F2. Reducing Wastewater Point Source Nitrogen Losses to Surface Waters

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Municipal and industrial wastewater treatment facilities remove nitrogen (N) based on their treatment facilities technology and influent N levels. This chapter focuses on potential wastewater N reductions based on additional treatment technologies that could be installed at some treatment facilities.

As mentioned in Chapter D2 of this report, Minnesota currently has over 900 point sources that actively discharge to surface waters. Of these point sources, approximately 64% are domestic wastewater treatment plants (WWTPs) and approximately 36% are industrial facilities. In total, it is estimated that wastewater point sources discharge an average annual total nitrogen (TN) load of approximately 28,131,772 pounds statewide. Most of this load is from municipal dischargers (24,316,038 pounds/year TN, 86%); the remainder is from industrial facilities (3,815,734 pounds/year TN, 14%).

Nitrogen removal processes

Nitrogen removal from wastewater relies on a number of factors. Two key elements are time and temperature. There must be adequate treatment time for the desired biological activity to occur and the wastewater must be warm enough to insure that the biological activity can occur.

Raw domestic wastewater typically ranges from 20 to 70 mg/L of TN with a typical strength of around 40 mg/L (Water Environment Federation, 2006), consisting of approximately 60% ammonia and 40% organic N. Bacteria take in (assimilate) N from wastewater in a process known as *assimilation*. In the aerobic treatment process, most of the organic N is changed to ammonia in a process known as ammonification. Then all the ammonia is available to the nitrifying organisms. Biological N removal is a two-step process that involves nitrification and denitrification. Nitrification is an oxidizing process that occurs in the presence of oxygen under aerobic conditions using bacteria to oxidize ammonia to nitrite (NO_2), and then using another type of bacteria to oxidize the nitrite to nitrate (NO_3). The treatment process requires both a long solids retention time and hydraulic retention time. Denitrification is a reducing process that occurs in the absence of oxygen under anoxic conditions using bacteria to reduce nitrate to nitric oxide, nitrous oxide and N gas, with the N gas released to the atmosphere from the treatment tank wastewater surface. Nonbiodegradable organic N that is in particulate form is not removed through these processes, but rather through the physical process of solids separation (sedimentation or filtration). For details on estimated TN effluent data from different types of wastewater treatment plants, see the Assumptions and Methods portion of Chapter D2 and Table 2 of that chapter. Table 2 of Chapter D2 shows typical TN effluent values ranging from 6 mg/L at a small pond system up to 19 mg/L at a large class A-type of mechanical plant.

For optimum nitrification, a solids retention time (SRT) long enough to allow a stable population of nitrifiers to be maintained in the process is necessary. The target SRT will vary with temperature, dissolved oxygen, pH, and ammonia concentration. Temperature must be greater than about 45^{o} F to provide a stable population of nitrifiers. A hydraulic retention time (HRT) long enough to allow biomass enough time to react with the ammonia is also necessary. Systems with longer HRTs are less likely to see ammonia break-through due to temperature changes, or variations in flows and loadings.

For optimum denitrification, an anoxic zone that is mixed well and has dissolved oxygen levels less than 0.1 mg/L is necessary. Denitrifying bacteria are facultative and prefer to use oxygen to metabolize Carbonaceous Biochemical Oxygen Demand (CBOD). Any oxygen in the zone will be used before the bacteria start to reduce the nitrate. Sufficient readily degradable CBOD in the anoxic zone is also necessary. Carbon augmentation may be necessary with low CBOD to N ratios and nearly all separate stage denitrification.

Treatment time at a typical mechanical plant, such as an activated sludge plant or trickling filter with contact stabilization, is accomplished through the use of tanks. Tanks can be laid out in a variety of configurations, depending on the type of treatment units.

For aerated wastewater pond systems, N removal may be possible with additional treatment processes. Nitrification can be achieved by either adding an additional treatment unit after the ponds, such as some kind of fixed-film aeration tank/reactor or by modifying the aerated pond system by installing dividing baffling in the pond(s) along with the possible addition of media. A treatment unit for denitrification would also need to be added. This could also include the need for additional clarification. As with mechanical plants, adequate detention time to support the desired biological activity and proper dissolved oxygen concentrations is a key part of the treatment.

