2006 Monitoring Report for Crystal Lake, Ellington/Stafford, CT

Prepared For:

The Town of Ellington
and
Crystal Lake Association

Prepared By:

Northeast Aquatic Research

George W. Knoecklein

74 Higgins Highway

Mansfield Center, CT 06250

Final Report

June 11, 2007

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

Monitoring

This report presents results of lake sampling conducted by Crystal Lake Residents during 2004, 2005, and 2006. The monitoring program generally consists of 2 to 4 lake visits per season. This should be increased to 6 or 7 per season, especially to include both April and October conditions.

Water Clarity

The Secchi disk depth was generally good during the summer but was not as good in the spring consistent with a prior described pattern of lower clarity during April and May and better clarity during the summer. Long-term trends indicate that Crystal Lake water clarity has been declining over the past 3 years. The trend of decreasing clarity may be part of a long-term cycle of increasing and declining clarity however. Storm water testing has indicated that the drainage basin is contributing nutrients and sediments to the lake during winter and early spring months. However, no storm water samples have been collected since 2003. Clarity readings should be taken frequently during the 2007 and 2008 seasons to determine if clarity improves.

Total Phosphorus

Total phosphorus of the lake water has remained low, with most values at or below 10 ppb. Internal loading of phosphorus from bottom sediments during the summer still does not appear to be occurring.

Oxygen

The lake has overall very good oxygen conditions down to a depth of about 20 feet. Below that, oxygen decreases with depth until about 26 feet where the water generally had no oxygen during the summer. In 2004 - 2006 the anoxic boundary was located at about 30 feet indicating that more oxygen was present deeper in the water than in most prior years.

INTRODUCTION

This report presents the results of water quality monitoring at Crystal Lake in Ellington and Stafford, Connecticut. The work was performed volunteers from the Crystal Lake Association (CLA). The CLA has been conducting annual water quality monitoring, through the work of volunteers, since 1996. New water quality data is presented in this report that was collected during the growing seasons of 2004, 2005, and 2006. The growing season is defined as the sampling months beginning in April and ending in October.

The in-lake testing was performed during different months of each of the three years:

2004 = 19-April, 30-May, 2-July, 7-August

2005 = 2-June, 18-July, 28-August

2006 = 27-April, 5-June, 3-August , 4-October

During each sampling visit, water quality testing was conducted at one station located at the deepest part of the lake. The testing included collecting water quality samples from 1, 7, and 13 meter depths, with additional samples collected from 3 and 10 meters. Each sample was analyzed for total phosphorus, and ammonia nitrogen, although some samples were also analyzed for alkalinity, conductivity, total iron, total manganese, and pH. During each sampling event the dissolved oxygen concentration and water temperature, were also measured. The in-situ measurements were made at each one meter depth increment from top to bottom. The water clarity was measuring using a Secchi disk.

Baseline tributary samples were collected at Aborn Brook and analyzed for total phosphorus, nitrate nitrogen, conductivity, turbidity and pH.

General Lake Characteristics

Crystal Lake is a 183 acre lake in Ellington and Stafford, Connecticut. The lake has maximum and mean depths of 15.2 meters (50 feet) and 6 meters (20 feet), respectively. The deepest water is located in the center of the lake. The lake has a volume of about 3,784 acre-feet (1,247 million gallons). It is fed principally by Aborn Brook, located in the southeast corner of the lake. In addition to Aborn Brook, there are several smaller streams and storm water discharge culvert outfalls to the lake. The outlet is located at the northern end of the lake. The total drainage basin area is about 2,101 acres (not including the lake surface area), however 488 acres of this consists of the Devils Hopyard Swamp and its catchment that only drains to Crystal Lake during 25 year or larger storm events. This makes it somewhat complicated in deriving runoff and flushing characteristics for the lake. Because it is unlikely that a storm large enough to cause the swamp to discharge to the lake will occur in any given year the swamp area will be left out of calculations for general conditions. The estimated total annual runoff to the lake is about 1,151 million gallons (not including the swamp area). The ratio of the inflow rate and the total lake volume is 1.0 meaning that the water in the lake is replaced, on average, about once every year.

IN-LAKE RESULTS

Secchi Disk Depth

The Secchi disk depth is a simple method of measuring the water clarity and an indirect way of measuring the quantity of pelagic (meaning in the open water) plankton in the lake. The relationship between algae in the water and water clarity has been refined over the last 25 years such that water clarity is now an accepted method of assessing the trophic state of a lake. The trophic state is the condition of the lake based on available nutrients, phosphorus primarily and nitrogen secondarily. As these nutrients increase in concentration in lakes the algae become more numerous and water clarity declines. A Secchi disk measurement is a quick and easy way to gain insight into the trophic state of a lake using the scale in **Table 1** (published by CT DEP). The concentration ranges for phosphorus and nitrogen increase going down the column while the Secchi disk decreases showing that as the level of nutrients in a lake increase, the water clarity declines. The data in **Table 1** has been arranged to show six different categories along what is actually a continuous gradient of phosphorus concentrations.

Table 1. Lake Trophic Categories.

Category	Phosphorus (ppb)	Nitrogen (ppb)	Secchi Depth (m)
Oligotrophic	0 – 10	0 – 200	6+
Oligo-mesotrophic	10 – 15	200- 300	4 - 6
Mesotrophic	15 – 25	300 - 500	3 - 4
Meso-eutrophic	25 – 30	500 - 600	2 - 3
Eutrophic	30 – 50	600 - 1000	1 - 2
Highly Eutrophic	50+	1000+	0 - 1

The complete record of Secchi disk data for Crystal Lake, including the 2004 – 2006 measurements is given in **Table 2.** The clarity during the 2004, 2005, and 2006 was very similar to the record of the data from the lake with summer values of at least 4 meters. The trend of having summer water clarity readings better than the spring readings was continued during the last three years indicating that there was less algae or other turbidity causing factors in the water during the summer than there was during the spring. The spring values tend to be in the between 2 and 4 meters while the summer values tend to be higher generally as good as 5 meters.

