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
4th Quarter and Final 2006 Annual

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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 4th quarter period of 2006, and conclusions are reached about the data as it was accumulated for the entire year.

The 4th quarter typically begins with low-to-medium nitrate levels in area rivers. As the water cools, and then eventually freezes, in-stream biological uptake ceases. For other reasons that are not well understood, and not explained solely by the end of in-stream uptake, nitrate levels climb throughout the quarter, usually peaking as the year ends. This can require nitrate removal or blending for DMWW finished water to remain below the 10 mg/L limit for treated drinking water. Part of this late-season nitrate increase may be due to fall application of anhydrous ammonia to cultivated fields.

After crops dry and are harvested in the fall, little moisture uptake occurs throughout the DMWW watersheds. Overland runoff again can become significant during precipitation events. Early season snowfall can also melt, creating runoff events. During normal precipitation years, agricultural drain tiles flow with water during the fourth quarter. This water can contain high levels of nitrate.

Precipitation in the Raccoon River Watershed was near normal to slightly below normal during October. Both November and December saw precipitation levels significantly above normal. Temperatures were also much above normal during this period. Average daily flows in the Raccoon reflected these climatic conditions, and were at or near 10-year highs for much of the period.

II. River Flow into Off-River Storage Reservoirs

Water was delivered from the Raccoon River into the Park Ponds at a 1.2 million gallon per day (mgd) rate every day of the 4th quarter. This affected a constant overflow estimated at 200,000 gallons per day. Improvements and modifications to the levee system separating the ponds from one another continued during the fourth quarter, 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, and water continued to flow into this basin throughout the fourth 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. Water volume delivered to this west basin was estimated to be 4.7 mgd. The affect of this basin on infiltration gallery yield will be discussed later in the report.

At the Maffitt Treatment Plant site, Raccoon River injection into the gravel pit known as Crystal Lake took place until October 16th, when maintenance and climatic issues required cessation of river water injection. Water from Crystal Lake was used for treatment in the plant also until October 16th. The utility did not want to deplete the volume of water in the lake, so the decision was made to interrupt its use. On November 7, the utility began injecting 0.7 mgd of water from radial collector well 1 into the lake to increase water elevation. Nitrate levels were monitored in well 1 water during this time so that mass balance calculations could be performed for the purposes of this project. All told during 4th quarter, 47 million gallons of lake water was used for treatment in the Maffitt plant; 37 million gallons of river water and 38 million gallons of water from well 1 were injected into the lake. During the 4th quarter, low nitrate dilution water was not needed; water from Crystal Lake simply enhanced yield from the wells.

The solar-powered circulators operated throughout the 4th quarter and continued to suppress cyanobacteria blooms. This data will be presented later in the report.

III. Physical Data

Physical data monitored throughout the course of this project included total river flow, temperature, river flow volume into off-river storage reservoirs, and flow out of the reservoirs, either back to the river or into the treatment plant. The following graphs depict physical parameters monitored during the fourth quarter.

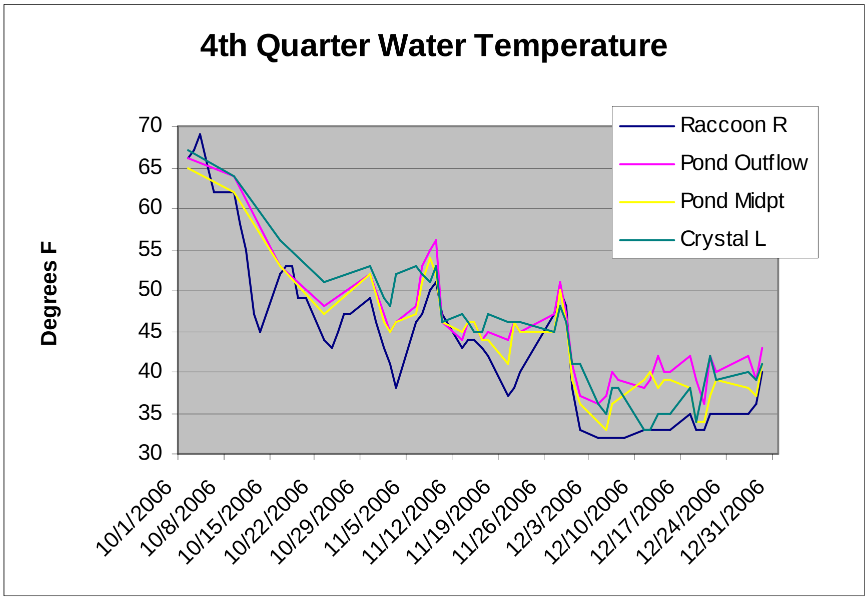

Figure 1: Water Temperature

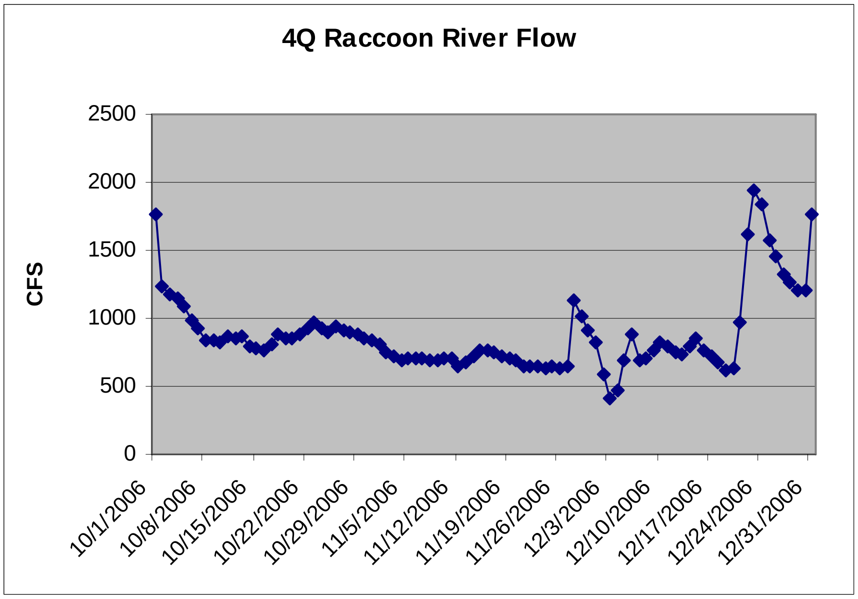

Figure 2: Raccoon River Flow

Rain events toward the end of September started a trend of relatively high river flows throughout the fourth quarter. Daily average flow volumes were at or near 10-year highs for the entire quarter. Water temperatures were somewhat higher than expected toward the end of the quarter. Generally, lakes are frozen over in Iowa by the end of December. The off-river storage reservoirs never had much more than a skim layer of ice throughout the quarter.

IV. Biological Data

A. Cyanobacteria

Repression of cyanobacteria is critical to the success of the off-river storage for nitrate mitigation scheme, and monitoring of the various sample locations was an important part of this project. Blooms of cyanobacteria can impart unpleasant tastes and odors to the finished water, and under some conditions the organisms can produce substances that have human toxicity. Thus, they are an emerging issue to the water industry as more becomes known about their life processes and the deleterious affects they can have on finished drinking water.

As has been mentioned in previous reports, the Crystal Lake (gravel pit at the Maffitt Plant) water is circulated with two solar-powered devices. These draw 3000 gallons of water from near the bottom of the lake and then distribute it by laminar flow across the lake's surface. An additional 7000 gallons per minute of flow is induced by this circulation. Although previous reports touched on the distribution of phosphorous playing a role in repression of the cyanobacteria, the author now believes that the repression mechanism is entirely due to disruption of the 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.

Cyanobacteria did in fact remain manageable throughout the 4th quarter and the entire calendar year of 2006. The utility's goal was to maintain numbers in the lake below 100,000 cells per ml. At levels below this, the number of cyanobacteria in the total source water blend (Crystal Lake water is diluted by radial collector well water) remain below the recommended level of 15,000 cells/ml. Figure three below illustrates cyanobacteria numbers throughout 2006 and contrasts their levels with those seen in 2005.

