Susan and Rice Marsh Lake
Use Attainability Analysis

Prepared for
Riley-Purgatory-Bluff Creek Watershed District

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Lake Susan and Rice Marsh Lake

Use Attainability Analysis

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Executive Summary

This report describes the results of the Use Attainability Analysis (UAA) for Lake Susan and Rice Marsh Lake. The UAA provides the scientific foundation for a lake-specific best management plan that will maintain or attain the existing and potential beneficial uses of Lake Susan and Rice Marsh Lake. Because the two lakes' watersheds are adjacent, and because Lake Susan drains to Rice Marsh Lake, the UAA for both lakes was conducted in tandem. The results of both analyses are presented in this report.

This study includes both a water quality analysis and an analysis of possible remedial measures for Lake Susan and Rice Marsh Lake and the lakes' watersheds. The conclusions and recommendations are based on historical water quality data and on the results of an intensive lake water quality monitoring program conducted in 1997. In addition, the analysis relies on computer simulations of land use impacts on water quality in Lake Susan and Rice Marsh Lake. The watershed model, in combination with the lake model, was calibrated to the 1997 data set. After calibration, best management practices (BMPs) were evaluated to compare the relative effect of BMPs on total phosphorus and chlorophyll *a* concentrations and Secchi disc transparencies (i.e. measurements of water clarity).

The *1989 Lake Riley Chain of Lakes Improvement Project Work Plan* (RPBCWD, April 5, 1989) identifies total phosphorus concentrations consistent with general lake use categories. The document indicates that a "Level II" water body (supporting boating but not full-body water contact activities such as swimming or scuba diving) should have total phosphorus concentrations in the 45 to 75 μg/L range. A "Level III" water body (supporting fish and wildlife populations, and providing aesthetic viewing) should have total phosphorus concentrations in the 75 to 105 μg /L range. These two ranges provide realistic targets for total phosphorus concentrations Lake Susan (Level II) and Rice Marsh Lake (Level III).

Specific water quality goals for Lake Susan and Rice Marsh Lake have not been previously established by the Riley-Purgatory-Bluff Creek Watershed District (RPBCWD), and neither the Minnesota Pollution Control Agency (MPCA) nor the Minnesota Department of Natural Resources (MDNR) have established specific water quality targets for the lakes. Similarly, the natural resource managers in the two cities in which the lakes are located (Chanhassen and Eden Prairie) have not established water quality goals for either of the two lakes[1]. Despite the lack of specific water quality targets for the lakes, the RPBCWD expects both lakes to continue as valued recreational assets to the community. Lake Susan should continue to be used for boating and fishing (although its water quality would not be expected to be generally suitable for swimming). Rice Marsh Lake should continue primarily as an aesthetic amenity, supporting fish and wildlife without being expected to provide significant opportunities for boating or swimming.

The lakes' position within the Riley chain of lakes also makes lake water quality management important. Fed by the water draining from Lakes Lucy and Ann, Lake Susan and Rice Marsh Lake in turn drain to Lake Riley. Lake Riley is a key recreational resource for the Cities of Chanhassen and Eden Prairie, and for the RPBCWD in general. Because water leaving Rice Marsh Lake discharges directly to Lake Riley, it is important to keep phosphorus concentrations as low as possible in Rice Marsh Lake (and the upstream lakes Susan, Ann, and Lucy).

MNLEAP[2] modeling (to ascertain pre-settlement lake water conditions) suggests that prior to agricultural use and urbanization of the lakes' watersheds, the average summer total phosphorus concentration in Lake Susan was 52 μg /L, and 62 μg /L in Rice Marsh Lake. Urban impacts are evident in the fact that in recent years, total phosphorus concentrations in Lake Susan and Rice Marsh lake have averaged 90 μg /L and 207 μg /L respectively. However, the water quality data collected by the RPBCWD over the past 25 years shows that the average total phosphorus concentrations in both lakes have been declining, and specific watershed and lake management initiatives may allow substantial continued improvement.

For the UAA analysis, current (1997) Lake Susan and Rice Marsh Lake water quality data were evaluated based on a standardized lake rating system. The rating system uses the lake's total phosphorus, Chlorophyll *a*, and Secchi disc transparency measurements to assign the lake to a water quality category that best describes its water quality. Water quality categories include oligotrophic (i.e. excellent water quality), mesotrophic (i.e. good water quality), eutrophic (i.e. poor water

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1 Only one specific goal of any sort was identified for either of the two lakes: an ad hoc goal (50-60 ug/L summer average phosphorus concentration) for Lake Susan that was mentioned in a February 1999 report (*Lake Susan Restoration Evaluation for 1998*, Blue Water Science) to the City of Chanhassen.

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

quality), and hypereutrophic (i.e. very poor water quality). Total phosphorus, chlorophyll *a*, and Secchi disc transparency are key water quality indicators for the following reasons.

- Phosphorus generally controls the growth of algae in lake systems. Of all the substances needed for biological growth, phosphorus is typically in shortest supply and therefore is the "limiting" nutrient.
- Chlorophyll *a* is the main pigment in algae. The amount of Chlorophyll *a* in the water indicates the abundance of algae present in the lake
- Secchi disc transparency is a measure of water clarity, and water clarity is inversely related to the abundance of algae. As water clarity diminishes, recreational uses for a lake become more and more limited.

Figures EX-1 and EX-2 (all Executive Summary tables and figures are located at the end of the summary) summarize the seasonal changes in the concentration of total phosphorus, chlorophyll *a*, and Secchi disc transparency for Lake Susan and Rice Marsh Lake during 1997. The total phosphorus data shown are compared to a standardized lake trophic state rating system on Figure EX-3. Lake Susan's average 1997 summer total phosphorus concentration (95 μg /L) places the lake in the hypereutrophic category; such is also the case with Rice Marsh Lake (168 μg /L). Figures EX-1 and EX-2 show that there is significant seasonal variation in the water quality of Lake Susan and Rice Marsh Lake. Both show reduced transparency, increased chlorophyll *a*, and increased total phosphorus during late summer.

The watersheds of both Lake Susan and Rice Marsh Lake are already mostly urbanized, although the Lake Susan Watershed shows relatively more area in a natural condition (Figure EX-4 and Table EX-1). In the urbanized portion of the watersheds, residential use (primarily medium-density) predominates, with both watersheds showing significant commercial and industrial use toward the north. In the Lake Susan watershed, significant portions of the remaining natural and agricultural areas (in the southwest and northwest portions of the watershed) are scheduled for future residential and commercial use. Rice Marsh Lake's watershed has relatively less area remaining available for urban use; most of that is scheduled for conversion to residential use.

Conclusions of Use Attainability Analysis

The following conclusions were derived from the analysis of collected lake and watershed data, and from the computer simulations of watershed runoff impacts on Lake Susan and Rice Marsh Lake's water quality:

- Land use information shows that the lakes' watersheds are mostly urbanized, however, future development and redevelopment within the watershed can be expected to result in density increases, increased impervious area, and increased phosphorus loading to the lake.
- Analysis of monitored lake total phosphorus, chlorophyll *a*, and Secchi disc transparency for 1989, 1993, and 1997 indicate significant variability from year to year. The variability reflects annual and seasonal variations in watershed runoff amounts, and also is a result of the complex interactions between weather conditions and in-lake phosphorus dynamics. Within the variability a generally downward trend in phosphorus concentrations may be discerned, and lake and watershed management initiatives have the potential for further diminishing watershed phosphorus loading and in-lake phosphorus concentrations. Such initiatives will increase the lakes' suitability for the uses they now provide.
- Macrophyte (i.e. aquatic plant) surveys were conducted during June and August 1997. The current macrophyte communities in Lake Susan and Rice Marsh Lake are diverse. Notably, Lake Susan shows thriving populations of white and yellow water lilies, unusual for metropolitan lakes. However, both lakes show significant portions of their littoral zones dominated by the exotic plant curly leaf pondweed (*Potamogeton crispus*). The life cycle of this aquatic plant includes an early (July) die-off. Following the die-off, the dead plants decompose and release phosphorus into the lake water. As a result, the large stands of curlyleaf pondweed in the lakes may be contributing to the frequently observed late summer increases in the lakes' phosphorus concentrations. The plant fragments themselves may also be partly and directly responsible for the lakes' diminished transparency in late-summer.
- Analysis of many years of water quality sampling data indicates that neither Lake Susan nor Rice Marsh Lake is likely to show large increases in transparency even with optimal watershed management and control of phosphorus loading to the lakes. Nevertheless, the 1998 data collected for Lake Susan suggests that alum treatment of the lakes may provide

a means of providing noticeable improvements in water clarity. The 1998 data show that seasonal improvements are significant, and the improvements in water clarity may extend over several years if the alum treatment succeeds in sealing the lake sediments to prevent phosphorus release.

- Analysis of the recently collected phytoplankton and zooplankton data (1989 and 1997) provides no significant guidance for lake management. However, preservation of healthy and diverse aquatic communities is central to the lakes' roles as regional recreational amenities; these biological communities will benefit from improved lake management.
- Computer simulations and observed water quality data indicate that phosphorus inputs to the lake are from watershed and atmospheric loads (external sources). Internal loading (phosphorus release from the lake bottom sediments) also appears to have a significant impact on the water quality of both Lake Susan and Rice Marsh Lake. The sampling data indicate that the consistently high August phosphorus concentration in both lakes results from phosphorus release from the lake sediments.
- Water quality simulations using the P8 model indicate that dry weather conditions will produce the greatest strain upon water quality in Lake Susan and Rice Marsh Lake. This is so despite the higher total load of phosphorus to the lake during wet weather; wetter weather results in larger volumes of relatively less concentrated water passing through the lakes, so that in-lake phosphorus concentrations remain low. Despite the diminished phosphorus loading under dry conditions, the lakes' flushing rate is also diminished, so the in-lake phosphorus concentrations become elevated.

Recommended Best Management Practices to Improve Water Quality

The following BMPs should be considered for implementation by the District to maintain and enhance the beneficial uses of Lake Susan and Rice Marsh Lake under all climatic conditions. (It should also be noted that the proposed management initiatives will have a direct impact on Lake Riley, which receives outflow water from Lake Susan and Rice Marsh Lake.) The anticipated cumulative effects of implementing the management recommendations are illustrated on Figures EX-5 and EX-6. The cumulative water quality benefits are illustrated in terms of anticipated declines in summer average phosphorus concentrations.

- **Implement**—It was assumed that the Water Management Plans of the City of Chanhassen, the City of Eden Prairie, and the RPBCWD would be completely implemented. Therefore, properly designed stormwater treatment ponds would accompany future urbanization. This assumption was accounted for in the water quality modeling and in the estimates of costs for water quality treatment upgrades and additions. Ponds that would be improved or added as a consequence of future urbanization include 2.1, 2.2, 3.13, 3.62, 3.14, 3.52, 3.91, and 3.92 in the Lake Susan Watershed; and ponds 1.3, 3.10, 4.1, 4.4, and 5.4 in the Rice Marsh Lake watershed (Figure EX-7).

- **Upgrade**—Upgrading the existing ponds in Lake Susan and Rice Marsh Lake's watershed that do not currently meet NURP criteria[3] would result in improved runoff treatment effectiveness and reduced phosphorus loading to the lake. Optimal treatment effectiveness requires that the ponds be designed to have wet detention volumes capable of storing the runoff that would result from 2.5 inches of rainfall over the individual subwatershed (for a local pond) or group of subwatersheds (for a regional pond). In some cases, space limitations make it impossible to achieve the optimum wet detention volume, but increasing the wet detention volume will nevertheless improve water treatment. For Lake Susan, pond 3.21 would be upgraded; for Rice Marsh Lake, improvements are recommended for ponds 2.1, 2.2, 2.4, 2.6, and 6.5 (Figure EX-8).

  Bringing existing ponds into compliance with NURP guidelines is not expected to produce significant water quality benefits. Phosphorus loading to the lakes is expected to be reduced by 3 to 5 lbs. per year for Lake Susan and by 6 to 12 lbs. per year for Rice Marsh Lake. For both lakes, these relatively small loading decreases correspond to a small (0-1 μg /L) reduction in the lake's summer average total phosphorus. The actual amount of the reduction in loading and lake phosphorus concentrations will depend on climatic conditions and other factors. **The cost of making the upgrade for the single Lake Susan pond is approximately $27,000; for Rice Marsh Lake the upgrade cost for the five ponds would be approximately $191,000.**

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3 As defined in: William Walker, *Design Calculations for Wet Detention Ponds (prepared for the St. Paul Water Utility and the Vadnais Lake Area Water Management Organization),* October 1987.

- **Add**—Within the two lakes' watersheds, there are several locations at which the addition of water quality treatment ponds could provide significant reductions in phosphorus loading under ultimate watershed conditions. The ponds would be added to provide treatment for watershed areas already urbanized but not currently served by ponds. For Lake Susan, the ponds to be added include: 1.2, 2.4, 3.42, 3.71, 3.93, 3.94, 3.95, and 3.96. For Rice Marsh Lake, pond additions are recommended for subwatersheds 1.1, 2.5, 2.8, and 6.9 (see Figure EX-8). As a result of these pond additions, phosphorus loading to the two lakes is expected to be reduced by 66 to 123 lbs. per year for Lake Susan and by 55 to 106 lbs. per year for Rice Marsh Lake. For Lake Susan, the corresponding reduction in the lake's summer average total phosphorus concentration is expected to be 12 to 18 μg/L; for Rice Marsh Lake a reduction of 9 to 16 μg/L is expected. The actual amount of the reduction in loading and lake phosphorus concentrations will depend on climatic conditions and other factors. **The cost of adding these eight ponds to the Lake Susan watershed would be approximately $341,000; for Rice Marsh Lake the cost for the four ponds would be approximately $201,000.**

- **Treat**—In-lake alum treatment of the lakes is expected to provide both a temporary and a long-term improvement in the water quality of the lakes. The temporary benefit (lasting from one to two years) results from the alum's ability to remove phosphorus from the water column. The phosphorus removal inhibits algal growth by depriving the algae of a needed nutrient. Additionally, temporary improvements in water clarity result from the "cleansing" of the water column that occurs as the alum floc settles and removes suspended particulate matter. Long-term benefits to the lake are expected to result from the alum's ability to bind phosphorus after the alum comes to rest on the lake sediment surface. In both lakes, prevention of phosphorus release from the sediments can be expected to significantly reduce summer average phosphorus concentrations. In Lake Susan, summer average phosphorus reductions are expected to be on the order of 30 μg/L; in Rice Marsh Lake this reduction is expected to be approximately 65 μg/L. Alum treatment would be conducted on a periodic basis, at approximately 10-year intervals. The cost of alum treatment depends on the lake area, and the open-water areas of Lake Susan and Rice Marsh Lake are quite similar. **The per-treatment cost for each lake is expected to be approximately $34,000.**

Under the assumptions of the modeling used for this study, implementation of the water management initiatives described above will result in Lake Susan's meeting the Level II water quality goal (average summer TP equal to or less than 75 μg/L) in all but the dry year. For Rice Marsh Lake, the less stringent Level III goal (average summer TP equal to or less than 105 μg/L) is met under all modeled climate conditions. It is worth noting that alum treatment alone is projected to allow Lake Susan to meet the Level II goal in the calibration year. The modeling assumptions for Rice Marsh Lake result in the prediction that alum treatment alone would allow the lake to meet its Level III goal in all but the dry year.

Executive Summary Table

Table EX-1

Land Use Comparison - Present vs. Ultimate

Lake Susan Watershed

Land Use Category	Existing Land Use Area (Acres)	Percent of Total Area	Ultimate Land Use Area (Acres)	Percent of Total Area
Natural	512	43%	286	24%
Agricultural	84	7%	0	0%
VLDR	40	3%	30	2%
LDR	32	3%	25	2%
MDR	194	16%	357	30%
HDR	51	4%	106	9%
Institutional	3	0%	3	0%
Highway	25	2%	32	3%
Commercial	49	4%	49	4%
Industrial	197	17%	299	25%
Total	1186		1186	

Rice Marsh Lake Watershed

Land Use Category	Existing Land Use Area (Acres)	Percent of Total Area	Ultimate Land Use Area (Acres)	Percent of Total Area
Natural	257	30%	218	26%
Agricultural	69	8%	0	0%
VLDR	35	4%	29	3%
LDR	63	7%	69	8%
MDR	165	19%	201	24%
HDR	53	6%	47	5%
Institutional	37	4%	37	4%
Highway	22	3%	66	8%
Commercial	139	16%	168	20%
Industrial	13	1%	18	2%
Total	853		853	

Notes:

VLDR = Very Low Density Residential (<1 housing unit per acre)

LDR = Low Density Residential (1-4 housing units per acre)

MDR = Medium Density Residential (4-8 housing units per acre)

HDR = High Density Residential (>8 housing units per acre)