Table 2. Secchi Disk Depth Data Record For Crystal Lake

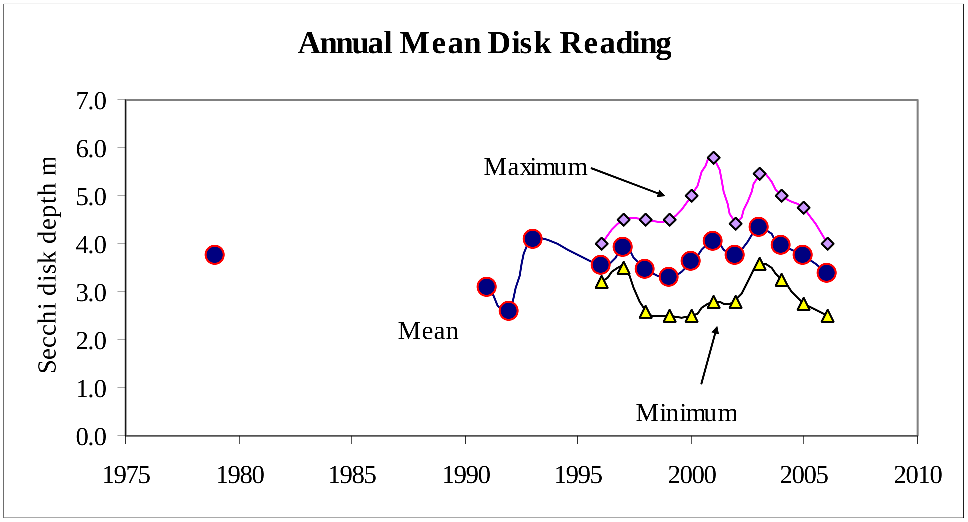
Date	Secchi (meters)
10-Apr-79	3.5
13-Aug-79	4
9-Jul-91	3.3
15-Oct-91	2.9
26-Jun-92	2.6
22-Jul-93	4.1
19-May-96	3.2
28-Jul-96	3.7
1-Sep-96	4
12-Oct-96	3.3
5-Apr-97	4.5
17-May-97	4.5
29-Jun-96	3.7
17-Aug-97	3.5
23-Aug-97	4
1-Sep-97	4
29-Mar-98	2.8
26-Apr-98	2.9
30-May-98	2.6
13-Jul-98	3.4
26-Jul-98	3.1
11-Aug-98	3.6
30-Aug-98	4.5
13-Sep-98	4.5
27-Sep-98	3.8

Date	Secchi Depth (meters)
26-Apr-99	2.5
31-May-99	2.6
27-Jun-99	4.5
6-Sep-99	3.6
4-Jun-00	2.5
16-Jul-00	2.5
23-Jul-00	4
11-Aug-00	4.1
22-Sep-00	5
1-May-01	2.9
29-May-01	2.8
24-Jun-01	4.5
1-Jul-01	4.5
28-Jul-01	5.8
26-Aug-01	3.6
9-Sep-01	4.25
4-May-02	2.75
27-May-02	4
21-Jul-02	4.4
18-Aug-02	3.6
28-Sep-02	4
14-May-03	3.6
30-Jun-03	4
21-Jul-03	5
26-Aug-03	5.45
30-Sep-03	4
31-Oct-03	4

Date	Secchi Depth (meters)
19-Apr-04	3.9
31-May-04	3.25
1-Jul-04	5.0
6-Aug-04	3.75
1-Jun-05	2.75
17-Jul-05	4.75
28-Aug-05	3.75
26-Apr-06	2.5
4-Jun-06	3.0
3-Aug-06	4.0
4-Oct-06	4.0

The average Secchi disk readings as well as the minimum and maximums from each year between 1990 and 2006 is presented in **Figure 1**. The chart shows that the mean Secchi disk depth has been declining over the last 3 years, although this trend of oscillating Secchi disk depths appears to have occurred in the past and may be part of long term normal trends in water clarity. The mean disk reading for 2006 was about what it was in the late 1990's. If the trend of decreasing annual average continues to show a decline as opposed to an upturn than water clarity may be in jeopardy of significant long term impairment. It is warranted at this time to consider the decreasing trend in water clarity as an indication that storm water impacts to the lake are a significant factor that needs attention. The maximum and minimum water clarity readings from each season over the last 4 years have also be declining. Although these values have not decreased lower than minimums recorded in the past, those limits were equaled in 2006 suggesting that 2007 and 2008 monitored for improving water clarity trends.

Figure 1. Annual Average Secchi Disk Readings At Crystal Lake between 1990 and 2006



Total Phosphorus

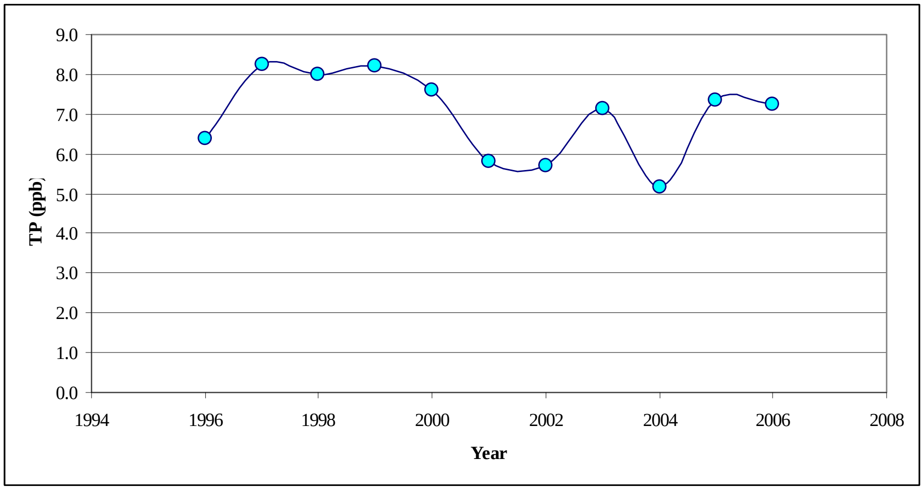
In the previous section phosphorus was implicated as the primary cause of poor water clarity in lakes. The categories shown in **Table 1** indicate that as phosphorus increases water clarity decreases. The incremental changes associated with the increase in phosphorus concentration are referred to as trophic categories. The total phosphorus concentrations in Crystal Lake water was sampled on 4 dates in 2004, 3 dates in 2005, and 4 dates in 2006. The total phosphorus concentration test results are shown in **Table 3**.

