Practical Management of a Gravel Pit as a Nitrate Removal Reservoir

Presented is a standard model of a typical year, as calculated from four years of data ranging from 2001 through 2004.

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The former gravel pit known as Crystal Lake is used for off-river storage of Raccoon River (RR) water, and as natural way to reduce nitrate concentrations of river water for the purpose of low-nitrate dilution water for the Maffitt Treatment Plant. This author has graphed and distilled various parameters relating to the two bodies of water, and then developed a profile of two standard years: one as we now manage Crystal Lake and another to reflect changes in water management paired with technological additions. This author believes that this will help decide what should be the major additions and changes to the Raccoon River/Crystal Lake/Maffitt plant system.

Studied were the following components: Turbidity & phosphate, turbidity & sediment accumulation, nitrate, water temperature, RR water level, pumpage demand, and cyanobacterial blooms.

Turbidity & Phosphate:

The turbidity level is the most important physical characteristic of the Raccoon River and Crystal Lake water to manage. Heavy addition of sediment may cause some concern because of the physical accumulation of silt, but the key concern will be the addition of total phosphate. Phosphate is an important cyanobacterial and algal nutrient, especially when paired with nitrate. If it is allowed to accumulate in Crystal Lake, the late summer cyanobacterial blooms may become larger and more difficult to contain. Phosphate does not travel through soil as nitrate does, because it attaches to or becomes a component of dirt particles. This means that the particulate material that the Raccoon River carries likely will be a dominant source of phosphate for Crystal Lake. (Phosphate from waste water plants and farm manure may be dissolved in the river water and be independent of the turbidity level.)

Various proposals for how phosphate input can be minimized have been made. One idea involves the construction of a marshy wetland area between the RR and Crystal Lake. Another focuses on the inclusion of a sediment settling pond in place of the wetland concept. This author advocates injection of only low turbidity RR water into the lake.

If Raccoon River water is pumped into Crystal Lake only when the turbidity level is equal to or lower than 100 NTU's, the amount of sediment and phosphate will be minimized. The average number of days that this will be possible will be 291 (80% of the year), as calculated from four years of data from 2001 through 2004.

	2001	**2002**	**2003**	**2004**
Number of Days RR ≤100NTU's	285	296	320	261

Keeping the nitrogen to phosphate ratio higher than 15:1 (and ideally above 29:1) will help keep cyanobacteria from blooming (e.g. a nitrate level of 10mg/L should be accompanied by less than 0.66mg/L phosphate). Algal, cyanobacterial, heterotrophic bacterial, and zooplankton growth depends on available carbon as much as nitrogen and phosphate. The ratio of use of these nutrients by bacteria during bioremediation efforts amounts to 100:10:4 (C, N, P).
(www.Bioremediate.com/algae.htm.)

Calculations of nutrients become complex when a lake system is actively processing those nutrients. We already have shown that a steady inflow of high nitrate water is diluted and biologically processed so that the nitrate levels throughout the lake drop lower than 5mg/L. Should nutrient ratios be assessed with regard to high levels injected into the lake, or should they be assessed using the levels that seem to equilibrate throughout the lake? This author believes that the equilibrium Crystal Lake seems to maintain would be a valid target for nutrient level assessment.

The Raccoon River has dissolved ortho-phosphate levels that are usually below 0.2mg/L. The sediment related total phosphate level can be around 1mg/L or higher. This heavy phosphate load makes it important that we adhere to a program of low turbidity input into Crystal Lake.

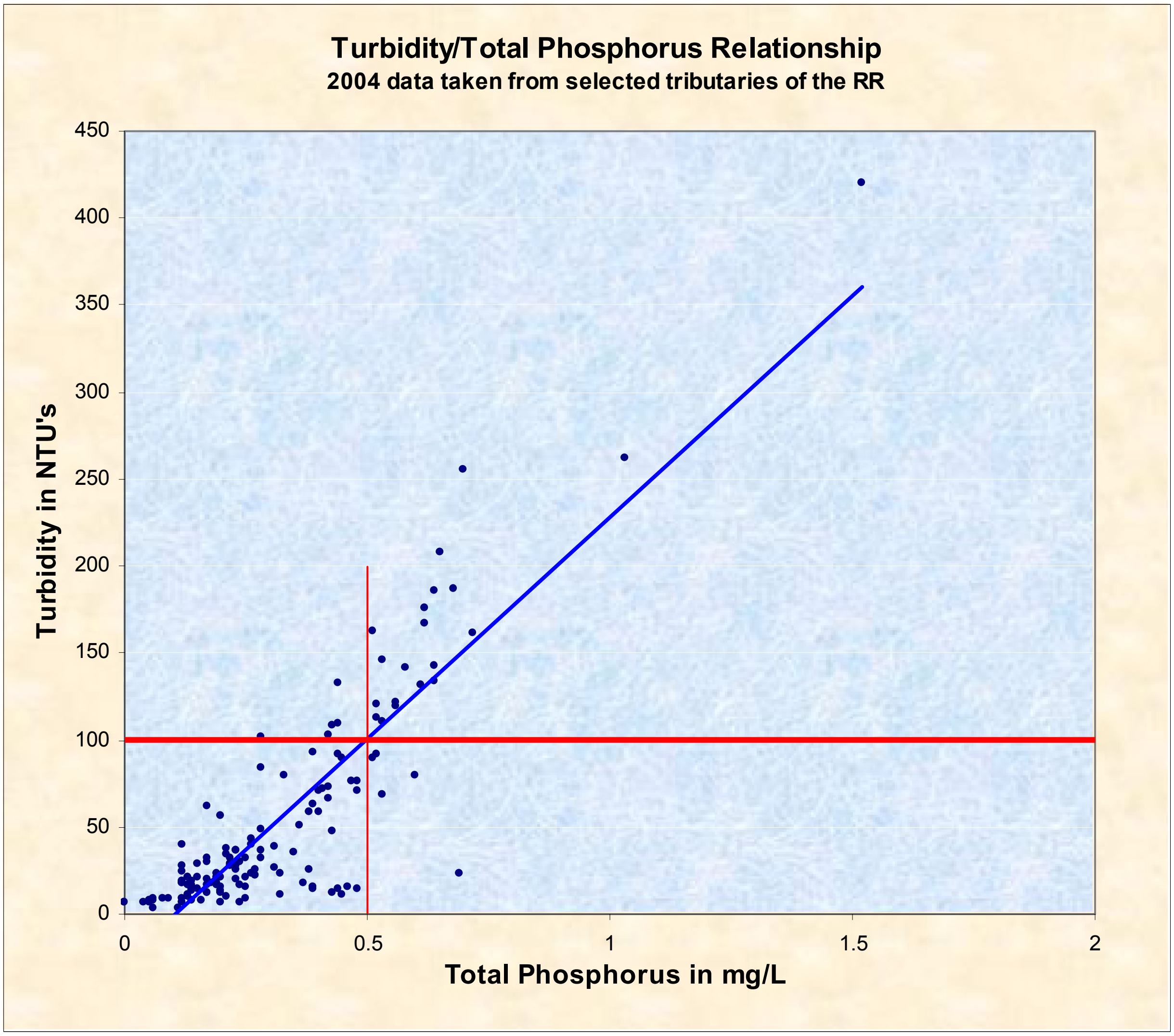
Also, the fauna of Crystal Lake, especially the fish, is likely significant in adding to the organic carbon and other transient nutrients, but it is this author's belief that a balanced ecosystem is better managed than a sterilized one, where beneficial microbial activity is thwarted.

The Floridian bioremediation company referenced above also sells a *Bacillus* strain that purportedly consumes excess nutrients in bodies of water so that the nutrient balance no longer favors cyanobacterial growth. A similar situation occurred in this author's pilot ponds in 2004, where filamentous algal growth inspired by water flow and aeration apparently consumed nitrate and phosphate so that cyanobacterial growth was minimized.