Executive Summary Figures

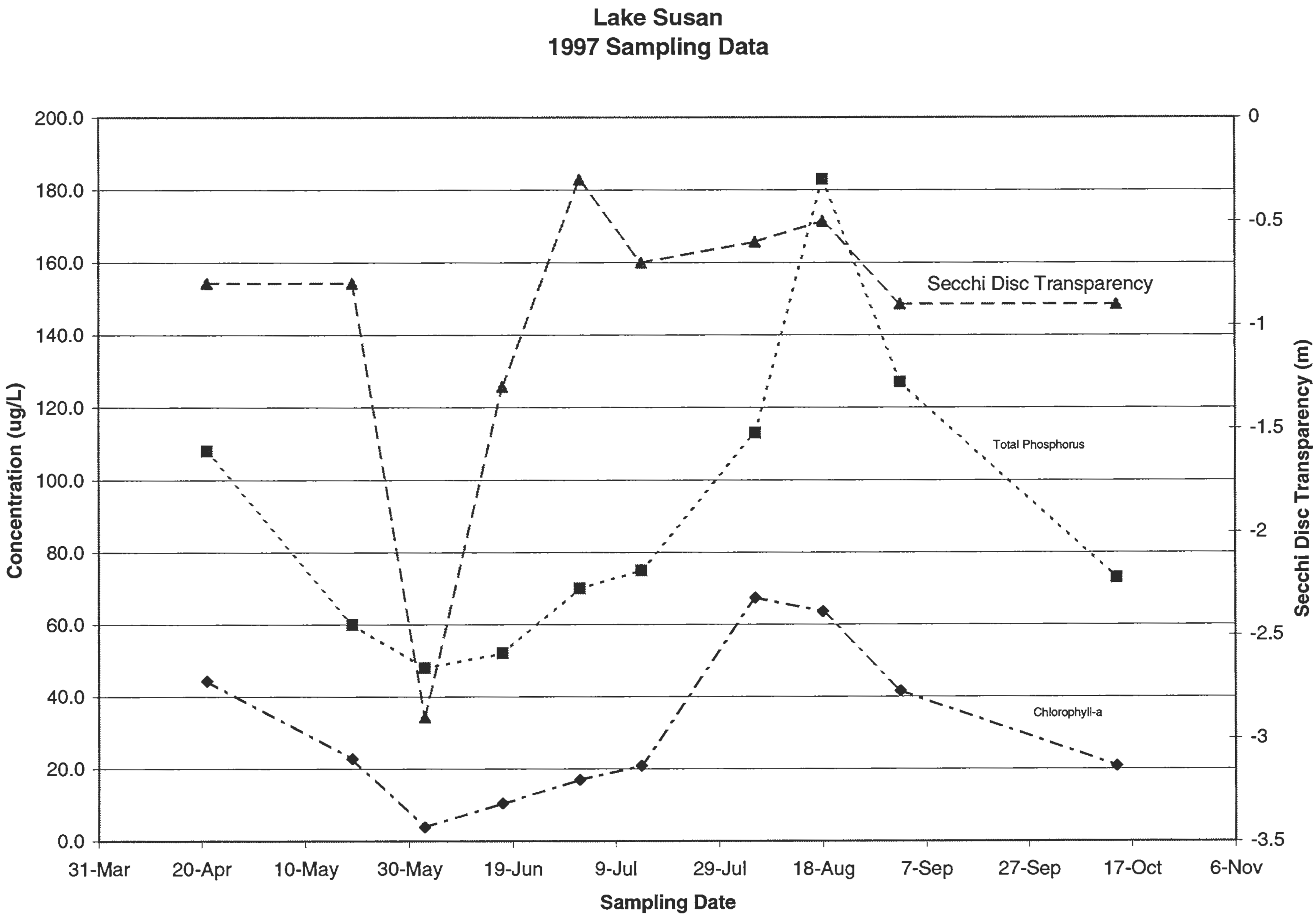

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Figure EX-1

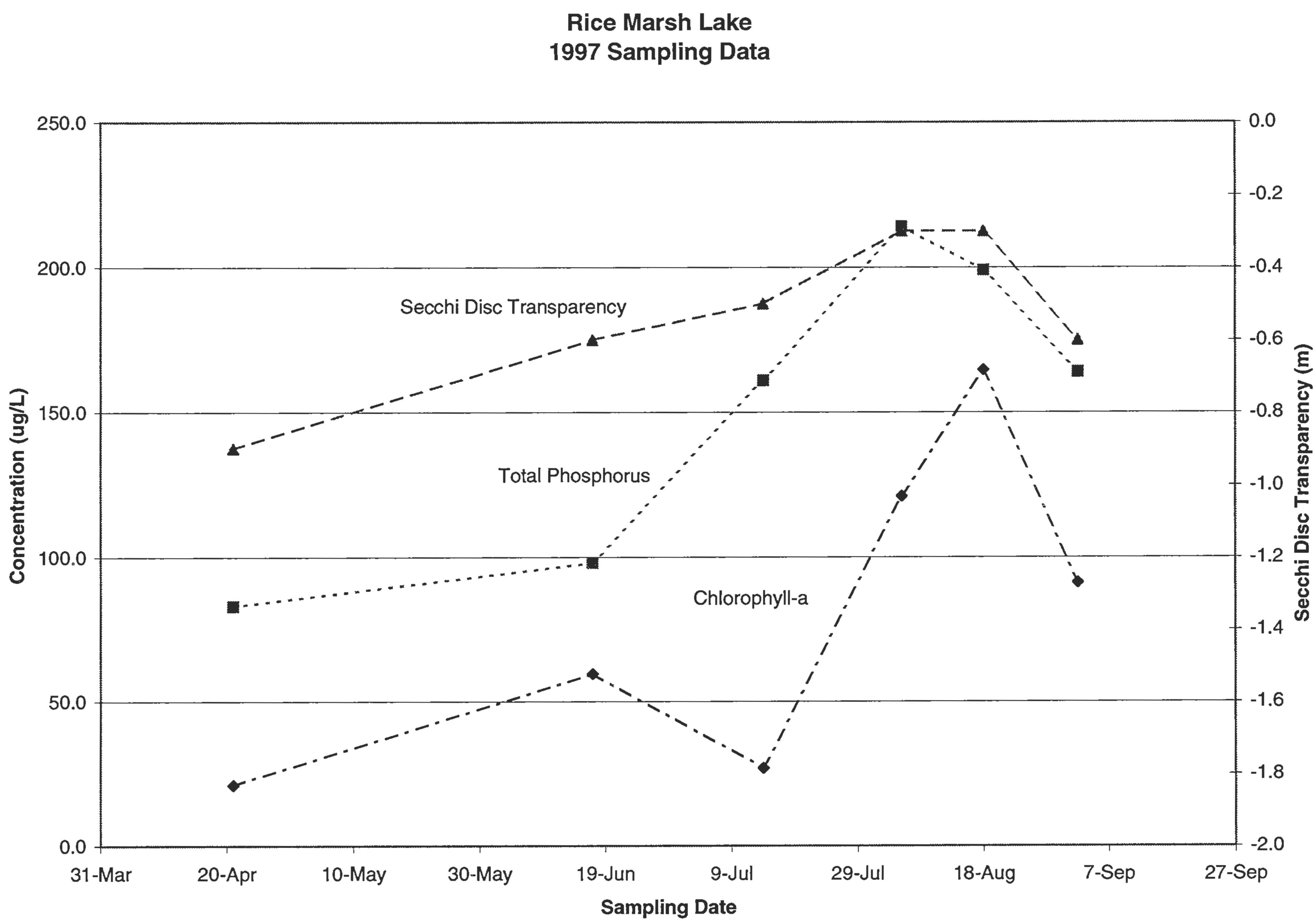

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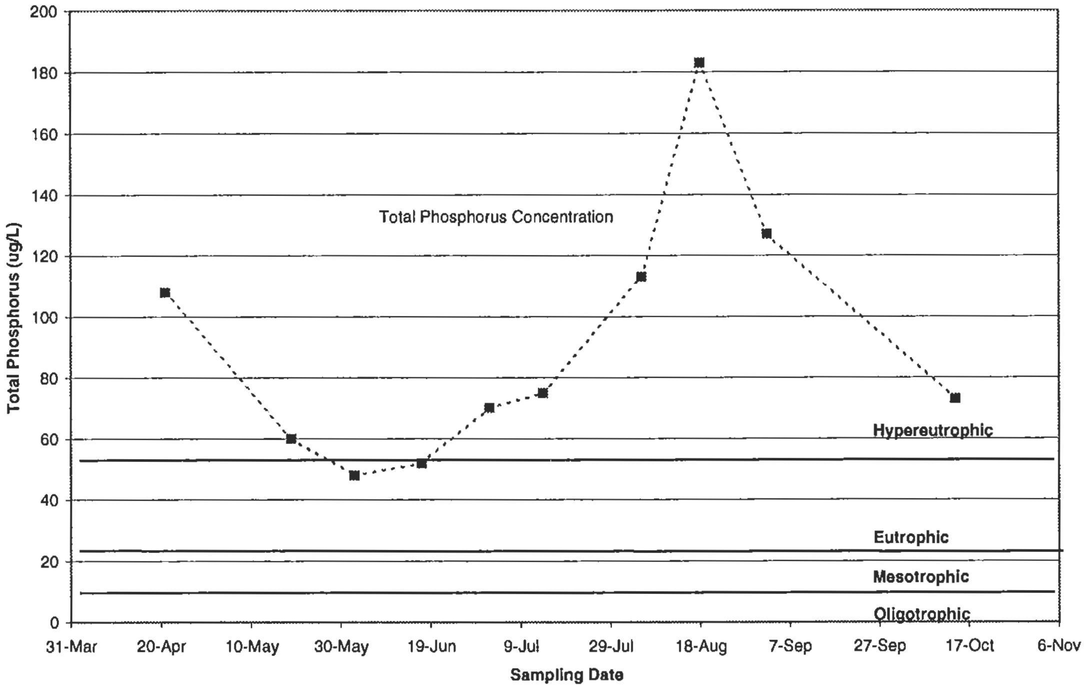
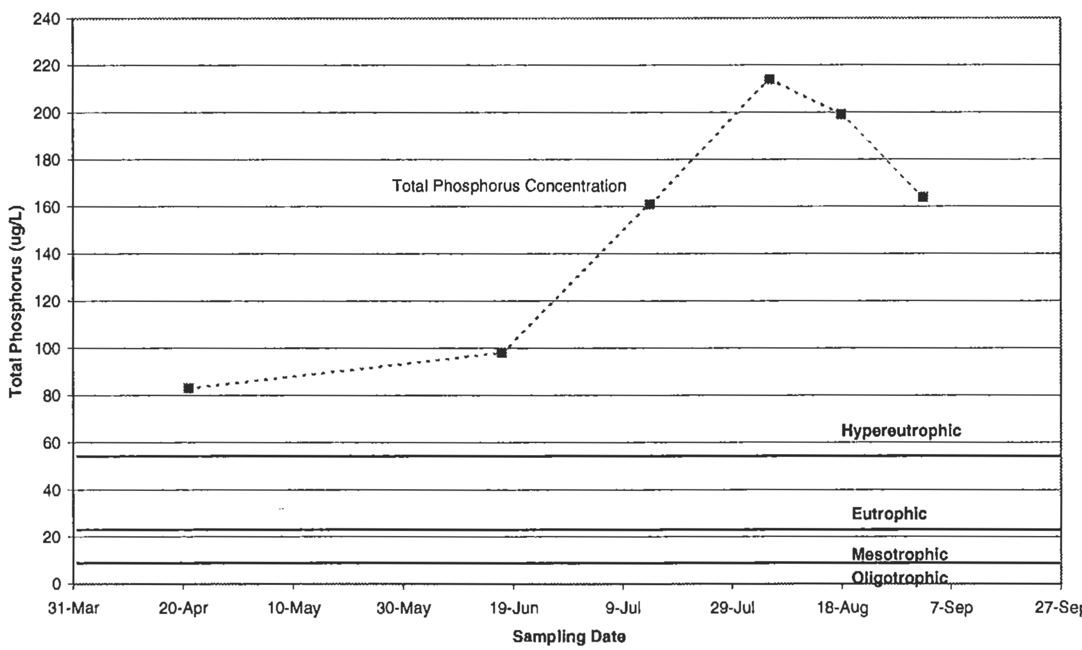
Figure EX-2

Lake Susan
1997 Sampling Data



Rice Marsh Lake
1997 Sampling Data



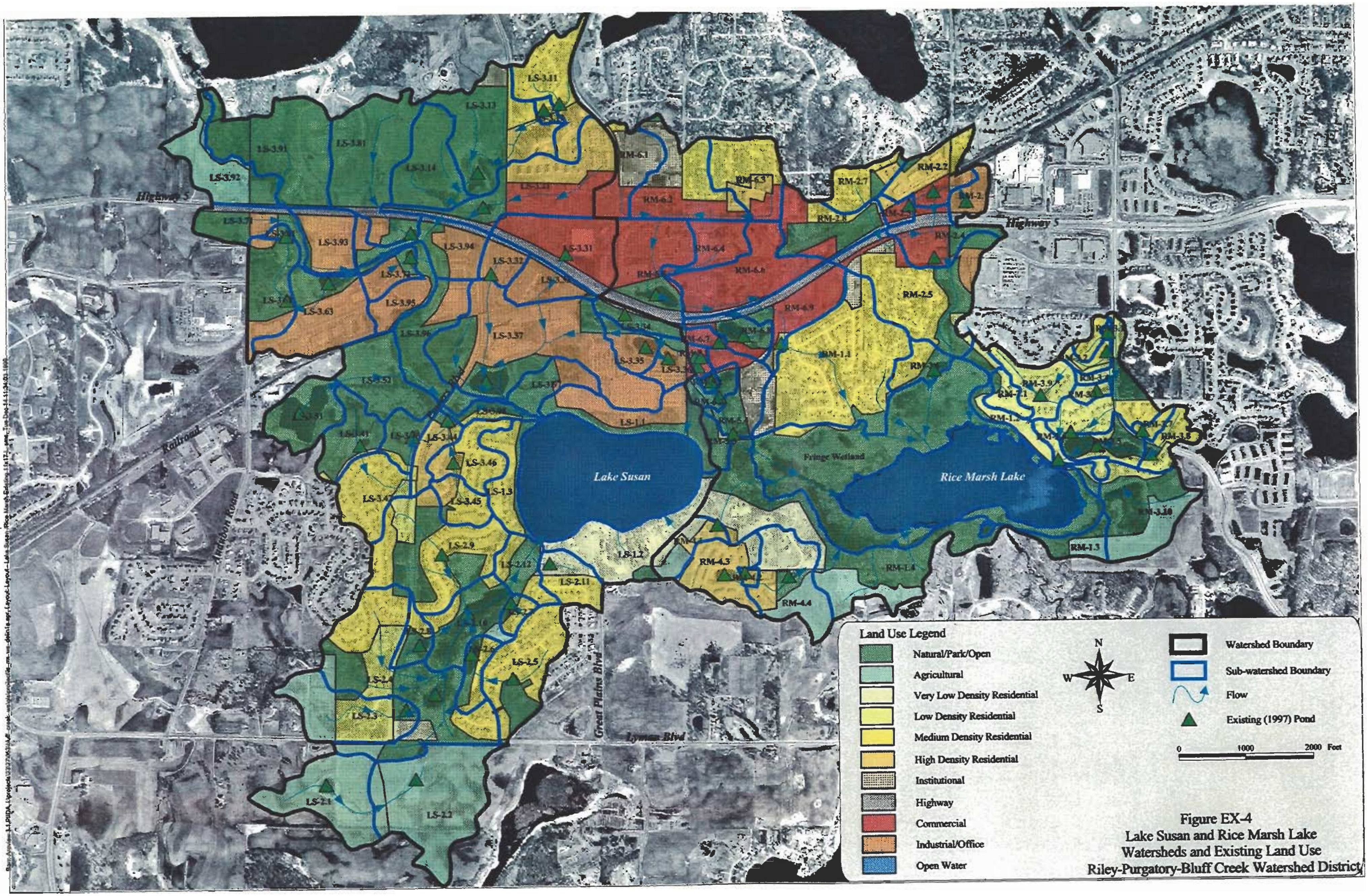
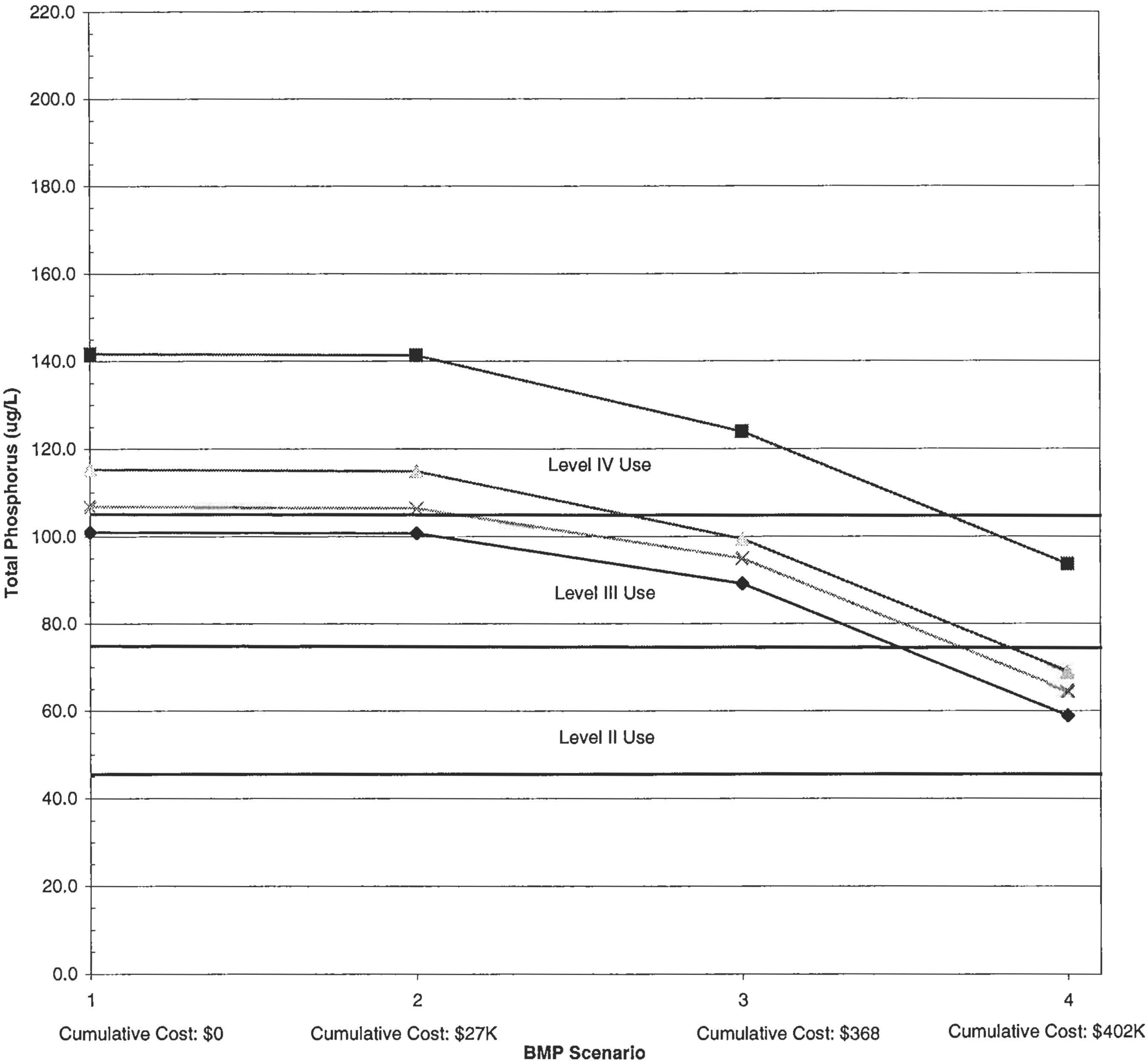


Figure EX-4
Lake Susan and Rice Marsh Lake
Watersheds and Existing Land Use
Riley-Purgatory-Bluff Creek Watershed District

Lake Susan: Estimated Total Phosphorus ; Ultimate Watershed Conditions

With and Without Watershed Improvements and Lake Treatment



BMP Legend:

1 No Action: Ultimate urbanization conditions with no watershed improvements

2 Upgrade -- Upgrade all existing treatment ponds to NURP standards

3 Add-- Add additional ponds in watersheds 1.2, 2.4, 3.14, 3.42, 3.52, 3.71, 3.91, 3,92, 3.93, 3,94, 3,95, and 3,96

4 Treat -- Provide in-lake alum treatment at regular intervals (approx. every 10 years)

Model Calibration Year (1996-1997) (34" of Precipitation)
Dry Year (1987-1988) (19" of Precipitation)
Average Year (1994-1995) (27" of Precipitation)
Wet Year (1982-1983) (41" of Precipitation)

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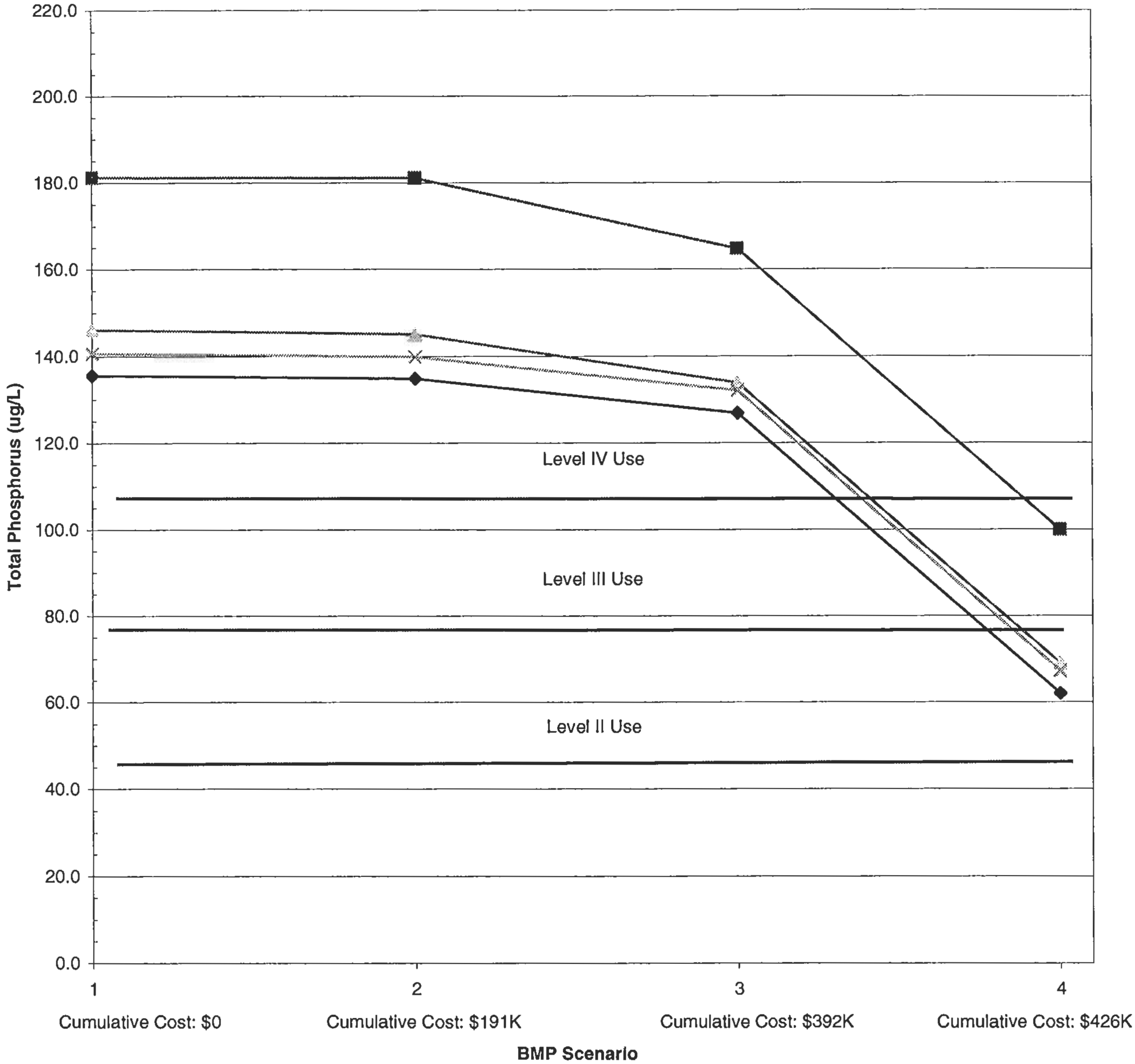
Figure EX-5