Table 3. Crystal Lake Total Phosphorus Concentrations (ppb), 2004 - 2006.

	2004					2005				2006			
Depth	19-Apr	30-May	2-Jul	7-Aug	*Depth*	2-Jun	18-Jul	28-Aug	*Depth*	27-Apr	5-Jun	3-Aug	4-Oct
1	8	7	6	3	*1*	8	7	7	*1*	8	9	6	6
3	~	6	~	3	*3*	13	7	4	*3*	7	9	8	6
7	9	10	12	4	*7*	9	12	11	*7*	10	11	9	7
10	~	6	~	4	*10*	6	8	11	*10*	6	7	13	8
14	9	14	66	4	*14*	11	19	35	*14*	9	13	23	11

The 1 meter sampling depth, representing the water where most algae are located, had phosphorus concentrations that were consistently below 10 ppb. The long-term average 1 meter phosphorus concentration has varied between 5 and 8 ppb, in 2006 it was slightly more than 7 ppb. The detection limit, or the potential laboratory error, for total phosphorus is between 1 and 2 ppb for a confidence limit of +/- 2 ppb. This indicates that most phosphorus values collected over the last 10 years or so are relatively similar (see **Figure 2**).

Figure 2. Average Epilimnetic Phosphorus Concentration in Crystal Lake.



The average whole water column phosphorus concentration ranged between 8 and 11 ppb, **Table 4**. Using the average water column phosphorus concentration, the lake has remained at the high end of the oligotrophy category (lakes characterized as having a phosphorous concentration between 0 and 10 ppb see **Table 1**). The data in **Table 4** shows that the lake has had a similar seasonal average phosphorus concentration during the last 11 years. The variation of phosphorus concentration during the season can be determined by the standard deviation of the seasonal data. In **Table 4** the standard deviation of phosphorus concentration is given. The deviation has been low indicating that there is generally little variation in concentration during the season. The exception to this is during 2004 there was a large deviation in phosphorus concentration because phosphorus concentration at the bottom reached at maximum of 66 ppb.

Table 4. Crystal Lake Average Seasonal Water Column Phosphorus Concentration, 1996 – 2006.

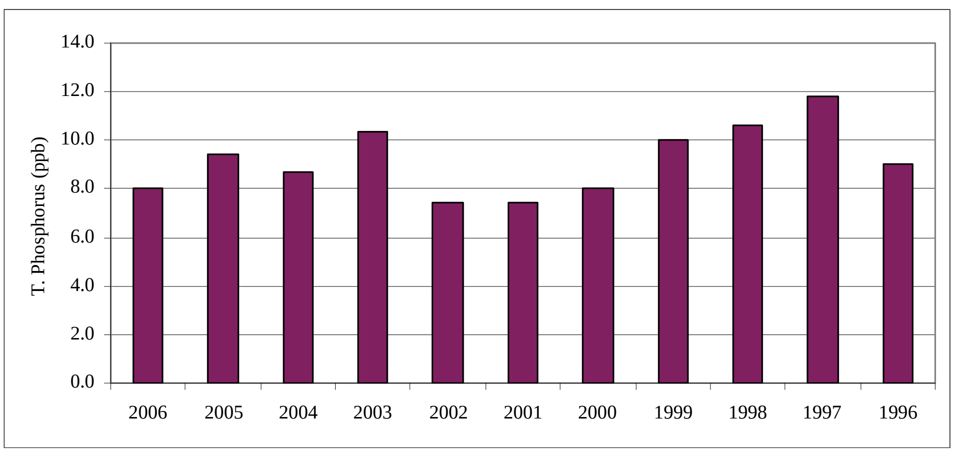
Year	Average Water Column Phosphorus Concentration (ppb)	Standard Deviation
2006	9.3	3.6
2005	11.2	7.5
2004	10.7	15.1
2003	9.3	3.5
2002	8.5	3.9
2001	8.4	3.7
2000	8.1	4.6
1999	10.2	5.0
1998	10.2	6.5
1997	10.3	5.6

1996	9.2	6.4

The spring phosphorus concentration is defined as the concentration of phosphorus in the lake water after ice-out or at some time during the early spring while the lake is still un-stratified (see the section on temperature for an explanation of stratified and stratification). It indicates the quantity of phosphorus that will be available for summer algae growth as well as the carry over of phosphorus from the prior year. A 10 year record of spring phosphorus values is given in **Figure 3**. The spring phosphorus in 2006, 8 ppb, was at a level consistent with the long term average, 9.1 ppb.

