Nitrate and Bacteria in the Raccoon River:

Historical Perspective and 2004 Summary

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The Raccoon River Watershed

The Raccoon River rises in Buena Vista County, Iowa, and travels approximately 200 miles to its confluence with the Des Moines River in the city of Des Moines. The mainstem of the Raccoon River, also known as the North Raccoon in its upper stretches, has two main tributaries: the Middle and South Raccoon Rivers. The Middle Raccoon River rises in northwest Carroll County and flows 76 miles to join the South Raccoon near Redfield, IA. The South Raccoon River rises near the Guthrie-Audubon County line and flows 50 miles until its confluence with the Middle Raccoon. The combined flows of the Middle and South Raccoon join the North Raccoon near Van Meter, a few miles downstream from Redfield.

The entire Raccoon River Watershed drains 17 counties and 3600 square miles, 6.4% of Iowa's total area. The river flows through the western part of the Des Moines Lobe, a very young geological formation left behind by the last Wisconsinan ice age. All three branches of the Raccoon were influenced by glacial melt water, and the current course of the Middle Raccoon roughly traces the furthest edge of glacial advance. The landscape of this region was shaped only 12,000 to 16,000 years ago, much more recently than the rest of Iowa. Soils in the Des Moines Lobe are among the most fertile on earth, and of the Raccoon River watershed's 2.3 million acres, 1.7 million (74%) are cultivated for corn and soybeans. Small portions of the watershed lie in the Southern Iowa Drift Plain and the Northwest Iowa Plains. A map of the watershed is shown in Figure 1.

Figure 1: Raccoon River Watershed

Captain James Allen and his Dragoon explorers were likely the first Europeans to extensively explore the Raccoon River Watershed, this in 1844. His journals describe numerous lakes scattered throughout both wet and dry prairie, and bears and elk being killed for food during the expedition.

No one alive today has seen the Raccoon River in its natural state. Prior to European settlement, lands making up the watershed were largely wet prairie. Early settlers transformed the landscape into agricultural land through removal of native plants and systematic drainage, a process that continues to this day. The prairies and wetlands of the region were largely gone by 1890. This landscape modification dramatically altered the character, appearance, and water quality of the river to the extent that the river would be largely unrecognizable to people who saw it prior to 1860.

The Raccoon River as a Source of Potable Water

The Raccoon River, and shallow groundwater wells heavily influenced by it, are the primary water sources for the Des Moines Water Works. Approximately 500,000 people (17% of the Iowa's population) regularly consume this water, and about 15 billion gallons of it is treated annually for consumption. Lake Michigan and the Mississippi and Missouri Rivers are the only surface water sources that supply more water, and more people, in the Upper Midwest.

Des Moines Water Works (DMWW) has been using Raccoon River-influenced groundwater for more than a century at its Fleur Drive Treatment Plant. A three-mile-long infiltration gallery, 30 feet underground, runs parallel to the river and collects water as it seeps from the river through the surrounding soil structure. Direct use of river water began in the late 1940's. Collector wells adjacent to the river were constructed in 2000, and supply water to the Maffitt Treatment Plant.

Water Quality Background

Prior to settlement, Iowa rivers were proportionally influenced more by groundwater, as opposed to surface runoff, than in the present day. Native perennial vegetation retained precipitation and snowmelt much more than bare ground and row crops. Iowa's wetlands trapped runoff before it made its way to streams, and enhanced transfer of water to underground aquifers. The shallow groundwater then made its way into the rivers through the surrounding alluvium. This process filtered the surface runoff, as opposed to the present day where a much higher proportion of the water reaching the rivers gets there directly through overland runoff and agricultural tile drainage. In the present day, groundwater still contributes to river flows, especially during dry periods, but the proportion of water reaching the river in this manner likely has diminished.

Alteration of the landscape affected both the flow and water quality of the Raccoon River. Many small tributaries have been straightened and are now nothing more than drainage ditches. Subterranean tiles channel precipitation straight to the streams, short-circuiting nature's process of percolation into underground aquifers. This causes greater fluctuations in river flows and prevents removal of contaminants before the water enters the river. This unnatural process has increased nutrient and solid loads of the river to much higher levels than in the pre-agricultural era.

Extensive and reliable water quality data for the Raccoon River is available for only about the last 30 years for nitrate, and 10 years or less for most other measures of water quality. This document will evaluate how Raccoon River water quality for 2004 compares to the historical record, and which direction water quality in the river appears to be headed in the coming years. These measures were selected for assessment: nitrate and coliform bacteria. Of course, there many other indicators of water quality than just nitrate and bacteria. But the ecology and economy of the region have made these parameters the focal point when discussing Raccoon River water quality, and they are the two designated impairments by the Iowa Department of Natural Resources. As mentioned earlier, a high percentage of the land is cultivated and fertilized with anhydrous ammonia. In addition, there are approximately 47 registered feedlots, 127 unregistered feedlots, 54 permitted animal feeding operations, and about 40 municipal wastewater treatment plants, all contributing to the nitrate and bacteria load. The data presented here show that there is an urgent need to stem the deteriorating water quality tide, if use of the Raccoon River as a source of drinking water is to continue into the next generation.

