

5.1 Compiled Data

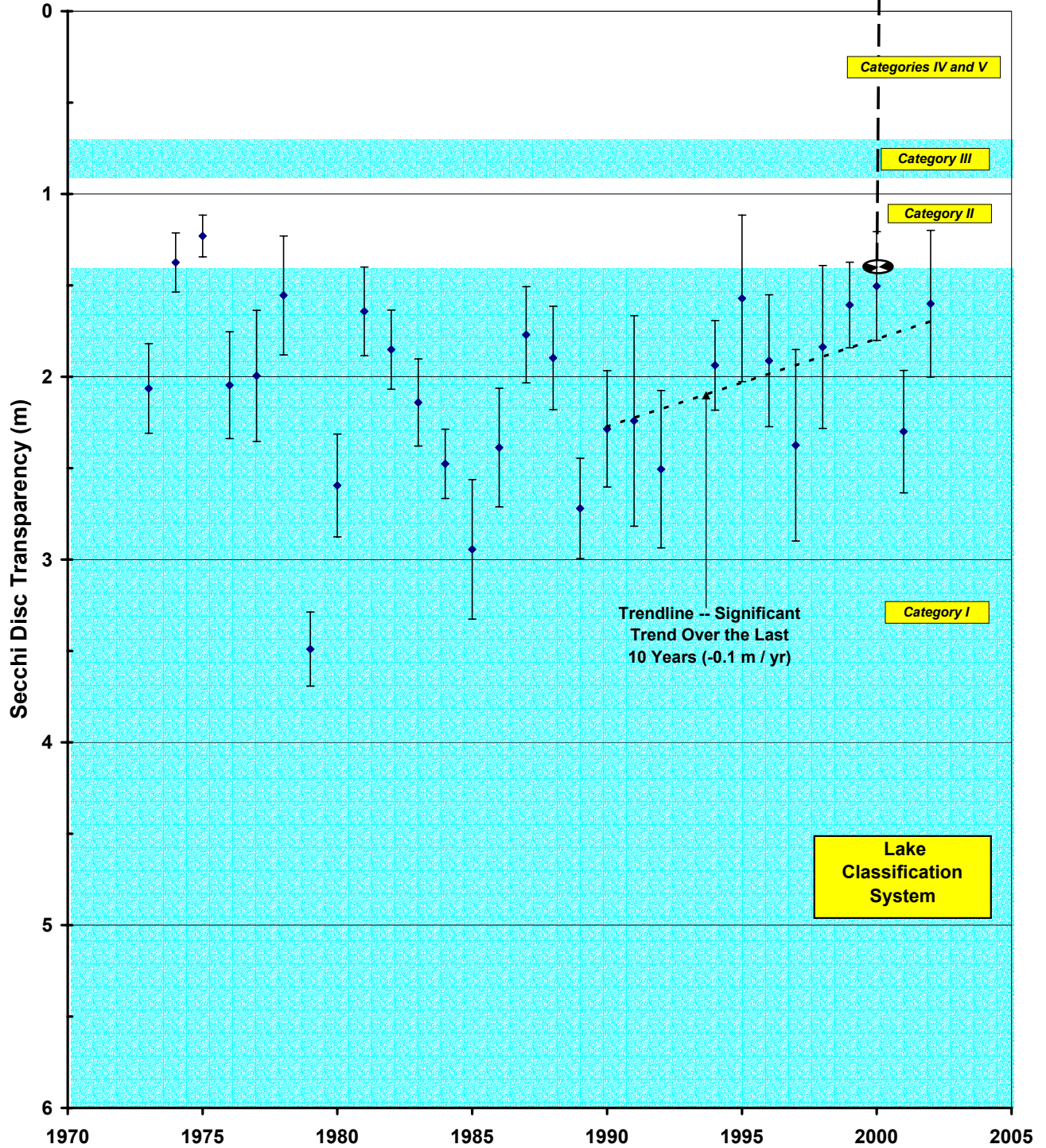
Water quality and limnological data acquired during the preparation of this management plan are compiled in Appendices A through G. Appendix A contains the tabulated results from pond surveys conducted throughout the Crystal Lake watershed along with pond data taken from development plans or using ArcView and estimated average depths. Appendix B is the tabulated 2002 in-lake water quality data for each sampling stations shown on Figure 4-1. Selected water quality parameters from Appendix B are analyzed and summarized in the discussion below. Appendix C has temperature, dissolved oxygen and total phosphorus isopleths, based on water quality data collected from Crystal and Keller Lakes during 2002. Selection of P8 model parameters during the calibration process is detailed in Appendix D. Appendix E contains a copy of the most recent MDNR fisheries survey and a summary of the historical fisheries data. In-lake water quality modeling results for Mystic Bay, Maple Island Bay, Bluebill Bay, and Buckhill Bay are summarized in Appendix F for various assumed combinations of watershed runoff BMPs. Appendix G contains the detailed cost estimated for the BMPs analyzed in this study. These results of the compiled data are discussed later in this section.

5.2 Trend Analyses of Total Phosphorus, Chlorophyll *a* and Secchi Disc Transparency Data

5.2.1 Crystal Lake

A trend analysis of Crystal Lake's water quality data was completed to determine if the lake had experienced significant degradation or improvement during the years for which water quality data are available. The trend in a variable was considered significant if the slope of the regression was statistically significant at the 95 percent confidence level. Summer water quality data has been collected for Crystal Lake periodically since 1973. Summer average values (the typical averaging period was late-May through early-September) were calculated and analyzed in a trend analysis (i.e., linear regression and analysis of variance). Although the trend analysis of historical water Secchi disc transparency data (see Figure 5-1) for Crystal Lake indicates no long-term (over the 29-year period of record) water quality trends, the lake's overall condition has generally degraded during the past 12 years at a rate of roughly 0.1 meters of Secchi disc transparency per year. This degradation is most likely due to the concurrent transition of natural open lands into low-density residential and commercial development. Although the analysis found no significant trends over time for chlorophyll *a* and total phosphorus (see Figures 5-2 and 5-3), both of these water quality parameters have generally deteriorated over the last 12 years.

**Figure 5-1
Crystal Lake: Summer Average
Secchi Disc Transparencies Trend Analysis**



Note: All data points represent the summer average value (± 1 Standard Error).

Figure 5-2
Crystal Lake: Summer Average Surface
Chlorophyll a Concentrations Trend Analysis

