Diversion and Off-River Storage for Biological Denitrification of Raccoon River Water

for the Purposes of Drinking Water Treatment and
Nitrate, Chloride, and Total Dissolved Solids Load Reductions

Iowa's North Raccoon River Watershed—HUC 07100006

Technical Performance Report
3rd Quarter 2006

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October 24, 2006

I. Overview

On January 2, 2006, staff at Des Moines Water Works (DMWW) began investigation of the flow dynamics, chemistry, and microbiology of the DMWW off-river storage system for the purposes of nitrate mitigation. This report summarizes data accumulated during the 3rd quarter period of 2006.

The 3rd quarter typically begins with high nitrate levels in area rivers, but as river flows subside, water temperatures and biological activity increase, river water turbidity decreases, and crop uptake of nitrogen begins, nitrogen levels plummet throughout August and September. It is unusual for DMWW to require use of its nitrate removal facility after July 15 in most years.

Iowa can see substantial rainfall throughout the summer. But because maturing crops retain much of the moisture, less overland runoff and tile flow occurs as a result of these summertime rains, when compared to springtime rainfall.

Much of Iowa experienced near-drought conditions from May through July, but rainfall returned to normal and above-normal levels for August and September, and this pattern was characteristic of the Raccoon River watershed as well. These climatic conditions are reflected in the water quality data for the third quarter, which was somewhat atypical and which will be discussed in this report.

II. River Flow into Off-River Storage Reservoirs

Water was delivered from the Raccoon River into the Park Ponds using either a 0.8-million gallon per day (mgd) or a 4.7-mgd pump, depending on the conditions required to affect an overflow in the ponds, every day during the 3rd quarter. Some amount of water overflowed back to the Raccoon River every calendar day except four: August 3rd through the 6th, when the pumps were down for maintenance. Improvements and modifications to the levee system separating the ponds from one another continued, and likely will continue for a period of years. A large excavation one mile west of the flooding station (basin 17) was filled during the 3rd quarter. This impoundment is separate from the east ponds and does not overflow to the river; but, like the east ponds, it functions as yield enhancement for the groundwater collection system at Fleur Drive, and as a treatment sink where nitrate is consumed by microorganisms and algae.

At the Maffitt Treatment Plant site, Raccoon River injection into the gravel pit known as Crystal Lake took place on every calendar day except one during the 3rd quarter. Likewise, water from Crystal Lake was used for treatment in the plant every day except one during the 3rd quarter. A power outage on August 20 interrupted flow into and out of the lake. A total of 331 million gallons was used from the lake. This served as low-nitrate dilution water during the early part of July, but once nitrate levels subsided in the radial collector wells, this water simply enhanced yield from the wells and perhaps reduced the amount of water needed from the Fleur Drive Plant, reducing the need for nitrate removal. A total of 292 million gallons of Raccoon River water was injected into the lake.

The solar-powered circulators operated throughout the 3rd quarter and proved to be highly effective in repressing cyanobacteria. This data will be presented later in the report.

III. Physical Data

Accumulation of physical data is critical if DMWW staff is to able to identify, characterize, and quantify the various parameters necessary for effective denitrification of river water in the off-river storage reservoirs. These parameters are believed to be total river flow; reservoir acreage, depth, and volume; temperature; river flow volume and rate into the reservoir; and flow out of the reservoir, either back to the river or into the treatment plant. The graphs on the next page depict physical parameters monitored during the third quarter.

