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
2nd Quarter 2006

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July 25, 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 2^{nd} quarter period of 2006.

The second quarter typically is the most dynamic period of the year, both in terms of water quality and river flow. Spring rains affect river water quality in two ways. First, overland runoff can produce high levels of turbidity and coliform bacteria in Iowa streams. Nearly all native vegetation has been eliminated in the Raccoon River watershed, and row crops do not serve as effective buffers for large precipitation events. Furthermore, corn and soybean plants still are relatively small in April and May, further limiting their moisture retention potential. Second, spring rains serve to recharge groundwater moisture. This flushes soluble contaminants such as nitrate through the soil profile into agricultural drainage tile systems, which are extensive in the Raccoon River Watershed. This is why the second quarter typically sees the worst water quality of the year. April of 2006 saw relatively normal precipitation in Iowa, but May and June were unusually dry, and June was especially warm. This was reflected in the water quality data, especially in the levels of coliform bacteria seen in the Raccoon River. Raccoon River flows at the end of June were near or below record low flows for the dates.

II. River Flow into Off-River Storage Reservoirs

From April 1 until April 26, water was delivered from the Raccoon River into the Park Ponds using the 0.8 million gallon per day (mgd) pump used during the first quarter. On May 9, a 4.7 mgd pump replaced the smaller pump, and water was introduced to the ponds much more aggressively for three days until the ponds were completely full. Then, flow was resumed using the 0.8 mgd pump so that a constant overflow of water was affected in the ponds. Most of the levee system separating the ponds was repaired and improved during May and June. The ponds continued to remain functional as yield enhancement for the groundwater collection system at Fleur Drive, and as treatment sinks 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 79 of 91 days. River water injection was interrupted on a few days due to mechanical difficulties with the river water injection pump, and was stopped from 4/1 through 4/9 due to high river water turbidity. Water from Crystal Lake was used for treatment in the plant every day during the second quarter except April 1, 2, and 3. A total of 331 million gallons was used as low-nitrate dilution water, serving to reduce nitrate concentrations in water obtained from the radial collector wells at the Maffitt Plant.

On March 13, two solar-powered circulators known as Solar Bees were installed on Crystal Lake. These devices draw water up from the lake bottom and distribute it over the lake surface via laminar flow. Their intended purpose is to repress cyanobacteria while enhancing conditions favorable to green algae. The observed effect of these devices on denitrification and repression of cyanobacteria will be discussed here.

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 below depict physical parameters monitored during first quarter.

