Iowa DNR Wastewater Treatment Technology Assessment No. 09-01

Evaluation of Full-Scale LemTec Biological Treatment Facilities for Wastewater Design Review Considerations by the Iowa Department of Natural Resources January, 2010

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Background – General LemTec Process Description

Lemna Technologies offers a LemTec biological treatment process that uses covered earthen structures that includes a series of aerobic cells followed by a covered settling cell. An attached growth media reactor, commonly termed a Lemna Polishing Reactor (LPR), is sometimes used after the settling cell to enhance biological treatment. Cells in series consist of one or several complete-mix aerated cells and/or one or several partial-mix aerated cells and a settling cell. Cells are generally covered by LemTec Modular Insulated Covers. The LPR process is a patented, fixed film reactor consisting of aerated, submerged, attached growth media modules.

Aeration and mixing in aerated cells are provided by a combination of fine bubble diffusers and/or floating mechanical mixers. According to full-scale performance reports that have been provided by Lemna Technologies, complete-mix aerated cells are provided with mechanical mixing power ranging from 13.4 to 30 horsepower per million gallons (HP/MG) provided by mechanical surface aerators or 0.12 standard cubic feet per minute per square foot (SCFM/SF) provided by diffusers. Mixing energy in partial-mix aerated cells is supplied by 6.7 to 8.0 HP/MG mechanical aerators and by 0.01 SCFM/SF diffusers.

Biosolids are not recirculated within the treatment system. As described by Lemna Technologies, sludge handling efforts have been confined to the settling cell and desludging of the settling cell is reportedly not required for 6 to 8 years. Full scale systems have been in operation for several years in other states.

The LemTec Modular Insulated Cover System is a floating cover system used for insulation, odor elimination and algae control. This system is comprised of individual casings of closed-cell insulation sealed between two sheets of durable geomembrane. The manufacturer reports that insulation R-factors are offered ranging from 4 to 20.

New Process Analysis for DNR approval

Iowa Wastewater Facilities Design Standards (IA 14.4.3), state that the Department encourages rather than obstructs the development of new methods or equipment for treatment of wastewater. The Department of Natural Resources (Department) may approve wastewater treatment processes and equipment other than those for which design standards are provided under the condition that the operational reliability and effectiveness of the process or device shall have been demonstrated with a suitably-sized prototype unit operation at its design load conditions. Various forms and design basis of LemTec processes have been approved in Iowa and some other states.

The purpose of this document is to evaluate operating LemTec facility information and establish minimum design guidance and criteria that can be accepted by the Department for the LemTec Biological Wastewater Treatment Process based on the New Process Evaluation requirements as outlined by IA 14.4.3. Due to lack of available performance data under design load conditions for operating facilities, this process evaluation and design guidance is based on data provided to or obtained by the Department for a number of full-scale operational treatment facilities at various locations in the Midwest (see Map 1) at their current operating conditions. The evaluation is limited by the quality and quantity of available data and also by the various unit process combinations in different LemTec applications. This evaluation will be subject to updates as further information becomes available. One of the primary goals of the evaluation is to identify criteria consistent with observed cold weather nitrification capability. Adherence to design guidance set forth in this document does not constitute a guarantee of process performance by the Department.

Facilities Evaluated

Lemna Technologies has recently submitted four Process Evaluation Reports to the Department for LemTec wastewater treatment facilities located in Plymouth, IL, Springerton, IL, Jasonville, IN, and Wittenberg, WI. Locations can be seen in Map 1. Process Evaluation Reports had been submitted previously for full-scale facilities at Brownsville, WI and Poplar, WI. These reports, which include process design parameters, design layouts, sampling and monitoring data, provided the data and technical information for evaluating this relatively new wastewater treatment process, as required by Iowa Wastewater Treatment Design Standards, IA14.4.3. The department also contacted some of the state approval agencies and facility personnel directly. All information gathered was considered in this evaluation. Special site visits were not made by the Department.

In addition to the six full-scale facilities that were described in the Process Evaluation Reports, three other LemTec process facilities that have recently been approved in Iowa are also evaluated here with monitoring data collected at each site since the beginning of their operation. The Iowa facilities are located at Strawberry Point, Sheffield and Wheatland. Full-scale performance data from these Iowa facilities not only provide further data for new process evaluation, but also provide process and performance verification of the design basis of these Iowa facilities. They were approved prior to this evaluation and without the information from all facilities in other states.

Various LemTec Unit Process Design Configurations

The term “cell” is used in this document to designate the individual “unit” process of the total LemTec Biological Treatment Facility. The term “pond” is used to describe the individual earthen structure that is enclosed by embankments. A pond can include more than one cell separated by baffles.

In the full-scale facilities that have been evaluated, different process diagrams existed. For example, some facilities used only partial-mix aerated cells in series while some facilities used one or two complete-mix aerated cells in series followed by one or two partial-mix aerated cells, and a settling cell. Four facilities had an LPR unit after the settling cell for the reported purpose of providing or improving nitrification.

“Complete-mix” and “partial-mix” are different biological unit processes. In a complete-mix cell, an aerobic condition is maintained at all times at all locations and solids are kept suspended at all times. In a partial-mix cell, the upper layer is aerobic, while some solids settle and anaerobic degradation of the organic matter may occur. Biodegradable organic matter conversion into gases or cell tissues and biological nitrification rates are much faster in a complete-mix cell than in a partial-mix cell because of thorough mixing. Aeration cells operate with suspended solids, whereas the LPR submerged fixed film media reactor is another type of biological unit process using similar mechanisms as a trickling filter or a rotating biological contactor. It uses a submerged attached growth media which maintains a population of bacteria on the media to oxidize BOD and to nitrify.

Each full-scale facility evaluated had selected combinations of different unit processes in response to unique treatment objectives. The process variations are summarized in the second column of Table 1. The process descriptions show only the main treatment process without noting any required pretreatment. The main process description also does not differentiate whether the complete or partial mix cells are separated by earthen dikes or baffle walls since the dividing structure is considered to affect only operational reliability and flexibility. The impacts of cell division structures on temperatures were not evaluated. For all facilities evaluated, unit processes are assumed to have been operated in series. Therefore, no performance of operation in parallel is provided. It was observed that there were typically three aerated cells, comprised of partial-mix or combinations of complete-mix and partial-mix regimes being used in the treatment systems. Some of the LemTec applications are retrofits, making use of existing earthen cells. This resulted in some variability of unit sizing and flexibility.

Among evaluated facilities, there are four facilities using partial-mix cells only (Brownsville, WI, Plymouth, IL, Springerton, IL, and Jasonville, IN). Except for the Brownsville facility, the facilities all have LPR after the settling cell. The Brownsville aerated cells and settling cell are followed by another kind of attached-growth reactor, RBC, and a rapid sand filter.

Wittenberg, WI, Poplar, WI, and Iowa plants at Strawberry Point, Wheatland and Sheffield, have at least one complete-mix cell that is always the first cell, and at least one partial-mix cell. The Poplar facility has two complete-mix cells operated year round. The first complete-mix cell at Wittenberg is a full time complete-mix cell throughout the year, while the second aerated cell is operated as a complete-mix cell in winter and is operated as a partial-mix cell in summer. The three referenced Iowa facilities have operated for only one to two years, and were designed with a similar process flow diagram having one complete-mix cell followed by two partial-mix cells. Sheffield was the only LemTec plant in Iowa with stringent ammonia nitrogen limits and was granted a design variance for a configuration including only one independent complete mix cell. Wittenberg and Poplar, WI, both have supplementary treatment after the settling cell not included at the Iowa facilities. Poplar has LPR following the LemTec settling cell. At Wittenberg, after the settling cell, existing sand filters were retained for additional treatment in preparation for lower effluent limits according to Lemna. A new line has also been constructed which allows the direct discharge of effluent bypassing the filtration system. Reportedly, the filters have not been used to date. No LPR units were used at the three facilities in Iowa, where ammonia limits were not stringent at the time they were constructed.

Limits for the facilities that have nitrification requirements are shown in Table 1. Neither Brownsville nor Poplar has ammonia limits as NPDES permit requirements. But Brownsville, with RBC and sand filter after aeration cells, was designed to meet 2 mg/L ammonia nitrogen in final effluent. Plymouth, Springerton and Jasonville have more stringent effluent limits than other facilities. They all selected the same process, which is three partial-mix cells in series plus LPR units. Those facilities with one or two complete-mix cells but without LPR have been typically selected and designed to meet ammonia nitrogen limits that are less stringent than those facilities with LPR units.

Lemna Technologies reports that the choice of partial-mix and complete-mix can be based on varying cost factors such as existing lagoon sizes, available power supply or siting concerns.

Design hydraulic retention times (HRT) shown in Table 1 were calculated by using cell volume divided by design annual average flow. In Iowa, design flows for Strawberry Point, Wheatland and Sheffield were based upon the aerated lagoon design hydraulic loading equation in Chapter 18C.4.1. That is the average dry weather flow (ADW) plus 30% of the 30-day average wet weather flow (AWW-30) flow in excess of the ADW flow, or 100 gpcd, whichever is greater. From flow statistics, the design flow estimated from the aerated lagoon equation is comparable to annual average design flow. The HRT of each cell at each facility has been compiled in Table 1. Design HRT of aeration cells for the facilities with complete-mix cells is generally shorter than those without, except for Sheffield that utilized existing lagoon structures and has stringent ammonia nitrogen limits.

As mentioned, the full scale operations evaluated consist of differing combinations of processes selected for unique objectives. It is a challenge to compare this variety and provide a conclusive summary of design expectations for each with limited data.

LemTec Full-Scale Facility Performance Evaluation

Raw Wastewater Quality

The raw wastewater quality of all facilities is comparable to typical municipal wastewater. However, some exceptions were found, particularly with high BOD_5 influent. Springerton, IL, had BOD_5 influent increased to a range of 400 mg/L to 1125 mg/L from May 2007 to July 2007. The cause was unclear. Another period of abnormally high BOD_5 influent was found in the Poplar facility, which had an average of 930 mg/L in monthly average from June 2007 to March 2008. The Village of Poplar believes the average loadings reported to the State of Wisconsin are skewed higher than they should be with the high concentrations attributed to influent samples which included cleanup waste one day per week at a local industry. The Village of Poplar had reportedly accepted septage for a time but no longer received septage during this monitoring period. Data after March 2008 for Poplar has not been received. Lemna Technologies claims these loading rates exceeded what they consider the design parameters.

Effluent Limits Requirement

The secondary effluent limitations in the National Pollution Discharge Elimination System (NPDES) for the LemTec facilities in Iowa are as follows:

- Carbonaceous BOD_5 ($CBOD_5$) shall not exceed a mean of 25 mg/L and 40 mg/L for effluent samples collected over 30 and 7-day consecutive periods, respectively. The 30-day average percent removal shall not be less than 85 percent.

- TSS shall not exceed a mean of 30 mg/L and 45 mg/L for effluent samples collected over 30 and 7-day consecutive periods, respectively. The 30-day average percent removal shall not be less than 85 percent.

- The effluent pH value shall be within the limits of 6.0-9.0.

Ammonia effluent limits vary from the most stringent end-of-pipe limits to relatively relaxed limits depending on stream designation, stream flow and other factors. Tables 3 shows an example of end-of-pipe ammonia limits for a LemTec covered aerated lagoon in Iowa.

Monthly or weekly performance data from each facility are presented from Figure 1 to Figure 9. In addition to performance data for the plant effluent, for better understanding of the unit processes in LemTec treatment, Poplar has collected transectional performance data from each unit operation, see Figures 10 to 12.