Rice Marsh Lake: Estimated Total Phosphorus ; Ultimate Watershed Conditions

With and Without Watershed Improvements and Lake Treatment



BMP Legend:

1 No Action: Ultimate urbanization conditions with no watershed improvements

2 Upgrade -- Upgrade all existing treatment ponds to NURP standards

3 Add-- Add additional ponds in watersheds 1.2, 2.4, 3.14, 3.42, 3.52, 3.71, 3.91, 3,92, 3.93, 3,94, 3,95, and 3,96

4 Treat -- Provide in-lake alum treatment at regular intervals (approx. every 10 years)

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Average Year (1994-1995) (27" of Precipitation) — Wet Year (1982-1983) (41" of Precipitation)

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Figure EX-6

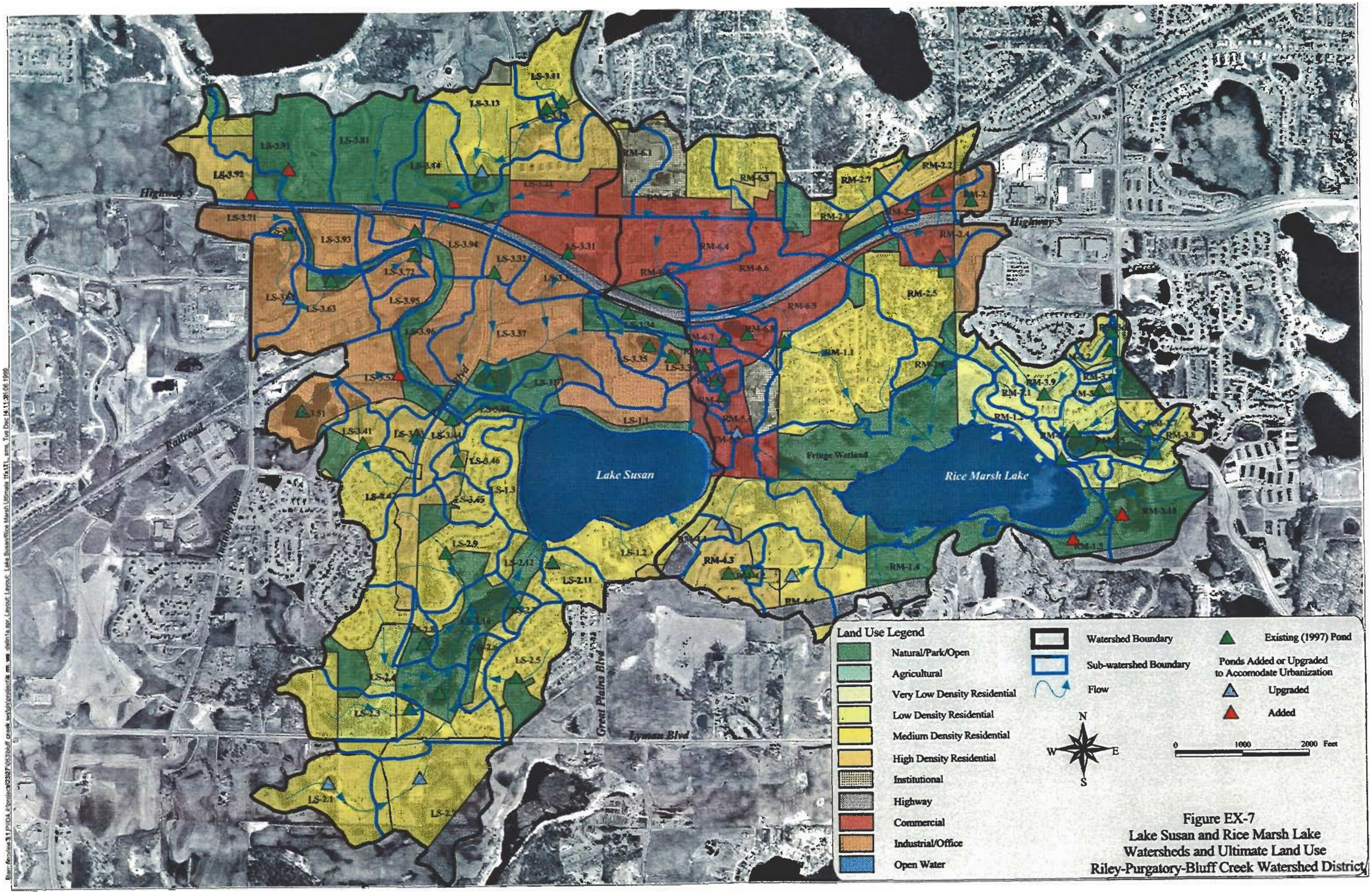

Figure EX-7
Lake Susan and Rice Marsh Lake
Watersheds and Ultimate Land Use
Riley-Purgatory-Bluff Creek Watershed District

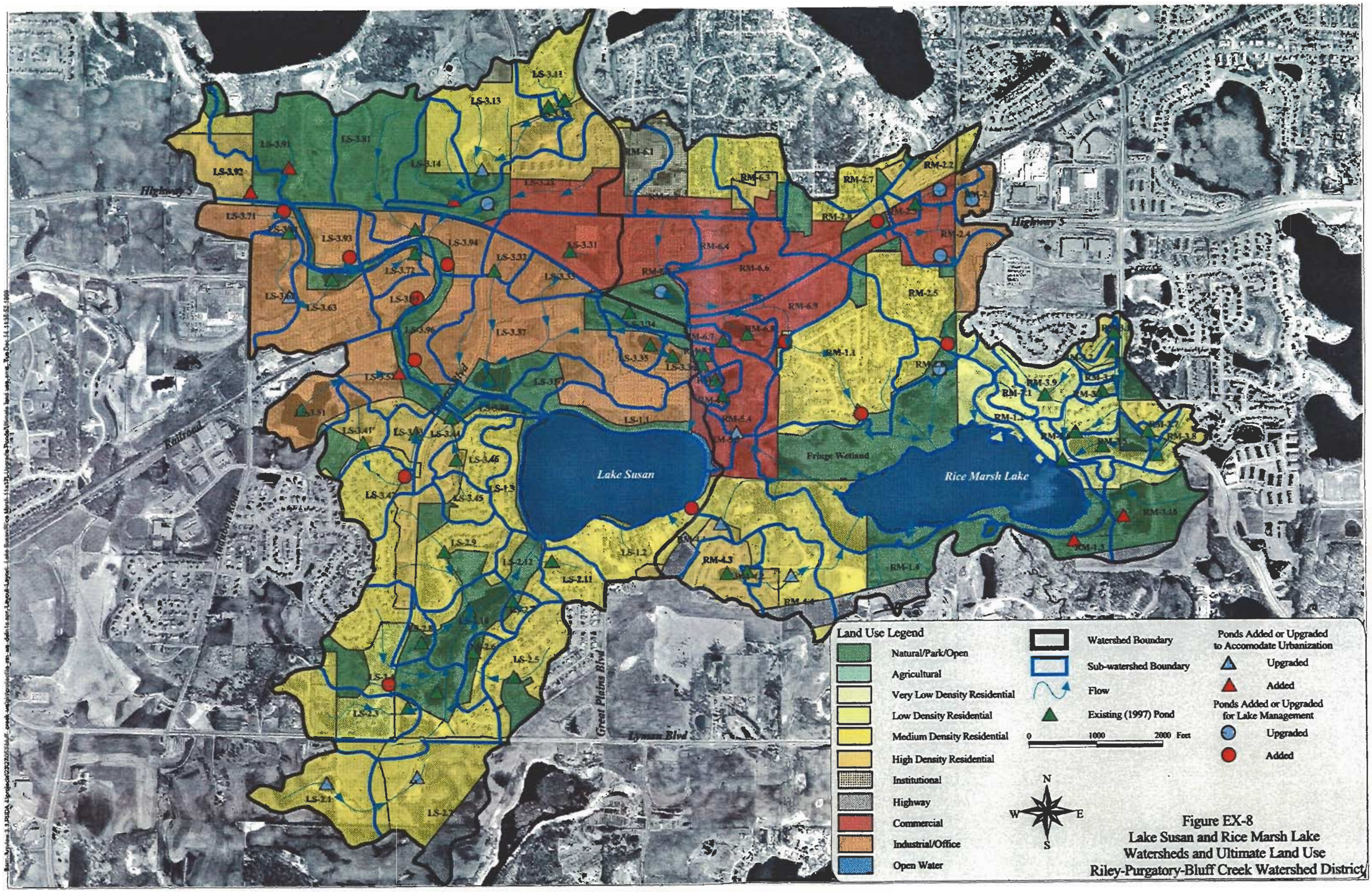

Figure EX-8
Lake Susan and Rice Marsh Lake
Watersheds and Ultimate Land Use
Riley-Purgatory-Bluff Creek Watershed District

1.0 Introduction

This report details the results of a Use Attainability Analysis (UAA) of Lake Susan and Rice Marsh Lake. The UAA is a structured scientific assessment of the chemical, physical, and biological conditions in a water body. The analysis includes diagnosis of the causes of observed problems and prescription of alternative remedial measures intended to result in the attainment of intended beneficial uses of Lake Susan and Rice Marsh Lake. The analysis is based on historical water quality data, the results of an intensive 1997 lake water quality monitoring program, and computer simulations of watershed runoff (given current land use and projected future conditions) calibrated to the 1997 data set. Water quality goals for the lakes were identified based on the lakes' beneficial uses (e.g., swimming and fishing). Management options were then assessed to determine attainment or non-attainment of the lake's beneficial uses.

1.1 Purpose and Process of the UAA

The intent of the UAA is to provide a means by which the effects of various watershed and lake management strategies can be evaluated.

To evaluate management strategies, it is first necessary to identify the intended uses of the lake in question. With these uses in mind, appropriate water quality goals for the lake can be established and reviewed. Once the intended uses and corresponding goals for the lake have been identified, it becomes possible to evaluate lake and watershed management strategies.

The UAA uses a watershed runoff model and a lake water quality model; the lake water quality model predicts changes in lake water quality based on the results of the watershed runoff model. Using these models, various watershed and lake management strategies can be evaluated to determine their likely effects on the lake. The resulting lake water quality can then be compared with the water quality goals for the lake to see if the management strategies are able to produce the desired changes in the lake. Using the tools of the UAA, the cost-effectiveness of the management strategies can also be evaluated.

1.2 Watershed and Lake Water Quality Modeling Tools

Central to the water quality analysis is the use of a water quality model that predicts the amount of pollutants that reach a lake via stormwater runoff. During development of the District's Water Management Plan (1986), a simplified model using literature-based export rate coefficients was used to estimate the annual water and phosphorus loads to the lake. The 1986 Plan recommended using the water quality model XP-SWMM (the EPA's Stormwater and Wastewater Management Model with a graphical interface by XP Software) in the UAA to provide a more precise estimate of water and phosphorus loads. However, because the P8 model (Program for Predicting Polluting Particle Passage through Pits, Puddles and Ponds; IEP, Inc., 1990) provides more accurate predictions of phosphorus loads to a lake than XP-SWMM, the UAA uses the P8 model instead.

The P8 model requires hourly precipitation and temperature data; long-term climatic data can be used so that watersheds and BMPs can be evaluated for varying hydrologic conditions. To properly develop and calibrate the model also requires an accurate assessment of land use and impervious percentages, pond system morphology, flow routing, and lake water quality. After supplying the required input data, the P8 model was used to estimate both the water and phosphorus loads introduced from the entire watershed of Lake Susan and Rice Marsh Lake.

The phosphorus and water loads estimated with P8 for the 1996-1997 water year were entered into a separate in-lake mass balance model so that the phosphorus concentration could be estimated for the lake itself. These modeled 1997 phosphorus concentrations were compared to 1996-1997 monitoring data to calibrate the in-lake model and ensure that it was producing reasonable results. The calibrated model was then used to estimate phosphorus loads and concentrations under future land-use with varying climatic regimes and best-management practice options. Details of the modeling results, and a discussion of management opportunities are presented later in this report.

When evaluating the results of the modeling, it is important to consider that the results provided can be assumed to be more accurate in terms of relative differences than in absolute results. The model will predict the percent difference in phosphorus reduction between various BMP options in the watershed fairly accurately. It also provides a realistic estimate of the relative differences in phosphorus and water loadings from the various subwatersheds and major inflow points to the lake. However, since runoff quality is highly variable with time and location, the phosphorus loadings estimated by the model for a specific watershed may not necessarily reflect the actual loadings, in absolute terms. Various site-specific factors, such as lawn care practices, illicit point discharges and erosion due to construction are not accounted for in the model. The model provides values that are considered to be typical of the region, given the land uses identified for the watershed in question.

1.3 Joint Consideration of Lake Susan and Rice Marsh Lake

Separate UAAs were conducted for Lake Susan and for Rice Marsh Lake. However, because of the lakes' proximity within the District, and because the water quality of Lake Susan affects that of Rice Marsh Lake, the analyses of Lake Susan and Rice Marsh Lake were conducted simultaneously. Because of the close relationship of the two lakes and their watersheds, the results of the UAAs for both lakes are presented in this single report.

1.4 Scope

This UAA evaluates current and future conditions for Lake Susan and Rice Marsh Lake. As a result, the watershed analysis intrinsic to the UAA focuses on the local watersheds of the two lakes. However, the two lakes are part of a chain of lakes and the water quality of each lake in the chain affects all lakes downstream. As a result, the water quality analysis for Lake Susan must take into account the inflows that Lake Susan receives from Lakes Ann and Lucy (upstream). Similarly, Rice Marsh Lake will be affected by the inflows it receives from Lake Susan, and therefore from Lakes Ann and Lucy.

The UAA for Lake Susan and Rice Marsh Lake accounts for the effects of the inflows from the upstream lakes by allowing for their contribution to phosphorus and water loading in the in-lake mass balance phosphorus model. For the upstream lakes, separate UAAs (with P8 modeling of those lakes' watersheds) have already been conducted (see *Lake Lucy and Lake Ann Use Attainability Analysis*, Barr Engineering Company, May 1999). Assuming that the water quality goals are met by implementation of water quality management initiatives as outlined in the UAAs for those lakes, the present UAA uses the water quality predictions from the modeling of the upstream lakes as input for its own lake water quality models. Therefore, the present model does not explicitly deal with the watersheds of the upstream lakes, despite their influence on the water quality of Lake Susan and Rice Marsh Lake.

1.5 General Framework of the UAA

Several steps were necessary for the evaluation of the watershed, lake, and management initiatives conducted for this UAA. Those steps are outlined in the sections that follow.

1.5.1 Identification of Goals and Expectations

To evaluate lake management strategies, it is first necessary to establish the criteria against which outcomes can be measured. To identify those criteria, past District documents were consulted, and the municipalities concerned (City of Chanhassen, and City of Eden Prairie) were interviewed. The present and future uses of the lake were also considered.

1.5.2 Assessment of Current Conditions

For both Lake Susan and Rice Marsh Lake, an evaluation was made of the condition of the lakes' watersheds, biological communities, and water quality.

The watershed analysis involved examination of recent (1977) aerial photographs to identify and delineate current land uses. A review of city and watershed district reports and maps was also conducted to chart surface and storm sewer routing. Subwatersheds within the larger lake watersheds were identified through consultation of previous reports; the subwatershed delineation was confirmed by field investigations (which were also used to confirm land-use patterns and storm water routing). Existing ponds were surveyed to allow correct evaluation of the ponds' current water treatment performance.

Biological communities were evaluated through consideration of past sampling of the lakes' phytoplankton, zooplankton, and macrophyte communities. Further information with respect to the aquatic communities was gathered through interviews with the DNR's regional fisheries manager.

Current lake water quality was assessed through examination of recent and historical water sampling data. In particular, the evaluation of current lake water quality was based on the results of an intensive 1997 data collection program. The 1997 data were also used in calibration of the current water quality model used in the UAA.

1.5.3 Assessment of Future Conditions

The future condition of Lake Susan and Rice Marsh Lake will depend primarily on changes occurring in the land use for the two watersheds. Future watershed conditions were identified based on ultimate landuse mapping provided by the cities of Chanhassen and Eden Prairie, and by means of assumptions with respect to Best Management Practices (BMPs) that are currently required by the District and therefore likely to be incorporated as a result of ongoing urbanization. Using the assumed future watershed conditions, the P8 model was used to predict watershed loading of the lake under various climatic conditions. The watershed loadings were then used as input to the in-lake model to provide predictions of future water quality.

1.5.4 Evaluation of Management Strategies

Having modeled the watershed loading and lake response under assumed future conditions, it is possible to evaluate the potential of various watershed and lake management strategies. Several likely approaches to watershed and lake management were selected and evaluated under various climatic conditions. Costs of the strategies were estimated so that those costs could be compared to the in-lake benefits that the management initiatives are expected to provide.

2.0 Identification of Goals and Expectations

2.1 General: District Plan Water Quality Goals

The approved *Riley-Purgatory-Bluff Creek Watershed District Water Management Plan*, 1996, (Plan) inventoried and assessed all of the District lakes. The Plan discusses goals for all of the Riley-Purgatory-Bluff lakes. These goals address recreation, water quality, aquatic communities, water quantity, and wildlife. Wherever possible, Riley-Purgatory-Bluff Creek Watershed District (District) goals for Round Lake have been quantified using a standardized lake rating system termed the Carlson's Trophic State Index (TSI). This rating system considers the lake's total phosphorus, chlorophyll *a*, and Secchi disc transparency measurements to assign it a water quality index number that reflects its general level of fertility. The resulting index values generally range between 0 *a*nd 100, with increasing values indicating more fertile conditions.

Total phosphorus, chlorophyll *a*, and Secchi disc transparency are key water quality parameters upon which TSI statistics are computed, for the following reasons (see also Appendix A, which gives an explanation of important concepts related to lake water quality and management):

- Phosphorus generally controls the growth of algae in lake systems. Of all the substances needed for biological growth, phosphorus is typically the limiting nutrient.

- Chlorophyll *a* is the main pigment in algae. Therefore, the amount of chlorophyll *a* in the water indicates the abundance of algae present in the lake.

- Secchi disc transparency is a measure of water clarity and is inversely related to the abundance of algae.

Although any one or all three parameters can be used to compute a TSI, it is water transparency that is most often used. This is because public perception of water clarity is most directly related to the perception of the water's suitability for recreational use. The TSI rating system is scaled to place a mesotrophic (medium fertility level) lake on the scale between 40 and 50, and high and low fertility lakes (eutrophic and oligotrophic) toward the high and low ends of the TSI range, respectively. Characteristics of lakes in different trophic status categories are listed below with their respective TSI ranges:

1. **Oligotrophic**—[20 ≤ TSI ≤ 38] clear, low productivity lakes, with total phosphorus concentrations less than or equal to 10 μg/L, chlorophyll *a* concentrations less than or equal to 2 μg/L, and Secchi disc transparencies greater than or equal to 4.6 meters (15 feet).

2. **Mesotrophic**—[38 < TSI ≤ 50] intermediate productivity lakes, with 10 to 25 μg/L of total phosphorus, 2 to 8 μg/L of chlorophyll *a*, and Secchi disc measurements of 2 to 4.6 meters (6 to 15 feet).

3. **Eutrophic**—[50 < TSI ≤ 62] high productivity lakes relative to a basic natural level, with 25 to 57 μg/L of phosphorus, 8 to 26 μg/L of chlorophyll *a*, and Secchi disc measurements of 0.85 to 2 meters (2.7 to 6 feet).