Nitrate

History

Much of the focus on Raccoon River water quality has been directed at this nutrient, primarily because it is a regulated drinking water contaminant, and water treatment designed to remove it is difficult and expensive. The Environmental Protection Agency's Maximum Contaminant Limit (MCL) for nitrate-nitrogen is 10 mg/L. This is the maximum amount of the contaminant that can legally be present in finished drinking water.

Prior to 1910, average nitrate levels in the Des Moines and Cedar Rivers were both <1 mg/L (1), so it's safe to assume that the Raccoon River had similarly low levels at that time. By 1945, data indicates that the Des Moines River likely had peak nitrate episodes of 8 mg/L (1), and that shallow groundwater was becoming contaminated (2). This is about the time that cases of nitrate poisoning were first reported, and these were in Iowa (2). Nitrate pollution prior to 1945 was almost exclusively due to mineralization of organic nitrogen contained within the soil. Cultivation of row crops helped speed this process, and hasten the transfer of nitrogen from the land to ground and surface water.

Corn grows rapidly and needs more *available* nitrogen in a relatively short growing season than the soil can provide, even though the amount of total nitrogen in the soil is many times what is needed for a crop. Prior to 1945, this available nitrogen largely came from biological nitrogen fixation, achieved by rotating corn with alfalfa.

Following World War II, Iowa agriculture began a transition from agrarian, family-oriented operations to an industrial model, a transition that continues to this day. With this transition came a gradual abandonment of the corn/alfalfa rotation and a reliance on chemical fertilizers (now usually in the form of anhydrous ammonia) to provide the jolt of nitrogen needed by corn. Nitrogen levels in the Raccoon River have been climbing ever since. Figure 2 below tracks nitrogen applied to Iowa corn since 1986 (3). By and large, application rates and total applied N have remained fairly constant the last 18 years.

Raccoon River at Fleur Drive Overview

Nitrate levels in the Raccoon River showed no sign of subsiding during 2004. Measured at the DMWW's Fleur Drive Treatment Plant, the average* nitrate-N concentration for the year was 7.96 mg/L, the second-highest annual average of the last 10 years, and the 5th-highest since extensive monitoring began at DMWW in 1974. Table 1 below lists the ten highest annual average N concentrations in the river since 1974.

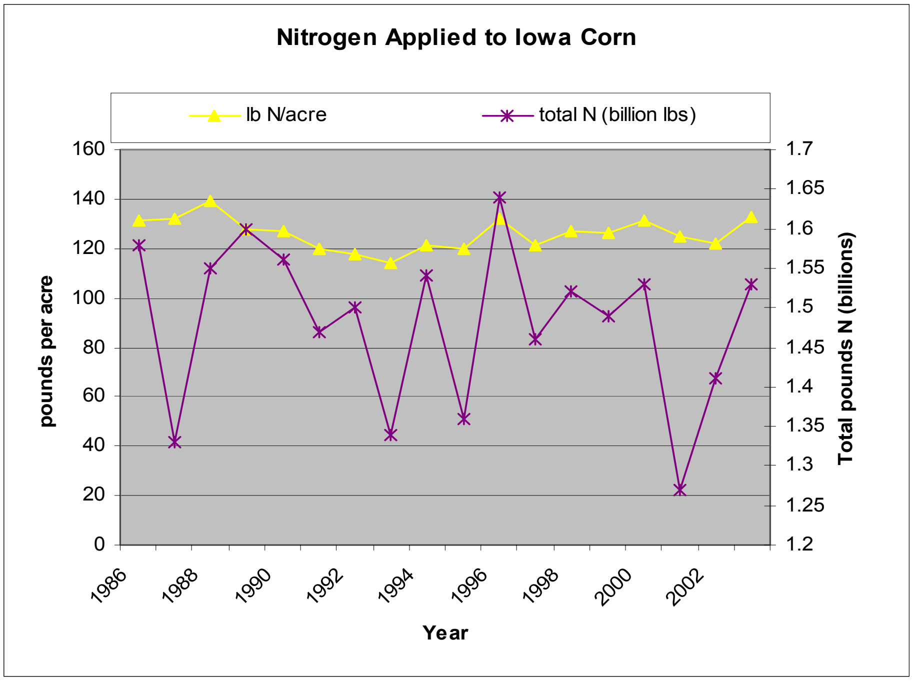

Figure 2

Year	Nitrate-N mg/L
2002	10.22
1979	9.63
1992	9.31
1991	8.52
2004	**7.96**
1998	7.91
1999	7.69
1980	7.65
1987	7.58
1986	7.50