Secondary Limits Performance Evaluation

In general, it is evident that the LemTec process can meet secondary limits. Occasional $CBOD_5$ violations have been observed. Performance has been monitored in Poplar, WI, since June 1999. Figure 6 depicts $CBOD_5$ and TSS performance from January 2003 to March 2008. Poplar does not have long term ammonia effluent data because ammonia limits are not included in its NPDES permit. Five years of Poplar performance data showed that the $CBOD_5$ 30-day average limit was violated frequently from December 2005 to March 2008, with a total of 14 violations. During the same period, there were three violations of TSS effluent limit. Figure 6 also shows a general trend of gradual increases of the final effluent concentrations in $CBOD_5$ and TSS following settling. It was reported by plant personnel that the facility had recently experienced problems of too much solids in the settling cell and plugging of the LPR media.

How this Poplar trend relates to a period of septage loading which ended in Spring ’07 or reported industrial spike loading is unknown. Sludge build-up or deviating from recommended sludge removal schedules could also be involved. Wisconsin DNR requested a plant evaluation and an action plan to be done for the facility. Even though Poplar has no ammonia effluent limit, the difficulty of the LPR operation is most likely indicative of loading problems.

Springerton, IL, had one report of $CBOD_5$ effluent exceeding its monthly limit of 25 mg/L, see Figure 3. This may relate to the influent loadings shown in Figure 3. Wheatland, IA, had two months of TSS violations, see Figure 9. The other facilities appear to have no problems meeting secondary effluent limits.

Poplar, WI, and Brownsville, WI, have data for showing secondary effluent parameters (BOD and TSS) after aerated and settling cells as well as after attached growth media (LPR). See Figures 1, 10, and 11. From Figure 1, it can be seen that the partial-mix cells alone were not enough to meet standard secondary limits in Brownsville. The RBC process has to be relied on for further treatment. At Poplar, BOD and TSS removal have been completed by two complete-mix cells, a partial-mix cell and a settling cell.

Ammonia Nitrogen Limits Performance Evaluation

As described previously, RBC and a rapid sand filter were provided following Brownsville's partial-mix LemTec process to meet 2 mg/L of ammonia nitrogen. Figure 1, Brownsville Performance Data, shows $CBOD_5$, TSS and ammonia nitrogen effluent after the LemTec settling cell versus the plant final effluent. After the settling cell, Brownsville ammonia nitrogen effluent did not meet 2 mg/L. The average ammonia nitrogen concentration after settling is 12.3 mg/L. At the plant final effluent, the ammonia nitrogen has been reduced to an average of 0.05 mg/L. Even in summer months, the partial-mix cells alone did not dependably treat ammonia nitrogen to 2 mg/L. For instance, Figure 1 shows that the ammonia nitrogen after the settling cell was 6.33 mg/L in July 2001 and 5.25 mg/L in June 2003. The ammonia nitrogen after RBC was 0.04 mg/L and 0.078 mg/L for July 2001 and June 2003, respectively.

The other three facilities that have the same partial-mix unit process as Brownsville (Plymouth, IL, Springerton, IL, and Jasonville, IN), have all met their respective ammonia effluent limits. Most of the ammonia nitrogen effluent values in Plymouth and Springerton are less than 1 mg/L. Most of the ammonia nitrogen effluent values in Jasonville are less than 2 mg/L. The performance can be seen from Figures 2, 3, and 4.

Ammonia nitrogen effluent limits that require 13 mg/L in summer and 16 mg/L in winter for the Wittenberg plant have all been met, see Figure 5. Results from Wittenberg, WI, showed ammonia nitrogen effluent values less than 1 mg/L except for the first three weeks of May of 2006, September and October of 2006 when ammonia nitrogen effluent was more than 1 mg/L. Ammonia effluent levels started to drop gradually down to less than 1 mg/L when operation of the second cell was changed from partial-mix to complete-mix in October, 2006. The Village of Poplar monitored ammonia nitrogen effluent in 2003. Data in Figure 12 display that Poplar's final effluent ammonia nitrogen concentrations are satisfactory and range from 0.06 to 0.38 mg/L.

Data from Strawberry Point, IA, show effluent ammonia nitrogen of less than 1 mg/l from May 2007 to December 2007, but effluent ammonia nitrogen ranged from 2.34 to 9.38 mg/L in colder months from January to March, 2008. Data for the same cold months in 2007 also showed high ammonia nitrogen effluent values, which were between 2.45 to 7.25 mg/L. Strawberry Point may have lower influent temperature than other facilities due to the long storage time of raw waste in the City's north lagoon prior to entering the LemTec system. However, this lagoon may also reduce the impact of peak wet weather flows and also provide some benefit of treatment of the raw wastewater also. Regardless, Strawberry Point met its relatively relaxed average ammonia nitrogen effluent limits (9.4 mg/L summer, 24 mg/L winter) stated in the wastewater construction permit. This demonstrates that care should be used in planning consistent ammonia removal in applications where waste temperature may be lower than normal (10 degrees C)

The City of Sheffield, IA, has provided excellent and consistent ammonia nitrogen effluent quality since the operation started. Performance data show several months of operation at less than 1 mg/L.

Actual HRT Based on Annual Average Flows

In a biological wastewater treatment system, solids retention time is a critical factor for reduction of ammonia nitrogen. Because the LemTec process includes no provisions for biosolids recirculation, solids retention time (SRT) is equivalent to hydraulic retention time (HRT).

Design HRT has been shown in Table 1 for each facility. However, the actual operational HRT under influent hydraulic loading is much longer than the design HRT for every facility. Table 2 summarizes the actual average HRT for each cell as well as for the total aerated cells. Standard deviation of each individual HRT has also been shown to indicate the wide spread of the actual HRT. The longest average total HRT has been found to be 62.7 days in the Springerton, IL, plant. The shortest average total HRT is 17.5 days in Wheatland, Iowa. For one partial-mix cell, the longest HRT is 20.9 days at Springerton (1^{st}, 2^{nd}, or 3^{rd} cell) while the shortest is just 4.9 days at Strawberry Point (3^{rd} cell). For the complete-mix cell, the longest HRT is 9.9 days at Sheffield, IA, (1^{st} cell) while the shortest is just 5.8 days in the summer and 11.6 days in the winter at Wittenberg (1^{st} cell only in summer; 1^{st} and 2^{nd} cell in winter). The last column in Table 2 shows the ratio of actual HRT to the design HRT and indicates that all the facilities have been operated significantly under their design hydraulic loadings.

Wastewater Temperature in LemTec Covered Cells

Water temperature is an important factor in nitrification of wastewater. LemTec Modular Covers offer insulation R-values from 4 to 20. The heat retention characteristics of a covered cell in a cold operating environment have been studied in the Brownsville facility for the winters of 1999 to 2001. The first pond with two partial-mix cells is covered with 25,000 square feet of R-15 cover and has a design total detention time of 10 days at a 10-foot water depth. The second pond with a partial-mix cell and a settling cell is covered with 33,000 square feet of R-10 cover and has a 14-day design detention time. Brownsville’s heat retention study shows that the modular cover can maintain a wastewater effluent temperature with an average heat loss of 4˚C or less from the influent temperature, even operating at detention times longer than their design..

It is assumed that the facilities evaluated are in a region with a similar climate. The covers conserve influent wastewater temperature in winter, and expand the geographic region that earthen-based aerated wastewater treatment can be used and achieve effective ammonia nitrogen reduction. The limited temperature data from Plymouth, IL, Brownsville, WI, and Poplar, WI, show that Brownsville and Poplar winter effluent temperatures are not much less than Plymouth effluent temperature, even though Poplar is about 500 miles north of Plymouth (see Map 1). Plymouth has influent and effluent temperatures from February 2006 to December 2006. Poplar has influent and effluent temperatures from January 13, 2003 to November 13, 2003. Brownsville’s temperature data was monitored from January 2001 to August 2003. At Plymouth, the lowest effluent temperature is 6˚C which occurred in February 2006, while the influent was 8˚C at that time. At Poplar, the lowest effluent temperature is 5.2˚C, which was recorded on January 23, 2003.

Design Review Considerations for LemTec Biological Process

Actual performance data demonstrates the treatment capability of this process. The HRT that was "designed" for each full-scale facility has seldom been realized in actual operation. Therefore, it is unknown whether the level of performance cited in this Evaluation Report for existing facilities will be repeated when the facility is operated under the design loading.

The Process Evaluation Report shows in the design spreadsheet sizing criteria for BOD_5 removal in a complete-mix cell and in a partial-mix cell. For BOD_5 removal design, the commonly used first-order, complete-mix model is used and the BOD_5 reduction coefficient, which is 2.5 d^{-1} for a complete-mix cell and 0.28 d^{-1} for a partial-mix cell, at 20°C standard condition, is used. However, no design basis can be found in the reports of the referenced facilities for ammonia nitrogen removal. The importance of knowing the sizing criteria for ammonia removal is that the size of the aeration cell in a biological process is typically controlled by ammonia removal rather than by BOD_5 removal. Lemna Technologies reports that in their partial-mix systems, the aerated cells were not intended to provide complete nitrification and therefore recommended LPR units as well.

The only basis for ammonia nitrogen removal performance is empirical data. From the full-scale facilities and their performance evaluation, it can be seen that one of the most important features about the LemTec treatment process is that it can be designed by a different combination of its unit processes or of other traditional wastewater processes, depending upon treatment objectives, plant loadings, temperature, site conditions, and etc. Even with the same design process layout, the cells can be covered or open, which can affect not only cell temperature but also nitrogen removal mechanisms.

Since loading conditions for the evaluated facilities have not approached their "design" numbers in sufficient durations to provide meaningful support, it is important to note that the design review of the LemTec wastewater process can only be based on the evaluation of actual performance at actual plant loading rates for the purpose of compliance with the expectations of IA 14.4.3 for new process evaluation. The Department will review a new process design based on the following criteria that were observed from the full-scale performance unless new engineering data, which meets IA 14.4.3 (Required Engineering Data for New Process Evaluation), is presented in the future to justify revision.

1. Hydraulic Retention Time of LemTec Aerated Cells

From various design configurations that were used for full-scale facilities, information is considered adequate for the following two major process layouts. The number of aerated cells is three and they are operated in series.

a) Aeration with Partial-Mix Cells and LPR

Additional treatment (such as LPR) is necessary for significant nitrification when using only partially-mixed cells. Brownsville, WI, Plymouth, IL, Springerton, IL, and Jasonville, IN, all have three covered partial-mix aeration cells in series with no complete-mix cells. As described before, Brownsville has an RBC and sand filter after the aeration cell process while Plymouth, Springerton, and Jasonville all have LPR units at the end. Plymouth, Springerton, and Jasonville have very stringent ammonia nitrogen limits, which are similar to the end-of-pipe ammonia nitrogen limits in Iowa (Table 3). Performance at all three facilities shows very promising ammonia removals, see Figures 2, 3, and 4. However, the information only shows overall performance (in the partial mixed cells and including the LPRs). No conclusion can be made for efficiency of the LPR following only partial-mixed cells since no settling cell effluent quality data is available. On the other hand, with effluent data being collected from a point prior to the RBC, the Brownsville (WI) facility shows that ammonia nitrogen was not reduced enough by only partially mixed aeration cells, see Figure 1. This can only leave inference that the attached growth biofilm process, such as LPR, RBC or sand filter, provides an important and necessary function of nitrification when partial-mix cells are to be designed like these facilities.

The three partially-mixed cells equally sized at 9.4 days HRT each is an acceptable design. Among the partial-mix only facilities, the shortest average total HRT based on annual average actual flow is 28.3 days for all three cells and that was observed from the facility in Jasonville, IN. Jasonville's three equally sized partial-mix cells each provided 9.4 days of actual average HRT. Jasonville's effluent quality is the most consistent even with the lowest HRT of all the partial-mix systems. It is noted that flow equalization reduces the flow variability at this facility. It can be concluded that the LemTec process with three covered partial-mix aeration cells in series followed by LPR should be designed with a minimum of 9.4 days HRT in each cell and 28.3 days total for all three aerated cells. The aeration cell water temperature should not be lower than the 6°C recorded at Plymouth (influent temperature of 8°C) . Three cells should be sized equally. LPR or another kind of attached growth media supplemental reactor shall be provided to achieve ammonia nitrogen removal. A simplified example for partial-mix cells is provided in Appendix I.