4. **Hypereutrophic**—[62 < TSI ≤ 80] extremely productive lakes which are highly eutrophic, disturbed and unstable (i.e., fluctuating in their water quality on a daily and seasonal scale, producing gases, noxious and toxic substances, experiencing periodic anoxia and fish kills, etc., with total phosphorus concentrations greater than 57 μg/L, chlorophyll *a* concentrations greater than 26 μg/L, and Secchi disc measurements less than 0.8 meters (less than 2.7 feet).

2.2 District Goals for Lake Susan and Rice Marsh Lake

The District Plan lists current water quality conditions (and corresponding TSI indices) for Lake Susan and Rice Marsh Lake. It also shows the anticipated water quality under ultimate urbanization conditions, based on water quality modeling conducted for the Plan. However, neither of these can be construed as water quality goals for the lakes.

Neither have other agencies been involved in goal-setting for these two lakes. Because neither of the two lakes is expected to be widely used for swimming or other full-body contact aquatic recreation, the Minnesota Pollution Control Agency (MPCA) is not involved in setting water quality goals for the lakes. For each of the two lakes, the District Plan identifies the TSI rating corresponding to the lake fishery classification system of the Minnesota Department of Natural Resources (MDNR). However, conversations with MDNR staff indicate that the lake transparency (indicated by the MDNR TSI values) should be considered only as a representative value for a lake of the given fisheries lake class. Therefore, the MDNR cautions that fishery-related TSI values should not be construed as goals for the lakes.

In a further effort to identify any established water quality targets set for the two lakes, the Cities of Chanhassen and Eden Prairie were contacted. The natural resource managers for the two cities confirmed that they knew of no specific water quality goals that have been established by the municipalities for either of the two lakes[4].

This review showed that specific water quality goals for Lake Susan and Rice Marsh Lake have not been previously established by the RPBCWD, the MPCA, the MDNR, or by the local municipalities. However, despite the lack of specific water quality targets for the lakes, the RPBCWD expects both lakes to continue as valued recreational assets to the community. Lake Susan is expected to continue to be used for boating and fishing (although its water quality would not be expected to be generally suitable for swimming). Rice Marsh Lake is expected to continue primarily as an aesthetic amenity, supporting fish and wildlife without being expected to provide significant opportunities for either boating or swimming. Realistic water quality goals for the lakes will therefore be those that protect and enhance these recreational uses for the two lakes.

Other references were consulted in an effort to identify appropriate water quality targets for the lakes. The *1989 Lake Riley Chain of Lakes Improvement Project Work Plan* (District, April 5, 1989) identifies total phosphorus concentrations consistent with several general lake use categories. The document indicates that a "Level II" water body (supporting boating but not full-body water contact activities such as swimming or scuba diving) should have total phosphorus concentrations in the 45 to 75 µg/L range. A "Level III" water body (supporting fish and wildlife populations, and providing aesthetic viewing) should have total phosphorus concentrations in the 75 to 105 µg/L range. These two ranges provide realistic targets for total phosphorus concentrations for Lake Susan (Level II) and Rice Marsh Lake (Level III).

These water quality goals were compared with recent years' sampling , and with MINLEAP[5] modeling (to ascertain pre-settlement lake water conditions). MINLEAP modeling suggests that prior to agricultural use and urbanization of the lakes' watersheds, the approximate average summer

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4 Only one specific goal of any sort was identified for either of the two lakes: an *ad hoc* goal (50-60 ug/L summer average phosphorus concentration) for Lake Susan that was mentioned in a February 1999 report (*Lake Susan Restoration Evaluation for 1998*, Blue Water Science) to the City of Chanhassen.

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

total phosphorus concentration in Lake Susan was 52 μg/L, and 62 μg/L Rice Marsh Lake. Urban impacts are evident in the fact that in recent years, total phosphorus concentrations in Lake Susan and Rice Marsh lake have averaged 90 μg/L and 207 μg/L respectively. However, the water quality data collected by the District over the past 25 years shows that the average total phosphorus concentrations in both lakes have been declining, and proactive watershed and lake management may allow substantial continued improvement.

Based on the above considerations, this report recommends that a reasonable water quality goal for Lake Susan would be to maintain total phosphorus (TP) concentrations in the lake at levels lower than 75 μg/L. The lake's history suggests that this TP would correspond to a chlorophyll *a* concentration of approximately 37 μg/L, and a Secchi transparency of 0.7 meters. This Secchi transparency corresponds to a TSI_{SD} score of 65.

Similarly, for Rice Marsh Lake, this report recommends that a reasonable water quality goal would be to maintain total phosphorus (TP) concentrations in the lake at levels lower than 105 μg/L. Rice Marsh Lake's history suggests that this TP would correspond to a chlorophyll *a* concentration of approximately 42 μg/L, and a Secchi transparency of 0.3 meters. This Secchi transparency corresponds to a TSI_{SD} score of 77.

2.3 Expected Benefits of Water Quality Improvements

In the past, relatively little attention has been given to water quality improvements for Lake Susan and Rice Marsh Lake. The lack of previously established goals for the two lakes provides some evidence of this inattention, as does the relatively high average summer phosphorus concentrations the two lakes currently experience. Nevertheless, improving water quality in each lake is important for several reasons.

2.3.1 Enhancement of Recreational Use

Lake Susan is used primarily for boating and fishing, and owing to its relatively shallow basin is not likely to develop as a significant swimming lake. However, improved water transparency will improve the attractiveness of the lake even for non-contact aquatic activities (such as canoeing or kayaking, sailing, or motor boat use), and may make limited-contact aquatic use (water skiing, and use by personal watercraft enthusiasts) more possible.

MDNR fisheries personnel also note that a lake's fishery is improved as water quality improves. The improvement occurs as a result of improved food chain dynamics and increased vegetative habitat for spawning and fish refuge. These benefits to recreational anglers may be expected to accrue as a result of improved watershed and lake management.

For Rice Marsh Lake, decreases in phosphorus concentrations and resulting transparency improvements are likely to improve the lake's aesthetic appeal, make fish kills less likely, and reduce the frequency of odor-producing algal blooms that thrive on over-fertilization of the waters. Such improvements will make the lake more pleasant for both the many neighbors and hikers that frequent the paths encircling Rice Marsh Lake. The lake's role as an important fish spawning area for other area lakes (particularly Lake Riley) is also likely to be enhanced by water quality improvements.

2.3.2 Improvements in Aquatic Habitat

Improving the eutrophic status of Lake Susan and Rice Marsh Lake is expected to benefit the aquatic communities of each lake. Reduced eutrophication typically results in reduced algal concentrations and increased transparency. These changes allow for greater plant and animal diversity, as species with less tolerance for low light and low oxygen are once again able to populate the lake and its littoral regions. Higher diversity and improved habitat for the communities lowest on the food chain (algae, zooplankton, etc.) are reflected in benefits to higher-order species-from benthic invertebrates through birds and mammals.

2.3.3 Benefits to Downstream Water Bodies

As has been mentioned previously, Lakes Susan and Rice Marsh Lake are part of a chain of lakes linked by Riley Creek. The water quality in each lake along the chain is the principal determinant of the water quality of the creek as it flows from the lake, and thereby has a strong influence on the water quality of the next-downstream lake into which the creek flows. In the case of Lake Susan, the next-downstream lake is Rice Marsh Lake. The lake downstream of Rice Marsh Lake is Lake Riley, which is generally considered an important recreational resource for the southwest metro area. Therefore, improvements in the water quality of Lake Susan and Rice Marsh Lake will promote important improvements in Lake Riley's water quality. Furthermore, water quality improvements will benefit Riley Creek itself, and ultimately the Minnesota River into which it drains.

3.0 Lake Basin and Watershed Characteristics

The following sections describe the unique characteristics of the lake basins of Lake Susan and Rice Marsh Lake. General features of the land use in the lakes' watersheds—under both present and future conditions—are discussed. The network of water storage and treatment ponds is also described, as well as the flows in and out of the lake.

3.1 Lake Basin Characteristics

Lake Susan-Lake Susan has a water surface of approximately 81 acres, a maximum depth of approximately 16 feet, and a mean depth of 10 feet. The lake volume is approximately 800 acre-feet.

The exact lake area, depth, and volume depend on the water level of the lake, which has been observed to vary between a high measurement of 882.5 feet MSL (1986) and a low measurement of 879.5 feet MSL (1977). Since 1970, the water level has usually been between 880.5 and 881.5 feet MSL. The approximate water surface area, depth, and volume (given above) are as measured at the average water level of 881.1 feet MSL. The water level in the lake is controlled mainly by weather conditions (snowmelt, rainfall, and evaporation) and by the elevation of the streambed of Riley Creek, over which Lake Susan drains to the east.

Lake Susan is relatively shallow and has a relatively large littoral area. As such, the lake would be expected to be prone to frequent wind-driven mixing of the lake's shallow and deep waters during the summer. One would therefore expect Lake Susan to be *polymictic* (mixing many times per year) as opposed to lakes with deep, steep-sided basins that are usually *dimictic* (mixing only twice per year). Daily monitoring of the lake would be necessary to precisely characterize the mixing dynamics of a lake, but the limited data gathered from Lake Susan strongly suggests that the lake is indeed polymictic.

Rice Marsh Lake-Rice Marsh Lake has an open water surface area of approximately 81 acres (the open water area is variable, depending on the seasonally-varying coverage of the lake's cattail fringe), a maximum depth of approximately 10 feet, and a mean depth of approximately 5 feet. The lake volume is approximately 350 acre-feet.

The lake area, depth, and volume depend on the water level of the lake, which has been observed to vary between a high measurement of 877.0 feet MSL (1978) and a low measurement of 872.0 feet MSL (1976). Since 1970, the water level has usually been between 874 and 876 feet MSL. The approximate water surface area, depth, and volume (given above) are as measured at the average water level of 875.8 feet MSL. The water level in the lake is controlled mainly by weather conditions (snowmelt, rainfall, and evaporation) and by the elevation of the streambed of Riley Creek, over which Rice Marsh Lake drains to the southeast.

Rice Marsh Lake is quite shallow, especially in comparison with its large surface area. Therefore, as is the case with Lake Susan, Rice Marsh Lake would be expected to be prone to frequent wind-driven mixing. As is the case with Lake Susan, daily monitoring of the lake would be necessary to precisely characterize its mixing characteristics, but the limited data gathered from Rice Marsh Lake strongly suggests that this lake is also polymictic.

3.1.2 Flow Conditions in the Lakes

For both Lake Susan and Rice Marsh Lake, Riley Creek both supplies and drains the lake basin. In general, water is not detained significantly by the lakes; inflows to the lakes from Riley Creek and the lakes' immediate watersheds are soon discharged through the Riley Creek outlets. As opposed to landlocked basins, therefore, the water levels in these lakes fluctuate relatively little. This feature of the two water bodies allows the lakes to be considered (for lake water quality modeling purposes) as having volumes that do not vary significantly over time.

3.2 Watershed Characteristics

3.2.1 Lake Susan

Not counting the land area that drains to Lake Susan indirectly, after the water passes through Lake Ann or Lake Lucy, the watershed of Lake Susan (its "immediate" watershed) is approximately 1198 acres. Several types of land use exist within the immediate watershed of Lake Susan. These land uses—present and future, are discussed in the following sections.

3.2.1.1 Present Land Use

Based on analysis of 1997 aerial photographs, Lake Susan's immediate watershed is dominated by three primary types of use (see Figure 1 and Table 1; all figures and tables are located at the end of the report). Forty-three percent of the watershed is in a "natural" state, and vegetated with naturally-occurring or cultivated trees, shrubs, or grasses. Twenty-six percent of the land is devoted to residential use of various densities. Seventeen percent is used for industrial uses, and so is occupied primarily by factories, warehouses, and parking lots. The remainder of the watershed (14 percent) is taken up by agricultural, commercial, and highway uses.

The relatively high proportion of land still in natural condition is significant. These "natural" lands include significant park areas, but also a large marsh/wetland complex in the south central portion of the watershed, and a natural creek corridor along Riley Creek as it flows from Lake Ann from the northwest. Small parcels of land zoned for commercial, residential and industrial use also still remain in their natural condition. Future conversion of these natural areas to other uses will place additional stress on Lake Susan.

3.2.1.2 Future Land Use

The immediate watershed of Lake Susan was analyzed with respect to probable future land use patterns by consulting with City of Chanhassen officials, and by examination of the City's "Chanhassen 2000" ultimate land use plan. However, the Chanhassen 2000 plan was not followed exactly in evaluating ultimate land use conditions for use in watershed modeling. Exceptions were made based on observations as to regional land-use trends, and based on planning information received from MnDOT regarding the Highway 212 corridor.

Future land use is expected to vary substantially from present use (see Figure 2 and Table 1). The three primary future land uses are expected to be residential (of varying density, but primarily medium density)—43 percent; industrial—25 percent; and natural—24 percent. All agricultural land is expected to have been converted to other uses (principally residential), and the proportion of commercial and highway use will remain approximately the same as at present. The proposed Highway 212 corridor is expected to intersect a small portion of the Lake Susan watershed, on the southern edge of subwatershed LS-2.2.

3.2.1.3 Implications of Expected Land Use Changes

Because much of the immediate watershed of Lake Susan is currently in a natural state, the lake currently is benefiting from these areas' low impervious fraction and consequent low phosphorus loading. Projections of future use suggest that approximately half of this land will be converted to residential and industrial use, greatly increasing the impervious fraction. The increased water quantity and pollutant loading that will result will require proper storage and treatment of the stormwater runoff if Lake Susan's water quality is to be maintained or improved.

In addition, the increase in residential area (from 26 percent to 43 percent) implies an increase in the watershed's population density. It is likely that the population increase will cause Lake Susan to experience an increase in recreational use, and lake management expectations may be raised as a result.

3.2.2 Rice Marsh Lake

The overall watershed of Rice Marsh Lake includes the areas that drain to it only after passing through Lake Ann, Lake Lucy, or Lake Susan. However, the immediate watershed of Rice Marsh is approximately 853 acres. The immediate watershed's land uses—present and future, are discussed in the following sections.

3.2.2.1 Present Land Use

Based on analysis of 1997 aerial photographs, Rice Marsh Lake's immediate watershed is dominated by three primary types of use (see Figure 1 and Table 1). Thirty-six percent of the land is devoted to residential use of various densities. Thirty percent of the watershed is classified as "natural". Sixteen percent is used for commercial uses, and so is occupied by stores, restaurants, theaters, and parking lots. The remainder of the watershed (16 percent) is taken up by agricultural, institutional, highway, and commercial uses.

By contrast to the Lake Susan watershed, the watershed for Rice Marsh Lake has relatively little land available for conversion to more intensive urban uses. The 257 acres currently identified as natural are unlikely to undergo urbanization-most of these acres make up the wetland fringe surrounding Rice Marsh Lake. Only the relatively small (8 percent) fraction of agricultural land is susceptible to changes that will substantially affect the nature of the watershed's runoff.

3.2.2.2 Future Land Use

The immediate watershed of Rice Marsh Lake was analyzed with respect to probable future land use patterns after consulting with officials from the City of Chanhassen and the City of Eden Prairie, and after examination of the "Chanhassen 2000" ultimate land use plan. It was assumed that there would be little re-development of existing areas, but that commercial and industrial coverage would become somewhat denser. In addition, based on information from MnDOT, some areas would be affected by the planned Highway 212 corridor. In general however, future land use is expected to vary only slightly from present use (see Figure 2 and Table 1). Like they are now, the three primary future land uses are expected to be residential—40 percent; natural—26 percent; and commercial—20 percent.

All agricultural land is expected to have been converted to other uses (principally residential and commercial), and the proportion of institutional and industrial use will remain approximately the same as at present. The proposed Highway 212 corridor is expected to intersect the southern portion of the Rice Marsh Lake watershed at several locations; these locations are shown in subwatersheds RM-1.3, 1.4, 3.10, 4.1, and 4.4. This will increase the highway land use within the watershed to 8 percent.

3.2.2.3 Implications of Expected Land Use Changes

Only a relatively small portion of the immediate watershed of Rice Marsh Lake is expected to undergo conversion to more intensively urban land uses in the future. As a result, neither the quality nor the quantity of the stormwater runoff from the watershed should be expected to change greatly as a result of ongoing urbanization. Land use changes can be expected to be accompanied by provision for storage and treatment ponds to mitigate the effects of those changes.

3.3 Lake Inflows and Drainage Areas

3.3.1 Lake Susan

Because the watershed modeling depends on the evaluation of the watershed conditions as they relate to stormwater runoff, the hydrology of the Lake Susan watershed is discussed in the following sections.

3.3.1.1 Inflow Points

The majority of the water entering Lake Susan arrives via two inflow points. Riley Creek, in addition to carrying water discharged from Lake Ann, drains the northern and west central portion of the watershed. Stormwater runoff from the southern portion of the watershed enters the lake via a small canal draining the large pond and wetland complex southwest of Lake Susan. The remainder of the stormwater entering the lake does so via overland flow across the subwatersheds that drain directly to the lake.

3.3.1.2 Major Drainage Areas

The direct subwatersheds for Lake Susan include LS-1.1 through LS-1.3 (see Figure 1).

Subwatersheds LS-2.1 through 2.12 comprise a major drainage area that discharges to Lake Susan from the southwest. These primarily residential subwatersheds drain through a series of smaller ponds that eventually drain to the wetland complex (comprised of parts of LS-2.4, 2.6, 2.7, 2.8, 2.9, 2.10, and 2.12) and large open-water pond area in LS-2.10.

Another large drainage area is made up of subwatersheds LS-3.31 through 3.37. These subwatersheds, devoted primarily to industrial and commercial use, achieve water treatment mainly by the large regional detention pond located in subwatershed LS-3.37. This large pond discharges to Riley Creek approximately 600 feet upstream of the creek's point of discharge to the lake.

Several of the Lake Susan subwatersheds form relatively small drainage groups with local ponds providing water quality treatment. The small groups include LS-3.11 through 3.14; LS-3.41 through 3.43; LS-3.51 and 3.52; and LS-3.61 through 3.63. Flows from these small groups reach Lake Susan via Riley Creek.

Two subwatersheds—LS-3.72 and LS-3.82—have no connections to other subwatersheds upstream or downstream, but are each provided with their own pond to allow storage and water quality treatment. Both ponds discharge to Riley Creek. The remainder of the Lake Susan subwatersheds (including LS-3.71, and LS-3.91 through 3.98) are adjacent to the creek and drain directly to it without the benefit of any water quality treatment.

3.3.2 Rice Marsh Lake

Because the watershed modeling depends on the evaluation of the watershed conditions as they relate to stormwater runoff, the hydrology of the Rice Marsh Lake watershed is discussed in the following sections.

3.3.2.1 Inflow Points

Riley Creek enters Rice Marsh Lake via a fairly well-defined channel flowing into the west end of the open water portion of the lake. Another identifiable point of inflow is at the east end of the lake, where a pond network discharges directly to the lake's open water. However, by contrast to Lake Susan, much of the water reaching the open water portion of Rice Marsh Lake arrives indirectly, forced to first diffuse through the wetland fringe surrounding the lake. Such is the case with the water arriving via the intermittent creeks that drain the north and northwest portions of the lake's watershed, for the water flowing from the southeastern and southwestern subwatersheds, and from the lake's direct subwatersheds.

3.3.2.2 Major Drainage Areas

The direct subwatersheds for Rice Marsh Lake include RM-1.1 through 1.4 (see Figure 1).

In addition to the direct subwatersheds, five major subwatershed groups comprise Rice Marsh Lake's immediate watershed. Each of these groups is served by a network of treatment ponds, the most downstream of which discharges to the lake either directly or indirectly.

The group of subwatersheds RM-2.1 through RM-2.6 comprises the north central portion of the watershed, and is devoted to a mix of residential, commercial, and industrial use. The ponds in this group drain through a creek that flows through the large regional pond (in subwatershed RM-2.6) before discharging to the wetland area north of the lake.

A residential area with an extensive network of treatment ponds lies to the east of the lake. These subwatersheds (RM-3.1 through 3.9) drain to the large pond/wetland area in RM-3.5, and through the smaller pond at RM-3.6 before discharge to the lake.

The subwatershed group comprised of RM-4.2 through 4.4 has a pond for each of the subwatersheds; the ponds are connected through the pond at RM-4.4 and drain to the lake through its wetland fringe from the southwest. This subwatershed group is primarily residential, with additional land currently under agricultural use.