Table 1: Ten Highest Annual Average Nitrate Concentrations in the Raccoon River at Fleur Drive since 1974

Since annual average nitrate concentrations are highly variable, one must be cautious when drawing conclusions about trends. One way to conservatively assess trending is to track 5-year running annual averages. This allows climactic and human variables that

***Annual average nitrate concentrations are calculated by averaging monthly averages, rather than daily averages. This prevents skewing of data due to frequent monitoring during high nitrate episodes.**

may cause dramatic changes in nitrate concentrations to be evened-out over a longer period of time. Figure 3 is such a representation for Raccoon River nitrate since 1978. Following the black linear trend line, one can see that the five-year running annual average has trended from about 4.5 mg/L in 1978 to about 7.7 mg/L in 2004, an increase of 71% in 26 years. At this rate, annual average nitrate-N in the river should regularly exceed the 10 mg/L drinking water limit in about 18 years.

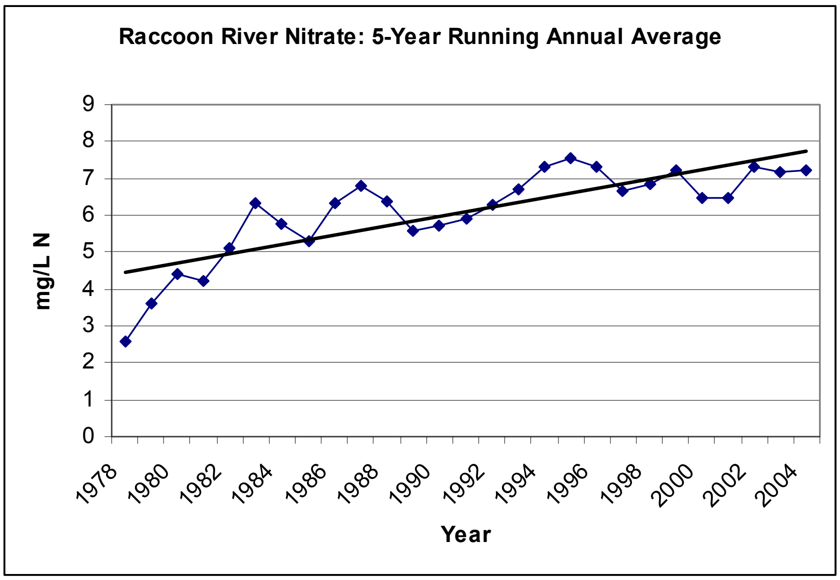

Figure 3

Figure 2 showed that total nitrogen applied, and nitrogen application rates, are constant since 1986, so the upward trend in the Raccoon River is not readily explained by increased application of nitrogen. Nitrate is very soluble so one potential hypothesis for the upward trend in the Raccoon River could be increased precipitation levels. Data since 1974, however, show this not to be the case.

Figure 4 below tracks average nitrate levels with annual precipitation in the city of Des Moines. Naturally, precipitation levels will vary throughout the watershed; however, precipitation trends in Des Moines should mirror those in the watershed. The blue lines in the graph show actual annual precipitation, and the trend for the period. The pink lines likewise show annual average nitrate and the trend. Obviously, the trends are going in different directions.

Since much of the nitrogen application takes place in the spring, and since Raccoon River nitrate levels often peak in the May-June period, spring (Mar-May) precipitation versus annual nitrate concentrations are tracked in Figure 5. Although spring precipitation levels are trending upward slightly, the trend is of a much smaller magnitude than is the nitrate upward trend.

This is not to say that precipitation has no effect on river nitrate. It's well known that individual precipitation events can cause large temporary increases in nitrate concentrations. There also seems to be a loose connection between low nitrate levels and very dry years (and springs), as evidenced in 1985, 1988, and 2000. However, years and springs with near normal-to-above normal precipitation can have highly variable nitrate levels. For example, 1979 had near-normal spring and annual precipitation, but had an extremely high average nitrate level. Likewise 2002, which had slightly below normal spring and annual precipitation levels, saw the highest annual average nitrate concentration ever.

