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2003 Lake Delton Water Quality Monitoring Technical Report

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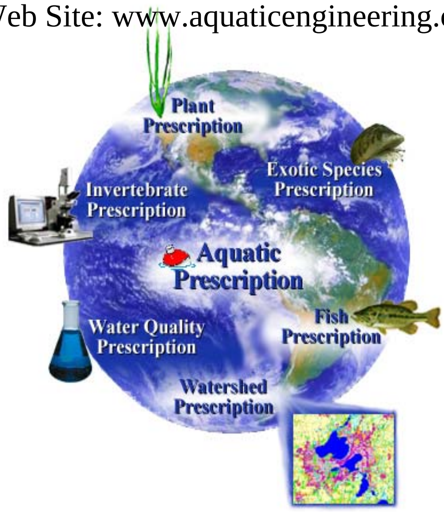

2003 Lake Delton Water Quality Monitoring Technical Report

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February 2007

In cooperation with the Wisconsin Department of Natural Resources

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Village of Lake Delton

Frank J. Kaminski	Village President
Kay C. Mackesey	Village Treasurer
Leslie Bremer	Village Trustee
Gordon Priegel	Village Trustee
David Shanks	Village Trustee
Thomas Webb	Village Trustee
Todd Nelson	Village Trustee
Jim Rodwell	Village Trustee
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Executive Summary

Lake Delton is a drainage lake located in Sauk County, Wisconsin, near the Wisconsin Dells. It is a 76-year-old eutrophic impoundment on Dell Creek with a surface area of 267 acres. The dam sustaining Lake Delton is just upstream of the Wisconsin River and within the Village of Lake Delton.

Lake Delton is one of the most intensively used recreation lakes in the state of Wisconsin. There are a number of resorts and businesses on Lake Delton that depend on the lake's navigability and water quality. It is becoming widely noticed that the economic value of lakes is directly related to water quality and a healthy aquatic plant community (Krysel *et al.*, 2003).

This report addresses water quality monitoring activities occurring on Lake Delton in 2003 and early 2004. The goals of the monitoring were to:

- evaluate the trophic state of Lake Delton and compare results to 1992's water quality monitoring
- determine the current state of Lake Delton's major tributaries and their contribution to water quality related problems in Lake Delton
- make recommendations for future management and monitoring activities that are beneficial for the economic and ecological value of Lake Delton

Water samples collected from Lake Delton in the spring of 2003-2004 indicate that the water quality has remained constant or slightly improved since that last study was performed in 1992. Lake Delton's tributaries generally showed they are in a state of decline in 2003 compared to the 1992 study.

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1.0 Introduction

Lake Delton is a drainage lake located in Sauk County, Wisconsin, in the Village of Lake Delton near Wisconsin Dells. It is a 76-year-old eutrophic impoundment on Dell Creek with a surface area of 267 acres, a maximum depth of 16 feet, and an average depth of approximately 8 feet. The dam sustaining Lake Delton is just upstream of the Wisconsin River and within the Village of Lake Delton.

Lake Delton is one of the most intensively used recreation lakes in the state of Wisconsin. There are a number of resorts and businesses on Lake Delton that depend on the lake's navigability and water quality. It is becoming widely noticed that the economic value of lakes is directly related to water quality (Krysel et al 2003).

This report addresses water quality monitoring activities occurring on Lake Delton during 2003-2004. Aquatic Engineering personnel collected water samples from Lake Delton and its tributaries. The goals of water quality monitoring were to:

- evaluate the trophic state of Lake Delton and compare results to 1992 water quality monitoring
- determine the current state of Lake Delton's major tributaries and their contribution to water quality related problems in Lake Delton
- make recommendations for future management and monitoring activities that are beneficial for the economic and ecological value of Lake Delton

2.0 Project Overview

2.1 Water Quality

Water quality is related to the perception of lake condition. It is usually determined by measuring total phosphorus, chlorophyll-*a*, and Secchi depth and assigning a trophic state. Trophic state is an estimate of the biological productivity of a lake. Generally a low to moderate state of productivity is desired by most recreationists. The three general trophic categories are oligotrophic, mesotrophic, and eutrophic. An oligotrophic state indicates that a lake is very unproductive, resulting in very clear water and low biological productivity. A eutrophic lake is highly productive due to enrichment of nutrient (phosphorus) levels. Highly productive lakes may exhibit algal blooms, dense aquatic plant growth, and murky water conditions. Oxygen depletion may also affect fish and other aquatic organisms. A mesotrophic lake lies somewhere in between the oligotrophic and eutrophic conditions.

The three determinants of trophic state are total phosphorus, chlorophyll-*a*, and Secchi depth. They all estimate lake productivity but from a slightly different perspective. Phosphorus is often the limiting nutrient in lakes and is therefore the fuel that allows plants and algae to grow. As a result, excessive phosphorus most often leads to excessive plant and/or algae growth.

Algae are small photosynthetic organisms and can be found either floating in the water column or attached to various substrates (rocks, plants, decaying material, etc.). They contain a pigment called chlorophyll that is present in concentrations proportional to the amount of algae. As the amount of measurable chlorophyll increases, so do the chances that a nuisance algal bloom will occur on a lake.

The last measure of trophic state is Secchi depth. It is a direct measure of water clarity determined by lowering an 8-inch black and white disc into the water column until it disappears from view and measuring its depth. In most cases, Secchi depth is proportional to amount of algae present.

Lake management activities are often directed at reducing the amount of phosphorus in the water column. Managing phosphorus inputs to the lake should reduce the amount of algae (and trophic state) over time or at least maintain the current condition of the lake. However, evidence also suggests that if external sources of phosphorus are controlled, internal mechanisms and recreational activities may still cause problems to persist. During the summer, many lakes will become thermally stratified. Thermal stratification occurs when water near the surface (epilimnion) becomes warmer and therefore less dense than water near the bottom (hypolimnion) of the lake. The thermocline, where the warm water meets the cold water, can become so pronounced that normal wave action is not enough to mix the two layers. Internal loading occurs within stratified lakes because phosphorus becomes more soluble in water when oxygen depletion occurs. Soluble phosphorus can then migrate from the lake bottom to the upper areas of the water column during turnover events (lake mixing) and effectively fertilize the lake the following year. In shallow lakes, intense recreation (boating, wave-runners, etc.) may stir up bottom sediment. Since most sediment contains phosphorus, some phosphorus may be released into the water column (Asplund 2000).