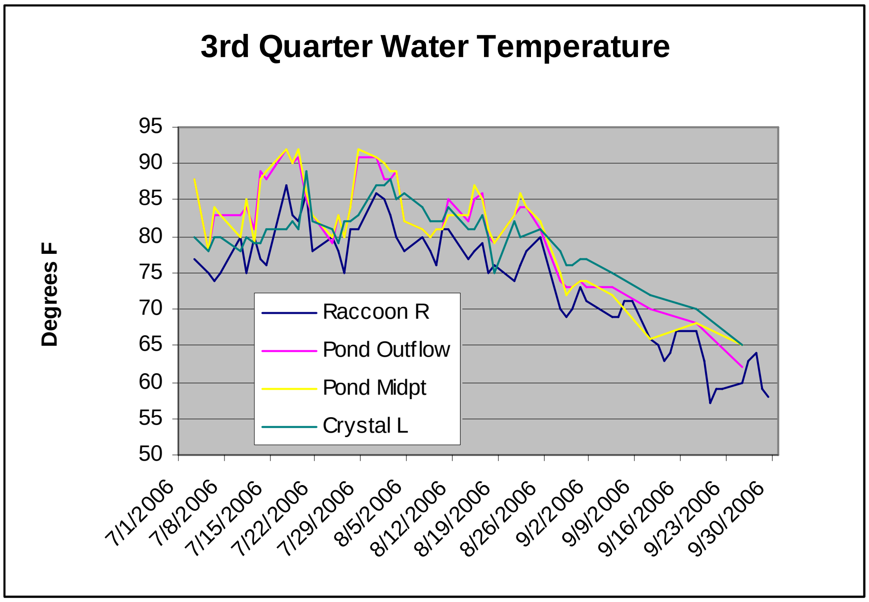


Figure 1: Water Temperature

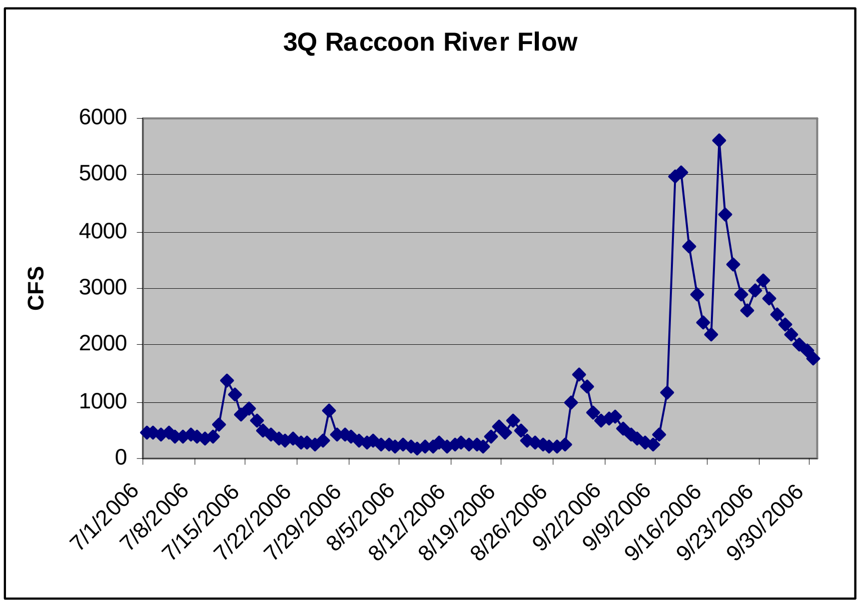


Figure 2: Raccoon River Flow

Surface water temperatures peaked perhaps a little earlier during 2006 than normal. Water temperatures at the end of July were very high, in some cases exceeding 90F in the park ponds. Both water temperature and river flow reflect the 2006 climatic conditions seen in Iowa: hot and dry in early summer, near normal temperatures and normal-to-above normal precipitation in mid to late summer. A few significant rain events in early August did not dramatically increase river flows; this illustrates the capacity of mature crops and dry soil to retain the water, preventing overland runoff and increased tile flow. Rain events toward the end of September did increase river flow several-fold. Crops are drying at this time and no longer using water. Soil moisture was also higher at this time due to normal August precipitation levels.

IV. Biological Data

A. Cyanobacteria

Intensive monitoring of cyanobacteria continued during the third quarter. This data is critical to DMWW and the rest of the water industry, because blooms of these organisms impart unpleasant tastes and odors to the finished water, and under some conditions the organisms can produce substances that have human toxicity. DMWW also is interested in what role they play in the consumption of nutrients, especially nitrogen, in an off-river storage system.

As mentioned in the 2nd quarter report, two solar-powered circulators, known as Solarbees, were installed in Crystal Lake on March 13. These devices use a solar-powered impeller to draw 3000 gallons per minute of water from near the bottom of the lake and then distribute it by laminar flow across the lake's surface. This indirectly induces about 7000 gallons per minute of additional flow. This flow of water is thought to repress cyanobacteria via two mechanisms: even distribution of phosphorous throughout the water column, which nullifies the mobility advantage cyanobacteria have over green algae; and the simple fact that continuously-moving water disrupts cyanobacteria ability to regulate buoyancy. These devices were not in place during 2005. During 2005, cyanobacteria numbers were maintained at manageable levels in Crystal Lake only until mid-July. Also of interest is whether or not repression of cyanobacteria will either enhance or disrupt the consumption of nitrate by the lake's biota.

Cyanobacteria did in fact remain manageable throughout the 3rd quarter, which typically is the worst time of year for blooms. As long as concentrations remain below 100,000 cells/ml in Crystal Lake water, which is diluted by radial collector well water, their numbers are below the reasonable level of concern for DMWW. Figure three below illustrates cyanobacteria numbers throughout 2006 and contrasts their levels with those seen in 2005.