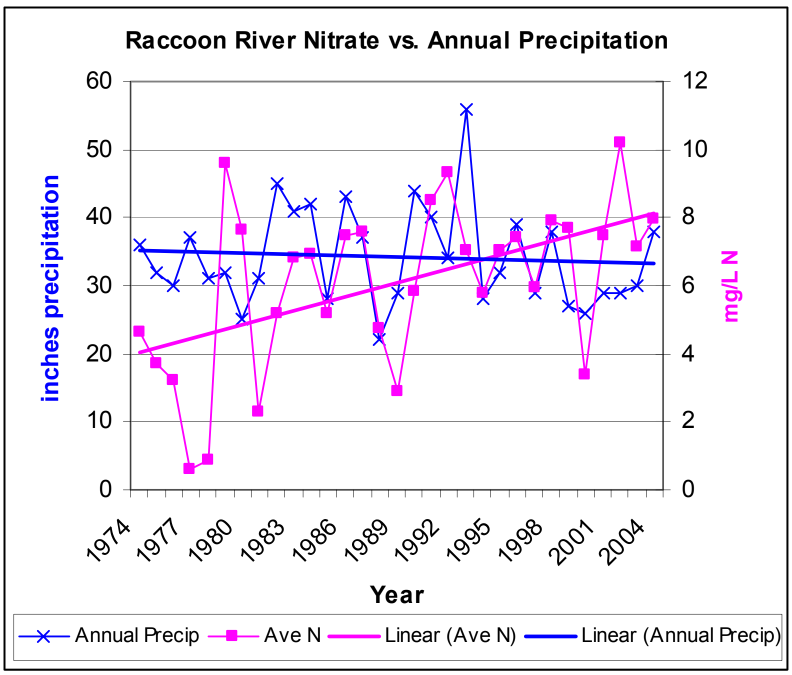

Figure 4: Annual Precipitation vs. Annual Average Nitrate

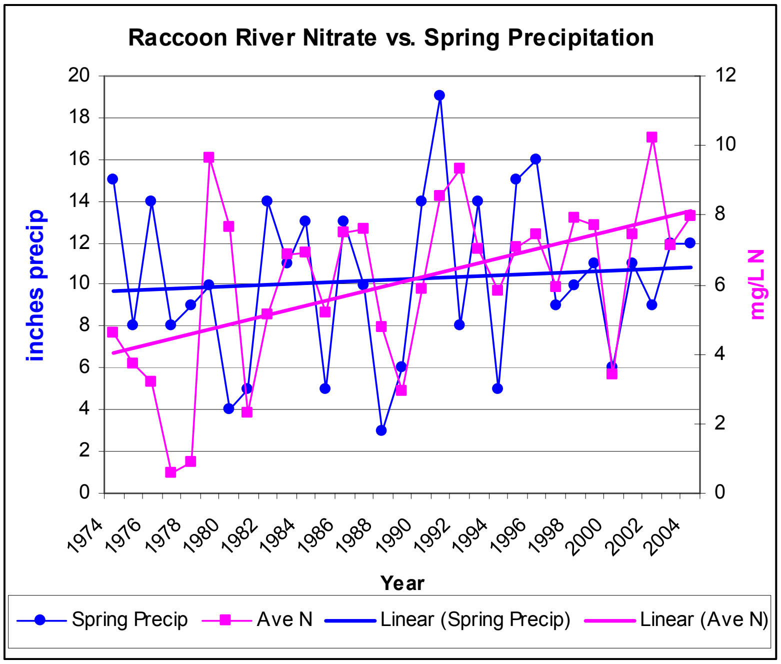

Figure 5: Spring Precipitation vs. Annual Average Nitrate

A plausible hypothesis is that nitrate concentrations are dependent on the average *magnitude* of precipitation events during the course of a year. If the precipitation comes in many small-to-medium events that keep agricultural tiles constantly filled with running water, it seems likely that this would maximize river nitrate concentrations. Conversely, if precipitation events are few but large, this might spike nitrate concentrations for short periods of time but keep them low as an annual average. An investigation of this potential relationship would be interesting, but is beyond the scope of this study.

Another factor to consider is the possible "banking" of nitrate during dry years. If applied nitrogen from one year is carried over to subsequent years, this may cause elevated nitrate concentrations during years with normal precipitation.

Finally, the increased reliance on man-made drainage in the form of subterranean drain tile has likely contributed to the rise in nitrate concentrations.

Monthly Trends

Nitrate concentrations in the Raccoon River follow a very predictable "S" curve as the year progresses, as shown in Figure 6. This month-to-month trend recurs almost every year, with only the magnitudes changing.