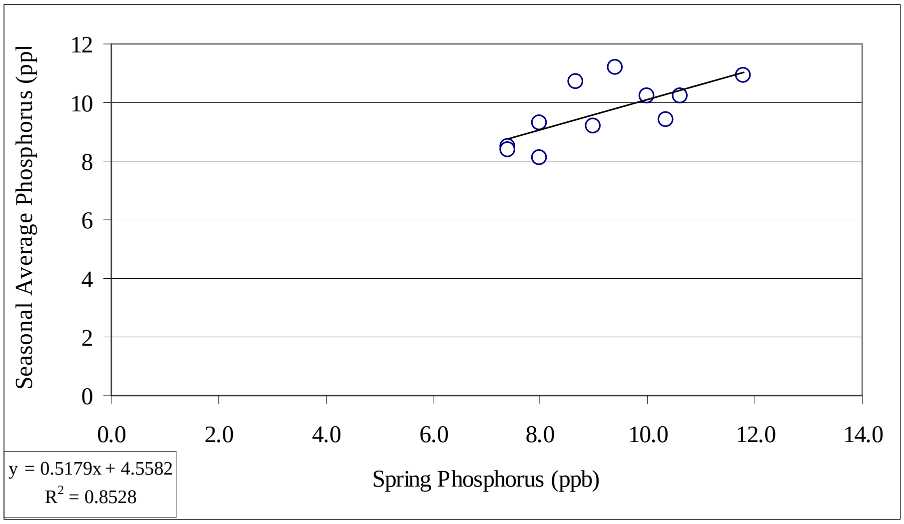
The spring phosphorus concentration can be used to predict the summer Secchi disk depth using the models given in the appendix. The predicted water clarity, based on the spring phosphorus concentration of 9 ppb, was 4.4 meters. This value is generally exceeded during at least one month during the summer with the data in **Figure 1** showing that the general, or average, clarity in the summer is around 4.5 meters.

Figure 3. Spring Phosphorus Concentration In Crystal Lake, 1996- 2006.



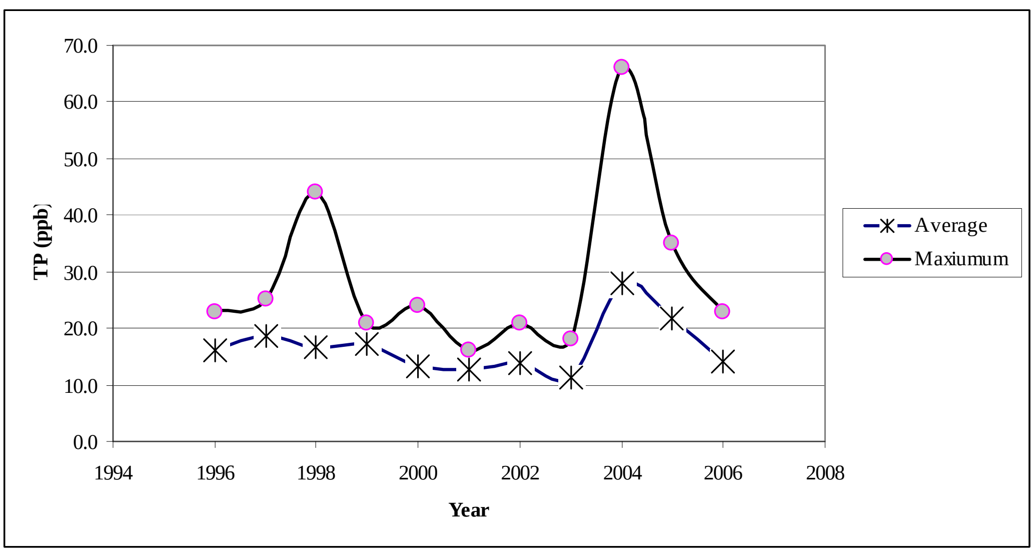
The phosphorus data show that the lake is oligotrophic with respect to phosphorus concentration, the primary indicator of lake condition. Some variation has occurred in both spring phosphorus concentration and the seasonal average concentration suggesting that there is a variation in the load to the lake. The variation in spring phosphorus concentrations predicts that phosphorus loading to the lake varies between 74 Kg to 148 Kg per year. Based on an average spring concentration of 9 ppb the average annual load would be around 110 Kg phosphorus. The relationship between the spring phosphorus concentration and the average phosphorus concentration in the lake is significant, explaining about 85% of the variation (**Figure 4**).

Figure 4. Relationship Between Spring Phosphorus and Seasonal Average Phosphorus at Crystal Lake.



The 13 meter sample, representing the deepest water of the lake where oxygen is frequently at low levels during the summer. The average seasonal phosphorus concentration at the bottom has been consistently under 20 ppb between 1996 and 2003 (**Figure 5**). During 2004 and 2005, average bottom water phosphorus increased slightly over the long term trend but was back to normal in 2006. The maximum concentration in 2004 was 66 ppb suggesting some contamination of the sampled water with bottom sediments. The data in Figure 5 indicates that internal loading at Crystal Lake is at minimum levels.

Figure 5. Average and Maximum Bottom Water Phosphorus Values at Crystal Lake.