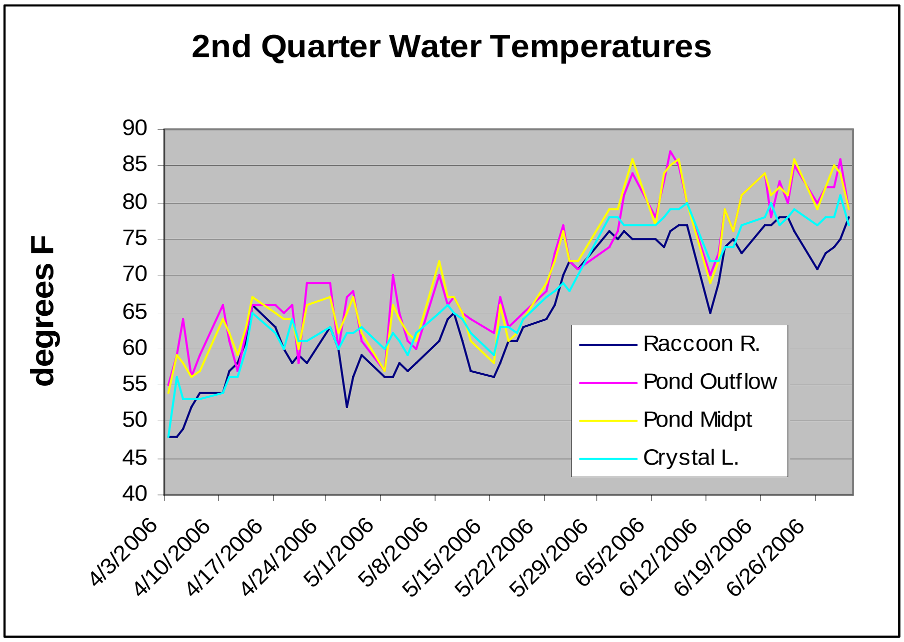

Figure 1: Water Temperature

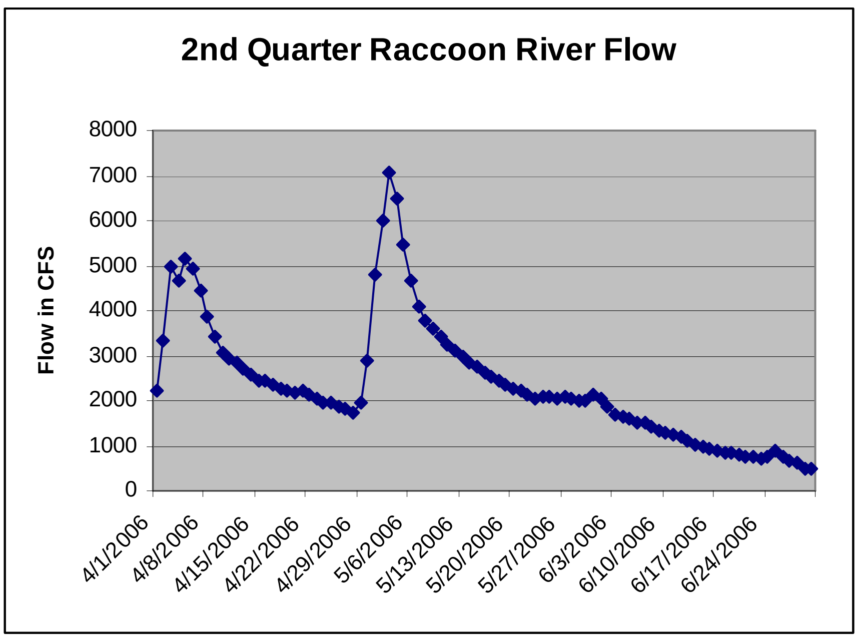

Figure 2: Raccoon River Flow

A few things are of note in Figures 1 and 2. The first is water temperatures. Temperatures near 90F, as was seen in the Park Ponds, are unusual for June. River water temperatures in the high 70s during June, as was seen in 2006, are not unheard of, but high nonetheless. River flow reflected two large precipitation events but was quite low from mid

May until the end of June. The river flow of 467 CFS on June 30 was near the record low for the date.

IV. Biological Data

A. Cyanobacteria

Intensive monitoring of cyanobacteria continued during the second 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.

Two solar-powered circulators, known as Solarbees, were installed in the gravel pit (Crystal Lake) on March 13. These devices use a solar-powered impeller to draw water from near the bottom of the lake and then distribute it by laminar flow across the lake’s surface. About 3000 gallons per minute of lake water is directly affected by each Solarbee in this way, and another 7000 gallons of movement is induced. 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, so DMWW is keenly interested in whether or not they will repress cyanobacteria growth in the continuous-river-water-injection/off-river storage system. During 2005, cyanobacteria numbers were maintained at manageable levels in Crystal Lake 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 numbers remained at manageable levels in Crystal Lake throughout the 2nd quarter, as depicted in Figure 3. 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 considered manageable. The predominant genus in Crystal Lake has been *Aphanimozenon*, which DMWW believes is a relatively benign species. The Park Ponds, however, saw a large bloom of cyanobacteria in May, also shown in Figure 3. This presents problems if DMWW is to use overflow water from the ponds as low-nitrate dilution water in the future. Typically, DMWW is using the nitrate removal facility in May, and therefore low-nitrate dilution water is needed during this month. Therefore, large cyanobacteria blooms that early in the year will need to be avoided if water from the ponds is to be used for treatment. Furthermore, a variety of ominous genera appeared in the ponds: *Anabaena*, *Cylindrospermopsis*, and *Oscillatoria*, all of which are known to cause taste and odor problems and undergo toxin production.