Where facilities have more relaxed ammonia nitrogen limits (more relaxed than the limits in Table 3) and choose to use a partial-mix only design, cell sizing based on the following complete-mix cells in series model can be accepted. Even though partial-mix cells are not mixed completely as the model assumes, it is common practice to use the complete-mix model and first-order reaction rate kinetics to approximate ammonia nitrogen removal performance. Before using the complete-mix, first-order model, ammonia nitrogen reaction coefficient in partial-mix aerated lagoon shall be established. The design equation for a series of n equal sized cells is as follows:

$$t = (n/k)\left[(C_0/C_n)^{1/n} - 1\right] \qquad (1)$$

Where C_n = effluent NH_3-N concentration from cell n, mg/L
C_0 = influent NH_3-N concentration to first cell, mg/L
k = ammonia nitrogen reaction coefficient, d^{-1}
n = number of cells in series

Conversion of the reaction rate coefficient to temperature other than 20°C shall be according to the following formula:

$$k = k_{20}\theta^{(T-20)} \quad (2)$$

Where T = cell temperature in °C
Θ = temperature correction factor

The values for k and Θ are unknown and shall be determined experimentally for a covered partial-mix cell reactor or from performance monitoring from partial-mix unit process at design load conditions.

b) Aeration With Complete-Mix Cells

The facilities in Strawberry Point and Wheatland showed inconsistent ammonia nitrogen removal performance. This is not unexpected because the systems were not designed to meet end of pipe effluent limits. These facilities have the lowest HRTs of all evaluated facilities. Therefore sizing information from these two facilities would not be acceptable as a reliable sizing criterion for meeting end of pipe limits.

Design HRT of complete-mix cells will be allowed case-by-case following the activated sludge nitrification kinetics curve in Figure 13. According to Downing, *et al*, if all the biomass in the complete-mix cell is suspended, if DO is maintained at 2 mg/L, if sufficient alkalinity is present, if there are no toxic materials present, and if the influent conditions do not vary significantly, the relationship among effluent ammonia nitrogen concentrations, the temperatures and the hydraulic retention time can be presented in Figure 13. The HRT given by Figure 13 is a minimum HRT and based on ideal conditions. A safety factor (SF) is not included in Figure 13.

At Poplar, WI, after passing through the first complete-mix cell (average HRT of 8.7 days), most of the influent ammonia nitrogen had been reduced to less than 4 mg/L, see Figure 12. After the second complete-mix cell with the same HRT as the first cell, ammonia nitrogen has been reduced to less than 0.2 mg/L. The ammonia nitrogen concentrations in the remaining partial-mix cell, settling cell and LPR unit have nearly leveled off.

The HRT of Poplar's equally-sized complete-mix cells is supported by the basic kinetics of nitrification in activated sludge process. In Figure 13 it can be seen that, at the stated ideal conditions, the effluent ammonia nitrogen can reach 1 mg/L when 8.2 days of HRT is provided in winter. So, with two complete-mix cells each operating at an average of 8.7 days of detention time and a complete-mix regime, ammonia nitrogen removal can be adequately accomplished within the first two cells at Poplar. When this occurs, the nitrifier population and effectiveness of the LPR is unknown.

Wittenberg, WI, data show relatively consistent performance. Low hydraulic variability and changing the operation mode of the second aeration cell in winter to a complete-mix operation logically assisted ammonia nitrogen removal. Total HRT in Wittenberg aeration cells is 23.1 days on average based on annual average flows. Changing the mode of operation of a cell from partial to complete-mix would require additional operational care and attention.

Based on the empirical information and data from operations at both Poplar and Wittenberg, a total aeration cell HRT of at least 23.1 days at annual average flows is acceptable for a LemTec process using three aeration cells in series with at least the first cell being a full-time (year-round) complete-mix cell and the second aeration cell being able to operate as a complete-mix cell in winter. Design HRT of complete-mix cells must depend on cell water temperature and effluent ammonia nitrogen limits on a case-by-case situation by following the curve in Figure 13. A simplified example design for complete-mix cells is provided in Appendix I.

Sheffield, IA, has shown a satisfactory ammonia removal performance with a complete-mix cell providing 9.9 days of actual average HRT. But Sheffield's total actual HRT of 35 days, is the longest among the facilities with complete-mix cells. This, along with a large settling cell could explain the good treatment results.

2. Design Hydraulic Loadings

To meet stringent end-of-pipe ammonia nitrogen limits, operating facility performance indicates that consistent results can be correlated to acceptable HRTs at the Jasonville, IN, partial-mix facility and the Wittenberg, WI, complete-mix facility. It is noteworthy that both facilities have relatively low hydraulic variability. Jasonville's flow variability is likely due to significant flow equalization preceding the process. Wheatland, IA, has fairly low variability also, but it also has the lowest HRT and ammonia nitrogen results are not consistently low. This seems to indicate a preference for low hydraulic variability for optimum process performance. This is consistent with the concern for biosolids retention since the process has no biosolids controls.

a) Aeration with Partial-Mix Cells and LPR

In this process mode, the design hydraulic loading is the design average flow, which is the average of the daily volumes to be received for a continuous 12 month period expressed as a volume per unit time. Alternatively, the design hydraulic loading in IA 18C.4.1.2 for aerated lagoons can also be used for LemTec with partial-mix aeration cells and LPR. This is because the design HRT is derived by averaging the monthly HRT that is calculated by dividing the cell volume by the monthly flow. When design HRT and design hydraulic loading are determined, total aeration cell volume is determined by multiplying the HRT and the design hydraulic loading.

b) Aeration with Complete-Mix Cells

Design hydraulic loading for complete-mix cell is the average wet weather flow. A more refined approach would be to use Figure 13 or the formula (A-1) as shown in Appendix I, with design monthly 30-day average flow needs used for determining the required cell volume.

3. Sizing of LPR Unit in the LemTec Process

There is no performance data showing that the LPR unit has been operated under a "design" load since the LPR is always the last unit process and in the evaluated facilities, most of the BOD and ammonia nitrogen had been treated by the aeration process. Therefore, any loading rate that is calculated from the actual performance data will inevitably underestimate the treatment capability of the installed LPR media. Nevertheless, from the Poplar, WI, facility, the average ammonia removal rate is 0.022 lb. ammonia nitrogen oxidized/1000 ft^2/day at a standard temperature condition of 22˚C. The observed BOD removal is zero. A similar design should be used until more is known about LPR capabilities and design variables.

In an LPR process proposal, Lemna Technologies Inc. suggests a design BOD removal based on the removal rate of 0.0025 lbs BOD/ft^2/day (at 20˚C) and a design ammonia nitrogen removal rate based on 0.55 lb. ammonia nitrogen oxidized/1000 ft^2/day (at 22 ˚C). These removal constants are higher than observed at Poplar and need further evaluation by either pilot or full-scale study. The department believes that loading rates for attached growth media are media specific, especially for the LPR proprietary process. A recommendation as to a loading rate criteria is not possible based on current empirical information. A question remains as to the effectiveness of an LPR during and after the time when nitrification is taking place in preceding aerated cells. At such time as the aerated cells may not be providing complete nitrification, will there be nitrifying biomass in the LPR until it has time to build up?

Lemna Technologies claims that they would typically recommend LPR units for facilities with ammonia limits below 8-10 mg/l since in some cases, proceeses using only complete-mix lagoon scenarios cannot meet single digit effluent limits.

In complete-mix designs using acceptable HRT sizing options, LPR use is not required as a minimum.

4. Piping Arrangement

The ponds and piping should be designed such that reliability and flexibility of operation are provided. All systems shall be designed with piping flexibilities to permit isolation of any pond without affecting the transfer and discharge capabilities of the total system, IA 18C.6.2. The ability to discharge the influent waste to a minimum of two ponds and to all primary ponds in the system shall be provided as a minimum. Although the LemTec process is not a typical aerated lagoon system addressed by IA 18C, using this provision is acceptable for providing a reasonable reliability, comparable to conventional aerated lagoons.

5. Mixing and Aeration Requirement

a) Mixing in Complete-mix cells

The removal rate of biodegradable materials in an aerated cell is a function of the concentration of biomass suspended in the water column. Power intensity required for the suspension of settleable solids in aerated cells is a function of several factors—concentration and nature of the suspended solids, basin size and shape, and the type of aeration system used. Studies (Malina *et al.* 1972) show that 30 HP/MG can maintain all settleable solids in suspension when mixed liquor suspended solids concentration is 250 mg/L and temperature is 10°C.

For fine bubble diffusers applied in floor cover configuration, 0.12 SCFM/SF of air must be supplied to provide complete mix.

b) Mixing in Partial-mix cells

Mixing in a partial-mix cell must be provided by 8.0 HP/MG by mechanical aerators in accordance with Lemna recommendations..

c) Aeration Needs

For the oxygen requirement, aeration equipment shall be capable of supplying a minimum of 1.8 lbs. O2/lb. of BOD5 and 4.6 lbs. O2/lb. TKN and maintain DO of 2.0 mg/L at all time.

6. Solids Settlement after LPR

Whether a final settling process is needed after LPR is determined by the loading received by LPR. When an LPR is not expected to be loaded significantly due to reliable upstream treatment completed by aeration cells, the LPR does not need to be followed by any settling process. On the other hand, if the process depends on LPR as a significant removal process (such as a partial-mix only system), as opposed to a polishing factor, then the concern of solids generation due to biological activity on LPR media must be addressed. Additional information on LPR loading and removal data would be beneficial for sizing the units.

7. Unit Process Reliability

Unit process reliability for the number of ponds or independent reactors and sludge storage will be based on IA 14.5, considering this process as a combined carbonaceous oxidation and nitrification process.

LemTec Biological Process Design Guidance Summary

Based on the available performance data, the following design guidance for the LemTec facilities can be presented. Limited by the quality and quantity of available data, this design guidance will be subject to review and revision when new information becomes available.

1. Two types of design configurations will be accepted. Type I is three partial-mix cells followed by a LPR unit or other kind of attached growth reactor, such as RBC, sand filter, etc. Type II has three aeration cells including the first cell being a year-round complete-mix cell, the second cell providing complete-mix at least in winter and the third cell being a partial-mix cell.

2. In determining the minimum partial-mix cell volume or the minimum total volume for complete-mix/partial-mix facilities, hydraulic flow used to determine cell sizes shall be based upon the ADW flow plus 30 percent of the AWW flow in excess of the ADW flow, or 100 gpcd, whichever is greater in accordance with IA 18C.4.1.2. In determining the minimum complete-mix cell volume for a complete-mix/partial-mix facility, design hydraulic loading is the average wet weather (AWW) flow.

3. Design HRT for Type I facility (partial-mix cells with LPR) must be at least 28.3 days total (aerated cells) at the hydraulic flow used to determine cell sizes in accordance with Section 18C.4.1.2. Three cells should be as equally sized as possible.

4. For Type II facility (complete-mix cells and partial-mix cell), a total HRT of 23 days (aerated cells) at the hydraulic flow used to determine cell sizes in accordance with Section 18C.4.12. must be provided. Design HRT for each complete-mix cell must follow the activated sludge nitrification model in Fig. 13 or Equation A-1.

5. Flow variability should be evaluated since more consistent performance may result from low hydraulic variability. Flow equalization prior to the LemTec process should be considered in systems with high variability.

6. No BOD_5 or ammonia nitrogen removal constant for an LPR unit can be supported by current performance data. Review of LPR sizing depends on further information. When needed, LPR sizing should be consistent with others at operating facilities.

7. Independent ponds and piping shall be designed based on design standards in IA 18C.6.2 as a minimum. In general, a facility with any pond out of service should be able to treat at least 50 percent of the organic loading to levels that will comply with all water quality based and technology based effluent limits.