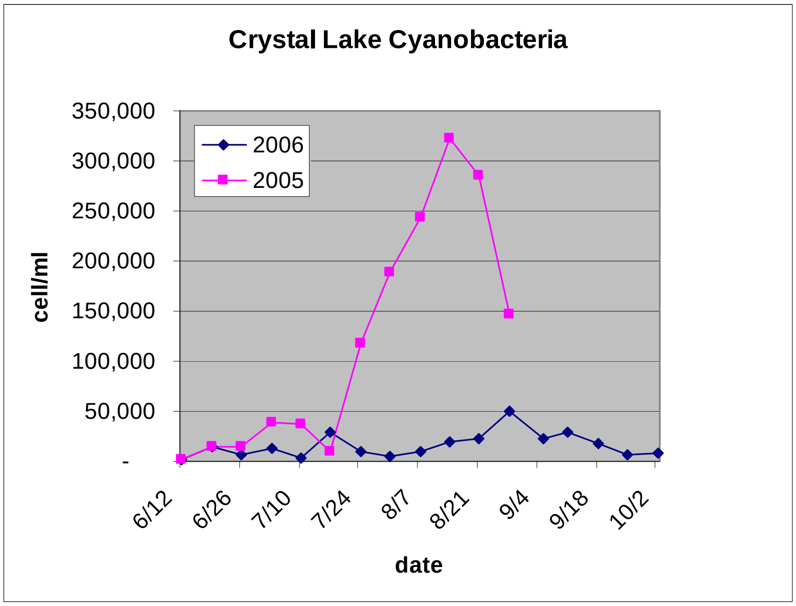


Figure 3: Crystal Lake Cyanobacteria, 2005 vs. 2006

Monitoring was discontinued in 2005 after September 1. Figure 3 clearly shows the effectiveness of the circulators in repressing cyanobacteria populations. This enabled DMWW to continue using the relatively low-nitrate Crystal Lake water throughout the 3rd quarter, whereas in 2005 water use was interrupted in mid-July. Figure 4 illustrates cyanobacteria numbers in all the surface waters of concern to this report during 3rd quarter. The park pond outfall showed the highest average numbers of cyanobacteria at about 34,000 cells/ml, roughly three times the numbers seen in the pond midpoint. This is a strong indication that detention time is a very important factor for cyanobacteria blooms in the off-river storage reservoirs. Water detention time at the pond outfall is about 11 days, whereas at the midpoint it is about 5-6 days. No large blooms were seen in the Raccoon River, despite high water temperatures, high levels of nutrients, and relatively low flows. This illustrates the importance of water tranquility/circulation as a factor for cyanobacteria repression. The potentially large numbers of cyanobacteria in the pond outfall present an obstacle for DMWW that will need to be addressed in the future if this water is to be used as low-nitrate dilution water in the Fleur Drive Treatment Plant.

The predominant genus during the 3rd quarter was again *Cylindrospermopsis* with some *Pseudanabaena* also observed.

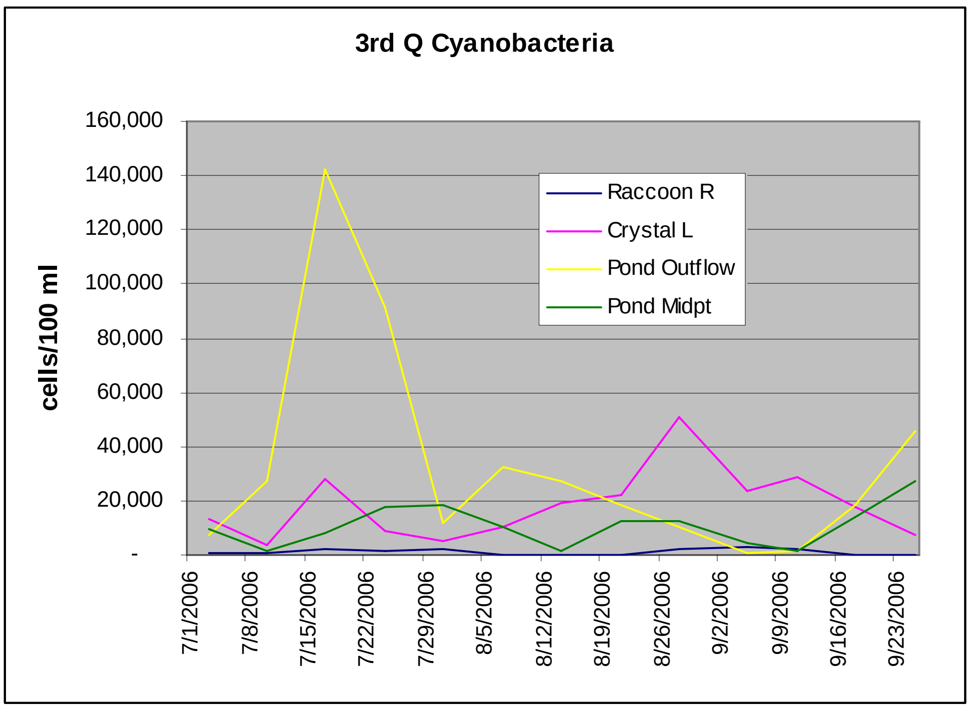


Figure 4: 3rd Quarter Cyanobacteria

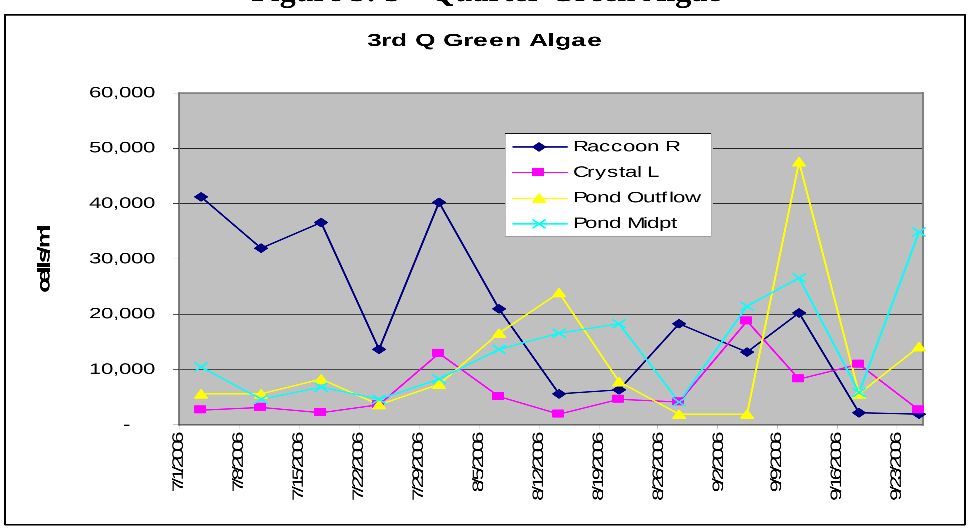
Cylindrospermopsis and *Pseudanabaena* are known to cause taste and odor problems and undergo toxin production. Per the work plan, one sample from the park ponds and one sample from Crystal Lake were evaluated during 3rd quarter for cyanotoxins by Greenwater Laboratories (Palatka, FL). The laboratory report is included in the appendix of this report. No cyanotoxins were detected in either sample, one piece of evidence that the presence of cyanobacteria does not necessarily result in toxin formation.