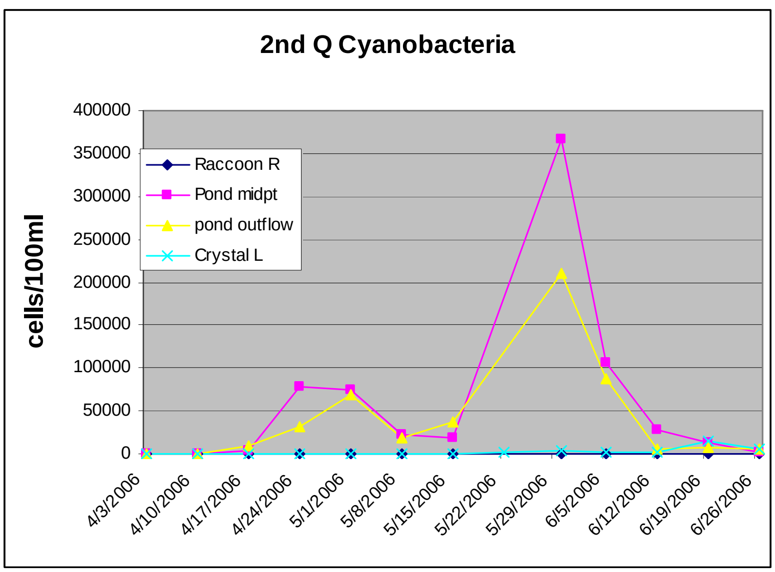

Figure 3: Cyanobacteria

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. Figure 4 shows green algae counts for the second quarter. The Raccoon River began to experience its large bloom of green algae earlier than usual this year. This likely reflects the dry climatic conditions, which reduce sediment-related turbidity and make conditions favorable for blooms. Crystal Lake green algae remained at unexceptional levels, while pond green algae were perhaps lower than expected, based on Raccoon River concentrations.

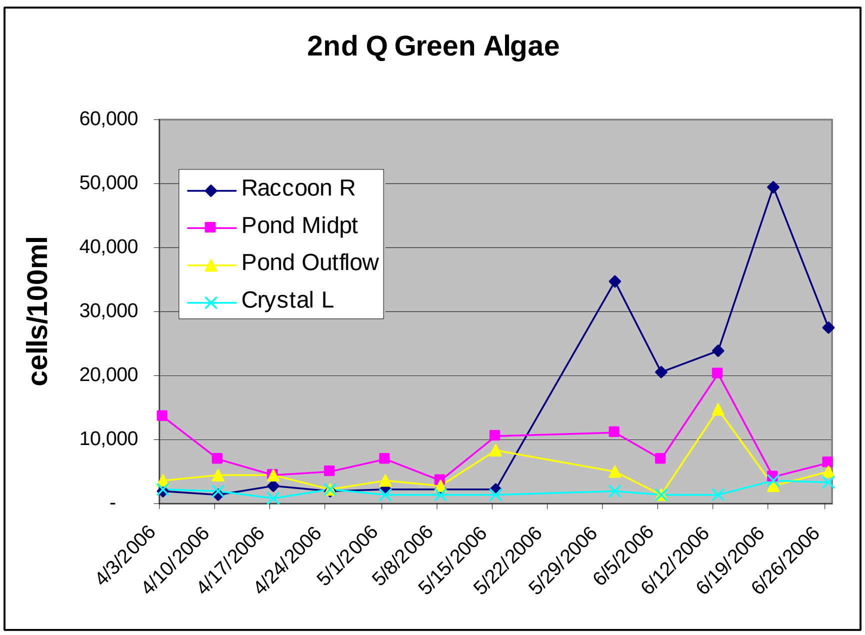

Figure 4: Green Algae

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 5 on the next page depicts their abundance in the Raccoon River, while Figure 6 illustrates their concentration in the other three samples.