8. For a partial-mix cell, mixing energy of 8.0 HP/MG (mechanical) and 0.01 SCFM/SF must be provided to maintain minimum power intensity. For a complete-mix cell, mixing power of 30 HP/MG from mechanical aerators or 0.12 SCFM/SF from fine bubble diffusers must be provided. Complete mixing power, if provided by a combination of mechanical aerators and diffusers, needs to be evaluated on a case-by-case situation

9. A minimum of 1.8 lbs. O2/lb. of BOD_5 and 4.6 lbs. O_2/lb. TKN must be provided by a diffused aeration system if the facility has both BOD and ammonia nitrogen removal requirements and nitrification is proposed in the aeration cells. DO levels of 2.0 mg/L must be maintained in the aerated cells at all time.

10. If an LPR is not expected to be loaded significantly due to upstream treatment completed by aeration cells, the LPR does not need to be followed by any settling process. If the LPR process is accounted as a significant removal process, the design should address solids generation and removal due to biological activity on LPR media.

11. Reliability of treatment equal to a combined carbonaceous oxidation and nitrification activated sludge process including settling shall be met.

12. Facilities with the first and the second cells being partial-mix cells should have cells configured to accommodate possible conversion to complete-mix cells.

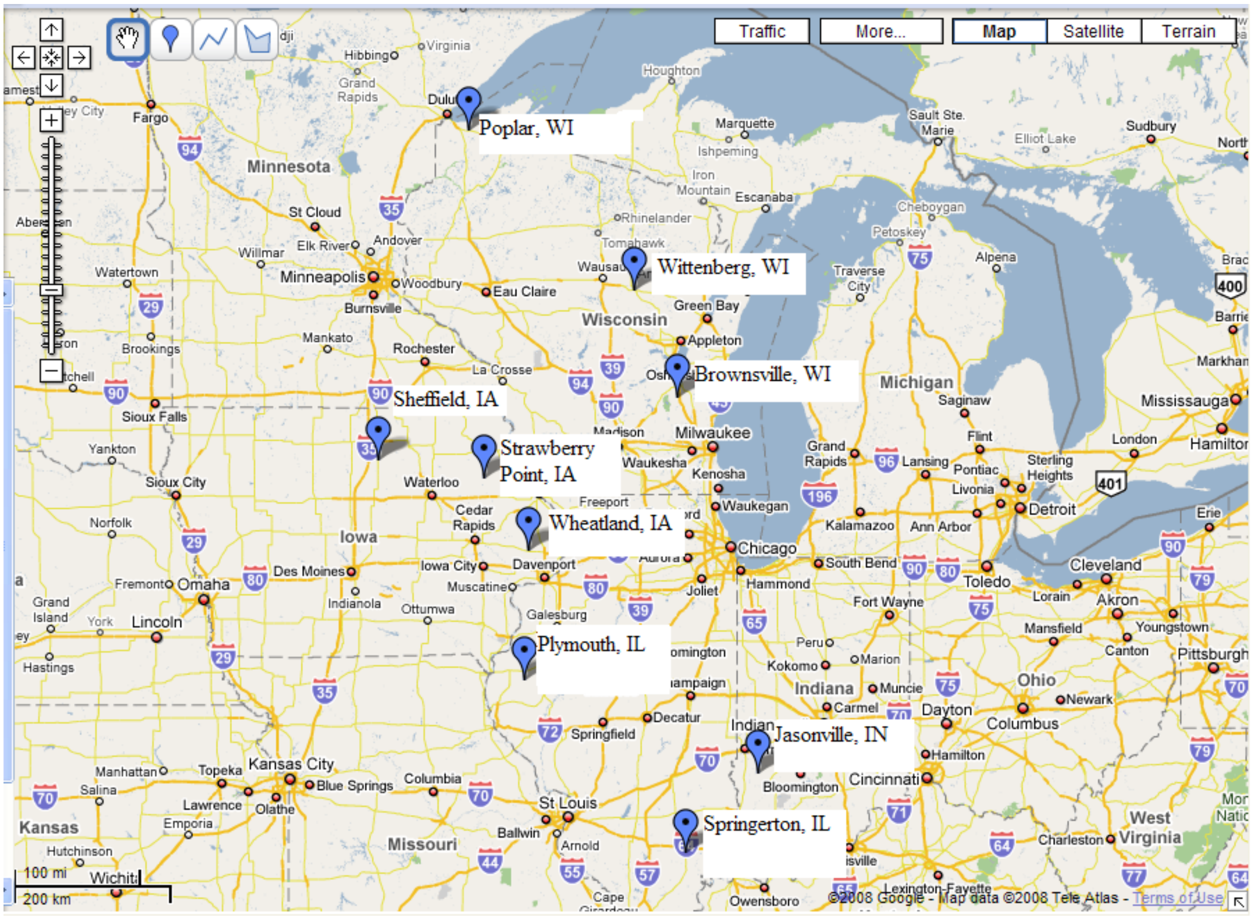
13. Sufficient sludge storage and pretreatment shall be provided in the design of all facilities. Sludge accumulation and removal is a concern for any lagoon process.

14. Special considerations may be necessary where unique circumstances exist that could affect wastewater characteristics such as short term peak flows or wastewater temperature.

References

Downing, A. L., and G. Knowles, Population Dynamics in Biological Treatment Plants. Presented at the 3rd Conference of the IAWPR, Munich, 1966.

Malina *et al.* 1972, Design Guides for Biological Wastewater Treatment Processes. Report CRWR-76. Center for Research in Water Resources, University of Texas, Austin, 1972



Map 1. Geographical Locations of LemTec Biological Wastewater Treatment Facilities in Study

Table 1. Variation of LemTec Biological Treatment Process Design Features

Facilities	Types of Process[4]	Design Flow[6], MGD	Cell Design HRT, Days					Effluent Limits[1], NH3-N mg/L	
			Cell1	Cell2	Cell3	Total Aerated	Settling	Summer	Winter
Brownsville, WI	PM-PM-PM-S-RBC-SF	0.125	4.8	4.8	6.8	16.4	6.8	---[2]	---[2]
Plymouth, IL	PM-PM-PM-S-LPR	0.060	8.3	8.3	8.3	24.9	11.6	1.9	2.6
Springerton, IL	PM-PM-PM-S-LPR	0.02	6.7	6.7	6.7	20.1	10	1.8	7.0
Jasonville, IN	PM-PM-PM-S-LPR	0.55	5.3	5.3	5.3	15.9	7.5	1.46	2.12
Wittenberg, WI	CM-PM-PM-S-SF, summer CM-CM-PM-S-SF, winter	0.328	3.4	3.4	6.7	13.5	6.7	13	16
Strawberry Point, IA	CM-PM-PM-S	0.276	5.1	5.1	3.8	14	6.3	9.4	24
Wheatland, IA	CM-PM-PM-S	0.277	4	4	3.5	11.5	4.6	6.3[3]	28[3]
Sheffield, IA	CM-PM-PM-S[5]	0.389	7.7	5.9	13.6	27.2	28.3	2.9	14.1
Poplar, WI	CM-CM-PM-S-LPR	0.037	5.4	5.4	5.4	16.2	8.1	None	None

1. Effluent limits in this study include standard secondary limits and ammonia nitrogen limits.
2. Brownsville does not specify ammonia effluent limits, but indicates its design to meet 2 mg/L of NH_3-N with LemTec process followed by RBC and rapid sand filter.
3. Wheatland was designed to meet NH_3-N limits based on year 2002 best guess limits of Iowa. Year 2006 best guess NH_3-N limits for Wheatland are 1.0 mg/L and 5.8 mg/L for summer and winter, respectively.
4. In description of different combinations of unit process, the following acronyms are used.
   - PM: Partial-mix aerated cell
   - CM: Complete-mix aerated cell
   - S: Settling cell
   - LPR: Lemna Polishing Reactor
   - RBC: Rotating Biological Contactor
   - SF: Sand Filter
5. In Sheffield facility, the first cell (complete-mix) and the second cell (partial-mix) are covered. The third cell (partial-mix) and the settling cell are open.
6. Design flows for Brownsville, Plymouth, Springerton, Jasonville, Wittenberg and Poplar are annual average flow. Design Flows for Strawberry Point, Wheatland and Sheffield are based upon the ADW flow plus 30% of the 30-day average wet weather flow (AWW-30) flow in excess of the ADW flow, or 100 gpcd, whichever is greater.

Table 2. Actual Hydraulic Retention Times in Aerated Cells of Full-Scale LemTec Facilities

Facilities	Cell 1 HRT (d)		Cell 2 HRT (d)		Cell 3 HRT (d)		Total Actual HRT (d)	Actual HRT/Design HRT (%)
	AVE	STD	AVE	STD	AVE	STD		
Brownsville, WI	11.5	3.1	11.5	3.1	16.4	4.4	39.4	240
Plymouth, IL	13.5	4.1	13.5	4.1	13.5	4.1	40.6	163
Springerton, IL	20.9	7.3	20.9	7.3	20.9	7.3	62.7	312
Jasonville, IN	9.4	3.3	9.4	3.3	9.4	3.3	28.3	178
Wittenberg, WI	5.8	0.9	5.8	0.9	11.6	1.8	23.1	171
Strawberry Point, IA	6.4	2.2	6.4	2.2	4.9	1.7	17.7	126
Wheatland, IA	6.1	4.1	6.1	4.1	5.3	3.6	17.5	152
Sheffield, IA	9.9	5.2	7.6	4.0	17.5	9.2	35	129
Poplar, WI	8.7	2.7	8.7	2.7	8.7	2.7	26.0	160

Table 3. Sample End-of-Pipe Ammonia Nitrogen Limits Covered Aerated Lagoon (Iowa)

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	**Dec**
Ave (mg/L)	5.2	5.8	2.8	2.1	1.8	1.3	1.1	1.0	1.5	2.8	3.4	4.0
Max (mg/L)	19.9	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4