2.2 Water Quality, Recreation, and Property Value

Water quality affects the aesthetic value of lakes and the economic value of lake property. A eutrophic condition may cause conditions such as nuisance macrophytes and algal scums. Swimming may become unpleasant due to weed density, low water clarity, and noxious odors. Fishing may be affected in a similar manner. This results in a lower aesthetic and recreational value of a lake. Krysel *et al.* (2003) linked these biological and recreational use changes to the economic value of lake property in Minnesota. An increase in overall Secchi depth of one meter increased the value of a square foot of lake property by an approximate average of $30 per square foot. Similarly, a decrease in Secchi depth of one meter corresponded to a projected loss of lake property values. This shows that in the absence of any real concern of the biological condition of a lake, all lake residents are highly vested in the water quality and resulting trophic state.

3.0 Methods

3.1 Water Quality Monitoring

Water quality samples were collected from Lake Delton four times in 2003-2004 and three times from Lake Delton's tributaries in 2003 (Figure 1). Sampling occurred in April, July, and September of 2003 and January of 2004. Bacteria samples for *Escherichia coli* (*E. coli*) were also collected throughout the Lost Canyon Creek watershed in September 2004 (Figure 2). Selected water quality parameters were also measured on-site with HACH probes[1].

3.1.1 Lake Delton

All Lake Delton water quality samples were collected from mid-lake at elbow's length depth below the lake surface and at the point of maximum depth (~3 m) with a Van Dorn sampling device. Spring, summer, and fall samples were collected from a boat, while the winter samples were collected through a hole drilled into the ice. Samples were preserved in the field, stored on ice, and mailed overnight to the Wisconsin State Lab of Hygiene[2]. Parameters measured in the spring, fall, and winter were total phosphorus, total nitrogen, and chlorophyll-*a*. Additional parameters measured during the summer sampling event included soluble reactive phosphate, nitrate plus nitrite, ammonia, total suspended solids, total dissolved solids, true color, chloride, fecal coliform, and alkalinity.

In addition to the grab samples collected, a depth profile was generated at one meter intervals in the field. These parameters included pH, dissolved oxygen, temperature, conductance, and turbidity.

[1] A HACH Sension 156 probe was used to measure dissolved oxygen, conductivity, pH, and temperature in the field while a HACH turbidometer was used to measure turbidity.

[2] July samples were received at the Wisconsin State Lab with ice melted so results were approximate for that sampling period.

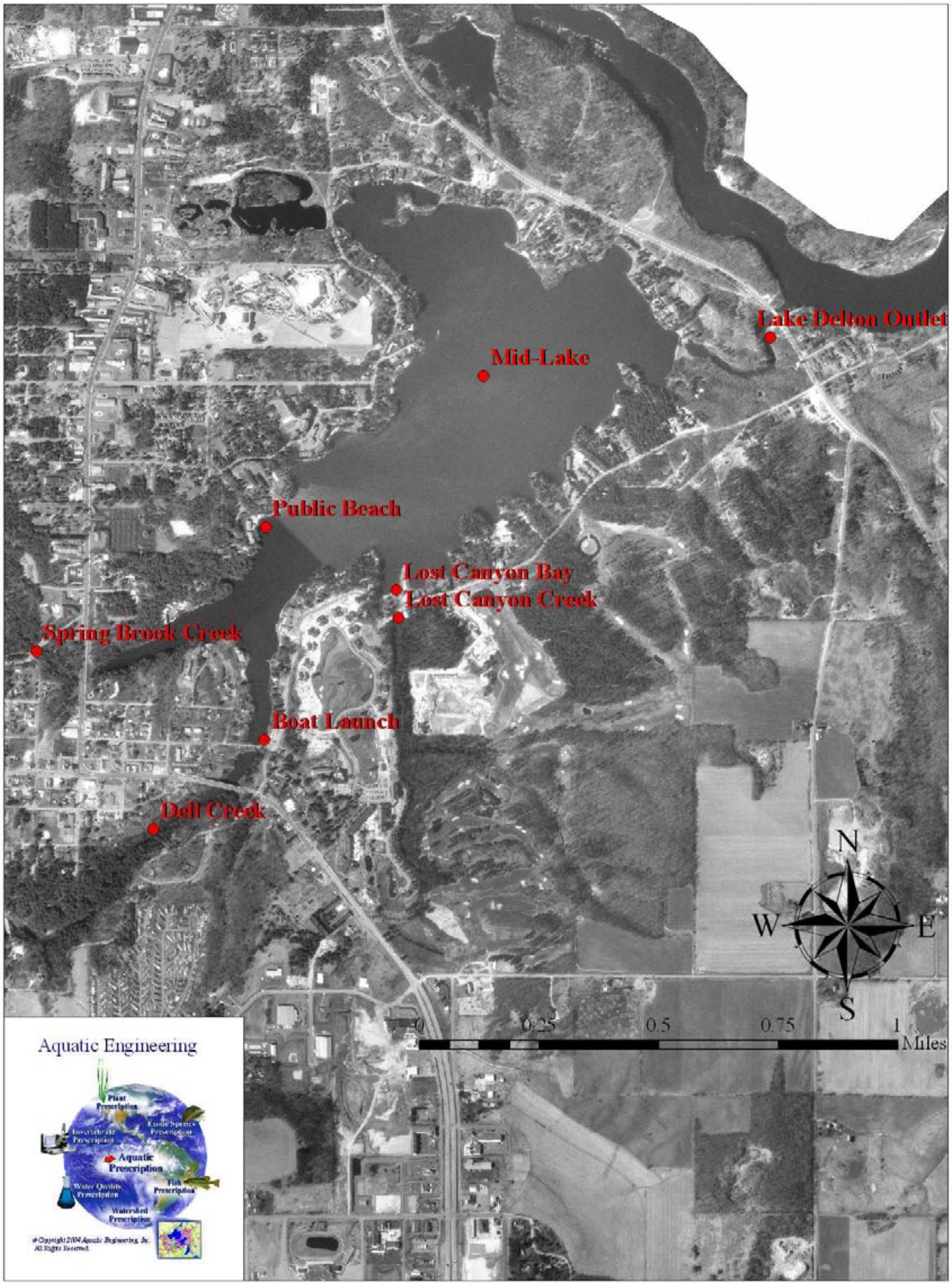

Figure 1. Water sampling locations for Lake Delton water Quality monitoring 2003-2004, Lake Delton (Sauk County), WI.