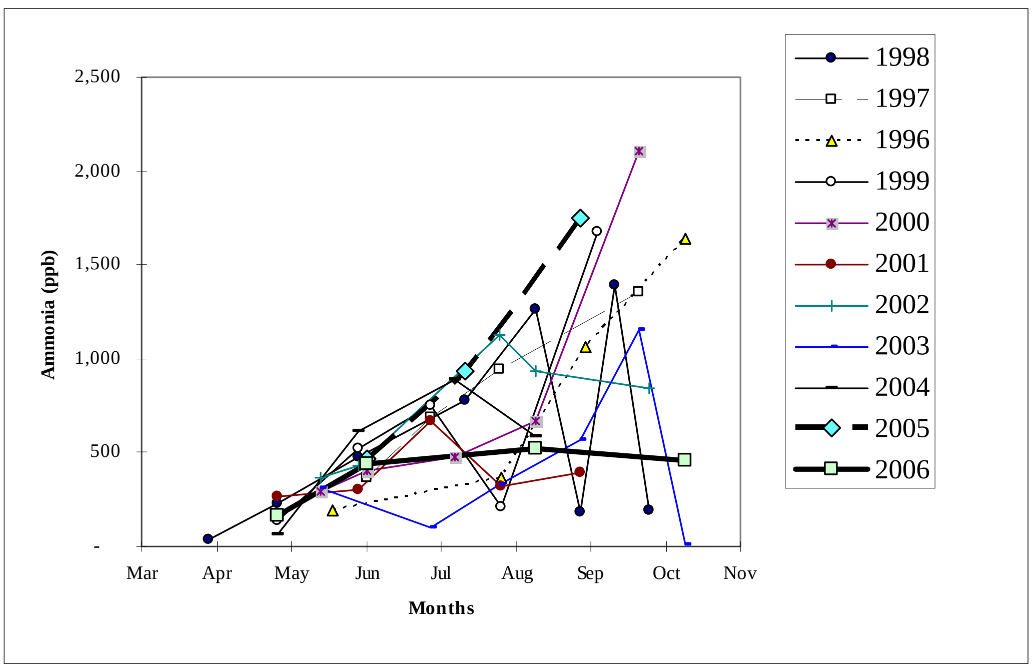
Nitrogen

Nitrogen is the next most important plant nutrient in lakes. The nitrogen in lake water occurs in two basic forms, inorganic and organic. The inorganic form is commonly represented by nitrate, and ammonia, and to lesser extent by nitrite. The organic form consists of organic nitrogen. All three forms have been tested for in Crystal Lake, although during the last couple of years only ammonia nitrogen has been analyzed for in the samples.

Ammonia-Nitrogen

Ammonia is another form of dissolved nitrogen that occurs commonly in lake water. Again because it is dissolved it is readily used by plants especially algae. However, unlike nitrate it is unstable in the presence of oxygen, being rapidly converted to nitrate when dissolved oxygen is available. Generally, there is little detectable ammonia in the water samples except those from the deepest sample. Results from the deep water samples are shown graphically in **Figure 6**. The summer increase of ammonia at the bottom has shown variation in accumulation with some years showing large accumulated ammonia such as 2005 when a maximum concentration of 1,750 ppb while in other years such as 2006 when the maximum ammonia concentration didn't exceed 500 ppb. This suggests that during some years oxygen diffusion to deep waters offsets the decomposition occurring there while in other years it does not.

Figure 6. Ammonia - Nitrogen Concentrations At 13 Meters, 1996-2006.



Temperature and Oxygen Results

Temperature

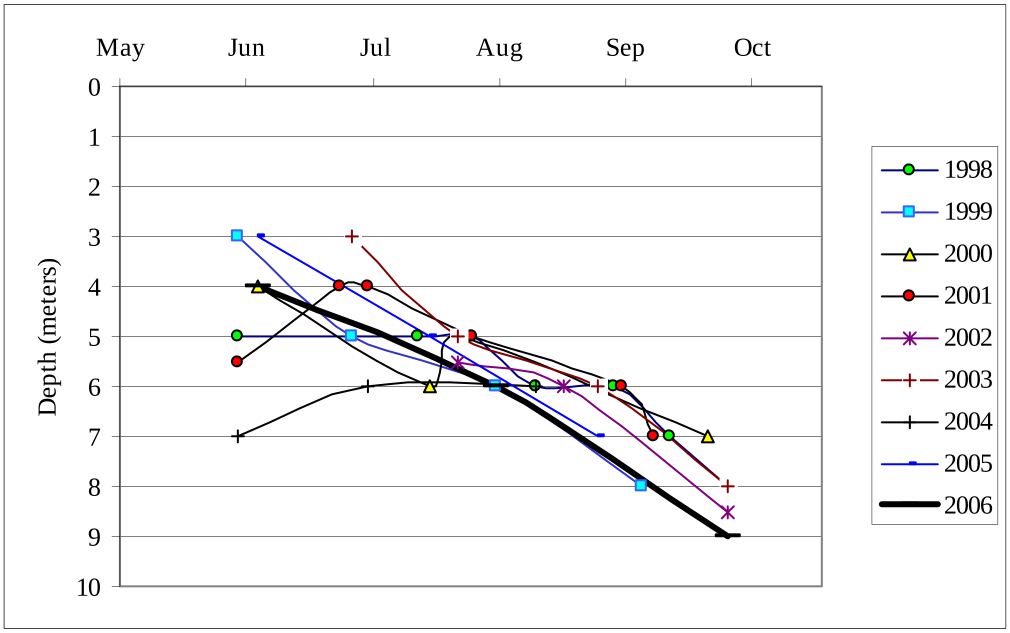
Thermal stratification is the boundary that is caused when water on the top of the lake is warmer than the water at the bottom of the lake. Warm water is less dense, or lighter in weight, than cold water so cold water sinks to the bottom and warm water floats over it. The sun warms the top 20 feet or so of the lake causing this warmer water to become lighter than the deeper water that is not illuminated which remains cold and heavy. Generally, somewhere in the middle depth of the water column the temperature changes quickly in a couple of meters of depth. When warm water sits on top of cooler water, the two layers don't not mix. When this happens, the two layers are stratified, with the upper layer freely mixing due to wind action on the lake surface and the bottom layer isolated and stagnant. The degree or strength of the stratification can be calculated by the rate of temperature change between each meter water depth. Stronger stratification means greater stagnation of the water below but also means that there will be less diffusion of materials across the boundary.

The lake typically develops a thermal boundary in May at 6 meters which becomes strengthened during the season. Through July and August and into September the thermocline gradually deepens from 5 meters to 8 meters. The lake is well mixed in October and in April when there is no thermocline.

The location of the thermocline during each of the seasons of 1998 to 2006 is shown in **Figure 7**. The general trend has been for the thermocline to form around 4 meters in the water column in early May, and then to gradually move deeper during the course of the season ending at around 8 meters in September. This can be seen in the graph in **Figure 7** as the lines move from upper left to lower right signifying the sinking of the thermocline into deeper water as the summer progresses. The warming of the surface of the lake by the sun and the action of wind causes this downward movement of the thermocline.