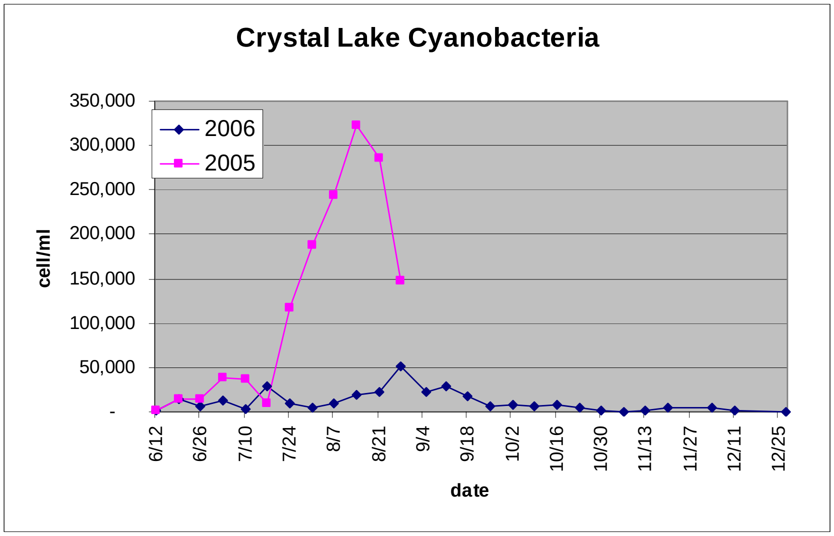

Figure 3: Crystal Lake Cyanobacteria, 2005 vs. 2006

Monitoring was discontinued in 2005 after September 1. Clearly, cyanobacteria numbers remained manageable even though very-high-nutrient water was injected into Crystal Lake. The opinion of this author is that the circulation induced by the solar powered devices was the reason 2006 cyanobacteria numbers were so much lower than those observed in 2005.

Figure 4 illustrates cyanobacteria numbers in all the sample locations during 4th quarter. The park pond outfall once again had the highest average cyanobacteria population, reinforcing the idea that detention time is a very important factor for cyanobacteria blooms in the off-river storage reservoirs. Water detention time at the pond outfall was about 11 days during the 4th quarter, whereas at the midpoint it is about 5-6 days. No large blooms were seen in the Raccoon River. A relevant question was: were cyanobacteria numbers in the off-river storage reservoirs dependent upon nitrate or total nitrogen levels? The answer to this question was no in all cases: Crystal Lake, pond midpoint, and pond outfall. Graphs of this data are shown on the next page.

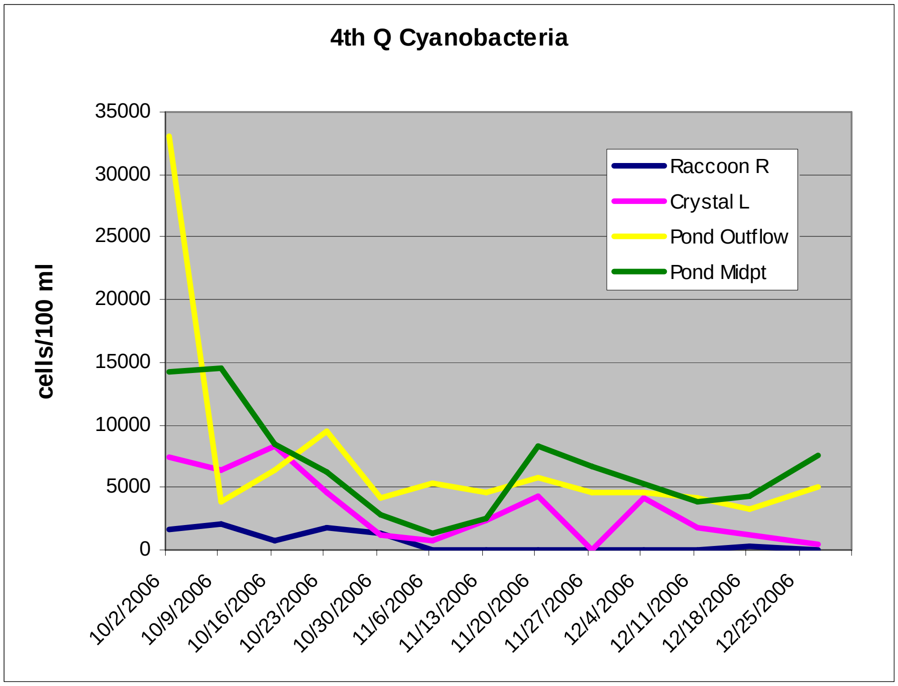

Figure 4: 4th Quarter Cyanobacteria

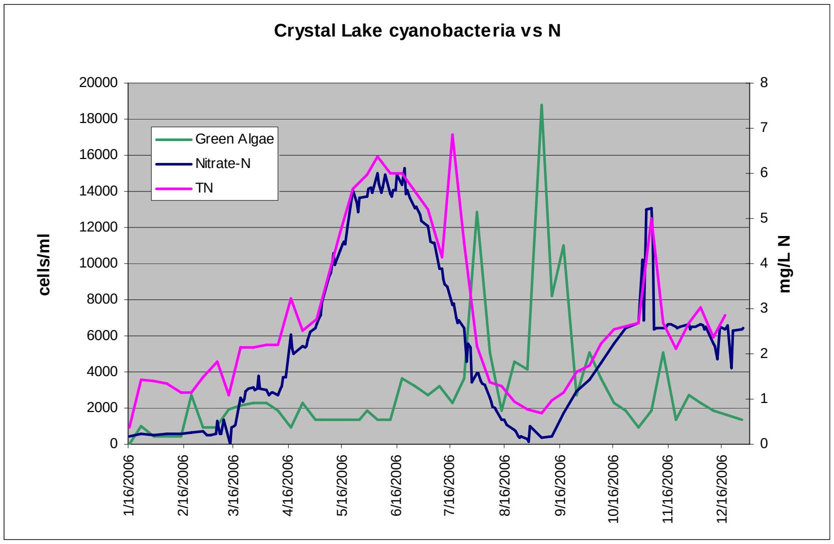

Figure 5: Crystal Lake Cyanobacteria vs. N

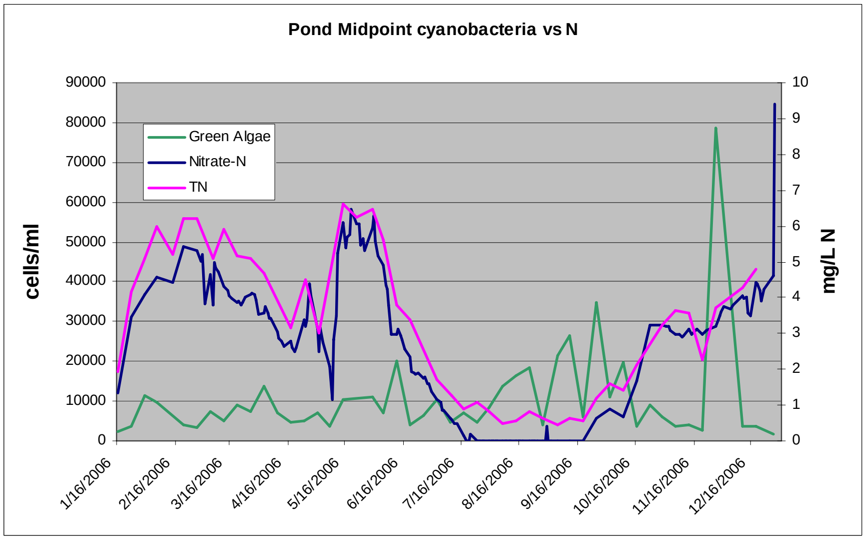

Figure 6: Pond Midpoint Cyanobacteria vs. N

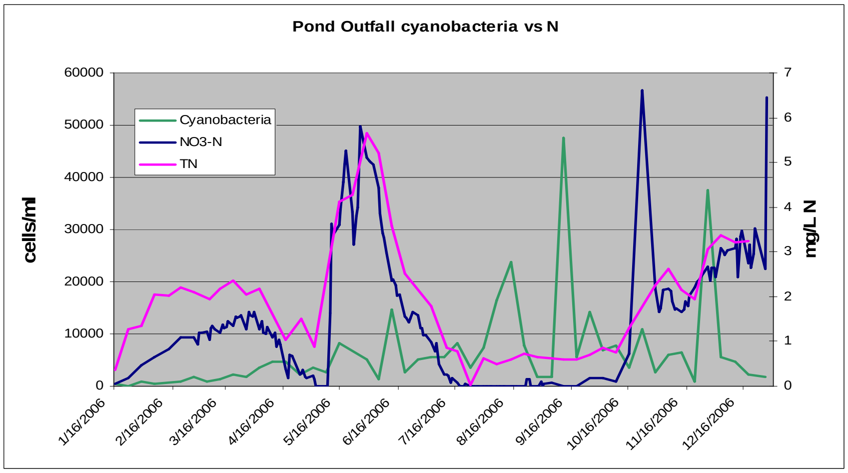

Figure 7: Pond Outfall Cyanobacteria vs. N

It is apparent that factors other than nitrogen control blooms of the cyanobacteria, which is consistent with other known research. These factors likely include climatic conditions and the N:P ratio.

Per the work plan, one sample from the park ponds and one sample from Crystal Lake were evaluated during 4th 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, as was the case during the 3rd quarter.

B. Green Algae

Green algae are important to this investigation because they assimilate nitrate into their cells, converting it to organic nitrogen and theoretically could reduce nitrate concentrations in the surface waters of interest. DMWW staff had speculated that this nitrogen uptake might be significant in reducing nitrate numbers in the Raccoon River. 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.