Wastewater temperature is the other key element. Raw wastewater temperature varies seasonally and is important because of the significant effect temperature has on the biological process. Heat loss also varies from plant to plant, depending on the treatment units being used. Wastewater temperatures must be greater than about 45° F to provide a stable population of nitrifiers. When wastewater temperatures fall to around 40° F, the nitrification/denitrification process becomes prohibitively slow.

For mechanical plants, wastewater temperatures usually do not fall below this level. Wastewater usually moves through a plant quick enough so that the temperature does not have a chance to drop below 45° F. Also, many mechanical plants have covers on many portions of the plant, especially the head works (grit removal and screening) and the primary clarifiers. For systems with septic tanks, wastewater temperatures in the winter can easily fall below the needed level for N removal. Most septic tanks are buried but they are buried without any insulation and the wastewater can remain in the tank for enough time for the water to cool. This is similar in aerated ponds. Aerated ponds are exposed to the elements and the wastewater easily cools while going from pond to pond prior to discharge. This also applies to stabilization ponds.

The above information regarding temperature was used to estimate N reduction potential at wastewater plants throughout the state. It was estimated that N removal could be implemented at mechanical wastewater treatment plants all year long. While N removal may be possible at aerated ponds during some of the warmer months, it would not be an easy process. Because of this, the analysis below assumes that N removal would not be achieved at aerated ponds. It was also estimated that N removal could not be implemented at stabilization ponds and septic tank-based systems. Of course, this is a general estimation. In reality, each plant would need to be individually evaluated to determine if and/or how N removal could and/or would be implemented. It should also be noted that the operation of a wastewater treatment plant can be a delicate process, easily upset by changes in influent flow and/or loading. This can cause problems in the nitrification process and especially in the denitrification process. In some cases an additional carbon source, such as some type of syrup product, is added to the wastewater.

Nitrogen removal levels from two technologies

The two primary methods of N removal from wastewater evaluated in this study are Biological Nutrient Removal (BNR) and Enhanced Nutrient Removal (ENR). A third tier of nutrient removal, called Limit of Technology (LOT), is sometimes considered (Section 3 of the Iowa Nutrient Reduction Strategy, Iowa Department of Natural Resources [2012].

Biological Nutrient Removal is most commonly associated with sequenced combinations of aerobic, anoxic and anaerobic processes which facilitate biological denitrification via conversion of nitrate to N gas. Effluent limits achievable using BNR at WWTPs that treat primary domestic wastewater are approximately 10 mg/L TN (Iowa Department of Natural Resources, 2012). For a mechanical WWTP the typical type of treatment would be activated sludge, which could be in the form of an oxidation ditch, sequencing batch reactor or "regular" aeration tanks. Another common option is a trickling filter followed by contact stabilization. Contact stabilization is achieved using tanks similar to aeration tanks. Adequate detention time is a key factor in achieving BNR and N removal.

Enhanced Nutrient Removal typically uses BNR along with filtration to achieve lower effluent N levels. This may also involve chemical addition. Effluent limits achievable using ENR at WWTPs are approximately 6 mg/L TN (Iowa Department of Natural Resources, 2012). For a mechanical WWTP the typical type of treatment would be similar to those listed above in the BNR description with the addition of some type of denitrification filter. As mentioned above, adequate detention time is a key factor.

Limit of Technology is generally associated with the lowest effluent concentrations that can be achieved using any treatment technology or combination of technologies. Potential technologies may include tertiary chemical addition with filtration, advanced effluent membrane filtration and ion exchange. It appears that there may not be consensus establishing specific treatment requirements for LOT or what effluent values could be achieved. The effluent values would be something less than the 6 mg/L TN value associated with ENR. Due to the lack of consensus surrounding LOT, there is no reduction estimates made based on this technology. Reduction estimates have been made on BNR and ENR.

Utilizing the above information as a guide, TN reductions were estimated at facilities based on BNR and ENR application. BNR and ENR, it was assumed, could be applied to mechanical facilities. It was assumed that BNR and ENR could not be applied to aerated ponds, stabilization ponds and septic tank-based systems.

