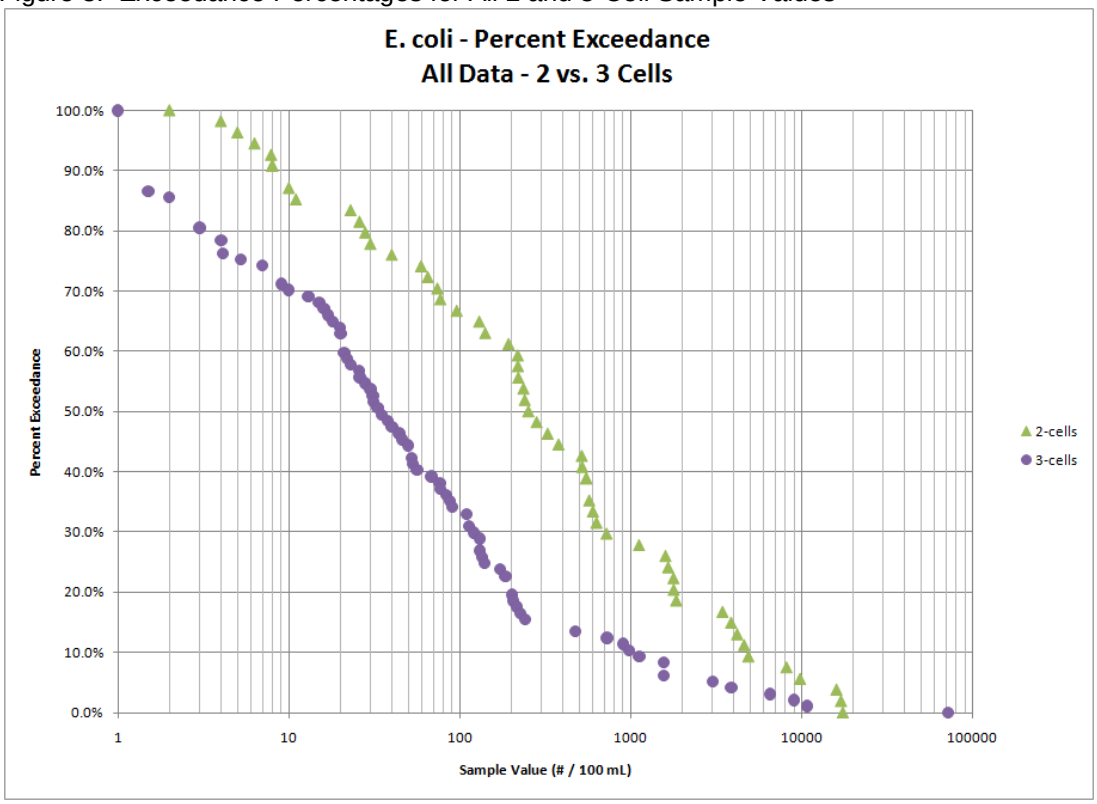
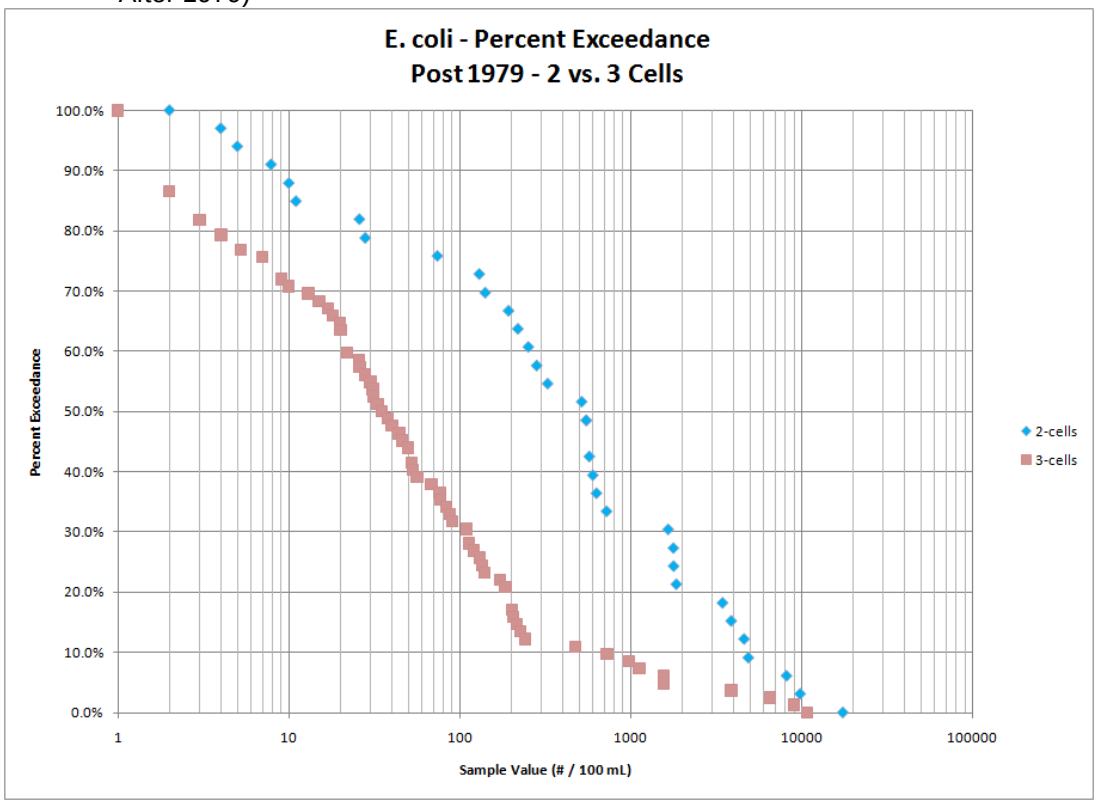