Figure 1. Brownsvill (WI) Performance Data

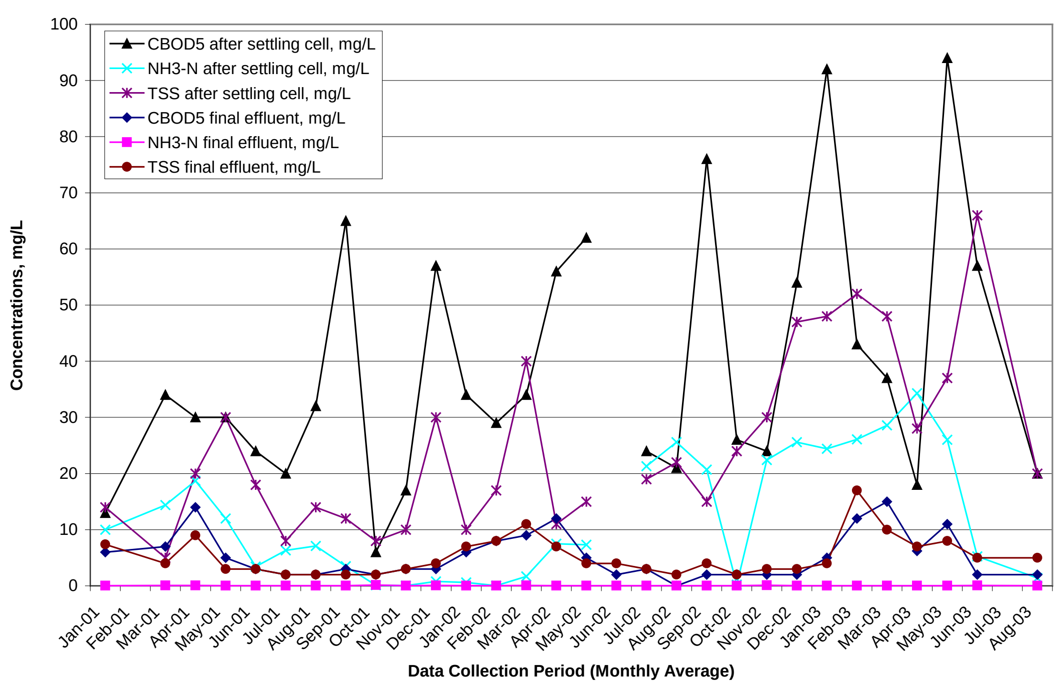
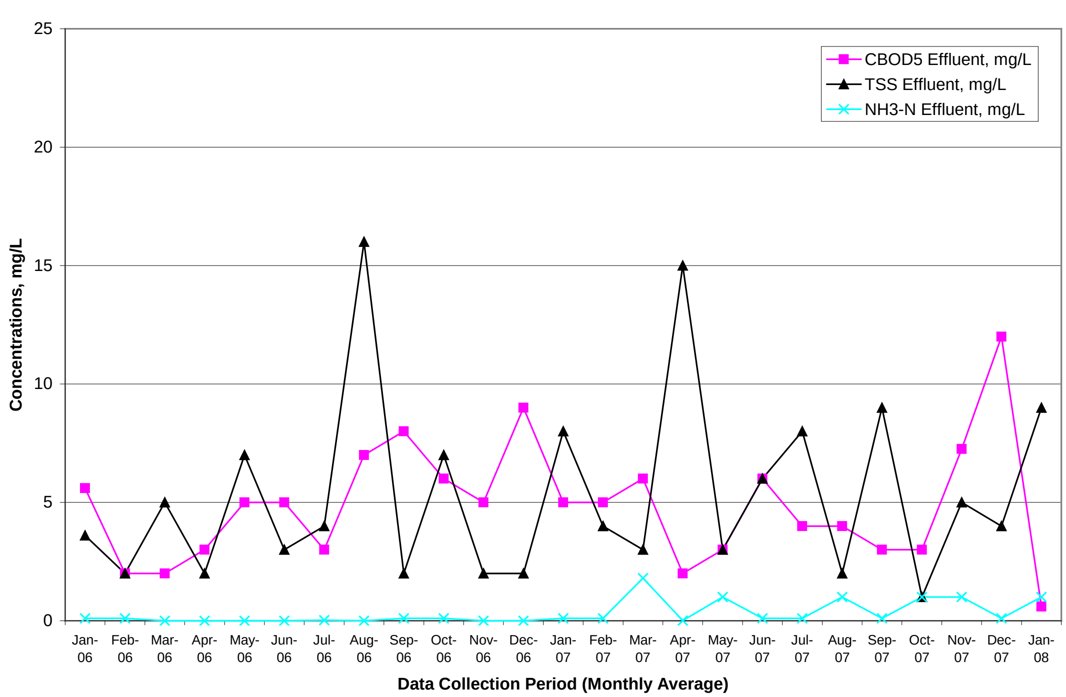


Figure 2. Plymouth (IL) Performance Data



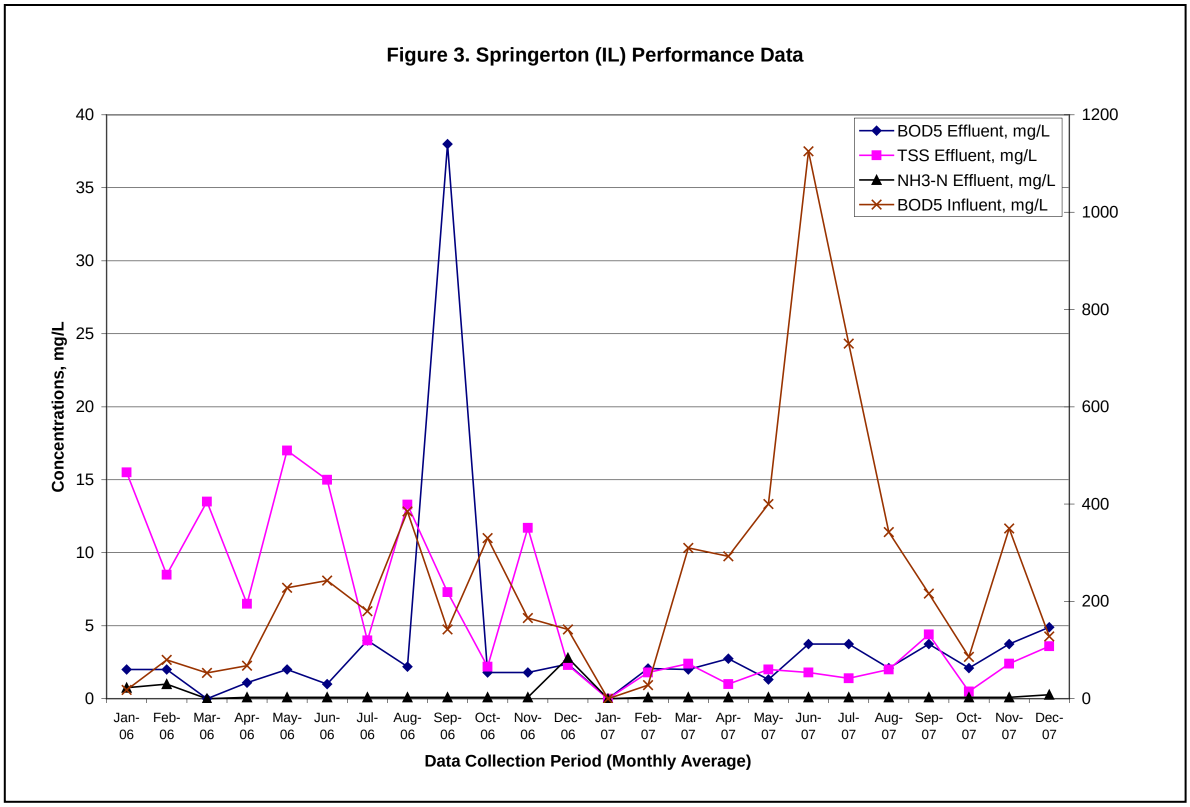


Figure 3. Springerton (IL) Performance Data
Concentrations, mg/L
BOD5 Effluent, mg/L
TSS Effluent, mg/L
NH3-N Effluent, mg/L
BOD5 Influent, mg/L
Jan-06
Feb-06
Mar-06
Apr-06
May-06
Jun-06
Jul-06
Aug-06
Sep-06
Oct-06
Nov-06
Dec-06
Jan-07
Feb-07
Mar-07
Apr-07
May-07
Jun-07
Jul-07
Aug-07
Sep-07
Oct-07
Nov-07
Dec-07
Data Collection Period (Monthly Average)

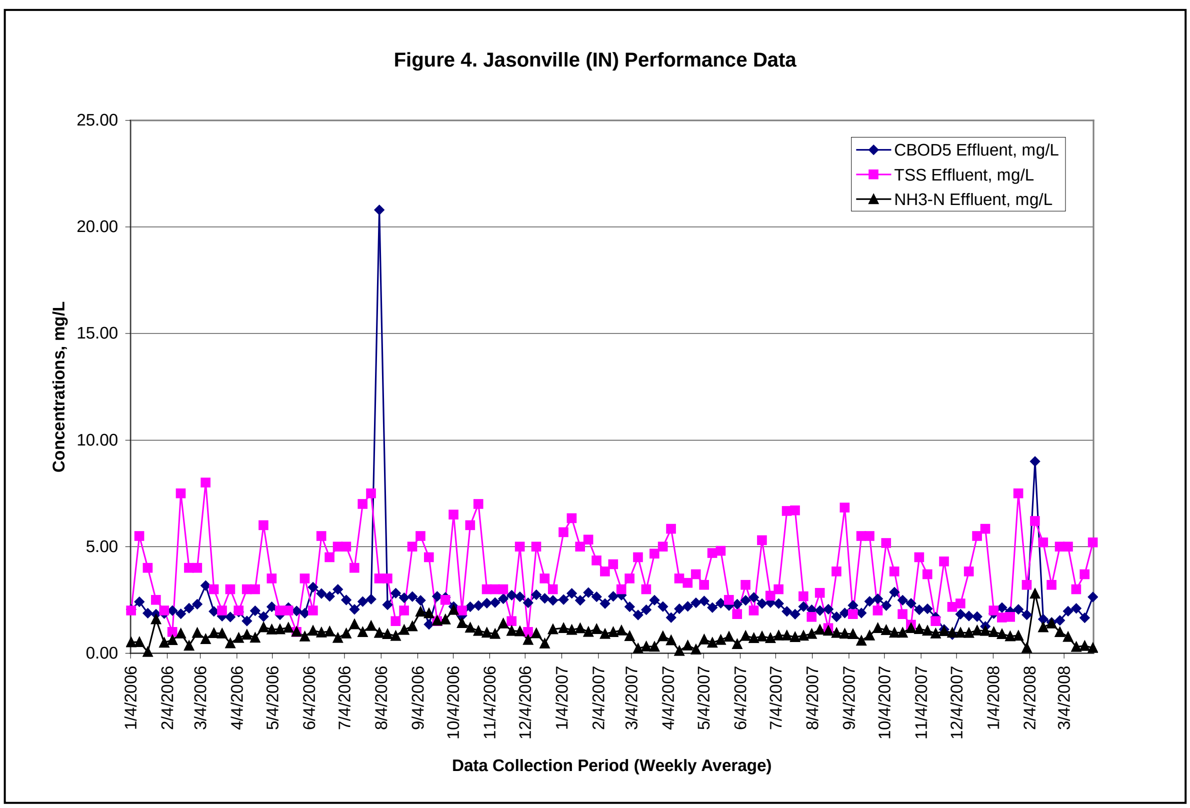


Figure 4. Jasonville (IN) Performance Data
Concentrations, mg/L
CBOD5 Effluent, mg/L
TSS Effluent, mg/L
NH3-N Effluent, mg/L
Data Collection Period (Weekly Average)