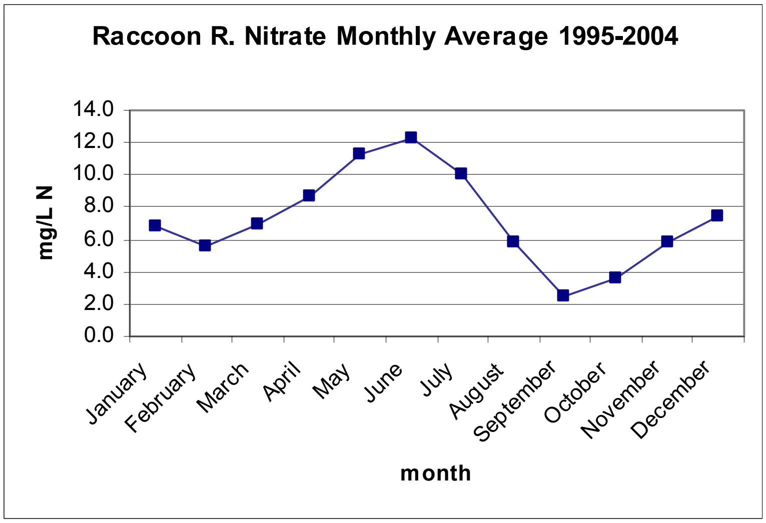

Figure 6

In the spring, the ground begins to thaw, the spring rains arrive, farmers apply nitrate to their fields, and river nitrate begins its steady climb to a June peak. Over the last decade, three entire months (May, June, July) average above the drinking water MCL of 10 mg/L. Nitrate levels drop quickly during late summer as the fields dry and crops deplete soil nitrate. Then in late fall, nitrate levels begin to rise again. This cold-weather peak is less well-understood. Nitrogen is applied to fields in fall, so certainly that is a factor. But other factors also likely contribute: wastewater lagoon discharge and a slowing of biological denitrification in the soil and river water with the onset of cold weather. The river is heavily influenced by groundwater during the winter, and winter-time river nitrate levels are likely representative of shallow groundwater nitrate in the watershed.

Although annual average precipitation does not correlate well with annual average nitrate concentrations, it appears precipitation patterns do have something to do with the month-to-month "S" curve shown previously in Figure 6. Figure 7 below tracks river nitrate and precipitation during 2004, and it is apparent that there is a rough similarity between the nitrate curve and the precipitation curve.

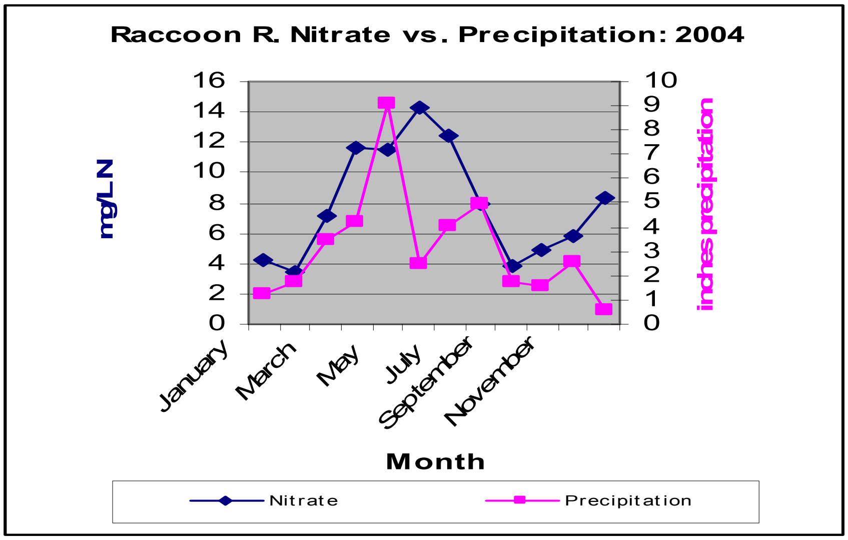

Figure 7

During the 1995-2004 period, river nitrate levels trended up for 11 of the 12 calendar months. The only month that is trending down is November, likely a reflection of the practice to delay fall nitrate application until soil temperatures fall below 50°F. Figure 8 shows the monthly trends since 1995.

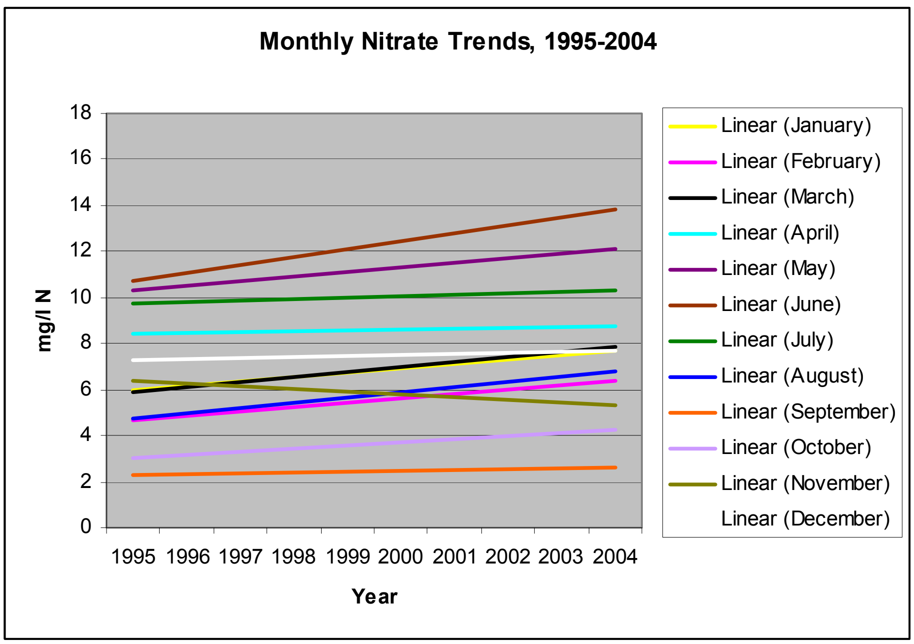

Figure 8

Raccoon River Sub-watersheds

The Raccoon River Watershed has three main sub-watersheds: the North, Middle, and South Raccoon Rivers. Since 2000, DMWW has worked with Agriculture's Clean Water Alliance to monitor water quality from approximately 40 sites scattered throughout the three watersheds. This sampling and monitoring has taken place from April through August each year.