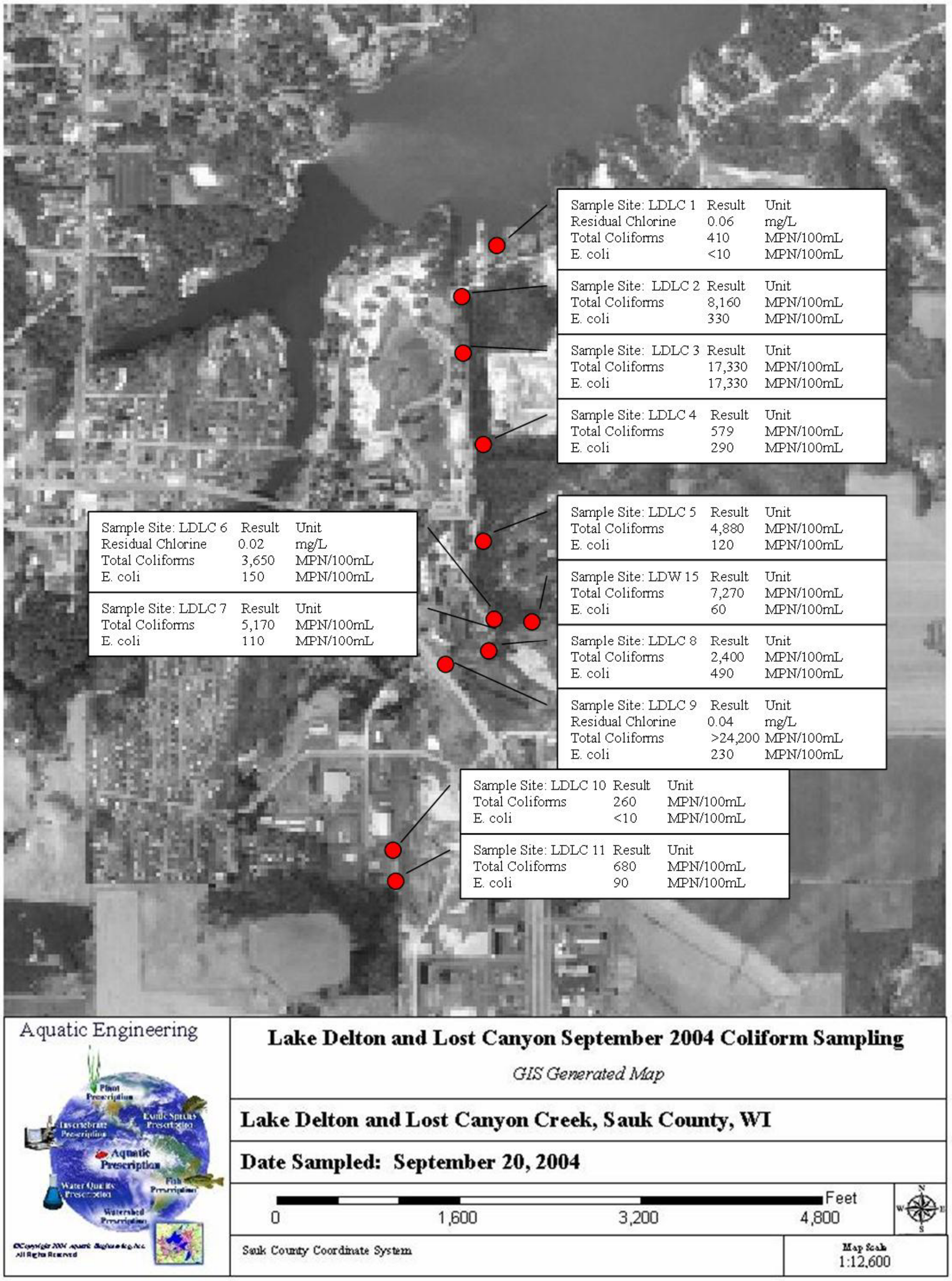

Figure 2. Water sampling locations for Lost Canyon Creek *E. coli* monitoring September 2004, Lake Delton (Sauk County), WI.

3.1.2 Lake Delton Tributaries

Surface grab samples were collected from each tributary in the spring, summer, and fall of 2003 (Figure 1). Parameters measured were total phosphorus, total nitrogen, total suspended solids, and fecal coliform. All samples were collected from the respective stream channels. Samples were preserved in the field, stored on ice, and mailed overnight to the Wisconsin State Lab of Hygiene[3]. Bacteria samples for *Escherichia coli (E. coli)* were also collected in Lost Canyon Creek in September 2004 (Figure 2). Bacteria samples in 2004 were analyzed by an independent state-certified lab (Davy Laboratories in La Crosse, WI). During all sample events, the pH, temperature, dissolved oxygen, conductance, and turbidity were measured on site with HACH probes.

3.3 Data Analysis and Trophic State

Trophic state was calculated for each sampling period for the Lake Delton samples using the following equations (the units of measurement required for each parameter are included as a subscript in the equation):

$TSI_{SD} = 60 – 14.41* \ln (SD_m)$

$TSI_{chl} = 9.81* \ln (chl_{\mu g}) + 30.6$

$TSI_{TP} = 14.42 * \ln (TP_{\mu g}) + 4.15$

The following scale is used to evaluate trophic state (Lillie and Mason 1983):

TSI < 30	oligotrophic
40 < TSI < 50	mesotrophic
TSI > 50	eutrophic

[3] July samples were received at the Wisconsin State Lab with ice melted so results were approximate for that sampling period.

4.0 Results and Discussion

4.1 Water Quality Monitoring Results

Water quality monitoring results for Lake Delton and its perennial tributaries are summarized in the following sections. Results from 2003-2004 monitoring were compared to results from 1992 water quality monitoring to determine the effectiveness of watershed management activities and begin to detect the presence of long-term trends.

4.1.1 Lake Delton

Trophic state index (TSI) values are a way to predict the expected biological condition of a water body based on particular chemical measurements. It is important to remember that the predicted TSI values may not actually reflect the biota present in a water body. The phosphorus, chlorophyll-*a*, and Secchi depth TSI values predict Lake Delton is in a eutrophic to hyper-eutrophic state (Table 2). Blue-green algae should be the dominant aquatic organism, and algal blooms and macrophyte problems should be severe. Severe taste and odor problems are also expected. The impacts of water quality also would be expected to extend to the fishery, where a mixture of warm-water fish and rough fish should be expected.

Water samples collected from Lake Delton in the spring of 2003-2004 indicate that the water quality is similar to those values determined during the last study was performed in 1992 (Table 1). Values for phosphorous, chlorophyll-*a*, and Secchi depth support this statement. This may be a good indicator for Lake Delton being that the water quality is similar between the 1992 and 2003-2004 studies. This similarity indicates that activities in the watershed may not have improved conditions on Lake Delton. However, based off of these two studies, there has not been further decline of the resource. Depth profiles of the water column measuring dissolved oxygen and temperature indicated normal conditions for a eutrophic impoundment (mixed-drainage type) lake with relatively constant values from the surface to bottom (Figures 3 and 4). Dissolved oxygen remained high enough to support aquatic life. Conductivity was low in the summer, fall, and winter and high in the spring. The increased values in the spring are likely due to runoff resulting from precipitation events washing road salt into the lake (Figure 5). The pH of Lake Delton indicates it is more alkaline than typical Wisconsin lakes, but pH should not have negative effects on the lake ecosystem (Figure 6).