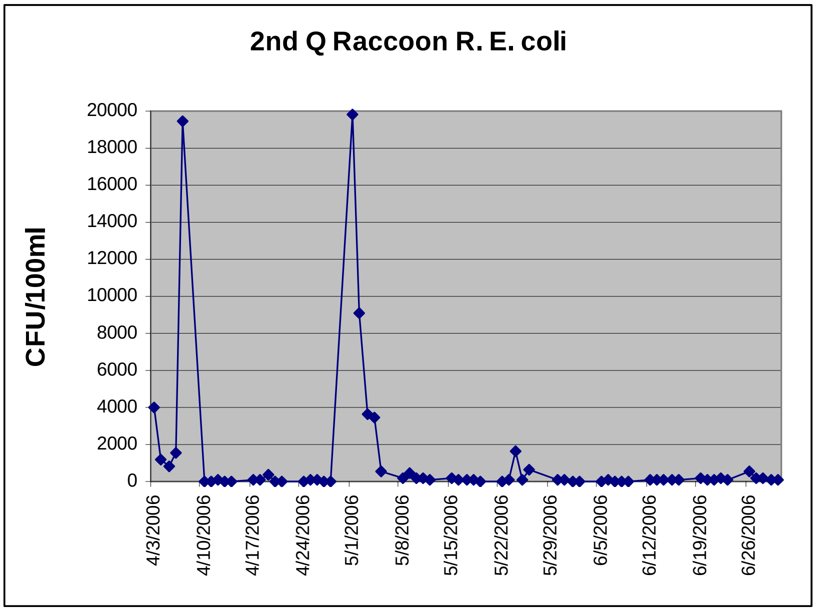

Figure 5: Raccoon R. *E. coli*

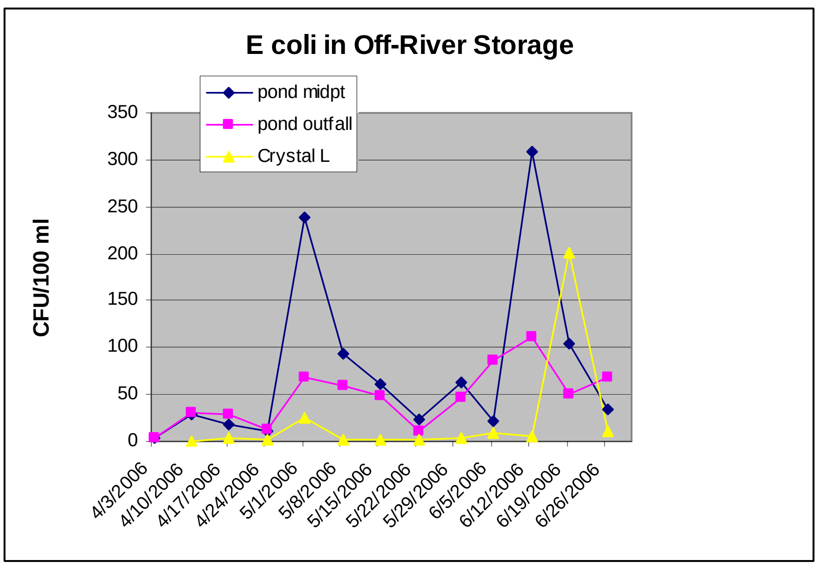

Figure 6: *E. coli* in Off-River Storage

Two things stand out about the *E. coli* data. One, the surprisingly low numbers seen in the Raccoon River during the 2nd quarter, which is usually the worst time of year for bacteria impairment. Levels exceeding the safe contact limit of 200 CFU/100ml were measured on only 14 days. This is astonishing, considering the record low number for a calendar year is 88 days, which occurred in 2000. This likely reflects the dry climatic conditions, but hopefully also reflects improvements in livestock manure management and human wastewater treatment.

The other thing that stands out about the *E. coli* data is the relatively low levels in the off-river storage reservoirs. It continues to be apparent that *E. coli* are perishing in the ponds and Crystal Lake after entering in the river water.

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 7 below shows 2nd Quarter nitrate results for the four sample locations.

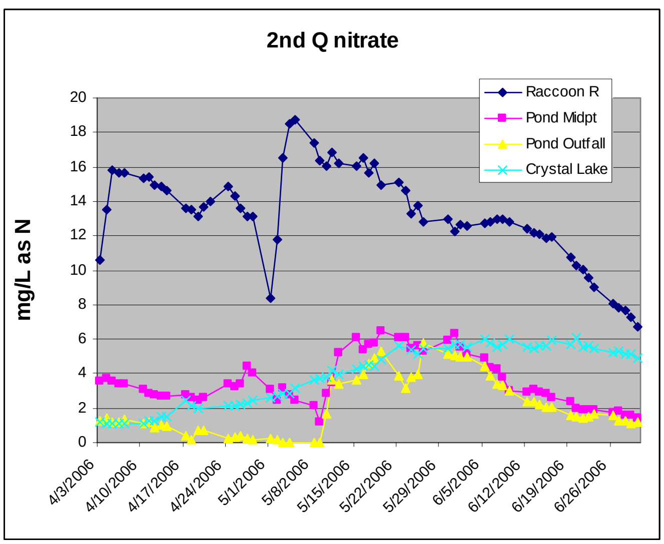

Figure 7: 2nd Quarter Nitrate Data

The 18.7 mg/L measurement for the Raccoon River on May 5 was the highest nitrate level seen at the DMWW Fleur Drive Plant since November of 1979. Nitrate levels throughout the second quarter remained high in the river, despite the dry weather. Nitrate levels exceeded the drinking water standard of 10 mg/L on 56 of 64 measurement days. Because of low river flows, nitrate loads were not spectacularly high.