Figure 9: Exceedance Percentages for 2 and 3-Cell Sample Values (CDLs Constructed After 1979)




Ammonia Results

Summary statistics for all ammonia samples sorted by the number of lagoon cells are shown in Figure 10. Note that an "ammonia sample" for the purposes of this evaluation is the facility's reported monthly average which may or may not consist of average results from more than one physical sampling event. Reported "non-detects" were assigned a value of 0.1 for the purposes of statistical evaluation. Statistics for the post-1979 subset are shown in Figure 11 and exceedance percentages are shown in Figures 12 and 13. Again, all 2-cell CDLs constructed after 1979 are variance-approved configurations.

Observations/Notes:

- The general trend of increased performance for 3-cell vs. 2-cell systems observed from 2005-2006 and 2009-2010 data is also reflected in the NPDES data set.
- The median value from the NPDES data set for 2-cell variance approved systems is significantly less than that observed in the 2009-2010 sampling (0.44 vs. 1.9 mg/L).
- The performance of 4-cell systems is worse than one would expect (higher average and median values than 3-cell CDLs). However, this is likely attributable to the small number of 4-cell facilities with ammonia monitoring data (3 total, 2 constructed after 1979).
- Both 2 and 3-cell systems appear capable of achieving low effluent ammonia concentrations. Sample values from 2-cell systems exhibit greater variability,

consistent with the observed data from previous years, although a greater maximum value was observed for 3-cell samples.

- Again, no attempt was made to discern whether the facilities included in the NPDES data set are hydraulically or organically overloaded, or what their modes of operation or discharge were during the time preceding or during discharges.