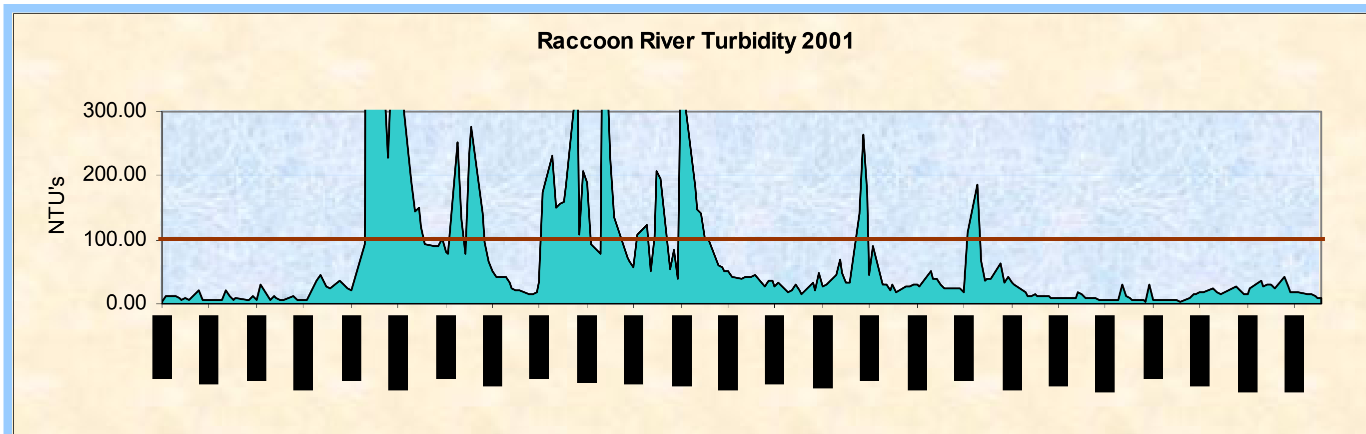
I now have my pilot ponds indoors under bright lights. One pond has grown a large mass of filamentous algae from surface to bottom, without aeration. A similar alga grows in Crystal Lake. It likely serves as a nutrient consumer much like the Floridian *Bacillus* strain. Such algae can be a nuisance in particular waterways, but this would not be as likely in a static lake such as Crystal Lake, where there is no significant current or recreational boats, etc. Once the nutrients are assimilated, the algal growth should diminish along with the microflora. However, aggressive circulation of the water with aerators may select for excessive growth of this filamentous algae so that it physically obstructs the aerators or the DMWW water intake.

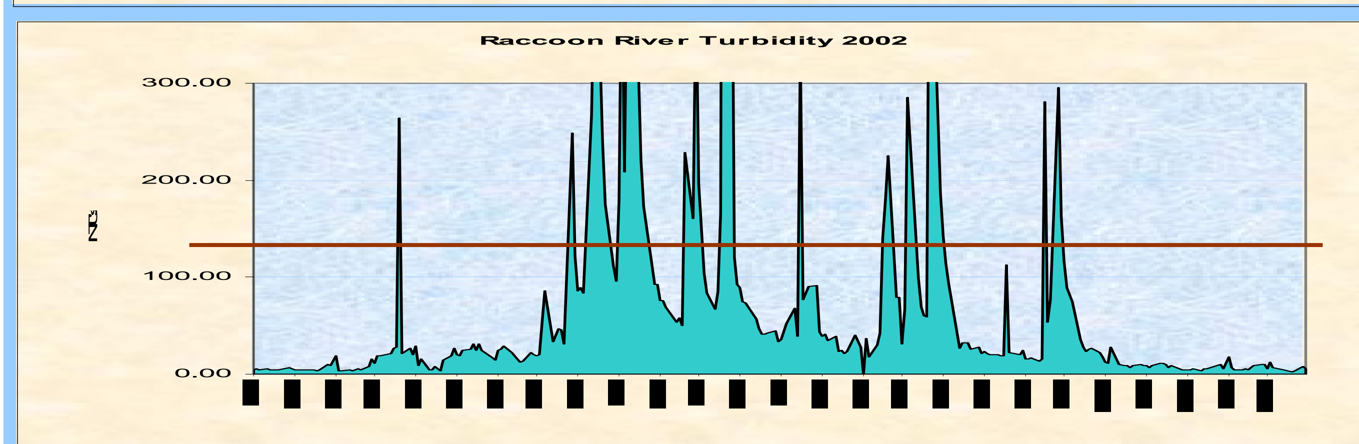
Total phosphate data from selected tributaries of the RR were generated and compiled at DMWW by Carter Woodruff and Gordon Brand.. This data shows a relatively direct relationship between total phosphate and turbidity levels. After viewing the data charts and graphs of the yearly turbidity dynamics, a theoretical injection threshold of 100

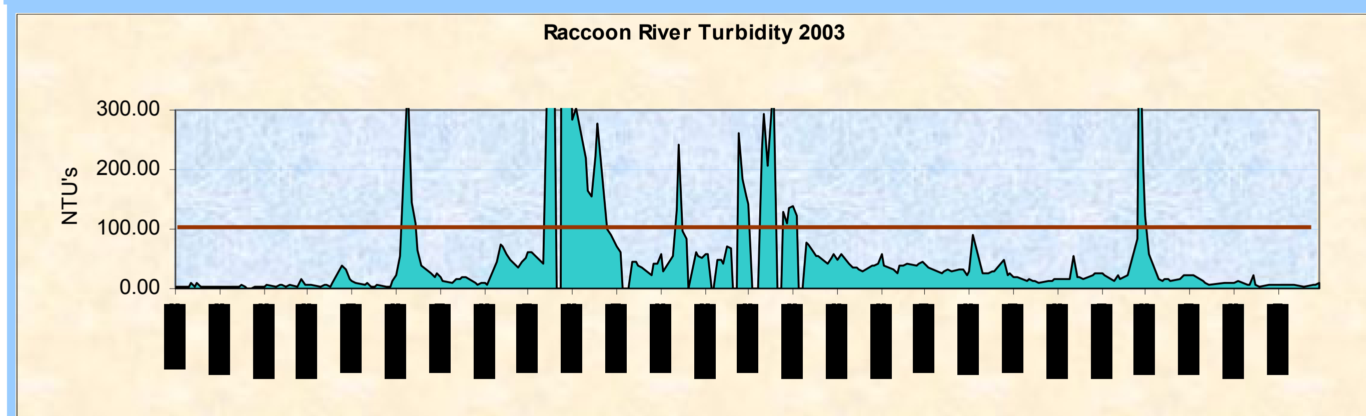
NTUs was selected. The red vertical line indicates the 0.5 mg/L phosphate threshold, which is rarely exceeded at turbidities less than 100 NTU. This will keep the nitrogen: phosphate ratio above the 15:1 target for preventing cyanobacterial blooms.