Despite the high river nitrate levels, nitrate concentrations in the off-river storage reservoirs remained relatively low. This is very encouraging. The water turnover time in the park ponds is thought to be about 11 days, yet the nitrate level peaked at about 6.5 mg/L at the midpoint and never exceeded 6 mg/L in the outflow. This lends credibility to the idea that the overflow water can indeed be used as low-nitrate dilution water for the Fleur Drive Plant. Water in Crystal Lake (a total of about 200 million gallons) was completely exchanged with Raccoon River water 1.5 times during the quarter, and nitrate levels only barely exceeded 6 mg/L. This data will be used to calculate denitrifying capability for the off-river storage reservoirs, and will be used to create parameters (surface area, depth, flow volume, etc.) in the coming months that hopefully will be used by other utilities. We also hope that farmers in the watershed will use this information to create treatment sinks that capture tile effluent water, and by extension prevent nitrate from entering tributaries of the Raccoon River.

Consumption of nitrate begins much earlier in the park ponds than in Crystal Lake. This is due to a variety of factors, including fertility, depth, turbidity, and very importantly, water temperature. Nitrate consumption is more rapid in the ponds than in Crystal Lake at any temperature.

When comparing 2005 data with 2006 data, 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. This is shown in Figure 8 below.

B. Total and Organic Nitrogen

Total nitrogen was assessed weekly at the four sites. 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 8 below illustrates average organic nitrogen data for the 2nd quarter.