The network of ponds serving the relatively small group of subwatersheds to the west-northwest of the lake (RM-5.1 through 5.5) drains to Riley Creek after it passes under Highway 101. These subwatersheds are primarily in natural and institutional use, but are scheduled to undergo conversion to residential and commercial use.

The large area to the northwest of Rice Marsh Lake—RM-6.1 through 6.9—is primarily commercial but also includes residential, institutional, and industrial areas. Few of the subwatersheds have their own ponds, but relatively large regional ponds in subwatersheds RM-6.5, 6.6, and 6.8 serve the area. These subwatersheds drain to the lake via a creek passing through RM-1.1, and discharge directly to the wetland fringe surrounding the lake.

RM-3.10 is considered a direct subwatershed for the lake, although it includes a central wetland portion that may offer some water quality treatment. RM-7.1 and RM-4.1 are unconnected subwatersheds, having no upstream or downstream watersheds. Each has a treatment pond that drains to the lake through the wetland fringe.

4.0 Current Lake Situation

4.1 Water Quality

4.1.1 Key Water Quality Indices and Eutrophic State

For both Lake Susan and Rice Marsh Lake, an intensive water quality sampling effort was made during the open-water season of 1997 in an effort to document the current conditions of the lakes. Several water quality indices were evaluated, including temperature, dissolved oxygen (DO), pH, specific conductivity (conductivity), total phosphorus (TP), chlorophyll *a* (Chl *a*), and Secchi disc transparency (transparency). Temperature, DO, conductivity, pH, and TP were all measured at regular intervals (typically 1 meter) throughout the water column to allow characterization of the lakes' stratification profiles.

Among the water quality parameters sampled, TP, Chl *a*, and transparency are the key determinants of water quality and eutrophic state for the lakes (see also Appendix A). 1997 sampling results for these three water quality parameters are presented graphically on Figures 4 and 5.

Because recreational use is greatest during the summer (June, July, and August) months, and because it is during these times that algal blooms and diminished transparency are most common, attention is usually focused on summer water quality in the upper (epilimnetic) portions of the lakes. For Lake Susan, the 1997 epilimnetic summer averages for TP, Chl *a*, and transparency were 95 μg/L, 32 μg/L, and 1.0 meters respectively. For Rice Marsh Lake, the 1997 epilimnetic summer averages for TP, Chl *a*, and transparency were 168 μg/L, 93 μg/L, and 0.4 meters, respectively.

For both lakes, these 1997 summer averages place the lakes in the hypereutrophic category. This characterization means that by comparison to other lakes, Lake Susan and Rice Marsh Lake are extremely rich in algal nutrients, susceptible to dense algal blooms, and exhibit low water clarity.

4.1.2 Baseline/Current Water Quality

4.1.2.1 Lake Susan

The "baseline" water quality of Lake Susan was determined by evaluating the average summer conditions (June to August) during the period from 1971 to 1984. More recent ("current") water quality (1988-1997) data were then compared to the baseline averages (see Table 2). Comparisons between Lake Susan's baseline and current water quality suggest a gradual improvement in the lake's water quality. Average summer epilimnetic total phosphorus decreased 18 percent (from 51 to 42 µg/L). Corresponding to the reduction in TP (nutrient) levels was a 22 percent decline in the average summer epilimnetic Chl *a*. Despite these improvements however, the lake's average Secchi disc transparency actually decreased slightly from 0.9 to 0.8 meters.

The absence of an increase in transparency corresponding to the lower TP and Chl *a* points to a feature of Lake Susan that appears consistent over the many years of sampling. At least at the high phosphorus levels the lake has historically experienced, significant transparency increases do not result from even fairly large reductions in TP. At the same time, it is important to recognize that the polymictic character of the lake and the intermittent nature of the water quality sampling make it difficult to draw firm conclusions regarding the patterns and trends for Lake Susan.

It should be noted that after an alum treatment was applied to Lake Susan in April of 1998, the lake's water quality improved greatly (see the summary of 1998 water quality measurements presented in Appendix B). Average summer values for total phosphorus were 38 µg/L, and transparency averaged 2.1 meters. Chl *a* concentrations were not measured, but based on past years' relationship between TP and Chl *a*, the average Chl *a* would probably have been approximately 38 µg/L during the summer of 1998. A rapid and dramatic decline in total phosphorus concentrations (with resulting changes in chlorophyll *a* and Secchi transparency) is to be expected with alum treatment, and was seen immediately following the April alum application. The dramatic phosphorus declines result from the alum floc "sweeping" the water column as the floc settles to the lake bottom. However, the extremely low post-treatment total phosphorus concentration (20 µg/L on 5/8/98) can be sustained only if the inflows from the lake's watershed are comparably low. Such is not the case for Lake Susan, and the late summer total phosphorus concentration (39 µg/L on 8/28/99) reflects the gradual re-equilibration of the lake with its watershed.

4.1.2.2 Rice Marsh Lake

The baseline water quality of Rice Marsh Lake was also determined by evaluating the average summer conditions (June to August) during the period from 1972 to 1984 (see Table 3). Current water quality data (1988-1997) were compared to the baseline averages. As is the case with Lake Susan, the comparison of baseline with current conditions suggest a gradual improvement in lake water quality.

Average summer epilimnetic total phosphorus decreased 48 percent (from 384 to 197 µg/L). Corresponding to the reduction in TP (nutrient) levels was an 11 percent decline in the average summer epilimnetic Chl *a*. However, despite these reductions in nutrient and Chl *a* concentrations, the lake's average Secchi disc transparency actually decreased from 0.8 to 0.5 meters.

Despite an almost 50 percent reduction in TP, the lake has shown little improvement (and in fact some decline) in transparency. This should not be surprising after examination of the sampling data collected over the past 25 years. As is the case with Lake Susan, analysis of historical records for Rice Marsh Lake shows that for this lake, transparency is not closely correlated with TP. However, as with Lake Susan, it is important to recognize that the polymictic character of the lake and the intermittent nature of the water quality sampling make it difficult to draw firm conclusions regarding the patterns and trends for the lake.

4.1.3 Trend Analysis

Trend analysis is a process by which changes in measured water quality indices can be evaluated as to their statistical significance; it is a way to determine whether apparent trends constitute a real improvement in lake water quality. The trend analysis for Lake Susan and Rice Marsh Lake considers the historical trends for the three key water quality parameters: TP, Chl *a*, and transparency. Figures 6 and 7 show the summer averages of these three key parameters for each of the two lakes over the period (1975-1997) used for the trend analysis. A regression line (which provides a close approximation of the "trend line") for each of the data sets is also plotted.

Both lakes show a downward slope in the trend lines for concentrations of both TP and Chl *a*. However, both lakes also show a flat or slightly upward-sloping trend line (showing a reduction in water clarity) for transparency. For a change in water quality to be judged as "significant", changes in all three water quality parameters must be shown to be statistically significant at the 95 percent confidence level.

Despite the downward trends in both TP and Chl *a* being significant at the 95 percent confidence level for Lake Susan, transparency has <u>not</u> improved significantly (there have been no transparency improvements significant at the 95 percent confidence level). For Rice Marsh Lake, the downward trend in TP is significant at the 95 percent confidence level. However, the improvement in Chl *a* was not significant at the 95 percent confidence level, and there has been no general improvement in transparency. Therefore, the test fails for both lakes; the conclusion is that neither lake has shown a significant improvement in water quality over the period analyzed (1975 to 1997).

4.2 Nutrient Loading

Both Lake Susan and Rice Marsh Lake receive phosphorus loads from external sources—from the upstream lakes via Riley Creek, and from runoff from the lakes' immediate watersheds. In addition, the data suggest that the two lakes also receive phosphorus loads from internal sources—from their own sediments via chemical and mixing processes. These sources of phosphorus are discussed in the following sections.

4.2.1 External Loads

Watershed analysis suggests that under existing conditions, Riley Creek carries a significant amount of phosphorus into the two lakes. This phosphorus comes from two sources—from the upstream lakes (Lake Ann in the case of Lake Susan, and Lake Susan for Rice Marsh Lake), and from those portions of the lakes' immediate watersheds that drain to the creek rather than directly to the lake.

Although the size of the immediate watershed for Lake Susan (1200 acres) is larger than that of Rice Marsh Lake (850 acres) the estimate of the annual external phosphorus load for Lake Susan (316 lbs.) is smaller than that for Rice Marsh Lake (540 lbs.). This apparent discrepancy is explained by several factors, primary among which is the difference in water quality of the upstream lakes.

Phosphorus inflows from upstream lakes are significant for both Lake Susan and Rice Marsh Lake. However, because of the relatively good water quality of Lake Ann, that lake is expected to contribute only 8 percent (27 lbs.) of the annual external phosphorus load to Lake Susan. By contrast, the relatively poor water quality of Lake Susan results in its contributing approximately 40 percent (213 lbs.) of the annual external phosphorus load for Rice Marsh Lake under existing conditions.

The relatively large fraction of land remaining in natural condition (see Section 4.2.1) in the Lake Susan watershed results also helps to reduce phosphorus loads to the lake. A fairly well-developed network of local and regional ponds helps to further mitigate phosphorus loading from urbanized areas of the watershed. Of the immediate watershed's annual load to Lake Susan, approximately 70 percent appears to be contributed by the more heavily industrialized northern portion of the watershed and several of the industrial subwatersheds drain without treatment directly to Riley Creek.

The immediate watershed of Rice Marsh Lake contains relatively less land in the natural state. In addition, the watershed contains large urbanized tracts (in the northwest, northeast, and central regions) that are poorly served by treatment basins. Analysis indicates that loading from the north and northwest portions accounts for approximately 30 percent of the annual load to the lake. A large residential tract (RM-1.1) at present drains untreated to the lake. Direct loading to the lake includes runoff from this tract, and accounts for 21 percent of the total annual phosphorus load to Rice Marsh Lake.

4.2.2 Internal Loads

In addition to being affected by the runoff from their immediate watersheds and the loading from upstream lakes, the water quality of both Lake Susan and Rice Marsh Lake appears to be strongly influenced by internal phosphorus loading (i.e. recycling of sediment-bound phosphorus to the overlying water column).

Internal phosphorus loading refers to the periodic release of phosphorus from the lake sediments, elevating the summer phosphorus concentrations above the level that would be expected if only external (watershed runoff) loads were supplying phosphorus. Chemical processes cause phosphorus to be released from lake sediments when dissolved oxygen concentrations become extremely low at the sediment-water interface. Low-oxygen conditions at the sediments, with resulting phosphorus release, are to be expected in eutrophic lakes where relatively large quantities of organic material (decaying algae and macrophytes) are deposited on the lake bottom (see also Appendix A for a discussion of lake stratification, mixing, and internal loading).

If the low-lying phosphorus-rich waters near the sediments remain isolated from the upper portions of the lake, algal growth at the lake's surface will not be stimulated. Shallow lakes and ponds can be expected to periodically stratify during calm summer periods, so that the upper warmer portion of the water body is effectively isolated from the cooler, deeper (and potentially phosphorus-rich) portions. Deep lakes typically retain their stratification until cooler fall air temperatures allow the water layers to become isothermal and mix again. However, relatively shallow lakes (such as Lake Susan and Rice Marsh Lake) are less thermally stable and may mix frequently during the summer periods. Shallow lakes are therefore frequently polymictic, experiencing alternating periods of stratification and destratification. It is the destratification, brought about by wind-induced mixing of the water column, that re-introduces phosphorus to the upper (epilimnetic) portion of the lake.

The eutrophic condition of Lake Susan and Rice Marsh Lake, along with their relatively shallow depths, would be expected to provide a situation in which frequent mixing and internal phosphorus loading are likely. And water quality sampling data collected over the past three decades for both

Lake Susan and Rice Marsh Lake provides indirect evidence of internal loading. Phosphorus concentrations are typically highest in August for the two lakes, after warm summer weather creates conditions favorable to sediment phosphorus release. Temperature-depth data shows alternating patterns of thermal stratification and de-stratification. The polymictic character of the two lakes is further demonstrated by the variations seen in the distribution of phosphorus concentrations. Near-sediment phosphorus concentrations are typically much higher than surface water concentrations—except in cases where the lakes are seen to be isothermal and well-mixed.

Internal loading in the two lakes was estimated based on historical lake data. For Lake Susan, it appears that internal loading adds an average of 66 lbs. of phosphorus to the epilimnion annually. The corresponding estimate of the internal load for Rice Marsh Lake is 71 lbs. This loading was included in the in-lake models (see the description of the in-lake models given below) that were used to predict summer average concentrations for the lakes.

4.3 Aquatic Communities

In addition to the physical and chemical indices of lake water quality, an evaluation of the plant and animal species that inhabit the water provides valuable information as to the health of the lake. An assessment of the current situation with respect to the two lakes' aquatic communities is given in the following sections.

4.3.1 Phytoplankton

The phytoplankton communities in Lake Susan and Rice Marsh Lake form the base of the lake's food web and affect recreational use of the lake. Phytoplankton, also called algae, are small aquatic plants naturally present in all lakes. They derive energy from sunlight (through photosynthesis) and from dissolved nutrients found in lake water. They provide food for several types of animals, including zooplankton, which are in turn eaten by fish.

An inadequate phytoplankton population limits the lake's zooplankton population and can thereby limit the fish production in a lake. Conversely, excess phytoplankton can alter the structure of the zooplankton community and interfere with sight-based fish predation, thereby also having an adverse effect on the lake's fishery. In addition, excess phytoplankton reduce water clarity; reduced water clarity can in itself make recreational usage of a lake less desirable.

Blue-green algae have been dominant in both lakes during the 1975 through 1997 period for which data exist (Table 4). As was the case in previous years, blue-green algae were generally the dominant types of phytoplankton observed in 1997 (Figure 8) in both lakes. Green algae were present in both lakes, and are considered beneficial in that they are edible to zooplankton and serve as a valuable food source. However, blue-green algae dominated the algal populations in both Lake Susan and Rice Marsh Lake after early July. Blue-green algae are considered a nuisance algae because they:

- are generally inedible for fish, waterfowl, and most zooplankters;
- float at the lake surface in expansive algal blooms;
- may be toxic to animals when occurring in large blooms;
- can interfere with recreational uses of the lake

Excess phosphorus loads—such as those seen in Lake Susan and Rice Marsh Lake—stimulate blue-green and green algal growth. The warm growing conditions during July and August are particularly favorable to blue-greens, and blue-greens have a competitive advantage over the other algal species during this time.

4.3.2 Zooplankton

Zooplankton—microscopic crustaceans— are vital to the health of a lake ecosystem because they feed upon the phytoplankton and are food themselves for many fish species. Protection of the lake's zooplankton community through proper water quality management practices protects the lake's fishery. Zooplankton are also important to lake water quality. The zooplankton community is generally comprised of three groups: cladocera, copepoda, and rotifera. If present in abundance, large cladocera can decrease the number of algae and improve water transparency within a lake.

There is not a surrogate measurement of zooplankton biomass similar to Chl *a* concentration for phytoplankton biomass. Therefore, zooplankton must be identified and counted to get an estimate of zooplankton biomass. Figures 9 and 10 show the zooplankton totals (expressed as the number of organisms per square meter of lake surface) for Lake Susan and Rice Marsh Lake on each of the 1981 through 1997 sampling dates. Tables 5 and 6 give the numeric basis on which Figures 9 and 10 are based. Each total shown is divided into the three main groups of zooplankton to give an indication of their relative abundance.

In Lake Susan, the rotifera were the dominant group in the early part of the summer (Figure 9). However, by mid-July, the copepoda had achieved dominance. By August, the cladocera had exceeded both the rotifera and the copepoda, and continued to dominate the zooplankton community throughout the remainder of the sampling season.

The composition of the zooplankton community was somewhat different in Rice Marsh Lake during 1977 (Figure 10). On the earliest sampling date (April 21), the zooplankton were dominated by the Copepods, which comprised 97 percent of the total. By mid-June, dominance had shifted to the rotifera. But as with Lake Susan, cladocera were the dominant group during the later part of the summer (mid-July through September).

Comparison of the zooplankton date for 1997 with that of past years suggests that the patterns seen in 1997 are typical for both lakes. Lake Susan has typically shown a large rotifer population, especially during early spring. Rice Marsh Lake tends to show a smaller rotifer population, but a larger and more stable copepod population.

The rotifers and copepods in lakes graze primarily on extremely small particles of plant matter and therefore do not significantly affect lake water transparency by removing algae. By contrast, cladocera graze primarily on algae and can increase transparency if they are present in abundance. *Daphnia spp*. are among the larger cladocera species and are considered especially desirable in lakes because of their ability to consume large quantities of algae. In both Lake Susan and Rice Marsh Lake, the Daphnia species' abundance was low (generally less than 10 percent of total numbers for Lake Susan and less than 4 percent for Rice Marsh Lake) during most of the sampling season. Lake Susan did show increased abundance on the 6/17 and 10/14 sampling dates, when the Daphnia species comprised approximately 20 percent of the zooplankton population. Larger cladocera would likely show a positive response (i.e., increase in abundance) if blue-green algae were reduced or replaced by more edible algal species in the two lakes.

Planktivorous fish (such as sunfish and bluegills) eat zooplankton and will preferentially select the large Daphnia. Therefore, to thrive, the Daphnia require either a refuge from predators (i.e. deep, well-oxygenated water) or a small predator population. Lake Susan could potentially provide Daphnia a deep-water refuge, but Rice Marsh Lake is probably too shallow. The introduction or increase in piscivorous fish such as walleye or northern pike in either lake would probably lead to an increase in the Daphnia population.

4.3.3 Macrophytes

Aquatic plants—macrophytes—are a natural and integral part of most lake communities, providing valuable refuge, habitat and forage for many animal species. The lake's aquatic plants, generally located in the shallow areas near the shoreline of the lake:

- Provide habitat for fish, insects, and small invertebrates
- Provide food for waterfowl, fish, and wildlife
- Produce oxygen
- Provide spawning areas for fish in early spring/provide cover for early life stages of fish
- Help stabilize marshy borders and protect shorelines from wave erosion
- Provide nesting sites for waterfowl and marsh birds

Surveys of the aquatic plant community in Lake Susan and Rice Marsh Lake were completed by the District during June and August of 1997. Survey results are presented in Appendix C, and are summarized below.

4.3.3.1 Lake Susan

During the June 1997 survey, macrophytes were found in Lake Susan only in the very shallow (less than 4 feet deep) portions of the littoral zone. In general, the lake was fringed with pondweed *(Potamogeton crispus* and *Potamogeton pectinatus*), but dense growths of white and yellow waterlily *(Nymphaea tuberosa* and *Nymphaea variegata*) were observed along the lake's western shore. Smaller stands of yellow waterlily were seen along the southern and eastern shores, with occasional patches of cattail and bulrush (*Typha spp.* and *Scirpus spp.*) dotting the shoreline.

A similar vegetation pattern was seen during the August 1977 sampling. However, as is typically the case for that species, much of the curly leaf pondweed *(Potamogeton crispus)* had died off by the August sampling.

Earlier years' macrophyte mapping shows patterns similar to those of 1997; the lake has historically shown a pondweed fringe with large stands of waterlily, and smaller patches of cattail and bulrush. However, comparison of the 1997 sampling to the most recent (1994) previous sampling indicates that stands of curly leaf pondweed are gradually being replaced by the native sago pondweed. Littoral areas populated by sago pondweed seem to be becoming more prevalent, and portions of the littoral area formerly unvegetated after the mid-summer curly-leaf pondweed die-off are now seen (in August) to be covered with sago pondweed.

It should be noted that curly leaf pondweed is an undesirable non-native species. It frequently replaces native species in lakes and exhibits a dense growth that may interfere with the recreational use of a lake. A dense growth also creates a convenient refuge for small fish, making it difficult for larger fish, such as bass, to locate and prey upon the small fish they need for food. As such, curly leaf pondweed can hinder gamefish production. Furthermore, the mid-season die-off that is a natural part of the life cycle of curly leaf pondweed can contribute (through plant matter decay) to increases in the lake's late summer epilimnetic phosphorus concentration. This non-native species is thus often held partially responsible for late summer algal blooms.

4.3.3.2 Rice Marsh Lake

A very broad (in places exceeding 1000 feet in width) cattail and purple loosestrife (*Lythrum salicaria*) fringe borders Rice Marsh Lake. In the open water areas, emergent macrophytes are present in areas of the lake less than 5 feet deep. Being a shallow lake, these macrophytes are present over approximately 50 percent of the open water area.