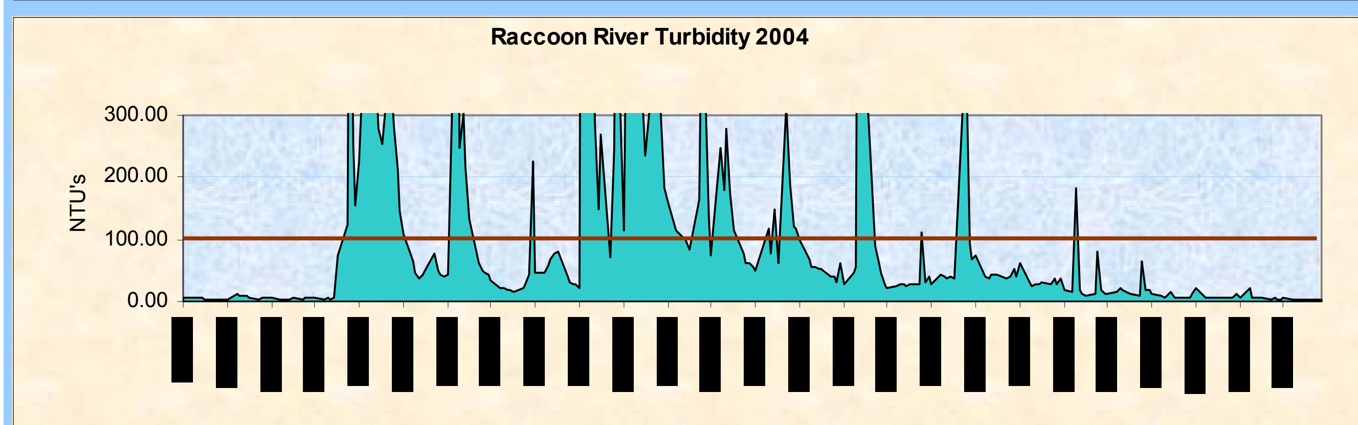


Raccoon River Yearly Turbidity Trends – 2001 through 2004



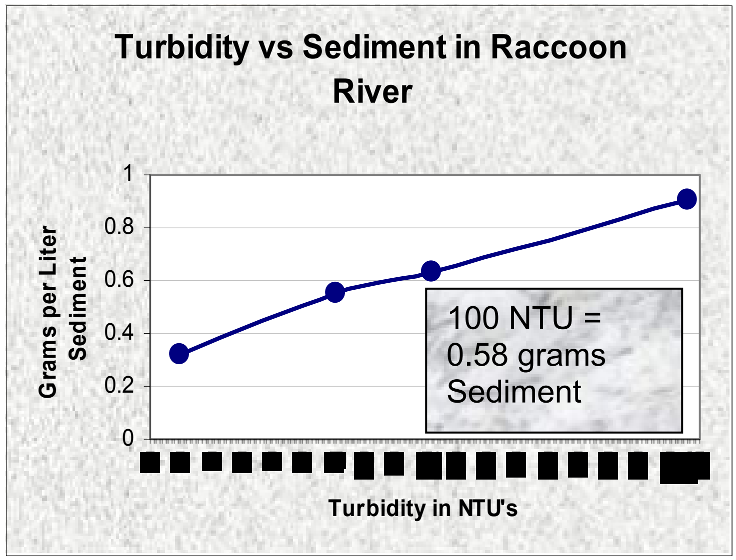






Turbidity & Sediment:
Sediment accumulation at 100NTU will be minimal relating to lake water volume replacement. By avoiding turbidities higher than 100 NTU, coarse, fast-settling sediment from turbulent water will be avoided. At times RR turbidity can exceed 1000 NTU.

One liter of water at 100NTU turbidity contains approximately 580 milligrams soil. The average turbidity below 100 NTU is 28.1. If 5 million gallons per day (mgd) of RR water is pumped into the lake, 5.51 million grams (12,150 pounds) of sediment will accumulate per day. This is equal to about 200 cubic feet of particulate matter.



Crystal Lake covers 62.5 acres. A one-foot thick layer of sediment covering its bottom would equal 2,670,000 cubic feet. The RR averages 291 days per year when its turbidity is less than or equal to 100NTU's. Considering these numbers, it would take over 30 years for the one-foot of sediment to accumulate, representing 1/25th of the lake depth.

Nitrate:
Nitrate levels of the Raccoon River will not be a controlling factor of the use of Crystal Lake, because the lake effectively dilutes and microbiologically reduces the nitrate level. The nitrate level of the RR from 2001 through 2004 exceeded 10 mg/L on 32% of all the days measured:

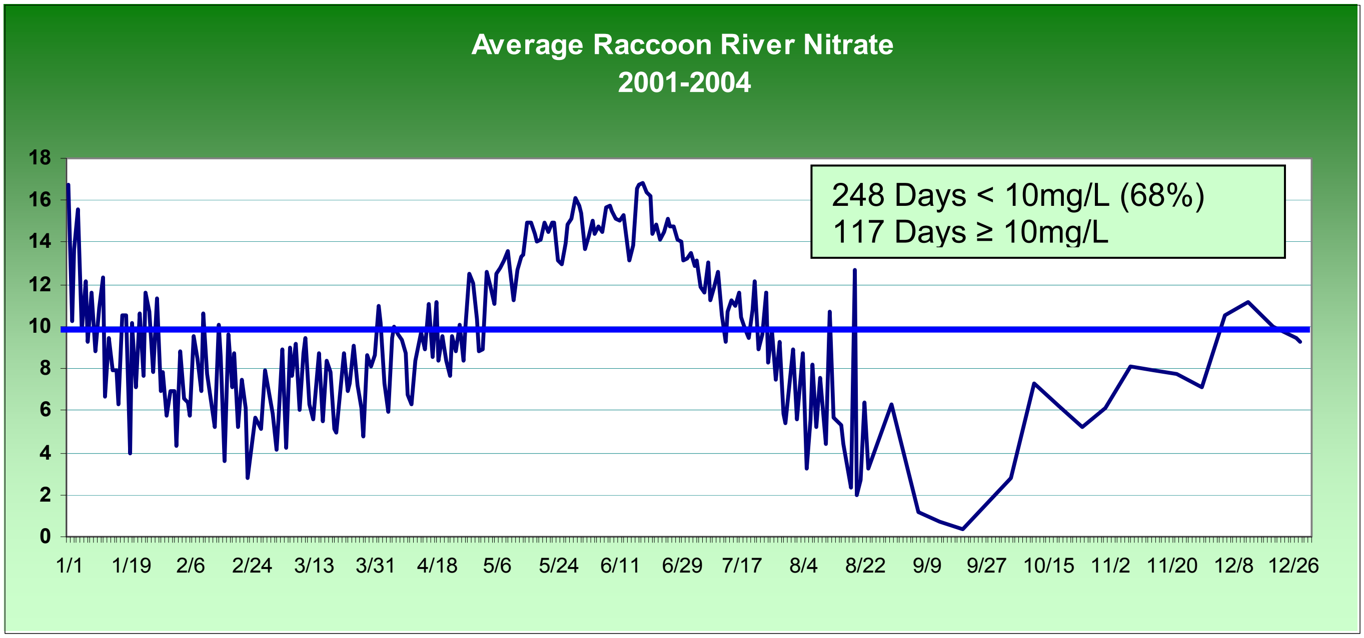
	2001	**2002**	**2003**	**2004**
Number of Days RR Nitrate was over 10mg/L	97	135	121	115

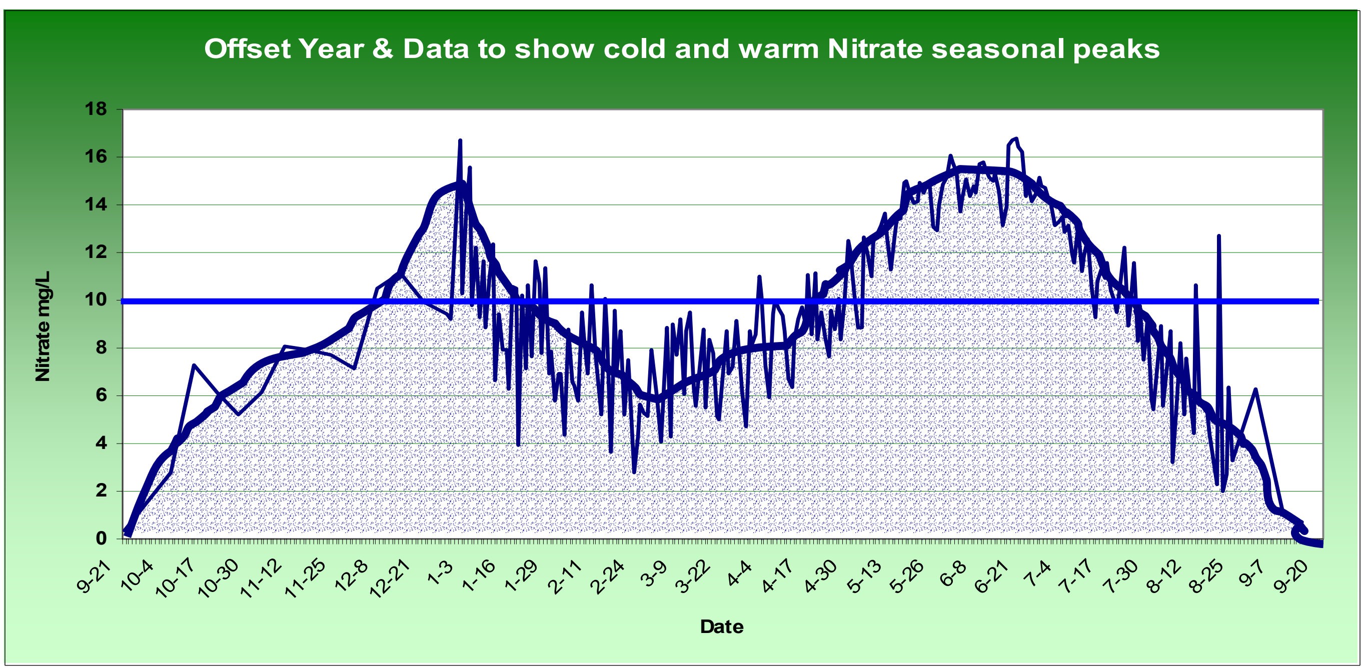
There are winter and summer nitrate peaks in the Raccoon River. The winter peak is likely from groundwater with high nitrate values due to artificial fertilizer applications, manure applications, and natural soil nitrate. This winter peak decreases once snow melt and spring rain dilutes the rivers. The summer peak grows once the spring rain dilution factor decreases, but the water table influence continues. This summer peak diminishes once precipitation becomes rarer and there is microbial activity in the rivers.