The location of the thermocline also is the defining characteristic for the depth of the epilimnion and the location of the hypolimnion. The epilimnion is the water layer above the thermocline while the hypolimnion is the water below the thermocline. For Crystal Lake the epilimnion is between 4 and 8 meters deep with an average August depth of about 6 meters.

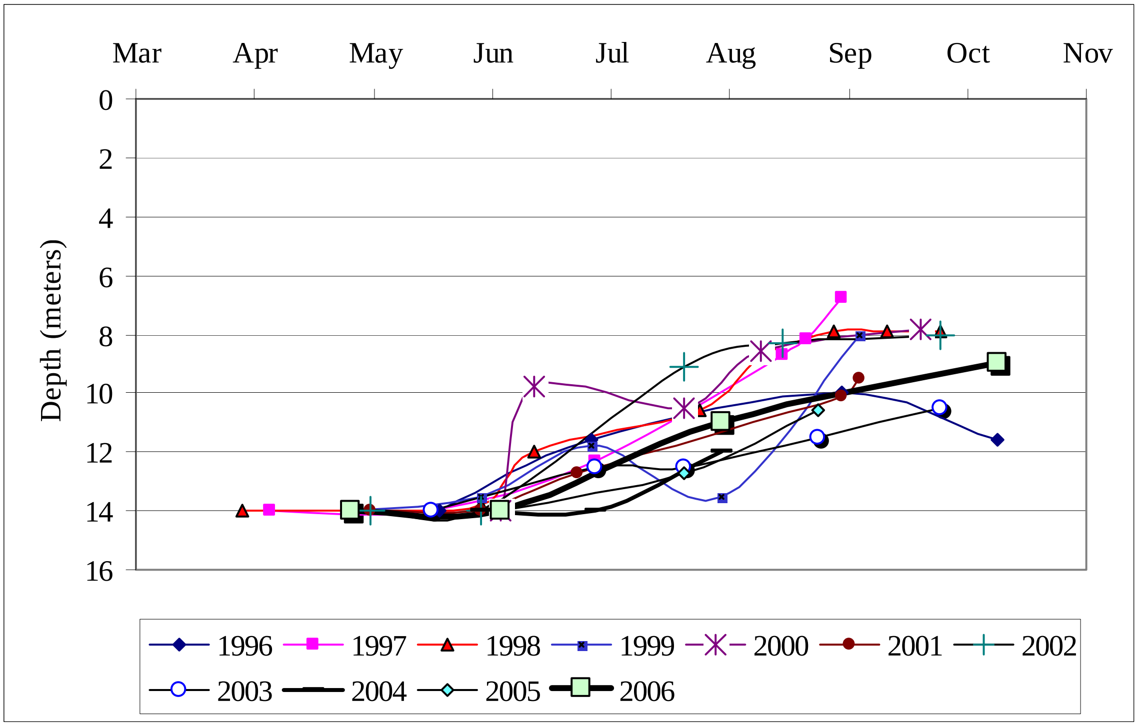
Figure 7. Crystal Lake Thermocline Depth 1998 – 2006.



Dissolved Oxygen

The dissolved oxygen concentration in lake water is a result of diffusion from the atmosphere and that created by plants living in the lake. Most of the dissolved oxygen is derived from the atmosphere. The amount of dissolved oxygen that water can hold in solution is based on the water temperature with more oxygen in colder water and less in warm water. Water below the thermocline typically looses dissolved oxygen during the summer months. The demarcation between water with little to no oxygen and water that is fully oxygenated is referred to as the anoxic boundary. The development of anoxic water generally begins in late May and ascends upward into the water column from below at a slow rate usually reaching a maximum ascent depth in late September. The maximum depth varies from year to year with deeper depths of 10 or 11 meters and shallower depths of 8 meters (**Figure 8**). This indicates that decomposition in the bottom most waters is not as yet severe and can be off-set by diffusion of oxygen from the upper most water based on different mixing and stratification conditions that occur from year to year.

Figure 8. Anoxic Boundaries In Crystal Lake 1996 – 2006.


Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
0
2
4
6
8
10
12
14
16
Depth (meters)
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006

DRAINAGE BASIN RESULTS

Basin Characteristics

The total watershed of Crystal Lake is approximately 2,284 acres, subtracting the lake area of 183 acres gives 2,101 acres of terrestrial drainage area. Of this approximately 488 acres consists of Devil's Hopyard Swamp and its drainage area. This area is thought to only discharge to Crystal Lake during storms of 25 year or greater storm events (MM 2002). Subtracting this area is practical when considering the general annual drainage basin area because during most rain fall events and during base flow conditions the Devil's Hopyard Swamp does not flow into the lake. This area should be considered when determining sizes of conveyance structures because during heavy rain events the added water from the swamp will be carried by Aborn Brook. The size of the drainage basin during rain events of less than a 25 year storm and during base flow conditions is approximately 1,613 acres, (2,101 acres – 488 acres = 1,613 acres).

The largest sub basin to Crystal Lake is Aborn Brook at 839 acres. The second and third largest sub basins were the #2 inlet, entering immediately east of the town beach, and #12 inlet, entering under Route 30 via the large culvert pipe, this is the drain responsible for the large sand bar in the northern area of the lake. Together these three inlets drain approximately 1,143 acres or about 70% of the total drainage area of the lake.

Regular Tributary Sampling

Only Aborn Brook is sampled as part of volunteer monitoring. The results of the sampling are presented in **Table 5**. The regular sampling results reflect the overall base flow water quality of the water flowing into Crystal Lake. These values can be used to evaluate the degree of change induced by storm water flows.