The June 1997 macrophyte survey showed most of the shallow portions of the lake dominated primarily by three varieties of pondweed: pondweed (*Potamogeton pusillus*), curly leaf pondweed, and sago pondweed. Coontail *(Ceratophyllum demersum*) was interspersed with the pondweed on the lake's eastern and southern sides, and dominated the macrophyte community on the west side of the lake. Except on the east side of the lake, large islands of white waterlily were seen on top of the submerged species (pondweed and coontail) covering the littoral zone.

The pattern of macrophyte coverage seen in June was not altered significantly by August of 1997. However, a mid-summer die-off of much of the curly leaf pondweed was evident, and two new species were identified in August. Star duckweed (*Lemna trisulca*) was observed among the submerged macrophytes on the west side of the lake, and muskgrass (*Chara spp.*) was found on the lake's east side. A floating island of cattail was identified at the western extent of the lake's open water zone.

The vegetative pattern observed in 1994 was not significantly different from that of 1997; generally the littoral zones were dominated by pondweed and waterlily. One additional pondweed species (Flatstem pondweed, or *Potamogeton zosterformis*) had been noted in the both the June and August

1994 macrophyte surveys, and a small patch of water shield (*Brasenia schreberi*) had been observed in June. As was the case with Lake Susan, the early summer die-off of curly leaf pondweed appears to have been more complete in 1994 than it was in 1997.

4.3.4 Fish and Wildlife

During 1992, the MDNR categorized all Minnesota lakes (including Lake Susan and Rice Marsh Lake) according to the type of fishery they might reasonably be expected to support. The MDNR's ecological classification system takes into account factors such as the lake area, percentage of the lake surface area that is littoral, maximum depth, degree of shoreline development, Secchi disc transparency and total alkalinity. The following sections discuss Lake Susan and Rice Marsh Lake with respect to the MDNR's fishery classification system and any fish sampling data available.

4.3.4.1 Lake Susan

Based on the MDNR's classification system, Lake Susan is a Class 38 lake. Lakes in this category are not expected to be premier fishing lakes, and are prone to occasional winterkill (when below-ice dissolved oxygen levels become too low to support game fish.)

Class 38 lakes would be expected to support primary fish populations comprised of northern pike, black bullhead, and bluegill. Secondary (less numerous) populations for Class 38 lakes typically include white sucker, yellow bullhead, pumpkinseed sunfish, black crappie, yellow perch, and walleye.

The MDNR's most recent (1994) Lake Survey Report for Lake Susan gives a somewhat guarded assessment of the status of the lake's fishery. The report states during the 1993 study of the lake that few fish of any species were caught in abundance, and that no game fish were caught in abundance. The most abundant fish caught in the survey were carp, black bullhead, and bluegill. Northern pike were caught in numbers considered normal for the lake type; fewer than average numbers of walleye, largemouth bass, and bluegills were caught. Small numbers of golden shiners, green sunfish, pumpkinseed sunfish, hybrid sunfish, white crappie, yellow bullhead, and yellow perch were also caught. The MDNR has stocked Lake Susan with walleye and largemouth bass in previous years (1990 and 1991).

As was mentioned above, Class 38 lakes are known to be prone to winterkill. This general observation is confirmed in the 1994 Lake Survey Report. Winterkills were reported by the MDNR in the years '54, '74 through '79, '85, '86, and '88 through '90. Species that are especially sensitive to low oxygen conditions are bluegills, sunfish and largemouth bass. More tolerant species include bullheads, northern pike and crappies.

Frequent winterkills are related to poor water quality. Hypereutrophic lakes (such as Lake Susan) produce relatively large quantities of algae during summer months. After the algae die and settle to the bottom of the lake, their decomposition uses oxygen that would otherwise be available to the fish population. The problem becomes especially severe in the winter when ice cover on the lake prevents transfer of oxygen from the atmosphere to the water.

The City of Chanhassen has maintained a mechanical aeration system on the lake during recent winters in an effort to prevent winterkill. In a further effort to improve Lake Susan's fishery, the City contracted with commercial fishermen to harvest carp and bullheads from the lake. During the winter and spring of 1988, commercial fishermen removed 18,700 lbs. of carp and 23,400 lbs. of bullheads from the lake. Additional measures to reduce the roughfish population of the lake were implemented in the spring of 1988: carp barriers were installed at the outlet of Lake Susan (between Lake Susan and Rice Marsh Lake) and between Lake Susan and the large stormwater pond (pond 3.10 see Figure 1) located north of the lake.

In addition to supporting its fish populations, Lake Susan provides habitat for seasonal waterfowl, such as ducks and geese, which find refuge and forage in the lake's diverse macrophyte communities in the lake's large littoral zone.

4.3.4.2 Rice Marsh Lake

According to the MDNR's classification system, Rice Marsh Lake is a Class 42 lake. Class 42 lakes, being relatively shallow and eutrophic, can be expected to experience frequent winterkills. The MDNR considers lakes of this class to be "marginal" fish lakes, and suggests that they may be better suited for wildlife than for support of a thriving game fish population.

The primary fish populations for Class 42 lakes would be expected to be comprised of white sucker, black bullhead, and bluegill. Secondary (less numerous) populations for Class 42 lakes typically would include northern pike, pumpkinseed sunfish, black crappie, and yellow perch.

Because it is not considered to be a significant regional fishery, the MDNR does not conduct fish surveys on the lake. However, the MDNR has noted that Rice Marsh Lake does serve as an important spawning area for northern pike migrating upstream from Lake Riley. It also appears to serve as a spawning area for carp.

The diverse macrophyte communities of Rice Marsh Lake provide habitat for migratory waterfowl such as ducks and geese. Its large fringe wetland area also provides important refuge and nesting habitat for many other wildlife species, including birds, mammals, and amphibians.

5.0 Water Quality Modeling for the UAA

Phosphorus levels in the two lakes are relatively high, and will continue to be greatly affected by the amount of phosphorus loading the lakes receive. As development continues in these watersheds, phosphorus loads can be expected to increase, worsening water quality in both Lake Susan and Rice Marsh Lake.

For this study, a detailed analysis of current and future discharges was completed to determine phosphorus sources and management opportunities to reduce the amount of phosphorus added to the lake. Phosphorus typically moves either in water as soluble phosphorus (dissolved in the water) or attached to sediments carried by water. Therefore, the determination of the volume of water discharged annually to Lake Susan and Rice Marsh Lake annually is integral to defining the amount of phosphorus discharged to the lake.

5.1 Use of the P8 Model

The P8 model was used (see Section 1.2) to estimate both the water and phosphorus loads introduced from the entire watershed of Lake Susan and Rice Marsh Lake. The model requires hourly precipitation data; long-term climatic data can be used so that watersheds and BMPs can be evaluated for varying hydrologic conditions.

When evaluating the results of P8 modeling, it is important to consider that the results provided are more accurate in terms of relative differences than in terms of absolute results. The model will predict the percent difference in phosphorus reduction between various BMP options in the watershed fairly accurately. It also provides a realistic estimate of the relative differences in phosphorus and water loadings from the various subwatersheds and major inflow points to the lake. However, since runoff quality is highly variable with time and location, the phosphorus loadings estimated by the model for a specific watershed may not necessarily reflect the actual loadings, in absolute terms. Various site-specific factors, such as lawn care practices, illicit point discharges and erosion due to construction are not accounted for in the model. The model provides values that can be expected to be typical of the region, given the watershed's respective land uses.

5.2 Water Quality Model (P8) Calibration

Because no 1997 data had been collected regarding the inflow water quantity or quality for either Lake Susan and Rice Marsh Lake, calibration of the P8 model was not possible. It was assumed that the adjustments made to the model calibration parameters for nearby Round Lake (see *Round Lake Use Attainability Analysis*, District, 1999) would be generally suitable for modeling Lake Susan and Rice Marsh Lake. The calibrated Round Lake parameters were therefore used in all P8 model runs for Lake Susan and Rice Marsh Lake.

The P8 model output, used as input for the in-lake model (described below) is thought to be best-suited for considering relative changes in loading under varying watershed conditions. Therefore, it was assumed that the calibration of the in-lake model (described below) would compensate for slight errors in the actual P8-predicted TP and water loads. Predicted in-lake phosphorus concentrations based on relative changes in TP loads and an in-lake model calibrated to match measured lake conditions could thereby be considered reasonably accurate.

5.3 In-Lake Modeling

While the P8 model is a useful tool for evaluating runoff volumes and pollutant concentrations from a watershed, a separate means is required for predicting the lake phosphorus concentrations that are likely to result from the loadings. For evaluating the resultant in-lake concentrations, the UAA uses a computer spreadsheet model based on the empirical equation set forth by Dillon and Rigler (1974).

5.3.1 Accounting for Internal Loading

Most of the empirical phosphorus models (including that of Dillon and Rigler) assume that the lake to be modeled is well-mixed, meaning that the phosphorus concentrations within the lake are uniform. This assumption is useful in providing a general prediction of lake conditions, but it does not account for the seasonal changes in phosphorus concentrations that can occur in a lake. Such changes occur in dimictic lakes when phosphorus is removed by settling from the epilimnion. As has been discussed, these changes can also occur seasonally as a result of internal loading. Extensions of the Dillon and Rigler model are therefore needed to allow the use of the P8-generated TP loads in providing reasonable predictions of summer average epilimnetic lake phosphorus concentrations.

Because the Dillon and Rigler equation predicts only the spring (or fall) mixed-lake phosphorus concentration for a lake, it can be expected that it will underpredict summer phosphorus concentrations for lakes that experience internal loading. To account for the internal loading experienced by Lake Susan and Rice Marsh Lake, the spreadsheet model was made to allow for a user-determined addition of phosphorus to the lake, thus providing for an upward adjustment of the

Dillon and Rigler prediction. The added phosphorus is in effect mixed with the entire volume lake to bring the phosphorus concentration to the desired value.

5.3.2 Calibration of the In-Lake Model

The need to adjust the Dillon and Rigler predictions to account for internal loading was confirmed in the analysis of the 1997 situation for Lake Susan and Rice Marsh Lake. The calibration procedure for the in-lake model, using 1997 watershed and lake data, is described below.

The 1997 watershed conditions for both lakes, which were evaluated using analysis of 1997 aerial photos and augmented by field investigations, were used as input for the 1997 (existing conditions) P8 model. The model used these conditions along with 1997 precipitation and climate data to provide an estimate of the watersheds' 1997 TP loads to the lake. The 1997 loads received from Lake Ann via Riley Creek were computed based on measured summer average TP concentrations in that lake, and on modeled water outflows from Lake Ann (see *Lake Lucy and Lake Ann Use Attainability Analysis*, District, 1999). Water and TP loads to Rice Marsh Lake generated by Lake Susan were computed based on in-lake modeling results for Lake Susan.

The in-lake model was thus provided with the estimated water and TP loads from the upstream lake, and the P8-generated estimates of water and TP loads from the lake's immediate watershed. The Dillon and Rigler equation - using an apparent settling velocity calculated according to the method of Vollenweider (1976) and a retention coefficient as formulated by Chapra (1976)—allowed reasonable agreement with observed early spring 1997 concentrations for both Lake Susan and Rice Marsh Lake. However, for both lakes, these predictions were significantly lower than the observed summer 1997 TP averages.

Phosphorus loading in addition to what was expected from the upstream lake and the immediate watershed was needed to calibrate the model to observed 1997 summer average epilimnetic phosphorus concentrations. For Lake Susan, the amount needed was found to be 66 lbs.; for Rice Marsh Lake the amount was 71 lbs.. This amount was determined by trial-and-error, using upward or downward adjustments as necessary to allow agreement with the 1997 summer TP averages. Once determined, the addition was assumed to be constant for all modeled years, and was left unaltered during subsequent modeling efforts for different years, future land uses, and varying climatic conditions.

5.4 Use of the P8/In-lake Model

The in-lake model, adjusted to account for internal loading and calibrated to measured 1977 lake concentrations, was subsequently used to estimate phosphorus loads and concentrations under varying climatic conditions and best-management practice options.

The annual watershed phosphorus loading for Lake Susan and Rice Marsh Lake under projected future land use conditions was estimated for four different years, each representing a distinct climatic future. The varying climatic conditions affect the lake's volume, outflow volume, and hydrologic residence time, and thereby affect the phosphorus concentrations within the lakes. The four years modeled were the:

- Wet year—an annual precipitation of 41 inches, the amount of precipitation occurring during the 1983 water year
- Model calibration year—an annual precipitation of 34 inches, the amount of precipitation occurring during the 1997 water year (The model calibration year is the year in which data were collected from the lake. The data were used to calibrate the P8 model and in-lake model.)
- Average year—an annual precipitation of 27 inches, the amount of precipitation occurring during the 1995 water year
- Dry year—an annual precipitation of 19 inches, the amount of precipitation occurring during the 1988 water year

In-lake modeling was used to evaluate the lakes' response to the P8-predicted loadings. Details of the modeling results, and a discussion of management opportunities follows.

6.0 Analysis of Future Conditions

The likely response of Lake Susan and Rice Marsh Lake to projected future watershed conditions under the four climate scenarios (described in Section 5.4) was evaluated using the P8 model in tandem with the calibrated in-lake model. The purpose of this portion of the UAA was to provide a means of evaluating the likely future lake condition if no management initiatives (apart from those the District already requires for newly urbanized areas) are taken. Modeling assumptions and results are presented in the following sections.

6.1 Future Condition Modeling Assumptions

For both Susan and Rice Marsh Lakes, the land use used in the modeling for the ultimate watersheds was as described in Section 3.2 of this report. In general, the land use for Rice Marsh Lake is not expected to change dramatically in future years. For Lake Susan, however, land use changes may substantially affect the quality and quantity of the runoff to the lake.

Implement - The District requires that developers provide detention ponds for urbanizing subwatersheds, and that the ponds are sized appropriately for the ultimate land-use conditions. For the P8 modeling conducted to evaluate future conditions, it was assumed that these District standards would be met; it was assumed that urbanizing subwatersheds would have appropriately-sized (in accordance with existing NURP criteria) ponds. Estimates were made of the required pond volumes, and these hypothetical ponds were included in the model as if they actually existed.

Therefore, in the future conditions modeling for the Lake Susan watershed, ponds were assumed to have been upgraded to meet NURP detention pond design criteria in subwatersheds LS-2.1, 2.2, 3.13, and 3.62; ponds meeting NURP criteria were added in subwatersheds LS-3.14, 3.52, 3.91, and 3.92. In the future conditions modeling for the Rice Marsh Lake watershed, ponds were assumed to have been upgraded in subwatersheds RM-4.1, 4.4, and 5.4; a pond was added in subwatershed RM-1.3 and 3.10. Figure 2 shows the locations of these urbanization-required pond upgrades and additions.

For the in-lake modeling of future conditions, it was also necessary to make assumptions as to the water quantity and quality that would be exported from upstream lakes to Lakes Susan and Rice Marsh Lake. For the estimates of future water quality in Lake Susan, it was assumed that all wetlands within the immediate watersheds of Lake Lucy and Lake Ann would be preserved. This assumption represents a likely future for the upstream watersheds—the lakes' watersheds will almost certainly be preserved under future conditions. Several other water quality management initiatives presented in the *Lake Lucy and Lake Ann Use Attainability Analysis* would allow for improved water quality in Lake Ann. However, the water quality benefits of these initiatives were not accounted for in the modeling for Lake Susan. Implementation of these additional initiatives will require discussion and District approval; the implementation of these more aggressive initiatives is less certain. Therefore, the more conservative water qualtiy assumption made for Lake Ann in modeling Lake Susan appears reasonable.

Finally, it should be noted that the water and phosphorus load that Lake Susan receives from Lake Ann is relatively small by comparison to that received from Lake Susan's immediate watershed. Approximately 30 to 40 percent of the modeled water load for Lake Susan originates in Lake Ann, but only approximately 10 percent of the phosphorus load. As a result, changes in the assumptions made regarding the water quality of Lake Ann will not have a dramatic impact on the water quality modeling results for Lake Susan.

By contrast, the phosphorus and water load that Rice Marsh Lake receives from Lake Susan is more significant: approximately 60 to 70 percent of the water and 40 percent of the phosphorus load to Rice Marsh Lake comes from Lake Susan. For the in-lake modeling of Rice Marsh Lake under future conditions, it was assumed that all pertinent District regulations would be implemented, and that all three additional management initiatives (Add, Upgrade, Treat—see Section 7.1) would be undertaken for Lake Susan. Therefore, the water quality and quantity amounts used as input for the in-lake modeling of Rice Marsh Lake were those generated from the in-lake modeling of Lake Susan when Lake Susan's water quality had been substantially improved by watershed and lake management. The assumption of substantially improved water quality in Lake Susan was made in light of the favorable results obtained as a result of the 1988 alum treatment of the lake.

6.2 Modeling Results

As was discussed in Section 5.4, four climate conditions (wet year, dry year, average year, and calibration year) were used in evaluating the likely water quality of Lake Susan and Rice Marsh Lake under future land use conditions. The water quality of Lake Susan under these four conditions was evaluated first so that the results of the water quality modeling for Lake Susan could be used in the evaluation for Rice Marsh Lake (as described above). The modeling results for ultimate land use projections under the four climate conditions for the two lakes are presented below.

6.2.1 Climate Conditions and Model Results

Water quality simulations using the P8 model indicate that dry weather conditions will produce the greatest strain upon water quality in Lake Susan and Rice Marsh Lake. This is so despite the higher total load of phosphorus to the lake during wet weather. Wetter weather results in larger volumes of relatively less concentrated water passing through the lakes, so that in-lake phosphorus concentrations remain low. Despite the diminished phosphorus loading under dry conditions, the lakes' flushing rate is also diminished, so the in-lake phosphorus concentrations become elevated.

6.2.2 Modeling Chlorophyll a and Secchi Disc Transparency

The P8 model used for the analysis predicts phosphorus loads to the lakes, and the in-lake model used to determine water quality in the lake itself gives results in terms of phosphorus concentrations. As such, the modeling provides no means of predicting Chl *a* or transparency values directly.

Several authors[6] have published equations giving general relationships between TP and Chl *a*, and between Chl *a* and transparency. These published equations are generally best-fit regression equations developed as general descriptions of the results of water quality analysis for many lakes. The published regression equations give reasonable indications of the algal growth and transparency dynamics for lakes of a particular class or region, but they may or may not be well-suited for application to a specific lake.

Comparison of the published equations with data for Lake Susan and Rice Marsh Lake showed that none of the published equations was suitable for representing the dynamics of these two District lakes. In particular, it was observed that the predicted response of transparency to Chl *a* and TP did not comport with the water quality data collected from the two lakes over the past 30 years. To provide a means of better predicting Chl *a* and transparency for the two lakes, individualized best-fit regression equations were developed for each lake using actual lake data. A variety of equation types (logrithmic, polynomial, exponential, etc.) were used in the analysis—the equation type giving the best fit (as measured by R^2 values) was selected. (To examine the data plots and regression lines as they were developed from the data, see Appendix D.) The regression equations developed for each lake are given below (TP and Chl *a* concentrations are expressed in µg/L; transparency values are in meters):

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6 See for example Osgood, 1989; or Carlson, 1977.

Lake Susan

$[\text{Chl } a] = 0.4977 \text{ X } [\text{TP}]$ $\quad R^2 = .4323$

$\text{Transparency} = 3.207 \text{ X } [\text{Chl } a]^{-0.4102}$ $\quad R^2 = .5479$

Rice Marsh Lake

$[\text{Chl } a] = 0..3002 \text{ X } [\text{TP}]$ $\quad R^2 = .2917$

$\text{Transparency} = 5.244 \text{ X } [\text{Chl } a]^{-0.5709}$ $\quad R^2 = .6428$

These equations are those that were subsequently used to give indications of what may be expected with respect to Chl *a* and transparency, given the P8/in-lake model results for TP. It should be noted that the response of Chl *a* to TP, and of transparency to Chl *a* is highly variable. This variability is reflected in the relatively low R^2 values shown above. The regression equations therefore can be expected only to allow a general indication of the lake response to changing TP, and the predicted Chl *a* and transparency values should not be construed as absolute.

It is also noteworthy that for both lakes, the data shows that transparency does not respond well to changes in Chl *a*, at least in the relatively high (usually greater than 50 µg/L) ranges of Chl *a* that the two lakes have experienced over the last 30 years. The regression curves (Appendix D) relating transparencies to Chl *a* for both lakes are remarkably flat when Chl *a* values exceed 40 µg/L. The data therefore suggest that even substantial reductions in Chl *a* (resulting from reductions in TP) are not likely to produce dramatic improvements in transparency for the two lakes. Nevertheless, transparency improvements in the lake would be expected with long-term TP reductions.