B. Green Algae

Green algae are important to this investigation in that they assimilate nitrate into their cells, converting it to organic nitrogen and in the process reduce nitrate concentrations in the surface waters of interest. So in this respect, green algae blooms can be beneficial to the utility. On the other hand, large numbers of green algae can also produce unwanted tastes and odors in the finished water. Furthermore, blooms of diatoms can plug the rapid sand filters DMWW uses at both plants, which leads to head loss, decreased run times, higher filter effluent turbidity, and water waste.

Whereas the Raccoon River had the lowest numbers of cyanobacteria, it had the highest numbers of green algae. Green algae numbers likewise diminish as the water proceeds through the park ponds, with the Raccoon River highest, the pond midpoint lower, and finally the pond outfall the lowest, exactly opposite what was observed for cyanobacteria. It appears that the circulation and turbulence that are characteristic of the Raccoon River and Crystal Lake favor green algae over cyanobacteria, perhaps due to the disruption of the buoyancy control abilities inherent to cyanobacteria. Figure 5 illustrates green algae counts for each site during the third quarter, and Figure 6 compares average cyanobacteria numbers with average green algae numbers during third quarter.

Figure 5: 3rd Quarter Green Algae



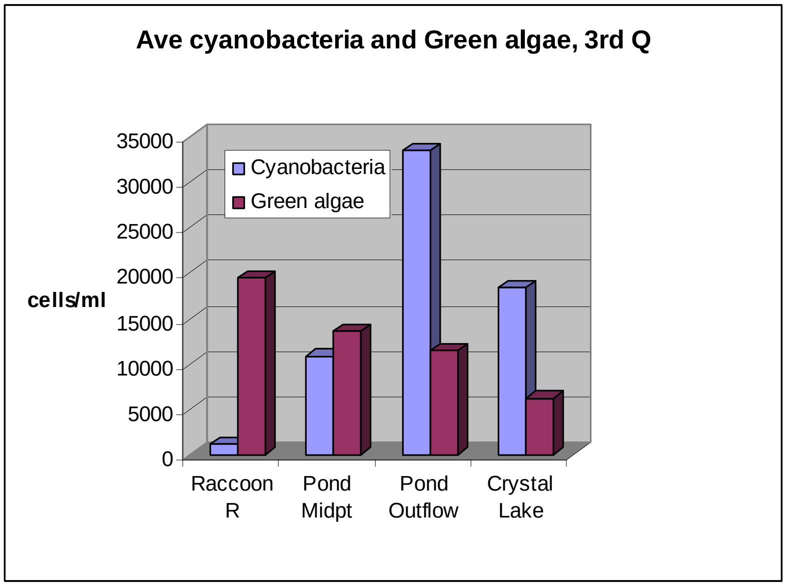


Figure 6: average cyanobacteria vs. average green algae

B. *E. coli*

Although *E. coli* likely play little or no role in denitrification, the utility is interested in their fate and numbers as river water is introduced into the off-river storage reservoirs. The Raccoon River is highly impaired by *E. coli*. Figure 7 depicts average and maximum *E. coli* measurements at each of the four sites during the third quarter.

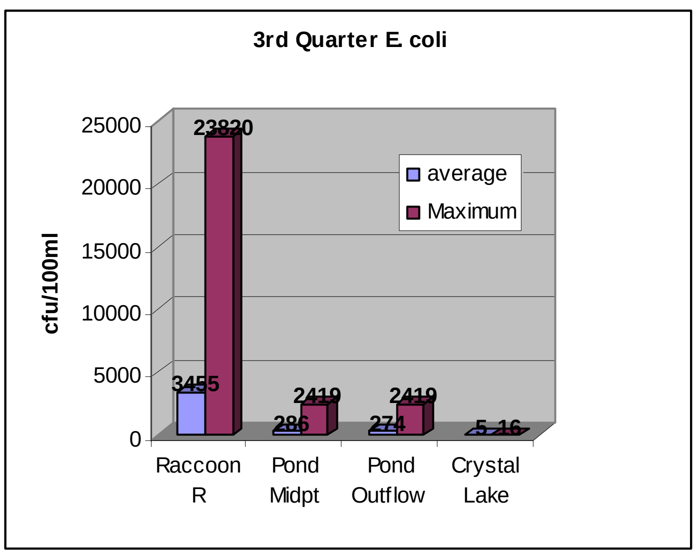


Figure 7: 3rd Quarter *E. coli*

Some surprisingly low *E. coli* numbers were observed in the river during the 2nd quarter. However, the third quarter saw a return to the historically high numbers observed in years past. A total of all the measurements made by DMWW during 3rd quarter showed Raccoon River *E. coli* exceeded the safe contact standard (200 CFU/100ml) 66% of the time. It continues to be apparent that *E. coli* perish after they are introduced into the off-river storage reservoirs, especially Crystal Lake. Numbers in Crystal Lake are likely lower than the ponds due to a much longer detention time.

IV. Chemistry Data

A. Nitrate

Because it is the primary treatment challenge for DMWW, and because the Raccoon River is one of the most nitrate-impaired streams in the U.S., this contaminant is the primary focus of this investigation. Figure 8 below shows 3rd quarter nitrate results for the four sample locations.