Table 1. Trophic State Index predictions for Wisconsin Lakes (Carlson and Simpson, 1996).

TSI	Classification	Predicted Condition
<30	Oligotrophic	Clear water, cold water fishery; oxygen throughout the year
30-40		Cool-water fishery; hypolimnia of shallow lakes may become anoxic
40-50	Mesotrophic	Water somewhat clear, high probability of anoxia in hypolimnia during summer
50-60	Eutrophic	Anoxic hypolimnia, macrophytes may be a nuisance; warm-water fishery
60-70		Blue-green algae problems; recreation is impacted
70-80	Hypereutrophic	Dense algae and macrophyte
>80		Algal dominated system

Table 2. Trophic state and raw data by sample date for 1992 and 2003-2004 mid-lake sampling Lake Delton water quality monitoring, Lake Delton (Sauk County, WI).

Date	TSI_P	P (µg/L)	$TSI_{chl\text{-}a}$	Chl *a* (µg/L)	TSI_{SD}	SD (M)
4/23/1992	65	70	73	78	66	0.67
7/23/1992	74	130	74	81	71	0.48
8/20/1992	72	110	70	55	NA	NA
4/14/2003	67	77	NA	NA	65	0.70
7/17/2003	70	95	68	43	75	0.35
9/25/2003	66	73	75	96	70	0.50
1/21/2004	60	47	66	37	NA	NA

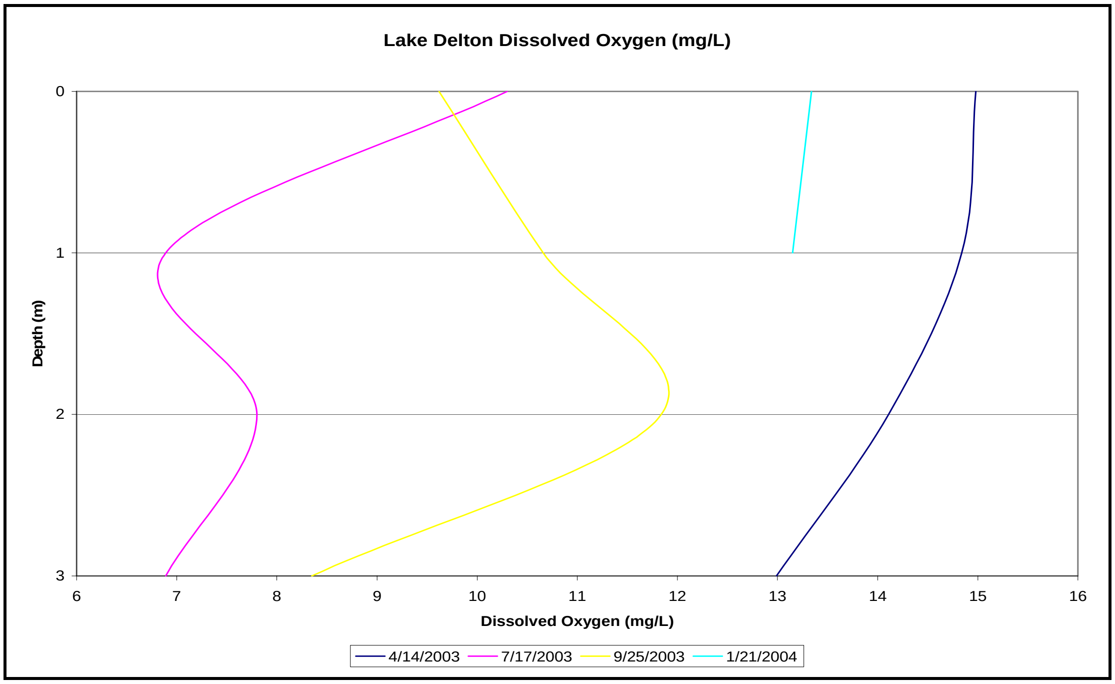

Figure 3. Dissolved oxygen depth profiles for Lake Delton water quality monitoring from 2003-2004, Lake Delton (Sauk County, WI).

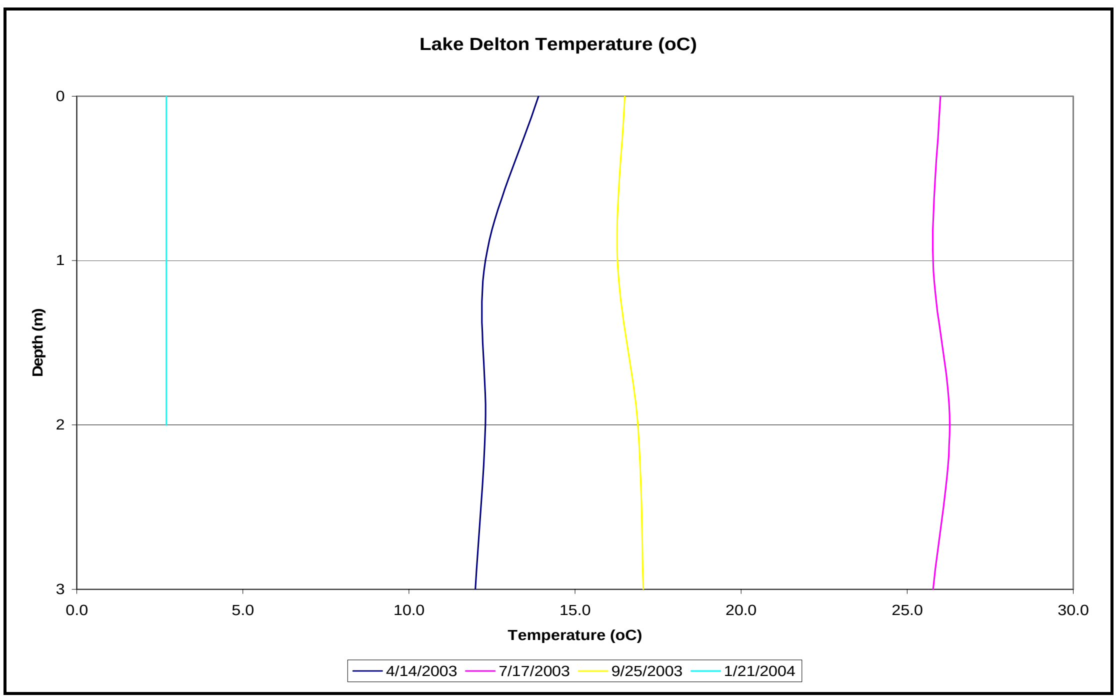

Figure 4. Temperature depth profiles for Lake Delton water quality monitoring for 2003-2004, Lake Delton (Sauk County, WI).