Figure 10: Box Plot of All Ammonia Data by Number of Lagoon Cells

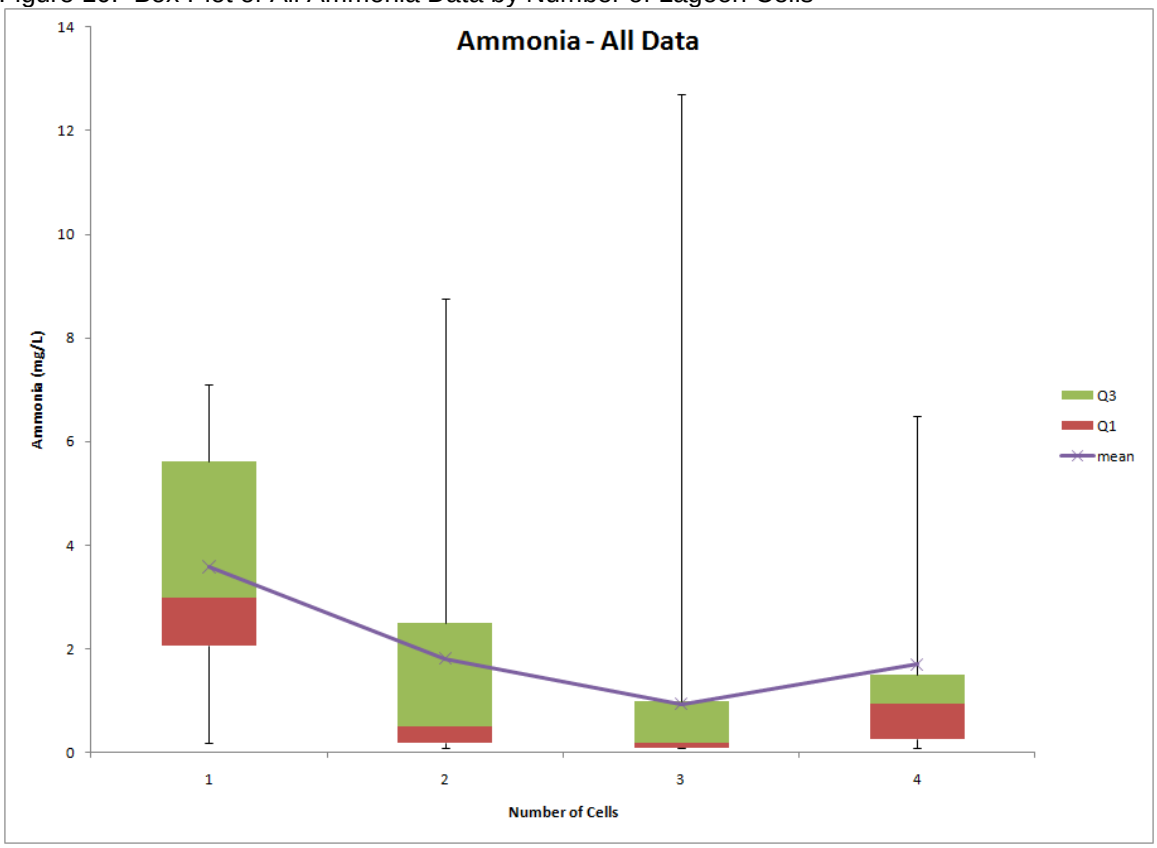


Figure 11: Box Plot of Ammonia Data by Number of Lagoon Cells - Constructed After 1979