The summer nitrate peak precedes DMWW's highest pumpage demand days of the year, providing time to add this water to Crystal Lake for denitrification. The winter peak occurs during the months when river water injection does not because of the frozen river and spring flooding conditions.

Cold water will minimize denitrification processes; however, the lake will provide dilution potential until it warms.

Raccoon River Yearly Nitrate Trends – 2001-2004





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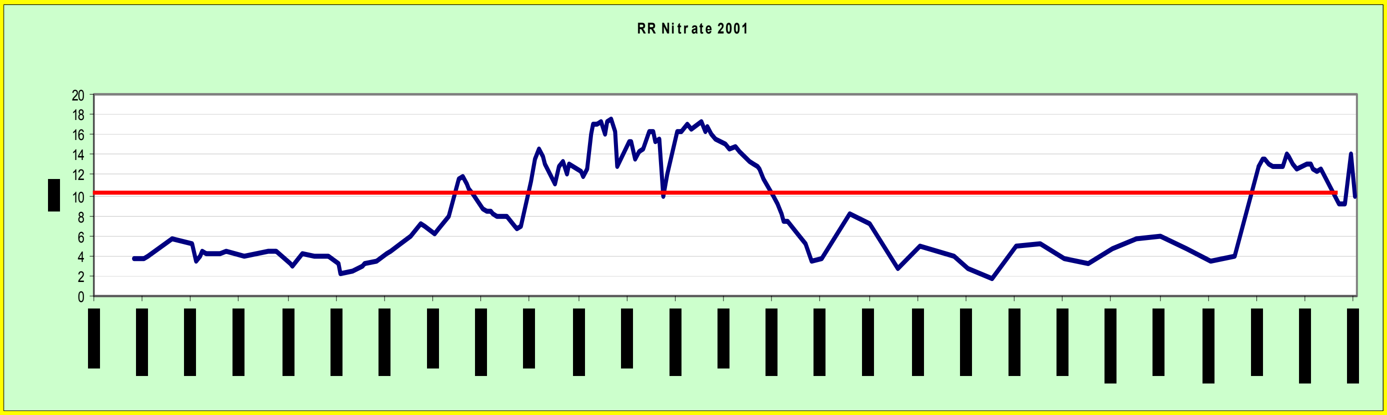
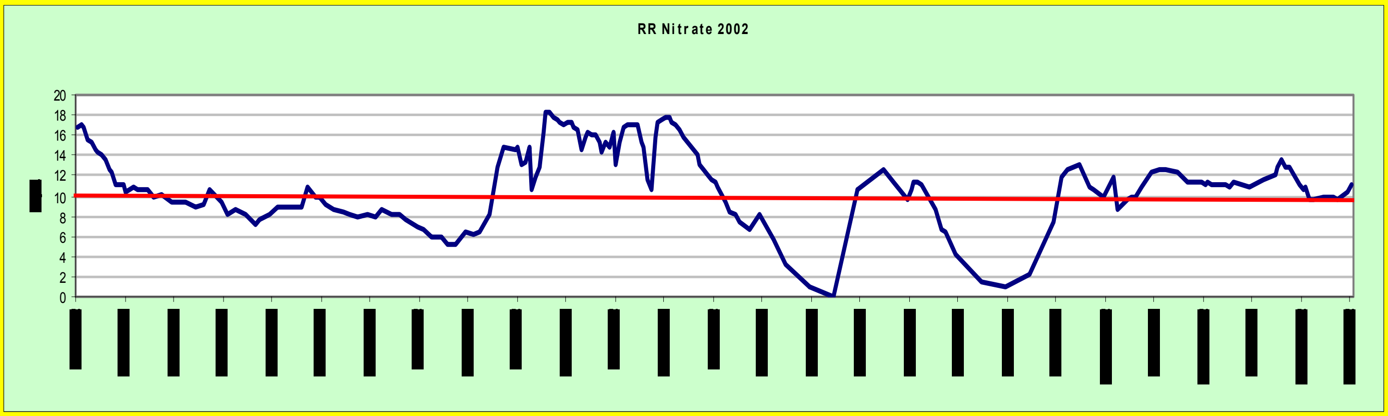
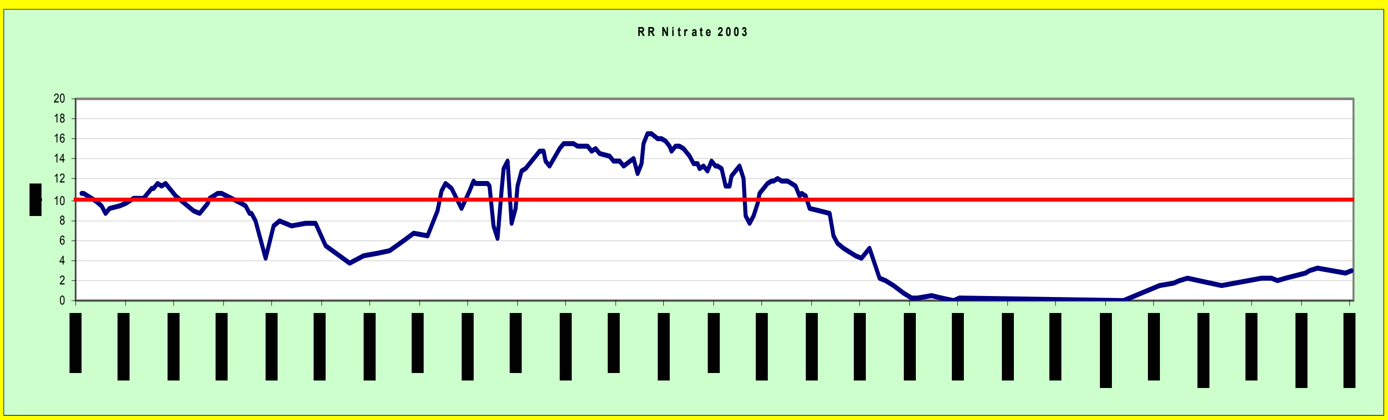
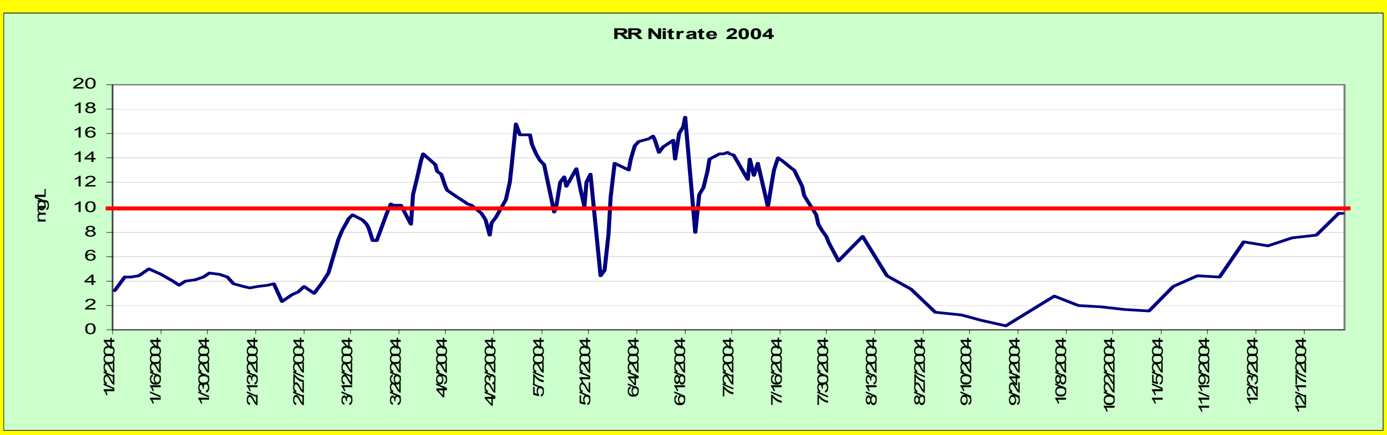