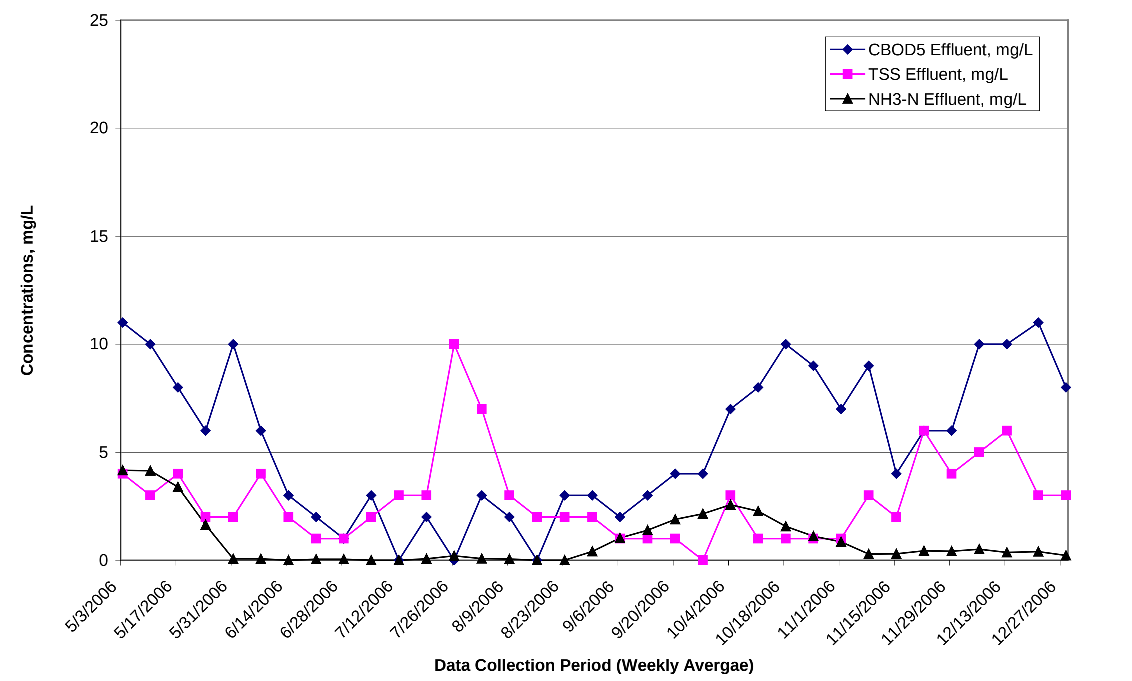


Figure 5. Wittenberg (WI) Performance Data

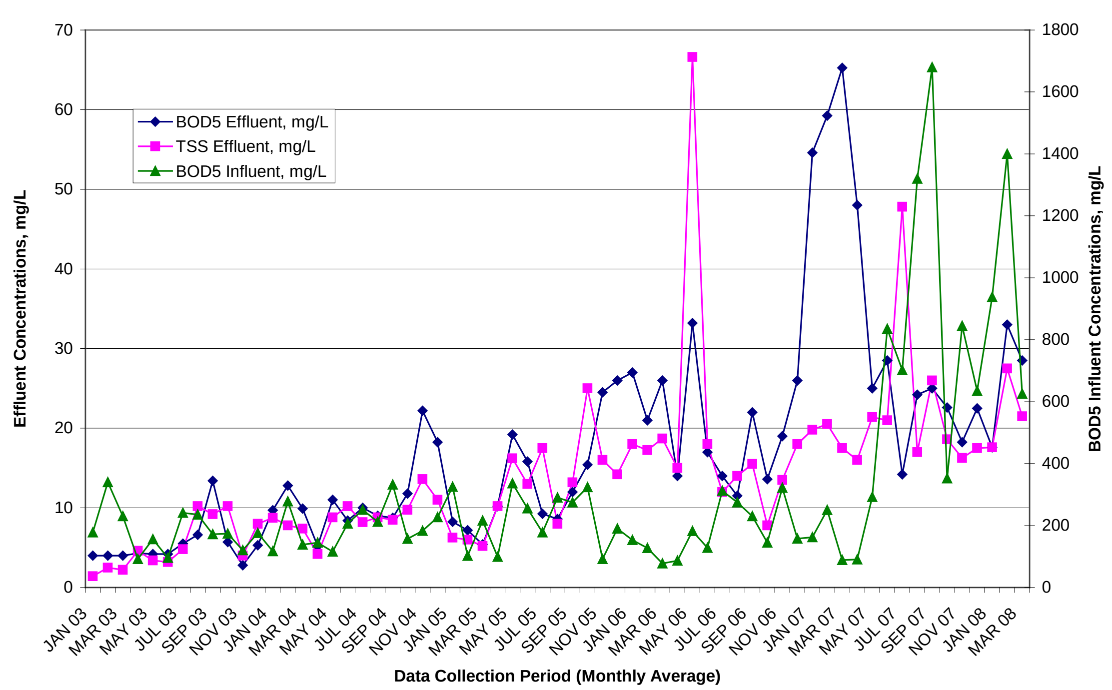


Figure 6. Poplar (WI) Performance Data

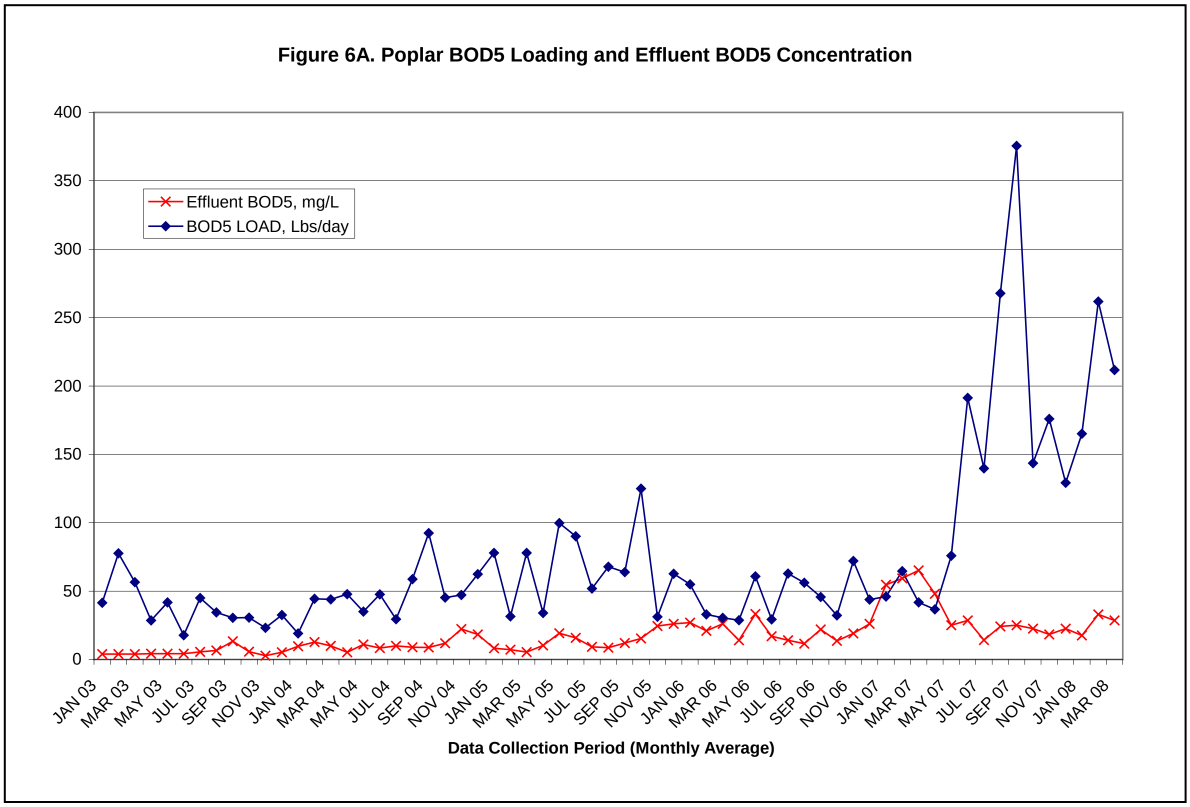


Figure 6A. Poplar BOD5 Loading and Effluent BOD5 Concentration
Effluent BOD5, mg/L
BOD5 LOAD, Lbs/day
0
50
100
150
200
250
300
350
400
JAN 03
MAR 03
MAY 03
JUL 03
SEP 03
NOV 03
JAN 04
MAR 04
MAY 04
JUL 04
SEP 04
NOV 04
JAN 05
MAR 05
MAY 05
JUL 05
SEP 05
NOV 05
JAN 06
MAR 06
MAY 06
JUL 06
SEP 06
NOV 06
JAN 07
MAR 07
MAY 07
JUL 07
SEP 07
NOV 07
JAN 08
MAR 08
Data Collection Period (Monthly Average)

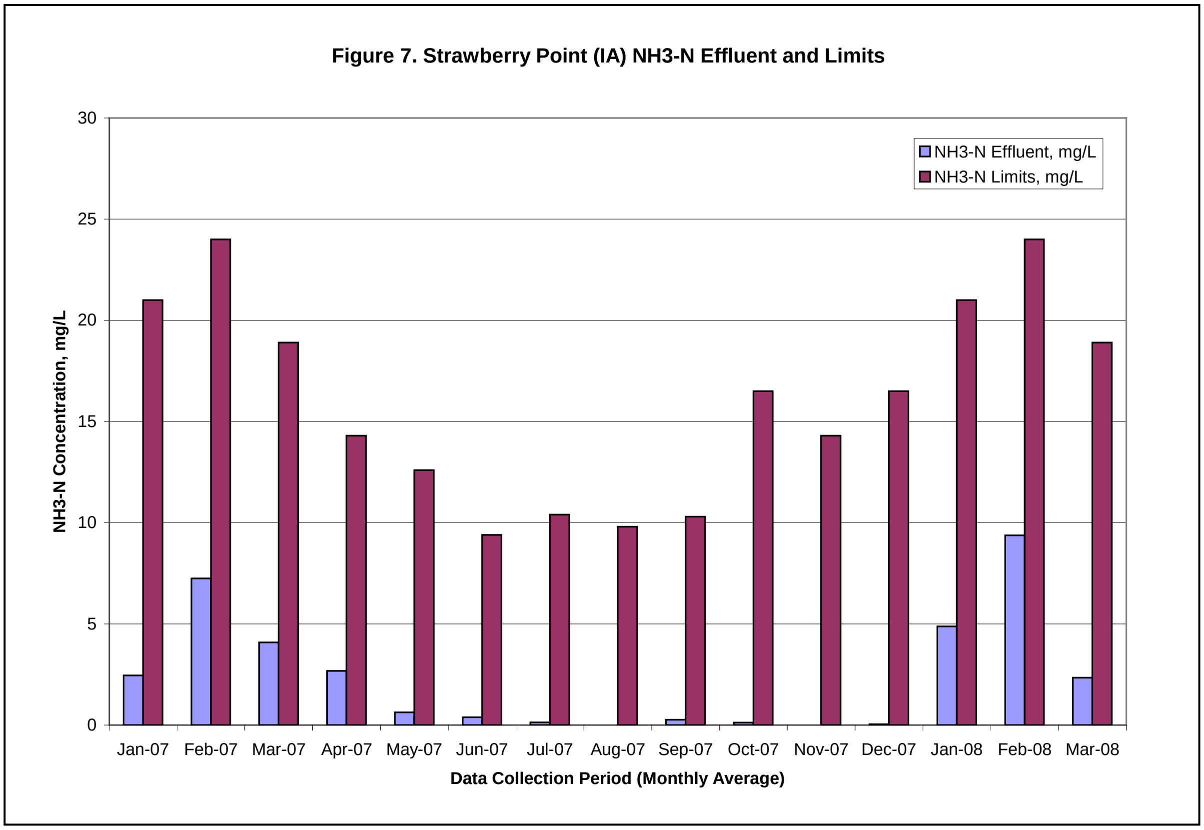


Figure 7. Strawberry Point (IA) NH3-N Effluent and Limits
30
25
20
15
10
5
0
NH3-N Concentration, mg/L
NH3-N Effluent, mg/L
NH3-N Limits, mg/L
Jan-07
Feb-07
Mar-07
Apr-07
May-07
Jun-07
Jul-07
Aug-07
Sep-07
Oct-07
Nov-07
Dec-07
Jan-08
Feb-08
Mar-08
Data Collection Period (Monthly Average)