Results of this monitoring show that the bulk of the nitrate load in the Raccoon Watershed comes from the North Raccoon River. This stands to reason, since this branch flows from the heart of the Des Moines Lobe, its land is the most intensely cultivated of the three branches, and it has the highest concentration of drain tile. Contrastingly, the South Raccoon Watershed, which flows primarily from the Southern Iowa Drift Plain, contributes the least amount of nitrate. Natural drainage in this watershed is much more developed, making subterranean drain tile unnecessary. Natural drainage is slower and enables natural processes to consume the nitrate before it reaches the major streams.

Figure 9 depicts a summary of nitrate results for the three watersheds since 2000. Although high, nitrate levels in the North Raccoon do not seem to be getting worse over the past few years. Discouraging, however, is an apparent upward trend in the Middle Raccoon, and indications are that nitrate concentrations in this branch may soon equal those seen in the North Raccoon drainage.

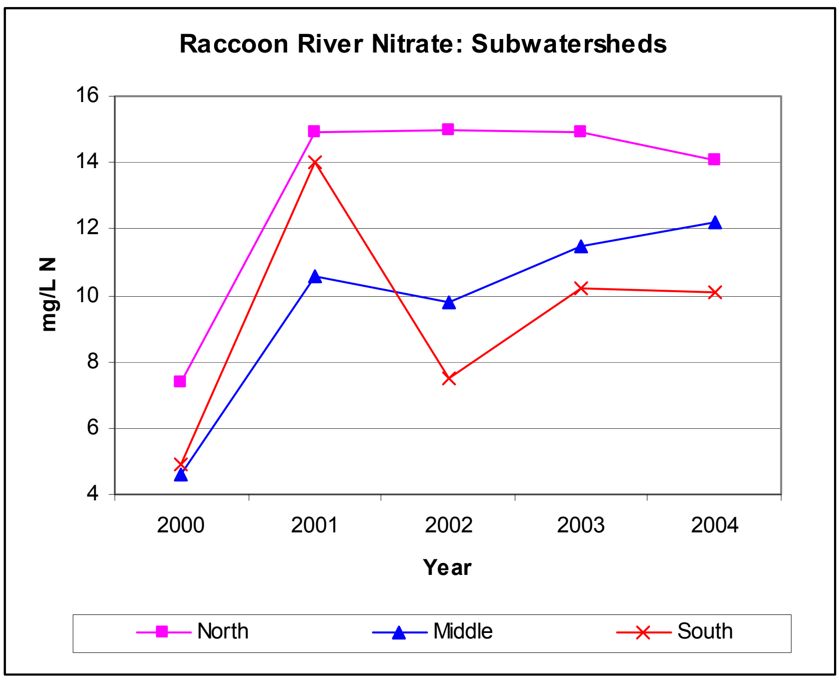

Figure 9: Raccoon River Subwatershed Nitrate

Notable Nitrate Episodes in the Raccoon Watershed

Date	**Site**	**Nitrate Concentration mg/L as N**
6/25/2002	Outlet Creek Near Storm Lake	49.4
8/26/2004	Outlet Creek Near Storm Lake	44.9
6/7/2001	Buttrick Creek	39.7
6/30/2004	West Buttrick Creek	33.8
6/21/2004	Elk Run Creek	32
6/21/2001	Elk Run Creek	31
5/27/1999	West Buttrick Creek	25
5/20/2004	Walnut Creek in Dallas County	21
5/15/2002	Fleur Drive	18.3
6/19/2002	Fleur Drive	17.8
5/30/2001	Fleur Drive	17.5
6/18/2004	Fleur Drive	17.4
1/2/2002	Fleur Drive	17

Table 2: High Nitrate Episodes

Nitrate Summary

Awareness of the nitrate problem has never been higher, but Raccoon River nitrate levels continue to increase. Since nitrogen application rates remain constant, it's not very clear why nitrate levels continue to rise. It could be that a huge bank of excess nitrate has been created deep in soils of the Raccoon Watershed, fueling an increase in groundwater nitrate which subsequently increases river nitrate. It's possible some of the nitrogen flowing down the Raccoon River today was applied to the land years ago. It's clear that the nitrate increase is not dependent on annual precipitation. An evaluation of the average magnitude of precipitation events over the last 10 years might indicate some connection.