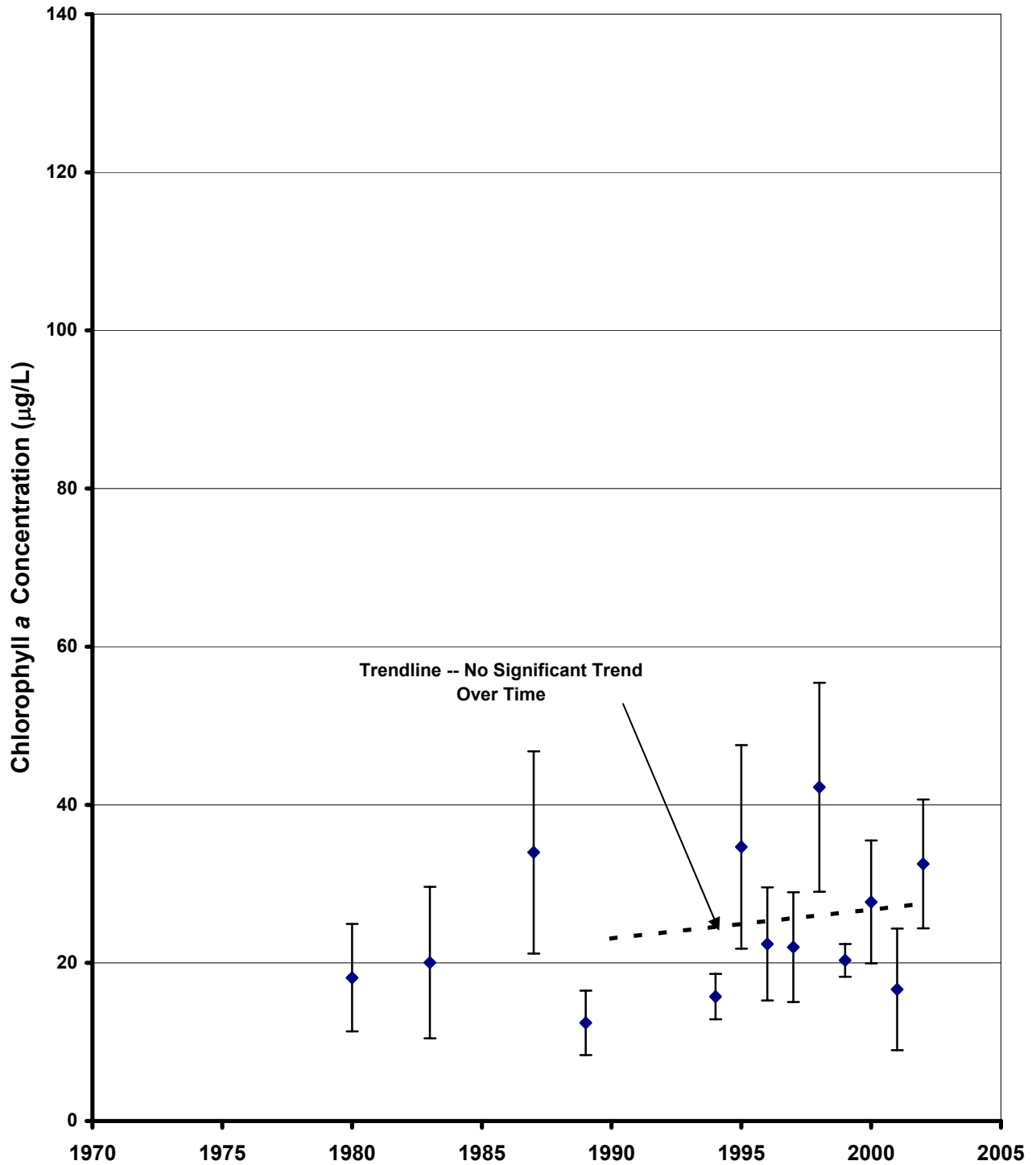
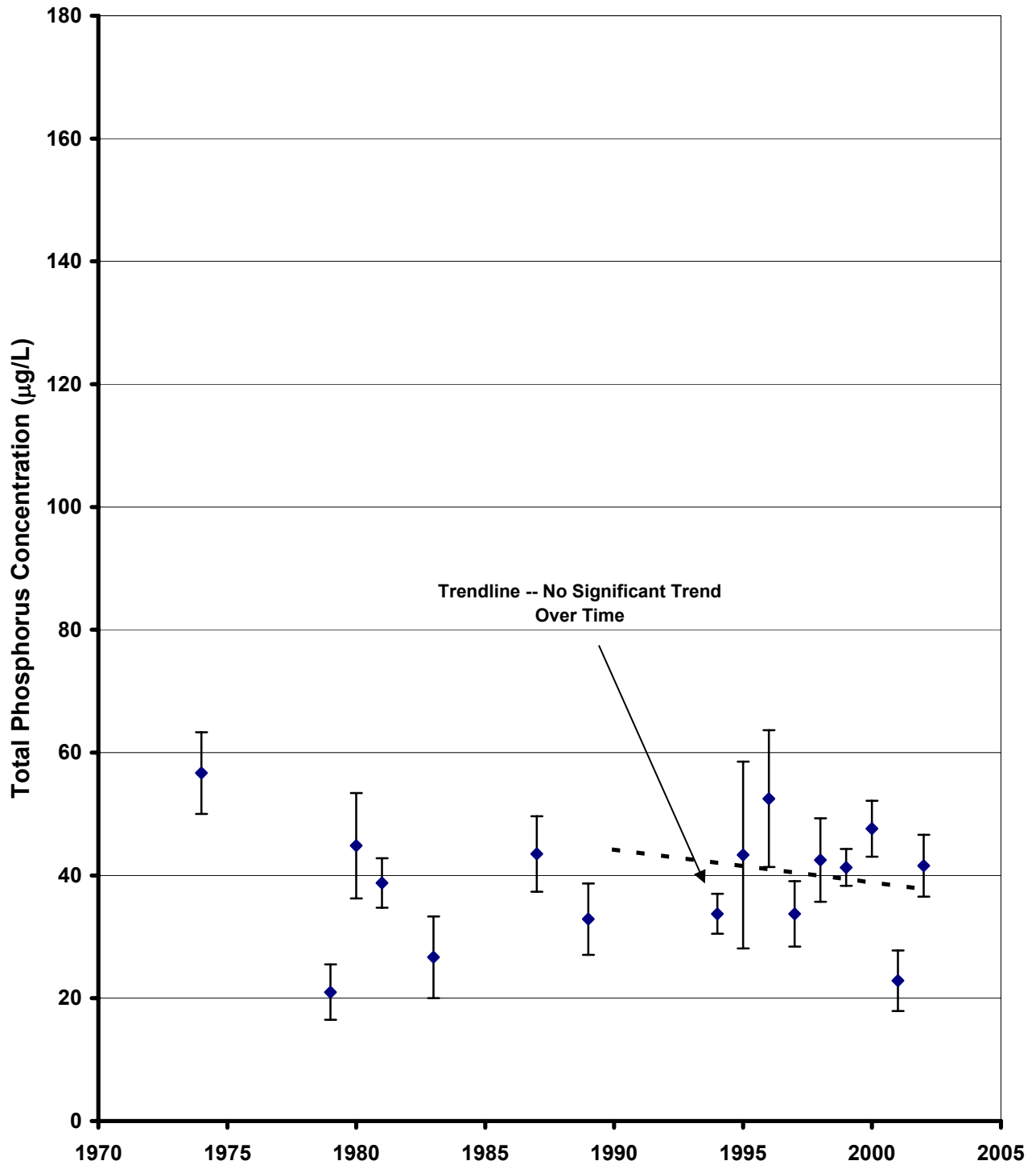


Figure 5-3
Crystal Lake: Summer Average Surface Total Phosphorus
Concentrations Trend Analysis



While a close relationship ($r^2 = 0.55$) between summer average total phosphorus concentration and Secchi disc transparency was observed, the following MPCA's phosphorus limited relationships provided the best fit between observed and predicted 2002 summer average water quality parameters.

$$\text{Log}[\text{Chl}] = 1.45 * \text{Log}[\text{TP}] - 1.18$$

$$\text{Log SD} = -0.59 * \text{Log}[\text{Chl}] + 0.89$$

where:

[TP] = measured or estimated epilimnetic (mixed surface layer) mean summer total phosphorus concentration ($\mu\text{g/L}$)

[Chl] = estimated epilimnetic (mixed surface layer) mean summer chlorophyll *a* concentration ($\mu\text{g/L}$)

SD = estimated mean summer Secchi disc transparency (m)

5.2.2 Keller Lake

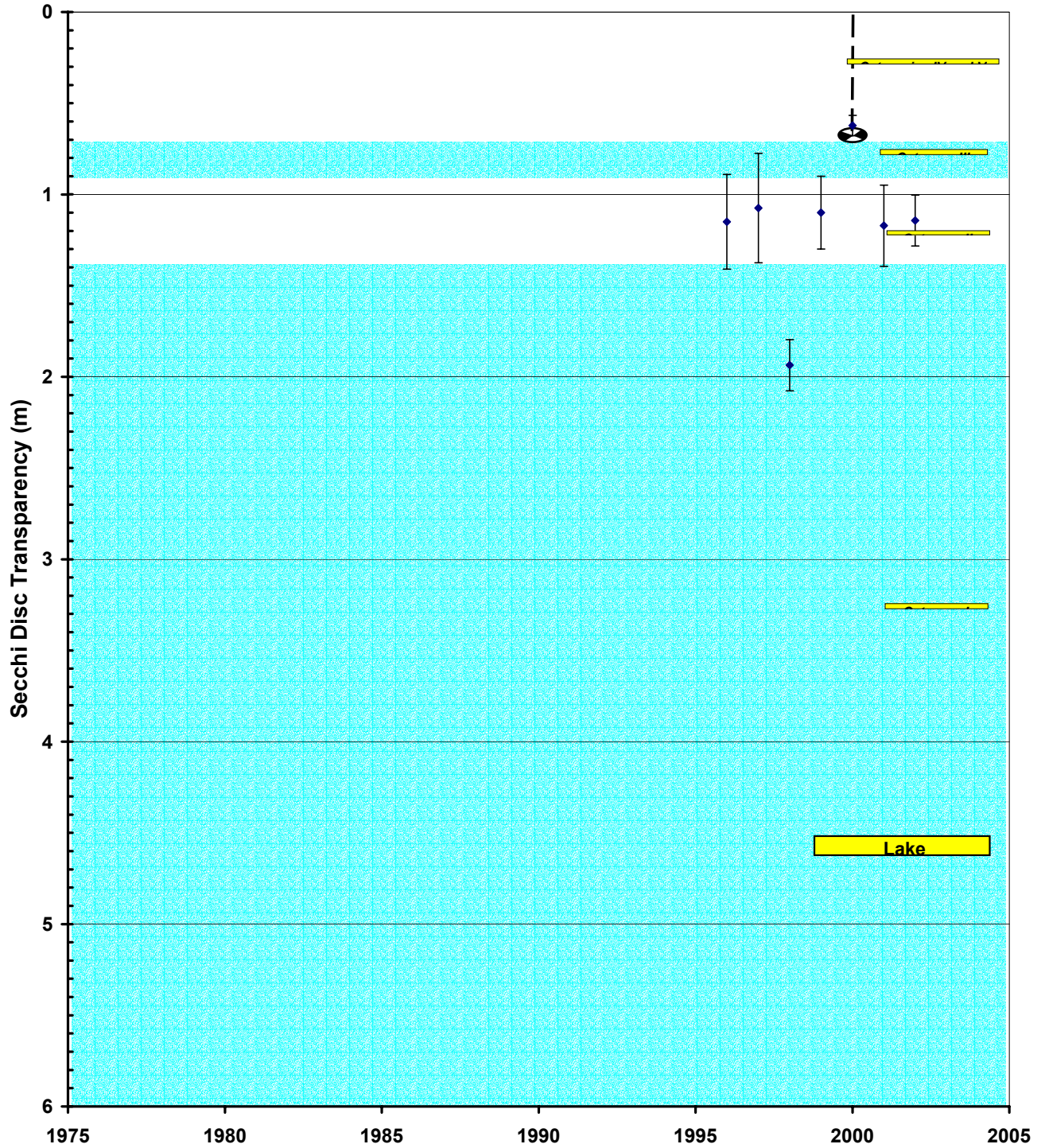
A trend analysis of Keller Lake's water quality data was also completed to determine if the Keller Lake had experienced significant degradation or improvement during the years for which water quality data are available. There was a noticeable improvement in water clarity from 1996 to 1998, and then a marked decline in the water quality between 1999 and 2002 (see Figure 5-4). This improvement in 1998 was likely partially the result of the Crystal Lake hypolimnetic withdrawal project (water quality demonstration project), as previously mentioned. Keller Lake water clarity has remained relatively unchanged, ignoring the 1998 summer average Secchi disc transparency. As a result there is no statistically significant trend in Keller Lake water clarity, total phosphorus, or chlorophyll *a* (see Figures 5-4, 5-5, and 5-6).

The compiled data for the summer average water quality variables show close relationships between: (1) total phosphorus and Secchi disc transparency; and (2) total phosphorus and chlorophyll *a* (see Figures 5-7 and 5-8). The following equations were derived from the Keller Lake data:

$$\text{SD} = -0.6784 \text{Ln}[\text{TP}] + 4.1786 \quad r^2 = 0.68$$

$$[\text{Chl}] = 0.0365[\text{TP}]^{1.499} \quad r^2 = 0.73$$

Figure 5-4
Keller Lake: Summer Average
Secchi Disc Transparencies Trend Analysis



Note: All data points represent the summer average value (± 1 Standard Error).

Figure 5-5
Keller Lake: Summer Average Surface Total Phosphorus
Concentrations Trend Analysis

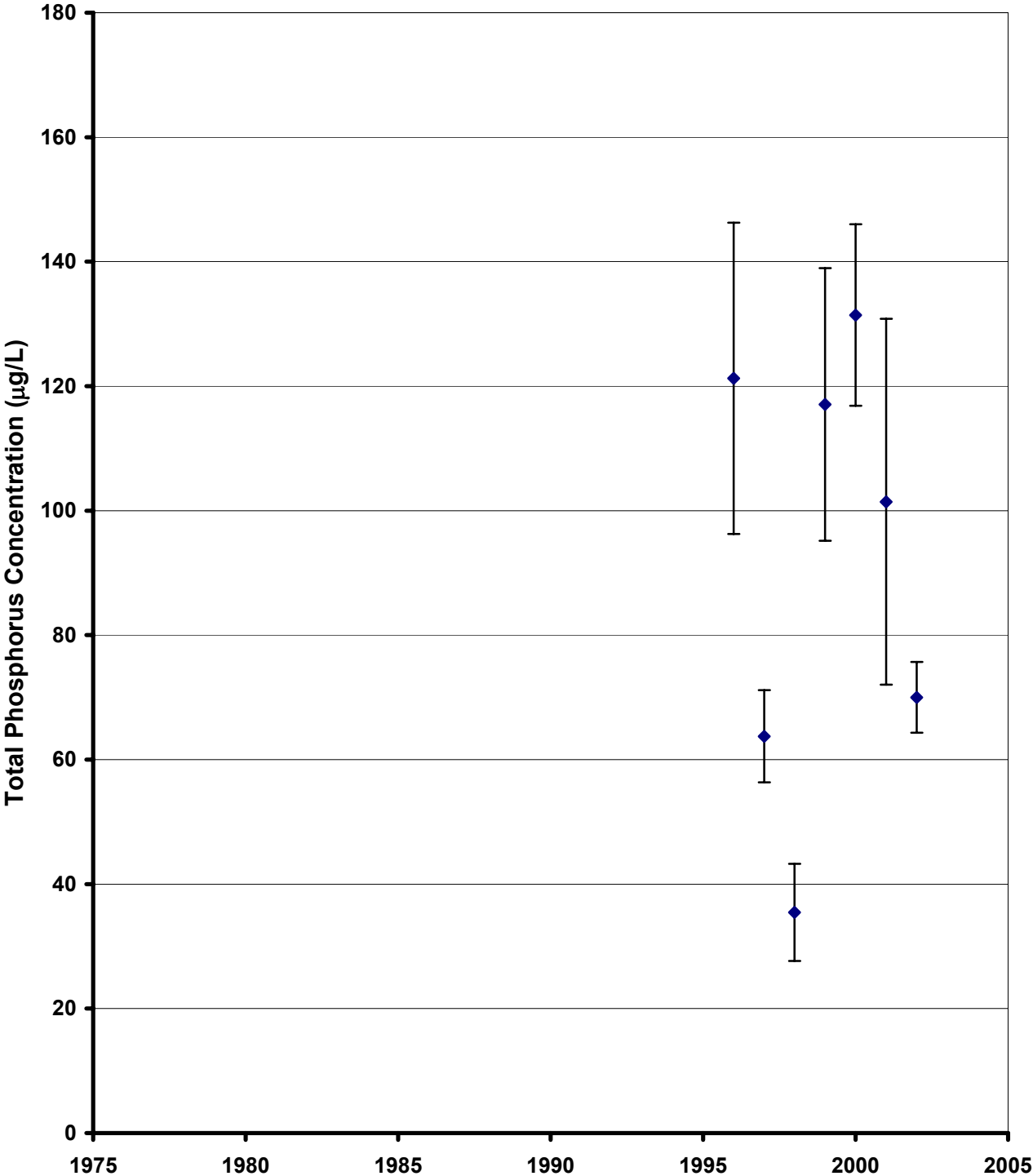


Figure 5-6
Keller Lake: Summer Average Surface
Chlorophyll a Concentrations Trend Analysis

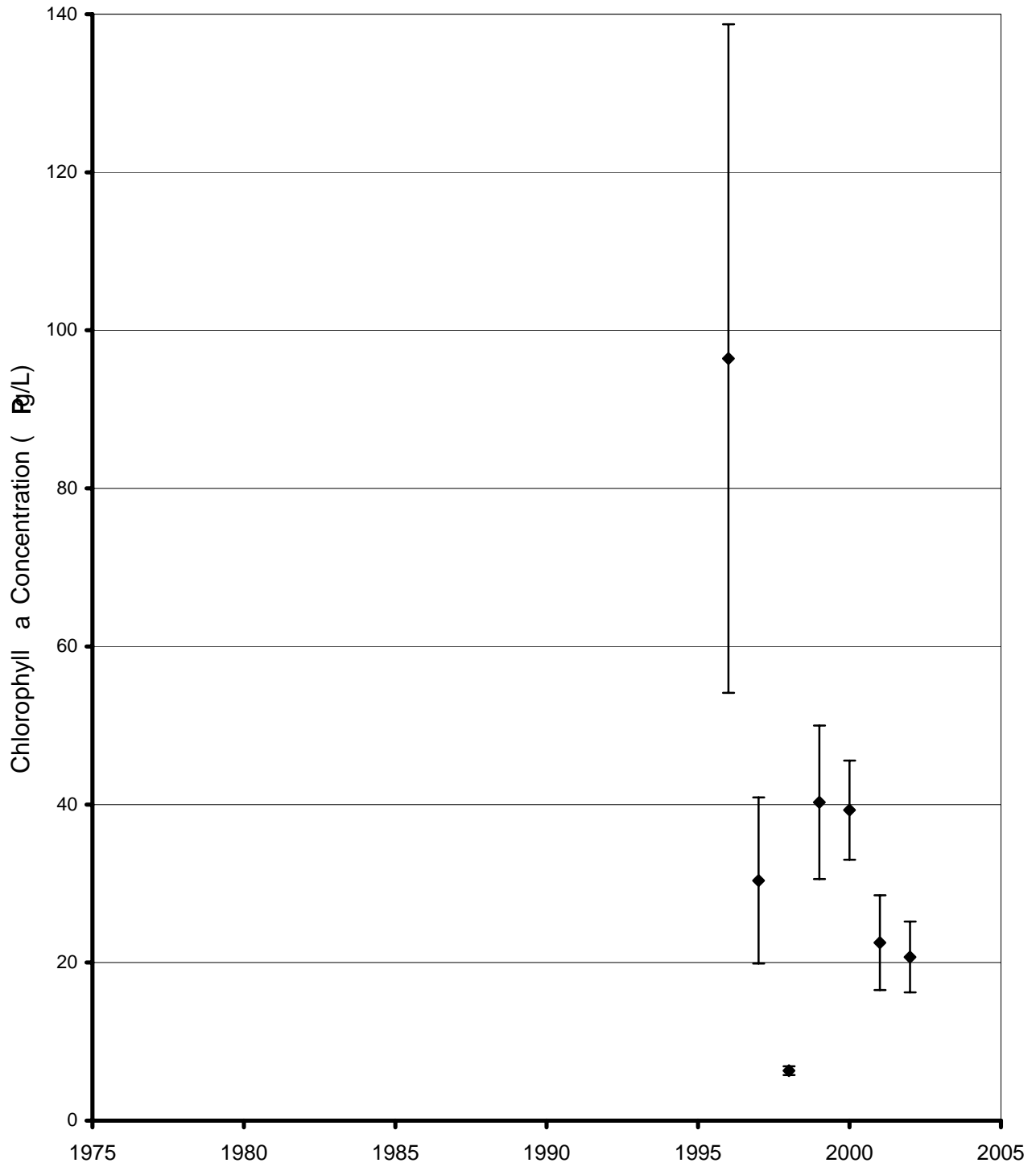


Figure 5-7
 Keller Lake Summer Average Secchi Disc Transparency as a Function of
 Total Phosphorus Concentration

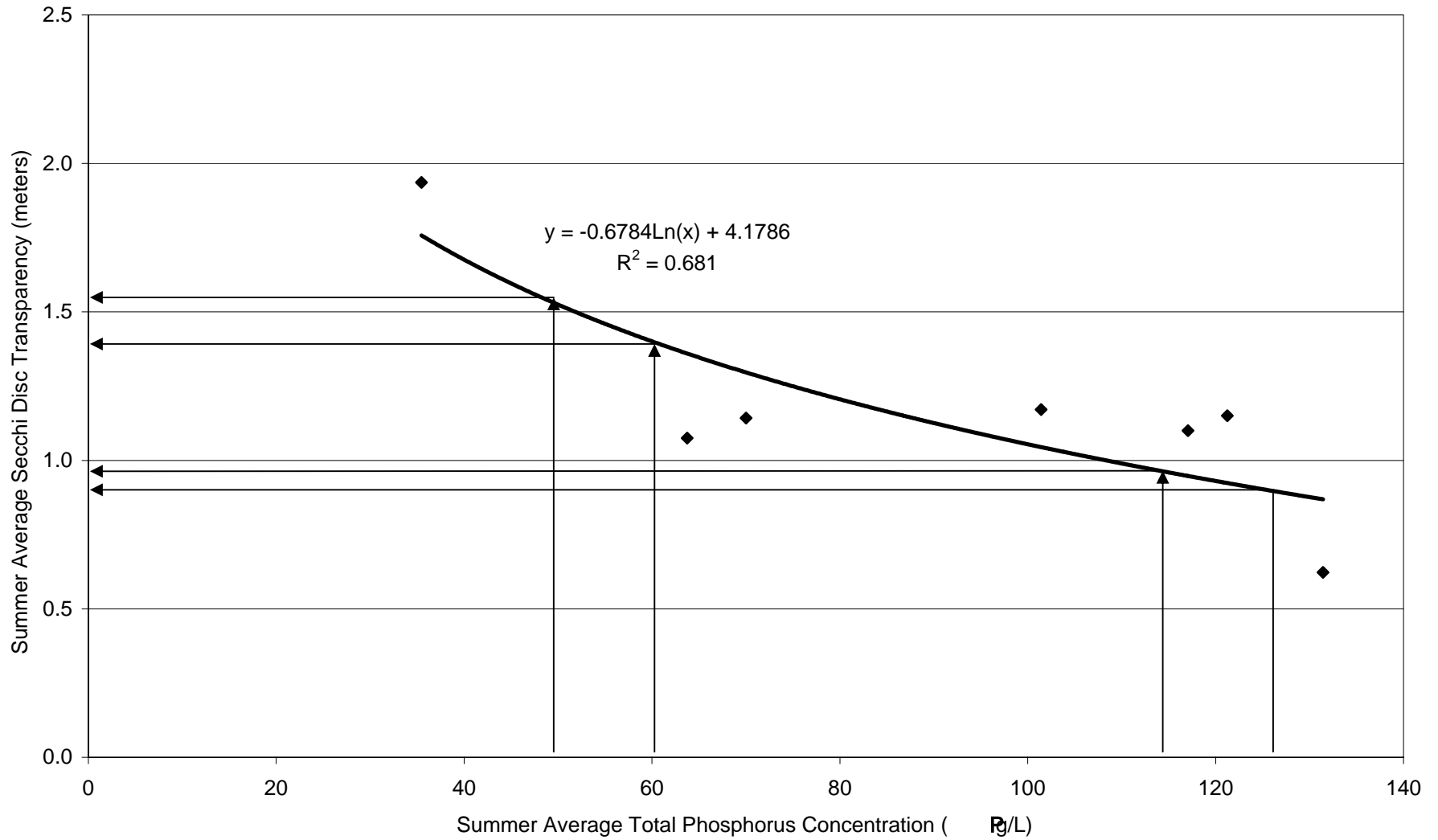
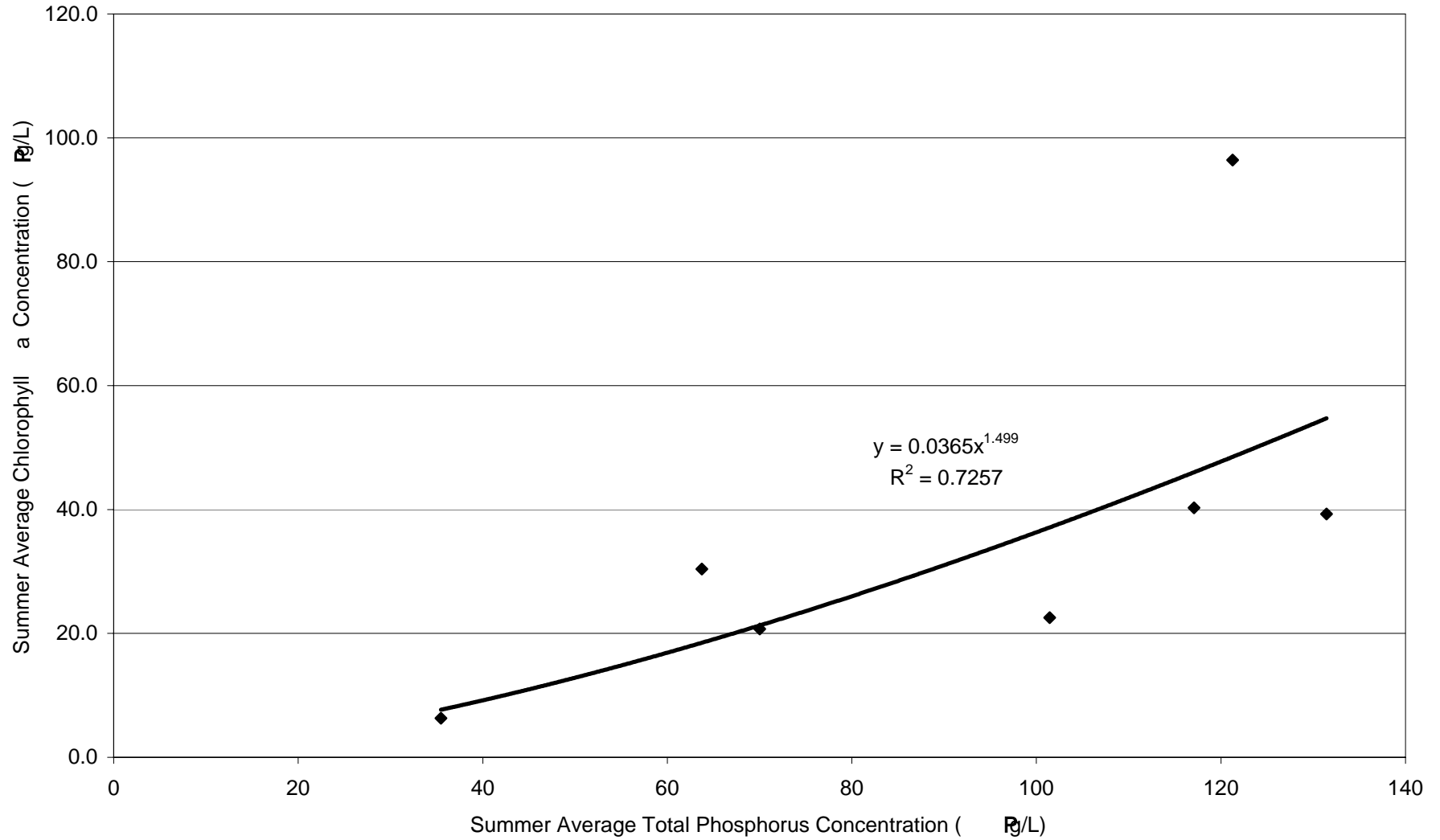


Figure 5-8
Keller Lake Summer Average Chlorophyll a Concentration as a Function of
Total Phosphorus Concentration



5.3 Seasonal Patterns in 2002 Water Quality Conditions

5.3.1 Phosphorus

Phosphorus is the plant nutrient that most often limits the growth of algae. Phosphorus-rich lake water indicates a lake has the potential for abundant algal growth, which can lead to lower water transparency and a decline in hypolimnetic oxygen levels in a lake.

5.3.1.1 Crystal Lake

Crystal Lake water quality exhibits significant variations, both temporally and spatially. For instance, the 2002 spring total phosphorus concentration was 18 µg/L for the main basin of the lake. This would place the lake at the upper end of the mesotrophic status category. However, due to summer inputs of phosphorus, primarily from watershed runoff, die-off of curlyleaf pondweed, and biochemical release by anoxic lake sediments, the corresponding summer average and late-summer concentrations rose to 41 µg/L and 68 µg/L during the calibration year (2002). The 2002 summer average total phosphorus concentration meets the BDWMO's goal. While the total phosphorus data collected from Crystal Lake during 2002 were generally within the eutrophic (i.e., nutrient-rich) category (Figure 5-9) during the summer, the latter total phosphorus concentration would classify Crystal Lake as hypertrophic. The pattern observed in the main basin for 2002 was similar to other years.

Observed variations in spring, early-summer peak, summer average, and fall overturn total phosphorus concentrations for Bluebill Bay, Mystic Bay, Maple Island Bay, Buckhill Bay, and the main lake basin are illustrated in Figure 5-10. The summer average total phosphorus concentrations vary from 39 µg/L in Buckhill Bay to 90 µg/L in Maple Island Bay due to the variability in summer phosphorus inputs from watershed runoff, die-off of curlyleaf pondweed, and biochemical release by anoxic lake sediments. The five basins exhibited somewhat different phosphorus concentrations during the growing season. The main Crystal Lake basin and Buckhill Bay had similar concentrations, with moderate concentrations during the spring period followed by higher phosphorus concentrations during the mid-summer period. Maple Island Bay exhibited phosphorus-rich conditions throughout the monitoring period with phosphorus levels steadily increasing to their peak in mid-July (indicative of an internal phosphorus loading problem). Mystic Bay exhibited a similar pattern with phosphorus concentration in the hypereutrophic category by mid-July.

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Figure 5-9 Crystal Lake—Main Basin 2002 Seasonal Changes in Total Phosphorus and Chlorophyll a Concentrations and Secchi Disc Transparencies

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Figure 5-10 Observed Seasonal Variation in Crystal Lake 2002 Total Phosphorus Concentration

5.3.1.2 Keller Lake

Water quality measurements for 2002 indicate that Keller Lake is a hypereutrophic system. Figure 5-11 summarizes the seasonal changes in concentration of total phosphorus and chlorophyll *a*, and Secchi disc transparencies for Keller Lake during 2002.

During the spring overturn period (early-April), the total phosphorus data collected were in the hypereutrophic (i.e., very poor water quality) category. This was likely the result of significant amounts of phosphorus added to the lake water by anoxic lake sediments during winter and by spring snowmelt runoff. The remaining data collected during 2002 also placed the lake in the hypereutrophic category. As Figure 5-11 illustrates, the epilimnetic (surface water, i.e., 0-2 meter depth) phosphorus concentration increased from the lake's spring steady-state concentration (59 µg/L) to the lake's summer average concentration (70 µg/L). This increase was due to additional phosphorus inputs from a combination of stormwater runoff and internal sources. The 2002 data did not indicate the extremely high total phosphorus concentrations during summer that have been observed historically (see Figure 5-12).

According to previous studies (Heiskary and Wilson, 1990) phosphorus concentrations of 60 µg/L typically result in the frequency of nuisance algal blooms (greater than 20 µg/L chlorophyll *a*) to be about 70 percent of the summer. Since Keller Lake's summer average phosphorus concentration was significantly greater than the 60 µg/L, Keller Lake likely experienced nuisance algal blooms greater than 70 percent of the summer.

5.3.2 Chlorophyll *a*

Chlorophyll *a* is a measure of algal abundance within a lake. High chlorophyll *a* concentrations indicate excessive algal abundance (i.e., algal blooms), which can lead to recreational-use impairment.

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Figure 5-11 Keller Lake—Main Basin 2002 Seasonal Changes in Total Phosphorus and Chlorophyll a Concentrations and Secchi Disc Transparencies

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Figure 5-12 Keller Lake Recently Observed (1996-2002) Total Phosphorus Concentration

5.3.2.1 Crystal Lake

The summer average chlorophyll *a* concentration in the main basin of Crystal Lake (32 µg/L) exceeds the BDWMO's chlorophyll *a* goal (see Figure 5-9). The chlorophyll *a* concentration paralleled the total phosphorus concentrations. Chlorophyll *a* levels began the 2002 season in the oligotrophic zone and deteriorated to 60 mg/L by early-July, placing the lake in the hypereutrophic zone. The chlorophyll *a* concentrations in mid-July were impacted by a whole-lake copper sulfate treatment. Immediately after the copper sulfate treatment the chlorophyll *a* concentrations decreased dramatically and then increased to hypereutrophic levels by fall in all of the basins except Mystic Bay.

The 2002 Crystal Lake chlorophyll *a* data indicate that the Mystic and Maple Island Bays experienced algal blooms prior to the July 10, 2002 sample (see Appendix B for 2002 bay water quality data). The concentrations in Mystic Bay only increased to 22 µg/L following the copper sulfate treatment. The summer average concentration in Buckhill Bay was similar to Bluebill Bay (24 µg/L and 25 µg/L, respectively), which would place the bays at the upper end of the eutrophic category. Maple Island Bay had the highest summer average chlorophyll *a* concentration during 2002 (39 µg/L).

5.3.2.2 Keller Lake

Current Keller Lake water quality data (2002 data) were also evaluated according to the trophic status categories. Most of the chlorophyll *a* measurements (0 to 2 meters) during 2002 were in the eutrophic and hypereutrophic categories throughout the monitoring period (see Figure 5-11). The early-May sampling date had the lowest chlorophyll *a* concentration observed during the sampling period placing the lake in the mesotrophic category. A peak in the chlorophyll *a* concentration was observed during late-June and late-September placing the lake in the hypereutrophic category. The data, including the summer average concentration (20.7 µg/L), indicate nuisance algal blooms (greater than 20 µg/L chlorophyll *a*) likely occurred during 2002, resulting in recreational-use impairment. The 2002 Keller Lake summer average chlorophyll *a* meets the BDWMO's goal.

5.3.3 Secchi Disc Transparency

Secchi disc transparency is a measure of water clarity. Perceptions and expectations of people using a lake are generally correlated with water clarity. Results of a survey completed by the Metropolitan Council (Osgood, 1989) revealed the following relationship between a lake's recreational-use impairment and Secchi disc transparencies:

- Moderate to severe use-impairment occurs at Secchi disc transparencies less than 1 meter (3.3 feet).
- Moderate impairment occurs at Secchi disc transparencies of 1 to 2 meters.
- Minimal impairment occurs at Secchi disc transparencies of 2 to 4 meters.
- No impairment occurs at Secchi disc transparencies greater than 4 meters

5.3.3.1 Crystal Lake

Secchi disc measurements in Crystal Lake generally mirrored phosphorus and chlorophyll *a* concentrations (Figure 5-9). The seasonal patterns clearly show that the lake's Secchi disc transparency is largely determined by algal abundance. The water clarity in the main basin of Crystal Lake generally deteriorated throughout the monitoring period. The spring Secchi disc transparency (2.5 m) was about 1.5 times better than summer average clarity (1.6 meters) and 3 times better than the fall overturn Secchi disc transparency (0.8 meters). As a result, the main basin begins the monitoring period in the mesotrophic status category and deteriorates to slightly hypereutrophic. The 2002 Crystal Lake summer average water clarity barely meets the BDWMO's goal. Throughout most of the summer the main Crystal Lake basin experiences moderate use-impairment and by late-summer the basin likely experiences severe use-impairment based on the Metropolitan Council study. Generally, the 2002 Secchi disc transparencies in the bays began the monitoring period near the mesotrophic zone and declined toward the hypereutrophic category. Maple Island Bay had the worst summer average clarity (1.0 meters) followed, in order of improving water clarity, by Bluebill Bay, Mystic Bay, and Buckhill Bay (1.2, 1.4, and 1.5 meters, respectively).

5.3.3.2 Keller Lake

The 2002 Keller Lake Secchi disc measurements were in both the eutrophic (i.e., poor water quality) and hypereutrophic (i.e., very poor water quality) categories. The summer average Secchi disc transparency (1.1 m) of the lake is considered eutrophic. The 2002 Keller Lake summer average water clarity meets the BDWMO's goal. The Secchi disc measurements ranged between 0.6 and 1.8 meters, with the highest Secchi disc transparencies occurring during April and mid-summer, the

same time periods when the chlorophyll *a* concentrations were generally at their lowest (see Figure 5-11). Therefore, the data indicate the lake's Secchi disc transparency is largely determined by algal abundance. Based on the Metropolitan Council study, the 2002 average summer Secchi disc transparencies indicate that Keller Lake experiences moderate recreational use-impairment.

5.3.4 Temperature, Dissolved Oxygen, and Phosphorus Isoleth Diagrams

Isoleth diagrams represent the change in a parameter relative to depth and time. For a given time period, vertical isopleths indicate complete mixing and horizontal isopleths indicate stratification.

Isoleth diagrams are useful for showing patterns with depth and time when sufficient depth profile data are available. Only the main Crystal Lake basin and Keller Lake were sufficiently deep to allow for isopleth diagrams of temperature, dissolved oxygen, and total phosphorus (see Appendix C for 2002 Crystal and Keller Lake isopleths).

5.3.4.1 Crystal Lake

During 2002 the main Crystal Lake basin was stratified between mid-June and mid-September, becoming completely mixed by September 24. The estimated thermocline depth began around 5 meters deep and remained at about the 4.0 meter depth until just prior to fall overturn. The dissolved oxygen isopleth diagram shows the depletion of oxygen from the bottom waters beginning in June. This has the effect of reducing the available habitat for organisms (e.g., fish and zooplankton). A dissolved oxygen concentration of 5.0 mg/L is considered the minimum desirable level for fish. The period of oxygen depletion (June and mid-September) in the hypolimnion matches the period of apparent internal phosphorus loading, shown in the total phosphorus isopleth diagram. The higher phosphorus concentrations in the hypolimnion during this period indicate the well-stratified lake has a significant internal loading from anoxic sediment. However, the strong thermal stratification limits the amount of phosphorus that mixes up into the epilimnion. Further analysis of the phosphorus levels in the epilimnion and hypolimnion and external phosphorus loading indicated that internal loading was the a major direct source of increased phosphorus concentrations in the epilimnion after the lake mixes at fall overturn (after stratification breaks down). Despite this finding that internal loading is significant in Crystal Lake, external phosphorus loads (i.e., watershed sources) remain the ultimate source of phosphorus in Crystal Lake. Internal loading will delay the lake's response to phosphorus loading reduction in the watershed. Large reductions in phosphorus loading from the watershed would eventually lead to reduced internal loading of phosphorus, although internal loading can be treated in the interim to achieve water quality goals.

5.3.4.2 Keller Lake

The temperature isopleth diagram indicates the Keller Lake stratified somewhat in late-June, but, overall, did not show a strong pattern of thermal stratification during the ice-out period of 2002. This is consistent with the presumption of frequent mixing (polymixis) in Keller Lake, because the lake is shallow and has exposure to the wind. The dissolved oxygen levels in late-June approached 1 mg/L indicating that Keller Lake may have experienced brief periods of anoxic sediments resulting in internal phosphorus loading. Phosphorus released from the sediments during these brief periods of oxygen depletion, which may have occurred between sampling events, did not accumulate in the hypolimnion because of the intermittent mixing of lake throughout the summer.

5.3.5 Macrophytes

Aquatic plants (i.e., macrophytes and phytoplankton) are a natural part of most lake communities and provide many benefits to fish, wildlife, and people. They are the primary producers in the aquatic food chain, providing food for other aquatic life. Macrophytes describe the aquatic plants growing in the shallow (littoral) area of the lake. The Crystal and Keller Lake macrophyte communities perform a number of valuable functions. These include:

- Habitat for fish, insects, and small aquatic invertebrates.
- Food for waterfowl, fish, and wildlife.
- Oxygen producers.
- Provide spawning areas for fish in early-spring.
- Helps stabilize marshy borders of the lake; helps protect shorelines from wave erosion.
- Provides nesting sites for waterfowl and marsh birds.

5.3.5.1 Crystal Lake

Although it was previously observed in Crystal Lake, macrophyte (i.e., lakeweed) surveys performed during June and August 2002 found no Eurasian watermilfoil present (Bluewater Science, 2002). However, another exotic weed, curlyleaf pondweed, was observed at nuisance levels over roughly 100 acres of the lake in early-June 2002 (see Figure 5-13). The June survey reported that curlyleaf pondweed was observed at about 95 percent occurrence rate with medium to dense growths. Curlyleaf pondweed is an exotic perennial, rooted, submersed aquatic vascular plant that was first noted in Minnesota about 1910 (Moyle and Hotchkiss, 1945). Native to Eurasia, Africa, and Australia, this species has been found in most of the United States since 1950, and is currently found in most parts of the world (Catling and Dobson, 1985). Curlyleaf pondweed is detrimental to lakes for three reasons:

- It tends to crowd out native aquatic macrophyte species.
- Dense colonies of the weed may interfere with recreational activities on the lake.
- After curlyleaf pondweed dies out in early-July, it may sink to the lake bottom and decay. When dense colonies of the weed decay, oxygen depletion and release of phosphorus may occur.

Coontail had the second highest rate of occurrence in the June survey (22 percent). Eight other aquatic plants were observed during the June survey (including white waterlily, northern watermilfoil, cabbage, Illinois pondweed, floating pondweed, claspingleaf pondweed, and stringy pondweed). By the August 2002 survey 16 aquatic plants were observed in Crystal Lake. The dominant macrophyte during this survey was coontail (92 percent occurrence rate) followed by water celery (35 percent occurrence rate). Curlyleaf pondweed was only observed at 4 out of 52 stations due to its life cycle.

5.3.5.2 Keller Lake

The Keller Lake aquatic plant survey report for 2000 (Blue Water Science, 2001) states that aquatic plant growth in the lake in 2000 was similar to the 1999 results, but less than what was found in 1998. Coontail and elodea were the dominant submerged plant species in the lake; stringy pondweed and curlyleaf pondweed were also observed. Plant coverage of the lake bottom in late-summer was about 30 percent in 2000 and 1999, compared to 60 percent coverage in late-summer 1998. Plant coverage was nearly 100 percent in the early-summer of 2000. Metropolitan Council reports indicate that aquatic plants covered nearly 100 percent of Keller Lake in mid-July 1999. The aquatic plant coverage and algae prevented sampling of the lake at that time. The 2001 report notes the following dominant plants in the springtime: curlyleaf pondweed in 1997, stringy pondweed in 1998, and back to curlyleaf pondweed in 2000. In late-May 2002, a dense nuisance growth of curlyleaf pondweed covering most of the lake littoral area was observed during routine water quality sampling.

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Figure 5-13 Curlyleaf Pondweed Growth (Source: Blue Water Science)

5.3.6 Fisheries

Fisheries form the top level of the food chain within the lake environment. Smaller fish feed upon the zooplankton and are food themselves for many larger fish species. The populations and species of fish can have an effect on lake water quality. Depending on the size and population, certain species of fish can adversely affect the zooplankton community, which will in turn, increase the number of algae and diminish water transparency within a lake.

5.3.6.1 Crystal Lake

The MDNR manages Crystal Lake as a panfish lake, but has also actively stocked the lake with tiger muskies to afford anglers opportunities to catch trophy fish. The MDNR classified Crystal Lake as a Class 34 fishery. Lakes in this category are good/fair permanent fish lakes, with rough fish such as carp and bullhead present. Results of a 2000 Crystal Lake fish survey are consistent with the species found in a Class 34 lake. The fish survey found that bluegill, sunfish, and pumpkinseed sunfish were the most abundant fish captured, but were considered small. Northern pike, as well as yellow, black, and brown bullhead were also present.

The lake's fishery is expected to be enhanced by the MDNR's continued stocking efforts, but sportfish stocking could also be having a beneficial effect on the water quality of Crystal Lake. Stocked tiger muskies will most likely consume the smaller bluegills and other fish that feed on algae-eating zooplankton. If zooplankton numbers increase, more algae may be consumed, thereby increasing water clarity.

5.3.6.2 Keller Lake

The MDNR classified Keller Lake as a Class 37 lake. Lakes in this category are subject to occasional winterkill. Results from a 1985 fish survey indicate a good population of small panfish (bluegill and black crappie), as well as a small population of relatively large northern pike. These results are consistent with the species expected in a Class 37 lake. The MDNR does not have a current fish stocking program for Keller Lake.

5.4 Water Quality Modeling Results

5.4.1 Baseline Lake Water Quality Status

The Minnesota Lake Eutrophication Analysis Procedure (MnLEAP) is intended to be used as a screening tool for estimating lake conditions and for identifying "problem" lakes. MnLEAP is particularly useful for identifying lakes requiring "protection" versus those requiring "restoration"

(Heiskary and Wilson, 1990). In addition, MnLEAP modeling has been done in the past to identify Minnesota lakes which may be in better or worse condition than they “should be” based on their location, watershed area and lake basin morphometry (Heiskary and Wilson, 1990). Results of MnLEAP modeling done for Crystal Lake suggests that Crystal Lake could achieve “better” water quality than is currently observed (Heiskary and Lindbloom, 1993). MnLEAP predicts a total phosphorus concentration of approximately 48 µg/L. The predicted phosphorus concentration has a standard error of 17 µg/L, which means that the BDWMO’s water quality goal of 45 µg/L for total phosphorus is within the range of what is realistically attainable for Crystal Lake. MnLEAP predicts a total phosphorus concentration in Keller Lake of 74 µg/L with a standard error of 21 µg/L. Therefore the goals established by the BDWMO are realistically attainable.

Vighi and Chiaudani (1985) developed another method to determine the phosphorus concentration in lakes that are not affected by anthropogenic (human) inputs. As a result the phosphorus concentration in a lake resulting from natural, background phosphorus loadings can be calculated from information about the lake’s mean depth and alkalinity or conductivity. Alkalinity is considered more useful for this analysis because it is less influenced by the modifying effect of anthropogenic inputs. Using the long-term average alkalinity values from the main basin of Crystal Lake and Keller Lake, the predicted phosphorus concentration from natural, background loadings should be 20-27 µg/L and 26 µg/L, respectively. This predicted concentration is lower than the BDWMO’s water quality goal for the Crystal and Keller Lakes total phosphorus concentrations and indicates that the BDWMO’s goal is attainable, given the appropriate phosphorus loadings.

5.4.2 Modeled Watershed Phosphorus Loadings

Using the calibration discussed in Section 4.4.1, the P8 model was used to simulate the flow and treatment of stormwater throughout the Crystal and Keller Lake drainage systems. The following three general scenarios were modeled:

- Existing (2002) land use conditions with no additional BMPs.
- Full-development land use conditions with no additional BMPs.
- Full-development land use conditions with various watershed and in-lake BMPs.

For each scenario, the stormwater runoff volume and phosphorus mass load entering each of the five basins of Crystal Lake and Keller Lake was estimated. The Dillon and Rigler (1974) in-lake empirical water quality model was then used to estimate the spring, early-summer peak, summer average and fall overturn phosphorus concentrations in each of the five basins of Crystal Lake and Keller Lake. The inflow phosphorus budgets for existing and full-development land use with no additional BMPs are shown on Figures 5-14 and 5-15.

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Figure 5-14 Crystal Lake Annual External Phosphorus Budgets: Existing (2002) and Full Development Land Use

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Figure 5-15 Keller Lake Annual External Phosphorus Budgets: Existing (2002) and Full Development Land Use

Most of the phosphorus that runs off a watershed is particulate (i.e., is associated with soil or debris particles). However, the P8 model assumes that 30 percent of the phosphorus that accumulates on a watershed is soluble (i.e., not associated with particles). While BMPs that rely on particle settlement, such as detention pond and grit chambers, are effective at removing phosphorus associated with particles in stormwater runoff, they are ineffective at removing soluble phosphorus.

5.4.2.1 Existing (2002) Land Use Conditions

5.4.2.1.1 Crystal Lake

For existing land use conditions, modeling simulations indicate a total phosphorus load from the watershed during 2002 of 582 lbs., and a watershed stormwater runoff volume of 1,775 acre-feet. The water and phosphorus loads are equivalent to 6.4 inches and 0.18 lbs./acre, respectively (assuming a terrestrial area of 3,315 acres). Table 5-1 shows data from other studies in the Twin Cities (Barr 1992, 1993, 1994, 1995a,b, 1997, 1999, Ramsey County 1988) for comparison. The average annual phosphorus yield in the Crystal Lake watershed (0.18 lbs./acre/year) is at the lower end of the range of corresponding yields determined for many other watersheds in the Twin Cities Metropolitan Area, and is presumably due to the abundance of wetlands and stormwater detention ponds within the Crystal Lake watershed that detain and improve the quality of runoff reaching Crystal Lake.

Table 5-1 Comparison of Areal Phosphorus Loadings

Watershed	Location	Watershed Area (acres)	Areal Loading (lbs./acre/year)	Source
Twin Lake/Site 37	Mpls. Chain of Lakes	1,714	0.21 ¹	Barr Engineering Co., 1992
Bass Lake/Site 17	Mpls. Chain of Lakes	1,385	0.31 ¹	Barr Engineering Co., 1992
Ramsey County Ditch 16	Lake Gervais/Little Canada	1,900	0.34 ¹	Ramsey County, 1988
Ramsey County Ditch 18	Kohlman Lake/Maplewood	6,500	0.36 ¹	Ramsey County, 1988
Crane Lake	Minnetonka	353 ³	0.47 ²	Barr Engineering Co., 1995a
Turtle Lake	Plymouth	369 ³	0.25 ²	Barr Engineering Co., 1995b
Parkers Lake	Plymouth	950 ³	0.73 ²	Barr Engineering Co., 1993
Sweeney Lake	Golden Valley	2,400 ³	0.38 ²	Barr Engineering Co., 1994
Lake Marion	Lakeville	4,519 ³	0.16 ²	Barr Engineering Co., 1997
Orchard Lake	Lakeville	2,012 ³	0.21 ²	Barr Engineering Co., 1999b
Crystal Lake	<i>Burnsville</i>	<i>3,370³</i>	<i>0.18⁴</i>	<i>This Study</i>
Keller Lake	<i>Burnsville</i>	<i>1,387³</i>	<i>0.27⁴</i>	<i>This Study</i>

¹ Phosphorus loads are based on water quality monitoring results.

² Phosphorus loads are based on P8 simulations for average precipitation and existing watershed conditions.

³ Excluding lake water surface and landlocked areas.

⁴ Phosphorus loads are based on P8 simulations for 2001-2002 climatic conditions and existing watershed conditions.

Figure 5-16 illustrates the areal phosphorus loading (lbs./acre/year) simulated by the P8 model for each subwatershed under both existing and full-development land use conditions. The color of each subwatershed represents the phosphorus load leaving the subwatershed after treatment/detention in any ponds or wetlands that are present. Therefore, land use conditions in a subwatershed may indicate potentially high phosphorus loads, but existing ponds and wetlands will reduce that load substantially. Due to the numerous wetlands and ponds, the areal loading from all subwatersheds under existing conditions is relatively low. In both the existing and full-development conditions, the highest phosphorus loading occurs in the areas along I-35. The commercial land use in this area typically consists of relatively large impervious (i.e., paved) areas. Impervious areas tend to collect dust, debris, lawn clippings and chemicals, automobile fluids, and trash and facility their transport to the storm sewer system, and ultimately to the lake. However, the City of Lakeville is requiring that this new commercial development result in less than a 70 percent total imperviousness in order to help mitigate both stormwater quantity and quality concerns.

Figure 5-17 illustrates the P8 simulated total phosphorus removal fraction for each ponding basin and the cumulative phosphorus loading removed (fraction) under both existing and full-development land use conditions. Throughout the Crystal Lake watershed, stormwater runoff flows sequentially through a number of ponds and wetlands before discharging to the lake. Each pond in such a sequence will receive stormwater not only from the immediately adjacent subwatershed area, but from the upstream ponds as well. As the stormwater passes through each pond in the series, additional phosphorus not removed in the upstream ponds will be removed. Therefore, while the performance of a single pond in a series of ponds may be low, the overall performance of all ponds in the series (the “cumulative removal”) will be high. The color of each subwatershed in Figure 5-17 represents the cumulative percent phosphorus removal in a series of sequential subwatersheds to that point (i.e. the color of each subwatershed represents the removal in that subwatershed and all upstream subwatersheds, taking into account sequential phosphorus removal in all wetlands and ponds).

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Figure 5-16 Crystal Lake Watershed: Existing and Full Development Total Phosphorus Export Rates for Each Subwatershed

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Figure 5-17 Crystal Lake Watershed: Existing and Full Development Cumulative Total Phosphorus Removal Fraction for Each Subwatershed

5.4.2.1.2 Keller Lake

Modeling simulations indicate a total phosphorus load from the Keller Lake watershed during 2002 of 392 lbs., and a watershed stormwater runoff volume of 728 acre-feet. Figure 5-15 illustrates the inflow phosphorus budgets for the whole lake. The phosphorus and water loads are equivalent to 0.27 lbs./acre and 6.3 inches, respectively (assuming a terrestrial area of 1,387 acres). Even though the land use in the Keller Lake watershed is similar to the Crystal Lake watershed the areal phosphorus loading in the Keller Lake watershed (0.27 lbs./acre/year) is higher than that of the Crystal Lake watershed (0.18 lbs./acre/year). This is likely the result of the Keller Lake watershed containing a large direct drainage area (watershed area that discharges runoff to the lake with little or no water quality treatment).

5.4.2.2 Full-Development Land Use Conditions/No Best Management Practices

It is important to note that this scenario was modeled for comparison purposes only. The cities of Burnsville, Apple Valley, and Lakeville require that all new developments must include construction of stormwater detention ponds designed using NURP (National Urban Runoff Program) design criteria. The expected phosphorus removal from such ponds ranges from 40 to 60 percent. Since development plans do not yet exist for most of the area in the watershed slated for future development, this condition could not be modeled; therefore, this scenario should be considered “worst case”, and will probably not occur.

5.4.2.2.1 Crystal Lake

For full-development land use conditions, modeling simulations indicate an annual total phosphorus load of 622 lbs., and a stormwater runoff volume of 1,904 acre-feet during a year with precipitation conditions similar to those observed during 2002. This represents a phosphorus load increase of 40 lbs. over that for existing land use conditions. The full-development phosphorus load is equivalent to 0.19 lbs./acre.

Figure 5-16 illustrates the individual subwatershed areal phosphorus loads for full-development conditions. It is evident from comparison to the similar map for existing conditions that the anticipated change in land use as development proceeds will result in higher phosphorus loads. The most dramatic increase in phosphorus load is along the I-35 corridor. The full-development land use for this corridor consists primarily of commercial areas; these land use types typically consist of relatively large impervious (i.e., paved) areas. Impervious areas tend to collect dust, debris, lawn clippings and chemicals, automobile fluids, and trash and facilitate their transport to the storm sewer

system, and ultimately to the lake. Therefore, as the amount of impervious area increases, the phosphorus load will increase, as well.

Most phosphorus that accumulates and runs off of a watershed is particulate (i.e., is associated with soil or debris particles). However, the P8 model inherently assumes that 30 percent of phosphorus that accumulates on a watershed is soluble (i.e., not associated with particles). BMPs that rely on settlement of particles to facilitate phosphorus removal, such as detention ponds or grit chambers, are effective at removing phosphorus associated with particles, but are minimally effective at removing soluble phosphorus. Figure 5-18 illustrates the soluble-phosphorus fraction of the runoff from each subwatershed. The preponderance of wetlands and detention ponds within the Crystal Lake watershed are highly effective at removing the particulate phosphorus from the watershed runoff. The simulations indicate that much of the phosphorus ultimately reaching Crystal Lake may be soluble rather than particulate. Therefore, addition of runoff detention ponds in some locations in the watershed may not be highly effective in removing additional phosphorus, however such ponds would certainly serve to remove additional total suspended solids.

5.4.2.2.2 Keller Lake

The Keller Lake watershed is essentially fully developed. There are only a few small areas where the existing land use is projected to change to a land use with higher imperviousness. Therefore, model simulations for 2002 climatic conditions indicate that both the phosphorus and water loads to Keller Lake will remain relatively unchanged. The phosphorus load is not estimated to increase while the water load increases by roughly 0.4 acre-feet.

Reserved for:

Figure 5-18 Crystal Lake Watershed: Existing and Full Development Cumulative Outflow Soluble Phosphorus Fraction for Each Subwatershed

5.4.3 Internal Phosphorus Load Calculation Results

Phosphorus enters the lakes from watershed runoff, atmospheric deposition, and sediment release. The latter is referred to as “internal loading” and it is often a significant source of phosphorus in lakes that have a history of high phosphorus loads from their watershed. Phosphorus released from the sediments is typically in a dissolved form, which can be quickly utilized by algae, leading to intense algae blooms. Internal loading is influenced by the lake’s mixing and stratification patterns.

5.4.3.1 Crystal Lake

Crystal Lake appears to be “dimictic” (becomes completely mixed twice per year). Phosphorus released from the sediments, therefore, builds up in the hypolimnion and can be entrained in the epilimnion as the thermocline begins to erode and the lake becomes more weakly stratified. The data indicates that internal loading is more likely to influence surface water phosphorus concentrations during mid-summer (early-July) and fall overturn.

Internal loading of phosphorus to Crystal and Keller Lakes was calculated from the following mass balance equation:

$$\text{Internal P} = \text{late-summer P} + \text{outflow P} - \text{runoff P} - \text{upstream P} - \text{atmosphere P}$$

The phosphorus mass balance was calculated for each of the five basins, based on existing land use conditions and phosphorus concentrations measured in 2002. Using the mass balance equation, the net internal loading for 2002 due to curlyleaf die-back was calculated to be 127 lbs. in the main basin, 9.6 lbs. in Bluebill Bay, 15.6 lbs. in Mystic Bay, 3.4 lbs. in Maple Island Bay, and 2.1 lbs. in Buckhill Bay. The internal phosphorus loading at fall overturn was estimated to be 231.4 lbs. in the main basin, 1.4 lbs. in Maple Island Bay, and 0.2 lbs. in Buckhill Bay. Bluebill and Mystic Bays were found to have no significant internal loading of phosphorus at fall overturn. In fact, calculations for these bays actually indicated a negative internal load, meaning it is serving as a sink rather than a source of phosphorus.

Despite this finding that internal loading is significant in Crystal Lake, external phosphorus loads (i.e., watershed sources) remain the largest source of phosphorus in Crystal Lake (see Figure 5-19). Internal loading will delay the lake’s response to phosphorus loading reduction in the watershed. Large reductions in phosphorus loading from the watershed would eventually lead to reduced internal loading of phosphorus, although internal loading can be treated in the interim to achieve water quality goals.

Reserved for:

**Figure 5-19 Crystal Lake Annual Phosphorus Budget (1,082 lbs) Model Calibration Year
(2002) Using Existing Land Use**

5.4.3.2 Keller Lake

Keller Lake appears to be “polymictic” (normally well-mixed). Phosphorus released from the sediments, therefore, does not build up in the hypolimnion. If, however, the bottom waters become anoxic (devoid of oxygen), even for short periods, internal phosphorus load from the lake sediments may occur. This is likely to occur during periods of high temperatures and low wind. In addition, elevated pH could cause the phosphorus that is bound to the iron compounds to be replaced with the abundant hydroxyl ions, thus releasing the phosphorus into the water column. The internal load of phosphorus could be transported to the entire lake as the wind increases and causes the lake to circulate.

The phosphorus mass balance was calculated based on existing land use conditions and phosphorus concentrations measured in 2002. Using the mass balance equation, the net internal loading for 2002 was calculated to be 12.8 lbs. in Keller Lake. In 2002, however, Keller Lake did not exhibit the large total phosphorus concentration increase that has been observed in previous years (see Figure 5-12). Therefore, a more typical internal load for Keller Lake would be 70.1 lbs. based on a trend fit to the observed Keller Lake total phosphorus data.

5.4.4. In-Lake Modeling Results

The estimated atmospheric, internal and watershed runoff phosphorus loads were applied to the Dillon and Rigler in-lake water quality model to predict the associated phosphorus concentration in each of the Crystal Lake basins and Keller Lake during 2002. Before determining the internal load, the closest fit to the observed spring phosphorus concentration of the individual basin during 2002 was used to choose the empirical lake water quality model. The annual internal phosphorus load discussed in the previous section, and additional watershed runoff loads were used to calibrate the model to the in-lake phosphorus concentration during the 2002 monitoring period.

5.4.4.1 Existing (2002) Land Use Conditions (Model Calibration)

The in-lake phosphorus model simulation of this watershed scenario was essentially used to validate the estimated watershed and internal loads, since actual in-lake data were collected during 2002. Figures 5-20 and 5-21 compare the simulated and the actual in-lake phosphorus concentrations for spring steady-state, early-summer peak, summer average and fall overturn for the main Crystal Lake basin and Keller Lake (Similar calibrations were performed for Bluebill Bay, Mystic Bay, Maple Island Bay, and Buckhill Bay). The modeling results are accurately predicting the observed total phosphorus concentrations for the individual basins for the time periods of interest. There were insignificant differences between observed and modeled spring steady-state phosphorus concentrations for several of the basins. Figures 5-20 and 5-21 also show the estimated impacts of internal phosphorus loading due to curlyleaf die-back and anoxic sediment release on in-basin water quality.

Reserved for:

Figure 5-20 Crystal Lake In-Lake Modeling Results for 2002 Climatic Conditions

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Figure 5-21 Keller Lake In-Lake Modeling Results for 2002 Climatic Conditions

The Metropolitan Council monitored Pond CL-21 throughout the summer of 1997. Using the calibrated P8 model and 1997 climatic conditions, the simulated flow weighted mean outflow total phosphorus concentration from Pond CL-21 was compared to 1997 observed data in order to help validate the model inflow concentrations. The observed pond total phosphorus concentration over the summer monitoring period was 171 mg/L while the model predicted a concentration of 186 mg/L for the same period. This suggests that the P8 model is reasonably representing Pond CL-21 and its watershed. The difference is likely due to the changes in land use between 1997 and 2002 (the P8 model was calibrated to 2002 data).

5.4.4.2 Full-Development Land Use Conditions/No Best Management Practices

The results of the in-lake, phosphorus model simulations indicate that the water quality in each basin of Crystal Lake will degrade as a result of watershed development, assuming no BMPs are constructed (see Figures 5-20 and 5-21). Because the Keller Lake watershed is essentially fully developed the water quality is not estimated to change significantly, as illustrated by the unchanged spring steady-state phosphorus concentration. For full-development conditions (with no BMPs), the internal loads described in Section 5.4.3 were assumed to remain constant into the future for all the Crystal Lake basins. The internal load for Keller Lake was estimated assuming a typical in-lake phosphorus trend. While these assumptions are needed to predict future water quality conditions, it is important to note that the future internal load would likely vary based on future climatic conditions (wind, temperature, precipitation) and the density of curlyleaf pondweed growth. Therefore the predicted in-lake water quality would also vary.

It is also important to note that this scenario was modeled for comparison purposes only. The cities of Burnsville, Apple Valley and Lakeville require that all new developments must include construction of stormwater detention ponds designed using NURP (National Urban Runoff Program) criteria. The expected removal from such ponds ranges from 40 to 60 percent. As stated previously, the additional phosphorus removal due to construction of NURP ponds within each new development could not be modeled with existing information; therefore, it is reasonable to expect that the in-lake phosphorus concentrations may be slightly lower than those listed above.