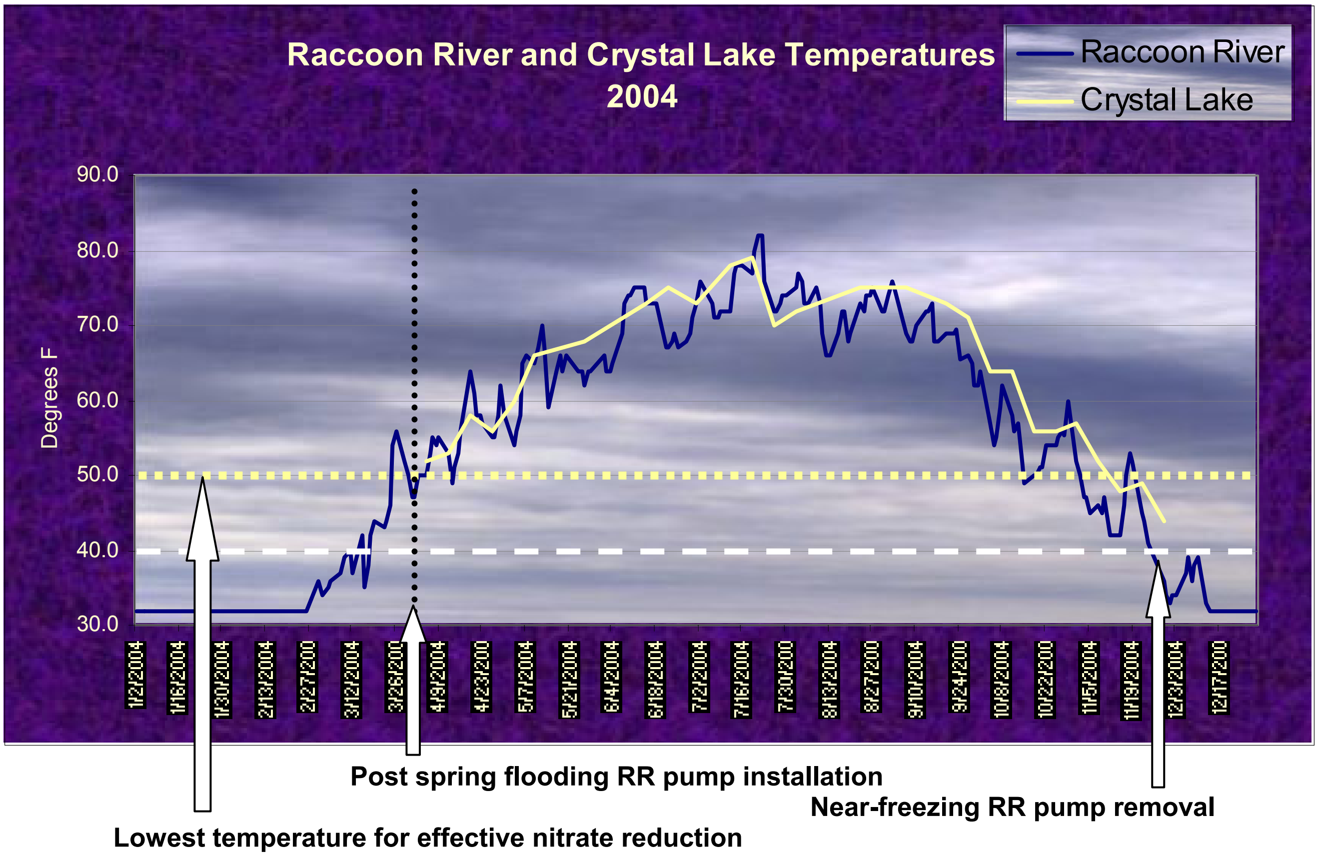






Water Temperature:
Water temperature will be a factor in controlling Crystal Lake management. Microbial denitrification is effective only above 50 °F, which occurs from early April to late November, equaling an average of 228 days (82%).

Raccoon River & Crystal Lake Temperatures – 2004



Once the fall temperature approaches freezing, the RR pump is shut off and removed. The average number of days when the water temperature is above 40 °F, when river water injection can take place, is 255. There are 75 days per year where the turbidity is >100NTU's. However, RR high water levels also obstruct DMWW's ability to extract river water with a bank-mounted pump. To be safe, the pump is not installed until around the first of April. There are 19 days during this flood-prone period where the turbidity is >100 NTU. There are 56 days (75 days – 19 days) when the turbidity is exceeds 100 NTU simultaneous with water temperatures greater than 40F. Of the 14 days between frozen water and April 1, there are 10 days where the turbidity is >100 NTU's, leaving a 9-day net loss to flood-worries. This shortens the potential open-water/ low-turbidity pump time to 190 days (52% of the year).

If a permanent river water intake were installed, the pumpage time could be maximized; equaling an increase of 175 days, (48% increase). The winter months would also have the lowest turbidity (and theoretically the lowest phosphate) levels making it valuable water to direct to Crystal Lake.

A river water intake would also minimize or negate the need to pump valuable radial collector well water into Crystal Lake.

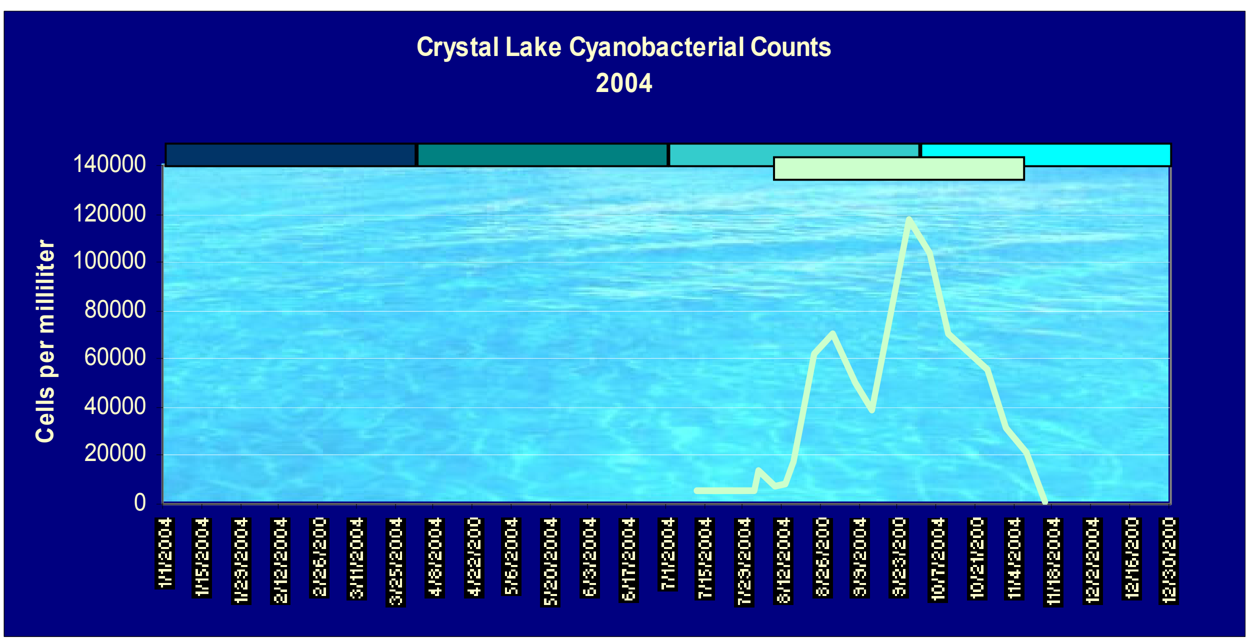
Cyanobacteria:
A recurrent problem with Crystal Lake is a large cyanobacterial bloom that occurs from mid-August to mid-November. This is only one-forth of the year, allowing free withdrawal of the low-nitrate Crystal Lake water for 9-months of the year. However, this period is during the highest water demand time of the year. It is also possible that this bloom will begin earlier in the year if the nutrient load in Crystal Lake becomes significantly greater.

AWWA guidelines address cyanobacterial taste and odor and toxin production. Blooms that tally between 500 and 2,000 cells/ml fall within Alert Level I, where taste and odor concerns should be addressed. Blooms of 2,000 to 15,000 cells/ml fall within Alert Level II, which suggests that toxin studies should be performed. Finally, blooms over 15,000 cells/ml fall within Alert Level III, where contingency plans for alternate source water should be considered.