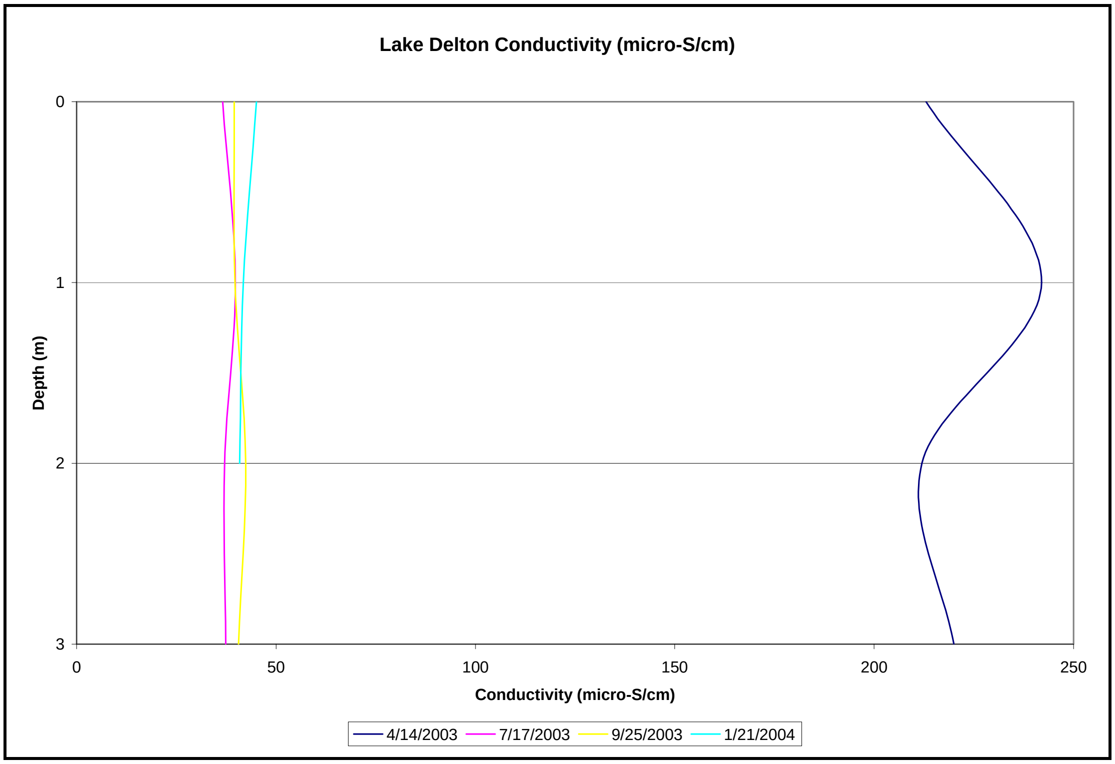

Figure 5. Conductance depth profiles fro Lake Delton water quality monitoring in 2003-2004, Lake Delton (Sauk County, WI).

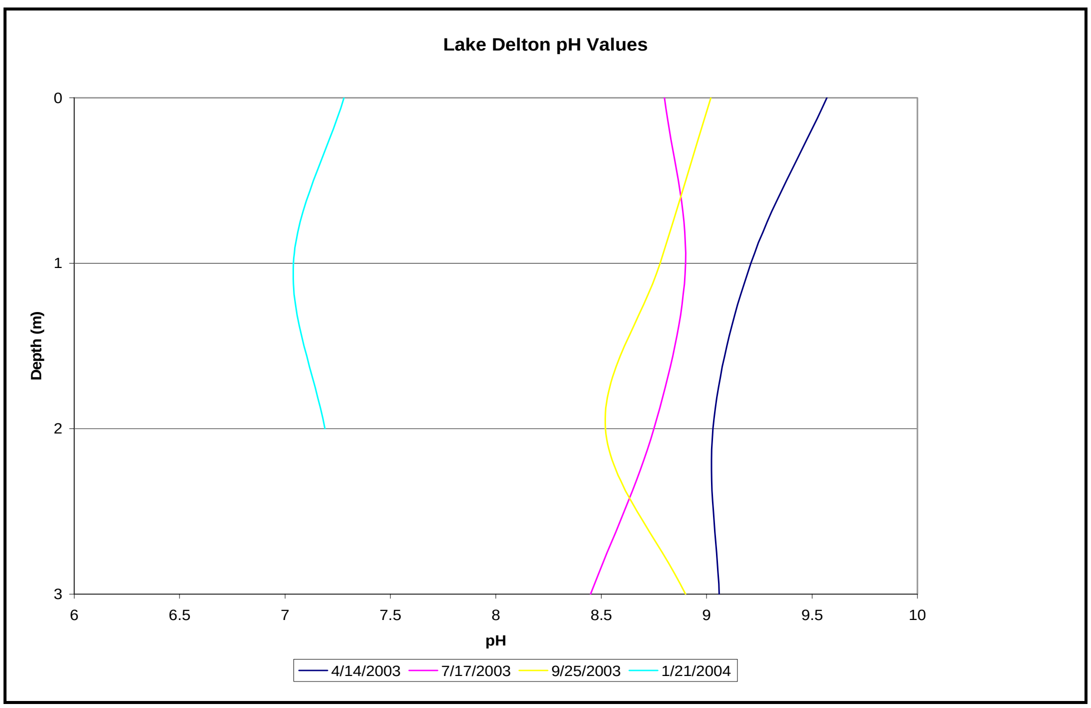

Figure 6. pH depth profiles for Lake Delton water quality monitoring in 2003-2004, Lake Delton (Sauk County, WI).

The predictions for Lake Delton based on TSI values appear to overestimate the actual degradation of the water quality. There is no reported aquatic plant problem in Lake Delton, and algae problems are either comparable or less than what they have been historically. The low Secchi depth values due to algal biomass and suspended sediment may be contributing to the lack of plants in Lake Delton. Due to the low light penetration into the water column, plants have a relatively shallow average maximum rooting depth (AEI, 2003) and algae are limited to the depth they can grow. Blue-green algae can regulate their position in the water column using gas filled bubbles called vacuoles. Typically, blue-green algae will grow in deep and shallow areas of the water column in clear water. If an event occurs that suddenly increases the turbidity of the water, algae will fill their gas vacuoles and settle at the water surface. Many algae die at the surface because they cannot deflate their gas vacuoles. Scums associated with over-productive lakes may form. Since Lake Delton has low water clarity, algae may not be able to grow in sufficient numbers to cause a problem at the water surface. This is supported by the general water color of Lake Delton in the summer months (brownish, cloudy) and could be in part caused by the high amount of boat traffic. Boat traffic is known to re-suspend sediment particles and increase turbidity.