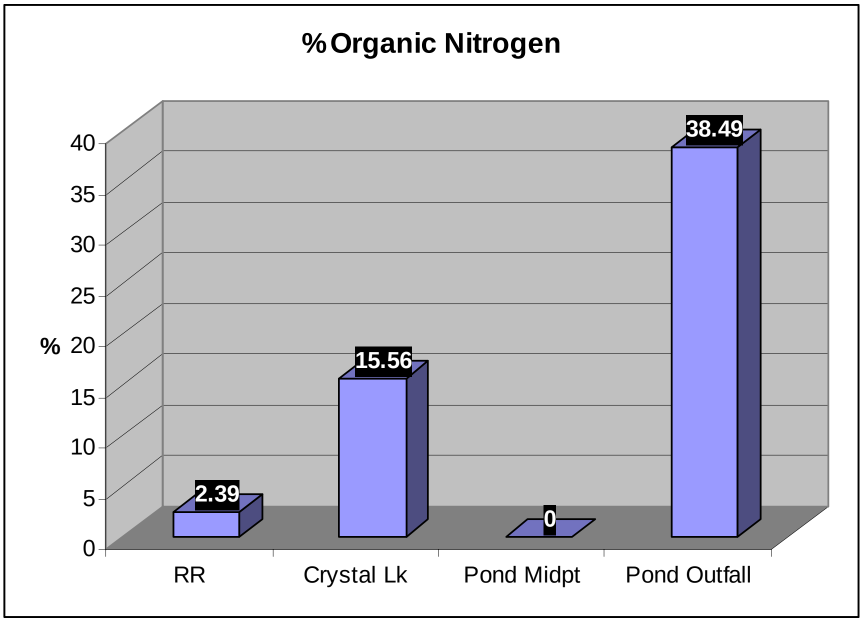

Figure 8: % Organic N of Total N

Even though the Raccoon River typically has the highest green algae populations, it has hardly any organic nitrogen, and its level would be even lower were it not for one data point of 27% at the beginning of the quarter. The pond mid-point site likewise has very little organic nitrogen. This would seem to indicate that at least early in the pond system flow pattern, almost all denitrification is due to dissimilative process, i.e. anaerobic denitrification by microbes, or consumption of the nitrate by heterotrophs and/or facultative organisms. It's obvious that by the time the pond water reaches the outflow, some of the nitrate-nitrogen has been fixed and converted to organic forms by organisms in the pond. It's also possible that cyanobacteria in the ponds are fixing nitrogen from the atmosphere, increasing organic nitrogen in outfall. It would also seem at this point that green algae are not responsible for summertime nitrate reductions in the Raccoon River. This is an important conclusion. One or all of three things must be happening in the Raccoon River as summer progresses: a) nitrate inputs diminish, b) anaerobic denitrification by strict anaerobes, or c) denitrification by heterotrophic and/or facultative bacteria. It's likely all three are happening. The organic nitrogen data will continue to provide insights on the various processes as the year continues and will be critical in identifying the primary mechanisms and organisms responsible for nitrate reductions—either assimilative or dissimilative—occurring in each body of water, so that the process can be optimized.

C. Other Chemistry Data

Other parameters that have been analyzed during first half of the year include Total Organic Carbon (TOC), total phosphorous (TP), ortho phosphorous (OP), turbidity, nitrite-nitrogen, and chloride. How these parameters and data relate to the primary parameters of interest (nitrate, bacteria, cyanobacteria) will be covered in the next two quarterly reports. All the second quarter data for these parameters is included with this report.

V. Other Data Considerations

A. Data Related to the Nitrate Removal Facility

The DMWW nitrate removal facility was operated for about 50 days during the second quarter. Two sampling events of the discharge were conducted, one during a mid-flow condition, and one during a low-flow condition. This data is included with this report. The mid-flow event took place on 4/17/06. Raccoon River flow that day was 2340 CFS. River samples were collected at 15 minute intervals 10' and 100' downstream from the DMWW nitrate facility discharge. Ion exchange nitrate removal vessels are regenerated with sodium chloride brine, with the resulting waste discharged to the Raccoon River. The utility maintains an NPDES permit for this discharge. The permit limits TDS in the discharge to 25.6 g/L. Measurements of the brine waste itself usually fall in the 9-13 g/L range for TDS. For the 4/17 sampling event, the maximum TDS measurement obtained for the 10' sample was 3.13 g/L. The maximum TDS measurement obtained for the 100' sample was 2.15 g/L. Maximum chloride measurements were 502 and 326 mg/L.

Another sampling event was conducted on 6/14/06 when the river flow was only 1023 CFS. Maximum TDS measurements that day were 6.2 and 1.8 g/L, 10' and 100' from the discharge respectively. Maximum chloride measurements in the river were 3500 and 760 mg/L. Obviously, eliminating the need for nitrate removal through other means, namely off-river storage denitrification, will reduce the chloride and TDS loads of the Raccoon River by at least some marginal amount. This data will be further scrutinized as the year progresses.

B. Cyanotoxin Data

Cyanotoxin analysis will take place during the 3rd quarter.

C. Data Completeness

1. Laboratory Measurements

The first quarter sampling plan called for a total of 1695 sample measurements, not including the nitrate removal facility discharge monitoring. Actual measurements successfully completed totaled 1647, for a completion rate of 97.2%. Fourteen analyses were rescheduled and run on the next calendar day.

2. Field Measurements

A total of 256 measurements were scheduled, and 255 were completed (99.6%).

VI. Third Quarter Plans

Daily monitoring will continue for the Raccoon River, the Park Pond system, and Crystal Lake. No further monitoring of the nitrate facility discharge will take place, because further operation is unlikely this year. Cyanotoxin monitoring will be conducted during the third quarter.

VII. Summary of Expenses

Labor						
Name	Position	hours	Rate	Labor	Benefits	total
Adams	Laboratory Technician	22.5	20.00	450.00	157.50	607.5
Brand	Senior Chemist	14	31.38	439.32	153.76	593.08
Corrigan	Dir. of Water Production	15	53.99	809.85	283.45	1093.30
Duff	Chemist	28	25.81	722.68	252.94	975.62
Jones	Laboratory Supervisor	80	37.84	3027.20	1059.52	4086.72
Webster	Chemist	9	24.94	224.46	78.56	303.02
Woodruff	Laboratory Technician	36	20	720.00	252.00	540.00
Hill	Microbiologist	18.50	31.85	589.23	206.23	795.46
Young	Laboratory Technician	43.5	18.02	783.87	274.35	1058.22
Clausen	Engineering Technician	3	22.28	66.84	23.39	90.23
Danley	Engineering Supervisor	11	37.53	412.83	144.49	557.32
grand total	**10700.47**					