Raccoon River green algae diminished substantially from the 3rd to 4th quarters. The pond midpoint had by far the highest numbers of green algae, and once again, green algae numbers diminish as the water proceeds through the park ponds. In all the sites tested, both cyanobacteria and green algae numbers diminished from 3rd quarter to 4th quarter, even though average nitrate levels increased. This is evidence that climatic factors are more important than the nitrogen levels for both green algae and cyanobacteria blooms. Figure 8 illustrates green algae counts for each site during the fourth quarter, and Figure 9 compares average cyanobacteria numbers with average green algae numbers during fourth quarter.

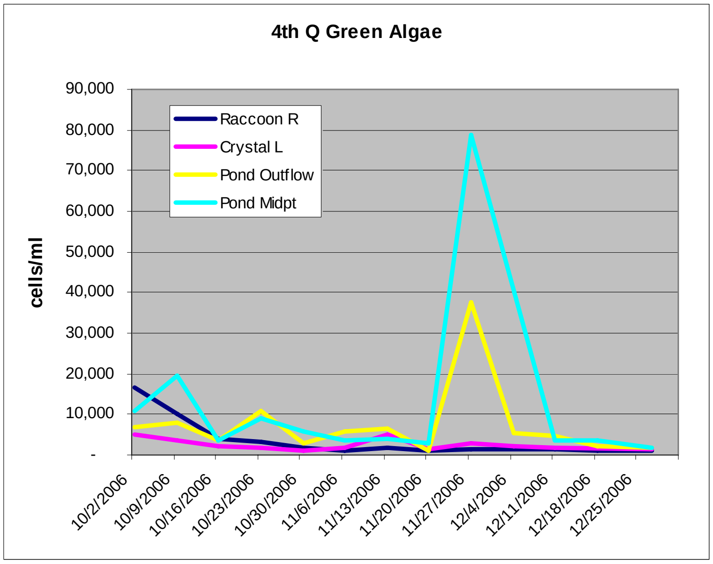

Figure 8: 4th Quarter Green Algae

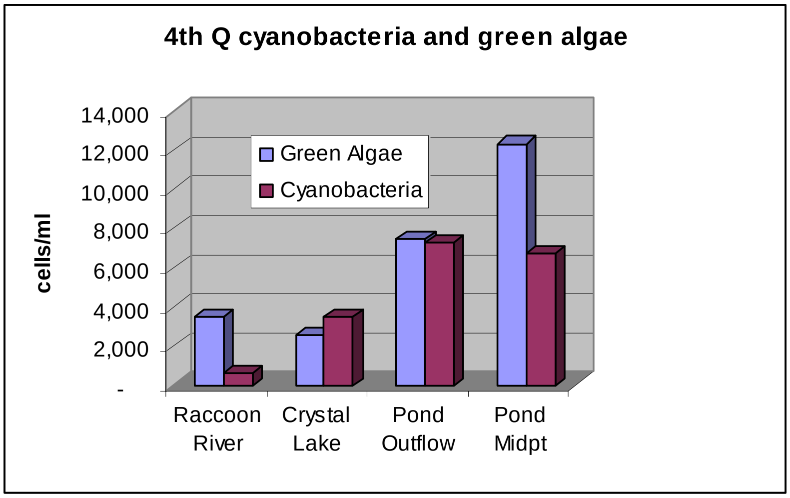

Figure 9: average cyanobacteria vs. average green algae

A good correlation between nitrogen values and green algae populations exists only for the pond midpoint location..

C. *E. coli*

Although *E. coli* 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 10 depicts average and maximum *E. coli* measurements at each of the four sites during the fourth quarter.

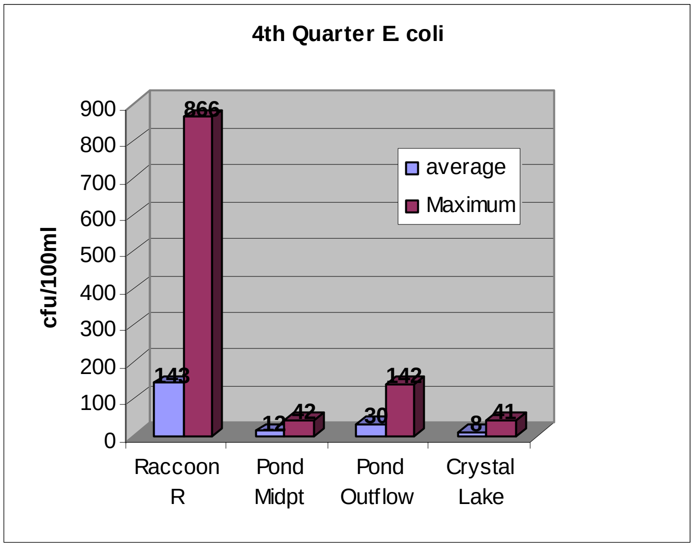

Figure 10: 4rd Quarter *E. coli*

Average *E. coli* levels at all four sites met the safe contact standard of 200 CFU/100ml. Two out of the 13 Raccoon River *E. coli* samples exceeded the safe contact standard, a large improvement from the 3rd quarter. When all DMWW samples are considered (not just the ones connected with this project), the safe contact standard was exceeded in the river 20% of the time, again a large improvement from the 3rd quarter, when the standard was exceeded 66% of the time. Unfortunately, not much recreation takes place in the river during the fourth quarter. It continues to be apparent that *E. coli* perish after they are introduced into the off-river storage reservoirs, based on the numbers seen in the Crystal Lake and the ponds.

V. Chemistry Data

A. Nitrate

DMWW's surface and groundwater sources are seriously impaired with nitrate, and the utility has struggled to meet the safe drinking water standard of 10 mg/L since 1979. Finding creative ways to mitigate the nitrate issue is the main thrust of this project. Figure 11 below shows 4th quarter nitrate results for the four sample locations.

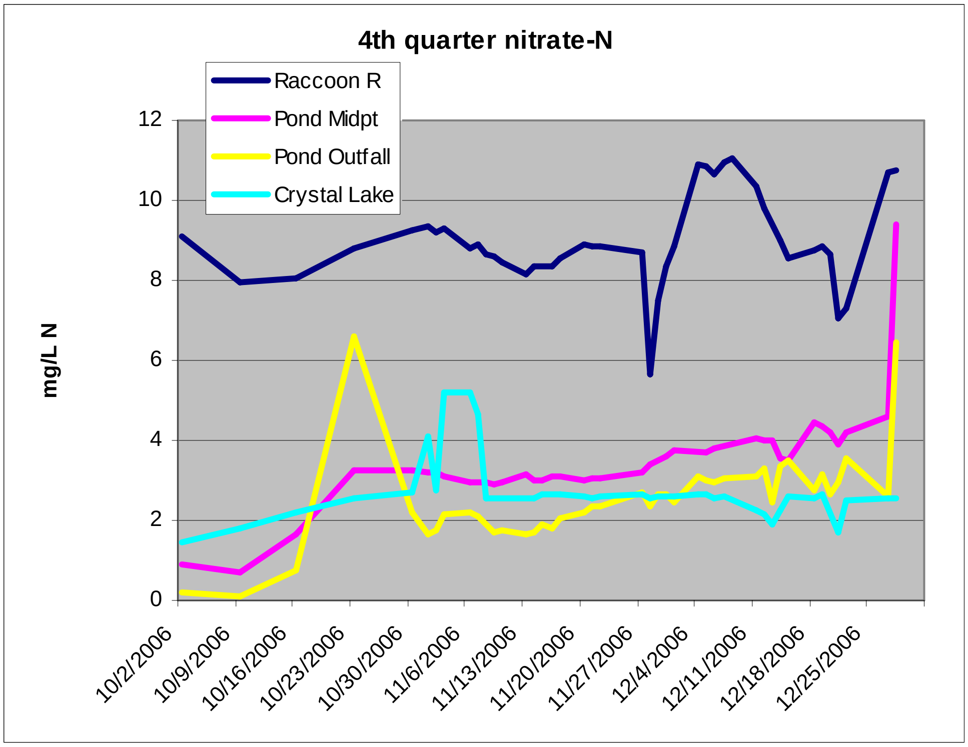

Figure 11: 4th Quarter Nitrate Data

Nitrate values were consistently high throughout the fourth quarter in the Raccoon River. High November and December nitrate levels are not unusual; high October levels are less common. Wet weather in late August, September, November, and December likely kept agricultural drain tiles running, contributing to the high nitrate concentrations. It could be that dry weather during the growing season left much nitrate unused and susceptible to runoff during the late 3rd quarter and 4th quarter. Raccoon River flows, as mentioned earlier, were well above average throughout the fourth quarter. As biological activity in the off-river storage reservoirs subsides with the cooler weather, nitrate levels increase in these samples. Why nitrate levels spiked in Crystal Lake during the first part of November is not clear, and this may be a sampling anomaly.