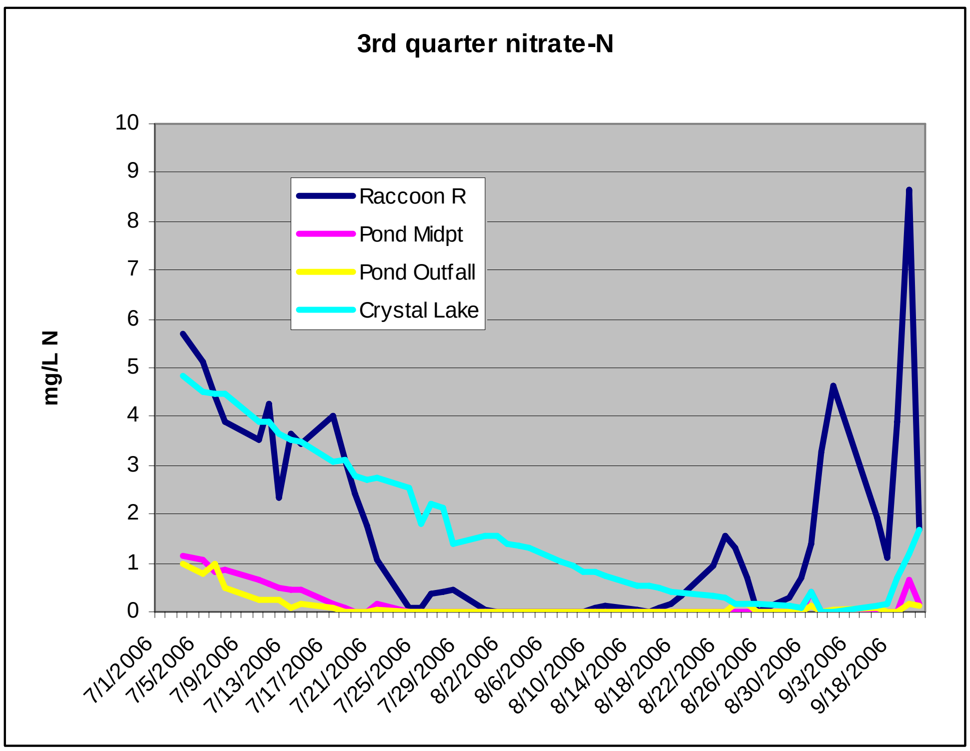


Figure 8: 3rd Quarter Nitrate Data

The most remarkable thing about the data in Figure 8 is the high nitrate values measured in the Raccoon River during September. This is quite unusual, and can be explained by the wet September weather; dry weather during much of the growing season left much nitrate unused and susceptible to runoff; and mineralization of soil during August due to the dry weather. Figure 8 illustrates how biological activity during mid-summer consumes nitrate rapidly in both the off-river storage reservoirs and the river. One can also see how the nitrate in the off-river storage responded to the high river nitrate episode at the end of September. Nitrate levels in the river never exceeded the drinking water standard of 10 mg/L during the 3rd quarter.

Low nitrate concentrations in the off-river storage reservoirs continue to be very encouraging. Assuming cyanobacteria can be controlled, it appears pond overflow water can indeed be used as low-nitrate dilution water for the Fleur Drive Plant.

As discussed in the 2nd quarter technical report, it's apparent the Solarbee circulators neither enhanced nor disrupted the process of nitrate consumption in Crystal Lake. This was very good news, and indicates that denitrification is not dependent on cyanobacteria to any large degree. A comparison of 2005 vs. 2006 (without and with the circulators) is shown in Figure 9, along with Raccoon River nitrate data.

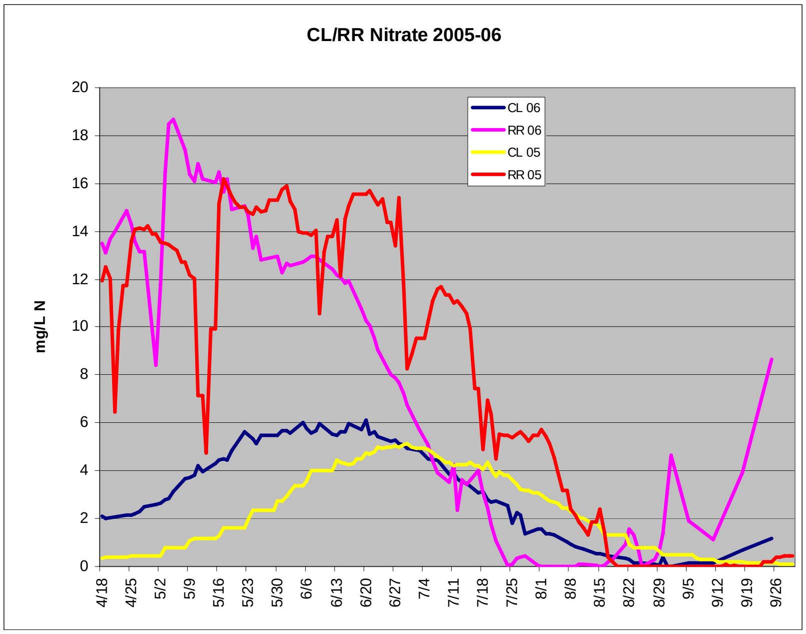


Figure 9: Crystal Lake and Raccoon River Nitrate, 2005 and 2006

The Crystal Lake nitrate peak is a little higher in 2006 than in 2005, and occurred slightly earlier. But, water injection began earlier in 2006 than in 2005, and nitrate levels were higher early in the year of 2006, when compared to 2005. At this point a conclusion can be reached: denitrification and repression of cyanobacteria are not mutually exclusive.