6.2.3 Water Quality Results

As is shown on Figures 11 through 16, future land use will affect the water quality of both lakes. It is most instructive to examine the water quality impacts via the lakes' projected summer average TP values (Figures 11 and 14). For Lake Susan, the projected summer average TP values show significant increases when compared to the recent ("current" average—see Section 4.1.2) summer average TP value of 90 µg/L for Lake Susan. Depending on the climate conditions modeled, these increases range from 20 µg/L (calibration year) to 64 µg/L (dry year).

Expected land use changes in the Rice Marsh Lake watershed will cause increases in annual phosphorus loading from the immediate watershed to the lake. However, under the assumptions of the model, these increases are compensated for by the improved water quality in Lake Susan. The relatively large quantity of dilute (with respect to TP) water assumed to be coming from Lake Susan has a flushing effect on Rice Marsh Lake, so that the in-lake model for ultimate watershed conditions predicts summer average TP values lower than the "current" value of 197.6 µg/L. The decreases in water quality are predicted to be greatest in wetter years, when decreases on the order of 60 µg/L are expected. In dry years, the model predicts a decline of only 16 µg/L.

Based on the regression equations shown above, average summer Chl *a* values can be expected to show corresponding changes (Figures 12 and 15). Depending on climate conditions, the predicted Chl *a* increases for Lake Susan—as compared with recent summer averages - are on the order of 34 µg/L (calibration year) to 35 µg/L (dry year). By contrast, for Rice Marsh Lake, the Chl *a* is predicted to diminish in accordance with the predicted declines in TP. Predicted Chl *a* values for Rice Marsh Lake range from 45 µg/L lower than the summer average Chl *a* value for the calibration year, to 32 µg/L lower for the dry year.

As noted previously, past years' data suggests that the TP and Chl *a* increases will not result in large changes in transparency. Under all modeled climate conditions, transparency will remain quite low—in the range of 0.7 meters for Lake Susan and 0.3 meters for Rice Marsh Lake. The modeled transparency decreases (from the current summer average) by approximately 0.2 meters under all modeled conditions for Lake Susan.

Paradoxically, the transparency is also predicted to decrease (by comparison with current summer average transparency data) in Rice Marsh Lake—despite the decrease expected for Chl *a*. This unexpected result is a consequence of the nature of the regression equation relating transparency to Chl *a* concentrations. That regression, based on many years of sampling data, predicts that transparency remains quite constant across a wide range of Chl *a* values. The equation predicts that transparency is approximately 0.3 meters for Chl *a* values between 75 and 175 µg/L. The current (1988-1997) transparency average for the lake is 0.5 meters, meaning that the model is therefore predicting a transparency decline of approximately 0.2 meters.

7.0 Evaluation of Possible Management Initiatives

Analysis of the modeling done to evaluate the likely future conditions for Lake Susan and Rice Marsh Lake indicated that improvements could be made within the lakes' watersheds and within the lakes themselves. The modifications necessary to effect these improvements (assuming future land-use conditions) were evaluated under the four climate conditions to determine what effect they might have on lake water quality. The modifications and their costs are presented in Section 7.1; the results of the modeling used to evaluate the benefits of the improvements are presented in Section 7.2.

7.1 Three Watershed/Lake Management Scenarios—Descriptions and Costs

Three options for providing for improved water quality in Lake Susan and Rice Marsh Lake are discussed in the following sections. The three options are given in order of the sequence in which they might reasonably be expected to be undertaken by the District. Explanations of the options, and projected costs for the proposed improvements are also provided below:

7.1.1 Upgrade

Analysis of the land-use patterns and the capacities of the existing ponds shows several deficiencies. Though the modeling of future conditions assumes the existence of ponds required by future urbanization, several subwatershed areas have existing ponds with volumes that are inadequate for providing effective sediment and phosphorus removal. Upgrading these ponds (by providing increased storage volume) is likely to be possible with minimal local disturbance, requiring dredging or possibly only reconfiguration of the pond outlet structure.

Optimal treatment effectiveness requires that the ponds be designed to have wet detention volumes capable of storing the runoff that would result from 2.5 inches of rainfall over the individual subwatershed (for a local pond) or group of subwatersheds (for a regional pond). In some cases, space limitations make it impossible to achieve the optimum wet detention volume, but increasing the wet detention volume will nevertheless improve water treatment.

Costs given below for the pond upgrades are based on the assumption that any increase in pond volume would be accomplished by excavation; excavation costs (in all of the cost estimates given for this report) are estimated at $8 per cubic yard. Actual costs for the upgrades would depend on the unique conditions at each pond that the District decides to upgrade, and a more precise determination of those costs would have to be done on a site-specific basis.

For Lake Susan, Scenario 1 assumes that the pond in subwatershed LS-3.21 would be upgraded (Figure 3) Cost for the upgrade of this single pond is estimated at $27K.

For Rice Marsh Lake, Scenario 1 assumes the upgrades of the ponds in the following subwatersheds: RM-2.1, 2.2, 2.4, 2.6, and 6.5 (Figure 3). The total cost for the upgrades of these five Rice Marsh Lake watershed ponds is estimated at $191K.

The modeled water quality results of these pond upgrades are presented in Section 7.2. Figure 3 shows the locations of the proposed pond upgrades for both the watersheds of Lake Susan and Rice Marsh Lake.

7.1.2 Add

In addition to the pond upgrades discussed in the previous section, analysis indicates that phosphorus loading from the watershed could be reduced significantly by providing ponds in certain subwatershed areas that currently have none. The ponds would be added to provide treatment for watershed areas already urbanized but not currently served by ponds. The precise location of any ponds added will depend on several factors, including land availability and cost, drainage routes to the ponds, and possibilities for routing of pond discharge. A comprehensive analysis of such factors was not conducted for this report. Rather, the assumption was simply made that it would be possible to install a pond at some location within the identified subwatersheds.

Land use patterns in the subwatersheds were compared with corresponding detention pond volumes to identify subwatersheds for which the addition of ponds could provide significant water quality benefits. Based on this analysis, ponds are proposed for several subwatersheds for each lake. The modeled water quality results of these pond additions are presented in Section 7.2.

For the Lake Susan watershed, the installation of new ponds is proposed for subwatersheds LS-1.2, 2.4, 3.42, 3.71, 3.93, 3.94, 3.95, and 3.96. The estimated total cost for the construction of these ponds is $341K.

For the Rice Marsh Lake watershed, the installation of new ponds is proposed for subwatersheds RM-1.1, 2.5, 2.8, and 6.9. The estimated total cost for the construction of these ponds is $201K.

Figure 3 shows the locations of the proposed pond additions for both the watersheds of Lake Susan and Rice Marsh Lake.

7.1.3 Treat

As has been discussed earlier in this report, there is significant evidence to suggest that internal loading is causing elevated summer average TP concentrations in both Lake Susan and Rice Marsh Lake. Alum treatment of the lakes is expected to diminish the extent of the internal loading, and may result in significant long-term declines in summer average TP values.

In-lake alum treatment of the lakes is expected to provide both a temporary and a long-term improvement in the water quality of the lakes. The temporary benefit (lasting from one to two years) results from the alum's ability to remove phosphorus from the water column. The phosphorus removal inhibits algal growth by depriving the algae of phosphorus, a required nutrient. Additionally, temporary improvements in water clarity result from the "cleansing" of the water column that occurs as the alum floc settles and removes suspended particulate matter. Long-term benefits to the lake are expected to result from the alum's ability to bind phosphorus after the alum comes to rest on the lake sediment surface—thus preventing transfer of sediment-bound phosphorus back to the water column (i.e. preventing internal loading).

Over time, the effectiveness of the thin alum blanket on the sediment surface diminishes. Estimates of the effective duration of a single alum treatment in preventing sediment phosphorus release vary from 5 to 15 years. This effective duration can be affected by several factors, including homogeneity of treatment, wind-driven mixing and sediment resuspension, and changes in the sediment-water chemical exchange dynamics that may result from the treatment itself. Despite the uncertainties, it is reasonable to assume that for Lake Susan and Rice Marsh Lake, the alum treatments would be conducted at approximately 10-year intervals. If necessary, the treatment interval could be adjusted based on the results of ongoing water quality modeling.

The cost of alum treatment depends on the surface area of the lake to be treated, but the open-water areas of Lake Susan and Rice Marsh Lake are quite similar. City of Chanhassen officials report that the 1998 alum treatment applied to Lake Susan cost $34K; the cost of treating Rice Marsh Lake is likely to be quite similar.

The modeled water quality results of the alum treatment are presented in Section 7.2.

7.2 Modeling Results Under Four Climate Conditions

Under the assumed conditions resulting from the three management initiatives (Upgrade, Add, Treat) described in Section 7.1, the watersheds of Lake Susan and Rice Marsh Lake were modeled using P8 to determine the resulting water and TP loads to the lakes. For each of the management initiative scenarios, it was assumed that future watershed conditions would incorporate detention ponds as required by District rules (Implement—see Section 6.1). The loading estimates provided by the P8 model were used as input the in-lake model, along with upstream lake inputs as described in Section 6.1. Modeling results for the management initiative scenarios are described in the following sections.

The modeling results for all modeled future conditions are presented graphically on Figures 17 and 18. Note that on these figures, modeling results for each scenario are given as though the management initiatives of the preceding scenario or scenarios have already been implemented. Therefore, for example, the modeling results shown for Scenario 3 (Add) assume that in addition to the ponds added under Scenario 3, ponds required by urbanization have been built (under the conditions of Scenario 1—Implement), and also that the pond upgrades identified for Scenario 2 (Upgrade) have been completed.

Table 7 details the loading and in-lake TP results for all the modeled scenarios.

7.2.1 Loading Estimates

A review of the loading to the lakes under the conditions of the various management initiatives is presented below. The lake loading is comprised both of the loading from the immediate watershed, and the loading received from the upstream lake.

Upgrade (Scenario 2)—The pond upgrades proposed for Lake Susan and Rice Marsh Lake are not expected to provide large TP loading decreases for either of the lakes. Table 7 shows that by comparison to the ultimate conditions baseline case (Scenario 1—Implement), TP loading from the immediate watershed of Lake Susan declines by only 3 to 5 lbs. per year under any climate conditions. For Rice Marsh Lake, the declines are more substantial, on the order of 10 to 12 lbs. per year.

Add (Scenario 3)—P8 modeling indicates that the pond additions outlined in Section 7.1.2 result in significant loading decreases for the lakes. Table 7 shows a decline of 49 to 56 lbs. TP per year for Lake Susan under all climate conditions. The watershed of Rice Marsh Lake, with fewer ponds added, shows smaller declines in annual TP loads. Modeling indicates that the added ponds reduce the loading to Rice Marsh Lake by approximately 26 lbs.

Treat (Scenario 4)—Alum treatment benefits the lake by controlling the lake's internal loading, but has no effect on the TP entering the lake from the surrounding watershed or from upstream lakes. Therefore, Table 7 indicates that treating the lake with alum results in no (external) load reduction.

7.2.2 In-Lake TP Results

The predicted average summer TP values provided by the in-lake models for Lake Susan and Rice Marsh Lake are controlled by several model inputs, including lake morphology, rainfall amounts, and loads received by the lakes. Under a given climate condition, the modeling assumes that only the loading (external and internal) varies. External loads, including watershed loads (detailed in Section 7.1.1) and the loading from the upstream lakes (Section 6.1) are the two principal determinants of the average spring overturn concentrations predicted by the model.

In addition, it is necessary to account for the average difference between the lakes' spring overturn concentration and their summer average TP concentrations. This difference, explained by internal loading, is assumed to be constant from year to year. The internal load for each lake is based on the 1997 calibration for each of the two in-lake models. As has been discussed, this load (110 lbs. for Lake Susan and 119 lbs. for Rice Marsh Lake) is in effect added to the lake water to result in summer average TP concentrations that take the internal loading into account. Internal loading is assumed for both lakes for Scenarios 1, 2, and 3, but the internal load is removed from the model to estimate the summer average TP concentration for Scenario 4.

For both lakes and all modeled years and treatment scenarios, Table 7 details the water and phosphorus loads, and the resulting predictions of TP, Chl *a*, and SD, and the resulting TSI value. The resulting predictions of TP are also highlighted in Figures 17 (Lake Susan) and 18 (Rice Marsh Lake).

For both Lake Susan and Rice Marsh Lake, Scenario 1 represents the "no action" condition in which no new watershed initiatives are undertaken. The following discussions of Scenarios 2, 3, and 4 describe modeling results by comparison to Scenario 1.

Upgrade (Scenario 2)—The relatively small decreases in TP loads provided by the pond upgrades proposed for Lake Susan and Rice Marsh Lake provide correspondingly small decreases in the predicted summer average TP values for the two lakes. Figure 17 (see also Table 7) shows that by comparison to the ultimate conditions baseline case (Scenario 1—Implement), summer average TP for Lake Susan is expected to decline by only 0 to 1 µg/L under any climate conditions. For Rice Marsh Lake (Figure 18), the declines are also on the order of 0 to 1 µg/L.

Add (Scenario 3)—By contrast to the small changes predicted for the Scenario 2 management initiatives, the in-lake model predicts substantial declines in summer average TP values resulting from the pond additions of Scenario 3. Figure 17 shows that the model predicts that Scenario 3 initiatives will result in a decrease of 17 µg/L for Lake Susan under wet conditions, with other modeled climate conditions showing similar but slightly smaller (11 to 15 µg/L) declines. The watershed of Rice Marsh Lake, with fewer ponds added under Scenario 3, shows slightly smaller declines in predicted summer average TP values (Figure 18, Table 7). TP declines of 7 to 16 µg/L are predicted.

Treat (Scenario 4)—Under the assumptions of the in-lake model, alum treatment will result in a decrease in summer average TP of approximately 30 µg/L for Lake Susan (Figure 17). The corresponding decrease for Rice Marsh Lake is expected to be on the order of 65 µg/L (Figure 18). These decreases, considered for modeling purposes to be constant from year to year (see also Table 7), are based on the 1997 calibration of the two in-lake models.

Under the assumptions of the modeling used for this study, implementation of the water management initiatives described above will result in Lake Susan's meeting the Level II water quality goal (average summer TP equal to or less than 75 µg/L) in all but the dry year (see Figure 17). For Rice Marsh Lake, the less stringent Level III goal (average summer TP equal to or less than 105 µg/L) is met under all modeled climate conditions (see Figure 18). It is worth noting that alum treatment alone (Scenario 4) is projected to allow Lake Susan to meet the Level II goal in the calibration year. The modeling assumptions for Rice Marsh Lake result in the prediction that alum treatment alone would allow the lake to meet its Level III goal in all but the dry year.

7.2.3 Projections of Chl *a* and Transparency

For this study, regression equations relating TP and Chl *a*, and Chl *a* and transparency for each lake were developed based on the results of many years of water quality data collection. It is believed that these equations provide the best possible indication of the Chl *a* and transparency values that are likely to be associated with a given TP concentration. However, for Lake Susan and Rice Marsh Lakes there is not a close correlation between these water quality parameters (see the discussion presented in Section 6.2.2). Therefore, Chl *a* and transparency predictions based on modeled TP values for the two lakes must be considered strictly as approximations. The predicted Chl *a* and transparency values should be regarded only as the center of a range of values that can reasonably be expected for these two variables for a given (modeled) TP concentration. It is only with these limitations in mind that the predicted Chl *a* and transparency values for the two lakes should be examined.

For Lake Susan, the cumulative decline in Chl *a* values resulting from the proposed Scenario 4 management initiatives can be expected to be on the order of 20 to 25 μg/L. The expected annual Chl *a* for the lake would therefore range from 29 to 47 μg/L, depending on the climate conditions. The transparency regression equation developed for Lake Susan indicates that average summer transparency for the lake would then be on the order of 0.7 to 0.8 meters.

For Rice Marsh Lake, the cumulative decline in Chl *a* values corresponding to the modeled Scenario 4 TP decreases would be on the order of 22 to 24 μg/L. The expected annual Chl *a* for the lake would therefore range from 19 to 30 μg/L, with the value dependent upon the climate conditions modeled. Based on these predicted summer average Chl *a* values, the transparency regression equation developed for Rice Marsh Lake indicates that average summer transparency for the lake would be on the order of 0.4 to 0.5 meters.

7.3 Other Possible Management Initiatives

In addition to the increases in pond numbers and volume described in the preceding sections, other watershed and lake management initiatives are likely to be of benefit to Lake Susan and Rice Marsh Lake. These additional initiatives are briefly discussed in the sections that follow.

7.3.1 General Housekeeping BMPs

Much of the stormwater runoff entering Lake Susan and Rice Marsh Lake is first detained and treated by upstream wet detention basins or wetlands. This detention will increase if the recommended water quality initiatives (Upgrade, Add) are effected. Water quality modeling simulations show that the upstream basins are effective at removing most course particulates and phosphorus associated with coarse particles. However, wet detention basins are not as effective at removing soluble phosphorus, or phosphorus associated with extremely small particles. Therefore, source control is also important in reducing the amount of phosphorus contained in stormwater runoff. Nonstructural (requiring no construction) watershed BMPs are effective at reducing the amount of phosphorus on-site, prior to transport into stormwater runoff.

It is not possible to model the effects of nonstructural BMPs accurately, but studies have shown that they are moderately effective at reducing phosphorus loads. Examples of effective nonstructural BMPs that would be appropriate for the Lake Susan and Rice Marsh Lake watershed include:

- Public education programs to inform the residents of the Lake Susan and Rice Marsh Lake watersheds of ways to reduce phosphorus loading through proper handling of yard wastes, fertilizers, pet wastes, soaps and detergents.
- Encouraging industrial/commercial areas to institute good housekeeping practices, including appropriate disposal of yard wastes, appropriate disposal of trash and debris, and appropriate storage and handling of soil and gravel stockpiles.
- Encouraging the installation of vegetated buffers between yards and wetlands and ponds.
- Encouraging the installation of vegetated buffers between yards and the shores of Lake Susan and Rice Marsh Lake.
- Encouraging an increase in depression storage within the watersheds. Increased depression storage, accomplished by various means including residential rainwater gardens, is expected to reduce the amount of runoff to the lakes. Soluble phosphorus, not normally removed by detention basins, can be effectively sequestered in the soils underlying depression storage basins. Thereby, the soluble phosphorus load to the lakes can be reduced.
- Performing regular street sweeping, especially in high density residential area, industrial/commercial areas, and any other areas containing large areas of impervious (paved surfaces), such as school and church parking lots. Spring and fall street sweeping will provide the most benefits for phosphorus source reduction.

7.3.2 Aquatic Plant Management

Because of the undesirable effects (see Section 4.3.3.1)of curly leaf pondweed (*Potemogeton crispus*) in both lakes, it may be useful to develop a macrophyte management plan to reduce the growth of this exotic weed curlyleaf pondweed in Lake Susan and Rice Marsh Lake. Potential in-lake TP reductions resulting from curly leaf pondweed control were not modeled for this study because the TP contribution of the curly leaf pondweed die-off can not easily be distinguished from the TP contribution of the sediments (i.e. internal loading). This difficulty is particularly evident in polymictic lakes such as Lake Susan and Rice Marsh Lake. Nevertheless, reductions in late summer in-lake TP concentrations would be expected if curly leaf pondweed were eradicated.

Controlling curlyleaf pondweed can be done by herbicide treatments applied from a barge or boat or by mechanical harvesting, or by a combination of these methods. Herbicide treatments are more effective at eradicating the plant but MDNR regulations limit the extent of the lake that can be treated in any year. Mechanical harvesting is more accepTable to the MDNR but provides only temporary benefits and must be repeated annually.

Several consecutive years of intensive herbicide treatments would most likely be required to bring the curlyleaf pondweed population down to acceptable levels. This is because the herbicide applications are unlikely to be 100 percent effective each year, and the desirable plants will require some time to recolonize the lake bottom areas currently infested with curlyleaf pondweed. Also, the curlyleaf pondweed turions can reside dormantly in the lake sediments for several years, and subsequently germinate and develop into viable plants. It is likely, but not certain, that the intensity of treatment would reduce annually.

Because of possible objections by the MDNR, it is recommended that plans to attempt curly leaf pondweed control be developed in close coordination with that agency.