That nitrate levels in the off-river storage reservoirs continued to be much lower than the river was very encouraging. Fourth quarter data confirms that pond overflow water can indeed be used as low-nitrate dilution water for the Fleur Drive Plant.

As discussed in previous reports, it continued to be apparent that the Solarbee circulators neither enhanced nor disrupted the process of nitrate consumption in Crystal Lake. This is evidence 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 12, along with Raccoon River nitrate data. This graph was also shown in the 3rd quarter report, but is repeated here because of its importance to the overall project.

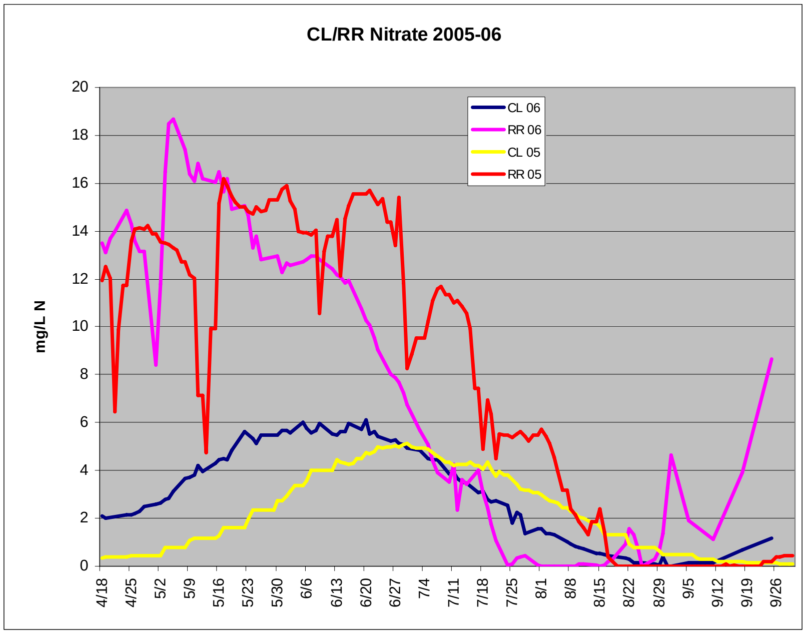

Figure 12: Crystal Lake and Raccoon River Nitrate, 2005 and 2006

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 4th 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 13 below illustrates average organic nitrogen data for each of the four quarters during 2006.

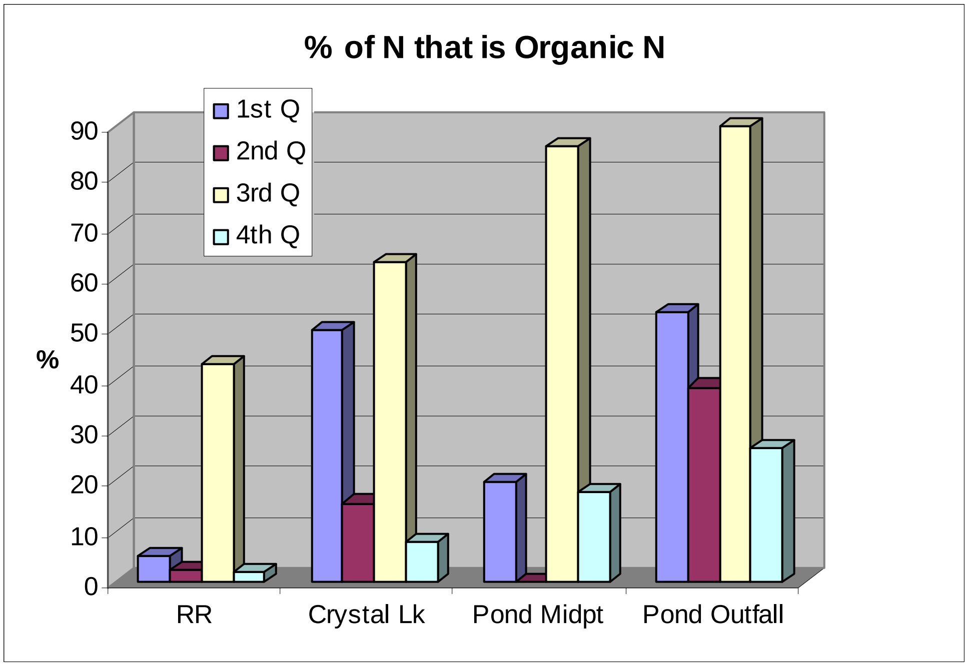

Figure 13: % Organic N of Total N

Obviously, the % of total nitrogen that is organic nitrogen is much higher during the peak water temperature period of the 3rd quarter. This is especially true of the Raccoon River. It's also obvious that as river water is introduced into off-river storage, some of the nitrate-nitrogen is converted to organic nitrogen, and this conversion peaks in the third quarter. Crystal Lake nitrogen data is shown in Figure 14 for the entire year. One can see that nitrate nitrogen tracks total nitrogen very closely, except in the third quarter when a gap develops, presumably due to in-lake uptake of nitrate. Similar gaps show up in the pond midpoint and outfall samples. In almost all samples taken throughout the year, whether in the ponds or the Raccoon River, high TN values are largely due to high nitrate concentrations.