When Crystal Lake has cyanobacterial blooms they can peak at over 100,000 cells/ml, seven-times or more above AWWARF's Alert Level III value. These blooms become DMWW's greatest concern, especially because they occur when demand is the greatest.

DMWW continues to withdraw water during these blooms, because the lake water is diluted with radial collector well water. However, when the cyanobacterial blooms exceed about 45,000/ml, DMWW must curtail use of Crystal Lake water. This is because insufficient well water volume is available to dilute cyanobacteria numbers to 15,000/m.

Crystal Lake Cyanobacterial Bloom – 2004
Raccoon River Flow Rates- 2001-2004



Management of Crystal Lake's cyanobacterial blooms could be conducted in any of five ways: *copper sulfate treatment, aeration, biological manipulation of nutrients, PAC treatment,* and *the restriction of water use during the blooms.*

- Early summer *copper sulfate treatment* would be effective in preventing growth of cyanobacteria, but it would require that applications of the toxic material be distributed from a boat. Copper sulfate eventually accumulates in lake bottoms, where it can be toxic to lower food-chain organisms, thus upsetting the lake's ecosystem.

  DMWW laboratory studies show that heterotrophic bacteria denitrify and would not likely be affected by copper sulfate, therefore keeping Crystal Lake's denitrification system intact; however, excessive application may eventually impinge on this also.

- It is possible to control algal and cyanobacterial growth with *aeration systems*. Pump Systems, Inc. makes a product called the SolarBee Reservoir and Pond Circulator (www.solarbee.com). Crystal Lake would require two of these systems totaling $75,000. They are solar powered and are effective in aerating and circulating the water of large bodies of water. These units can also be rented, which may be a more cost-effective option.

  Pump Systems, Inc. strongly supports their product. In addition, information from other sources and from DMWW in-house testing shows that aeration and water movement would minimize the yearly cyanobacterial bloom; however, the full efficacy of this product in Crystal Lake will have to be proved through its actual use.

- Biological manipulation of the nutrients in Crystal Lake could be attempted through the application of specially chosen, commercially purchased bacteria. This would have to be tested before its efficacy would be confirmed.

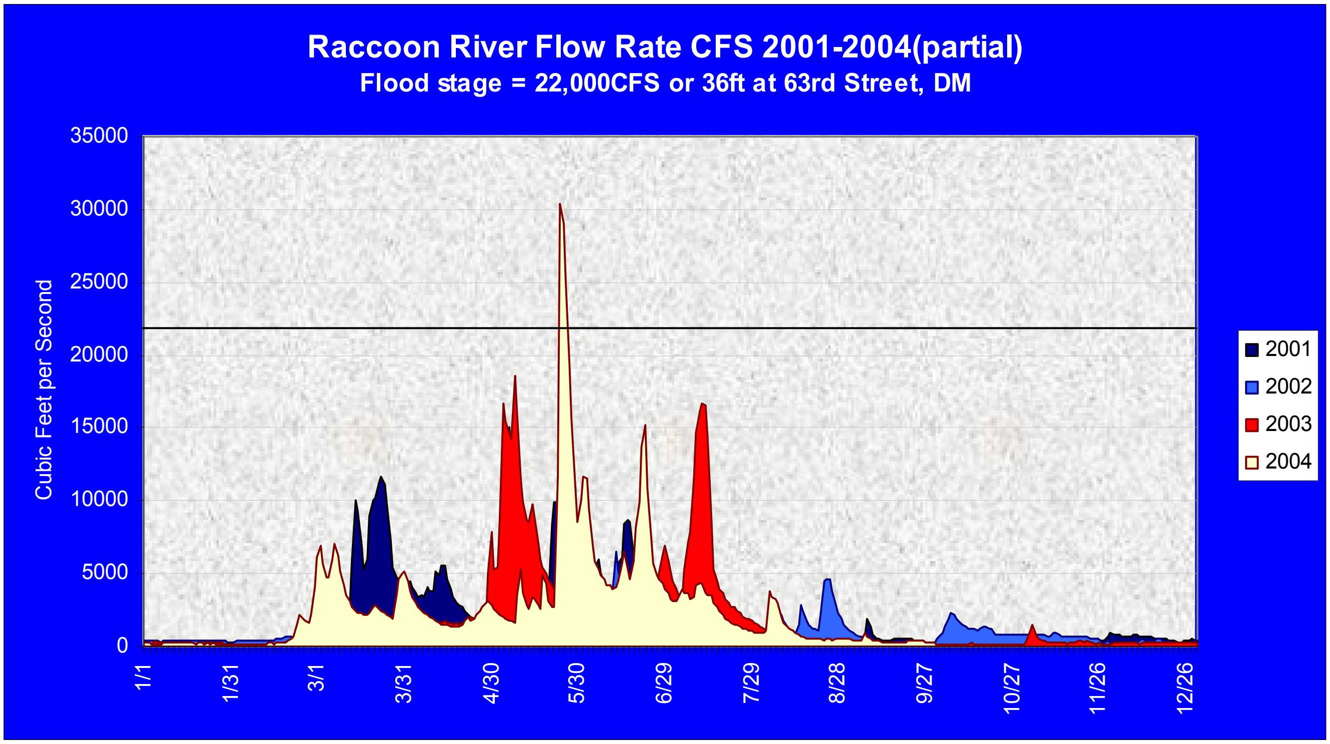
- *PAC* (powdered activated carbon) treatment ability at the Maffitt reservoir plant would simultaneously resolve the taste and odor and the cyanotoxin issues. All of the dissolved cyanotoxins *(microcystin, anatoxin-a, cylindrospermopsin, saxitoxin, and nodularin) are effectively removed with PAC, so full use of Crystal Lake, even during cyanobacterial blooms, would be possible. This author supports this option for cyanobacterial management. GAC (granular activated carbon) is known to have a short lifetime for cyanotoxins.

  Coagulation and filtration are both effective in the removal of particulate cyanobacterial elements (whole or partial cells). When it is paired with PAC, the combination would be efficient.
  **(Reference: USEPA Technical Service Center.)*

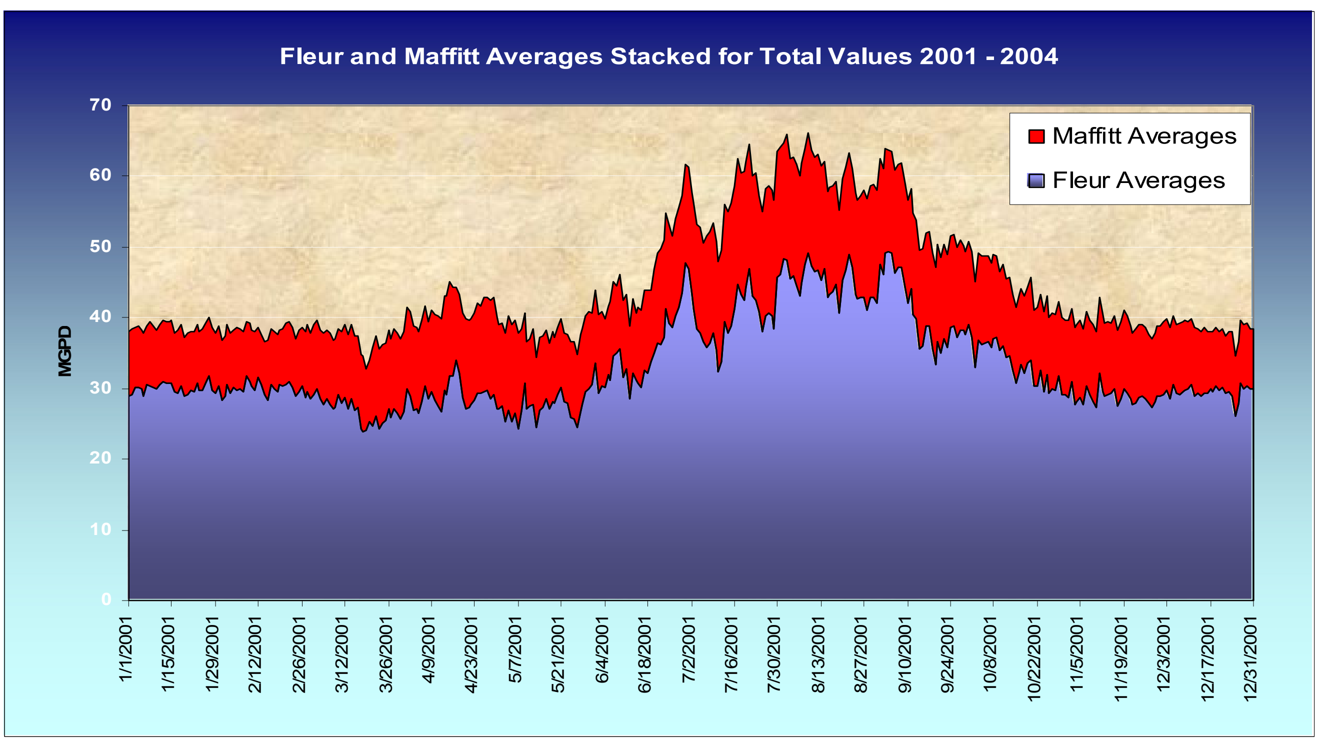
- Finally, the cyanobacterial late-summer bloom could be managed by reducing the amount of low-nitrate water being taken from Crystal Lake, in order to *dilute the odor and toxin components* with Maffitt well water.