Is there hope that the nitrate levels will begin to decrease? Some farmers are aware of and concerned about the problem, and are implementing practices that may make a difference. The delay of fall fertilizer application until soil temperatures fall below 50^{o}F is well-intentioned. There is little evidence that this practice, however, has made a difference in any month except November. If shallow groundwater levels are high throughout the Raccoon River watershed, it could take many years for river nitrate levels to subside, even if all fertilizer application ended, and this is not likely to happen. High nitrate levels in the Raccoon River did not happen overnight, and it's obvious that correcting the situation could take decades.

Coliform Bacteria

Background
Coliform bacteria are found everywhere in the environment. Fecal coliform, and *E. coli*, are found in the intestinal tract of vertebrates and their waste. These organisms are water quality indicators, and the presence of fecal coliforms, especially, is an indicator that water has been contaminated with human and animal waste.

Fecal coliforms enter the river in a variety of ways. One way is discharge from wastewater treatment facilities or storage lagoons. Incompletely treated wastewater can contain millions of fecal coliforms in only a few milliliters of water. Treated drinking water can legally contain <u>no</u> fecal coliforms.

Another source of fecal coliform contamination is livestock manure, either through runoff from feedlots, or from fields where manure has been applied. Fecal coliforms also enter the water from wildlife and urban runoff.

DMWW has been regularly monitoring coliforms in the Raccoon River since late 1996. The data that follows indicates the level of bacterial contamination of the river, and how 2004 compared to previous years.

Monthly averages
Somewhat surprisingly, total and fecal coliforms (*E. coli)* follow different month-to-month trends in the Raccoon River, as shown in Figures 9 and 10. Fecal coliforms peak in late spring—probably a reflection of two things: wastewater lagoon discharge and heavy spring rains flushing waste from feedlots and manure-applied fields. The generally accepted fecal coliform limit for safe swimming in natural waters is 235 colonies/100ml. One can see from Figure 9 that the Raccoon River meets this limit for only two months out of every year—January and February—not the best months for swimming. In fact the river contains these organisms at levels many times the standard for much of the year.

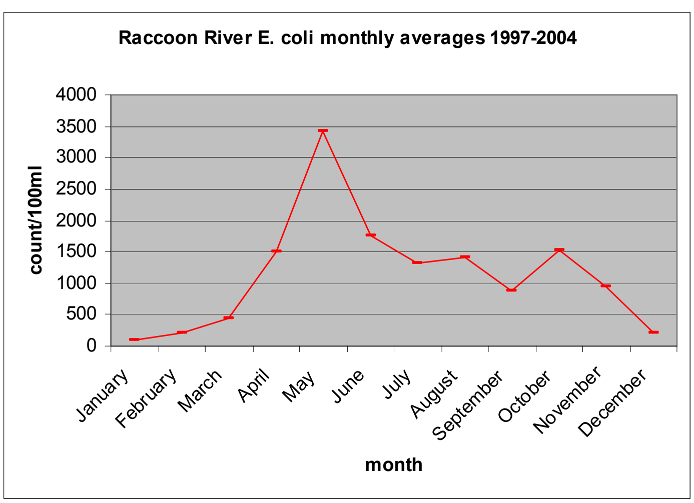

Figure 9

Total coliform concentrations peak in late summer. This might be an indication that there are a relatively constant total number of coliforms in the river, but are concentrated as flows decrease. The increases could also be due to propagation as the water reaches its maximum temperature in the summer.

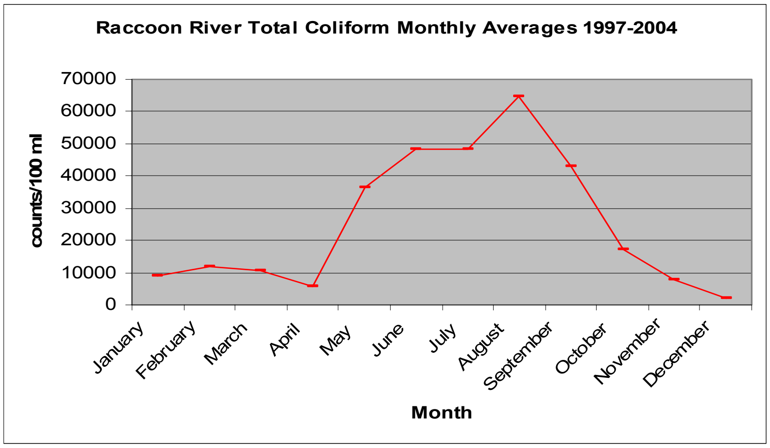

Figure 10

Annual Trends for Fecal Coliform

Eight years is not a long time when trying to determine a trend in water quality such as this. That said, fecal coliform concentrations appear to be trending up in the river since monitoring began in earnest in 1997. The red line in Figure 11 follows their numbers. Also plotted in Figure 11 is annual precipitation for the eight years, depicted by the blue line. One can see that *E. coli* concentrations very closely mirror annual precipitation levels. Very large precipitation events can overwhelm wastewater treatment systems and contribute to *E. coli* in the river; however, the striking similarity between long-term precipitation trends and river *E. coli* points to a higher dependence on agricultural sources than wastewater treatment plants. Human wastewater-borne coliforms should be relatively constant from year to year except in cases of copious rainfall events, and high river flows can actually dilute their numbers. The solid connection between *E. coli* and precipitation indicates that the majority of these organisms are due to runoff from feedlots and fields where manure has been applied.