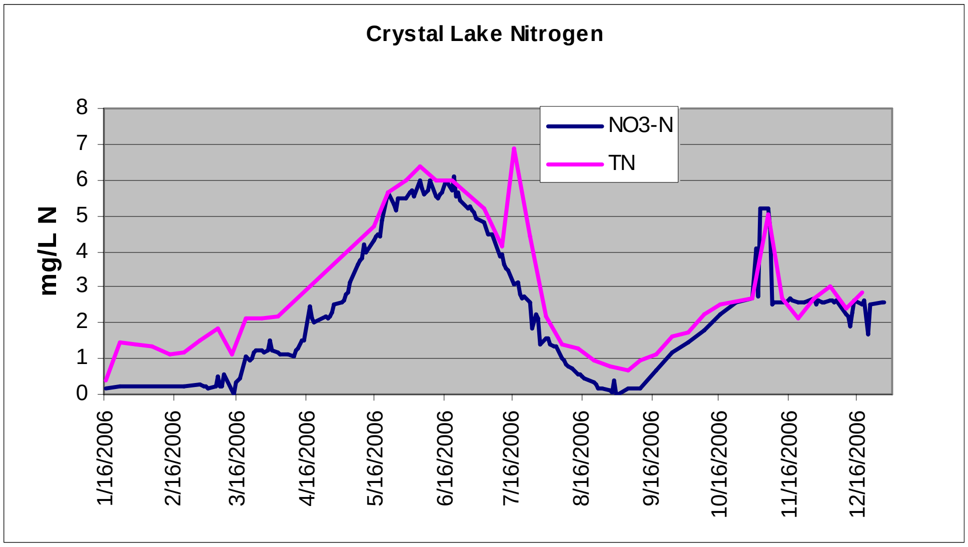

Figure 14: Crystal Lake, TN vs. NO3-N

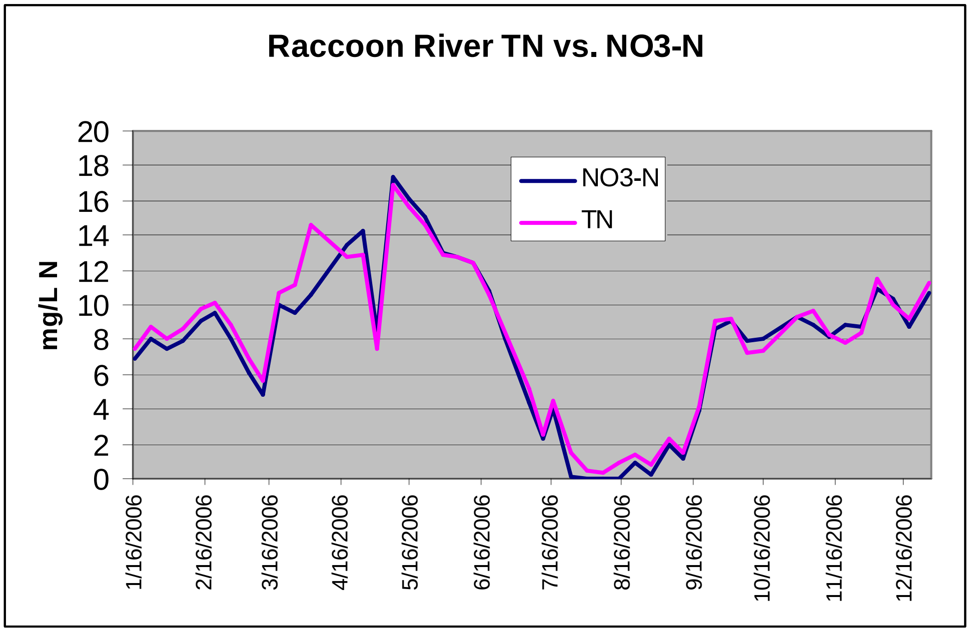

Figure 15: Raccoon River TN vs. NO3-N

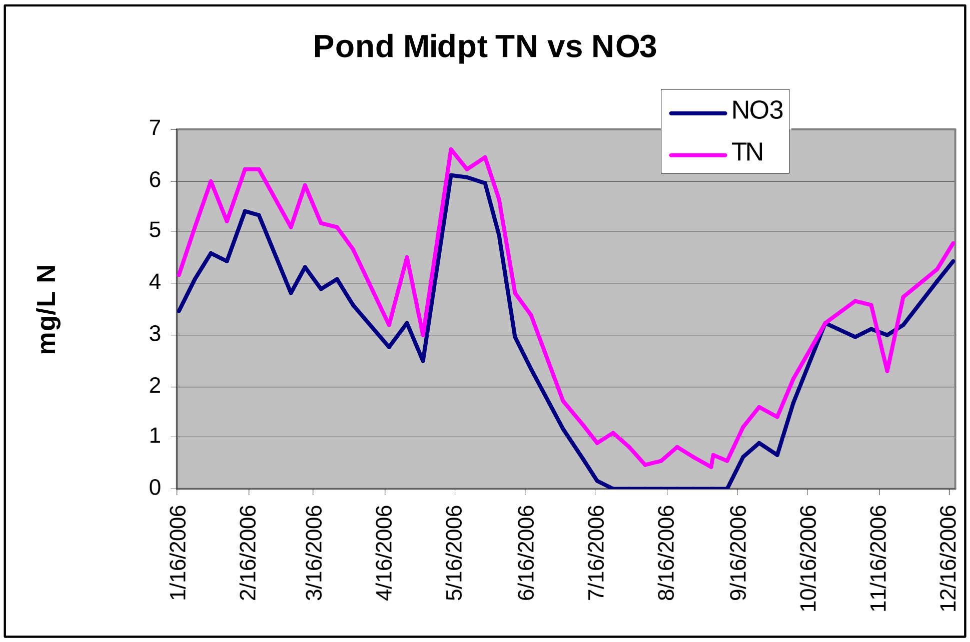

Figure 16: Pond midpoint TN vs. NO3-N

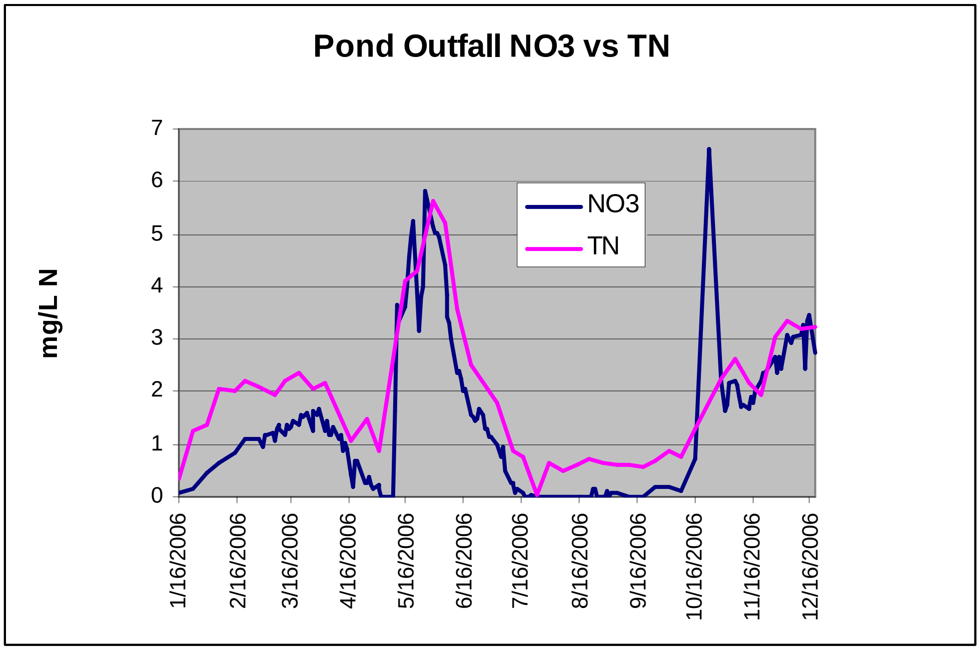

Figure 17: Pond Outfall TN vs. NO3-N

In the 3rd quarter the report, the author speculated that the denitrification process in Crystal Lake might be different than that seen in the ponds (assimilative vs. dissimilative). It has been discovered since that time that the 3rd quarter Crystal Lake TN data was transposed with TOC data. It is now believed that the denitrification processes in Crystal

Lake and the ponds do not substantially differ in mechanism, but only in magnitude. This will be discussed later.

C. Total Organic Carbon

Large day-to-day variations in TOC are observed only in the Raccoon River, as depicted in Figure 18. Seasonal variations likewise are not dramatic.

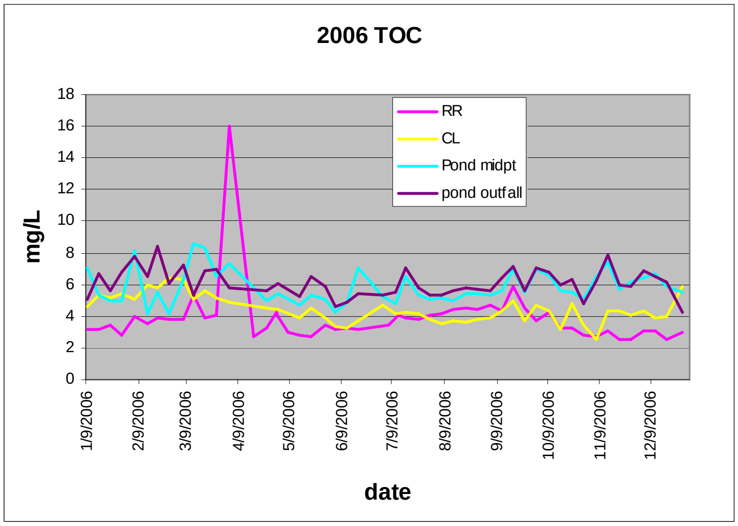

Figure 18: 2006 Total Organic Carbon

The relative average TOC level for the four samples was: pond outfall>pond midpoint>Crystal Lake>Raccoon River. This was predictable based on the levels of algae and cyanobacteria, which fix carbon and increase the total and dissolved organics in the water.

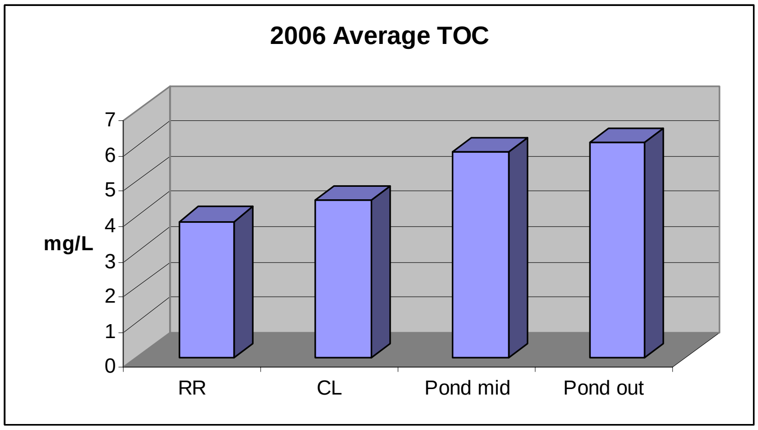

Figure 19: 2006 Average TOC levels

Certainly some organic carbon is needed for denitrification to occur, and both the Park Ponds and Crystal Lake apparently had sufficient TOC so that it was not a limiting factor.

D. Total Phosphorous

Phosphorous is an important water quality parameter because it usually is the limiting nutrient in Iowa waters, which contain an abundance of nitrogen. Figure 20 below illustrates average total phosphorous (TP) for 2006.

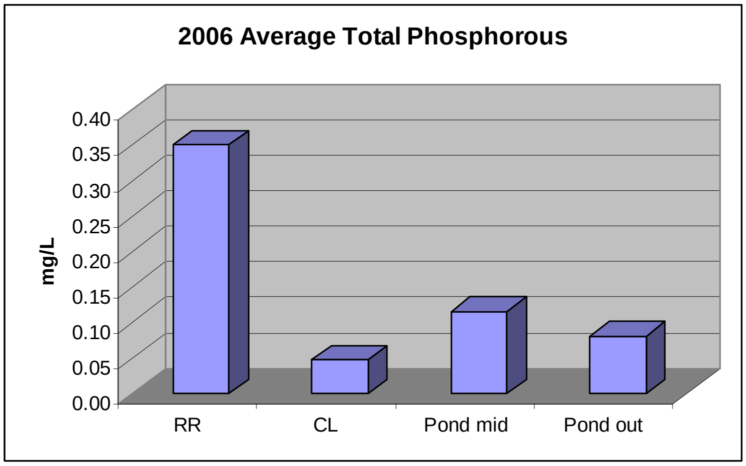

Figure 20: 2006 Average TP levels

The levels shown in Figure 20 are not remarkable by Iowa standards. The Raccoon River average is a significant amount phosphorous. Like nitrogen, much of the annual phosphorous load in the river occurs episodically, as shown in Figure 21.