  This author does not view this approach as being efficient over time. Crystal Lake offers a great opportunity for simultaneous treatment of Raccoon River water for nitrate and increasing the Maffitt Plant's production of low cost water, and this approach interferes with both effects.

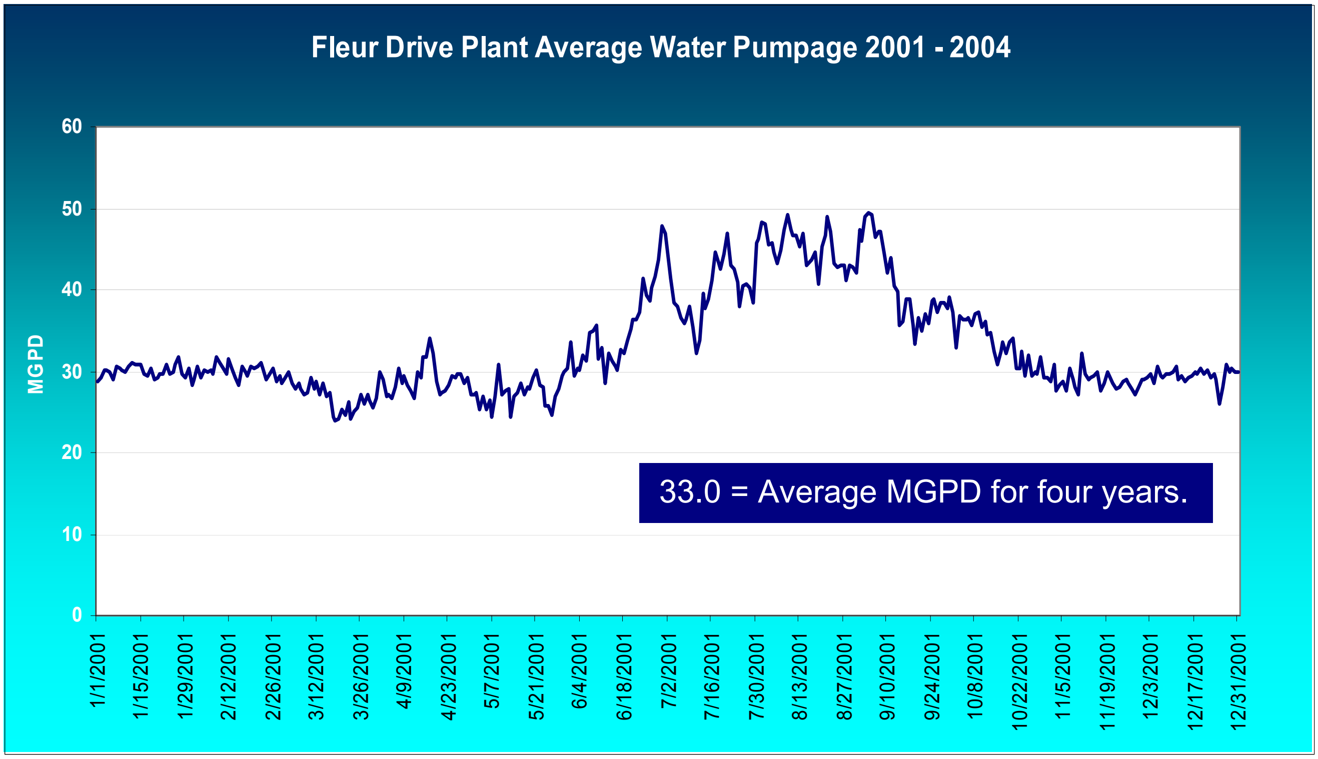
Raccoon River Flow Rates 2001-2004



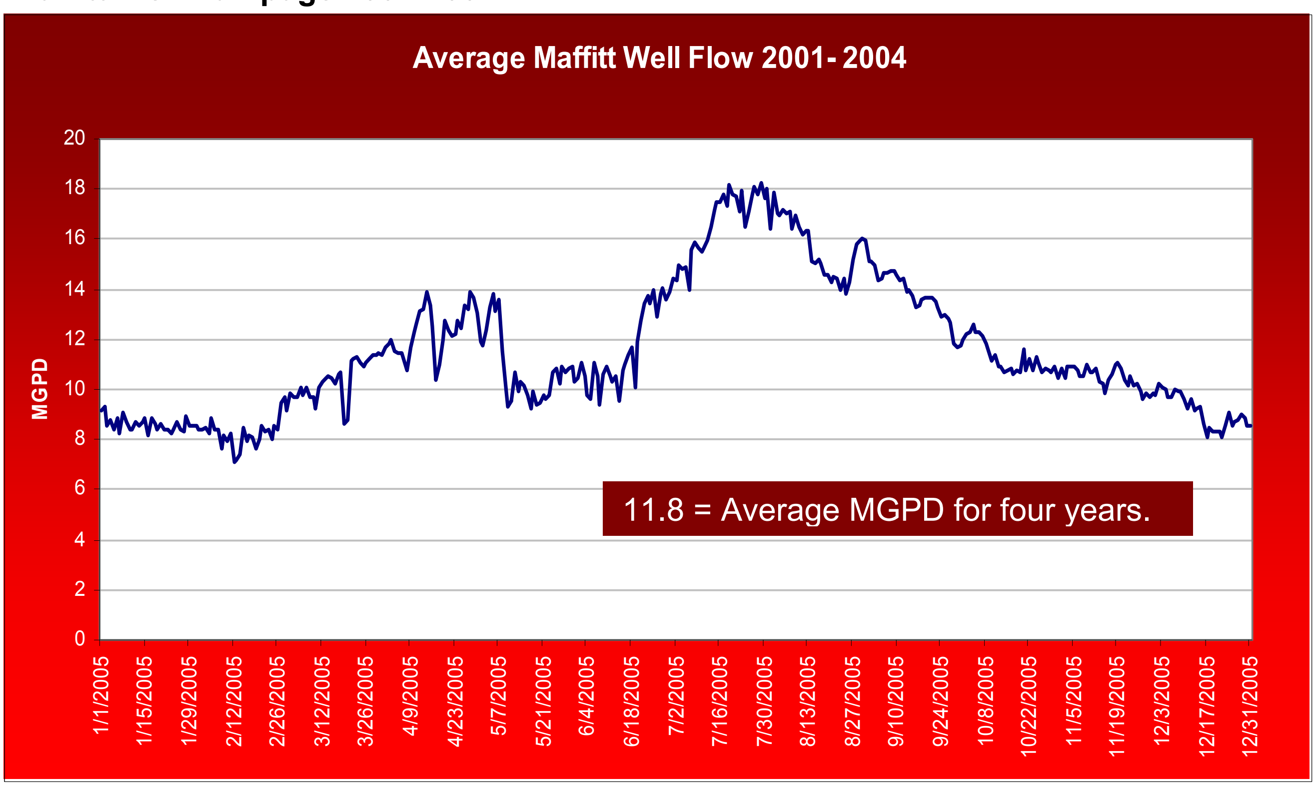
Fleur & Maffitt Average Pumpage 2001- 2004



Fleur Drive Plant Pumpage 2001-2004



Maffitt Well Pumpage 2001-2004



Summary:
Any one year has its unique patterns of the many factors that control water quality and Des Moines Water Works' use of it's various source water resources. This author has attempted to build a picture of a standard Crystal Lake operational year so that the utility can predict the benefit from injecting Raccoon River water and extracting the denitrified water for processing.