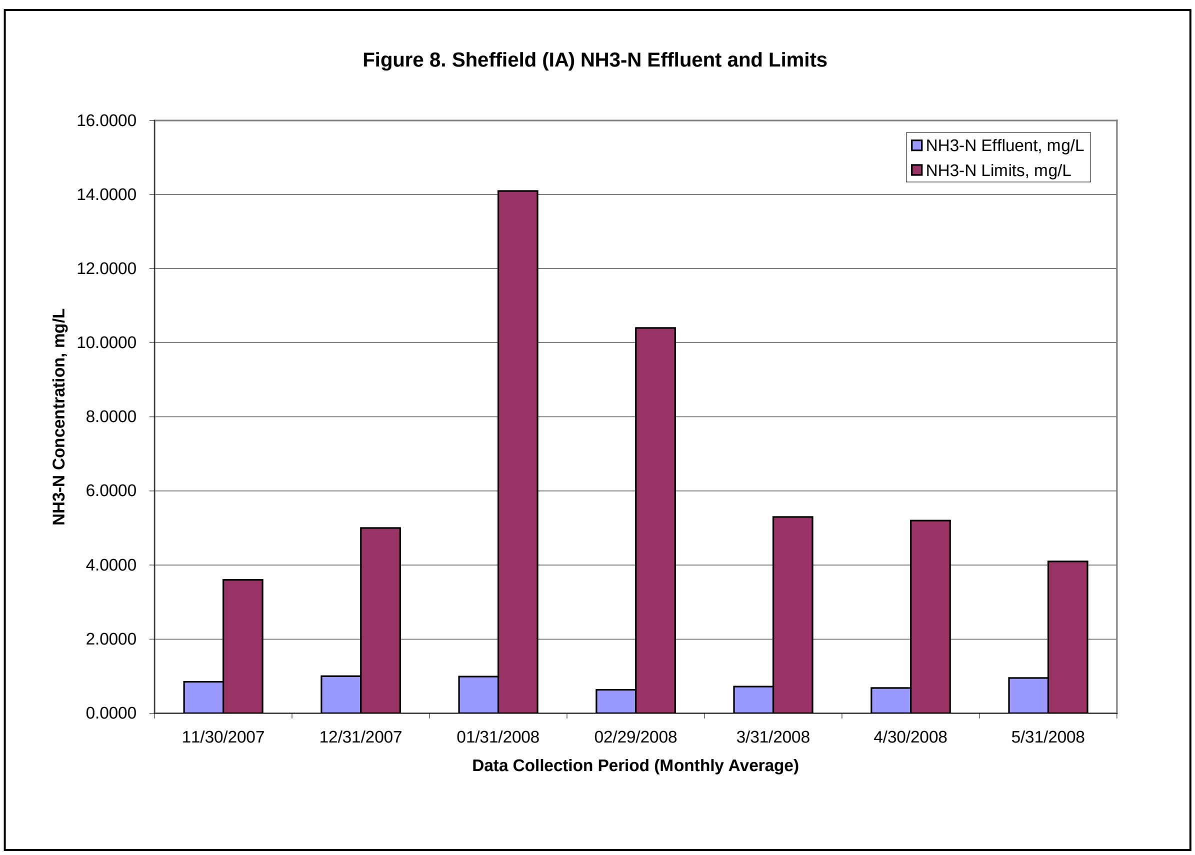


Figure 8. Sheffield (IA) NH3-N Effluent and Limits
16.0000
14.0000
12.0000
10.0000
8.0000
6.0000
4.0000
2.0000
0.0000
NH3-N Concentration, mg/L
NH3-N Effluent, mg/L
NH3-N Limits, mg/L
11/30/2007
12/31/2007
01/31/2008
02/29/2008
3/31/2008
4/30/2008
5/31/2008
Data Collection Period (Monthly Average)

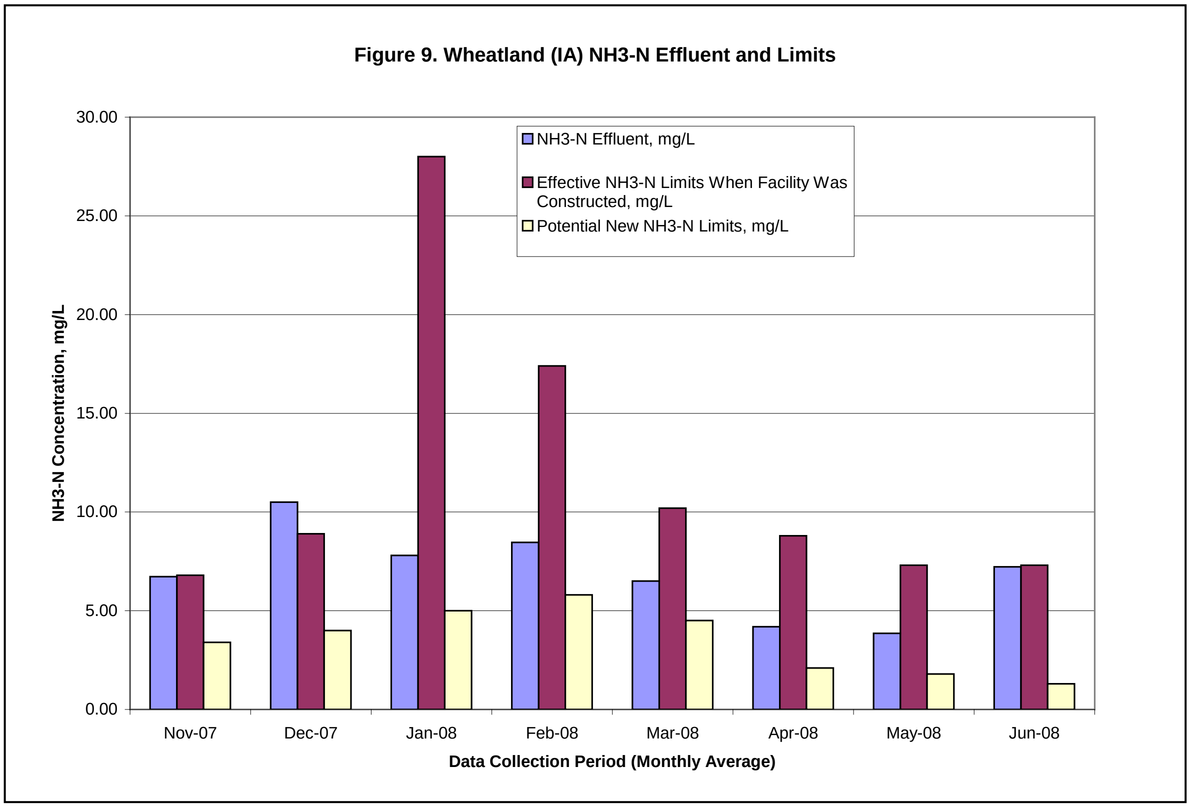


Figure 9. Wheatland (IA) NH3-N Effluent and Limits
NH3-N Effluent, mg/L
Effective NH3-N Limits When Facility Was Constructed, mg/L
Potential New NH3-N Limits, mg/L
NH3-N Concentration, mg/L
30.00
25.00
20.00
15.00
10.00
5.00
0.00
Nov-07
Dec-07
Jan-08
Feb-08
Mar-08
Apr-08
May-08
Jun-08
Data Collection Period (Monthly Average)

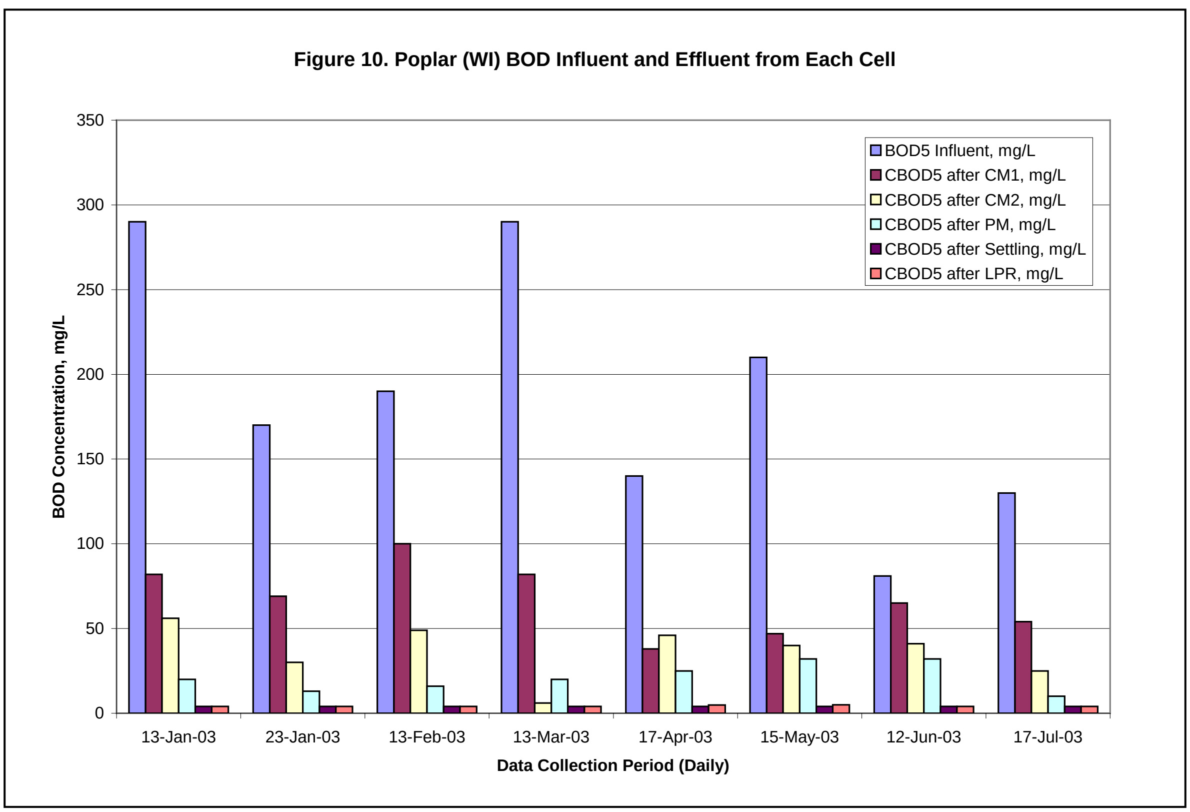


Figure 10. Poplar (WI) BOD Influent and Effluent from Each Cell
BOD5 Influent, mg/L
CBOD5 after CM1, mg/L
CBOD5 after CM2, mg/L
CBOD5 after PM, mg/L
CBOD5 after Settling, mg/L
CBOD5 after LPR, mg/L
BOD Concentration, mg/L
350
300
250
200
150
100
50
0
13-Jan-03
23-Jan-03
13-Feb-03
13-Mar-03
17-Apr-03
15-May-03
12-Jun-03
17-Jul-03
Data Collection Period (Daily)

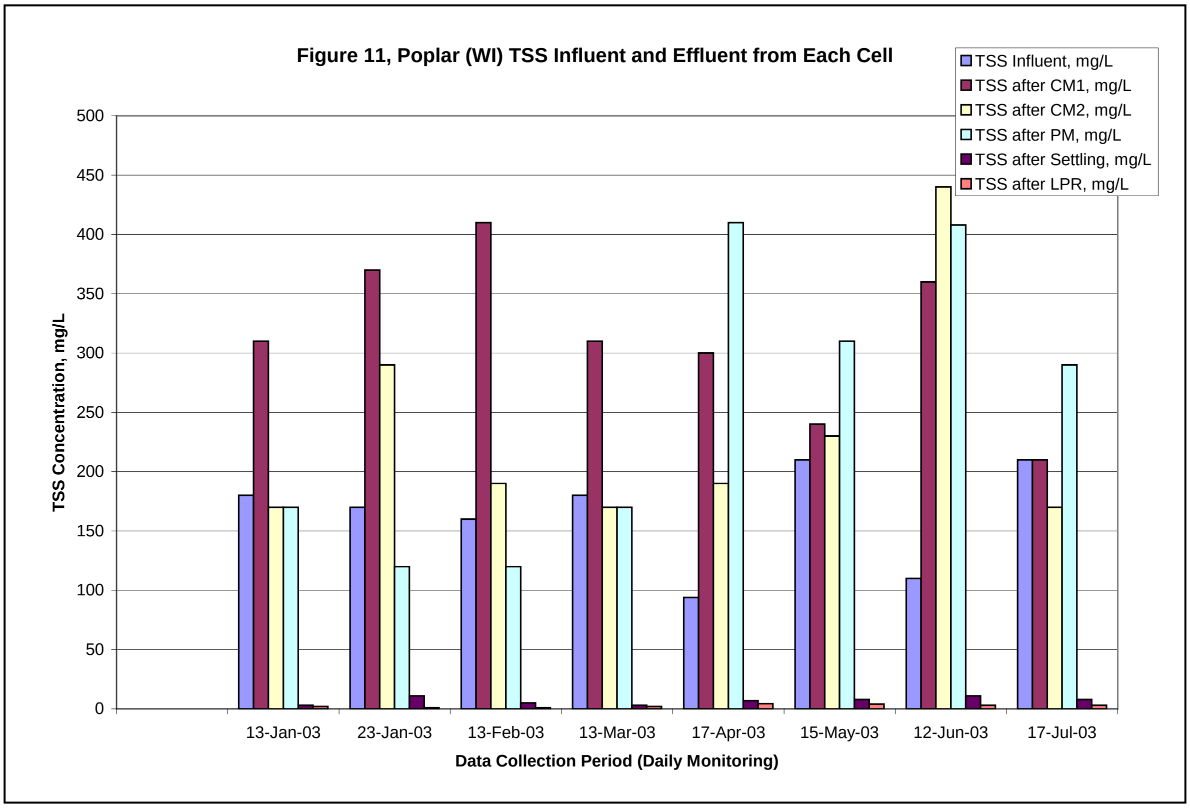


Figure 11, Poplar (WI) TSS Influent and Effluent from Each Cell
TSS Influent, mg/L
TSS after CM1, mg/L
TSS after CM2, mg/L
TSS after PM, mg/L
TSS after Settling, mg/L
TSS after LPR, mg/L
TSS Concentration, mg/L
0
50
100
150
200
250
300
350
400
450
500
13-Jan-03
23-Jan-03
13-Feb-03
13-Mar-03
17-Apr-03
15-May-03
12-Jun-03
17-Jul-03
Data Collection Period (Daily Monitoring)