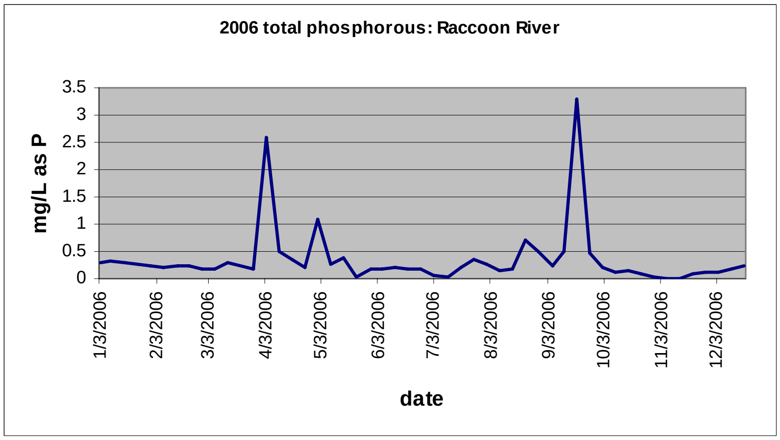

Figure 21: Raccoon River TP

E. Turbidity

Turbidity values for 2006 do not provide many insights to the denitrification process. One would expect turbidity in off-river storage to increase with algae and cyanobacteria numbers. This did occur, and Crystal Lake data is illustrated in Figure 22.

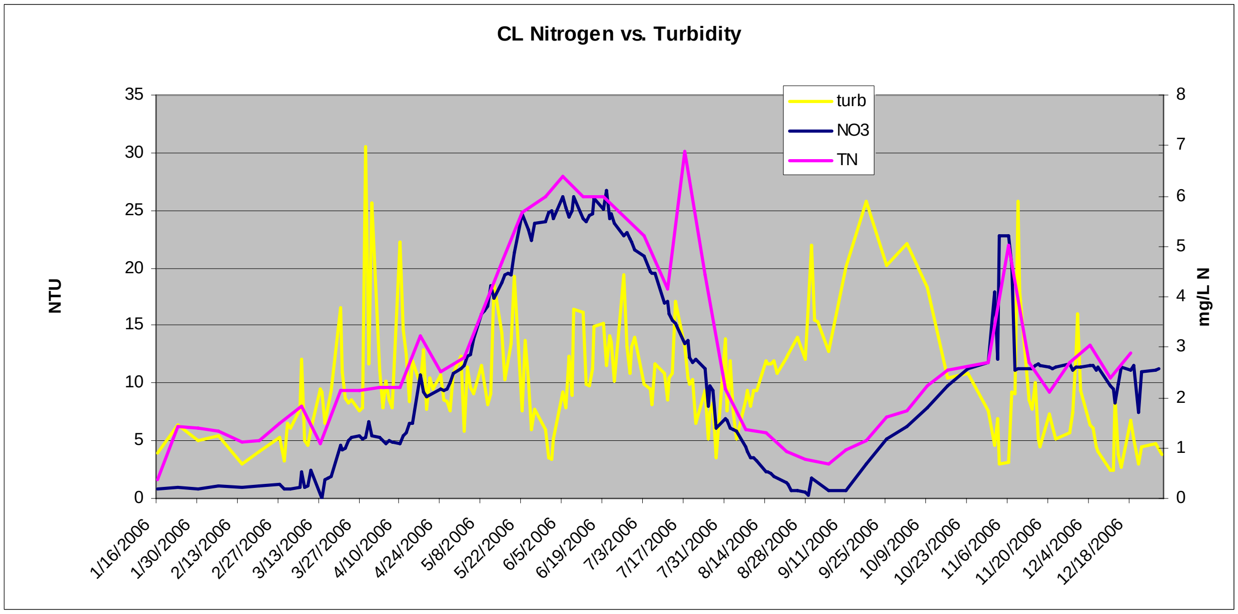

Figure 22: Crystal Lake Turbidity vs. Nitrogen

There is not a good correlation, however, with the drop in total nitrogen and nitrate nitrogen. Nitrogen levels begin to diminish before algae and cyanobacteria-related turbidity increases. This will be discussed further in the denitrification section.

F. Ortho Phosphorous

Ortho phosphorous data for the four sites throughout the year was uneventful, and the data was deemed unimportant for reaching conclusions about denitrification. A few Raccoon River samples contain O-P above the detection limit early in the year; otherwise most other samples did not contain O-P in detectable quantities.

G. Chloride

Chloride data was unremarkable and not highly dynamic. Average values hovered just above 30 mg/l for the river and pond samples, and just below 30 mg/l in Crystal Lake.

Raccoon River chloride does drop below 10 mg/L during high flow events. The pond samples did spike up to near 70 mg/l when earthmoving work was conducted on the levees.

VI. Denitrification Rates

A. Overview

As stated in the work plan, the author used available data from this project to estimate/calculate denitrification capacities for the off-river storage reservoirs.

Using nitrate concentrations in the lake and river, and water volumes in and out of the lake and ponds, calculating the denitrification rates for the off-river storage reservoirs 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, although which of these mechanisms is predominant will be discussed.

Figure 23 below illustrates the denitrification rates of the three off-river storage sample locations: pond midpoint, pond outfall, and Crystal Lake. There is one important caveat to this data. At certain times of the year, the total amount of nitrogen consumed in the first half of the ponds was mathematically equivalent to, or even exceeded that consumed in the entire pond system. This is likely an artifact related to changing flow patterns in the ponds, short circuiting that may take place when varying flows rates are injected into the ponds, and perhaps plug-flow dynamics, that make exact calculation of denitrification difficult at points other than the outflow. The calculated outflow denitrification rates are likely more accurate than those for the midpoint. That said, it is apparent that much or most of the denitrification in the pond system occurs within the first 5-6 days of detention time, considering that the total detention time in the ponds is usually about 11 days.

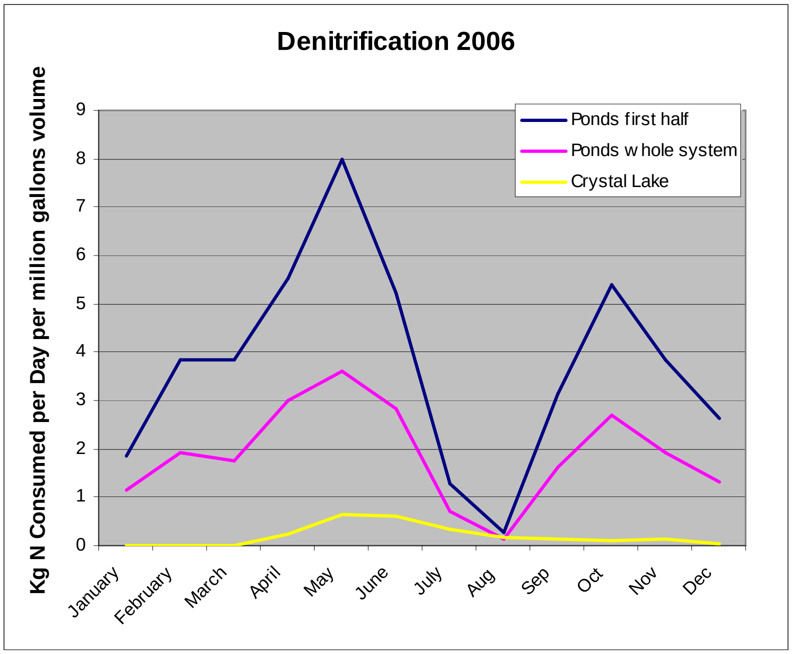

Figure 23: 2006 Denitrification

B. Effect of Nitrate Concentration on Denitrification

The number one factor determining the rate of nitrate disappearance is the nitrate concentration in the water body. The more nitrate there is, the faster it disappears. This is perhaps to be expected based on the known reaction kinetics of dissimilative denitrification. Figure 24 below illustrates this affect in the pond outfall samples.