The condition of denitrification in Crystal Lake was supported by actual experience during 2004. It appears that 10 mgd could be injected without lake nitrate exceeding manageable levels. This amount of RR inflow is minute compared to the lake volume and denitrification should not be hampered by an addition of 5 to 10MGPD, or more.

Efforts to minimize excess phosphate in the lake should be the primary goal, because an elevated phosphate level will encourage uncontrollable cyanobacterial growth.

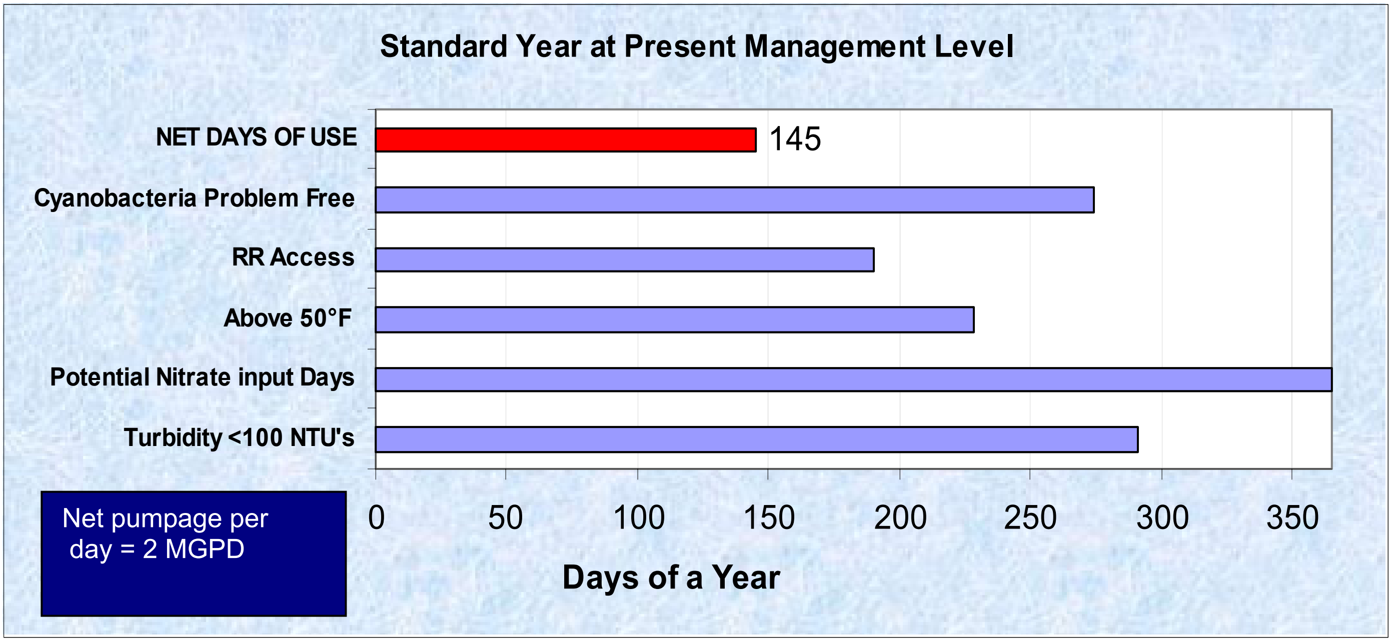
There are three significant changes that would maximize use of Crystal Lake. One would be the installation of a permanent river water intake that would resist flooding and pump RR into Crystal Lake year-round. The second would be the addition of a method to control the yearly cyanobacterial blooms or the toxins and taste and odor compounds that result from it. The third would be a restriction from pumping high-turbidity RR water into Crystal Lake, to minimize any increase in phosphate and sediment into the lake.

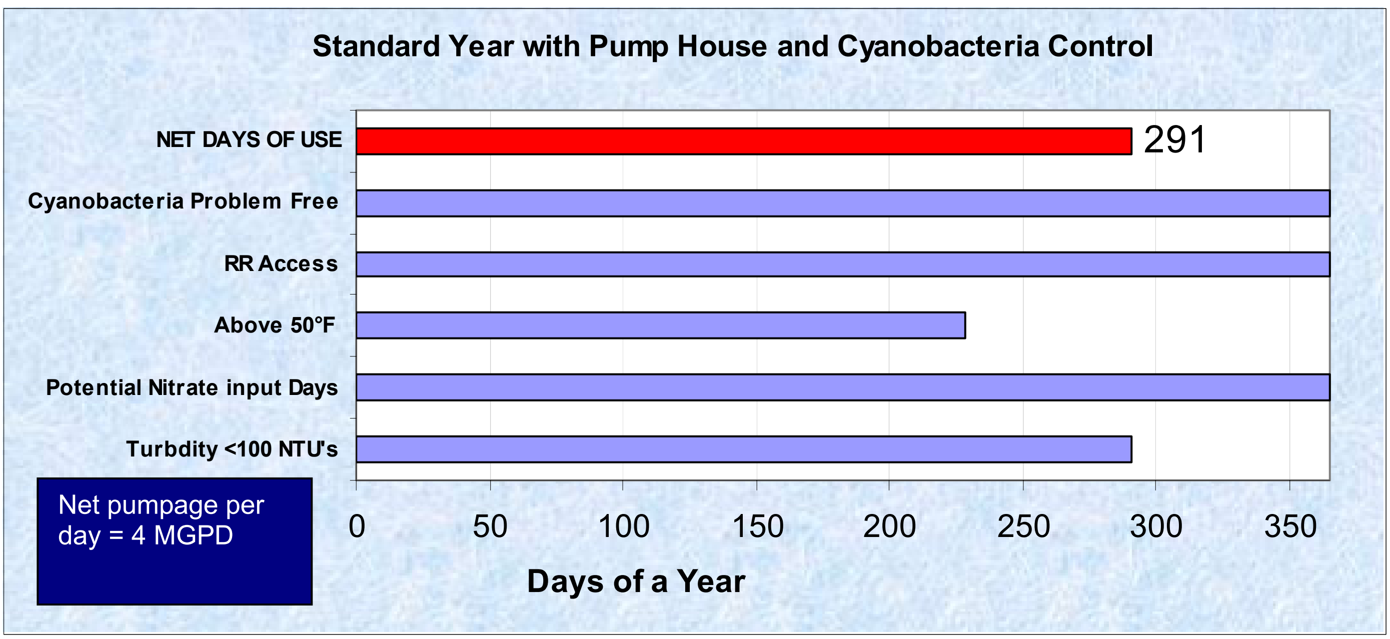
Data Summary Chart of Yearly Averages

Turbidity of the RR	291 days (80% of the year) ≤100 NTU's 190 days ≤100 NTU's open water/ low turbidity/flood-worry free pumping days.
Nitrate	117 days >10mg/L (32% of the year), 248 days <10mg/L
Water Temperature	228 days >50°F for denitrification (64% of the year) Bank-side pumping: 232 days (64% of the year) Pump-house pumping: 365 days
Cyanobacteria	Bloom mid-August through mid-November (3-months) Control Methods: 1. Copper Sulfate Addition to prevent blooms 2. Aeration to prevent blooms 3. Commercial biological nutrient control 4. PAC to remove toxins and taste and odor compounds 5. Reduced pumping during blooms

The following graphs show the construct of a standard year as one would expect with DMWW's present level of RR and Crystal Lake management, and how a year would transpire with the additions of a permanent river water intake and a cyanobacterial control method.

This data is fashioned around the following considerations. Over several years, lake input cannot exceed output for the average year. With this in mind, the maximum net days of use equal the maximum days of predicted Crystal Lake input, due to access to RR pumping, low turbidity levels, and days of pumpage lost to cyanobacterial blooms. A 50% loss of pumpage was calculated for the 3-months of cyanobacterial blooms. During these months it is not common to have high turbidity days. Emphasis on seasonal demand was not given, because it would be ideal to pump the full Maffitt capacity all year long to take advantage of the plant's low er production costs when compared to the Fleur Drive Plant.





The standard year for how DMWW presently manages the RR/Crystal Lake/Maffitt system would allow a net pumpage of 2.0 mgd. The standard year with a river water intake and cyanobacterial control would allow a net pumpage of 4.0 mgd. Installation of 10 MGPD pumps would double these net values.

Dennis Hill 2/18/05