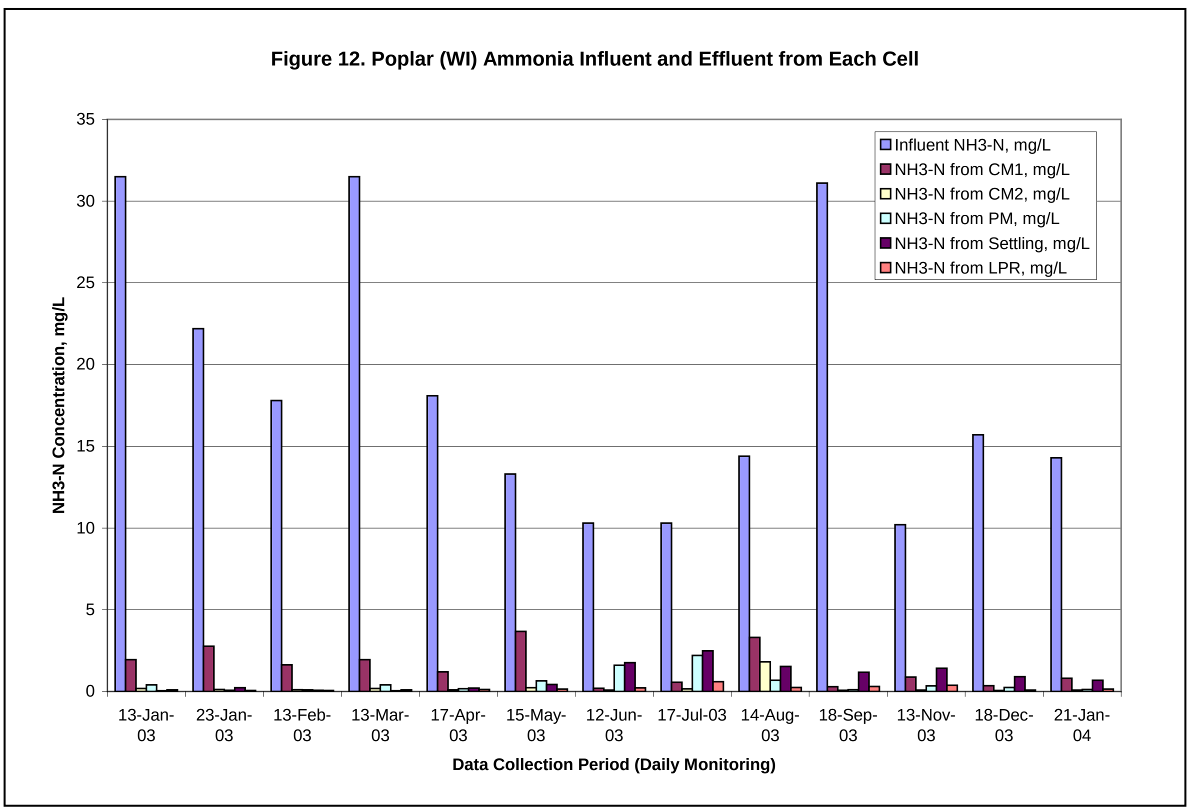


Figure 12. Poplar (WI) Ammonia Influent and Effluent from Each Cell
Influent NH3-N, mg/L
NH3-N from CM1, mg/L
NH3-N from CM2, mg/L
NH3-N from PM, mg/L
NH3-N from Settling, mg/L
NH3-N from LPR, mg/L
NH3-N Concentration, mg/L
0
5
10
15
20
25
30
35
13-Jan-03
23-Jan-03
13-Feb-03
13-Mar-03
17-Apr-03
15-May-03
12-Jun-03
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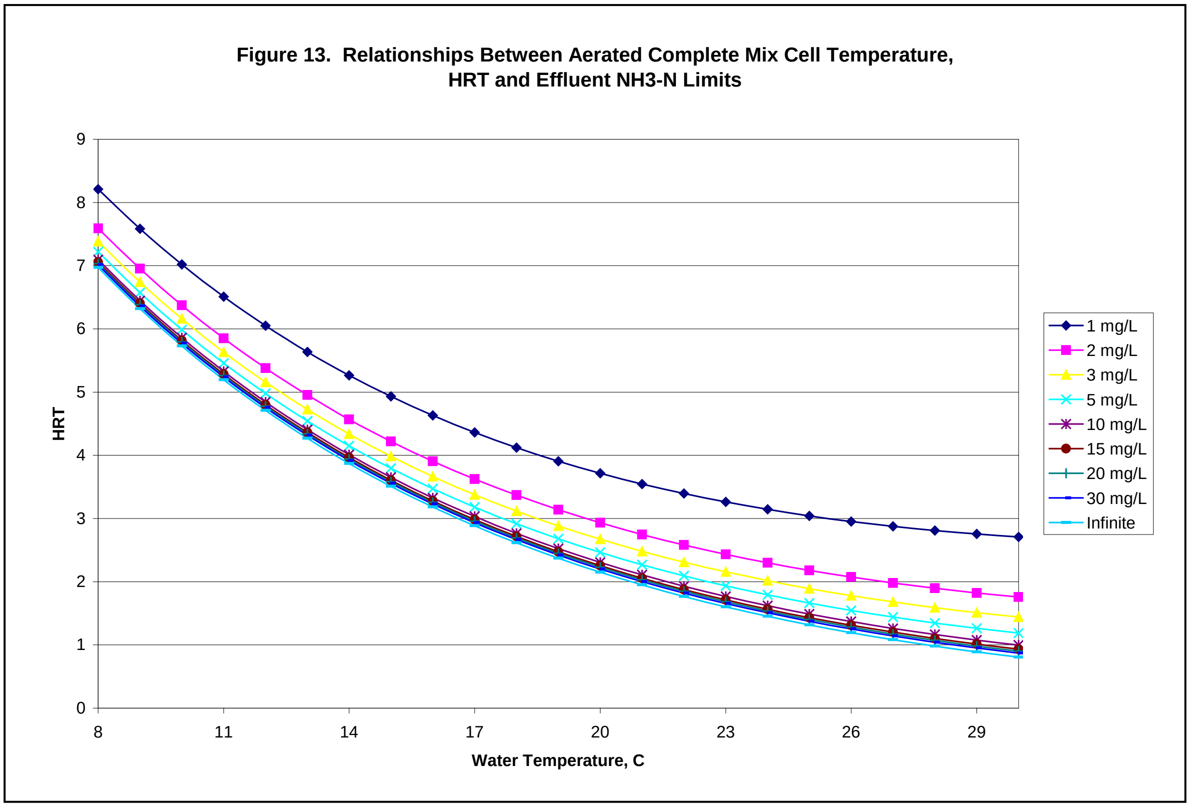
14-Aug-03
18-Sep-03
13-Nov-03
18-Dec-03
21-Jan-04
Data Collection Period (Daily Monitoring)



Equation A-1:

$$HRT = 1/\left[0.47 \times \left[e^{0.098\times(T-15)}\right] \times \left[1 - 0.833 \times (7.2 - pH)\right] \times \left[N/\left(N + 10^{0.051\times T - 1.158}\right)\right] \times \left[DO/\left(DO + 1.3\right)\right]\right]$$

Appendix I. LemTec Aerated Cell Sizing Example

Design Annual Average Flow = 0.5 mgd

Design Monthly Flows:

Month	**Flow (mgd)**
Jan	0.35
Feb	0.4
Mar	0.5
Apr	0.7
May	0.65
Jun	0.6
Jul	0.55
Aug	0.5
Sep	0.5
Oct	0.55
Nov	0.4
Dec	0.4

Design Wastewater Temperature:

Month	**Minimum Monthly Average Temperature (degrees C)**
Jan	6
Feb	8
Mar	9
Apr	12
May	16
Jun	17
Jul	18
Aug	19
Sep	18
Oct	17
Nov	14
Dec	11

Effluent Ammonia Limits (mg/L):

Month	*30-day Average*	**Maximum Day**
Jan	5.2	15.2
Feb	5.8	14.2
Mar	4.5	14.7
Apr	2.1	15.7
May	1.8	15.2
Jun	1.3	14.4
Jul	1.1	17.6
Aug	1.0	16.2
Sep	1.5	16.5
Oct	2.8	15.7
Nov	3.4	14.7
Dec	4.0	16.0

Type I Facility: Aeration with Partial-Mix Cells

Total HRT required = 28 Days
Number of aerated cells = 3 (assume cells are equally sized)

HRT of each aerated cell = 9.3 Days

Effective volume of each aerated cell = 9.3 days x 0.5 mgd = 4.7 million gallons

Type II Facility: Aeration with Complete-Mix Cells

a) Construct Time/Temperature Table using Figure 13 or Equation A-1

Month	*Ammonia Limit (mg/L)*	*Design Temperature (degrees C)*	*Required HRT (days)*	*Design Flow (mgd)*	**Required Volume (MG)**
Jan	5.2	5	9.58	0.35	3.05
Feb	5.8	6	8.69	0.4	2.87
Mar	4.5	6	8.75	0.5	3.30
Apr	2.1	8	7.56	0.7	3.74
May	1.8	11	5.93	0.65	2.59
Jun	1.3	14	4.94	0.6	2.41
Jul	1.1	17	4.23	0.55	2.19
Aug	1.0	19	3.91	0.5	1.95
Sep	1.5	20	3.19	0.5	1.81
Oct	2.8	18	3.15	0.55	1.88
Nov	3.4	11	5.58	0.4	1.71
Dec	4.0	9	6.64	0.4	2.21

From the table, the required volume for each complete-mix cell is 3.74 mgd (one of the complete-mix cells may be configured for operation as either complete-mix or partial-mix)

b) Determine the remaining partial mix cell size

Total HRT = 23 days at annual average flow.
Total Aerated Volume = 23 days x 0.5 mgd = 11.5 million gallons
Partial Mix Cell Volume = 11.5 – (2 x 3.74) = 4.02 million gallons

Equation A-1:

$$HRT = 1/\left[0.47 \times \left[e^{0.098\times(T-15)}\right] \times \left[1 - 0.833 \times (7.2 - pH)\right] \times \left[N/\left(N + 10^{0.051\times T - 1.158}\right)\right] \times \left[DO/\left(DO + 1.3\right)\right]\right]$$

HRT: days, for complete-mix cell.
T: Cell water temperature, °C
N: ammonia nitrogen effluent concentration limits, mg/L
DO: dissolved oxygen, 2 mg/L
pH: for pH >7.2, the second quantity in brackets is taken to be unity.