Water clarity reflects the biological productivity of a lake and the chemical properties of water. It consists of two components – turbidity and color. Turbidity is defined as the amount of material suspended in the water column, while color refers to materials dissolved in the water column. The turbidity in Lake Delton is low with the exception of the bottom sample collected in July (Figure 7). This is probably due to the high amount of boat traffic on Lake Delton during this period.

Color is a result of dissolved organic particles in the water column. It can affect the aesthetic qualities of a lake and the distribution of aquatic plants by reducing light penetration into the water column. Algae may cause a distinct green color as they decompose. Increased turbidity is the result of suspended particles in the water column. Color in Lake Delton is within the accepted conditions for the region. Recreational activities may cause sediments to re-suspend through propeller outwash in shallow areas of the lake. Soil types with small particles such as clay may also cause turbidity to increase independently of algal production.

The buffering capacity, or alkalinity, of Lake Delton makes it insensitive to acid rain impacts as a moderately hard water lake. However, the high alkalinity of Lake Delton may also make it more susceptible to algal blooms. This may become significant in the future since the Wisconsin Department of Natural Resources identified a potentially dangerous exotic blue-green algae species in Lake Delton in 2004.

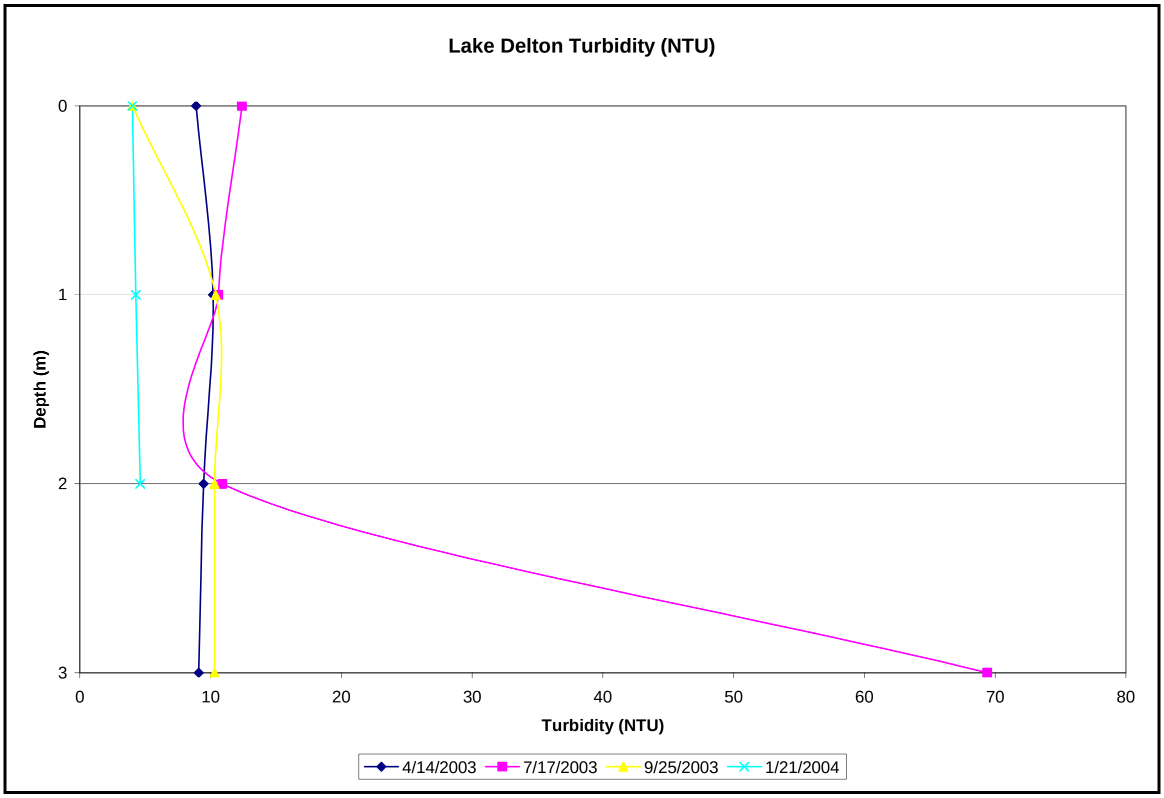

Figure 7. Turbidity depth profiles for Lake Delton water quality monitoring 2003-2004, Lake Delton (Sauk County, WI).

4.1.2 Lake Delton Tributaries

Lake Delton's tributaries generally showed they may be in a state of decline when compared to the 1992 study results (Table 3). In addition, due to lack of sampling events, one cannot directly compare the 1992 and 2003 tributary results. However, dissolved oxygen, total phosphorus, suspended solids, and total nitrogen levels were similar in both studies whereas temperature was higher in 2003. This increase in temperature may have been due to above average seasonal temperatures. If this increase in temperature is not uncommon, it would be detrimental to historic trout populations and other cold- and cool-water species found in Dell Creek and Spring Brook Creek. The temperature in Dell and Spring Brook Creeks exceeded 23 C in July sampling versus 13-18 C in the 1992 sampling. Even though we only have two years to compare, this may indicate that upstream areas of each creek are experiencing degradation in the form of increased impervious surfaces in their watersheds and/or loss of shading. Field notes related to in-stream habitat also revealed signs of sedimentation. At base flow conditions, suspended solids was relatively low ranging from 6-28 mg/L. Specific conductance was very high in the April sampling event and may indicate that he stream is experiencing pollutant loading during rain events where de-icing materials (salt, sand) and other materials quickly move over an impervious surface and wash directly into the streams, which will eventually be delivered to Lake Delton. Over time, pollutants and sediment may build up on the lake bottom and may accumulate in fish tissues, or the lake bottom may become shallower and require dredging.

In September 2004, an independent study at the request of the Village of Lake Delton documented unsafe levels of bacteria originating within the Lost Canyon Creek portion of the watershed. The one-day value for *E. coli* samples ranged from less than 10 to over 17,000 colony-forming units (cfu) per 100ml. Four of the 12 samples exceeded the EPA recommended one day maximum of 235 cfu/100ml and 8 of the 12 samples would be in excess of the EPA recommended 5-day geometric mean maximum value of 126cfu/100ml if bacterial concentrations remained the same. Based on the amount of *E. coli* found within the creek and area of the lake affected by the Lost Canyon Creek, the levels documented pose a potential public health risk until a one-day concentration of less than 235cfu/100ml or a 5-day geometric mean concentration of less than 126cfu/100ml is reached.

Table 3. Comparison of 1992 and 2003 water quality parameters for Lake Delton tributaries, Lake Delton (Sauk County, WI).