Statewide nitrogen reduction from wastewater point sources

Current TN load values are based on actual discharge flow as reported to the MPCA by individual permittees via their discharge monitoring reports. Actual discharge TN concentration data was also used when available, and where not available it was estimated based on the type of treatment facility. Since much of the TN data used to calculate the reductions are estimates and not based on actual discharge TN concentration data, N reduction estimates could change once more actual discharge data become available. For more details on the estimated TN effluent data, see the Assumptions and Methods portion of Chapter D2 and Table 2 of that chapter.

Current estimates of wastewater N loads from Chapter D2, along with N removal efficiencies from BNR and ENR technologies as previously described, were used to estimate statewide N load reductions potentially achievable for wastewater. Reductions due to the implementation of BNR and ENR at all applicable treatment facilities were calculated. Table 1 below, in addition to the estimated current TN load, includes the estimated TN loads if BNR and ENR was implemented. The table also includes the percent reduction compared to the current load.

Implementing BNR technology statewide will reduce N discharges at municipal wastewater discharge points by an estimated 46%, and by 9% at industrial wastewater points of discharge. Implementing ENR technology statewide will reduce N discharges at municipal wastewater discharge points by an estimated 66%, and by 29% at industrial wastewater points of discharge. Combining municipal and industrial wastewater N reductions, BNR and ENR implemented statewide will reduce wastewater point sources by an estimated 41% and 61%, respectively.

Table 1. TN loading rates for the whole state and potential reductions due to BNR and ENR

Discharge source	Current TN load - lbs/year	BNR - lbs/year & (% reduction from current)	ENR - lbs/year & (% reduction from current)
Municipal	24,929,970	13,211,169 (46% reduction)	8,152,457 (66% reduction)
Industrial	3,741,459	3,461,397 (9% reduction)	2,712,060 (29% reduction)
Total	**28,671,429**	**16,672,566 (41% reduction)**	**10,864,517 (61% reduction)**

Nitrogen reductions in select major basins

Table 2 below includes current TN loading rates for three major basins in Minnesota; the Minnesota River, the Upper Mississippi River, and the Red River of the North. Also included is the estimated TN load if BNR and ENR were to be implemented in each basin, comparing the percent reduction to the current load. Reductions have been included for these three basins due to the amount of attention that has been focused on these basins recently. Water quality issues in the Gulf of Mexico and Lake Pepin have focused attention on the Minnesota River basin and the Upper Mississippi River basin over the last 10 to 20 years. Water quality issues in the Red River of the North and Lake Winnipeg, where the Red eventually empties, have come to the surface in more recent years.

Percent reductions in the Minnesota River watershed and the Upper Mississippi River watershed are very similar. BNR percent reductions for the Minnesota and Upper Mississippi are 43% and 44%, respectively. For ENR, the N reduction estimates are 64% and 65% for the Minnesota and Upper Mississippi, respectively. Percent reduction values for the Red River of the North are lower but still substantial at 35% for BNR and 51% for ENR.

Table 2. TN loading rates for three watersheds and potential reductions due to BNR & ENR

Watershed	Discharge source	Current TN load- lbs/year	BNR - lbs/year & (% reduction from current)	ENR - lbs/year & (% reduction from current)
Minnesota River	Total	4,676,235	2,650,818 (43% reduction)	1,695,525 (64% reduction)
Upper Mississippi River	Total	14,249,666	7,941,375 (44% reduction)	5,010,724 (65% reduction)
Red River of the North	Total	659,696	429,850 (35% reduction)	326,314 (51% reduction)

As shown in the tables above, implementation of BNR or ENR could have a substantial impact on the TN discharged in Minnesota. It should be noted that these reductions are only estimates. Actual reductions can be influenced by numerous factors including but not limited to the amount of influent N a plant is receiving and the type of technology chosen. A full scale pilot study may be the only way to really determine the best technology for a given plant and the actual reductions that may occur when that technology is utilized. Currently in Minnesota there are two facilities with a TN limit of 10 mg/L. Both facilities use some form of activated sludge for treatment and both facilities have had problems meeting their TN limit. There are no TN limits lower than 10 mg/L.

References

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