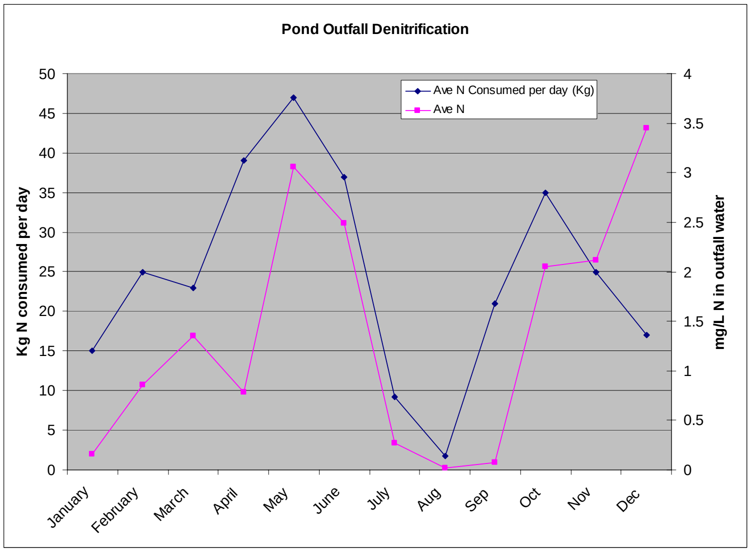

Figure 24: Pond outfall denitrification vs. nitrate concentration

One can see that nitrate is consumed most rapidly when concentrations are high, regardless of season of the year. Perhaps in December the effect of cold water is seen, when the nitrate concentration continues to go up, but the rate consumed decreases. Similar nitrate concentration-to-disappearance relationships are observed in the other two off-river storage sites. This is evidence that dissimilative denitrification is the predominant mechanism for the consumption of nitrate in both the Park Ponds, and not an assimilative mechanism used by algae and macrophytes.

C. Effect of Temperature

Somewhat surprisingly, there is not a strong dependence on temperature. Figure 25 illustrates the temperature-denitrification relationship in Crystal Lake. The most rapid period of nitrate consumption occurs prior to the warmest temperatures of the year. It must be said that denitrification rates may have continued to increase throughout the summer had more nitrate been present. As mentioned earlier, nitrate concentrations have the strongest influence on denitrification rates of the factors evaluated in this study.

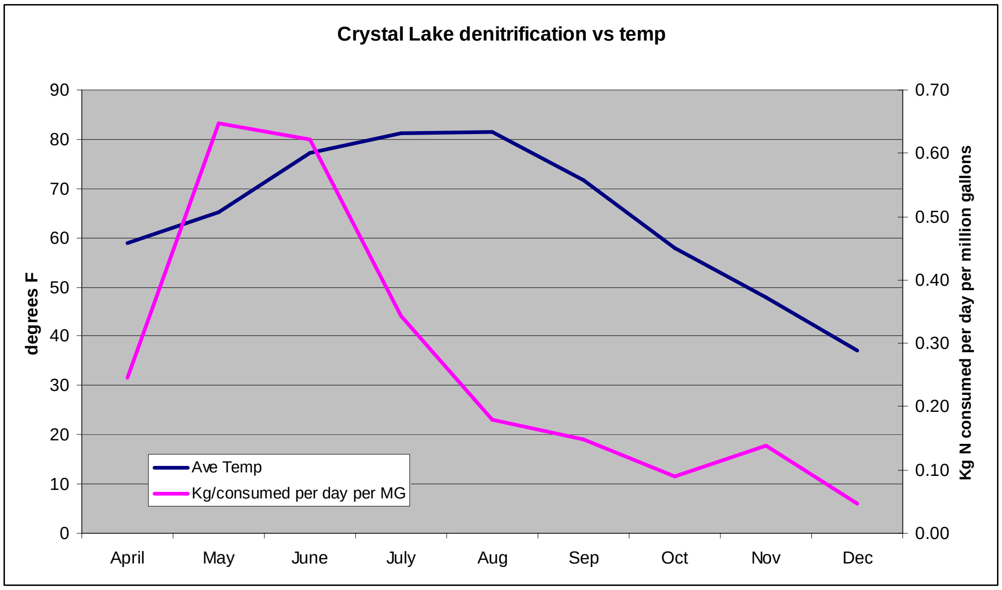

Figure 25: Crystal Lake denitrification vs. temperature

D. Effect of TOC

TOC concentrations remain fairly constant throughout the year, except during large runoff events in the Raccoon River. So there is no TOC dependence on denitrification rates observed within a water body. Figure 19 showed that average TOC values for the Pond Outflow, Pond Midpoint, and Crystal Lake were 6.1, 5.8, and 4.4 mg/L, respectively. The Pond Midpoint location has the highest average denitrification rate, but the second highest TOC value. Obviously, organisms need carbon for denitrification to occur. But it appears that organic carbon concentrations are not the limiting factor for denitrification in any of the three off-river storage locations.

E. Effect of Total Phosphorous

Figure 20 showed the average total phosphorous levels for the three off-river storage reservoir sites. Figure 26 below illustrates the average TP values for the three off-river storage locations vs. the rate of nitrate consumption from April through December. (January through March was not considered because there essentially was not denitrification in Crystal Lake during this time). There is a pretty clear correlation between phosphorous values and denitrification rates. This does not necessarily mean denitrification is dependent on phosphorous, but it seems likely that the rate will be slower in a phosphorous-deficient environment. This would not be expected to be the case in Iowa waters, which are very nutrient-rich with both nitrogen and phosphorous.

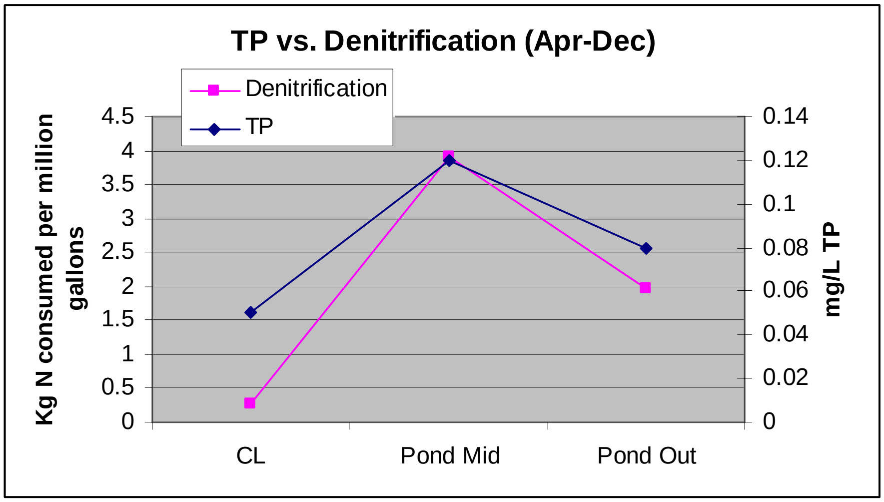

Figure 26: Denitrification vs. TP

VII. Implications for the Watershed

Nitrate impairment in the Raccoon River watershed is due to two factors: loss of natural systems and large inputs of nitrogen via anhydrous ammonia to row crops. One of the objectives of this project was to determine the practicality of using treatment sinks in the watershed that would capture high-nitrate tile water and detain it for a period of time sufficient to allow significant denitrification to occur. How could this occur, what volume of water would be necessary, and how many acres of land would this require?

There are 2.3 million acres in the watershed, with about 1.7 million in row crop. The average N load in the river at the DMWW Fleur Drive location from 1996-2005 was 17,800,000 Kg. The flow-weighted average nitrate-nitrogen concentration was 9.47 mg/L. The annual peak nitrate-N concentration can vary dramatically from year to year, but usually runs between 14 and 18 mg/L. What the goals are for the Raccoon River could be interpreted broadly. For DMWW, the peak value should not exceed 10 mg/L. To address hypoxia issues, average river nitrate levels below 3 mg/L are probably necessary.

Since the most effective treatment sinks in the DMWW study were shallow, wetland-like storage, as opposed to larger, deeper, lake-type systems, the treatment sink discussion focus on the shallow-system model. The author will use the pond outflow location as a model: 10 acres of surface area, average depth of 4 ft, with a total volume of 13 million gallons of water. The detention time in the DMWW example was 11 days.

The table below shows the denitrification rate for the pond outfall location throughout 2006:

Month	Kg/consumed per day per million gallons volume	Kg/Consumed per day total
January	1.15	15
February	1.92	25
March	1.77	23
April	3.00	39
May	3.62	47
June	2.85	37
July	0.71	9.2
Aug	0.13	1.7
Sep	1.62	21
Oct	2.69	35
Nov	1.92	25
Dec	1.31	17
Year Ave.	1.98	24.58

Table 1: Nitrogen consumed in 10 acre off-river storage, 4 ft. average depth

In the pond outfall example above, a total of 8972 Kg of nitrogen was removed from the watershed in 2006. The N load delivered to the ponds during 2006 was 9495 Kg. Since we have seen that denitrification rates increase rather dramatically with the nitrate concentration, it is possible that the denitrifying capacity of this sink could be much larger with higher nitrate concentrations, such as those seen in tile effluents, which can easily exceed 30 mg/L. In addition, it is apparent that much or most of the denitrification in the pond system occurs within the first half of the detention period (5-6 days). But for the purposes of this discussion, the author will assume that the pond outflow denitrification rate is a worst-case scenario for a designed and strategically-placed treatment sink in the watershed. It should also be pointed out that the lion’s share of the nitrate load in the Raccoon occurs during the April through June calendar period; this coincides nicely with peak denitrification rates in the pond.