Site	Date	Dissolved Oxygen (mg/L)	Temperature (^oC)	Conductivity (mS/cm)	Total Phosphorus (mg/L)	Total Nitrogen (mg/L)	Total Suspended Solids (mg/L)	Fecal (#/100ml)
Dell Creek	4/23/1992	8.1	9.7	NA	0.080	0.80	8	NA
Dell Creek	7/23/1992	7.6	18.7	NA	0.090	1.20	12	NA
Dell Creek	8/20/1992	8.8	19.3	NA	0.040	0.40	6	NA
Dell Creek	4/14/2003	11.15	13.9	246	0.085	0.70	8	NA
Dell Creek	7/17/2003	7.42	23.0	36.3	0.072	0.66	6	NA
Dell Creek	9/25/2003	NA	14.9	40.3	0.049	0.71	4	40
Lost Canyon Creek	4/23/1992	11.3	5.3	NA	0.130	0.70	37	NA
Lost Canyon Creek	7/23/1992	8.2	14.0	NA	0.430	1.50	7	NA
Lost Canyon Creek	8/20/1992	NA	NA	NA	NA	NA	NA	NA
Lost Canyon Creek	4/14/2003	10.21	10.3	515	0.187	1.30	11	NA
Lost Canyon Creek	7/17/2003	NA	NA	NA	NA	NA	NA	NA
Lost Canyon Creek	9/25/2003	NA	NA	NA	NA	NA	NA	NA
Outlet	4/23/1992	NA	NA	NA	NA	NA	NA	NA
Outlet	7/23/1992	NA	NA	NA	0.150	1.40	28	NA
Outlet	8/20/1992	7.9	20.5	NA	0.130	0.90	19	NA
Outlet	4/14/2003	8.91	19.1	240	0.087	0.96	13	NA
Outlet	7/17/2003	8.52	26.0	38.5	0.116	1.01	12	NA
Outlet	9/25/2003	NA	16.2	40.8	0.096	1.24	26	20
Springbrook Creek	4/23/1992	9.9	8.4	NA	0.050	0.80	6	NA
Springbrook Creek	7/23/1992	7.1	13.4	NA	0.140	0.80	11	NA
Springbrook Creek	8/20/1992	7.8	13.1	NA	0.160	1.00	56	NA
Springbrook Creek	4/14/2003	6.15	19.5	323	0.040	0.52	0	NA
Springbrook Creek	7/17/2003	6.96	23.3	43.2	0.073	0.65	12	NA
Springbrook Creek	9/25/2003	NA	10.3	30.3	0.028	0.35	0	800

5.0 Recommendations

5.1 Recommendations

Since Lake Delton's nutrient levels and trophic state are comparable to monitoring activities performed in the early 1990's, the Village of Lake Delton should continue to monitor the condition of the lake and its tributaries annually. Direct control of nuisance algal problems on a lake-wide scale is neither feasible nor required at this time even though the Wisconsin Department of Natural Resources reported finding an exotic blue-green algae species. In addition, large-scale applications of algaecides are not advised due to the potential toxic effects from the increased release of toxins resulting from breakdown of algal cells. Future lake monitoring should begin in the spring and continue through the fall. Taxonomic identifications of algal samples should occur if there are indications of toxic effects from blue-green algae.

Actions must be taken to address the external or internal sources of phosphorus to improve water quality in Lake Delton if increased water clarity is desired. Watershed improvement projects should occur in Lake Delton's watershed that would reduce nutrient, sediment, and bacteria inputs, especially near new developments. Such projects should include the creation and maintenance of riparian buffers for Lake Delton itself and its tributaries. Storm-water detention facilities such as those located in the upper reaches of Lost Canyon Creek should be constructed to mediate the impacts of development and increased impervious surfaces. Commercialized horse traffic within Lost Canyon Creek should cease during flow conditions. Since bacteria can remain alive in sediments for several weeks (Sherer *et al*., 1992), the sediments can re-suspend potentially harmful bacteria during future rain events. Given the potential impacts on Lake Delton from any commercialization of animals, within or directly adjacent to the tributaries of Lake Delton, local ordinances should be considered in an effort to maintain safe recreational use of this resource. Annual monitoring programs designed to evaluate phosphorus and bacterial loading to Lake Delton are also recommended in all tributaries (Spring Brook Creek, Dell Creek, and Lost Canyon Creek), and at mid-lake and the public beach.

Riparian buffer corridors should be maintained on all tributaries and around Lake Delton when possible. It is generally accepted that a natural buffer strip of any size will help reduce some sediment and bacterial transfer directly to the lake water. Several scientific studies have been conducted to determine the width a riparian buffer must be in order to produce a desired result (usually a certain percent decrease in sediment or nutrient load). Realizing that not all buffers are comprised of the same vegetation, soil type, and percent grade, one can conclude, under naturally occurring environmental conditions, that no one buffer size fits all. However, in an effort to create a realistic predictor of buffer size, Nieswand *et al.* (1990) proposed a generic formula for calculating buffer width:

$$\mathbf{W = k(s^{1/2})}$$

were W is the width of the buffer in feet, k is a constant of 50 feet (chosen as the minimum width for any effective buffer zone), and s is the percent slope as a whole number (i.e. 2% slope would be a value of 2).

It should be noted that any impervious surfaces within the calculated buffer zone are not to be included as part of the buffer width.

5.1.1 Monitoring Strategy

Lake Delton should re-initiate a Self Help monitoring program through the Wisconsin Department of Natural Resources or enlist a qualified conservation organization to monitor water quality on an annual basis. Monthly water quality monitoring should begin in April and continue through October and include a depth profile for pH, dissolved oxygen, and temperature at mid-lake at one meter intervals. An integrated surface sample collected over two meters at mid-lake for total phosphorus, total nitrogen, chlorophyll-*a*, and suspended solids or turbidity should be collected. Secchi depth should also be recorded bi-weekly. The water level of Lake Delton and precipitation should be monitored throughout the year to determine volume-weighted nutrient levels. Due to the recent discovery of exotic toxic algae in the region, it may be necessary to identify algal species present in the lake in the interest of public health. Algal samples should be collected with vertical tow nets in beach areas and at mid-lake and sent to a reputable laboratory such as Phycotech, Inc., or the Wisconsin State Laboratory of Hygiene for analysis.

Fecal bacteria are an indicator of pathogens in surface waters and estimate the risk of disease based on the chance of developing gastrointestinal disorders from ingestion of contaminated surface water. Contact with contaminated water can also lead a number of additional problems including ear infections, skin infections, and respiratory diseases. A monitoring program designed to ensure minimal human exposure to pathogens and to detect bacteria sources within the Lake Delton watershed should be initiated immediately due to the recent fecal coliform levels in Lost Canyon Bay and Lost Canyon Creek.