The water quality testing at Aborn Brook included total phosphorus, ammonia nitrogen, nitrate nitrogen, turbidity, conductance, and pH. The long term trends in phosphorus, and nitrate concentration and the turbidity are shown in the following set of graphs. Phosphorus shows a mean concentration of about 14 ppb over the last 10 years of recorded measurements, with most values between the range of 3 to 23 ppb, (**Figure 9**). Occasionally, higher values have been recorded but these have been rare, and have not been seen lately. Nitrate is an indicator of septic system loading and also influences rooted aquatic plant growth. The long term trend in nitrate is shown in **Figure 10**. The mean concentration of nitrate in Aborn Brook is 155 ppb and includes one very high value of 1000 collected in April 2004.

The turbidity of the stream indicates the cloudiness of the water and can be used as a surrogate of suspended solids or the sediment content of the water. Typically, clear water has a turbidity of less than 0.5 NTU. The turbidity values from the brook have shown a large fluctuation between about 0.7 and 4.9 NTU, with a mean of 2 NTU (**Figure 11**). This indicates that sediment is commonly carried by the stream with deposition occurring in the cove.

Table 5. Regular, Base Flow, Inlet Sampling Results, 2004 - 2006.

ABORN BROOK							
	2004	**2004**	**2005**	**2005**	**2005**	**2006**	**2006**
Parameter	**26-April**	**30-May**	**2-Jun**	**18-Jul**	**28-Aug**	**3-Aug**	**4-Oct**
Total Phosphorus (ppb)	28	14	14	13	27	21	4
Ammonia Nitrogen (ppb)	325	~	69	60	23	< 10	< 10
Turbidity (NTU)	~	1.7	2.8	1.5	4.7	4.9	1.4
Conductance (umhos/cm)	~	126	144	146	~	~	~
pH (Units)	~	6.5	6	6.5	6.7		6.4
Nitrate/Nitrite-Nitrogen (ppb)	1,000	122	78	140	139	90	123

Figure 9. Long Term Trend in Phosphorus Concentration At Aborn Brook.

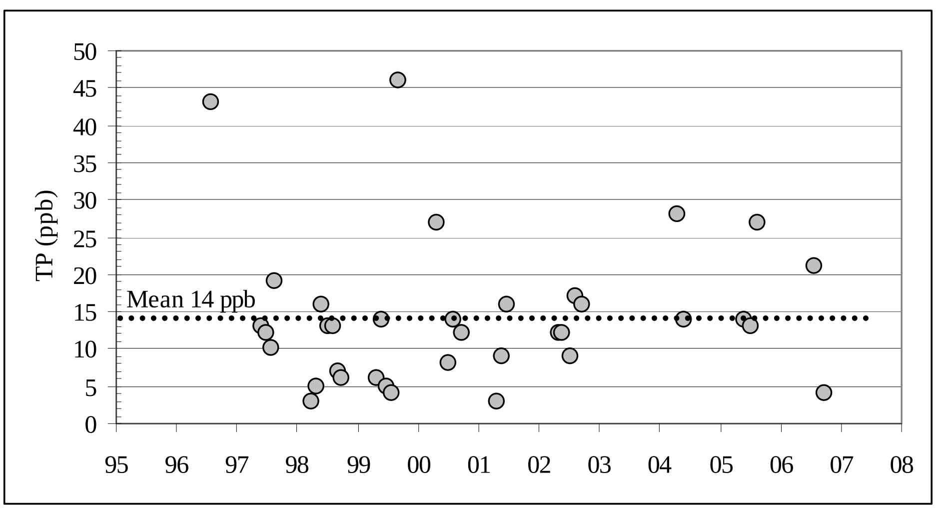


Figure 10. Long Term Trend in Nitrate Concentration At Aborn Brook.

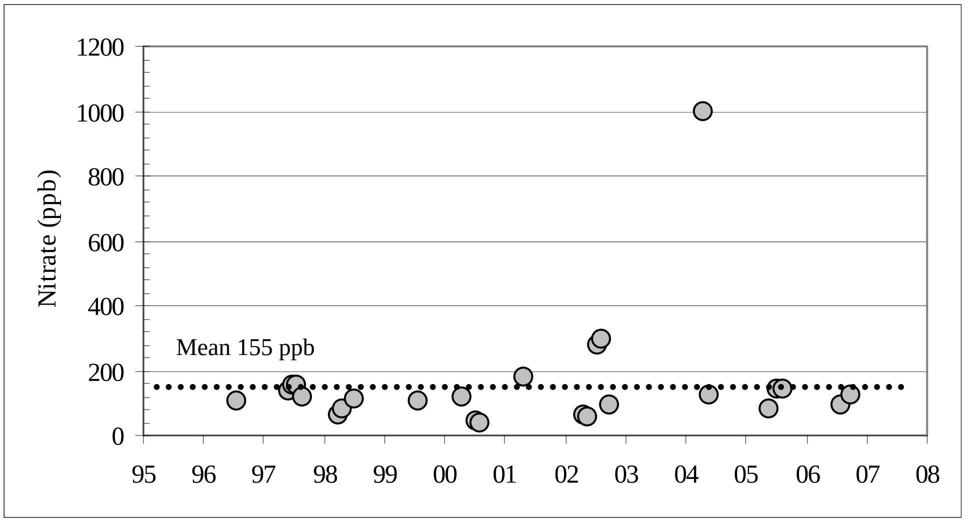
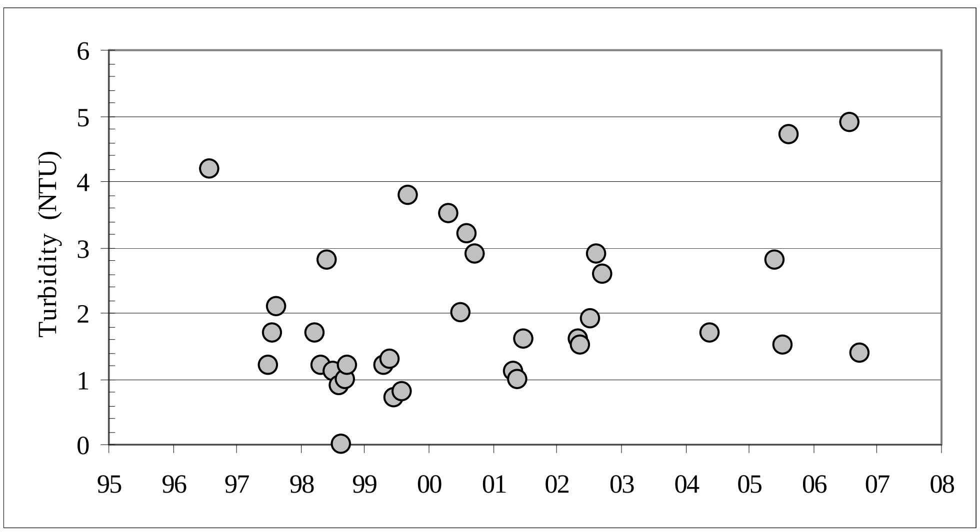