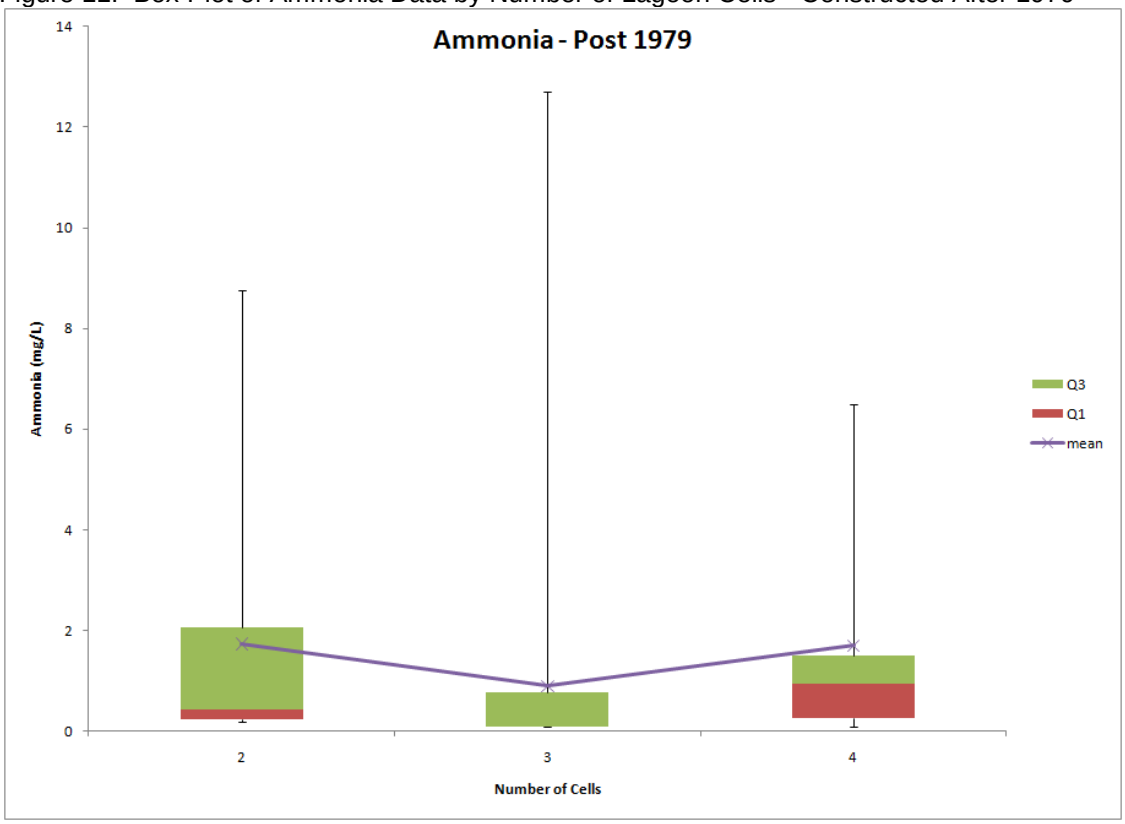



Figure 12: Exceedance Percentages for All 2 and 3-Cell Ammonia Sample Values

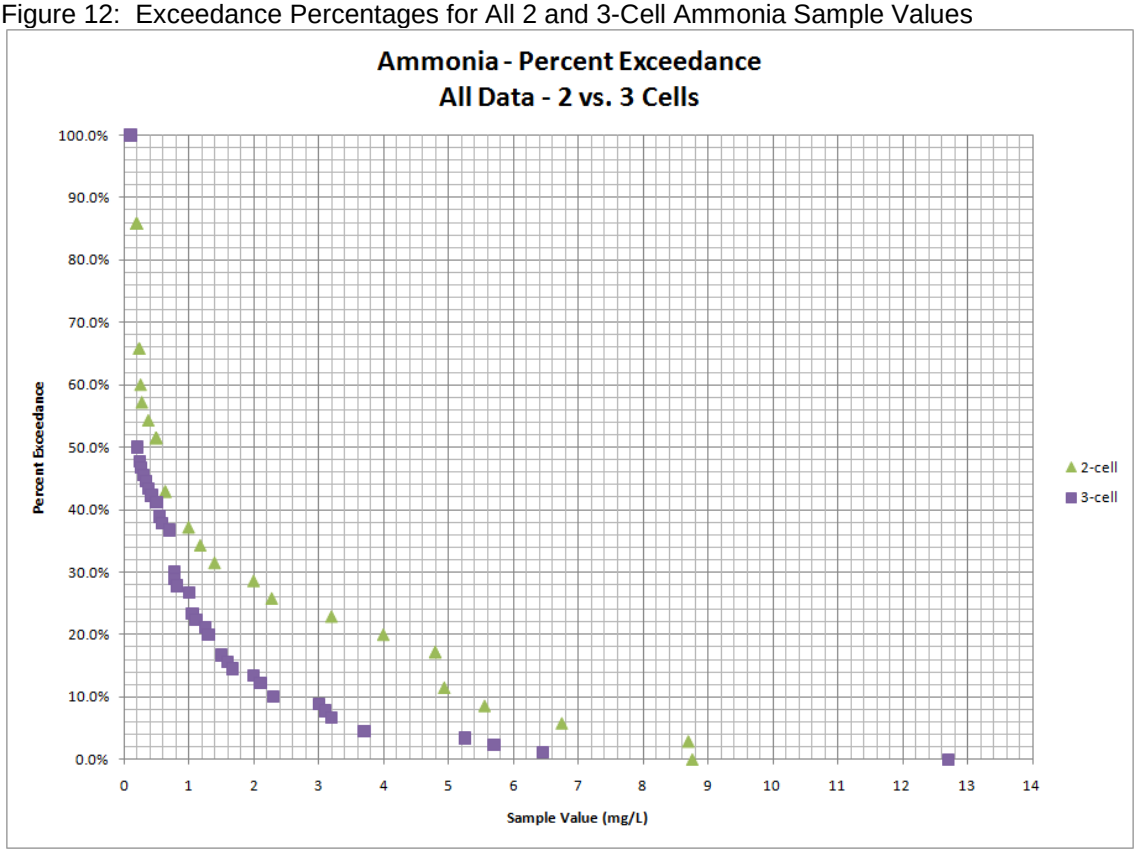
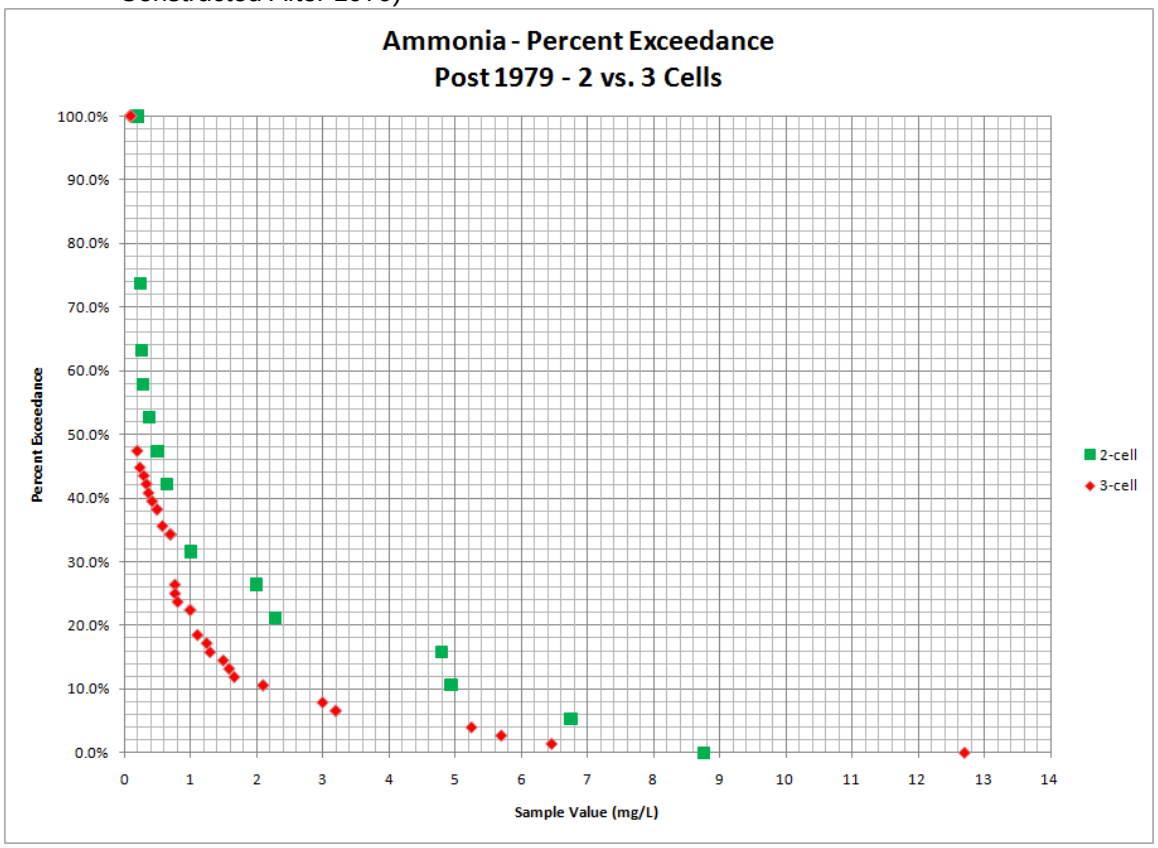


Figure 13: Exceedance Percentages for 2 and 3-Cell Ammonia Sample Values (CDLs Constructed After 1979)




## Conclusion

The NPDES data confirms a performance gap for both effluent bacteria and ammonia between 2-cell and 3-cell systems. While more effort could conceivably be expended to discern whether or not each facility in the data set is hydraulically or organically overloaded, doing so is unlikely to yield different results. The results from both special sampling efforts and NPDES reported data are in general agreement and the total sample size from this and previous sampling efforts should outweigh any effects from individual outliers (124 and 120 2-cell and 3-cell bacteria samples, 105 and 114 2-cell and 3-cell ammonia samples &106 separate CDL facilities sampled). Assessment of whether or not facilities are properly operated is a subjective determination since there are few operational requirements established in rule or NPDES permits.

With respect to relative performance for bacteria and ammonia, the data evaluation clearly demonstrates that 2-cell CDL facilities do not perform as well as 3-cell facilities. If bacteria and ammonia removal are considered measures of effectiveness, then 2-cell CDL facilities do not provide substantially equivalent or improved effectiveness compared to 3-cell CDL facilities.