B. Total and Organic Nitrogen

Total nitrogen continued to be assessed weekly at the four sites during the 3rd quarter. This parameter is important because it indicates the fate of the nitrate nitrogen—denitrification to the atmosphere, or assimilation into plant protein. From total nitrogen and nitrate data, we can deduce the % of total nitrogen that is organic nitrogen. Figure 10 below illustrates average organic nitrogen data for the 3rd quarter.

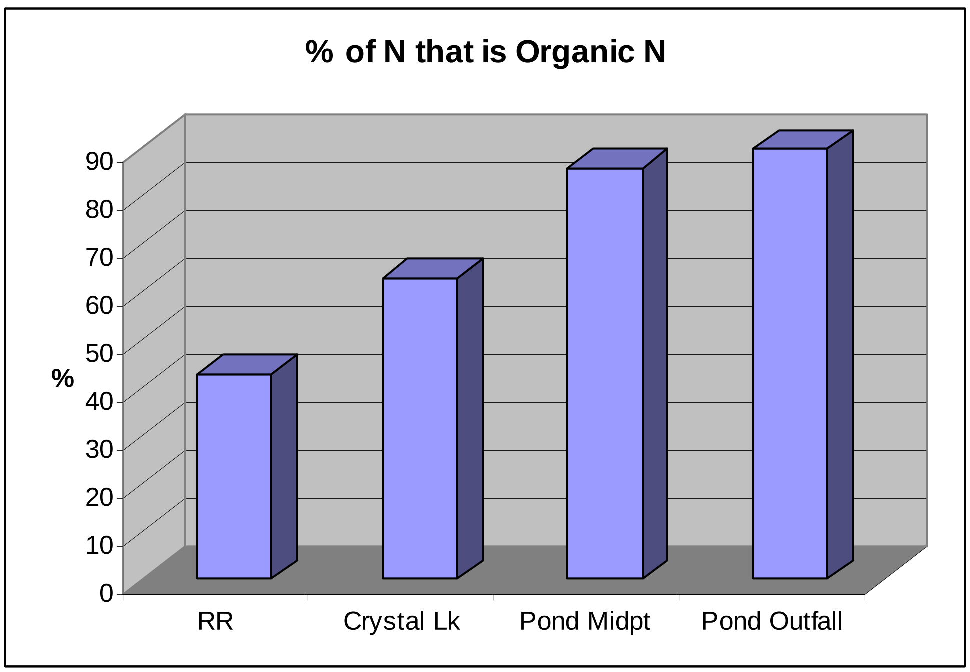


Figure 10: % Organic N of Total N

Two conclusions can be made concerning the data in Figure 10 and the other nitrogen data in this report. The first is that high N values are almost always due to high nitrate-N. The second conclusion is that as river water is introduced into off-river storage, some of the nitrate-nitrogen is converted to organic nitrogen. The percentage of organic nitrogen was also higher in the third quarter than in the second. This could be due to increased plant growth in the warmer water of the third quarter.

The total nitrogen data for Crystal Lake is especially interesting. Figure 11 below illustrates total nitrogen and nitrate-nitrogen during the 2nd and 3rd quarter.

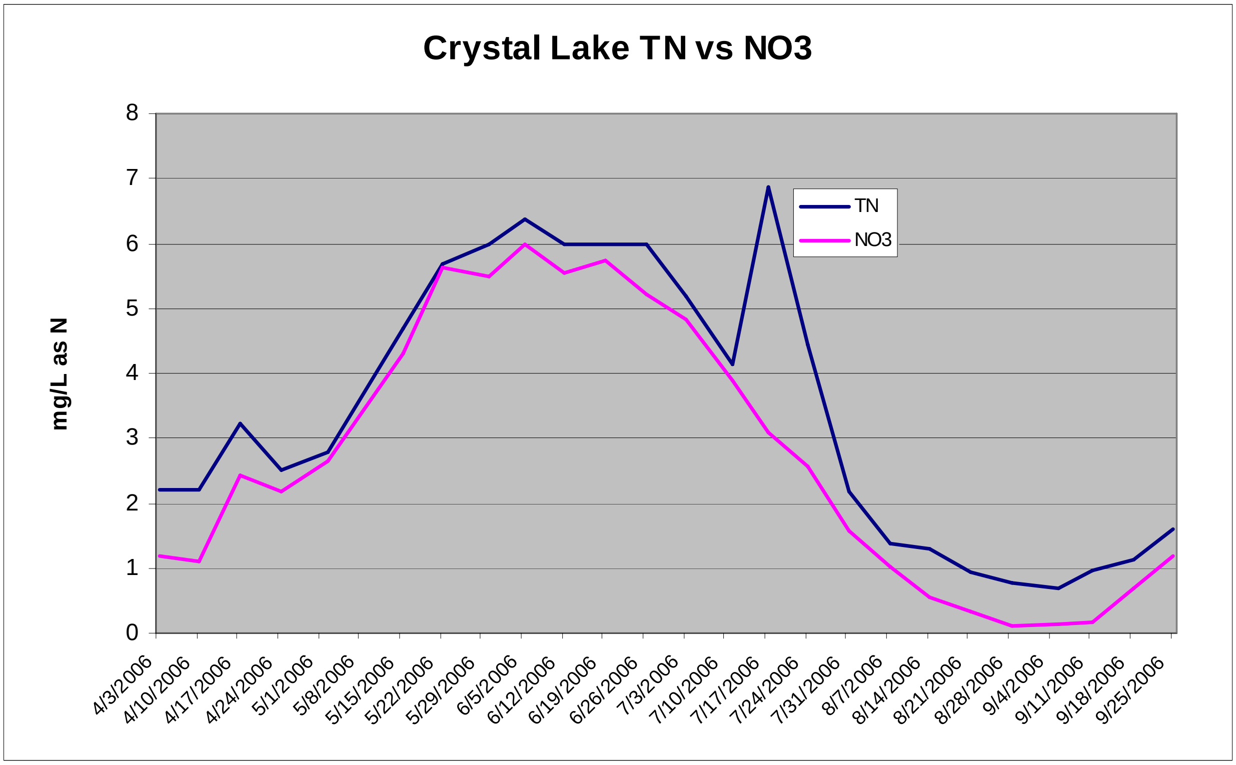


Figure 11: Crystal Lake, TN vs. NO3-N, 2nd and 3rd Quarter

For a few weeks during the summer, a gap develops between TN and NO3-N. Some assimilative denitrification, where nitrate nitrogen is converted to organic nitrogen by various microorganisms and plants in the lake, could be occurring during this time period. For the other three sites, there are not dramatic long-term differences between TN and NO3-N. At the other three sites, nitrate uptake likely is occurring exclusively by the dissimilative pathway, where nitrate-N is converted to NO, NO_2, and N_2. This is an important distinction and may be important when considering design parameters for off-river storage.

The question now becomes what organisms are responsible for this period when assimilative denitrification is occurring in Crystal Lake. The cyanobacteria data reporter earlier and the green algae data (Figure 12) would seem to indicate it is not these organisms. This would then leave bacteria or higher plants, or both, as the assimilating species. There was one short-lived spike in green algae numbers toward the end of July, but the assimilative denitrification appears to have begun prior to this.

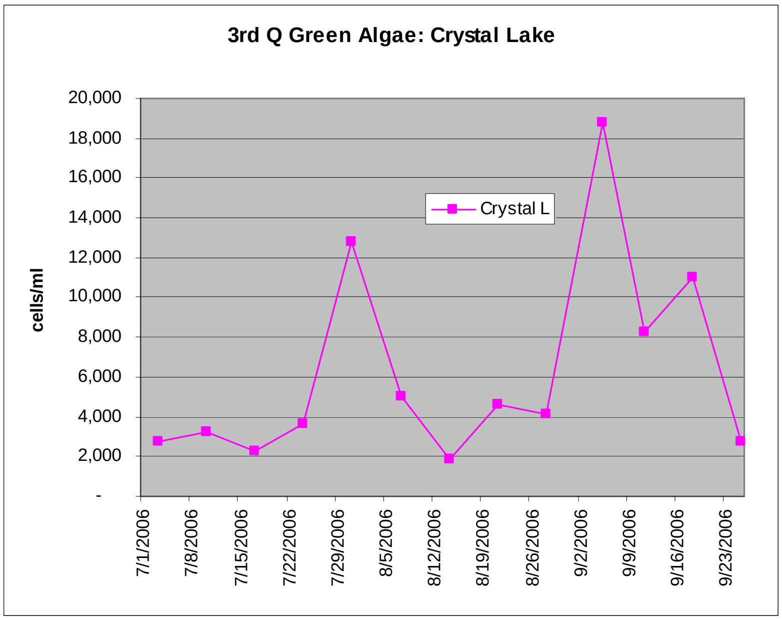


Figure 12: Crystal Lake Green Algae

C. Other Chemistry Data

Total Organic Carbon (TOC), total phosphorous (TP), and ortho phosphorous (OP) did not vary to any significant extent throughout the 3rd quarter for any of the four sample sites. At this time, these parameters do not appear to be that important for denitrification, either assimilative or dissimilative. OP was detected in only one of about 190 samples. TP numbers are not spectacularly high, but they are obviously high enough to maintain cyanobacteria in the park ponds. TOC values are similar at all four sites, with little temporal variation. The park ponds contain slightly more TOC than the river or Crystal Lake.

Turbidity (Figure 13) shows no real trend throughout the quarter, except that high river turbidities correlate with rain events. At this time it does not appear turbidity has a bearing on denitrification at the four sites. It should be mentioned, however, that high levels of turbidity in Crystal Lake or the park ponds could potentially disrupt the denitrification process, especially assimilation, should these high turbidity episodes somehow occur in the future.