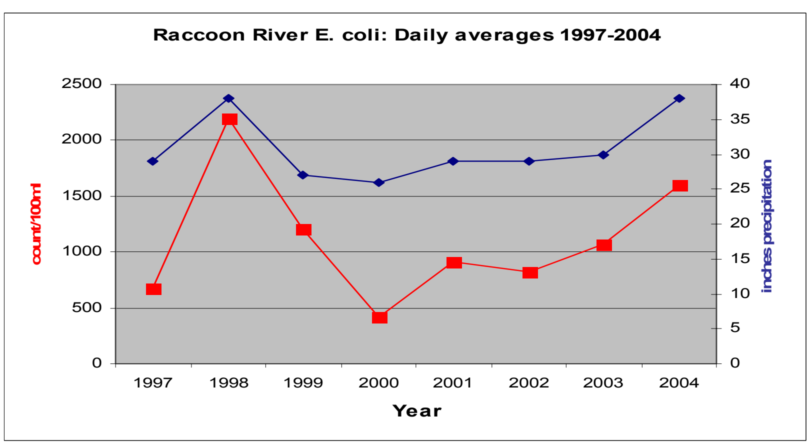

Figure 11

Interestingly, total coliform numbers do not have a similar dependence on precipitation levels, as shown in Figure 12. This, along with a different month-to-month variation when compared with *E. coli*, indicates that the sources of non-*E. coli* coliforms are different than that of *E. coli* itself.

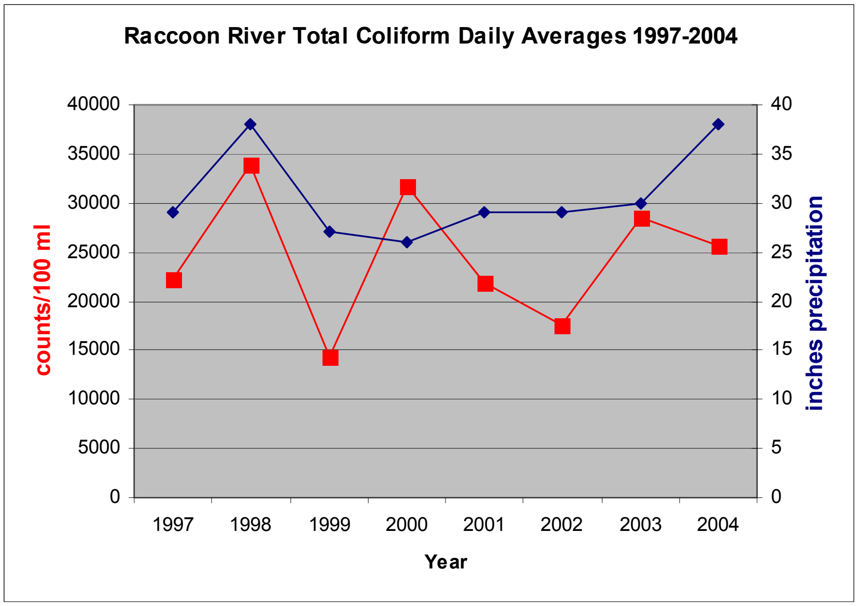

Figure 12

Notable* E. coli *Episodes in Raccoon River at Fleur Drive

Date	*E coli* colonies/100 ml
9/26/96	154020
5/24/04	48840
5/18/99	47860
5/22/01	43520
5/1/03	39780
11/6/03	32320
5/23/01	31300
5/10/04	31060

Table 3: *E. coli* Episodes

Coliform Bacteria Summary

In 2004, the <u>average</u> *E. coli* concentration in the Raccoon River is **seven times** greater than the limit for safe swimming. Over the last eight years, the annual average *E. coli* has never met the safe swimming standard. In only two months of the year, January and February, can the water be considered safe for swimming. It's important to remember that while bacteria can be harmful in and of themselves, they also are a possible indicator of other sinister contaminants associated with animal and human waste and that may be present in the river: viruses, parasites, antibiotics and other pharmaceuticals, and personal care products, to name a few. Whether this shameful situation can be corrected remains to be seen.

References

(1) United States Geological Survey, archival data supplied by John North, City of Cedar Rapids Water Department.
(2) "Iowa's Nitrogen Pollution Results from Feeding a Sick System," Dennis Keeney, in *The Des Moines Register*, May 19, 2000.
(3) Iowa State University Agronomy Extension, http://extension.agron.iastate.edu/soils/nitrogen_use.html