The figures in Table 1 can be used to estimate the number of acres of water surface area needed (assuming 4’ average depth) as treatment sinks to affect various reductions in Raccoon River N load. The table below illustrates this for an average N load year (17.8 million Kg).

% Load Reduction	Absolute Load Reduction (Kg)	Acres of treatment sink needed (4’ depth)
1	178,000	198
5	890,000	992
10	1,780,000	1984
25	4,450,000	4960

Table 2: Potential Raccon River Nitrate Load Reductions

The reader should bear in mind that these total acres would need to exist in 10-acre or smaller increments. The greater the number individual treatment sinks there are within the total acreage, the greater the load reductions will be. It is difficult to say how much of a reduction in nitrate peak levels would result from a given annual load reduction. But the author is of the opinion that an annual average 25% load reduction would likely reduce the peak value more than 25% since the peak values, which usually occur in late spring, corresponding to peak denitrification rates.

For the Raccoon River watershed, the approximately 5000 acres for 25% nitrate load reduction seems politically achievable. With land prices at about $4000 per acre, this would require a real estate investment of about $20 million. Of course, these parcels would need to be strategically located to intercept tile water, and would need to be designed with an optimum size (<5 acres) and depth (approximately 4’) in mind. Other existing natural systems, such as oxbow lakes that have been sealed off from the river, could also be integrated into this treatment sink scheme.

VIII. Implications for Drinking Water Utilities

A. Overview

Denitrification in off-river storage reservoirs has been effectively demonstrated by DMWW as a viable treatment strategy. It can be used alone or in conjunction with ion exchange and/or reverse osmosis. Utilities with severe nitrate impairment of the source water, like DMWW, will likely always need some emergency nitrate removal system, which usually will be the standard ion exchange and R.O. processes.

Unlike the treatment sink scheme described for nitrate reduction in the watershed, there are other considerations for a water utility that intends to use the water as drinking water source supply. These include, but are not limited to, taste and odor considerations, turbidity, pathogens, and cyanobacteria. Because of this, it is likely that a water utility will want a water body that will produce a slower denitrification process that will sufficiently reduce nitrate concentrations without precipitating a condition where life and its byproducts make the water unusable for treatment. This calls for a larger, perhaps deeper, body of water that serves not only as a denitrification vessel but also as a buffer to large nitrate episodes in the river. The 62 acre gravel pit (Crystal Lake) at the Maffit Plant enabled the utility to reduce the volume of water needing ion exchange treatment by several million gallons. Operation of the off-river storage system has reduced the amount of water needing treatment in the Fleur Drive nitrate removal facility by 85 million gallons during 2005-06. This resulted in load reductions in the Raccoon River (via reductions in discharge volume from the nitrate removal facility) of 25,500 kg nitrate (as N); 202,000 kg of sodium chloride, 122,000 kg of chloride, and 259,000 kg of Total Dissolved Solids.

Repression of cyanobacteria is a critical factor in being able to use off-river storage water. Iowa summertime weather, coupled with Iowa's nutrient-rich waters, are ideal conditions for these organisms. If the concept of off-river storage with the purpose of denitrification is to be successful, it must be done simultaneous with the repression of cyanobacteria at the source. There are various strategies used to accomplish this in the water industry: aeration, chemical treatment, and circulation. Use of the solar-powered circulators at Crystal Lake was proven to be highly successful in repressing cyanobacteria blooms and making the water usable for treatment throughout the entire year. Whether or not these would work to the same effect in the park ponds is yet to be seen. That application may be cost prohibitive as the pond system is divided by levees into a series of sections, each possibly needing a circulating unit.

B. Effect of Basin 17 on Infiltration Gallery Yield

During 2006, a new pond was completed in Waterworks Park, west of and distinct from the east ponds where monitoring for this project occurred. This pond has a surface area of about 20 acres and a maximum depth of 20'. It was filled with Raccoon River water in September.

As has been discussed in the proposal and previous reports, all the ponds lie above the shallow groundwater collection system (Infiltration Gallery) in Waterworks Park. Low-nitrate water from the ponds saturates the surrounding soil structure, and enhances water yield from the gallery. This is important because increased yield from the gallery reduces reliance on high-nitrate river water. How much the ponds enhance gallery yield is difficult to assess accurately since no accurate "before and after" data exists. The ponds were first created in 1931, and prior to 1950, total water demand never exceeded yield from the gallery. So it has been impossible to assess the total contribution of the ponds to gallery yield. Some estimates have been made based on nitrate levels; gallery nitrate typically is 50 to 80% of that in the Raccoon River. The gallery is considered to be under the influence of the Raccoon.

Filling this new pond enabled the utility to assess the influence of off-river storage on the yield of the shallow groundwater collection system. This is shown in Figure 27 below. For the four-month period of September through December, yield increased 633 million gallons over the ’97 to ’05 average. This is especially important when considering that this water is largely denitrified, and reduces the amount of high-nitrate river water that must be treated in the plant.

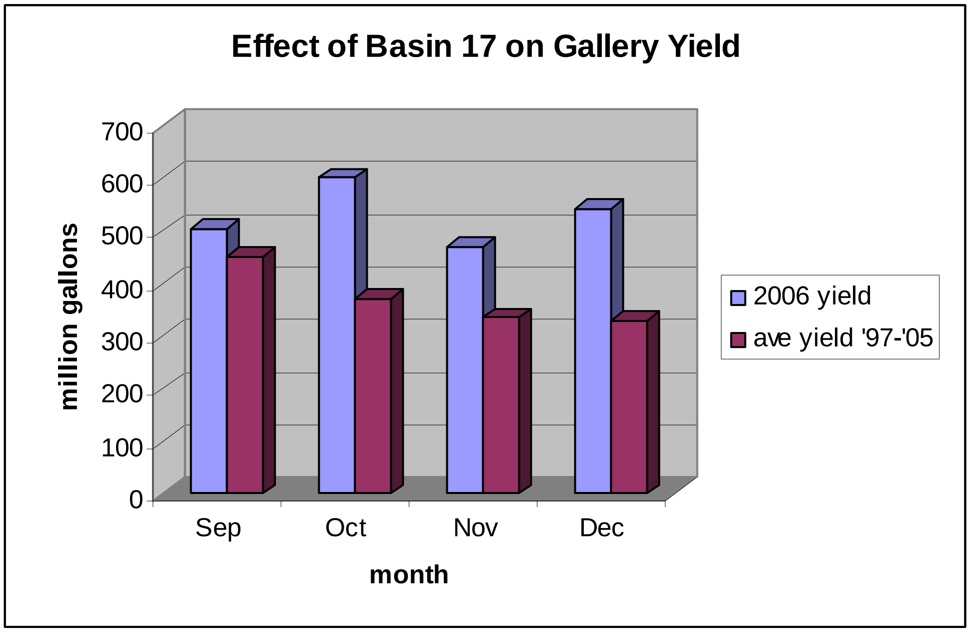

Figure 27: Effect of New Basin 17 on Gallery Yield

IX. Data Completeness

A. Laboratory Measurements

The plan for the fourth quarter called for a total of 1244 sample measurements. Actual measurements successfully completed totaled 1211, for a completion rate of 97.4%. Samples unobtainable due to ice were counted as completed.

B. Field Measurements

A total of 193 measurements were scheduled, and 190 were completed (98.4%)

A few samples were unobtainable due to ice—these were counted as completed.

X. 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."

Results of this study were presented to approximately 50 staff members of the Iowa Department of Natural Resources on January 10, 2007. Finally, results will be presented to the Department of Civil, Construction and Environmental Engineering at Iowa State University on March 6, 2007.

XI. Future Plans

The QAPP stated that at least one article for publication in a peer-reviewed journal will be submitted. Currently, the author, DMWW microbiologist Dennis Hill, and Keith Schilling of USGS are working on a publication that will focus on the *E. coli* data. The author also plans to work with Chris Knud-Hansen, Ph.D., limnologist with the Solarbee Co., to produce a publication that will focus on the cyanobacteria data. Finally, the author and DMWW senior chemist Gordon Brand will submit a paper for publication during 2007 that will focus on the denitrification data.

All four of the quarterly reports will be posted on the DMWW website (http://www.dmww.com/Laboratory.asp). The final fourth quarter report will be distributed to the various stakeholders (USGS, City of Cedar Rapids Water Department, Iowa Soybean Association, Des Moines River Water Quality Network, and Iowa DNR). Finally, Gordon Brand of the DMWW laboratory is beginning the process of entering this data into STORET.