Fecal coliform (or other suitable indicator organism such as *E. coli*) should be collected from each of the Lake Delton tributaries, mid-lake, and at the public beach twice weekly beginning in the spring (April, ice-off) during periods of high flow and precipitation at the lower-most location in the stream that is not affected by Lake Delton proper. Monitoring should continue throughout the summer and fall until ice-on for base flow periods due to the presence of animals in and near the stream channel in Lost Canyon Creek. Hydrologic flow monitoring and measurements should occur in the tributaries and outlet during each sampling event so that loading model for Lake Delton can be estimated from bacteria concentrations according to methods outlined in Simonsen *et al*. (1994). Permanent stream gauging stations should also be established at Spring Brook Creek, Dell Creek, Lost Canyon Creek, and the lake outlet that measure stage height and estimate flow. The bi-weekly flow estimates could then be used to generate a rating curve and construct an accurate water budget, bacterial loading, and nutrient loading models for Lake Delton.

In the event a single sample exceeds 235cfu/100ml or a 5-day geometric mean value exceeds 126cfu/100ml of *E. coli*, additional samples should be collected systematically at the headwaters and upstream to isolate the source of pollution. Once the contributing portion of the watershed is isolated, the Village of Lake Delton or other governing unit should negotiate a remediation plan that includes “Best Management Practices” or other suitable management practices to reduce bacterial loading to the receiving water body. Future consideration should also include a recreational use assessment focusing on the public uses, needs and impressions of Lake Delton.

6.0 References

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Appendix A:
Water Quality Raw Data

Site	Date	Depth (m)	Secchi Depth (m)	pH	Dissolved Oxygen (mg/L)	Temperature (^oC)	Conductivity (μS/cm)	Total Phosphorus (mg/L)	Total Nitrogen (mg/L)	Total Suspended Solids (mg/L)	Turbidity (NTU)	chl-a (μg/l)	Fecal (#/100ml)	SRP (mg/l)	NO3+NO2 (mg/l)	NH3-N (mg/l)	TDS (mg/l)	Chloride (mg/l)	Color (SU)	Alkalinity (mg/l)
LD-0	4/14/2003	0	0.7	9.57	14.98	13.9	213	0.077	0.98	NA	8.9	NA	NA	NA	NA	NA	NA	NA	NA	NA
LD-1	4/14/2003	1	NA	9.21	14.84	12.3	242	NA	NA	NA	10.2	NA	NA	NA	NA	NA	NA	NA	NA	NA
LD-2	4/14/2003	2	NA	9.03	14.11	12.3	212	NA	NA	NA	9.47	NA	NA	NA	NA	NA	NA	NA	NA	NA
LD-3	4/14/2003	3	NA	9.06	12.99	12.0	220	0.083	0.82	NA	9.1	NA	NA	NA	NA	NA	NA	NA	NA	NA
LD-LC	4/14/2003	0	NA	7.47	10.21	10.3	515	0.187	1.30	11	16.2	NA	NA	NA	NA	NA	NA	NA	NA	NA
LD-OUT	4/14/2003	0	NA	9.06	8.91	19.1	240	0.087	0.96	13	6.31	NA	NA	NA	NA	NA	NA	NA	NA	NA
LD-DC	4/14/2003	0	NA	8.01	11.15	13.9	246	0.085	0.70	8	5.08	NA	NA	NA	NA	NA	NA	NA	NA	NA
LD-SB	4/14/2003	0	NA	7.12	6.15	19.5	323	0.040	0.52	0	1.26	NA	NA	NA	NA	NA	NA	NA	NA	NA
LD-0	7/17/2003	0	0.35	8.8	10.3	26.0	36.6	0.095	0.96	15	12.4	43.3	NA	0	0	0.024	126	11.5	20	91
LD-1	7/17/2003	1	NA	8.9	6.89	25.8	39.8	NA	NA	NA	10.6	NA	NA	NA	NA	NA	NA	NA	NA	NA
LD-2	7/17/2003	2	NA	8.75	7.8	26.3	37.1	NA	NA	NA	10.9	NA	NA	NA	NA	NA	NA	NA	NA	NA
LD-3	7/17/2003	3	NA	8.45	6.89	25.8	37.4	0.210	1.59	57	69.4	NA	NA	0	0	0.03	132	11.6	20	92
LD-LC	7/17/2003	0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
LD-OUT	7/17/2003	0	NA	8.8	8.52	26.0	38.5	NA	NA	NA	9.92	NA	NA	NA	NA	NA	NA	NA	NA	NA
LD-DC	7/17/2003	0	NA	8.39	7.42	23.0	36.3	0.072	0.66	6	5.18	NA	NA	NA	NA	NA	NA	NA	NA	NA
LD-SB	7/17/2003	0	NA	7.22	6.96	23.3	43.2	0.073	0.65	12	4.78	NA	NA	NA	NA	NA	NA	NA	NA	NA
LD-0	9/25/2003	0	0.5	9.02	9.62	16.5	39.5	0.073	1.24	NA	4.02	95.6	NA	NA	NA	NA	NA	NA	NA	NA
LD-1	9/25/2003	1	NA	8.78	10.66	16.3	39.7	NA	NA	NA	10.4	NA	NA	NA	NA	NA	NA	NA	NA	NA
LD-2	9/25/2003	2	NA	8.52	11.84	16.9	42.4	NA	NA	NA	10.3	NA	NA	NA	NA	NA	NA	NA	NA	NA
LD-3	9/25/2003	3	NA	8.9	8.35	17.1	40.6	0.081	1.26	NA	10.3	NA	NA	NA	NA	NA	NA	NA	NA	NA
LD-LC	9/25/2003	0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
LD-OUT	9/25/2003	0	NA	8.65	NA	16.2	40.8	0.096	1.24	26	9.57	NA	20	NA	NA	NA	NA	NA	NA	NA
LD-DC	9/25/2003	0	NA	7.26	NA	14.9	40.3	0.049	0.71	4	4.9	NA	40	NA	NA	NA	NA	NA	NA	NA
LD-SB	9/25/2003	0	NA	7.17	NA	10.3	30.3	0.028	0.35	0	3.3	NA	800	NA	NA	NA	NA	NA	NA	NA
LD-0	1/21/2004	0	NA	7.28	13.34	2.7	45.1	0.047	0.53	NA	4.02	37	NA	NA	NA	NA	NA	NA	NA	NA
LD-1	1/21/2004	1	NA	7.04	13.15	2.7	41.8	NA	NA	NA	4.28	NA	NA	NA	NA	NA	NA	NA	NA	NA
LD-2	1/21/2004	2	NA	7.19	NA	2.7	40.9	NA	NA	NA	4.62	NA	NA	NA	NA	NA	NA	NA	NA	NA
LD-3	1/21/2004	3	NA	NA	NA	NA	NA	0.046	0.61	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA