Beaver Lake

Strategic Lake Management Plan

Prepared for
Ramsey-Washington Metro Watershed District

March 2005

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BARR

4700 West 77th Street
Minneapolis, MN 55435-4803
Phone: (952) 832-2600
Fax: (952) 832-2601

Executive Summary

The RWMWD Board of Managers was presented with this report in June, 2003. At that meeting, the managers decided that the best course of action was to pursue Management Option 2: Public Education and On-Lot Infiltration Practices throughout Watershed BL-203 (Beaver Lake's Immediate Watershed). This option is to be pursued gradually over time, its extent depending on the results of the Carver Lake Infiltration Study and future collaborative opportunities that arise between developers and other governmental agencies working in this watershed. It should be noted that other, future management options involving in-lake treatment were not completely ruled out, however, they are not recommended for action at this time. In particular, Management Option 4 (Phased Approach with Alum/Lime Slurry Beginning with In-Lake Pilot Tests) might be of interest to the District in the future, depending on the results of current research being conducted in Wisconsin and elsewhere.

This decision was based not only on the contents of this report, but also the input of the various other parties that were consulted during the course of Phases I and II of the SLMP process. Most parties felt that although the lake's current water quality conditions were acceptable, adopting a "Do Nothing" attitude toward the lake was not.

It should be noted that since June, 2003, there has been more discussion about the Minnesota Pollution Control Agency's (MPCA's) Impaired Waters List (on which Beaver Lake appears). Also, more information about the MPCA's Total Maximum Daily Load (TMDL) guideline that dictates which lakes are listed has become available. It now appears that Beaver Lake's TMDL guideline will be a TP concentration of 60 µg/L (this is expected to be the new guideline for shallow lakes).

Because Beaver Lake has neither typically met this guideline TP concentration in the past, nor will it likely meet this guideline in the future under Management Option 2, this issue will require more attention. The next step in the process, dictated by the MPCA, is the creation of a TMDL report to be submitted to the Environmental Protection Agency (EPA) after approval by the MPCA. Kohlman and Keller Lakes (the two other lakes within the RWMWD boundary that are listed as Impaired Waters) are slated to have TMDL reports completed and submitted in 2005. The outcome of this process for Kohlman and Keller Lakes will give the District staff and its Board guidance on whether the management recommendation described in this Beaver Lake SLMP needs revision in the future.

Beaver lake Strategic Lake Management Plan

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1.0 Introduction

The purpose of this report is to summarize the work that has been done for the Beaver Lake Strategic Lake Management Plan (SLMP), Phases I and II. This document is presented here to the Ramsey Washington Metro Watershed District's (District's) Board of Directors in order to solicit feedback and to foster discussion about the final direction of the Beaver Lake SLMP. The first section of this document will provide a brief background on the District's approach to SLMPs as defined in the *Watershed Management Plan* (Plan), (Barr, 1997.). The second section will provide a brief summary of Phase I of the project (the entire Phase I report is included in Appendix A of this report.) The third section will outline the work completed for Phase II of the project. The final section will summarize the various management options that were considered for Beaver Lake and will briefly discuss the most viable of the management options and their expected costs and water quality benefits.

2.0 The SLMP Process

The purpose of any lake SLMP created for the District is three-fold:

1. To define a water quality goal for the lake.
2. To determine whether the lake currently meets its water quality goal.
3. To determine what can be done to help the lake meet its goal.

In 1997, the District assessed the recreational use and water quality level of its lakes. Water use categories (Levels 1 through 5) were assigned to each lake. Preliminary water quality goals were established for each lake per the MPCA. The Plan states that each lakes' water quality goals may be changed during the creation of the SLMP.

Plan goals are in terms of Total Phosphorus (TP), Chlorophyll *a* (Chl *a*) and Secchi Disc Transparency (SD).

3.0 Phase I

Phase I began with gathering background information needed to embark on Beaver Lake's SLMP.

Beaver Lake was classified as a "Level 3" lake (for fishing) and was assigned a preliminary water quality goal of 60 µg/L Total Phosphorus (summer average concentration). Because the lake at that time had a summer average TP concentration well above 60 µg/L, this goal was described as "Restore". Table 1 shows the preliminary goals outlined in the Plan for Beaver Lake, as well as the lake's actual conditions in 1999.

Table 1 Beaver Lake's Water Quality Goals and 1999 Conditions

	Goal As Shown in 1997 Plan	1999 Summer Average Conditions
Total Phosphorus (TP)	60 µg/L	120 µg/L
Chlorophyll *a* (Chl a)	32 µg/L	20.5 µg/L
Secchi Disc (SD)	2.6 feet	5.2 feet

First, the water quality goal was assessed to determine whether it was, in fact, a reasonable goal considering the desired future of the lake. All of Beaver Lake's historical water quality data from the past 20 years were reviewed to provide an idea of the typical state of the lake. Figure 1 shows the growing season (June through August) TP concentrations in the lake from 1984 to 2002. Two specific TP concentrations are indicated on the graph, showing the lake's approximated TP concentration prior to human settlement (25 µg/L, Vighi and Chiaudani, 1985) and the MPCA's average TP concentration for "minimally impacted" lakes in Beaver Lake's ecoregion (61 µg/L Wilson and Walker, 1988). Figures 2 and 3 show the growing season (June through August) SD transparency and Chl *a* concentrations, respectively, from 1984 to 2002.

Growing Season (June through August) Mean Total Phosphorus Concentrations

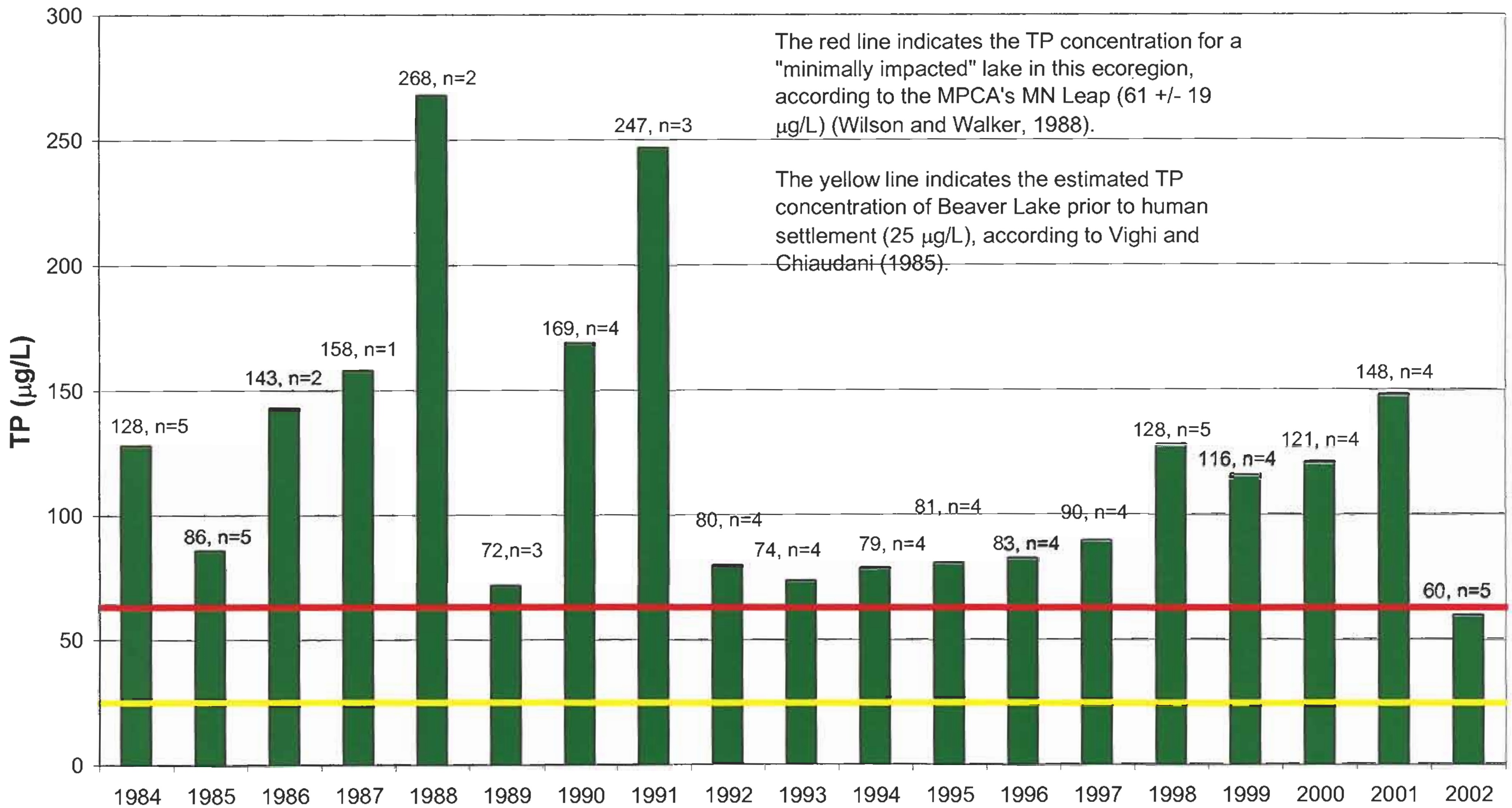
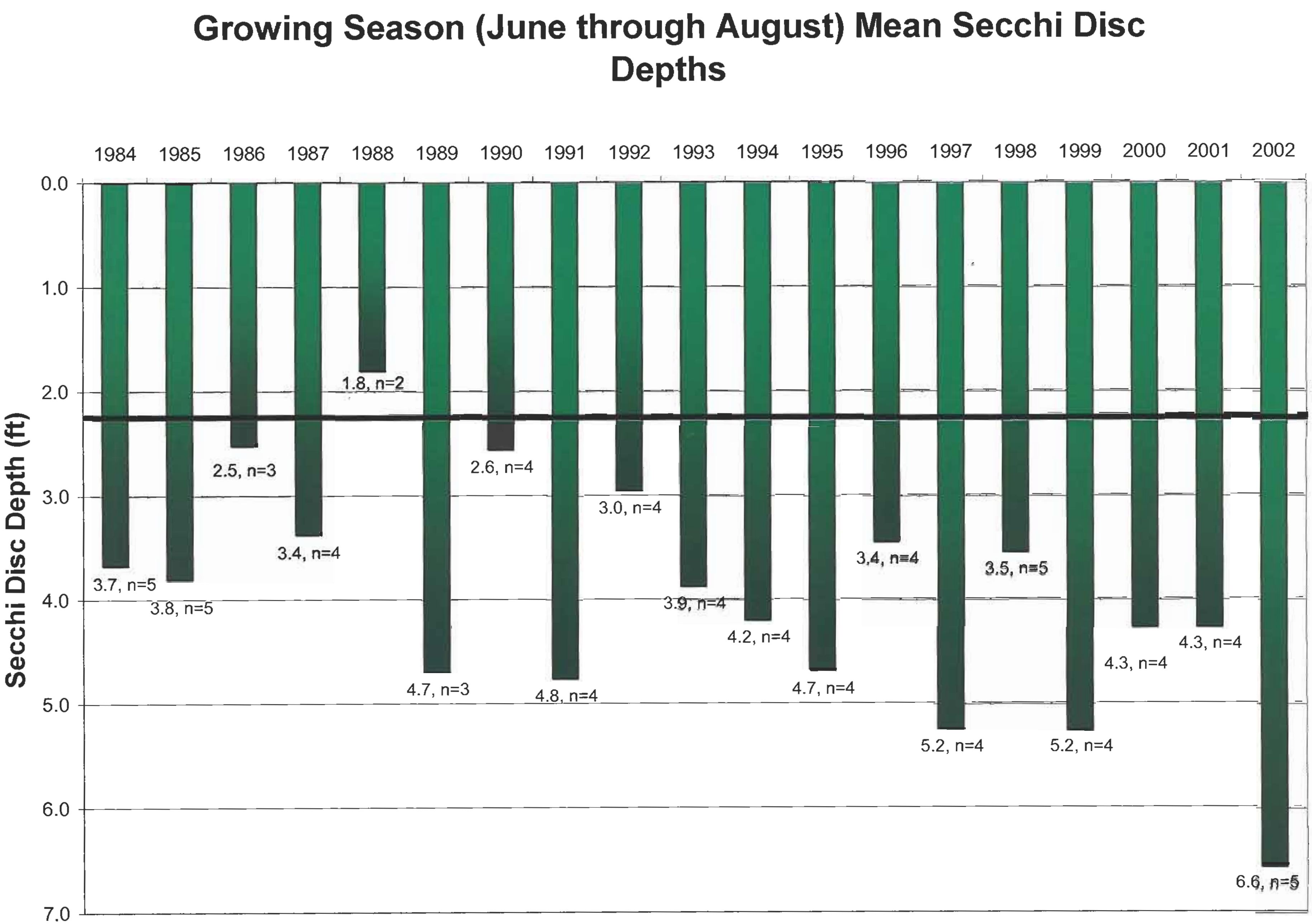


Figure 1



Growing Season (June through August) Mean Secchi Disc Depths
Secchi Disc Depth (ft)
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
3.7, n=5
3.8, n=5
2.5, n=3
3.4, n=4
1.8, n=2
4.7, n=3
2.6, n=4
4.8, n=4
3.0, n=4
3.9, n=4
4.2, n=4
4.7, n=4
3.4, n=4
5.2, n=4
3.5, n=5
5.2, n=4
4.3, n=4
4.3, n=4
6.6, n=5

Figure 2

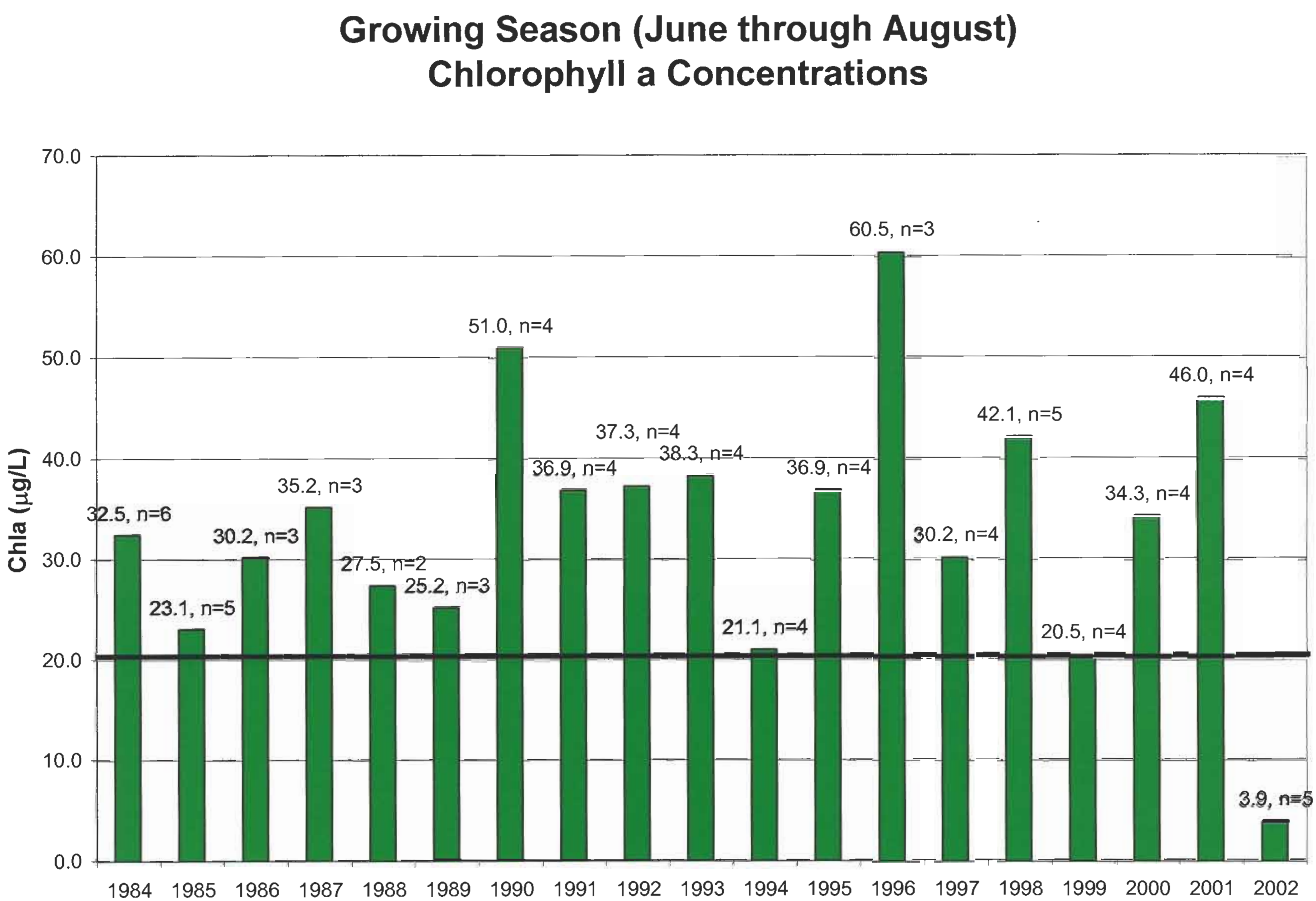

Growing Season (June through August)
Chlorophyll a Concentrations
Chla (µg/L)
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
32.5, n=6
23.1, n=5
30.2, n=3
35.2, n=3
27.5, n=2
25.2, n=3
51.0, n=4
36.9, n=4
37.3, n=4
38.3, n=4
21.1, n=4
36.9, n=4
60.5, n=3
30.2, n=4
42.1, n=5
20.5, n=4
34.3, n=4
46.0, n=4
3.9, n=5
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002

Figure 3

The lake's water quality varies widely from year-to-year. In all but one (2002) of the past 20 years, the preliminary TP goal for the lake (60 µg/L) is not met. WQ Stat was used to perform nonparametric seasonal Kendall analyses (Philips et al., 1989) to determine whether Beaver Lake's water quality has been significantly improving or declining over the past 10 years (1991 to 2001). The results of this analysis indicate that the SD water transparency of Beaver Lake has improved significantly (95 percent confidence interval) over this period of record. On average, the lake's transparency has increased annually at a rate of 0.07 feet per year. Hence, the lake's water transparency has been, in general, slightly increasing during the past 10 years. Chl *a* has also been significantly decreasing (90 percent confidence interval) during this period, at a rate of 0.8 µg/L/year. By contrast, TP has been increasing (95 percent confidence interval) at a rate of 4.6 µg/L/year during this period. In order for an overall change in water quality to be considered significant, all three water quality parameters must have the same trend. Therefore, no significant overall trend in water quality can be distinguished for Beaver Lake over the past 20 years.

The relationship between Beaver Lake's SD and TP was explored (Figure 4) to determine the expected benefit to the lake (in terms of increased summer transparency) that would result from reducing the lake's summer TP concentration. The fact that, in 1999, the lake's summer average TP concentration was 120 µg/L indicated that if Beaver Lake met its TP goal (60 µg/L), it would experience a 45 percent increase in transparency (moving from 3.1 feet to 4.5 feet, in climatic conditions similar to 1999). If the lake's water quality degraded further, however, reducing the lake's TP by greater percentages would result in a less efficient reduction in transparency due to the asymptotic relationship between TP and SD.

Minnesota Department of Natural Resources (MnDNR) staff were consulted about the current state of Beaver Lake's fishery. One of their most notable pieces of information was a recent study showing the relationship between water transparency and the health of the fishery. The study involved over 6,100 fish surveys from Minnesota lakes conducted since 1980. The data showed (Figure 5) that as SD decreased below 3 feet, the Centrarchid population (bluegills, green sunfish, hybrid sunfish and pumpkinseed sunfish) crashed and were replaced by rough fish (carp, suckers, bullheads). This change in fish population represented a dramatic decline in the quality of the fishery in these lakes. Because Beaver Lake's summer average SD transparency was close to 3 feet in 1999 (the year that was monitored for the Phase I modeling effort), this was a cause for potential concern.

Beaver Lake Secchi Disc Depth-TP Relationship

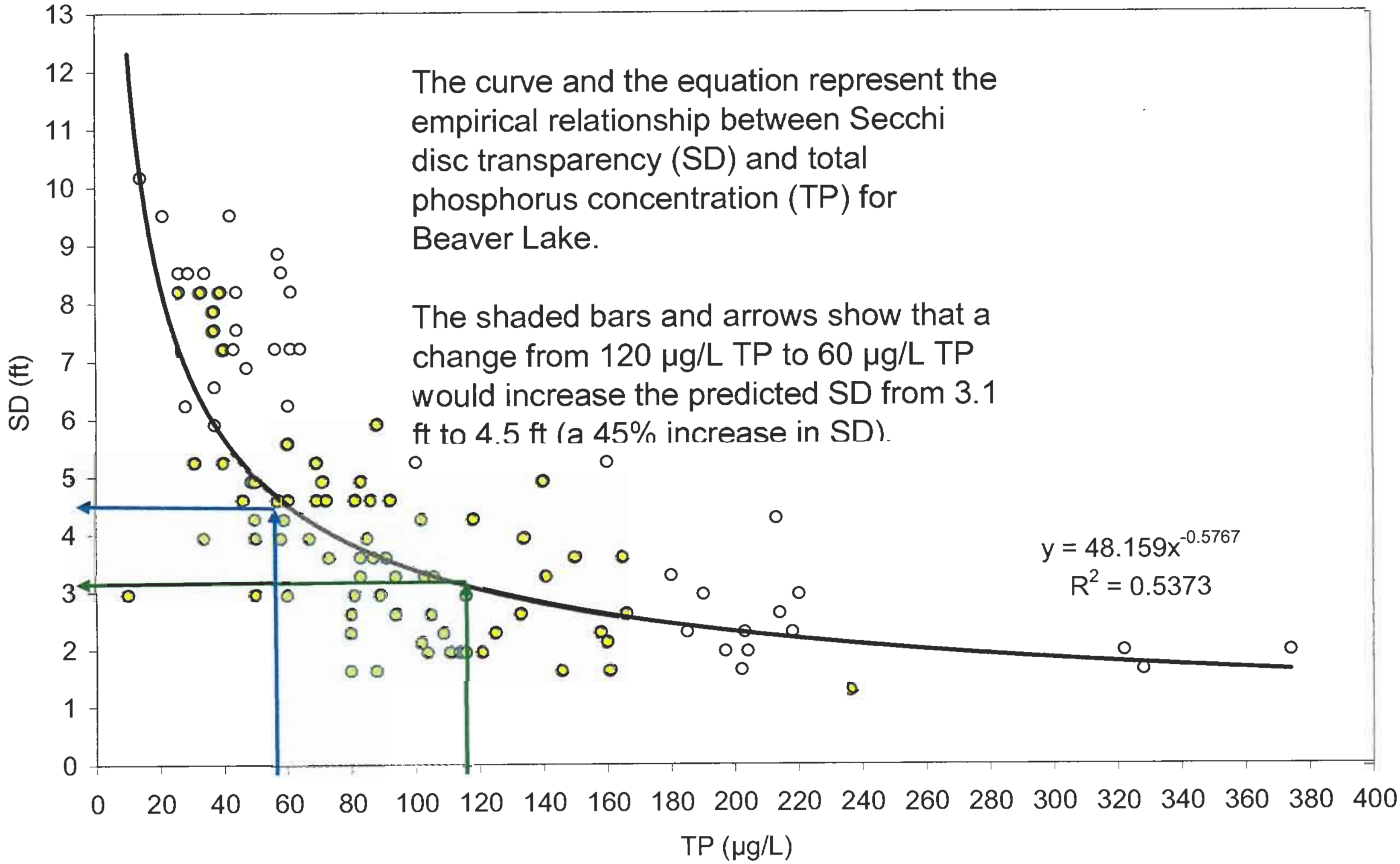
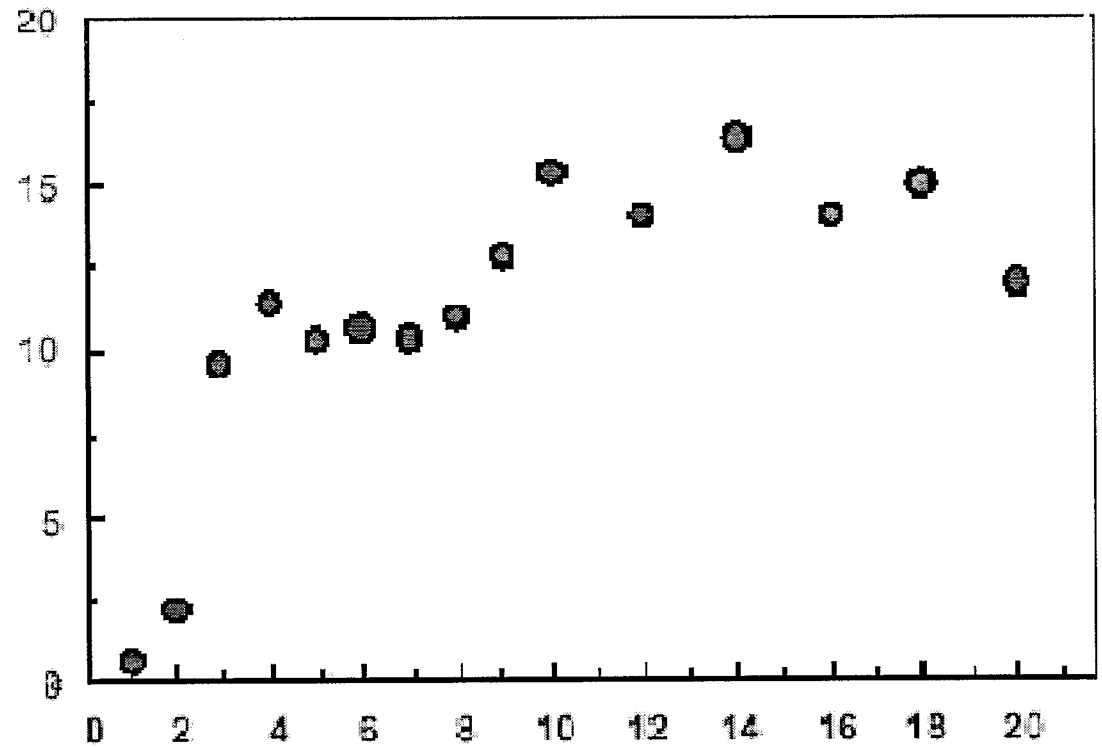


Figure 4

Fisheries Quality vs. Water Transparency

Median Catch of Small Centrarchids (# of Fish Per Trap Net)



Secchi Disc Transparency (ft)

Figure 5

The reason for this “crash” is not known- the fisheries data had already been collected and was plotted, revealing this relationship. Furthermore, whether the change in transparency caused the change in fish population or the change in fish population caused the change in transparency (rough fish are known to stir up lake bottoms) is unknown. Regardless, it is true that turbid waters favor rough, undesirable fish and that clearer waters generally support a more varied fish population. Therefore, this SD threshold is upheld as a potential guidepost for this project.

Also, the MnDNR has recommended that the average water quality for a Class 40 lake be a TSI_{SD} (Trophic State Index in terms of SD transparency) of approximately 62 or lower (i.e., a summer average SD transparency of about 5 feet or greater). The recommendation is based upon the water quality needs of the fishery found in a Class 40 lake. Currently, Beaver Lake’s water quality does meet this recommendation based upon 1999 data. However, there are recent years that Beaver Lake has not met the MnDNR’s recommendation (1996 and 1998, for example, with 3.4 feet and 3.5 feet summer average SD, respectively).

Figure 6 revisits the information presented in Figure 4, focusing on a 3-foot SD transparency and using different colors to indicate the month that each data point was collected. As shown on the graph, a TP concentration of 75 mg/L appears to be an important threshold. At TP concentrations less than 75 mg/L, SD is always greater than or equal to 3.0 feet. At TP concentrations greater than 75 mg/L, 44 percent of SD measurements are greater than or equal to 3.0 feet. At TP concentrations greater than 75 mg/L, 56 percent of SD measurements are less than 3.0 feet, and all of these measurements are from July, August and September- all important recreational months on the lake.

It was apparent that different local agencies may have very different ideas about the desired management strategy of Beaver Lake, and so an inter-agency meeting was called to discuss an appropriate goal. The participating agencies were:

- Ramsey County Environmental Services
- Ramsey County Parks and Recreation
- St. Paul Parks and Recreation
- Maplewood Parks and Recreation
- MPCA
- Metro Region DNR
- St. Paul Public Works
- City of Maplewood
- RWMWD staff

Beaver Lake SD-TP Relationship
With Color-Coded Months, 1984-2002

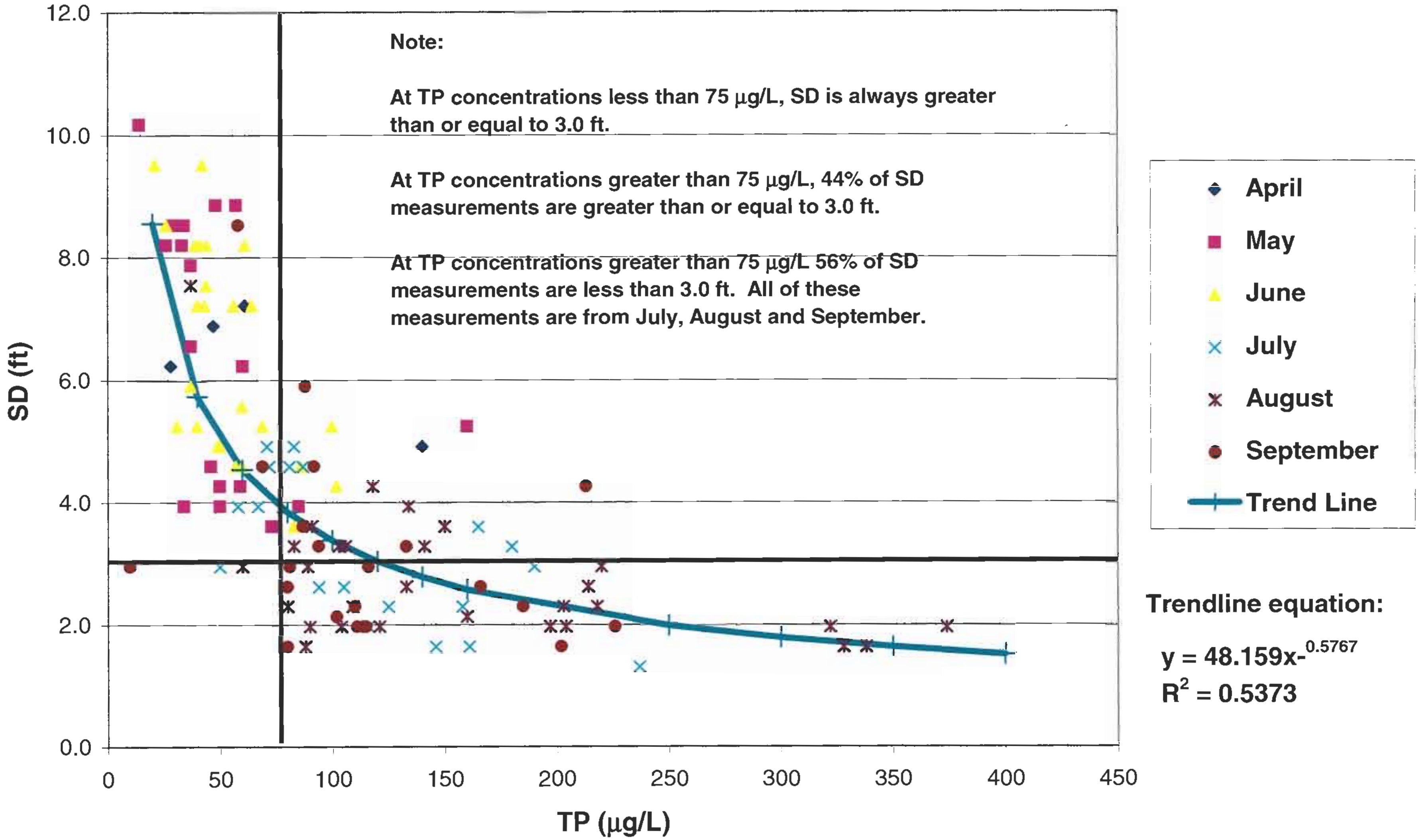


Figure 6

Representatives of most of these organizations attended the September 5, 2001 meeting to discuss their goals and priorities for Beaver Lake, given the information presented in the report. All parties agreed that while significantly improving the water quality of Beaver Lake was not a reasonable approach, keeping the lake at its current level of water quality was important. Specifically, it was agreed that the lake's transparency should be kept at or above 3 feet (considered a threshold level for the well-being of the lake's fish communities). All parties deemed this goal to be very important, justifying some action in either the lake's watershed and/or within the lake itself, to reduce total phosphorus (TP) loads in the lake. While no water quality goal was finalized, Phase I proceeded with this possible goal in mind.

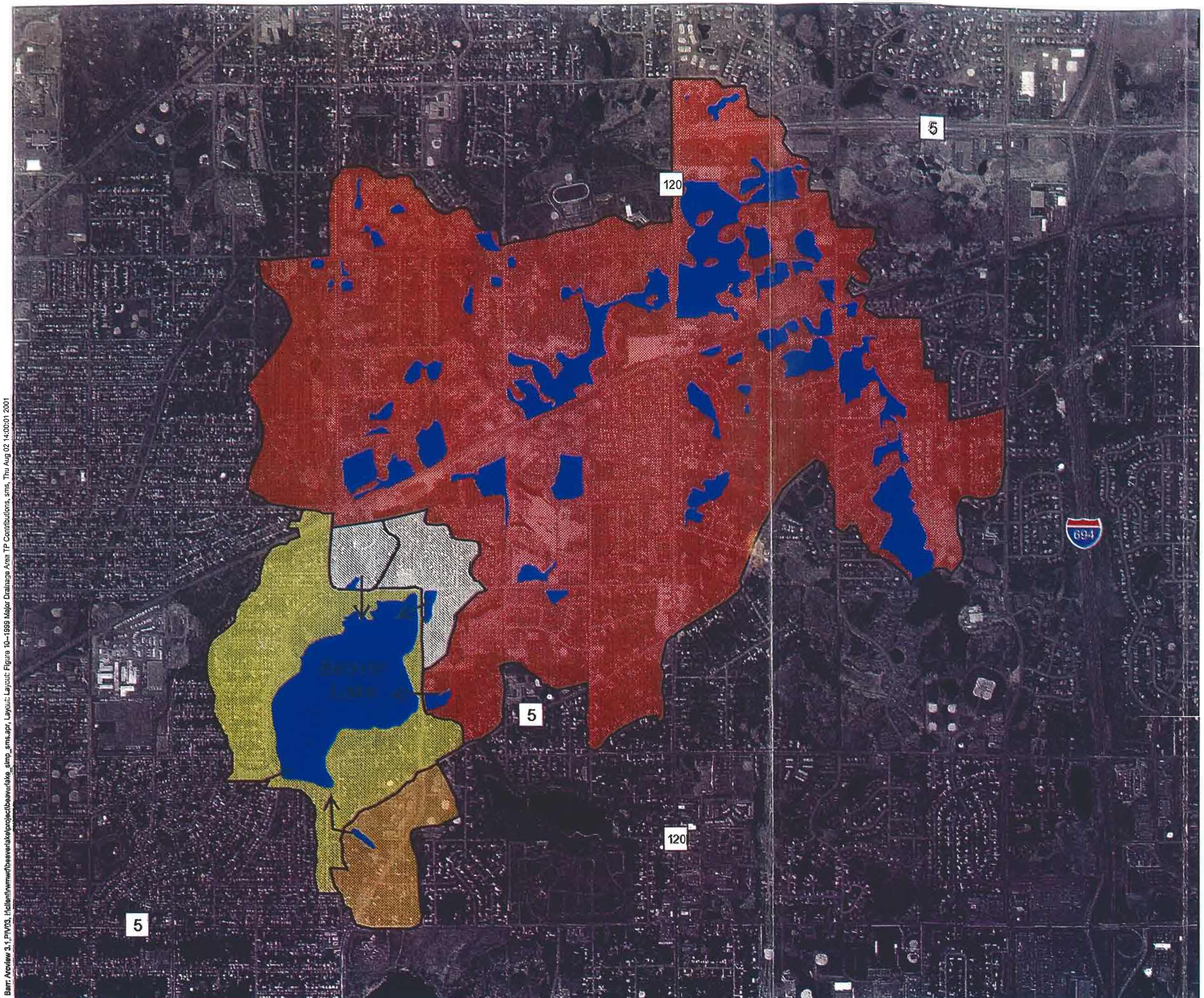
Three in-depth studies of the lake and its watershed were conducted: a macrophyte survey (2001), a watershed runoff study (1999) and an in-lake water quality study (1999).

The macrophyte study revealed much about the types of plants growing in Beaver Lake. The results are described in detail in the Phase I report. Of particular interest were the following results:

- Native coontail was the most abundant species.
- No Eurasian Milfoil was found.
- Non-native curly-leaf pondweed was present at 19 percent of the sampling locations.
- Native free-floating species (duckweed) was a large component in the plant community. (These plants can use nutrients from the water column).

The watershed runoff study incorporated many different types of watershed information into a P8 model of the Beaver Lake watershed. This model and a detailed account of its results are presented in the Phase I report (Barr, 2001). Figure 7 shows the relative contributions of total phosphorus (TP) from the five major drainage networks in the Beaver Lake watershed, prior to treatment in ponds and wetlands en route to the lake. Although the large watershed network in the northeast contributes a large amount of TP to the lake, it is mostly in soluble (hence, unsettleable) form by the time it reaches Beaver Lake due to treatment in the subwatershed's ponds and wetlands.

The in-lake water quality study was conducted in order to evaluate how the watershed loads of water and TP affected the water quality of Beaver Lake. After applying both published lake equations as well as a tailored mass balance spreadsheet model, we concluded that internal loading of TP could contribute up to approximately 25 percent of the total TP load to Beaver Lake, on average. Whether this load comes from the lake sediments or from a mid-summer die-off of macrophytes in the lake (Curlyleaf Pondweed, for example) was unknown.



Flow Direction
Ponds

Major Drainage Area
TP Contributions
(Percent of Total Load)

- 1%
- 2%
- 21%
- 4%
- 71%

N

1500 0 1500

Scale in Feet

Figure 7

BEAVER LAKE SUBWATERSHED
MAJOR DRAINAGE AREA TP
CONTRIBUTIONS FOR 1999
Ramsey-Washington Metro Watershed District

Ramsey-Washington Metro Watershed District

BARR

4.0 Phase II

The scope of the project's second phase was:

- To gather more evidence to confirm or deny the impact of Beaver Lake's internal load.
- To determine the release rate of TP from the lake's sediments.
- To calculate a dose of alum/lime slurry to inactivate the TP release from the sediments.

4.1 Evaluating the Internal Load to Beaver Lake

Detailed in-lake water quality monitoring data was collected from the lake from May to September, 2002 at various water depths. Figure 8 shows the 2002 TP concentration in Beaver Lake's epilimnion (surface waters) during the season. The summer average TP concentration was 60 µg/L. This was the first time that the lake had (according to the monitoring data) met its preliminary TP goal as proposed in the Plan.

Isopleth diagrams of Beaver Lake's 2002 water quality are shown in Figures 9 through 11. Isopleth diagrams represent the change in a parameter relative to depth and time. For a given time period, vertical isopleths indicate a complete mixing and horizontal isopleths indicate stratification. These diagrams can be particularly useful in visually detecting the presence or absence of an internal load of phosphorus in a lake. Figures 9 through 11 indicate that the lake experienced an internal load from its sediments in late-July/early-August. Heavy rains in late-August brought relatively clean water into the lake, dropping the lake's TP dramatically. In-lake modeling of 2002 indicates that the lake also may have been impacted by curlyleaf die-off in early-July.

The release rate results (presented below) further helped to confirm the presence and magnitude of the lake's internal load from its sediments. Incorporating this information into the in-lake water quality model showed that internal load from the lake's sediments increased the lake's summer average TP concentration by ~20 percent in 2002 and by ~50 percent in 1999. The degree of internal load to the lake appears to be heavily dependent on climatic conditions.

Beaver Lake Epilimnetic TP Concentration
2002 Monitoring Data

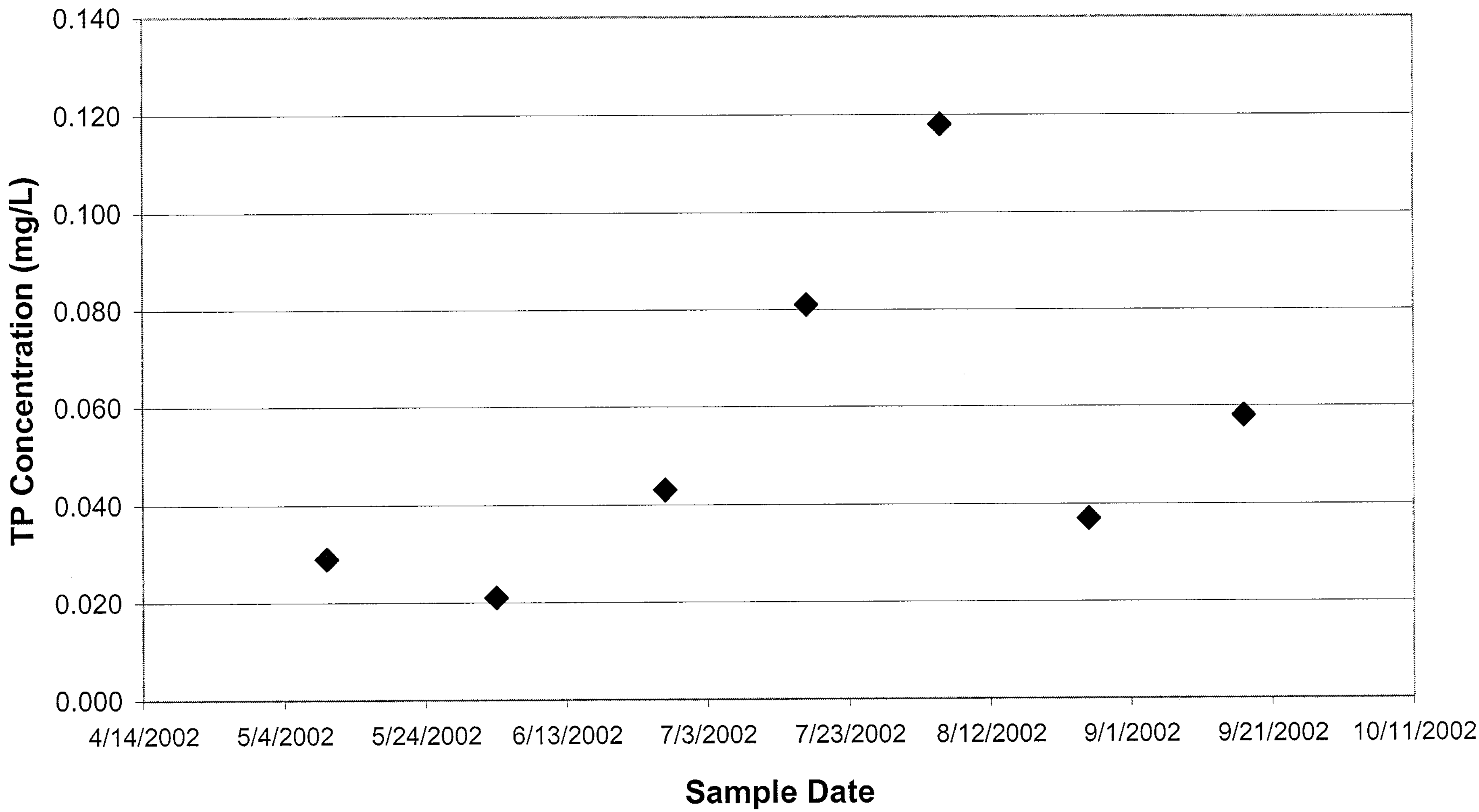
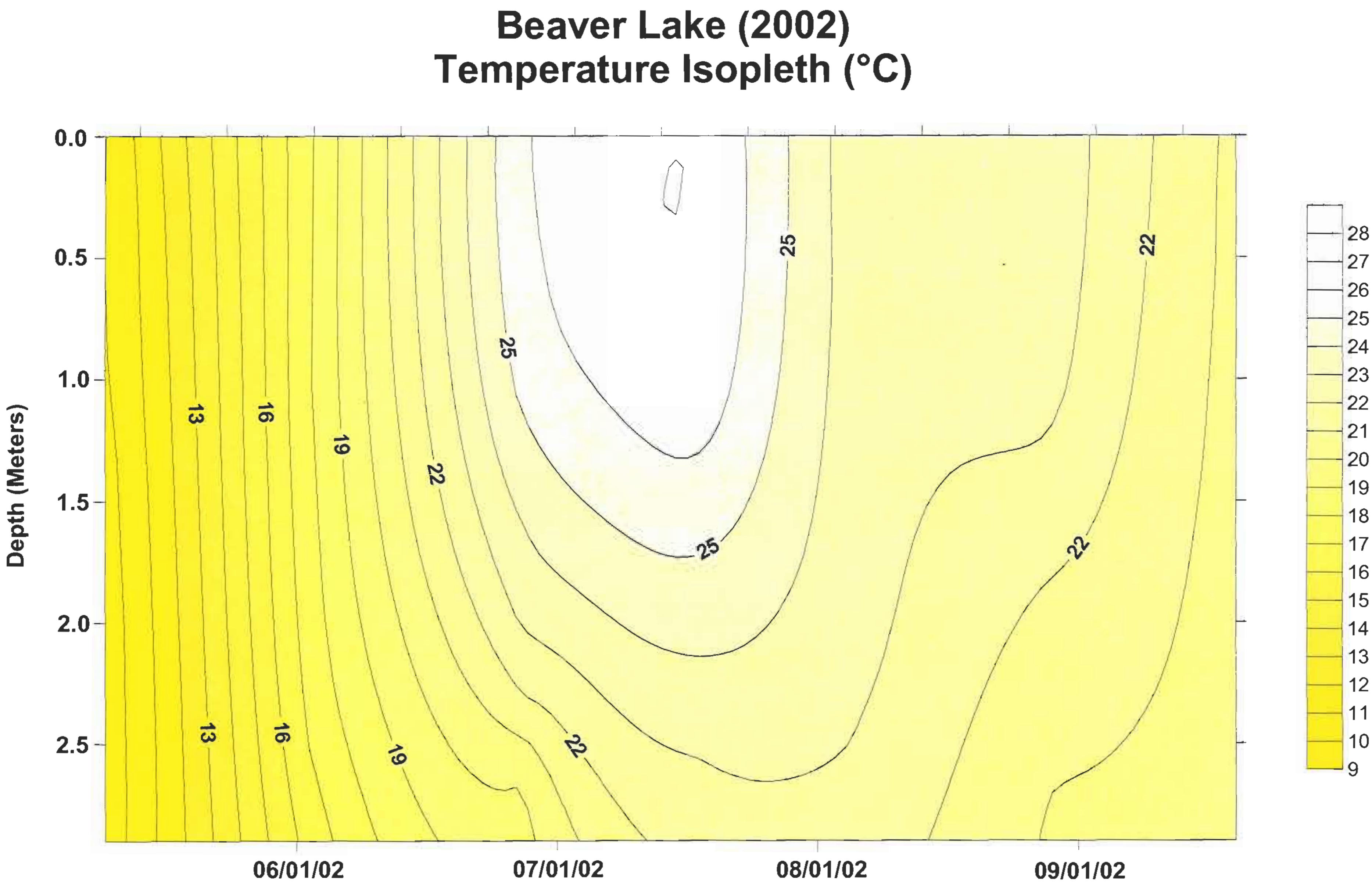


Figure 8



Beaver Lake (2002)
Temperature Isopleth (°C)
Depth (Meters)
0.0
0.5
1.0
1.5
2.0
2.5
06/01/02
07/01/02
08/01/02
09/01/02
13
16
19
22
25
28
27
26
24
23
21
20
18
17
15
14
12
11
10
9

Figure 9

Beaver Lake (2002)
Dissolved Oxygen Isopleth (mg/L)

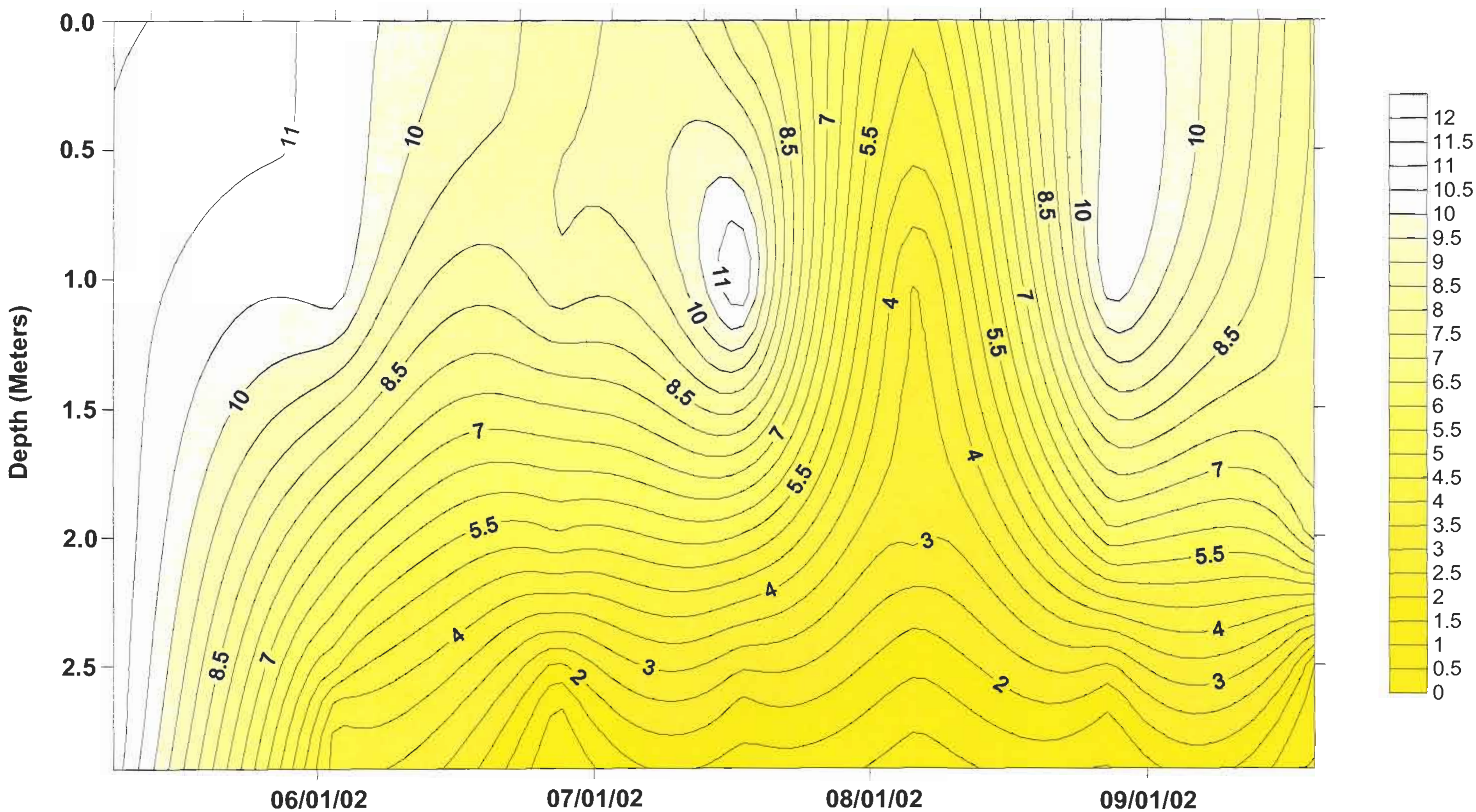


Figure 10

Beaver Lake (2002)
Total Phosphorus Isopleth (µg/L)

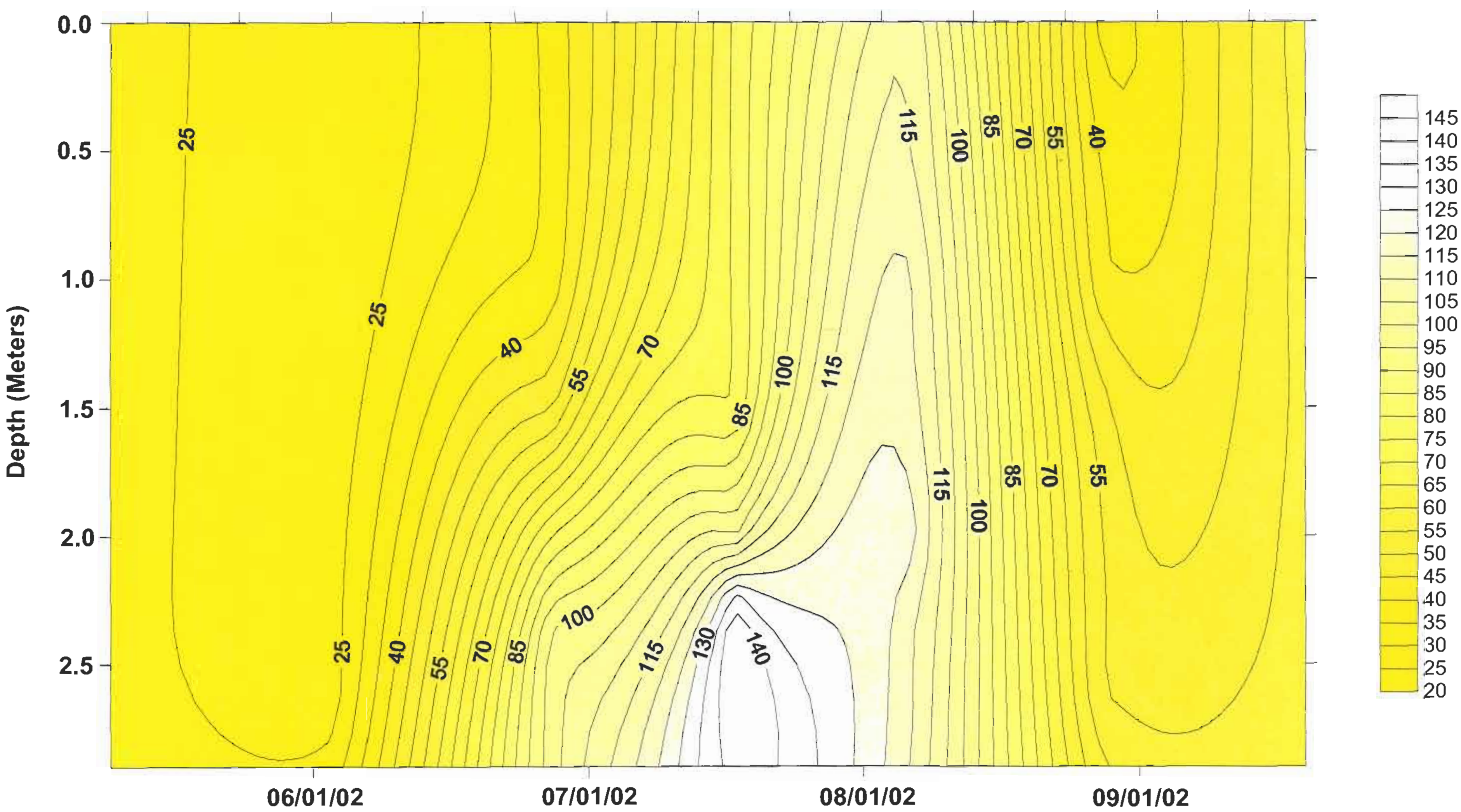


Figure 11

4.2 Sediment Core Microcosm Experiments

The sediment core experiments (Figure 12) represent a significant part of the Phase II effort. The purpose of these experiments was to calculate the actual release rate of extractable phosphorus from Beaver Lake's bottom sediments. The extractable phosphorus is the phosphorus that can travel from the sediments up into the water column, feeding algae and adversely affecting water quality. By determining its true rate of release, a much more reliable estimate of the magnitude of Beaver Lake's internal load can be made.

The sediment core experiments also served to test: (1) the effectiveness of different alum/lime slurry doses in controlling the phosphorus release from the lake's sediments; and (2) the stability of an alum/lime floc layer on top of the lake's sediments (Figure 13) (this can give an indication of the treatment's longevity).

Table 2 and Figure 14 show some of the results of the sediment core experiments.

Table 2 Results of the Sediment Microcosm Experiments

Microcosm	Sediment Total Phosphorus Release Rate
Control 1	29 mg/m^2/day
Control 2	35 mg/m^2/day
Treated 1- 25:1	8.4 mg/m^2/day
Treated 2- 25:1	8.1 mg/m^2/day
Treated 3- 50:1	2.4 mg/m^2/day
Treated 4- 50:1	3.4 mg/m^2/day

A 50:1 alum dose was deemed the most appropriate for Beaver Lake (should that management option be selected) because it would provide a 90 percent reduction in phosphorus release rate, and a 80 percent reduction in the phosphorus content of Beaver Lake's sediments. This is the dose that was assumed in the cost estimate for the treatment.

Beaver Lake Sediment Core Experiments: The Microcosms

Figure 12

Beaver Lake Sediment Core Experiments:
Sediments with Alum/Lime Floc Layer

Figure 13

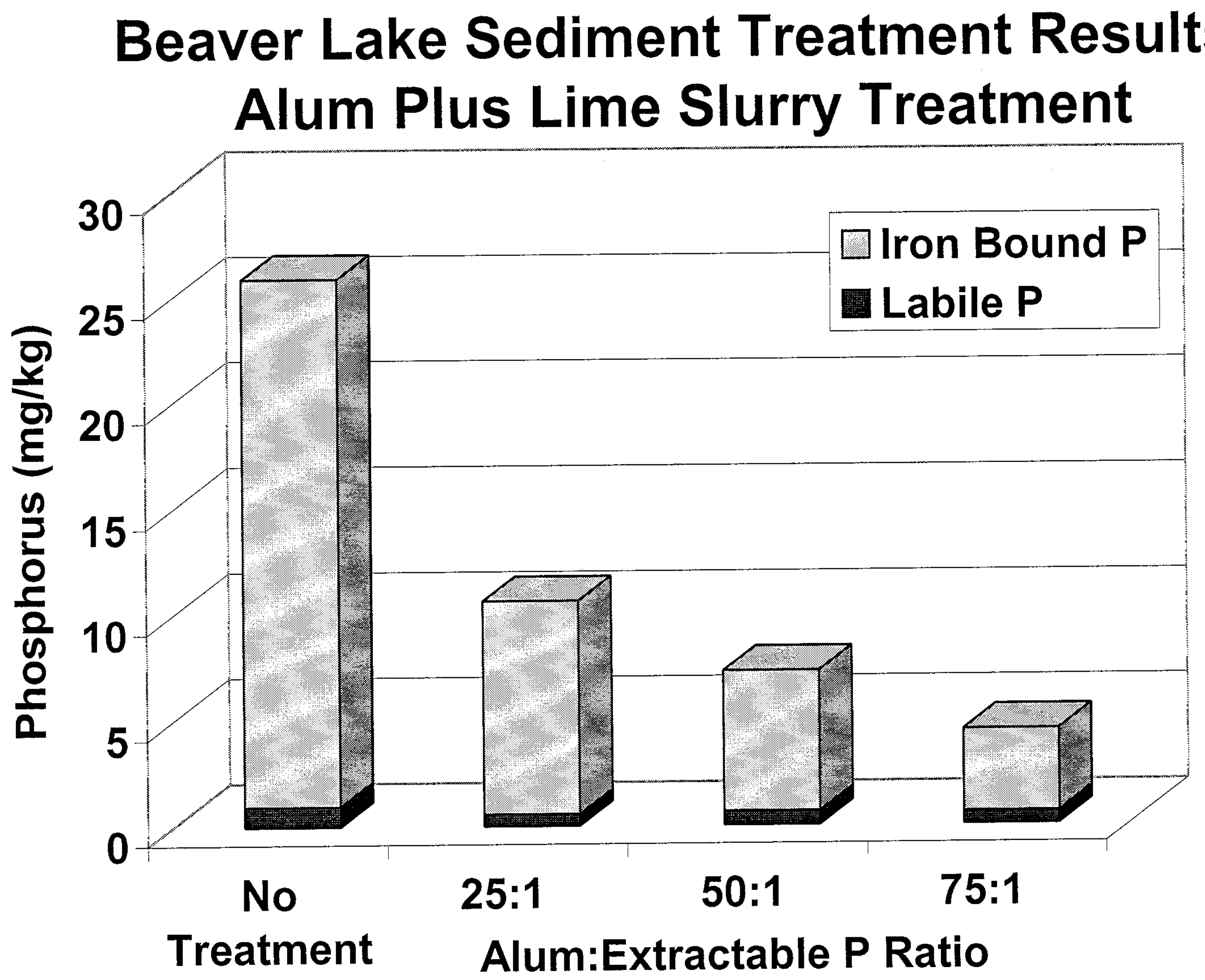

Beaver Lake Sediment Treatment Results:
Alum Plus Lime Slurry Treatment
Iron Bound P
Labile P
Phosphorus (mg/kg)
30
25
20
15
10
5
0
No Treatment
25:1
50:1
75:1
Alum:Extractable P Ratio

Figure 14

5.0 Management Options for Beaver Lake

Many different management options were considered for Beaver Lake. Several potential options were ruled out early in the process:

- **Mechanical harvesting of Curlyleaf pondweed**. Because native coontail is so pervasive in Beaver Lake, it would also be cut up in the process. Because native coontail can grow from fragments, it would likely become much more dense and choke out other kinds of desirable vegetation. Also, harvesting curlyleaf only combats a small part of Beaver Lake's internal load problem.
- **Hand harvesting of curlyleaf** Harvesting by hand would be an extremely time-intensive process that would at best, not affect the internal load from the sediments, and at worst, increase the load due to disturbing the sediments.
- **Using Barley straw as an algal growth inhibitor.** Although this technique has gained some interest in recent years, the EPA has placed it under the "pesticide" category and it can't be used until further study is completed.
- **Treating curlyleaf with herbicides.** This strategy would require treatment every single year. If a year is skipped curly leaf can easily invade, beating out native plant populations. Also, herbicides are largely non-selective, killing both nuisances and desirable species simultaneously.
- **Watershed load reductions.** Watershed load reductions through BMPs in the northeast watershed network are not feasible because: (1) the TP is largely in unsettlable form by the time it reaches the lake; and (2) alum treatment of inflows would not be feasible due to the large volumes of inflowing water and the cost to treat it.
- **Dredging the lake to prevent internal TP load from sediments and to limit the growth of curlyleaf**. This is clearly not a reasonable option in a fishing lake. Also, deeper lakes can also have internal loading problems.
- **Aerating the lake to keep sediments oxygenated, reducing the potential for internal load.** This is generally not a viable option in shallow lakes, as it tends to stir up the sediment, creating the potential for internal load. Aeration in shallow lakes during winter months is acceptable for fisheries health, however, as water quality is a lesser concern at these times of year.

Four potential "finalists" are presented here.

5.1 Management Option 1: Do Nothing

The Do Nothing option simply involves the continuation of current activities surrounding the lake and its watershed.

5.2 Management Option 2: Public Education and On-Lot Infiltration Practices throughout Watershed BL-203 (Beaver Lake's Immediate Watershed)

In response to questions raised at the inter-agency meeting, a second round of more detailed watershed modeling was conducted for the watershed immediately adjacent to Beaver Lake (BL-203) (Figure 15). The runoff from this watershed represents 34 percent of the overall TP load to the lake and receives very little treatment before reaching the lake. Therefore, it seemed a likely candidate for BMPs that could positively impact Beaver Lake's water quality. Portions of this study (presented in the *Beaver Lake SLMP: Phase I Summary and Phase II Recommendations Report* (October, 2001) are excerpted in Appendix B of this report because they outline one of the management options for Beaver Lake.

Essentially, after an extensive re-evaluation of BL-203's subwatersheds, it appeared that the best course of action (in terms of watershed management) may be to pursue public education and on-lot infiltration practices throughout BL-203 rather than undertake an extensive capital improvement project to reduce TP loads to the lake. Because capital improvement projects, such as the infiltration trenches described for subwatershed BL-203f and rainwater gardens throughout subwatersheds, BL-203c through BL-203e are likely to be very expensive and result in a fairly small reduction in the overall TP load to the lake (~5 percent to 20 percent)[1] , it may be wise to turn to in-lake treatments of Beaver Lake to make a bigger impact on the lake's water quality, if that is the ultimate goal for the lake.

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[1] The actual magnitude of treatment effectiveness depends on the climatic conditions of any given year (particularly the amount and intensity of the rainfall events throughout the year, and the extent to which infiltration projects are conducted throughout the subwatersheds. A 20 percent reduction in the lake's summer average TP concentration should be considered the absolute maximum that this option could achieve.

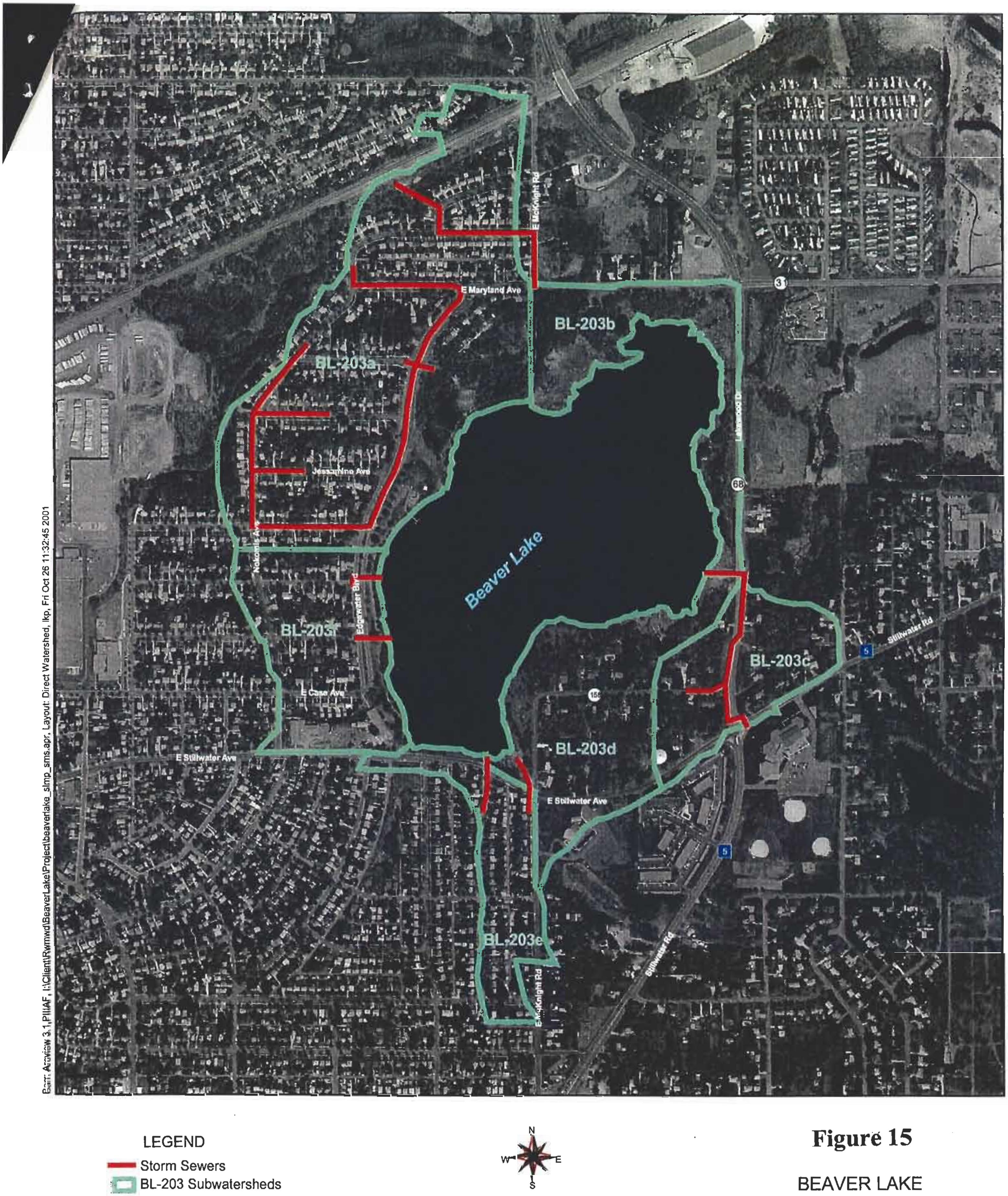

Figure 15

BEAVER LAKE
DIRECT WATERSHED
Ramsey Washington
Metro Watershed District

5.3 Management Option 3: In-Lake Alum/Lime Slurry Treatment of Beaver Lake's Internal Load

In-lake treatment has the benefit of directly addressing a significant source of Beaver Lake's summer TP- the internal load from both curlyleaf die-off and sediment loadings. While alum has been used as a lake management tool for decades, the addition of lime to control internal TP loads is a relatively new phenomenon. Detailed background information on this treatment technique is included in Appendix C of this report.

Sweetwater Technologies estimates that an alum/lime slurry treatment of Beaver Lake would cost approximately $92,500.

5.4 Management Option 4: Phased Approach with Alum/Lime Slurry Beginning with In-Lake Pilot Tests

Because alum/lime slurry treatments are relatively new and, therefore, potentially invite a higher level of risk than other, more known lake treatments, a 3-year pilot study is recommended for the lake. This phased approach would involve both treated and untreated (control) test plots in the lake from which duplicate sediment cores can be extracted and studied.

Phase I of the study would be to treat test plots with a 50:1 alum dose. Phase II would be an annual monitoring program involving sediment cores taken from the test plots. The location of the alum/lime layer in the sediment cores, as well as the extractable phosphorus, aluminum-bound phosphorus and the calcium-bound phosphorus present in the 0-4 cm, and 5-8 cm depth would be measured and recorded. If the alum/lime layer has sunk deeper than 8 cm, testing could also be conducted at deeper levels.

If the floc settles and the extractable phosphorus content of the sediment at or above the floc layer warrants additional treatment to achieve the lake's goals then additional treatment would be tested and/or recommended for the whole lake. The results of the test plots analyses will determine whether the 50:1 dose will accomplish the District goal or whether additional alum and lime may be needed to compensate for unforeseen conditions in the lake. During these 3 years, a continuation of the monitoring program for the lake, in terms of SD, TP and Chl *a* would be extremely helpful.

Sweetwater Technologies estimates that an alum/lime slurry treatment of a 1-acre test plot at Beaver Lake would cost approximately $8,200. The sediment core collection and analysis of the cores for mobile total phosphorus is estimated to total around $3,500 per year. The estimate assumes around

$1,900 in core collection/extrusion labor, $400 for sample expenses, $200 in lab analyses costs, and around $1,000 in data evaluation and letter report preparation costs.

5.5 Pros and Cons of Management Options 1, 2 and 3

5.5.1 Pros and Cons of Management Option 1: Do Nothing

The main “pro” for Option 1 is that there is no immediate monetary cost. If the status quo is deemed acceptable, then the “Non Degradation” goal could be considered to be met. This option may be a bit risky in the long run, however, if status quo watershed controls do not sufficiently hold the lake at its current water quality; if a lake’s TP is high, more TP needs to be removed to show a significant increase in transparency. Also, it is quite possible, given Beaver Lake’s water quality history that the lake would have years where it’s summer average SD will be less than 3 feet—a potentially important transparency threshold for the fisheries’ health.

It is hard to say what the future water quality of Beaver Lake would be if no management action is taken, based on the conflicting results of the trend analysis (described as a part of the Phase I summary in this report). Even if a goal of 75 µg/L TP is set for the lake, there would likely be several years where the lake does not meet its goal.

5.5.2 Pros and Cons of Management Option 2: Public Education and On-Lot Infiltration Practices Throughout Watershed BL-203 (Beaver Lake’s Immediate Watershed)

This option offers many potential benefits. Educating the public about how their activities affect their lake while simultaneously improving water quality is a desirable combination that could work well in Beaver Lake’s immediate subwatershed. On-lot infiltration practices have gained much attention of late. There are several wonderful resources available now (including Henderson et al., 1999 and Barr Engineering and Metropolitan Council, 2001) that can guide park personnel and private landowners toward developing basic, aesthetically pleasing, small-scale projects that can help to improve the water quality of Beaver Lake. Some local examples in Maplewood could provide further guidance.

The implementation of these education and infiltration projects, however, requires long-term commitment, both in terms of public contact and site maintenance (all too often neglected in these types of projects). Ultimately, these projects can be as (or more) expensive as in-lake treatments, with less noticeable improvements in lake water quality. The estimated benefit of implementing on-lot infiltration practices in Beaver Lake’s immediate watershed is a reduction in the lake’s summer average TP concentration on the order of 5 to 20 percent, depending on the climatic year and how extensive the infiltration practices are. Those “cons” notwithstanding, this option could still be considered a way of meeting a “Non Degradation” goal for Beaver Lake. If a goal of 75 µg/L were set for the lake, these practices could be expected to help the lake meet its goal under some, but not all years.

5.5.3 Pros and Cons of Management Option 3: In-Lake Alum/Lime Slurry Treatment of Beaver Lake’s Internal Load

This option has the potential benefit of targeting both of Beaver Lake’s assumed internal loads that significantly degrade water quality in the summer: Curlyleaf pondweed die-off in late-June, and the internal load from the lake’s sediments in late-July/August. The sediment core microcosm experiments have shown that this type of treatment technique is a viable option for the lake that would likely cause a noticeable increase in the lake’s transparency immediately after treatment and for approximately 10 years to follow.

Although alum is a tried and true lake management treatment, the alum/lime slurry combination is a new technique. Lime is effective in holding alum down in a cohesive layer over the sediments, where it might otherwise be resuspended in a shallow lake’s recurrent mixing action. Also, observations have indicated that lime may be effective in limiting the growth of curlyleaf, while allowing the growth of native plant species. Thus, this treatment could improve water quality in the short term as well as in several years to come by controlling the growth of this invasive species. The cost of an alum/lime treatment (estimated at $92,500) is relatively affordable, considering the expected water quality benefit. An alum/lime slurry treatment is expected to reduce Beaver Lake’s summer average TP concentration by anywhere from 20 percent to 50 percent, depending on climatic conditions in any given year. If a goal of 75 µg/L TP were set for the lake, this option would likely help the lake meet its goal during most years.

Although alum/lime slurry treatments are not expected to have any negative impacts on lake biota, it is important to remember that this is a new technology. It has been used only in a handful of lakes in Canada and the United States, and its actual treatment mechanism is currently unknown (though many hypotheses exist). Consequently, it is impossible to say that this treatment technology does not have any long term negative effects—long term research has simply not yet been conducted.

With this in mind, it may be within the District’s (and Beaver Lake’s) best interests to proceed more slowly with this new technology, using the phased approach described in Management Option 4.

5.5.4 Pros and Cons of Management Option 4: Phased Approach with Alum/Lime Slurry Beginning with In-Lake Pilot Tests

This approach has several benefits:

1. The District can be more assured of the expected impacts (both positive and negative) of an alum/lime slurry treatment in Beaver Lake.
2. After 3 years, alum/lime slurry treatments may have become a more common practice, making it easier to get permits from regulatory agencies.
3. The District will have a better idea of the dose needed for Beaver Lake.
4. The District has a few years to levy the money needed for a lakewide alum/lime treatment.

The drawback of this approach is that the pilot project itself could not be expected to result in much of an improvement of Beaver Lake's water quality. Rather, the purpose of the pilot project would be to gather information about a potential future whole-lake treatment of the lake to affect water quality.

5.6 Final Management Recommendations for Beaver Lake

The RWMWD Board of Managers was presented with this report in June, 2003. At that meeting, the managers decided that the best course of action was to pursue Management Option 2: Public Education and On-Lot Infiltration Practices throughout Watershed BL-203 (Beaver Lake's Immediate Watershed). This option is to be pursued gradually over time, its extent depending on the results of the Carver Lake Infiltration Study and future collaborative opportunities that arise between developers and other governmental agencies working in this watershed. It should be noted that other, future management options involving in-lake treatment were not completely ruled out, however, they are not recommended for action at this time. In particular, Management Option 4 (Phased Approach with Alum/Lime Slurry Beginning with In-Lake Pilot Tests) might be of interest to the District in the future, depending on the results of current research being conducted in Wisconsin and elsewhere.

This decision was based not only on the contents of this report, but also the input of the various other parties that were consulted during the course of Phases I and II of the SLMP process. Most parties felt that although the lake's current water quality conditions were acceptable, adopting a "Do Nothing" attitude toward the lake was not.

It should be noted that since June, 2003, there has been more discussion about the MPCA's Impaired Waters List (on which Beaver Lake appears). Also, more information about the MPCA's Total Maximum Daily Load (TMDL) guideline that dictates which lakes are listed has become available.

It now appears that Beaver Lake's TMDL guideline will be a TP concentration of 60 µg/L (this is expected to be the new guideline for shallow lakes).

Because Beaver Lake has neither typically met this guideline TP concentration in the past, nor will it likely meet this guideline in the future under Management Option 2, this issue will require more attention. The next step in the process, dictated by the MPCA, is the creation of a TMDL report to be submitted to the EPA after approval by the MPCA. Kohlman and Keller Lakes (the two other lakes within the RWMWD boundary that are listed as Impaired Waters) are slated to have TMDL reports completed and submitted in 2005. The outcome of this process for Kohlman and Keller Lakes will give the District staff and its Board guidance on whether the management recommendation described in this Beaver Lake SLMP needs revision in the future.

References

Babin, J., E.E. Prepas, and Y. Zhang. 1992. "Application of lime and alum to stormwater retention lakes to improve water quality." *Water Poll. Res. J. Canada*, Volume 27, No. 2, 365-381.

Babin, J., E.E. Prepas, T.P. Murphy, M. Serediak, P.J. Curtis, Y. Zhang, and P.A. Chambers. 1994. "Impact of lime on sediment phosphorus release in hardwater lakes: the case of hypereutrophic Halfmoon Lake, Alberta." *Lake and Reserv. Manage* 8(2): 131-142.

Barr Engineering Co. 1997. *Water Management Plan*. Prepared for Ramsey-Washington Metro Watershed District.

Barr Engineering Company. 1997. *Big Lake Macrophyte Survey and Management Plan*. Prepared for Church Pine, Round, and Big Lake Protection and Rehabilitation District.

Barr Engineering Company. 2001. *Big Lake Protection Grant LPT-67: Big Lake Macrophyte Management Plan Implementation*. Prepared for Church Pine, Round, and Big Lake Protection and Rehabilitation District.

Barr Engineering Co. August 2001. *Beaver Lake Phase I Report: A Summary of Current Conditions.* Prepared for Ramsey Washington Metro Watershed District

Barr Engineering Co. October 2001. *Beaver Lake SLMP: Phase I Summary and Phase II Recommendations Report*. Prepared for Ramsey Washington Metro Watershed District.

Barr Engineering Co. in coordination with the Metropolitan Council. 2001. *Minnesota Urban Small Sites BMP Manual: Stormwater Best Management Practices for Cold Climates*.

Burley, K.L., E.E. Prepas, and P.A Chambers. 2001. "Phosphorus release from sediments in hardwater eutrophic lakes: the effects of redox-sensitive and –insensitive chemical treatments." *Freshwater Biology* 46, 1061-1074.

Chambers, P.A., E.E. Prepas, M. E. Ferguson, M. Serediak, M. Guy, and M. Holst. 2001. "The effects of lime addition on aquatic macrophytes in hard water: in situ and microcosm experiments." *Freshwater Biology* 46, 1121-1138.

Heiskary, S. and B. Wilson. 1988. *Minnesota Lake Water Quality Assessment Report.* Minnesota Pollution Control Agency. 95 pp.

Henderson, C.L., C.J. Dindorf, and F.J. Rozumalski. 1999. *Lakescaping for Wildlife and Water Quality*. State of Minnesota, Department of Natural Resources. 175 pp.

Lind, C.B. 1997. "Phosphorus inactivation--chemical precipitants and strategies." NALMS Annual Conference, 2001. Workshop Curriculum Materials.

Murphy, T.P., E.E. Prepas, J.T. Lim, J.M. Crosby, and D.T. Walty. 1990. Evaluation of calcium carbonate and calcium hydroxide treatments of prairie drinking water dugouts. 1990. Lake and Reservoir Management 6(1): 101-108.

Nelson, L. 2003. Personal Communication. (L. Nelson is a staff person for the Sauk River Watershed District)

Phillips, R.D. J.C. Loftis, and H.P. Hotto. 1989. *WQ Stat II: A Water Quality Statistics Program*. Colorado State University. 42 pp.

Prepas, E.E., T.P. Murphy, J.M. Crosby, D.T. Walty, J.T. Lim, J. Babin, and P.A. Chambers. 1990. "Reduction of phosphorus and chlorophyll *a* concentrations following $CaCO_3$ and $Ca(OH)_2$ additions to hypereutrophic Figure Eight Lake, Alberta." *Environmental Science and Technology*, Vol. 24, No. 8, 1252-1258.

Prepas, E.E., D.T. Walty, T.P. Murphy, J.M. Babin, and P.A. Chambers. 1992. *Management of farm dugouts as water supplies: Use of lime for algal and macrophyte control.* Project Number: 89-0462.

Prepas, E.E., B. Pinel-Alloul, P.A. Chambers, T.P. Murphy, S. Reedyk, G. Sandland, and M. Serediak. 2001. "Lime treatment and its effects on the chemistry and biota of hardwater eutrophic lakes." *Freshwater Biology* 46, 1049-1060.

Prepas, E.E., J. Babin, T.P. Murphy. P.A. Chambers, G. J. Sandland, A. Ghadouani, and M. Serediak. 2001. "Long-term effects of successive $Ca(OH)_2$ and $CaCO_3$ treatments on the water quality of two eutrophic hardwater lakes." *Freshwater Biology* 46, 1089-1103.

Reedyk, S., E.E. Prepas, and P.A. Chambers. 2001. "Effects of single $Ca(OH)_2$ doses on phosphorus concentration and macrophyte biomass of two boreal eutrophic lakes over 2 years." *Freshwater Biology* 46, 1075-1087.

Vighi, M. and Chiaudani, G. 1985. "A Simple Method to Estimate Lake Phosphorus Concentrations Resulting from Natural, Background, Loadings." *Water Res.* 19(8): 987-991.

Wilson, C.B. and W.W. Walker. 1988. *The Minnesota Lake Eutrophication Analysis Procedure (MNLEAP)*, MPCA.

Zhang, Y., A. Ghadouani, E.E. Prepas, B. Pinel-Alloul, S. Reedyk, P.A. Chambers, R.D. Robarts, G. Methot, A. Raik, and M. Holst. 2001. "Response of plankton communities to whole-lake $Ca(OH)_2$ and $CaCO_3$ additions in eutrophic hardwater lakes." *Freshwater Biology* 46, 1105-1119.

Appendices

Appendix A

Beaver Lake Phase I Report-
A Summary of Current Conditions

Beaver Lake Phase I Report

A Summary of Current Conditions

Ramsey-Washington Metro Watershed District

August 8, 2001

Introduction

Beaver Lake is an 87-acre lake located in Ramsey County, primarily in the city of Maplewood (Figure 1). The Beaver Lake tributary watershed spans 1,841 acres in the cities of St. Paul, Maplewood, and Oakdale (Ramsey and Washington Counties). This Phase 1 report details the results of a recent study the Ramsey Washington Metro Watershed District conducted of Beaver Lake and its tributary watershed. The data presented in this report includes: historical water quality data, the results of a 1999 lake and watershed runoff water quality monitoring program and watershed pond survey, and computer simulations of current conditions using lake and watershed models calibrated to the 1999 water quality monitoring program data set.

This report provides information that will show the current condition of Beaver Lake and its subwatershed, in terms of its:

- Watershed Land Use,
- Water Quality,
- Fishery,
- Macrophyte community, and
- Sources of Phosphorus Loadings to the Lake (in terms of both watershed loads and internal loads)

The purpose of this Phase I report is to provide technical information. With this information, they may better understand the lake's historical and current condition and estimate the future conditions of the lake given current trends. In addition, it is hoped that this will allow those parties to properly assess and, if necessary, revise the goals and priorities for the lake. Also, as a part of this process, the information in this report is intended to assist the parties in clearly defining, or possibly re-defining, the future management roles and responsibilities associated with Beaver Lake.

Once the goals and priorities for the lake are re-established and management roles and responsibilities are re-defined, then, if necessary, Phase II of the study will be conducted. Phase II will include an evaluation and feasibility analysis of recommended improvement recommendations that will help to meet the long-term goals for the lake, established as a part of the Phase I process.

History of the District's Goals for Beaver Lake

In 1997, the Ramsey Washington Metro Watershed District (District) assessed the recreational use and water quality level of the lakes within the District's boundaries in order to define future management goals. The lake's primary recreational use is fishing. The District assigned Beaver Lake a "Level 3" water use category (of five categories where Level 1 has the highest number of recreational activities) based on its recreational uses. This classification system is the first step in establishing a relationship between the water body usage and the water quality expected by the users to effectively support those uses. Since the recreational appeal of a lake is often determined by it's water clarity, the District has specific categorical water quality goals that are associated with water clarity, which in turn are associated with the various water use category levels. Those specific goals for total phosphorus (TP), Secchi Disc and Chlorophyll *a* were chosen in reference to the Minnesota Pollution Control Agency's summer average guidelines for lakes in each ecoregion of Minnesota (MPCA, 1994). Therefore, the District's Total Phosphorus goal for a Level 3 lake (Beaver Lake) is 60 µg/L (presumably because this concentration is at the threshold for eutrophic-hypereutrophic conditions). The target levels of two other constituents (Secchi Disc and Chlorophyll *a*) were then calculated as a function of Total Phosphorus using published relationships.

Because the historical summer average TP concentration in Beaver Lake (~135 µg/L at the time that the Plan was written) exceeds the guideline concentration of 60 µg/L, the District gave Beaver Lake a management class of "Restore" in its 1997 Water Management Plan. Table 1 shows the in-lake concentrations measured in 1999, compared to the guideline values stated in the Plan.

Table 1:

	Goal As Shown in 1997 Plan	1999 Summer Average Conditions
Total Phosphorus (TP)	60 µg/L	120 µg/L
Chlorophyll *a* (Chl *a*)	32 µg/L	20.5 µg/L
Secchi Disc (SD)	2.6 ft	5.2 ft

It is interesting to note that while TP did not meet the current goal for Beaver Lake in 1999, the Chlorophyll *a* (Chl *a*) and Secchi Disc (SD) measurements did. This led us to believe that the estimated relationship between TP:Chla:Secchi disc used to set the District's Water Management Plan goals may not reflect the actual relationship of these constituents in the lake. Figure 2 shows the actual relationship between Secchi disc (SD) and Total Phosphorus (TP) in Beaver Lake based on the historical water quality data that has been collected for the lake. This figure shows that (on average) decreasing the lake's TP concentration from 120 to 60 µg/L would increase the lake's transparency (as measured by SD) by only 1.5 ft. The relationship confirms that large changes in total phosphorus concentrations are required to change the lake's Secchi disc transparency from its present level. Because transparency (as opposed to TP or Chl *a* concentrations) has the most direct effect on a lake's fish population, this is of particular interest when studying Beaver Lake.

The following questions, then, arise for involved parties' consideration:

1. Is fishing the primary recreational use associated with Beaver Lake and should the lake be managed according to that use?
2. Are the TP, Chla, and SD water quality goals listed in the District's Water Management Plan appropriate for Beaver Lake? If not, which goals are?
3. Given the Lake's current state, is it feasible to reduce TP loadings to meet the goal mentioned in the District's Plan? If so, who will pay for capital improvements that will meet those goals?
4. Is maintaining the lake in its current condition or improving the lake's condition more appropriate?
5. Which party is ultimately responsible for the long-term condition of Beaver Lake?

Land Uses in the Watershed

Existing land use in the Beaver Lake watershed were determined using May 2000 aerial photographs provided by the Metropolitan Council along with current land use maps from the municipalities. The existing land use conditions in the Beaver Lake watershed are shown on Figure 3. No significant land use changes are expected in the Beaver Lake watershed in the near future.

Of particular importance is the impervious area associated with each land use. Impervious area increases are directly correlated with increases in the volume of water and mass of phosphorus in storm water runoff. Hence, changes in land use that result in increases in impervious area generally result in increased phosphorus loading to downstream waters, such as Beaver Lake. In general, as the colors in Figure 3 become "warmer", the impervious area associated with each type of land use increases.

Both the cities of St. Paul and Maplewood are currently undertaking several programs to reduce nonpoint source stormwater pollution in the watershed of Beaver Lake. St Paul has been issued their stormwater NPDES Phase I permit and are in the process of implementing the prescribed programs. St. Paul recently issued its first annual report. This report outlines the activities undertaken by the city as required by the NPDES permit. Some of the activities include:

- Improved catch basin cleaning and maintenance
- City construction site erosion and sediment control
- Deicing material application to minimize runoff
- Street sweeping two times per year
- Inspection and maintenance of sediment ponds and outfalls
- City wide education programs including storm sewer catch basin stenciling

The City of Maplewood has completed a street improvement project that incorporates rainwater gardens as an element of the stormwater management plan. The rainwater gardens reduce the total volume of stormwater runoff and enhance water quality. The City has adopted this approach for future street reconstruction projects whenever feasible.

Past and Present Water Quality in Beaver Lake

Beaver Lake is a hypereutrophic lake. Hypereutrophic lakes are defined as extremely productive lakes that are highly fertile, disturbed and unstable (i.e., fluctuating in their water quality on a daily and seasonal scale, producing gases, odors, off-flavor and toxic substances, experiencing periodic anoxia, and fish-kills, etc.), with TP concentrations above 60 μg/L.

Figure 4 shows growing season (June through August) mean TP concentrations measured in Beaver Lake over many different years. Figure 4 also shows the number of samples that were included in the mean concentration (e.g. n = 4 means that 4 samples were averaged between June and August). Note that before 1992, sampling during the growing season was, in general, less frequent. It is important to keep this in mind when drawing conclusions from the trends of summer averages. In general, for a lake such as Beaver Lake, at least 5 representative samples taken during the growing season is recommended for accurate trend determination (MPCA, 1994).

For example, in 1988, only two samples were averaged to determine the growing season mean TP concentration of 0.268 mg/L. One of the samples was taken in July, while the other sample was taken in August- the June concentration was never sampled. Since the June concentration is normally lower than the July and August concentrations, a lower summer mean TP concentration would be expected for 1988.

Figure 5 shows the growing season mean Secchi Disc measurements taken at Beaver Lake. As in Figure 4, Figure 5 also shows the number of samples that were included in the mean SD measurement.

Figures 6 through 8 show the 1999 monitoring data in more detail, showing the individual sampling event results for TP, Chl *a* and SD. Where two points are shown for the same sampling event, samples were taken at both the surface and at ~2m below the surface of the lake.

State of the Fishery

During 1992, the MDNR classified Beaver Lake and other Minnesota lakes relative to fisheries. According to its ecological classification, Beaver Lake is a Class 40 lake, which signifies a small, shallow lake that is subject to occasional winterkill (Schupp, 1992). It should be noted that installation of an aeration system has effectively removed winterkills and has sustained the lake's fishery. The aeration system was installed during 1991. The classification, however, was based upon the lake's morphometry without consideration of the lake's aeration system.

The average conditions for a Class 40 lake are based upon data from 45 Minnesota Class 40 lakes. On average, a class 40 lake has a surface area of approximately 59 acres, a maximum depth of approximately 12 feet, a SD transparency of approximately 4 feet, and a littoral area which comprises approximately 90 percent of the lake's surface area (i.e., 44 acres). Beaver Lake has a surface area of approximately 87 acres, a maximum depth of approximately 15 feet, a SD transparency of about 5 feet, and a littoral area 60 to 70 percent of the lake's surface area.

The MDNR has recommended that the average water quality for a Class 40 lake be a TSI_{SD} (Trophic State Index in terms of SD transparency) of approximately 62 or lower (i.e., a summer average SD transparency of about 5 feet or greater). The recommendation is based upon the water quality needs of the fishery found in a Class 40 lake. Currently, Beaver Lake's water quality does meet this recommendation based upon 1999 data. However, there are recent years that Beaver Lake has not met the MDNR's recommendation (1996, 1996 and 1998, for example, with 3.6 ft, 3.6 ft and 4.6 ft summer average SD, respectively).

The lake's current fishery is comprised of panfish species, gamefish species, rough fish species, and other fish species. Species captured during the MDNR 2000 fisheries survey include:

- Panfish -- black crappie, pumpkinseed sunfish, and bluegills;
- Gamefish – largemouth bass, northern pike, and yellow perch;
- Rough fish – black bullhead and brown bullhead:
- Other fish – golden shiner, channel catfish, and white sucker.

Black crappies were the most abundant fish caught during the 2000 assessment. Most were small, with only 3.1 percent over 8 inches long. Bluegill and pumpkinseed sunfish were present in average numbers with one third of the fish over 6 inches long. Less than one-fifth of the fish were 8 inches long or longer (MDNR 2000).

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Northern pike were caught in this lake for the first time since 1976. Numbers were above average with several fish over 25 inches long. Largemouth bass were sampled in average numbers. A variety of sizes and ages were present, with the largest measuring 17.17 inches long. Yellow perch were caught in above average numbers, but below historic levels for this lake.

Black bullhead numbers were the lowest ever for this lake. One-fifth of the fish were at least 10 inches long. Brown bullhead were present in average numbers with over half of the fish at least 10 inches long (MDNR 2000).

Golden shiners were abundant with all fish sampled measuring 6 to 9 inches (MDNR 2000). Channel catfish were captured for the first time from this lake, with fish measuring 11.57 to 17.83 Inches long. Channel catfish have been stocked annually since 1997 (MDNR 2000).

An improvement in the lake's fishery appears to have occurred since the 1995 survey. All fish captured in the 1995 survey were small in size. In 2000, approximately one third of the bluegill and pumpkinseed sunfish were over 6 inches. Northern Pike were caught for the first time in 2000 and several fish were over 25 inches long. The data indicate an improvement in fish size had occurred.

Despite improvements in the lake's fishery, the 2000 survey data indicate the majority of fish in Beaver Lake are small in size. The large numbers of small fish in the lake indicated that heavy fishing pressure had removed the larger fish from the lake. Dave Zapetillo, MDNR east area fisheries supervisor, confirmed that Beaver Lake receives heavy fishing pressure. He has personally observed large numbers of people fishing along the lake's shoreline daily during the spring and summer period. Fishing pressure appears to have increased following a one time stocking of large bluegills from a MDNR rearing pond (Zapetillo 2001). The MDNR is currently working to improve the lake's fishery.

Current fisheries management of Beaver Lake consists of winter aeration and stocking. Recent stocking has included black crappie, bluegill, channel catfish, northern pike, and yellow perch. The MDNR intends to stock channel catfish and yellow perch on an annual basis and bluegill as needed.

Protection of the lake's water quality is important for the maintenance of the lake's fishery. MDNR evaluated data from its data warehouse to determine whether a relationship between water transparency and fishery quality occurred. The evaluation included the trap net data collected since 1980 in 6,109 fisheries surveys. The evaluation indicated that improved SD water transparency resulted in improved fishery. Fewer rough fish and increased numbers of small Centrarchids (i.e., bluegills, green sunfish, hybrid sunfish, and pumpkinseeds) occurred with increased SD water transparency (shown in Figure 9). The evaluation also indicated that below a SD transparency of 3 feet, the lakes' fishery "crashed" resulting in extremely low numbers of small Centrarchids and a value of 0 for the proportion of small Centrarchids (i.e., virtually all fish were rough fish) (also shown in Figure 9). The evaluation results indicate preservation of Beaver Lake's current transparency is necessary to maintain the lake's fishery. The data indicate the lake could experience a significant loss of small Centrarchids and a significant increase in rough fish should its average SD transparency decline below 3 feet.

As discussed above, large changes in total phosphorus concentrations are required to change the lake's Secchi disc transparency from its present level. This relative stability of the lake's transparency serves to reduce the challenge of maintaining the existing water clarity for the lake's fishery.

State of the Macrophyte Community

District staff conducted an aquatic plant survey on July 24th, 2001.The point intercept method incorporating Global Positioning System (GPS) technology (Madsen 1999) was used to assess the submersed aquatic plant community on Beaver Lake. This report section provides the survey results only. The complete report with tables and maps is attached.

Eleven floating-leaf and submersed plant species were identified in the survey (Table 1). The native coontail was the most abundant submersed vascular plant species (Figure 1). This is a fairly aggressive submersed plant in the District, doing well in relatively turbid pond and lake systems. It lacks true roots and obtains a majority of its nutrients through the water column. Flat-stem pondweed was the most abundant rooted macrophyte. This particular pondweed is considered a sensitive species to turbidity (Davis and Brinson 1980), and is an indication that Beaver Lake still has the ability to harbor desirable native submersed vegetation. The invasive non-native curly-leaf pondweed was present at approximately 19% of the sampling locations. In late June into early July, this pondweed is at its peak abundance. Thus, our sampling effort was at the period when curly-leaf pondweed was in decline. Observations prior to our sampling suggest that this invasive species did not reach nuisance levels during its peak. Numerous curly-leaf pondweed turions (reproductive structures) were noted on the Beaver Lake water surface. This invasive species has been present in Beaver Lake since at least 1984 (T. Noonan, Ramsey County, Pers. Comm.). The invasive non-native Eurasian water milfoil was not found in Beaver Lake during this sampling effort. A mix of native free floating-leaf species (i.e., star duckweed, common duckweed, great duckweed, and watermeal) was a large component in the littoral plant community. All of these species are able to extract nutrients from the water column and serve as indicators of nutrient enrichment.

Submersed plants were present at depths of up to seven feet. Light availability likely prevented rooted plants from establishing in deeper areas. There was a decline in percent frequency of coontail, floating-leaf species, and native submersed rooted species as water depths increased (Figure 2). Curly leaf pondweed was more common in the 3 to 7 foot depth range. Water lily was found in 1 to 5 feet of water. Individual sampling points averaged three plant species (Figure 3). The abundance rankings for individual species did not differ significantly, averaging approximately 2.5. Points with a high number of taxa, up to seven, had a mix of floating-leaf and submersed species; water depths at all of these sites were in the three to four foot range.

Total Phosphorus Loads from the Tributary Watershed

The water and TP loads to Beaver Lake from its tributary watershed were estimated using the P8 computer model (Program for Predicting Polluting Particle Passage through Pits, Puddles and

Ponds, IEP Inc. 1990). The model was calibrated to water quality and stream flow monitoring data collected at the largest inflow to the lake during summer of 1999. Approximately 79 % of the total Beaver Lake Subwatershed drainage area flows through this inflow channel. Figures 10 through 12 show the results of this modeling effort.

Figure 10 shows the relative contributions of total phosphorus (TP) from the five major drainage networks in the Beaver Lake watershed. The majority of the TP load runs off of the northeast portion of the watershed, contributing 71% of the total TP load. The area directly draining to Beaver Lake, receiving no treatment, contributes 21% of the total TP load.

Figure 11 illustrates the areal phosphorus loading (lbs/ac/yr) simulated by the P8 model for each subwatershed under 1999 conditions. 1999 was a fairly wet climatic year with 33.19 inches of precipitation. An average precipitation year is approximately 29 inches of rainfall. The color of each subwatershed in the figure represents the phosphorus load leaving the subwatershed before treatment/detention in any ponds or wetlands that are present. Land use conditions in a subwatershed may introduce potentially high phosphorus loads, but existing ponds and wetlands may reduce that load substantially. Figure 11, therefore, provides an indication of the pre-treatment areal phosphorus load rather than the actual areal phosphorus load from the subwatersheds.

Figure 12 illustrates the cumulative percent of phosphorus removal (%) simulated by the calibrated P8 model under existing land use conditions for 1999. Throughout the Beaver Lake watershed, storm water runoff flows sequentially through a number of ponds and wetlands before discharging to the lake. Each pond in such a sequence will receive storm water not only from the immediately adjacent subwatershed area, but from the upstream ponds as well. As the storm water passes through each pond in the series, additional, and remaining 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 12 represents the cumulative percent removal in a series of sequential subwatersheds (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).

The District's goal for pond treatment efficiency for TP is 60% (non-cumulative removal). The lower cumulative percent removal by the ponds toward the end of the long chain draining though BL-121 can be explained by the fact that the TP they receive is mostly in soluble form (and therefore is not easily settled out of the water column in the last few ponds).

Contribution of Internal Load to the Lake's Water Quality

To evaluate how the watershed loads of water and TP affected the water quality of Beaver Lake, the water and TP loads estimated by P8 were put into several in-lake equations, developed by Canfield and Bachman (1981), Dillon and Rigler (1974), and Nurnberg (1984). Some of these equations include terms for internal loading and some do not. It was instructive to compare the predicted, in-lake TP concentrations from each of these models. In doing so, we noticed that the models that included internal loading better predicted the summer average TP concentration in Beaver Lake for a variety of years with different climatic conditions (1995-1999).

Using this information, as well as the results of a mass balance model we created ourselves, we concluded that internal loading of TP could contribute up to approximately 25% of the total TP load to Beaver Lake. Whether this load comes from the lake sediments or from a mid-summer die-off of macrophytes in the lake (Curly-leaf Pondweed, for example) is currently unknown.

It is important to note, however, that this is a rough estimate of the internal load. In order for the lake's internal loading to be more precisely defined, a more rigorous water quality sampling schedule is needed. Ideally, if internal loading is to be re-examined for Beaver Lake, we recommend taking 10 samples during the spring and summer months. At each sampling event, samples should be taken at several depths (at least one sample per meter in the deepest part of the lake) in order to establish the profile of TP within the water column.

Summary

In summary, the following considerations should be included in any discussion about the future management of Beaver Lake:

- The current water quality goal (60 μg/L TP) for the lake may be inappropriate.
- The lake's transparency is relatively stable, given the high concentrations of TP that the lake experiences.
- Beaver Lake has been hypereutrophic for the past 20 years.
- The current state of the fishery appears to be acceptable; however, a decline in water transparency could have deleterious effects.
- The existing aquatic plant community is reasonably diverse and is beneficial to the water clarity and fishery habitat.
- Almost all of the ponds in the watershed appear to meet the District's goal of 60% TP removal.
- The TP reaching Beaver Lake through BL-121 has a relatively high fraction of soluble (non-settlable) TP. This accounts for 71 % of the total TP load to the lake
- The area that is the second highest contributor of TP to the lake (21% of the total TP load) receives no treatment (Beaver Lake's immediate watershed).
- There does appear to be an internal load of TP to the lake. Whether this load is from anoxic sediments or die-off of macrophytes (or both) is currently unclear.

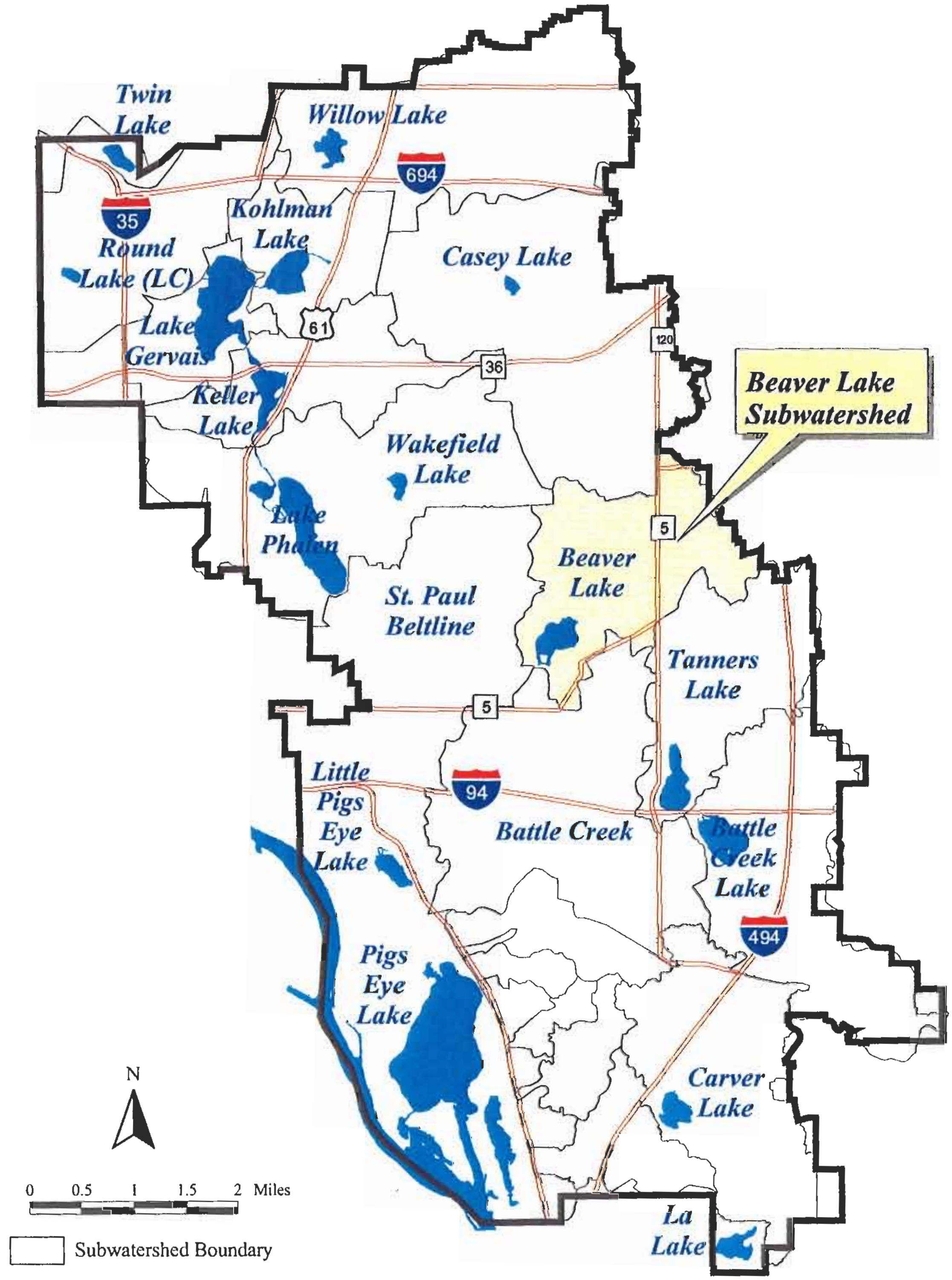

Figure 1

SITE LOCATION MAP
BEAVER LAKE SLMP

Ramsey-Washington Metro Watershed District

Ramsey-Washington Metro Watershed District

BARR

Beaver Lake Secchi Depth-TP Relationship

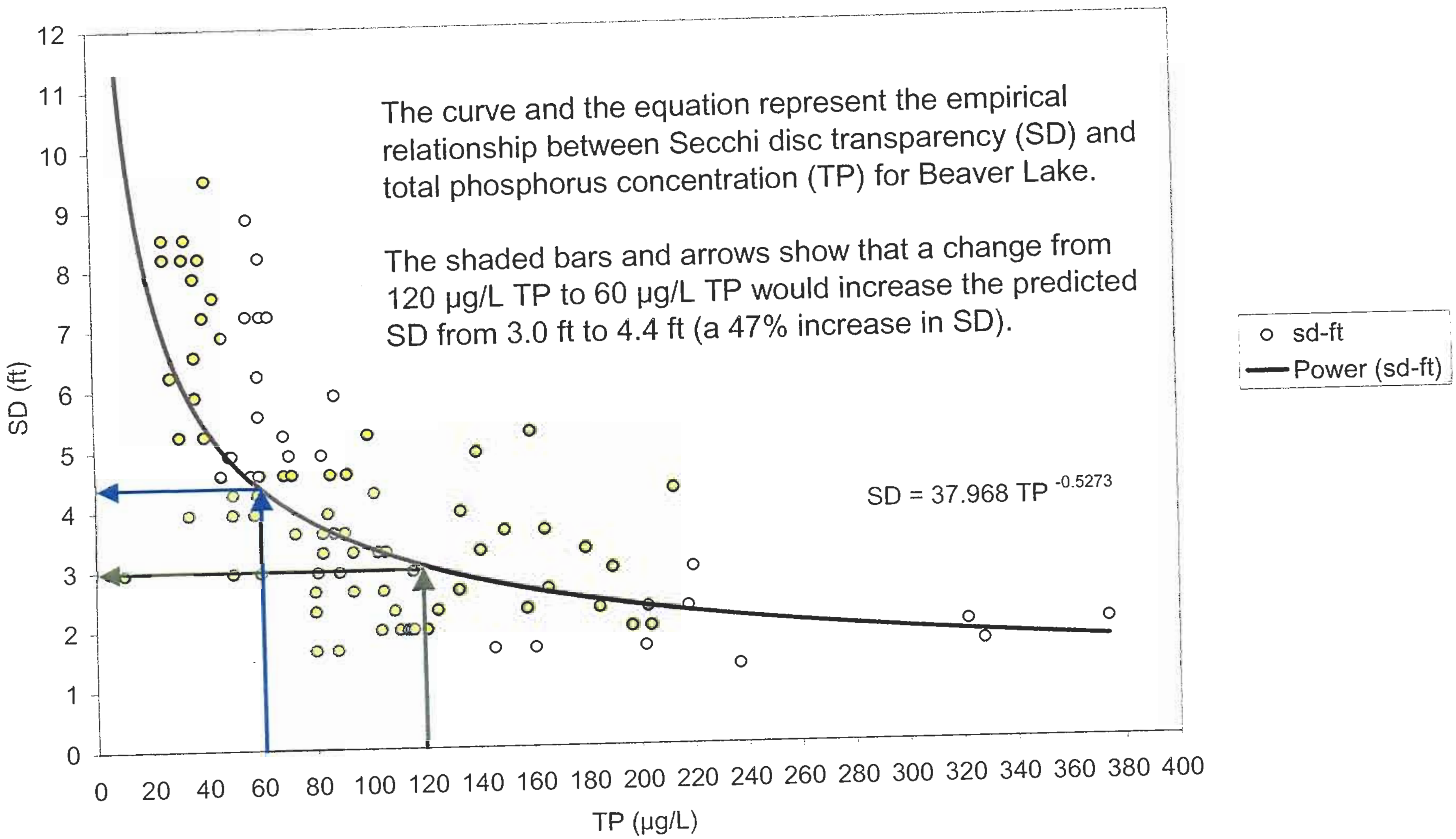

Figure 2

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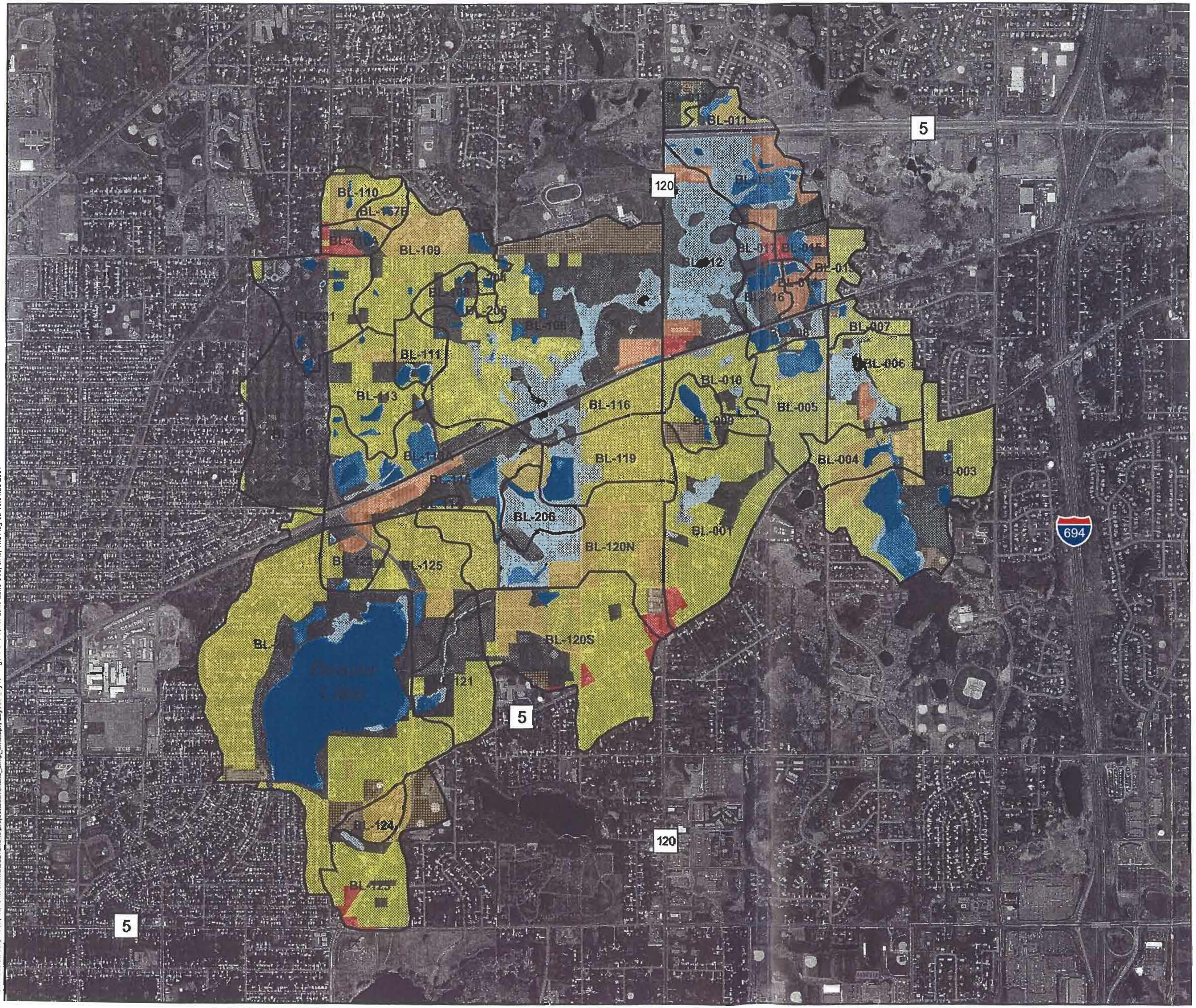


Watersheds

Land Use
- Natural/Park/Open
- Golf Course
- Agricultural
- Very Low Density Residential
- Low Density Residential
- Medium Density Residential
- High Density Residential
- Institutional
- Highway
- Commercial
- Industrial/Office
- Open Water
- Wetland

N

1500 0 1500

Scale in Feet

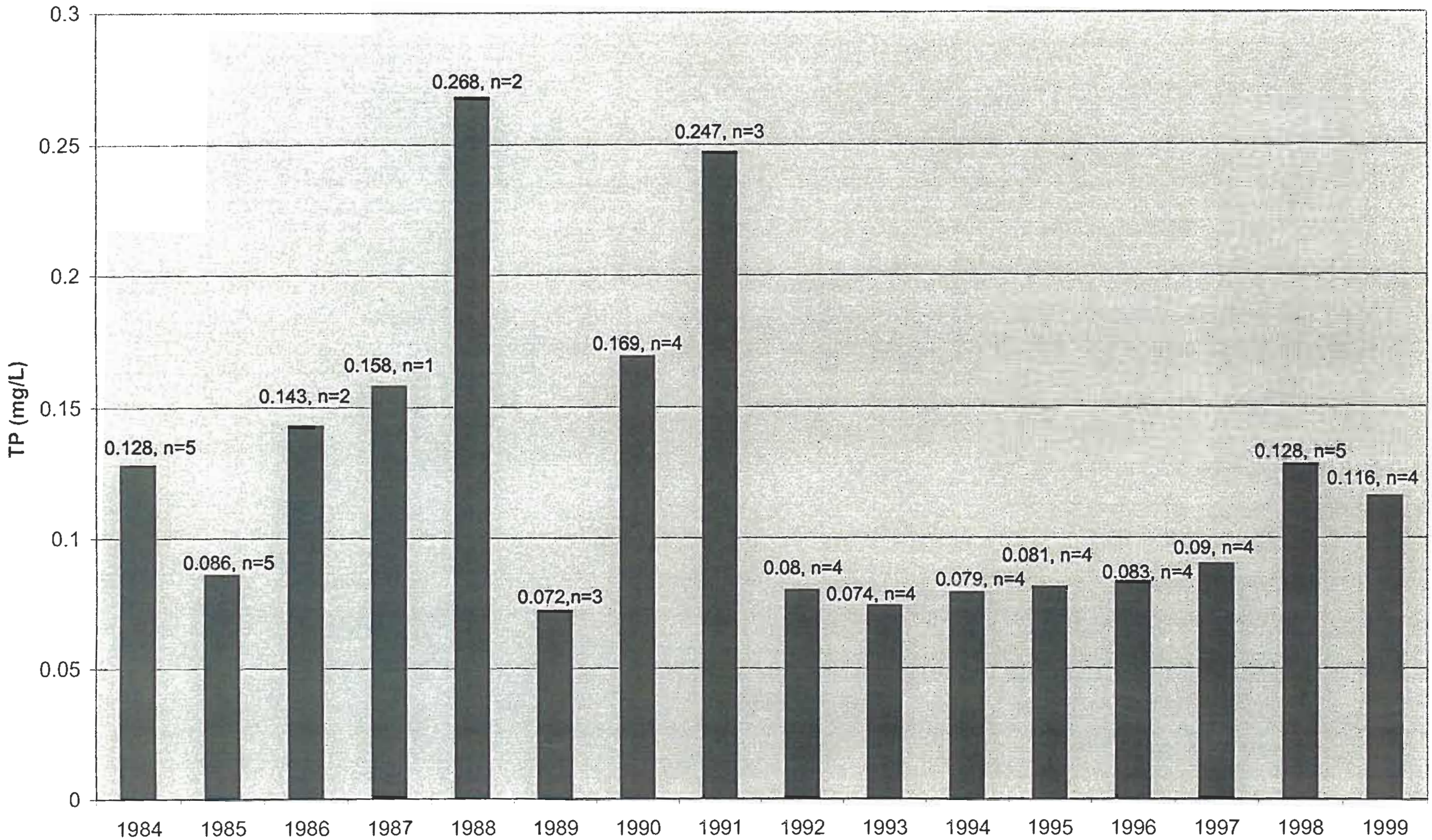
Figure 3
BEAVER LAKE SUBWATERSHED LAND USE
Ramsey-Washington Metro Watershed District

Ramsey-Washington Metro Watershed District

BARR

Barr: Arcview 3.1, PIV03, i:\client\rwmwd\beaverlake\project\beaverlake_simp_sms.apr, Layout: Layout: Figure 3--Beaver Lake Land Use, sms, Thu Aug 02 10:01:25 2001

Growing Season (June through August) Mean Total Phosphorus Concentrations



P:\Rwmwd_Projects\2362742\Historical Water Quality Data\Growing Season Means 1984 through 1999

Figure 4

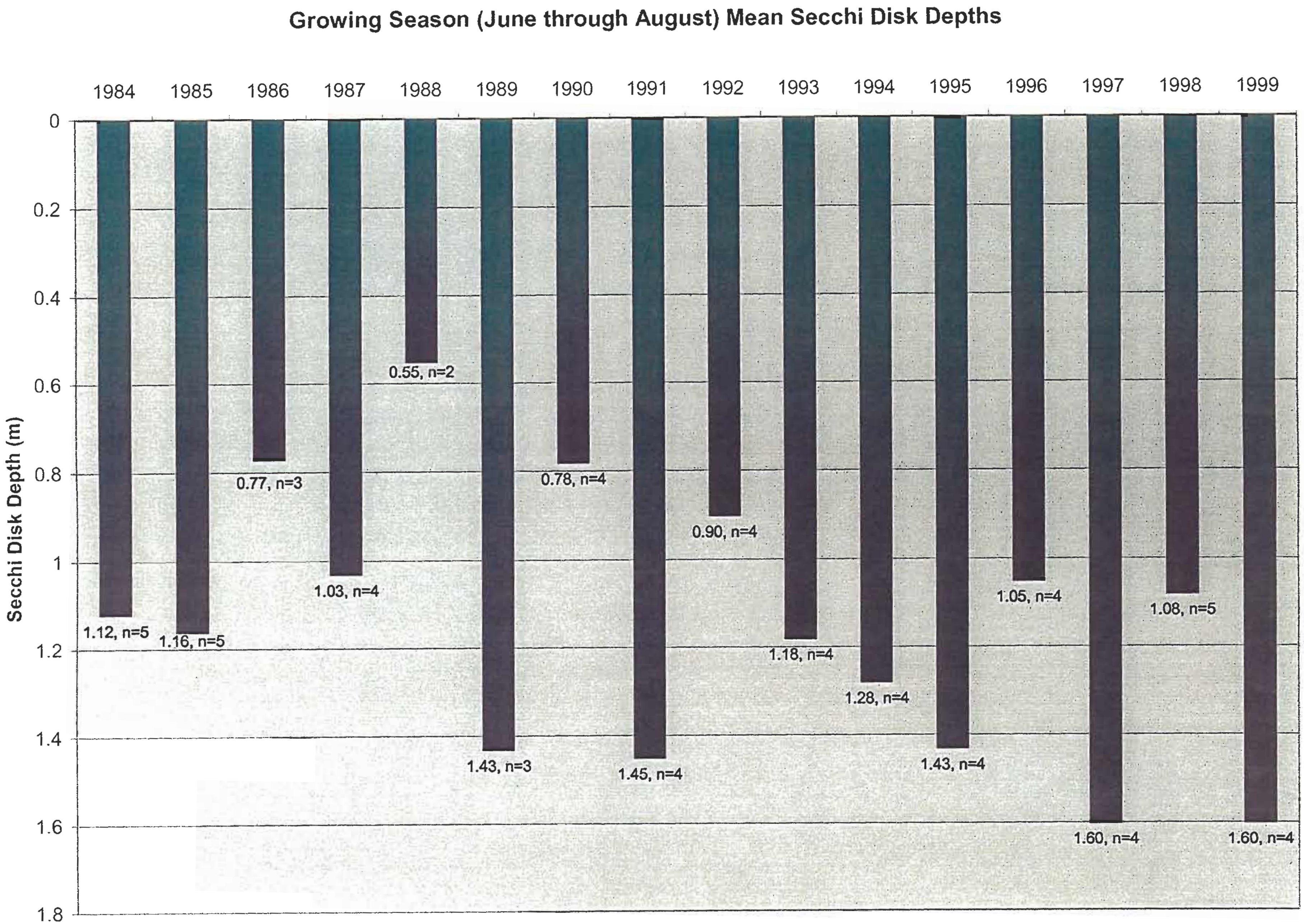


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Figure 5

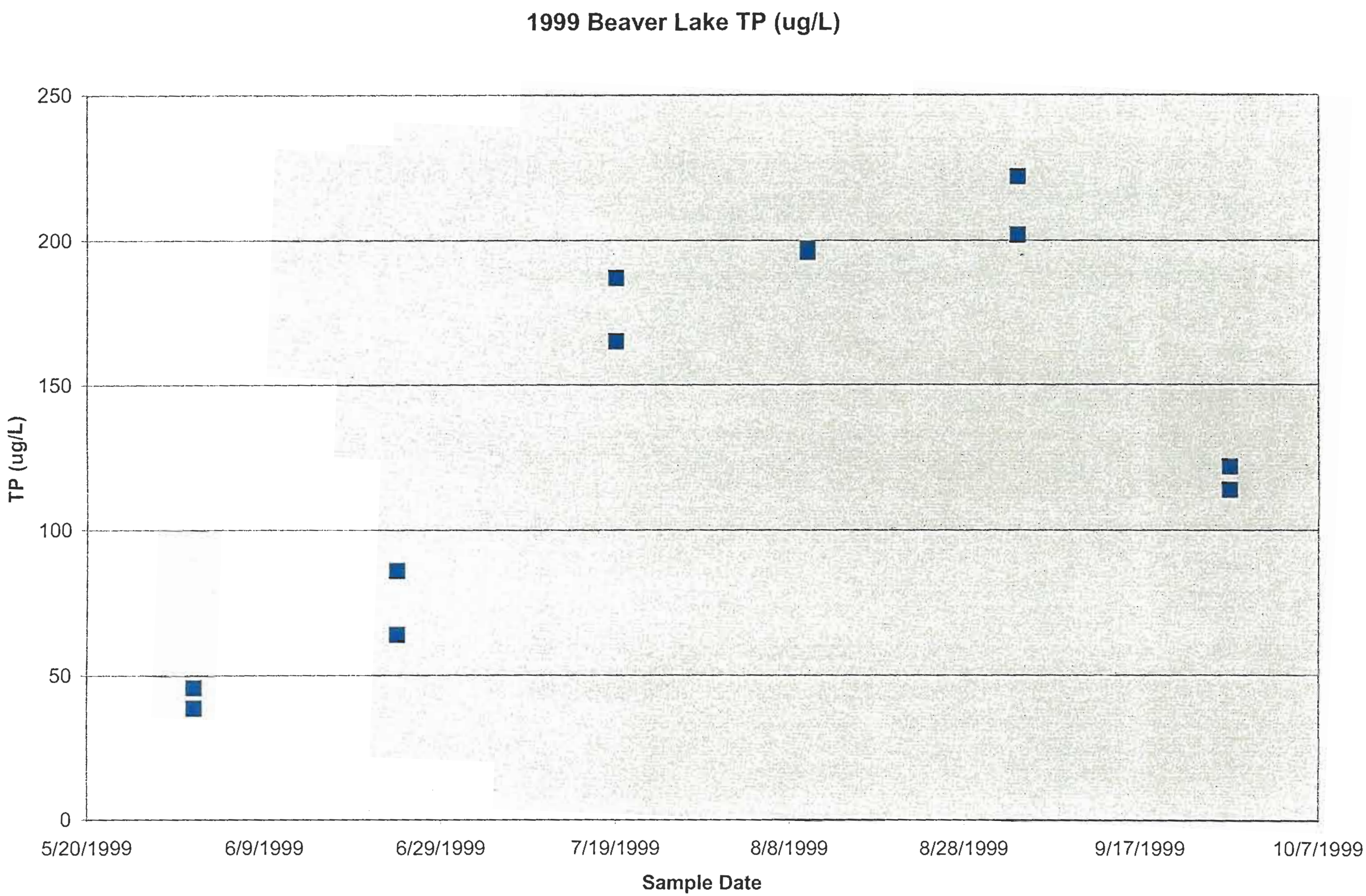

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Figure 6

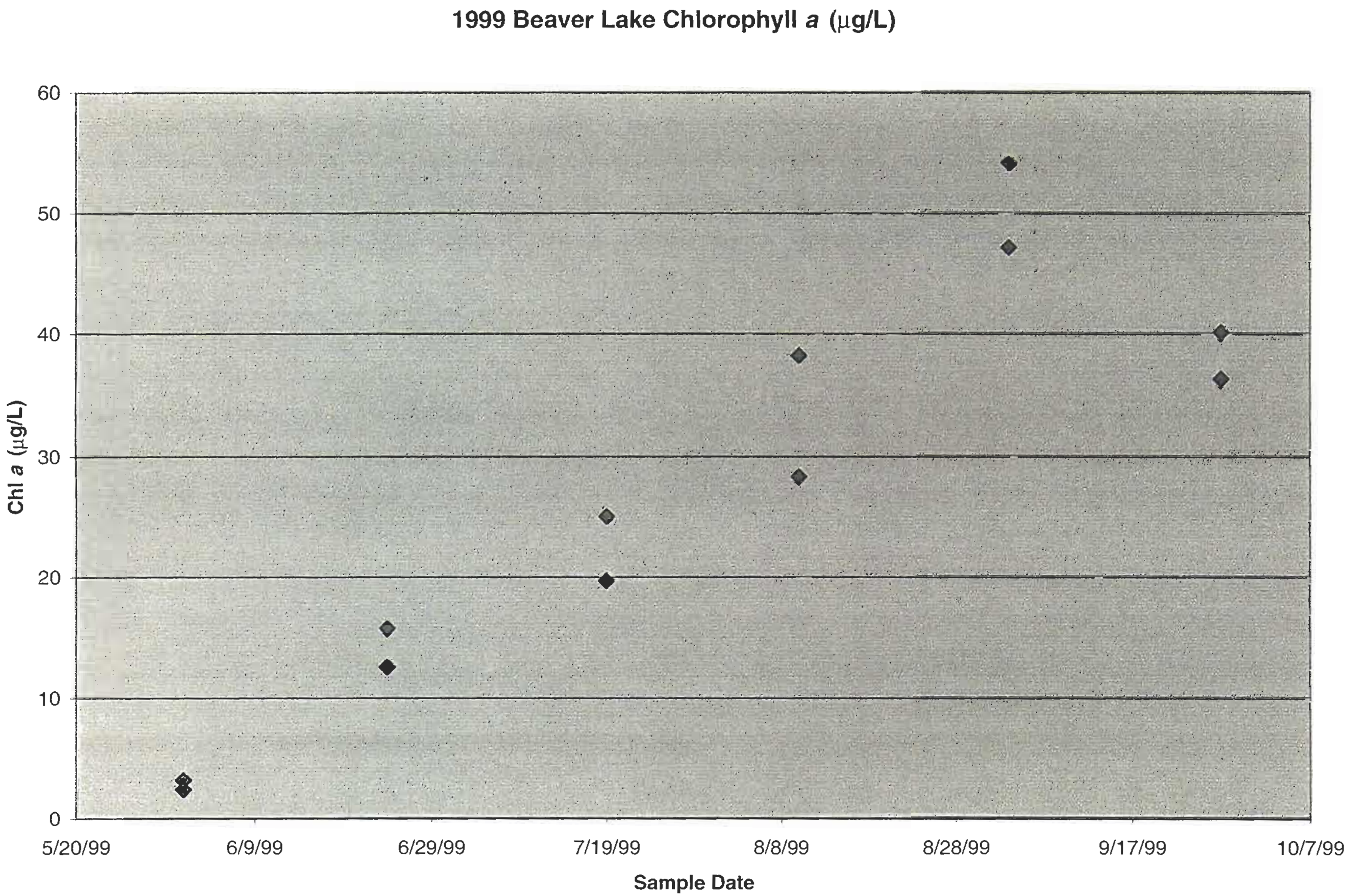

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Figure 7

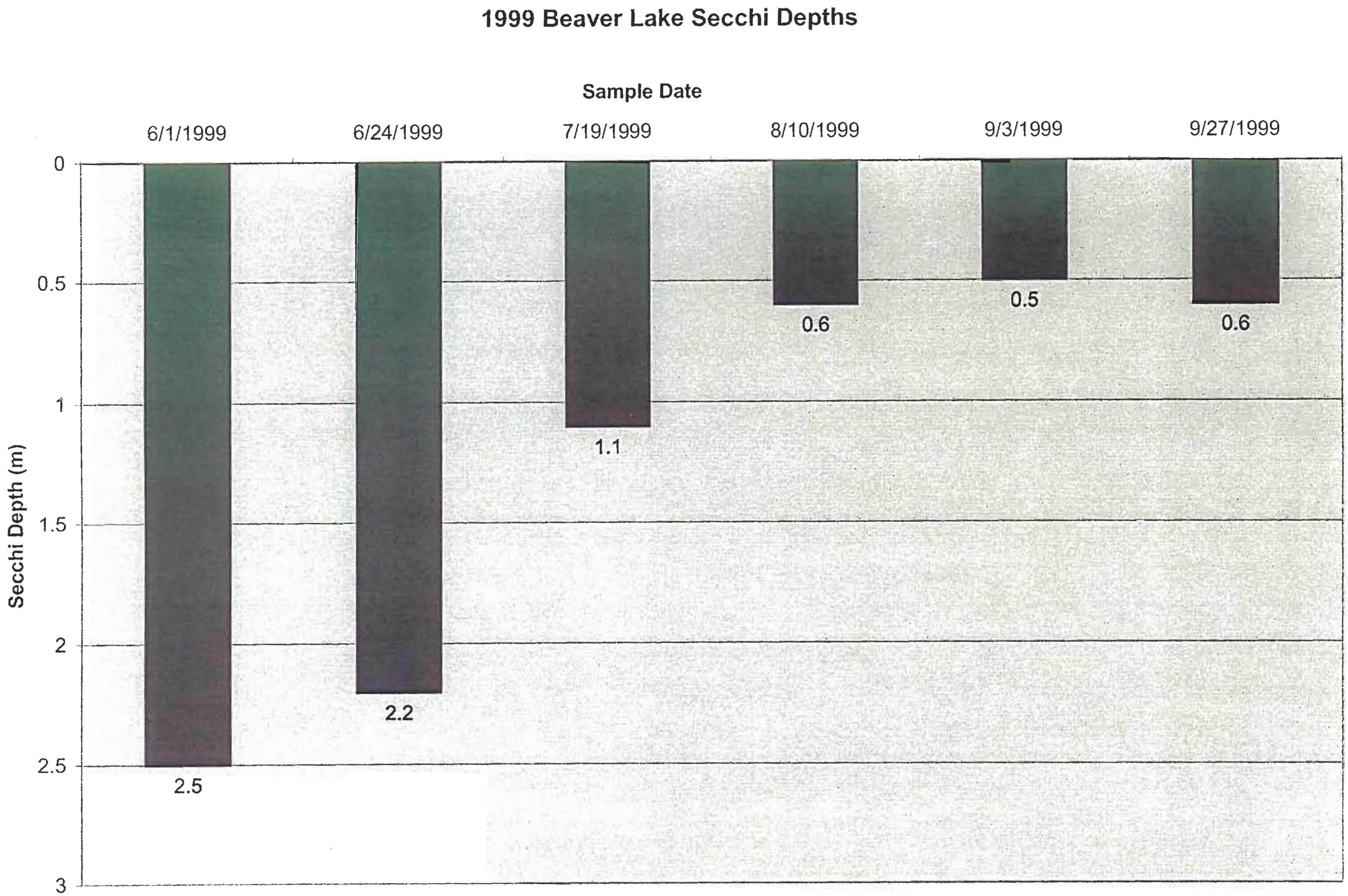

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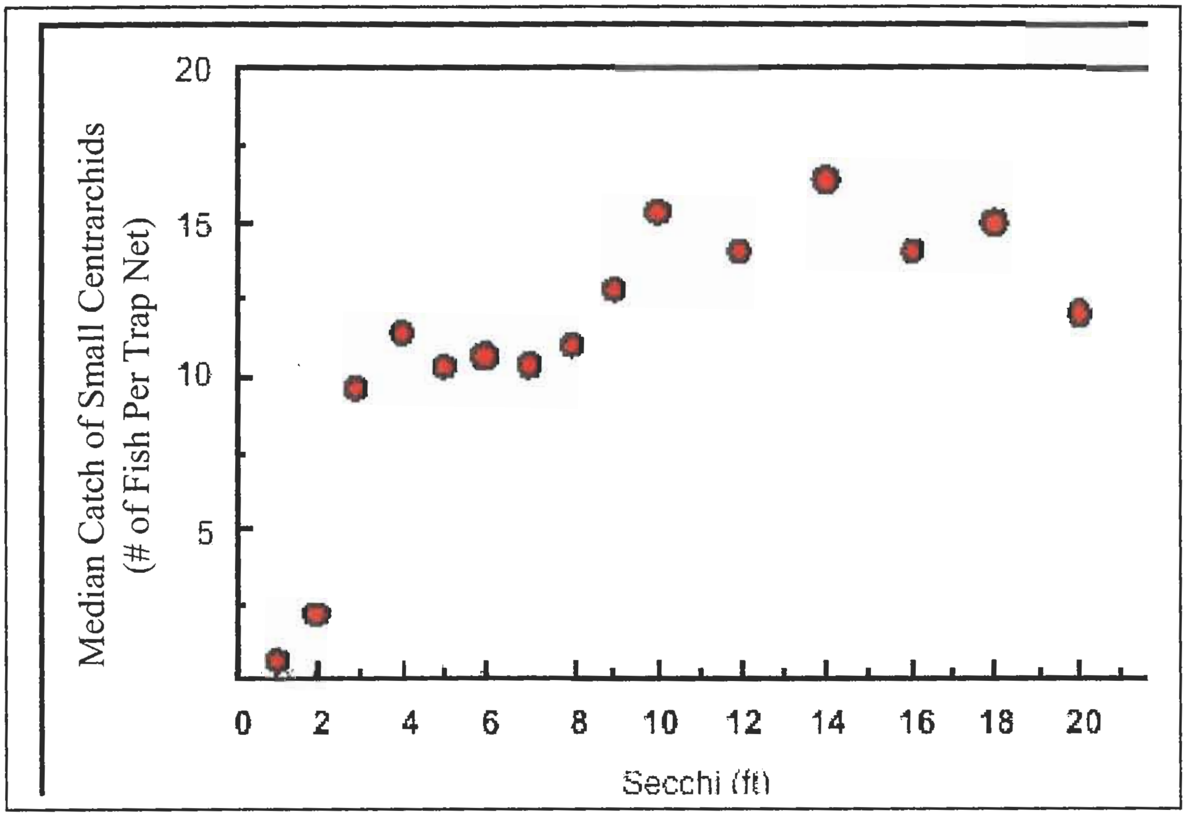
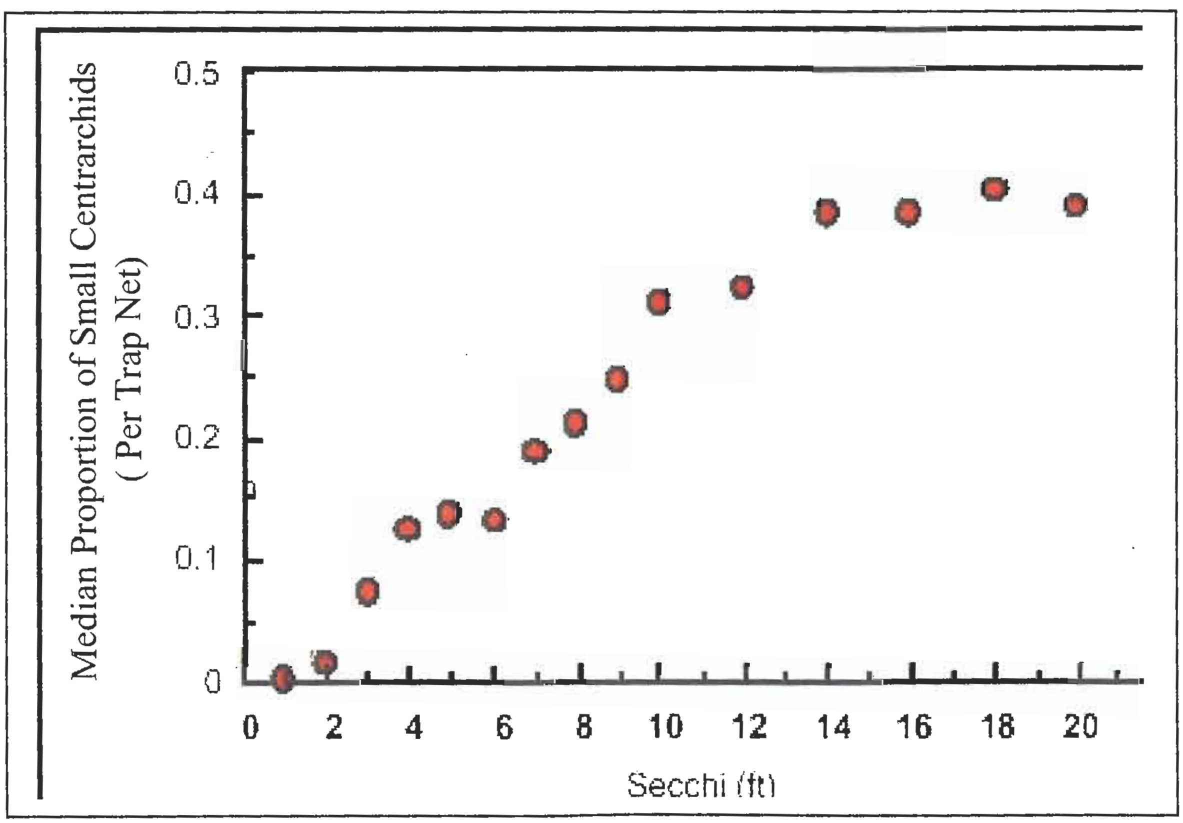
Figure 8

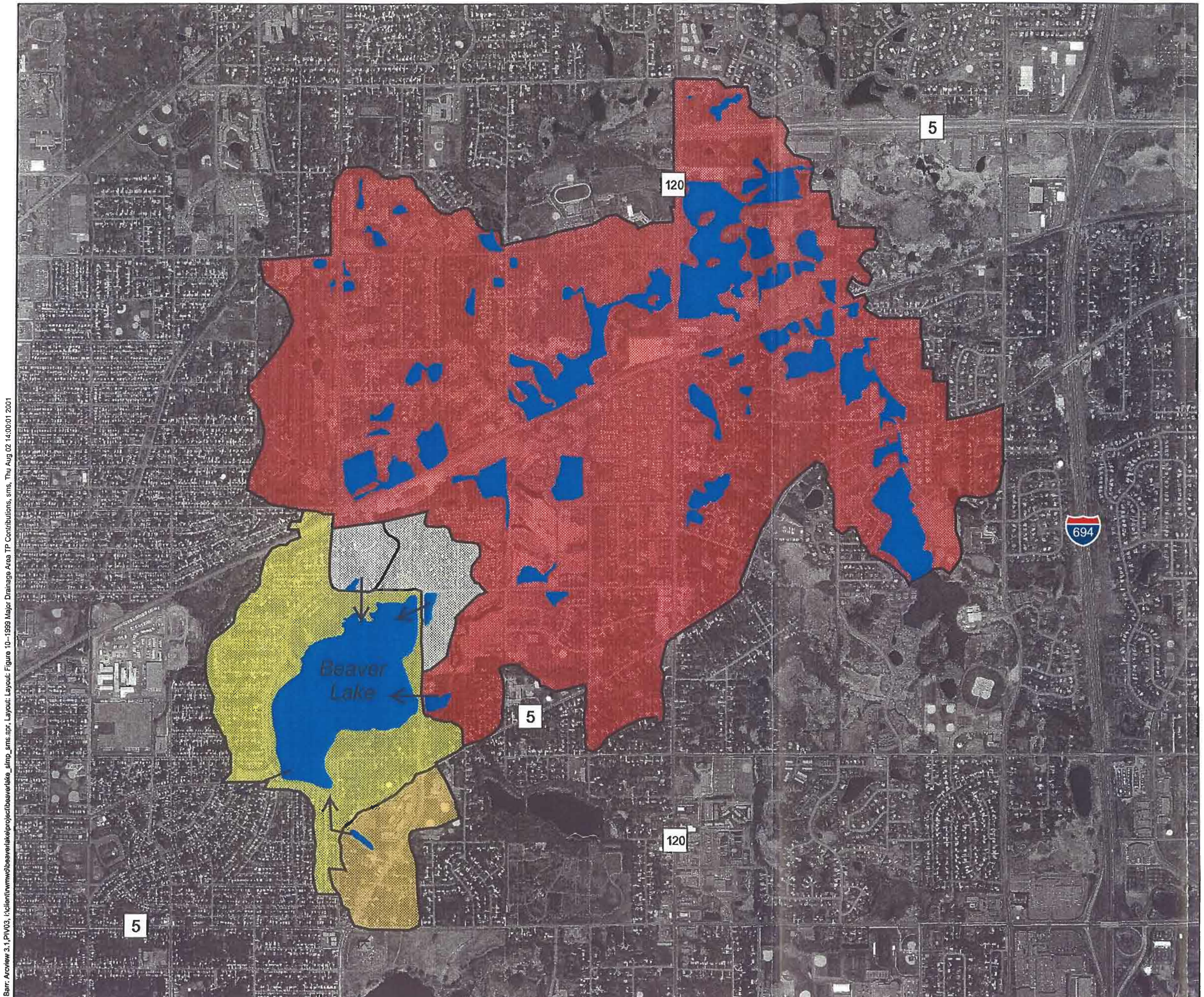
Fisheries Quality vs. Water Transparency





P:\Rwmwd_Projects\2362742\Fisheries\Figure 9 graphs.ppt

Figure 9



Flow Direction
Ponds

Major Drainage Area
TP Contributions
(Percent of Total Load)

- 1%
- 2%
- 21%
- 4%
- 71%

N

1500 0 1500

Scale in Feet

Figure 10

BEAVER LAKE SUBWATERSHED

MAJOR DRAINAGE AREA TP

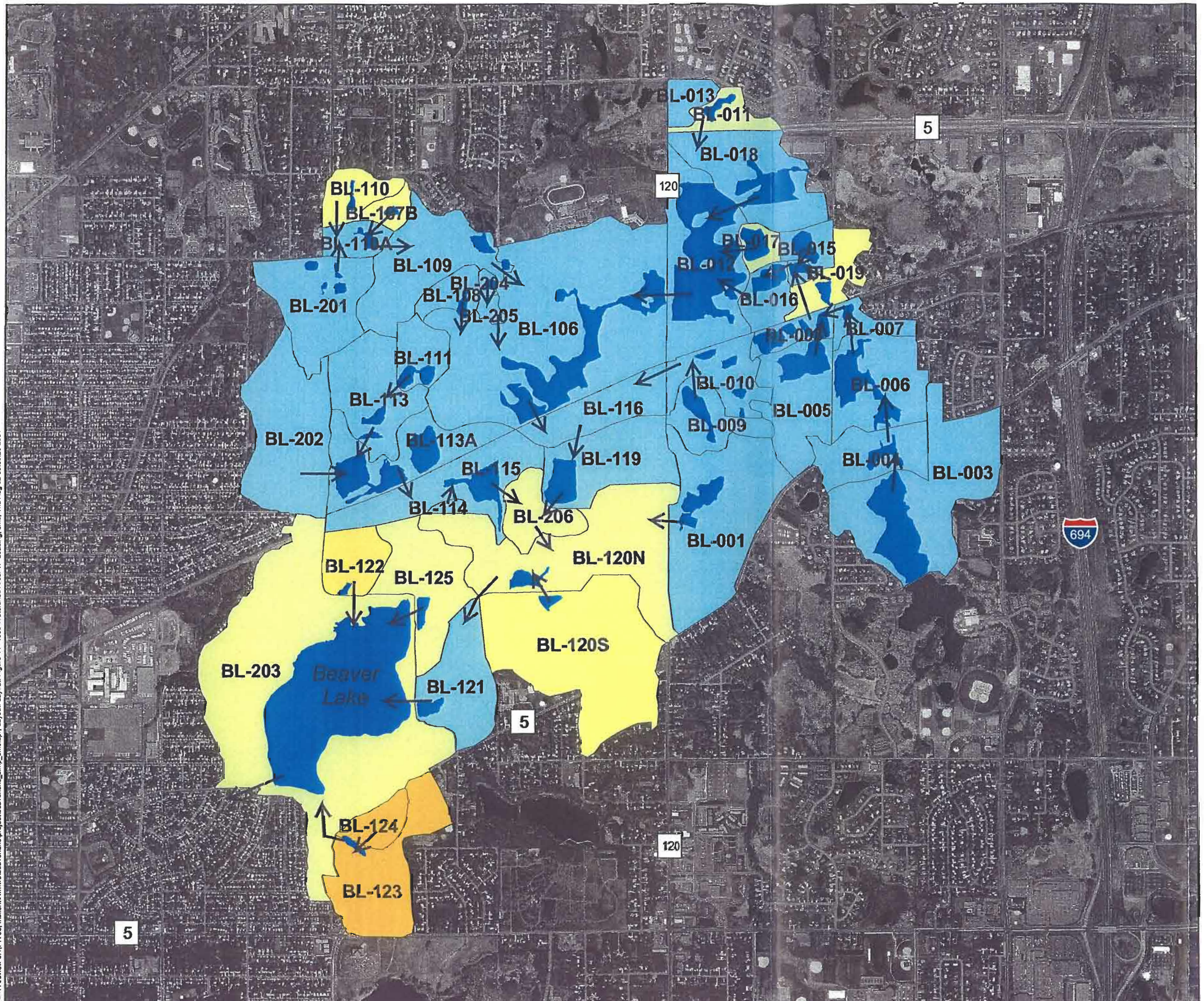
CONTRIBUTIONS FOR 1999

Ramsey-Washington Metro Watershed District

Ramsey-Washington Metro Watershed District

BARR

Barr: Arcview 3.1,PIV03, I:\client\rwmwd\beaverlake\project\beaverlake_simp_sms.apr, Layout: Layout: Figure 10--1999 Major Drainage Area TP Contributions, sms, Thu Aug 02 14:00:01 2001



Flow Direction
Ponds
Total WS Areal TP Loading (lbs/ac/yr)
0.1 - 0.3
0.3- 0.5
0.5 - 0.8
0.8 - 1.0
1.0- 1.3

N

1500 0 1500
Scale in Feet

Figure 11

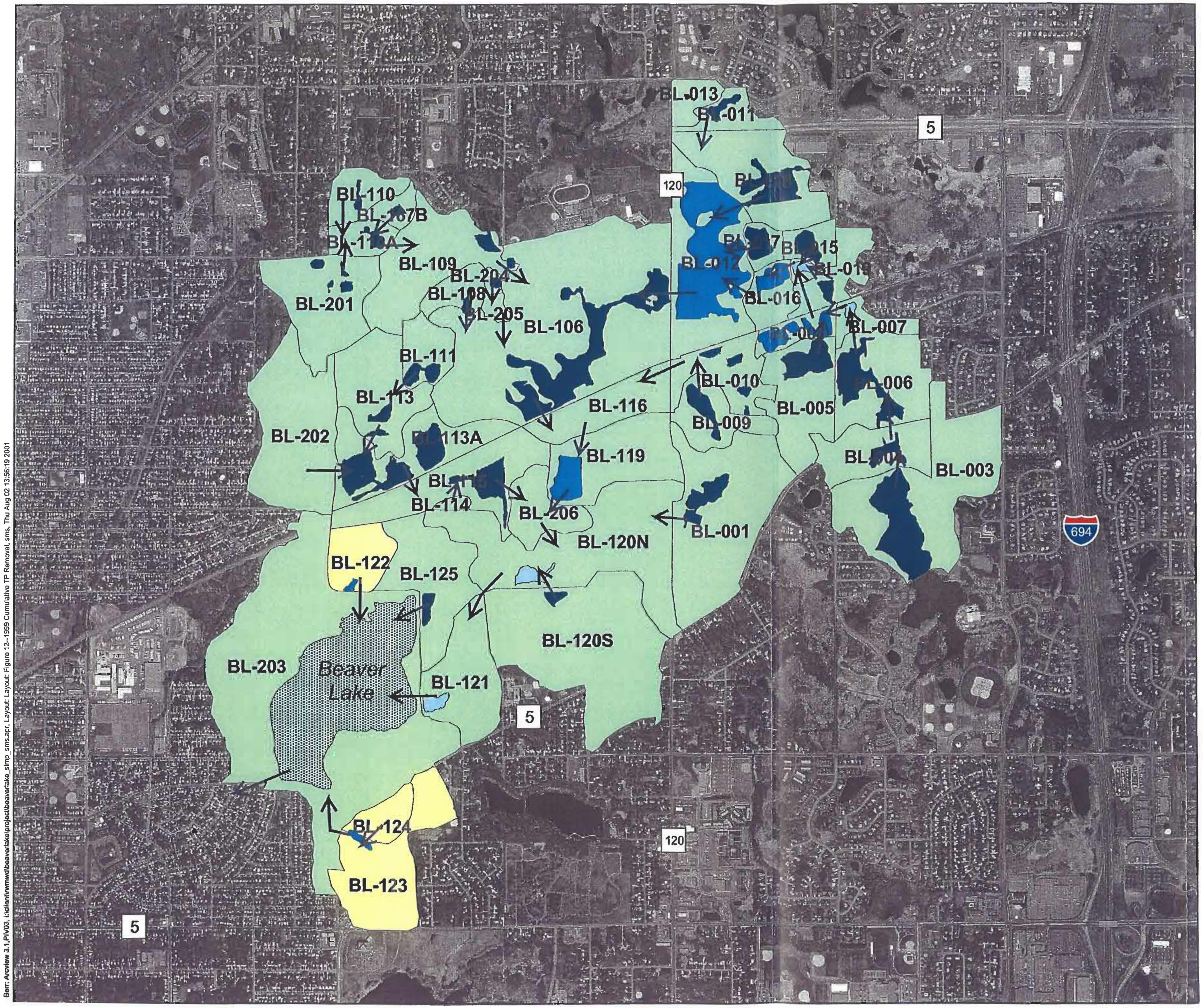
BEAVER LAKE SUBWATERSHED
AREAL TP LOADING

Ramsey-Washington Metro Watershed District

Ramsey-Washington Metro Watershed District

BARR

Barr: Arcview 3.1,P:\V03, I:\client\rwmwd\beaverlake\project\beaverlake_simp_sms.apr, Layout: Layout: Figure 11--1999 Watershed Areal TP Loading, sms, Thu Aug 02 09:56:29 2001



Flow Direction
Beaver Lake

Fraction TP Removed by Device

- 0 - 20%
- 20 - 40%
- 40 - 60%
- > 60%

Fraction of Cumulative TP Removed

- 0 - 20%
- 20 - 40%
- 40 - 60%
- >60%

N

1500 0 1500

Scale in Feet

Figure 12

BEAVER LAKE SUBWATERSHED
CUMULATIVE TOTAL
PHOSPHORUS REMOVAL

Ramsey-Washington Metro Watershed District

Beaver Lake Point Intercept Aquatic Plant Survey of the Littoral Zone

Bill Bartodziej, Robert Langer and Julie Vigness-Pint

Introduction

Aquatic plants are an integral component in Beaver Lake, providing fish and wildlife habitat, holding bottom sediments and lakeshore soils in place, and indirectly increasing water clarity. For this particular survey, we focused on the submersed and floating-leaf plant communities because they are the most dynamic in the Beaver Lake system, and relatively sensitive to changes in water quality. Additionally, active management of the submersed plant community is an option in improving overall lake quality. This type of survey data will aid in the lake planning process.

Methods

The point intercept method incorporating Global Positioning System (GPS) technology (Madsen 1999) was used to assess the submersed aquatic plant community on Beaver Lake. Sampling was conducted on July 24th, 2001. The point intercept method is currently being used by various resource management agencies, including the United Stated Geological Survey (Long Term Resource Monitoring Program) and the Minnesota Department of Natural Resources.

The crux of this method is that spot observations, presence/absence and abundance ranking data, are made at preselected locations covering the entire lake littoral zone. For the Beaver survey, evenly spaced (50-m) spot locations were superimposed on a geo-referenced aerial photograph in the software program ArcPad. The GPS unit was then linked with ArcPad in the field and boat position was plotted on a laptop computer. After reaching a point, all observational data (i.e., depth, substrate firmness, height of plants, plant species, and abundance rank) was directly entered into the ArcPad data logger. The GPS unit used in this survey provided at least 1-m accuracy.

For the plant component, a double-tined rake attached to a rope was used to collect specimens. At each point, the rake was thrown over the boat in a 1-m imaginary square. The same sampling station off the deck of the boat was used throughout the survey. After a collection was made, each species was identified and given an abundance ranking based on a percent cover of rake tines (Yin et al. 2000). Plant species that were in the 1-m sampling square but did not appear on the rake (e.g., floating leaf species) were also counted.

Percent Cover of Tines	Abundance Ranking
81-100	5
61-80	4
41-60	3
21-40	2
1-20	1

Presence/absence data can be statistically compared using the assumptions of a binomial distribution – Chi-square tests and related comparisons, rather than parametric tests based on normal distributions (Madsen 1999). Having plant data of this type will enable us to statistically compare species distribution by season or by year. This will be essential in determining the effects of watershed and lake management activities on the submersed and floating-leaf plant communities, as well as potentially assessing plant management activities. In using the point intercept method, Newman (1998) found that taking 40 to 100 samples in a lake littoral zone was adequate in producing solid estimates for common species – less than 20% error associated with the mean. Taking more than 100 samples typically did not provide better estimates. For the Beaver Lake survey, we sampled 95 points in the littoral zone.

Results

Eleven floating-leaf and submersed plant species were identified in the survey (Table 1).

Common Name	Scientific Name	Origin
Coontail	*Ceratophyllum demersum*	Native
Muskgrass	*Chara*	Native
Canada elodea	*Elodea canadensis*	Native
Common duckweed	*Lemna minor*	Native
Star duckweed	*Lemna trisulca*	Native
White water lily	*Nymphaea odorata*	Native
Curly-leaf pondweed	*Potamageton crispus*	Non-native
Flat-stem pondweed	*Potamageton zosteriformis*	Native
Pondweed (unknown)	*Potamageton* sp.	Native
Spirodela	*Spirodela polyrhiza*	Native
Wolffia	*Wolffia columbiana*	Native

Table 1: Plant taxa list generated from the point intercept aquatic plant survey – July 24th, 2001.

The native coontail was the most abundant submersed vascular plant species (Figure 1). This is a fairly aggressive submersed plant in the District, doing well in relatively turbid pond and lake systems. It lacks true roots and obtains a majority of its nutrients through the water column. Flat-stem pondweed was the most abundant rooted macrophyte. This particular pondweed is considered a sensitive species to turbidity (Davis and Brinson 1980), and is an indication that Beaver Lake still has the ability to harbor desirable native submersed vegetation. The invasive non-native curly-leaf pondweed was present at approximately 19% of the sampling locations. In late June into early July, this pondweed is at its peak abundance. Thus, our sampling effort was at the period when curly-leaf pondweed was in decline. Observations prior to our sampling suggest that this invasive species did not reach nuisance levels during its peak. Numerous curly-leaf pondweed turions (reproductive structures) were noted on the Beaver Lake water surface. This invasive species has been present in Beaver Lake since at least 1984 (T. Noonan, Ramsey

County, Pers. Comm.). The invasive non-native Eurasian water milfoil was not found in Beaver Lake during this sampling effort. A mix of native free floating-leaf species (i.e., star duckweed, common duckweed, great duckweed, and watermeal) was a large component in the littoral plant community. All of these species are able to extract nutrients from the water column and serve as indicators of nutrient enrichment.

Submersed plants were present at depths of up to seven feet. Light availability likely prevented rooted plants from establishing in deeper areas. There was a decline in percent frequency of coontail, floating-leaf species, and native submersed rooted species as water depths increased (Figure 2). Curly leaf pondweed was more common in the 3 to 7 foot depth range. Water lily was found in 1 to 5 feet of water. Individual sampling points averaged three plant species (Figure 3). The abundance rankings for individual species did not differ significantly, averaging approximately 2.5. Points with a high number of taxa, up to seven, had a mix of floating-leaf and submersed species; water depths at all of these sites were in the three to four foot range.

Maps, Figures 4-8, show the distribution of coontail, native rooted submersed species (i.e., flat-stem pondweed and Canada elodea), curly-leaf pondweed, free floating-leaf species (i.e., star duckweed, common duckweed, great duckweed, and watermeal), and white water lily. Points sampled in the north-central portion of Beaver were generally greater than 7 feet and were devoid of vegetation. Coontail, floating-leaf species, and native rooted species were widely dispersed and prevalent in all areas of the littoral zone. Curly-leaf pondweed seemed to be scattered throughout the lake, except for the northwest bay. White water lily was noted in the northeast and southwest portions of the lake.

Citations

Davis, G.J. and M.M. Brinson. 1980. Response of submersed vascular plant communities to environmental change. U.S. Fish and Wildlife Service Publ. FWS/OBS-79/33. Kearneysville, WV. 70 p.

Madsen, J. 1999. Point Intercept and Line Intercept Methods for Aquatic Plant Management. Aquatic Plant Control Technical Note MI-02. U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Newman, R.M. 1998. Assessing macrophytes in Minnesota's game lakes. MN DNR Research Report, Wetland Wildlife Populations and Research Group.

Yin, Y., J. Winkelman, and H. Langrehr. 2000. Long term resource monitoring program procedures: aquatic vegetation monitoring. Program Report 95-P002-7. U.S. Geological Survey.

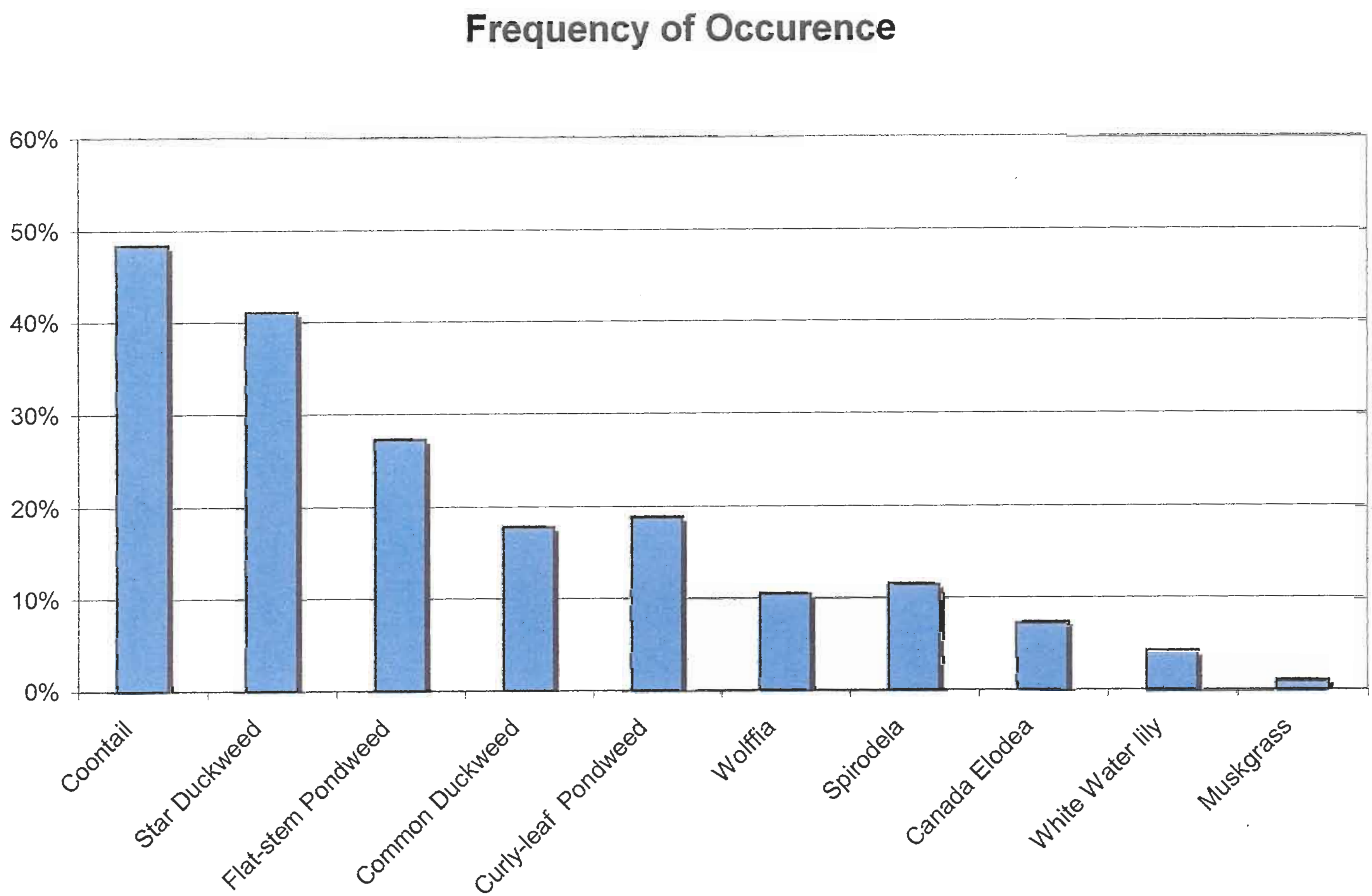
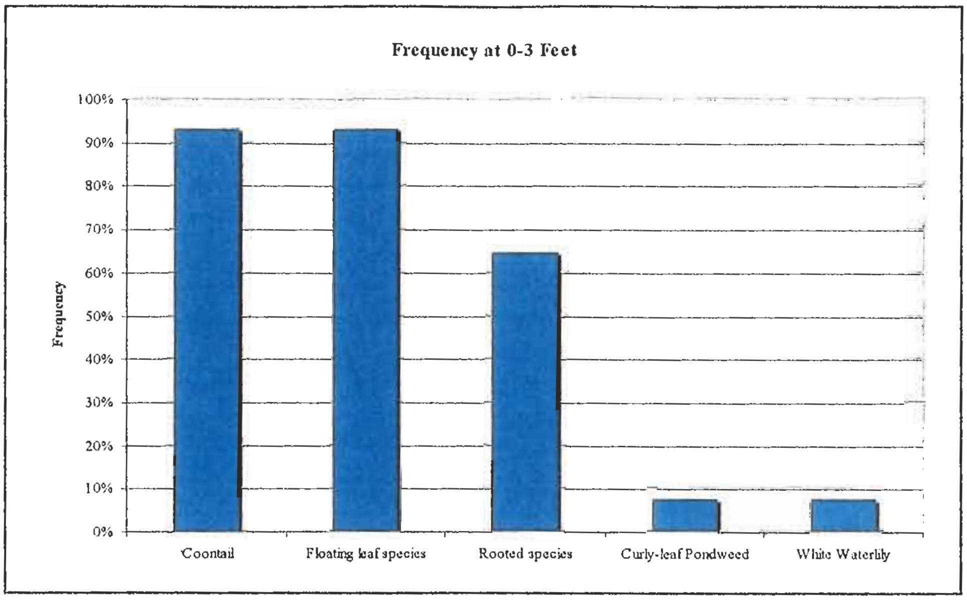
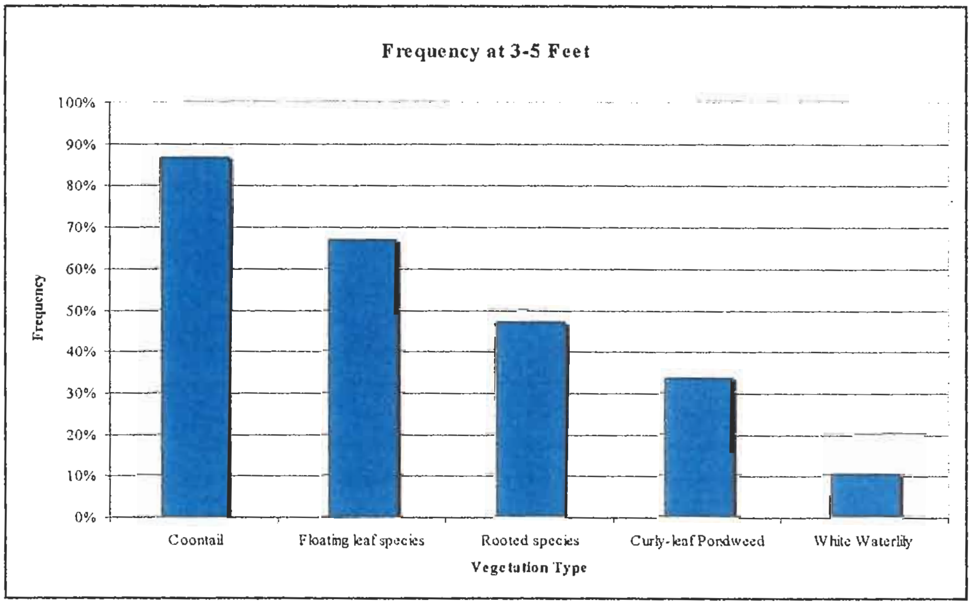


Figure 1: Percent frequency of occurrence of floating-leaf and submersed plant species.





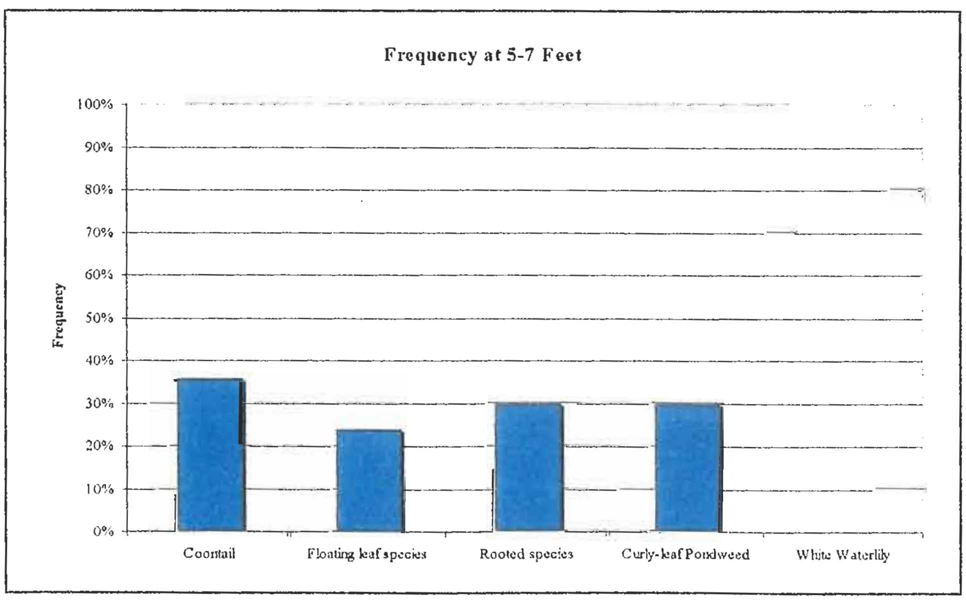


Figure 2: Percent frequency of occurrence for plant taxa and groups of taxa across 3 distinct depth ranges.

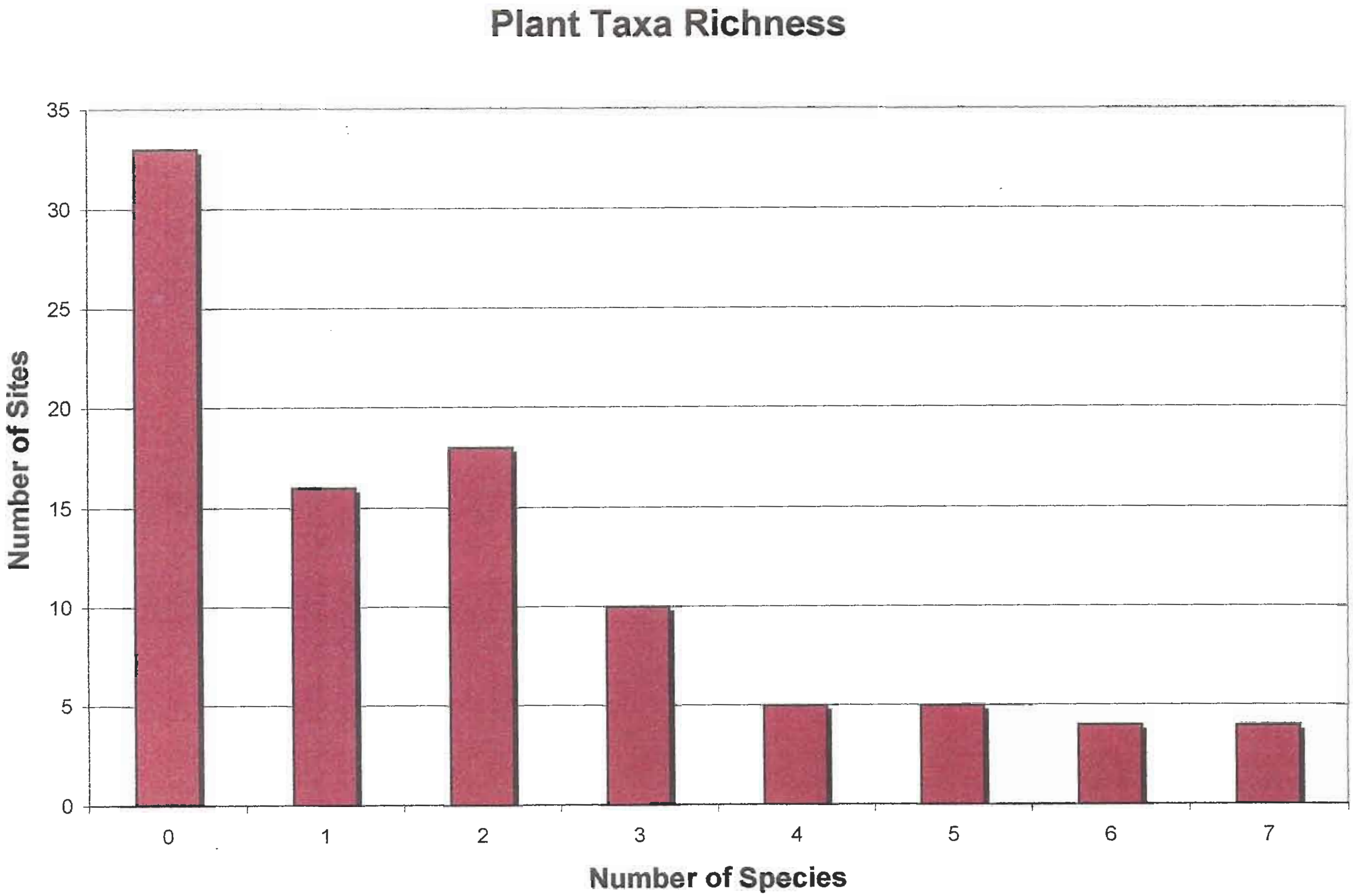
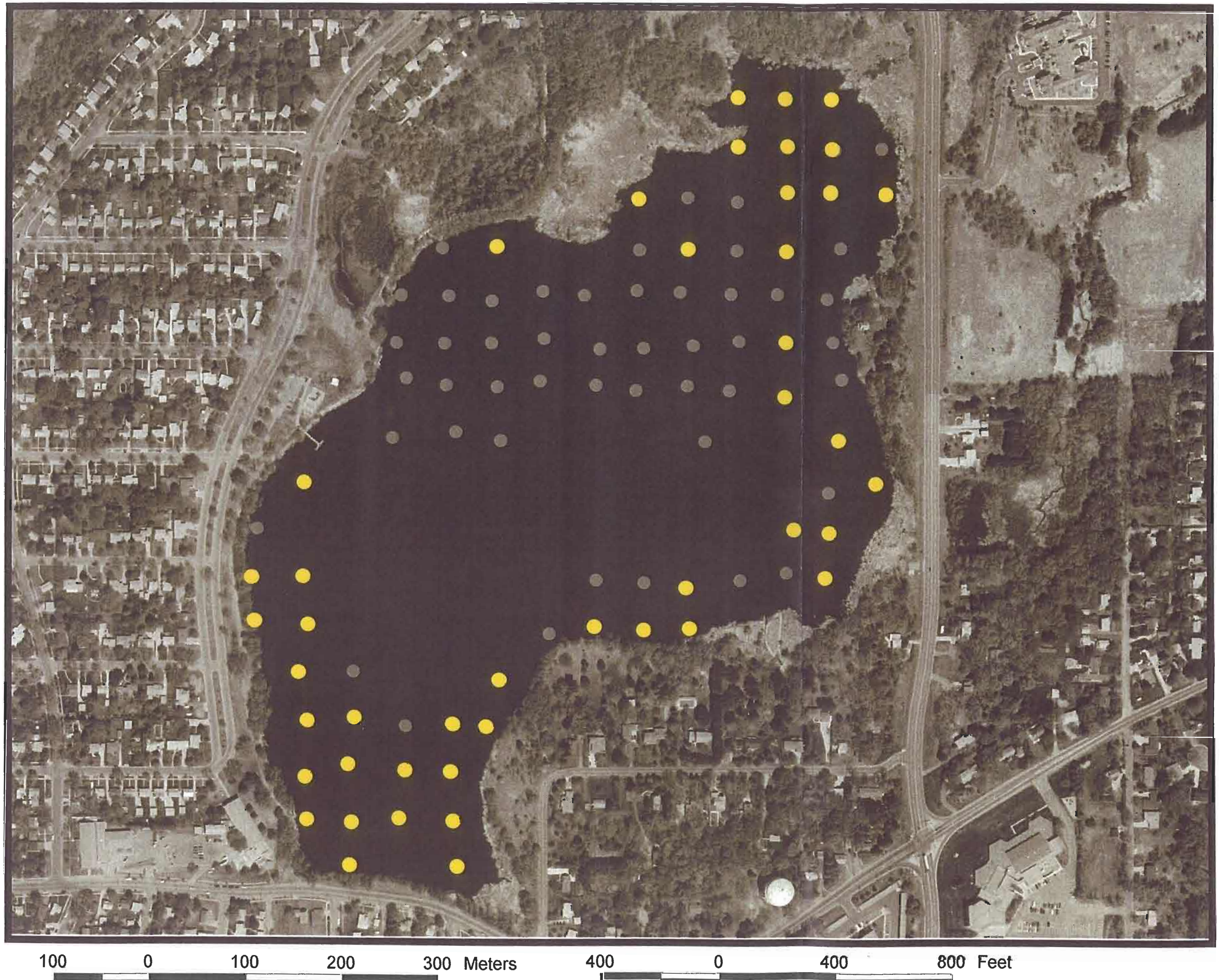


Figure 3: Taxa richness expressed by sample location versus total number of sites.



N
W E
S

Ramsey-Washington Metro Watershed District

2001 Beaver Lake
Submersed Aquatic Plant Survey

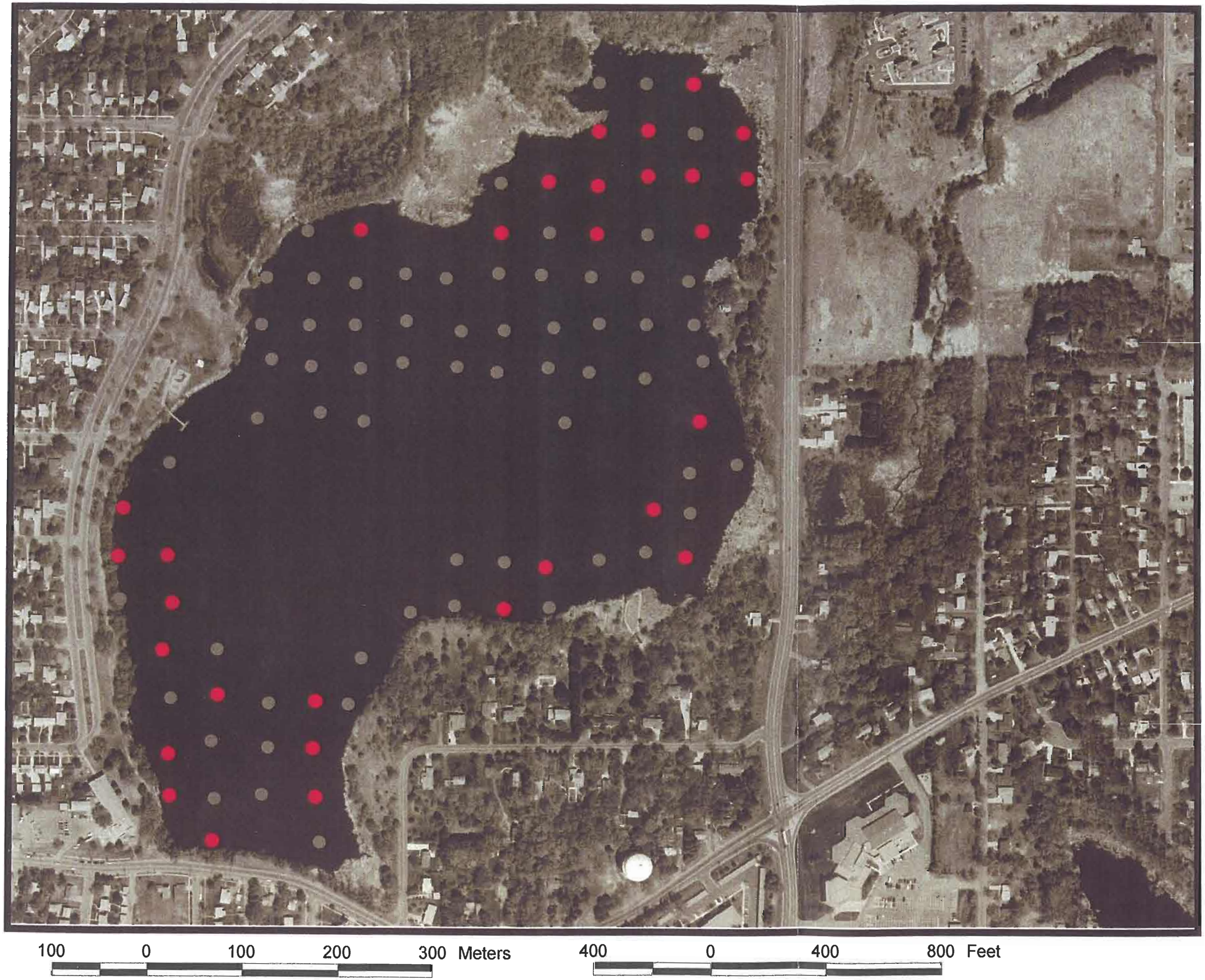
Points on map represent evenly spaced 50-m sample locations.

Coontail

Notes:

- 48% of the surveyed points had Coontail present.
- The center lake portion without points was at least 7 feet deep and devoid of vegetation.

Figure 4
Coontail Distribution



N
W E
S

Ramsey-Washington Metro
Watershed District

2001 Beaver Lake
Submersed Aquatic Plant Survey

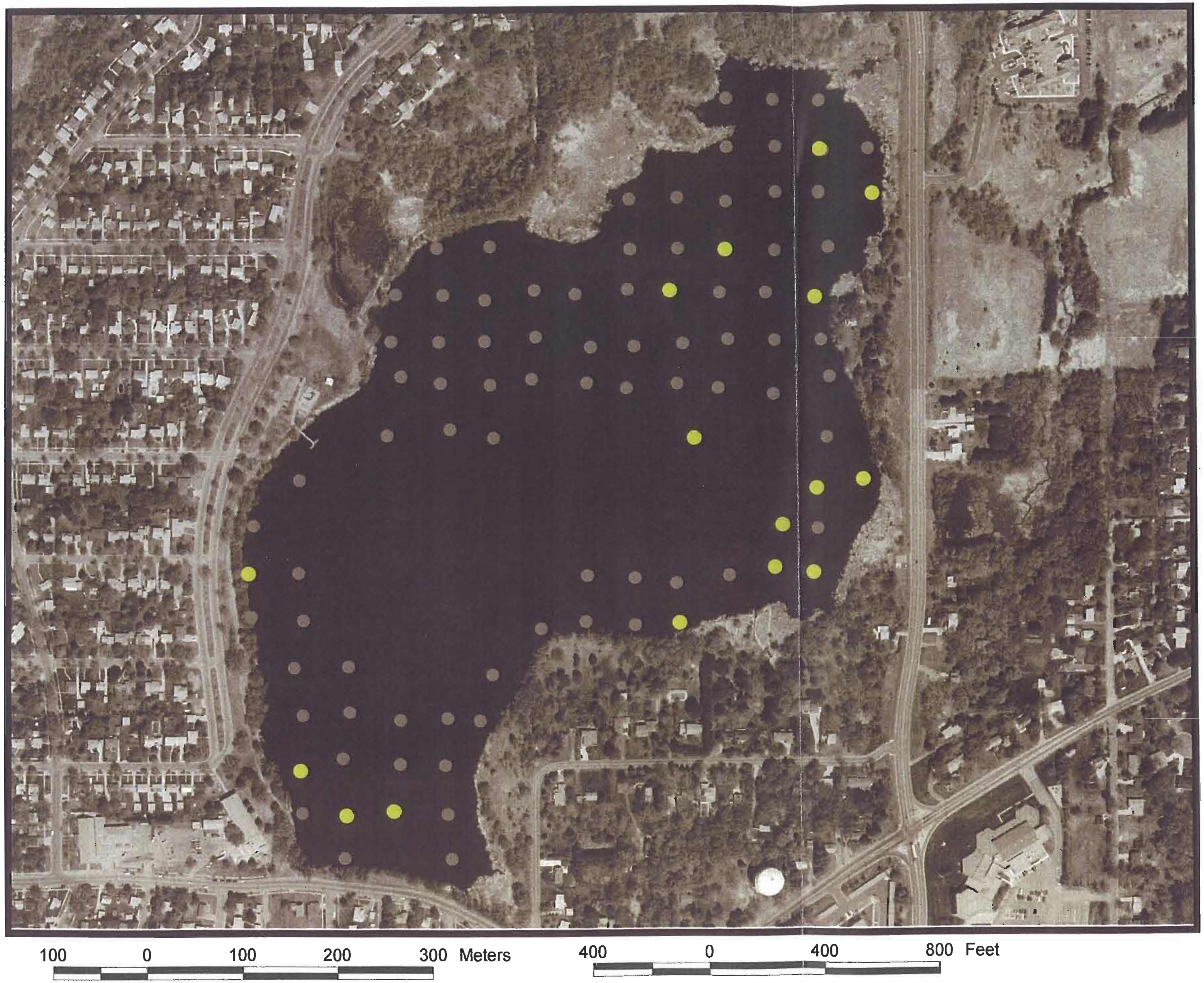
Points on map represent evenly spaced 50-m sample locations.

● Native Rooted Species

Notes:

- 32% of the surveyed points had Native Rooted Species present.
- The center lake portion without points was at least 7 feet deep and devoid of vegetation.

Figure 5
Native Rooted Species Distribution



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Ramsey-Washington Metro Watershed District

2001 Beaver Lake
Submersed Aquatic Plant Survey

Points on map represent evenly spaced 50-m sample locations.

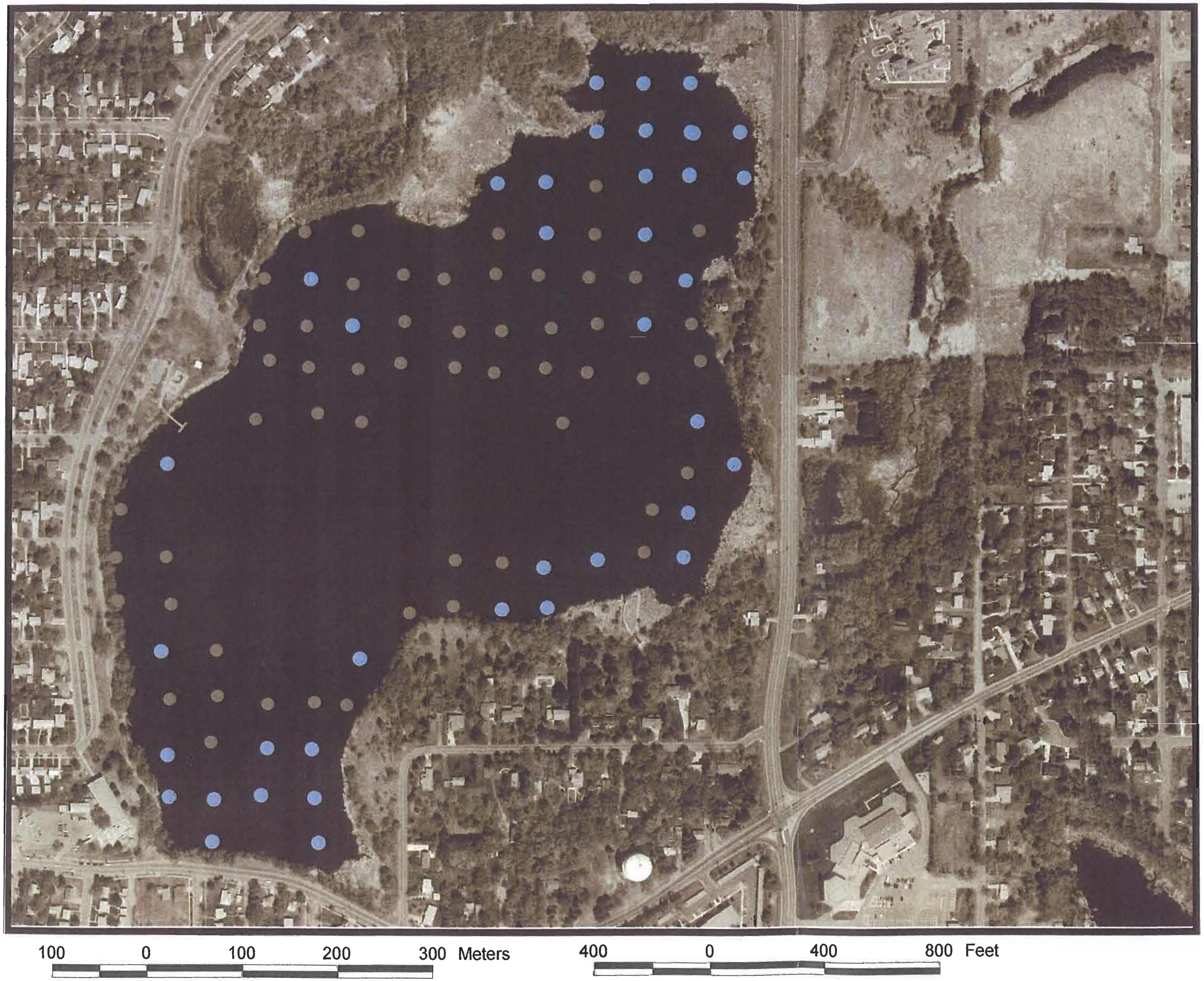
● Curly-leaf Pondweed

Notes:

- 19% of the surveyed points had Curly-leaf Pondweed present.
- The center lake portion without points was at least 7 feet deep and devoid of vegetation.

Figure 6

Curly-leaf Pondweed Distribution



N
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Ramsey-Washington Metro Watershed District

2001 Beaver Lake
Submersed Aquatic Plant Survey

Points on map represent evenly spaced 50-m sample locations.

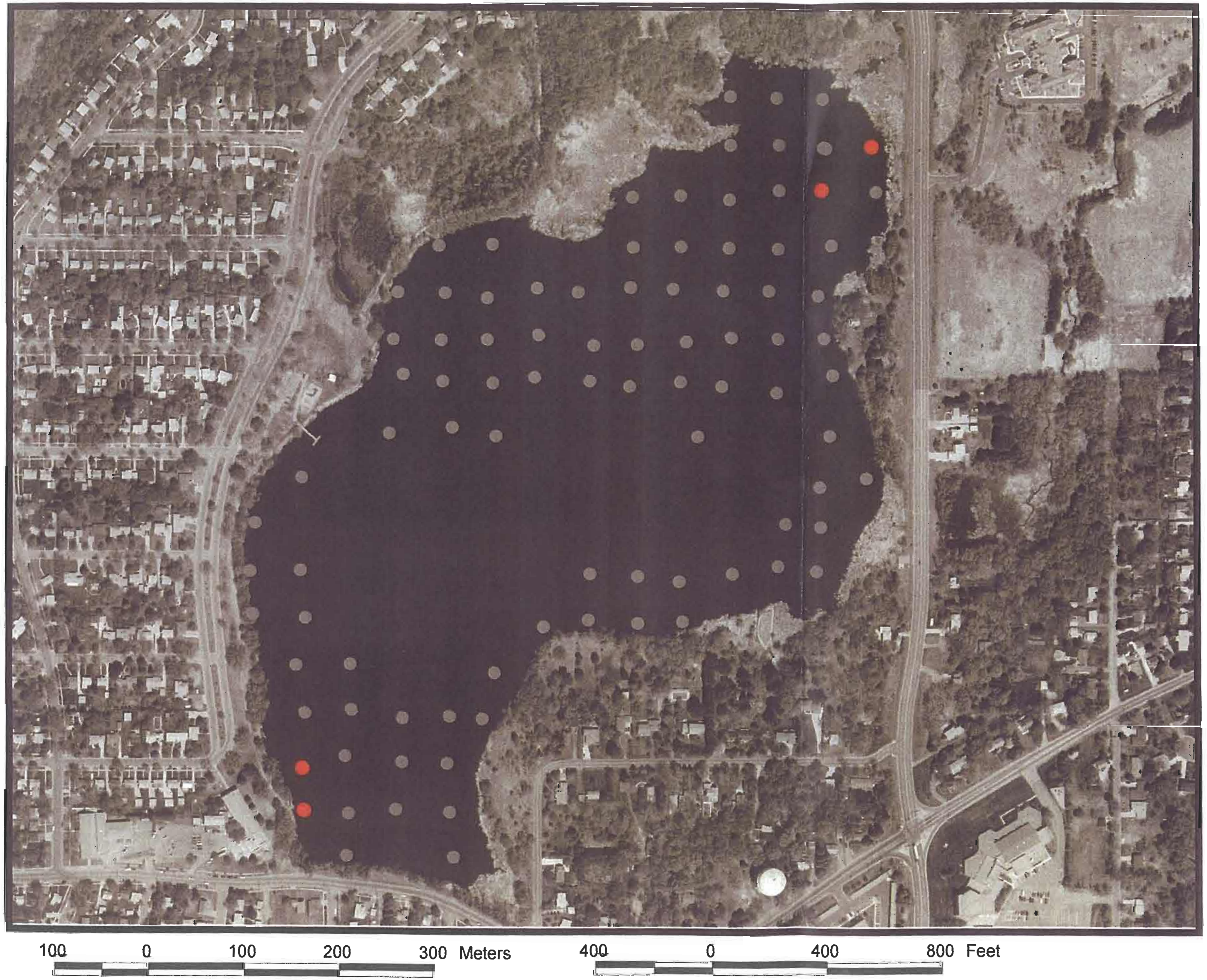
Floating-leaf Species

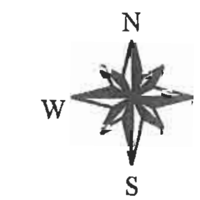
Notes:

- 42% of the surveyed points had Floating-leaf Species present.
- The center lake portion without points was at least 7 feet deep and devoid of vegetation.

Figure 7

Floating-leaf Species Distribution





Ramsey-Washington Metro Watershed District

2001 Beaver Lake
Submersed Aquatic Plant Survey

Points on map represent evenly spaced 50-m sample locations.

● White Waterlily

Notes:

- 4% of the surveyed points had White Waterlily present.
- The center lake portion without points was at least 7 feet deep and devoid of vegetation.

Figure 8
White Waterlily Distribution

Appendix B

Excerpt from Phase I Summary and Phase II Recommendations Report

Appendix B: Excerpt from Phase I Summary and Phase II Recommendations Report

In order to more closely assess the TP contribution of BL-203, we had to subdivide the watershed into 7 subwatersheds (Figure 15 in the main body of the *Beaver Lake Strategic Lake Management Plan (SLMP) report*, Barr, 2004). In doing so, we noticed that the subwatershed on the northwest side of the lake (named BL-203a in Figure 11 in the main body of the Beaver Lake SLMP report) actually does receive some treatment through the County wetland project there. The rest of the subwatersheds (BL-203b through BL-203f) receive virtually no treatment as they approach the lake.

P8 modeling conducted for the Phase I part of this study revealed that by the time the watershed runoff reaches the lake, roughly 34 percent of the lake's watershed TP load is from BL-203. 66 percent of the load is from the other watershed networks in the Beaver Lake watershed (networks terminating in BL-122, BL-125, BL-121 and BL-123). These other networks are much larger than BL-203, but their runoff is treated through a series of ponds and wetlands so the final TP load reaching the lake has been reduced through treatment. P8 was used again to estimate the TP load coming from each of BL-203's subwatersheds individually, compared to the load contributed from all of the other watershed networks combined. As Table B-1 shows, BL-203a through BL-203f contribute from 1 to 8 percent of the lake's total watershed TP load.

Table B-1: Relative Contribution of BL-203's TP Loads to Beaver Lake

Subwatershed Name	Relative TP Contribution to Beaver Lake (post existing treatment in the watershed)
BL-203a	8%
BL-203b	1%
BL-203c	5%
BL-203d	6%
BL-203e	6%
BL-203f	8%
All other subwatershed networks	66%

The conveyance of stormwater runoff in each of BL-203's subwatersheds is an important consideration in evaluating the feasibility of different treatment methods. The type of conveyance in each subwatershed is described below.

- BL-203a's runoff is carried to the wetland next to the lake via a network of stormsewers that drain to 2 different spots on the west and north sides of the County's constructed wetland.
- BL-203b's runoff is not concentrated at all- it travels overland to the lake.
- BL-203c's runoff is carried north via a network of stormsewers that connect to the stormsewer that collects outflow the pond in BL-121. This stormsewer then turns west and outlets into Beaver Lake.
- The north part of BL-203d's runoff is largely overland. A small section in the south part of the subwatershed is carried to the lake by a stormsewer network.
- Runoff from BL-203e is collected just south of Stillwater Ave. by two stormsewer pipes and carried to the lake.
- BL-203f's runoff is collected just west of Edgewater Blvd. by two stormsewer pipes and carried to the lake.

Any stormsewers mentioned above are shown on Figure 15 in the main body of the *Beaver Lake Strategic Lake Management Plan (SLMP) report, (*Barr, 2004).

Given the TP contribution of each of BL-203's subwatersheds and theirs stormwater conveyance characteristics, we made some conclusions about what kind of stormwater treatment options might be feasible for each subwatershed.

BL-203b is clearly not a good candidate for further treatment given its low TP contribution (only 1 percent), its dispersed inflows and the fact that it is void of residents who might be able to participate in housekeeping activities. Therefore, we have no recommendations for treatment in this subwatershed.

BL-203c and BL-203e are primarily residential subwatersheds. While their stormwater runoff is collected by stormsewers, there is not a clear place at the terminus of these stormsewer systems that could be used for a capital improvement project such as a wetpond, or some type of concentrated infiltration project (such as an infiltration trench or basin). However, good housekeeping measures that involve residents in these areas could be beneficial. Public education about "environmentally friendly" lawn care practices and on-lot infiltration (trying to infiltrate as much precipitation as possible on each individual lot before runoff occurs, i.e., rainwater gardens) are examples of how residents could be involved in reducing the TP load to the lake. Unfortunately, it is difficult and costly to accurately determine how much TP could be reduced by these methods- we know only that less TP would be generated. The cost of on-lot infiltration depends heavily on the complexity of the method. Rainwater gardens, for example can cost anywhere from a hundred dollars to several thousands of dollars, depending on the design. Other techniques, such as rain barrels, tend to be less expensive (~$80 per barrel), though perhaps less attractive. The effectiveness of these practices can be estimated by estimating the fraction of runoff intercepted throughout the subwatershed—this translates roughly to the fraction of TP load intercepted. For more detailed information on On-Lot Infiltration Practices, one can reference the Small Urban Sites BMP manual (Barr and Metropolitan Council, 2001).

BL-203d is unique among the subwatersheds in that it has a large number of residents with lots right on the lake. Although there are no obvious places for wetponds or concentrated infiltration projects (such as infiltration trenches or basins) in this subwatershed, residents could be taught to leave buffer zones (also called “filter strips”) between their mown yards and the lake in order to decrease the amount of runoff that reaches the lake. Filter strips are essentially cost-free. They simply involve allowing the grass and other plants to grow higher and thicker along shorelines so that runoff can be slowed and allowed to infiltrate before reaching the lake. Other kinds of plants can be incorporated into filter strips to improve aesthetics, of course, this tends to raise the price of the project. Other kinds of on-lot infiltration and/or public education could also be used in this area to decrease loadings.

The County wetland project in BL-203a already provides some stormwater treatment. P8 was used to estimate the magnitude of the wetland’s treatment efficiency. Based on the model results, it can be assumed that approximately 60 percent of the load entering the wetland from BL-203a is removed before reaching the lake. This level of treatment efficiency is consistent with the District’s goal of 60 percent removal; therefore, no further level of treatment is expected, or recommended for this subwatershed. While, the District’s goal of 60 percent TP removal is anticipated, public education efforts should extend through this subwatershed area as well.

BL-203f has several areas that could be appropriate for infiltration trenches. Infiltration trenches are generally recommended for small contributing areas (less than 2 acres). However, larger areas may be serviced if particular attention is paid to pretreatment of stormwater inflows. It is possible that the entire BL-203f subwatershed (25 acres) could be treated by a series of infiltration trenches if the following project considerations were included:

- Infiltration trenches would cover four medians in Edgewater Avenue and the open space area in BL-203a just south of the wetland, as pictured in Figure 3.
- Drop-in pretreatment devices (such as StormceptorTM) would be required at the inlet to the existing stormsewers under Edgewater Blvd. Pretreatment of stormwater runoff would be a crucial part of this infiltration trench design.
- Flow splitters (or other types of diversions) would need to be placed in the existing BL-203f stormsewers to divert the first 1" of runoff to the infiltration trench, while sending larger flows directly to Beaver Lake.
- Perforated pipe would need to be placed along the length of each infiltration trench connecting each median trench and leading to the larger infiltration trench in the open space of BL-203a.
- Soil borings would need to be taken in each trench, as well as in the open space in order to confirm the soil types in all areas (Type C in the medians and Type A in the open space were assumed for this preliminary evaluation).
- The groundwater level in these areas would require confirmation (assumed to be about level with the lake level for this evaluation).
- Trees would need to be removed from all medians.
- Public access to the open space would be discontinued. Once an infiltration trench was in place, no one could access the area.
- Utilities along the medians or in the open space would have to be moved.

This type of design could result in the removal of up to 60 percent of the incoming TP load before it reaches the lake. The cost (both design and construction) for an infiltration trench design of this magnitude would be on the order of $250,000. Of course, a smaller-scale infiltration trench project could be implemented to treat a smaller part of the subwatershed. However, the estimated cost of such projects do not appear to justify the benefit in terms of significantly reducing the lake's overall TP load (this project would remove approximately 60 percent of a maximum 8 percent of the total watershed load to the lake). Therefore, again, public education and small individual on-lot infiltration practices could be conducted in this subwatershed, although these practices are more difficult to control and have less predictable outcomes in terms of TP removal.

After an extensive re-evaluation of BL-203's subwatersheds, it appears that the best course of action may be to pursue public education and on-lot infiltration practices throughout the watershed rather than undertake an extensive capital improvement project to reduce TP loads to the lake. Because capital improvement projects, such as the infiltration trenches described for subwatershed BL-203f, are likely to be very expensive and result in a fairly small reduction in the overall TP load to the lake (~5 percent), it may be wise to turn to in-lake treatments of Beaver Lake to make a bigger impact on the lake's water quality

Appendix C:

Alum/Lime Treatment: A Lake Management Tool

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Chemical coagulation and clarification are important means of nutrient inactivation and management in surface waters. The most widely used coagulant, aluminum sulfate ($Al_2(SO_4)_3 \cdot 14H_2O$), has been treating water for centuries. Aluminum sulfate, known as alum, has been used to treat drinking water, wastewater, lakes, and other surface waters (Lind, 1997).

While alum has been used extensively throughout the world for decades, only a few select lakes have received lime and alum/lime treatments. The idea for the use of lime as a lake treatment tool is fairly recent, originating in Alberta, Canada in the late-1980's. Lime treatment of lakes and ponds was intended to solve a perplexing management problem.

On the Boreal Plain of western Canada, lakes are essential for domestic, municipal, and industrial water sources, and are often used for recreation and urban development (Prepas et. al., 2001). Man-made ponds on farms throughout western Canada (referred to as dugouts) are used as a water supply for farm operations (including household, livestock watering, and irrigation). In 1992, an estimated 25,000 dugouts were in use and more than half of the dugouts noted serious water quality problems. Problems included excessive algal growth (water greenness), macrophyte growth, and a strong taste and odor (Prepas et. al., 1992). Ellie Prepas, of the University of Alberta, worked with Engineering Services, Alberta Agriculture, to develop a new management technique involving the application of lime to dugouts and lakes to decrease nutrients and algal biomass. Lime treatment was believed to be a safe and economical management tool for dugouts, lakes, and other surface waters.

Lime ($Ca(OH)_2$, mixed with water to form a slurry, was added to lakes, ponds (dugouts), irrigation canals, and microcosm experiments. Lime slurry and liquid alum were added to three storm water retention lakes in Edmonton, Alberta. The Canadian research project spanned a 7-year period. Results were published in several journals, including *Freshwater Biology* 2001, Volume 46 (8) (Prepas et al.). Results of the alum/lime treatment of stormwater retention lakes were published in *Water Poll. Res. J.* Canada, 1992, Volume 27, No. 2, 365-381 (Babin, et al.).

The Canadian project determined:

- When water pH was kept in its natural range (i.e., <10), macrophyte biomass was controlled and invertebrate communities were unaffected.

- Application of a combination of alum and lime effectively controlled filamentous and planktonic algal growth by reducing phosphorus concentrations.
- A combination of lime, which elevates pH, and alum, which lowers pH, maintains the natural pH range of a lake during treatment.
- Lime controls macrophytes, precipitates algal cells, and removes phosphorus from the water column. However, it does not prevent sediment phosphorus release.
- A combination of lime and alum controls internal phosphorus loading by controlling sediment phosphorus release and macrophyte growth.

Because the focus of the Canadian project was control of phytoplankton, the discovery that lime effectively controls macrophytes was a surprising discovery. The Canadian research team observed that lime treatment consistently reduced macrophyte growth. Macrophyte data were collected throughout the 7-year project to evaluate the effectiveness of lime treatment as a macrophyte management tool. A brief discussion of the macrophyte evaluation follows.

The macrophyte evaluation involved lakes receiving a single dose of lime and lakes repeatedly treated with lime. Two lakes receiving a single dose of lime (74 to 107 mg/L $Ca(OH)_2$) observed a decrease in macrophyte biomass of up to 80 percent. Reference lakes observed no change in species or biomass. Two lakes were treated with lime repeatedly over a 7 -ear period (dose = 5 to 78 mg/L $Ca(OH)_2$ or $CaCO_3$). Only one of the two multiple dose lakes was studied. A 95 percent decline in macrophyte biomass was observed during the first 6 years of the study. Improved water clarity occurred and a species shift from floating plants (duckweed) to rooted plants was observed. In the 7th year of the study, the macrophyte biomass of the treated lake was the same as the pre-treatment biomass. The species shift from a low biomass species, duckweed, to higher biomass rooted species may explain the biomass increase in the treated lake during the 7th year of the study. Another explanation is that the improved water transparency may have resulted in increased macrophyte growth. Reference lakes observed no change in species or biomass during the 7-year period.

The treatment of two irrigation canals revealed the range of impacts that occur with dosing changes. One irrigation canal was treated with a low dose, 135 mg/L $Ca(OH)_2$, applied over a 24-hour period, and one irrigation canal was treated with a high dose, 210 mg/L $Ca(OH)_2$, applied over a 65-hour period. The low dose had no effect on the macrophytes, while the high dose eliminated all macrophytes for the first month after treatment. A survey 13 months after treatment indicated macrophytes were present in the high dose irrigation canal, but at a reduced density and biomass.

Microcosm experiments were completed and changes in biomass were measured. No consistent change in biomass was observed. However, when lime slurry doses were greater than 200 mg/L $Ca(OH)_2$ or mixed $Ca(OH)_2/CaCO_3$, plants lost their pigmentation and under natural conditions (turbulence or an age greater than 33 days) the plants would have broken up.

Data from the Canadian research project indicated lime treatment controlled macrophytes. Reduced plant biomass and species changes were observed following treatment. Lime is a nontoxic and economical tool for the effective management of aquatic plants.

The consistent benefits of lime treatment led to the completion of two projects by Barr Engineering Company. One project was a pilot project in Wisconsin and one project was a treatment of two Minnesota lakes. Results of the two projects follow.

The pilot project in Wisconsin involved an evaluation of three treatment options:

- Early-summer lime slurry treatment (doses were 150 g/m^2 $Ca(OH)_2$ during the first treatment year and 300 g/m^2 $Ca(OH)_2$ during the second treatment year).
- Spring herbicide treatment (diquat—Reward @ a dose of 2 gal/ac).
- Spring harvesting.

Replicate control and treatment plots were selected. Treatment occurred during 1998 through 1999 and a study of the plots occurred during 1998 through 2000. The study results indicated (Barr, 2001):

- All treatments were effective in 1998
- Harvesting was not effective in 1999.
- No harvesting residual effects were observed in 2000.
- Lime slurry and herbicide treatment were effective in all years.
- Lime slurry was more effective than herbicide in 1998.
- Herbicide was more effective than lime slurry in 1999.
- Residual effects from both treatments were observed in 2000.
- Lime slurry encouraged the growth of native species.
- Herbicide encouraged the growth of exotic species by creating open areas which were colonized by exotic species during the year following treatment.

- Lime slurry was the most effective treatment for reducing plant density, biomass, and encouraging the growth of native species.
- Curlyleaf pondweed was not observed in the lime treated plots, although the plant was found throughout the lake. A 1996 plant survey indicated curlyleaf pondweed was observed in 77 percent of the lake's sample points and was the most frequently sited species (Barr, 1997).

Two Minnesota lakes received a combined treatment of alum and lime slurry to control vegetation and reduce internal phosphorus loading. Lakes Clifford and Faille, located in the Sauk River Watershed District near Osakis, Minnesota, were treated with 30 grams aluminum per square meter and 300 grams $Ca(OH)_2$ per square meter during April of 2002. A third lake, Stevens, located between Clifford and Faille in the three-lake chain, was not treated.

Prior to treatment, Clifford and Faille noted high phosphorus concentrations, severe algal blooms, and poor water transparency throughout the summer. A very dense curlyleaf pondweed growth was observed in the lakes during the early-summer. A Sauk River staff person indicated efforts to boat on the lakes during the early-summer period, prior to treatment, were thwarted by the motor killing approximately every 10 feet due to the dense plant growths. District staff reported that no plant problems occurred after the alum/lime slurry treatment. Staff indicated the 2002 plant communities were comprised of sufficient native vegetation to support the lakes' fishery. Curlyleaf pondweed, an exotic species, was not observed in the lakes where alum and lime were applied. A small untreated bay and a rocky area inaccessible to the treatment barge noted curlyleaf pondweed growth in 2002. The siting of curlyleaf pondweed in the untreated areas confirmed the plant's ability to grow in the lakes. Its absence in the remaining portion of the lakes indicated the effectiveness of the alum/lime treatment to eliminate curlyleaf pondweed growth (Nelson, 2003).

Clifford and Faille observed excellent water transparency following treatment—the bottom was visible in both lakes. The water transparency in Clifford remained excellent throughout the summer (the bottom was visible all summer). Water transparency in Faille became poor following an 8-inch rainstorm during July. Stormwater from the City of Osakis was conveyed to Faille during the storm resulting in turbid water. Hot temperatures followed the storm and severe algal blooms occurred in Faille (Nelson, 2003).

The Canadian, Wisconsin, and Minnesota projects concluded that lime treatment effectively controls macrophyte growth, but did not determine the mode of action. Three hypotheses were suggested with a recommendation that further research be completed to determine whether they were true. The hypotheses are:

- Lime slurry treatment alters the lake's sediment chemistry. Specifically, the calcium in the lime may bind to phosphorus in the sediment or in the pore waters (water between sediment particles) making the phosphorus unavailable to plants. Immobilization of mobile phosphorus may create a phosphorus-limiting situation, thereby controlling the number of plants per square meter that may grow. Hence, lime treatment may control plant density by phosphorus limitation.
- Ammonia is vulnerable to change with changing pH conditions. The temporary change in pH resulting from the lime application may cause a change from NH_4 to NH_3. This change may create a nitrogen-limiting situation by changing available nitrogen to a form that is not available for plant growth. Hence, lime treatment may control plant density by nitrogen limitation.
- The temporary change in pH resulting from lime application may reduce carbon availability to plants, thereby interfering with plant photosynthesis. Hence, lime treatment may control plant density by carbon limitation.
- Lime precipitation on the plant leaves may interfere with plant photosynthesis. Hence, lime treatment may control plant growth by light limitation.
- Following a reduction in plant density, plants do not appear to rebound and the community seems to remain at a lower density.

The U.S. Army Corps of Engineers recently began a research project to study lime slurry effects on aquatic vegetation and define its mode of action. Mesocosm experiments are being conducted at the Eau Galle Aquatic Ecology Lab at Springfield, Wisconsin. Whole lake treatments are planned following completion of the laboratory experiments.

The results of the Canadian research projects, the Wisconsin pilot project, and the Minnesota whole lake treatments suggest treatment of Beaver Lake with a combination of alum and lime would effectively manage the lake's problematic internal phosphorus load. A treatment dose of 40 grams aluminum and 300 grams $Ca(OH)_2$ per square meter is recommended. Alum treatment is expected to reduce the lake's sediment phosphorus release rate by approximately 90 percent. Lime treatment is expected to effectively control the lake's macrophyte community. Reduction or elimination of the lake's curlyleaf pondweed by the lime treatment is expected to further reduce the lake's internal phosphorus load.