Figure 11. Long Term Trend in Turbidity At Aborn Brook.



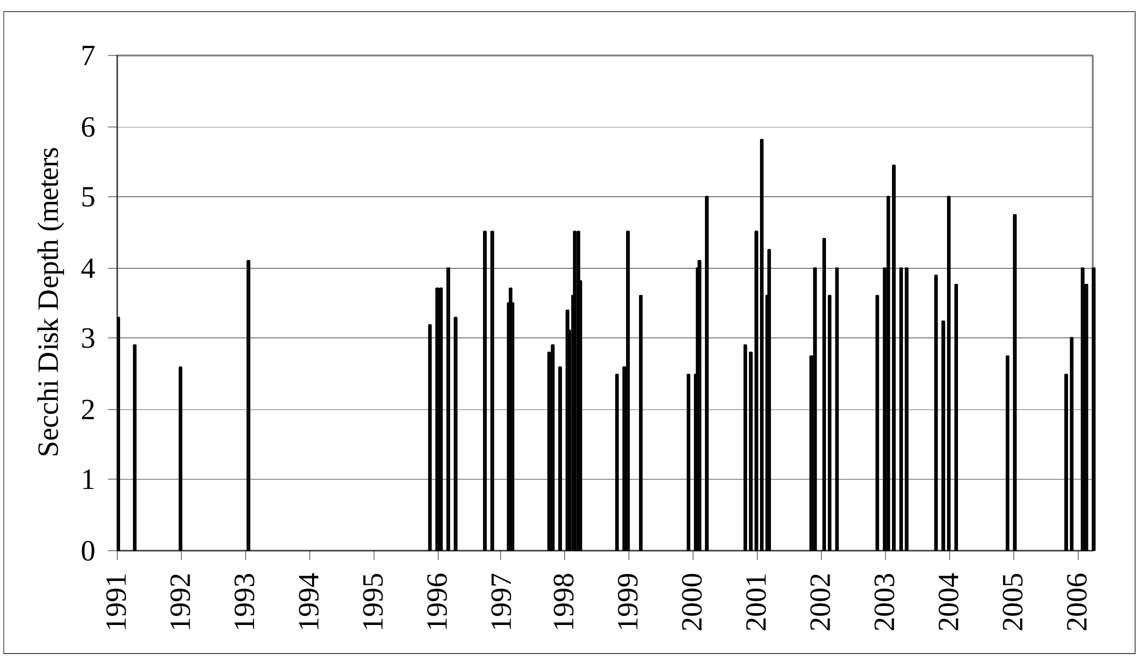
CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The lake had low phosphorus concentrations in the upper water column during this study. The levels remained below the upper oligotrophic threshold of 10 ppb. No internal loading of phosphorus from deep water anoxic sediments was detected, although some increase in concentration was observed at the bottom. The spring phosphorus has varied between 7 ppb and 12 ppb with a fairly consistent mean of about 9 ppb which predicts an annual phosphorus load to the lake of about 110 Kg. There appears to be a good relationship between the spring phosphorus concentration and the seasonal average concentration in the lake.

The long-term water clarity of the lake has varied between a low of 2.5 meters and a high of 5.8 meters, with a mean of 3.7 meters (**Figure 12**). The best water clarity occurs in the summer while the poorest readings occur in the spring. Although the trend over the last three years is for a generally declining water clarity this may be part of a long-term oscillation in clarity at the lake because the data from the last three years compares to readings from the late 1990's. After low readings in 1998 and 1999 clarity increased to high reading in 2000 and 2001.

Figure 12. Long Term Water Clarity Record for Crystal Lake, 1991 – 2006.



Recommendations

Continue the water quality monitoring of the lake. Using a 7 month sampling protocol, April to October, with possible under ice sampling in January and February.

The data from the last three years when combined with the long term record indicates that water clarity appears to be declining, at least over the last three years. It is important that clarity monitoring continue during the next couple of years at a higher frequency of measurements than has been common, that is at least 4 measurements during each season and preferably 7 or 8 measurements.

The resident monitoring program has provided a continuous record of data from Crystal Lake that now includes 10 years of information. The monitoring program needs to be supported such that it will continue into the future. Crystal Lake appears, at this time, to be in a stable condition based on the relative consistency of both phosphorus and Secchi disk depth. One of the principal factors in the lakes favor is that no internal loading appears to be occurring despite the presence of anoxia bottom water. If this fact were to change in the future the lake would almost certainly begin to shift into a new condition.

In addition to the stability represented by a lack of internal loading, the lake is currently subjected to storm water with very high concentrations of nutrients and sediments. The phosphorus appears to be well correlated with sediment loads indicating that most, if not all, the phosphorus in the storm water is being deposited at the outfalls as sediment deltas and in the case of Aborn Brook in the southeast cove. There was some agreement between loading estimates using both the storm water and the spring phosphorus concentration. This suggests that the drainage basin of the lake is at a critical point of development. This situation gives further reason to continue the monitoring of the lake.