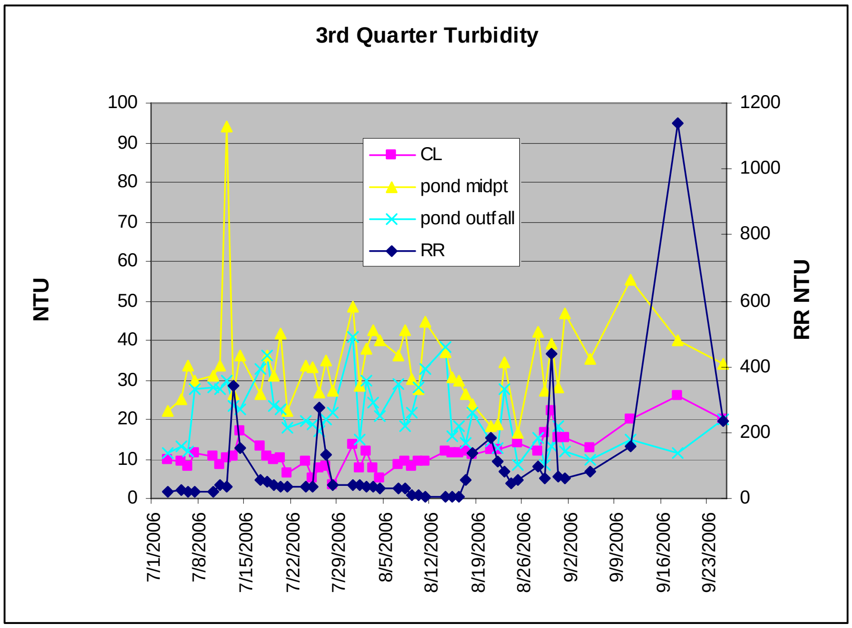


Figure 13: 3rd quarter turbidity

V. Other Data Considerations

A. Denitrification Rates

As stated in the work plan, the author will use available data from this project to estimate/calculate denitrification capacities for the off-river storage reservoirs. An attempt was made to do this for Crystal Lake using the 2nd and 3rd quarter data. This will also be calculated for the park ponds when 4th quarter data is complete. At this time it is felt that more data is needed for the park ponds.

Using nitrate concentrations in the lake and river, and water volumes in and out of the lake, calculating the denitrification capacity of the Crystal Lake is fairly straightforward. It should be said here that the term denitrification is used rather loosely; the author intends this to mean consumption of nitrate (either assimilative or dissimilative), rather than classic dissimilative denitrification to nitrogen by anaerobic microorganisms.

Figure 14 below charts three variables: Crystal Lake water temperature (F), average nitrate concentration in the lake (mg/L), and the rate at which nitrate was consumed in the lake per 10 million gallons of lake water volume.

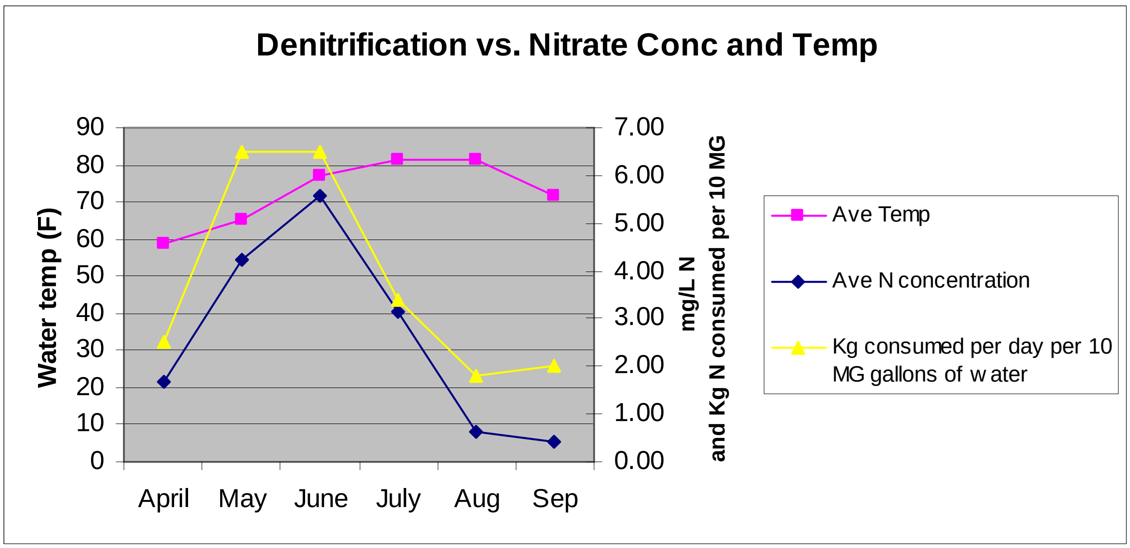


Figure 14: Crystal Lake Denitrification

It’s obvious that consumption of nitrate by the lake’s organisms is much more dependent on the actual nitrate concentration in the lake rather than water temperature. Therefore, the more nitrate in the lake, the faster it is consumed. This is what one might expect to see if anaerobic, dissimilative denitrification was occurring. The data in figure 11 seem to imply that both assimilative and dissimilative denitrification can occur in Crystal Lake. This question will be explored further during the fourth quarter.

B. Data Completeness

1. Laboratory Measurements

The third quarter sampling plan called for a total of 1324 sample measurements, not including the nitrate removal facility discharge monitoring. Actual measurements successfully completed totaled 1305, for a completion rate of 98.6%. Fourteen analyses were rescheduled and run on the next calendar day.

2. Field Measurements

A total of 207 measurements were scheduled, and 203 were completed (98.1%).

VI. Presentation of Data

Per the work plan, two trips were planned to State AWWA meetings to present the data and the progress of this project. One of these was taken during the third quarter. The author was invited to present this information at the Minnesota AWWA meeting in Duluth, MN on September 20, 2006, where the results were presented in an hour-long seminar titled "Using Off-River Storage for Biological Denitrification."

The author also presented results of this project at the Iowa AWWA meeting in Council Bluffs, IA on October 4, 2006, where the information was presented in an hour-long seminar titled "Monitoring and Control of Blue-Green Algae." This will be included in fourth quarter charges.

VII. Fourth Quarter Plans

Scheduled monitoring will continue during the fourth quarter, as outlined in the work plan. One additional sampling event will occur for cyanotoxins. Characterization of the nitrate consumption process in the park ponds and Crystal Lake will continue, and will be a critical part of the project. The denitrifying capacity of the park ponds remains to be calculated, and this will be conducted during the fourth quarter. Additional calculations using the Crystal Lake data will also take place.

Finally, these calculations will be used to estimate the total area and volume of treatment sinks needed in the Raccoon River Watershed to mitigate the nitrate impairment for the Des Moines Water Works and its customers, perhaps the most important aspect of the project.