8.0 Discussion and Recommendations

As indicated in Section 7.1.2, the goals set forth in this report for Lake Susan and Rice Marsh Lake can be met through the implementation of the water quality initiatives outlined in this report. Alum treatment of the lakes is expected to be particularly effective in achieving the goals. Under several of the modeled climate conditions, alum treatment alone is likely to allow the lakes to meet District TP goals. With the assurance that District goals can be met, the following sections discuss the relative advantages of the proposed initiatives, and propose a likely management strategy for the lakes.

8.1 Benefits and Costs

As has been discussed, several benefits are likely to accrue from improved watershed and lake management of Lake Susan and Rice Marsh Lake. These benefits include enhancement of the lakes' recreational use, improvements in the aquatic habitats provided by the lakes, and perhaps most importantly, water quality improvements in Lake Riley downstream. It is practically impossible to assign dollar values to these benefits, so that a formal benefit-cost analysis was not performed for this UAA. Nevertheless, it is instructive to compare the costs of the proposed management initiatives with the modeled decreases in in-lake summer average TP concentrations.

For both lakes, it is anticipated that substantial reductions in summer average TP concentrations can be achieved by means of periodically conducted alum treatment of the lakes (Scenario 4). If the assumptions of the UAA modeling are accurate, summer average TP reductions of 30 µg/L for Lake Susan and 65 µg/L for Rice Marsh Lake can be expected to result from alum treatment. By comparison to structural BMPs (such as pond construction), alum treatment is relatively inexpensive-$34K appears to be an accurate per-treatment estimate. It should be noted, however, that to permanently control internal loading in the lakes, alum treatment is expected to be required indefinitely at approximately 10-year intervals.

The pond additions proposed under Scenario 3 in this report can also be expected to provide significant reductions in TP loading, and in summer average TP values for the lakes. This is particularly true for Lake Susan, in which summer average TP values may be expected to decline by approximately 10 to 20 µg/L. For Rice Marsh Lake, the proposed pond additions are likely to provide a reduction of approximately 5 to 15 µg/L. However, these reductions in in-lake phosphorus concentrations are relatively expensive. The cost estimate for the pond construction required to produce the TP reductions in Lake Susan is $341K; the corresponding estimate for Rice Marsh Lake is $201K.

In terms of expected improvements in summer average TP values, the pond upgrades proposed under Scenario 2 appear to be most expensive. Average summer TP values are expected to decline only slightly (1 μg/L or less for both lakes) as a result of the pond upgrades. For Lake Susan, the proposed upgrade of the single pond may not be prohibitively expensive (the cost estimate is $27K for the excavation), but for Rice Marsh Lake the almost-negligible improvements in water quality would come at the relatively high estimated cost of $191K.

It is assumed that the Scenario 1 (Implement) improvements discussed in this report would be made as a part of the progression of the watersheds to their ultimate urbanization conditions. Therefore, the water quality improvements resulting from these improvements were assumed to occur at no additional cost to the District, and were not formally evaluated for this study.

Similarly, because no estimates of water quality improvements were possible for the other management initiatives considered in this report (housekeeping BMPs and curly leaf pondweed management), cost estimates were not developed for these initiatives. As a result, no comparison of costs and TP reductions for these initiatives was made for this report.

8.2 Preferred Course of Action

Alum treatment of the two lakes is likely to result in relatively large decreases in lake TP concentrations, and the treatment is relatively inexpensive. Particularly in light of the potential benefits to Lake Riley, alum treatment appears to be a cost-effective initiative. As such, it is recommended to the District.

The pond additions proposed under Scenario 3 can be expected to provide significant water quality benefits, but are relatively expensive. Because of the expected benefits to the lakes, this management initiative deserves further investigation. Further modeling and analysis could identify those subwatersheds in which the most substantial reductions in TP loading occur. Attention could then be focused on those most effective ponds, and possibilities for reducing the construction costs examined. The construction of less significant ponds could be deferred.

It appears that the pond upgrades proposed under Scenario 2 are not cost-effective. However, a case-by-case examination of the ponds in question may suggest means of increasing storage volumes in these ponds by means less expensive than the anticipated excavation. For example, outlet structures may be modified, or berms may be placed that effectively and cheaply increase the storage volumes of these ponds.

The pond upgrades and additions required under Scenario 1 would be made at no cost to the District, and it is expected that these improvements will be made as a matter of course. Similarly, the housekeeping BMPs discussed are often implemented as a part of normal watershed management activities, and as such may be effected at no additional cost to the District. As was mentioned previously, the benefits of curly leaf pondweed management are unclear, so its implementation may require separate analysis to determine its advisability and cost-effectiveness.

Finally, it should be mentioned that it is a general District goal to encourage public participation in all District activities and decisions that may affect the public. In accordance with this goal, the District seeks to involve the public in the discussion of this UAA. This goal is expected to be achieved through a public meeting to obtain comments on the Lake Susan and Rice Marsh Lake UAA.

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Tables

Table 1

Land Use Comparison - Present vs. Ultimate

Lake Susan Watershed

Land Use Category	Existing Land Use Area (Acres)	Percent of Total Area	Ultimate Land Use Area (Acres)	Percent of Total Area
Natural	512	43%	286	24%
Agricultural	84	7%	0	0%
VLDR	40	3%	30	2%
LDR	32	3%	25	2%
MDR	194	16%	357	30%
HDR	51	4%	106	9%
Institutional	3	0%	3	0%
Highway	25	2%	32	3%
Commercial	49	4%	49	4%
Industrial	197	17%	299	25%
Total	1186		1186	

Rice Marsh Lake Watershed

Land Use Category	Existing Land Use Area (Acres)	Percent of Total Area	Ultimate Land Use Area (Acres)	Percent of Total Area
Natural	257	30%	218	26%
Agricultural	69	8%	0	0%
VLDR	35	4%	29	3%
LDR	63	7%	69	8%
MDR	165	19%	201	24%
HDR	53	6%	47	5%
Institutional	37	4%	37	4%
Highway	22	3%	66	8%
Commercial	139	16%	168	20%
Industrial	13	1%	18	2%
Total	853		853	

Notes:

VLDR = Very Low Density Residential (<1 housing unit per acre)

LDR = Low Density Residential (1-4 housing units per acre)

MDR = Medium Density Residential (4-8 housing units per acre)

HDR = High Density Residential (>8 housing units per acre)

Table 2

Lake Susan
Comparison of Baseline and Current Water Quality Conditions
(Summer Average Data)

Chlorophyll a (ug/L)				Total Phosphorus (ug/L)				Secchi Disc Transparency (m)			
Baseline (1971-1984)		Current (1988-1997)		Baseline (1971-1984)		Current (1988-1997)		Baseline (1971-1984)		Current (1988-1997)	
1971:	38.1	1988:	47.5	1971:	120.5	1988:	83.0	1971:	1.1	1988:	0.9
1975:	48.0	1990:	28.5	1975:	124.5	1990:	60.0	1975:	0.8	1990:	0.8
1978:	64.5	1994:	72.2	1978:	159.0	1994:	122.0	1978:	1.2	1994:	0.5
1981:	42.4	1997:	32.1	1981:	112.5	1997:	95.4	1981:	0.8	1997:	1.0
1984:	62.2			1984:	59.5			1984:	0.8		
Range:	8 -121		4 -114	Range:	45 -208		24 - 183	Range:	0.4 - 1.9		0.3 - 2.9
Mean:	51.0		41.7	Mean:	115.2		89.7	Mean:	0.9		0.8

Notes: 1) Only June through August water quality data was included for determining summer averages.
2) Because they are not directly comparable, the post-alum treatment (1988) data were not included in this summary.

Table 3

Rice Marsh Lake
Comparison of Baseline and Current Water Quality Conditions
(Summer Average Data)

Chlorophyll a (ug/L)				Total Phosphorus (ug/L)				Secchi Disc Transparency (m)			
Baseline (1972-1984)		Current (1988-1997)		Baseline (1972-1984)		Current (1988-1997)		Baseline (1972-1984)		Current (1988-1997)	
1972:	188.5	1988:	111.6	1972:	708.5	1988:	324.0	1972:	0.3	1988:	0.5
1975:	132.5	1990:	97.6	1975:	548.0	1990:	176.3	1975:	0.3	1990:	0.5
1978:	28.5	1994:	47.6	1978:	229.0	1994:	162.3	1978:	2.0	1994:	0.8
1980:	130.0	1997:	93.1	1980:	295.0	1997:	168.0	1980:	0.3	1997:	0.4
1981:	69.7			1981:	319.0			1981:	0.5		
1984:	34.2			1984:	201.5			1984:	1.3		
Range:	5 - 224		12 - 242	Range:	123 - 722		98 - 395	Range:	0.1 - 2.0		0.2 - 1.4
Mean:	97.2		86.2	Mean:	383.5		197.6	Mean:	0.8		0.5

Note: Only June through August water quality data was included for determining summer averages.

Table 4

Lake Susan
Predominant Algal Taxa Encountered in Summer (Jun-Aug) Samples
1975-1997

Year	Division	Taxa
1975	Cyanophyta (blue-green algae)	Aphanizamenon flos-aquae
1981	Cyanophyta (blue-green algae)	Aphanizamenon flos-aquae
1984	Cyanophyta (blue-green algae)	Aphanizamenon flos-aquae
1988	Cyanophyta (blue-green algae)	Anabaena affinis
1990	Cryptophyta/ Cyanophyta (cryptomonads, blue-green algae)	Cryptomonas erosa/ Aphanizamenon flos-aquae
1994	Cyanophyta (blue-green algae)	Aphanizamenon flos-aquae
1997	Chlorophyta/ Cyanophyta (green algae, blue-green algae)	Chlamydomonas globosa & Oocystis parva, Anabaenopsis raciborski & Aphanizamenon flos-aquae

Rice Marsh Lake
Predominant Algal Taxa Encountered in Summer (Jun-Aug) Samples
1975-1997

Year	Division	Taxa
1975	Cyanophyta (blue-green algae)	Microcystis aeruginosa
1978	Cryptophyta (cryptomonad algae)	Cryptomonas erosa
1981	Cyanophyta (blue-green algae)	Anabaena flos-aquae
1984	Cryptophyta (cryptomonad algae)	Cryptomonas erosa
1988	Cyanophyta (blue-green algae)	Oscillatoria Agardhii
1990	Chlorophyta/Cryptophyta/Cyanophyta (green/cryptomonads/blue-green algae)	Chlamydomonas globosa/ Cryptomonas erosa/ Aphanizamenon flos-aquae, Oscillatoria Agardhii
1994	Cyanophyta (blue-green algae)	Aphanizamenon flos-aquae
1997	Cyanophyta (blue-green algae)	Anabaenopsis raciborski, Aphanizamenon flos-aquae

Table 5

Lake Susan Zooplankton Summary 1981-1997

Sample Date	Thousands of Organisms per square meter		
	Cladocerans	Copepods	Rotifers
Aug-81	505	1,113	2,797
Aug-84	594	413	1,255
Jun-90	154	516	548
Jul-90	116	141	262
Aug-90	188	252	184
Aug-90	45	176	262
Sep-90	186	230	295
Jun-94	340	272	464
Jul-94	1,188	681	1,490
Aug-94	1,023	913	1,873
Aug-94	929	370	1,149
Sep-94	1,401	222	1,432
Apr-97	30	698	15
May-97	192	1,195	1,543
Jun-97	772	522	3,898
Jun-97	547	695	203
Jul-97	265	292	2,391
Jul-97	452	651	218
Aug-97	584	361	288
Aug-97	1,699	340	820
Sep-97	1,307	299	259
Oct-97	903	802	161

Table 6

Rice Marsh Lake Zooplankton Summary 1981-1997

Sample Date	Thousands of Organisms per square meter		
	Cladocerans	Copepods	Rotifers
Aug-81	1,276	1,501	1,297
Aug-84	47	100	843
Aug-88	1,589	474	888
Jun-90	47	207	377
Jul-90	175	486	3,994
Aug-90	172	156	364
Aug-90	197	267	394
Sep-90	956	329	1,347
Jun-94	382	236	197
Jul-94	2,614	330	494
Aug-94	2,648	57	601
Aug-94	5,079	123	1,256
Sep-94	2,110	229	1,110
Apr-97	0	506	13
Jun-97	1018	380	1257
Jul-97	1100	268	414
Aug-97	977	251	517
Aug-97	1036	145	207
Sep-97	1171	377	488

Table 7

Lake Susan Loading and Water Quality Results

Scenario Number	BMP Strategy	Modeled year: 1983 (Wet conditions) Water Load (A-F)	TP Load (lbs)	TP (µg/L)	CHLa (µg/L)	SD (m)	TSIsd	Modeled year: 1988 (Dry conditions) Water Load (A-F)	TP Load (lbs)	TP (µg/L)	CHLa (µg/L)	SD (m)	TSIsd	Modeled year: 1995 (Average conditions) Water Load (A-F)	TP Load (lbs)	TP (µg/L)	CHLa (µg/L)	SD (m)	TSIsd	Modeled year: 1997 (Calibration year) Water Load (A-F)	TP Load (lbs)	TP (µg/L)	CHLa (µg/L)	SD (m)	TSIsd
1	Ultimate watershed conditions throughout, with no watershed improvements or lake treatment	2060	665	106.8	53	0.63	67	506	219	141.7	71	0.56	68	936	364	115.3	57	0.61	67	1540	481	101.0	50	0.64	66
2	Upgrade all existing ponds to meet NURP standards for the fully urbanized subwatershed; upgrade pond 3.21.	2057	660	106.4	53	0.63	67	502	216	141.3	70	0.56	68	933	361	114.9	57	0.61	67	1536	478	100.7	50	0.64	66
3	Upgrade pond 3.21 as in Scenario 2, and add ponds to those watersheds already urbanized but having inadequate ponds (1.2, 2.4, 3.42, 3.71, 3.93, 3.94, 3.95, & 3.96)	2001	542	95.0	47	0.66	66	452	153	124.0	62	0.59	68	884	274	99.4	49	0.65	66	1484	382	89.2	44	0.68	66
4	Provide additional pond volume as in Scenarios 2 and 3, and also treat the lake with alum on a periodic (approximately every 10 years) to minimize phosphorus release from the sediments.	2001	542	64.6	32	0.77	64	452	153	93.6	47	0.66	66	884	274	69.1	34	0.75	64	1484	382	58.9	29	0.80	63

Rice Marsh Lake Loading and Water Quality Results

Scenario Number	BMP Strategy	Modeled year: 1983 (Wet conditions) Water Load (A-F)	TP Load (lbs)	TP (µg/L)	CHLa (µg/L)	SD (m)	TSIsd	Modeled year: 1988 (Dry conditions) Water Load (A-F)	TP Load (lbs)	TP (µg/L)	CHLa (µg/L)	SD (m)	TSIsd	Modeled year: 1995 (Average conditions) Water Load (A-F)	TP Load (lbs)	TP (µg/L)	CHLa (µg/L)	SD (m)	TSIsd	Modeled year: 1997 (Calibration year) Water Load (A-F)	TP Load (lbs)	TP (µg/L)	CHLa (µg/L)	SD (m)	TSIsd
1	Ultimate watershed conditions throughout, with no watershed improvements or lake treatment	2997	816	140.7	42	0.31	77	620	241	181.2	54	0.27	79	1337	411	146.1	44	0.30	77	2230	584	135.6	41	0.32	77
2	Upgrade existing ponds (where possible, to NURP standards for the fully urbanized subwatershed). Add volume to ponds 2.1, 2.2, 2.4, 2.6, and 6.5.	2985	804	139.9	42	0.31	77	608	235	181.1	54	0.27	79	1326	402	145.1	44	0.31	77	2218	575	134.9	40	0.32	76
3	Upgrade ponds as in Scenario 2, and add ponds to those watersheds scheduled to undergo urbanization (1.3 and 3.10), and to those already urbanized but having inadequate ponds (1.1, 2.5, 2.8, and 6.9).	2958	710	132.1	40	0.32	76	582	186	164.8	49	0.28	78	1300	334	133.9	40	0.32	76	2192	499	126.8	38	0.33	76
4	Provide additional pond volume as in Scenarios 2 and 3, and also treat the lake with alum on a periodic (approximately every 10 years) to minimize phosphorus release from the sediments.	2958	710	67.2	20	0.47	71	582	186	99.9	30	0.38	74	1300	334	69.0	21	0.47	71	2192	499	62.0	19	0.50	70

Figures

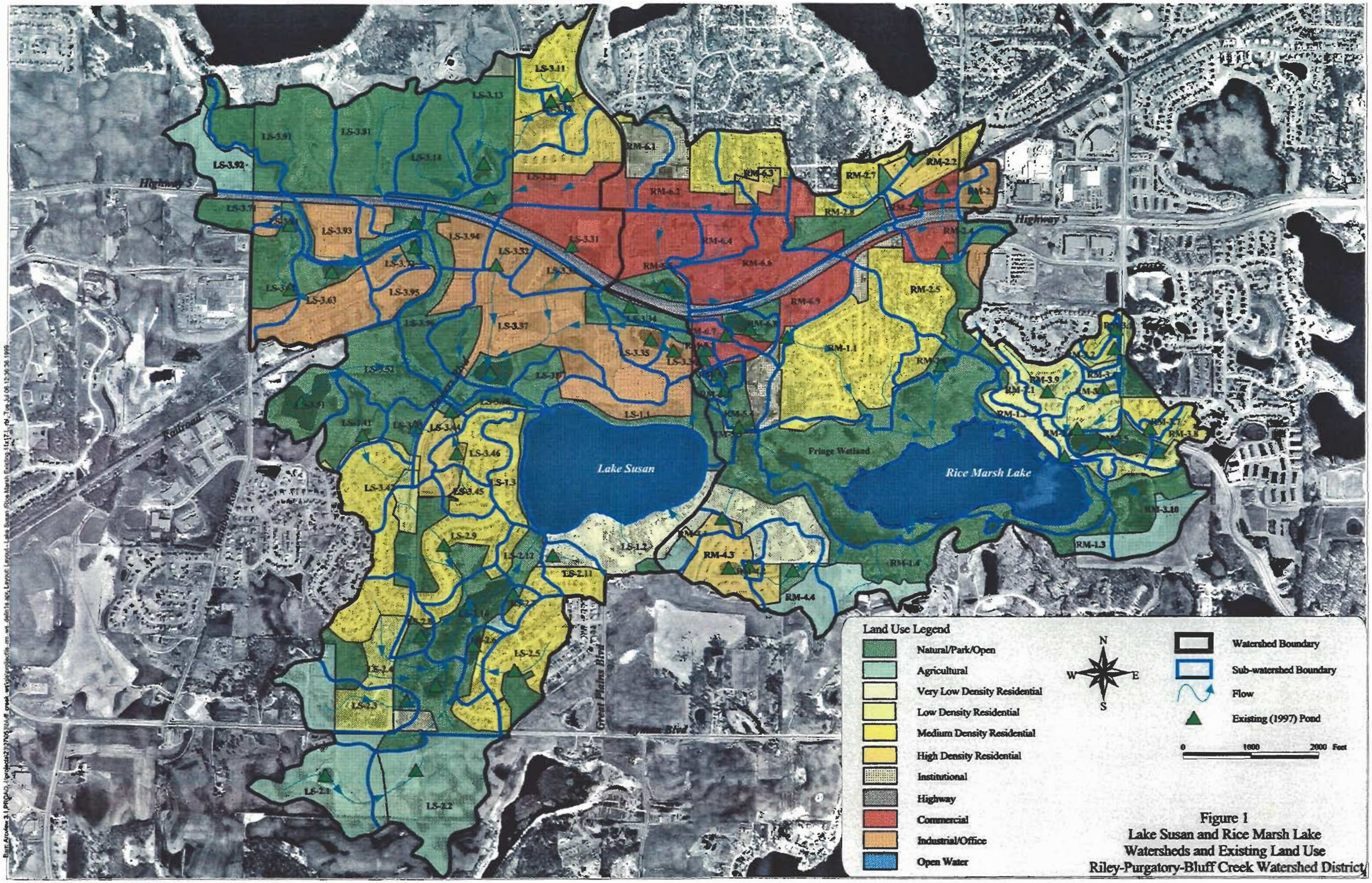


Figure 1
Lake Susan and Rice Marsh Lake
Watersheds and Existing Land Use
Riley-Purgatory-Bluff Creek Watershed District

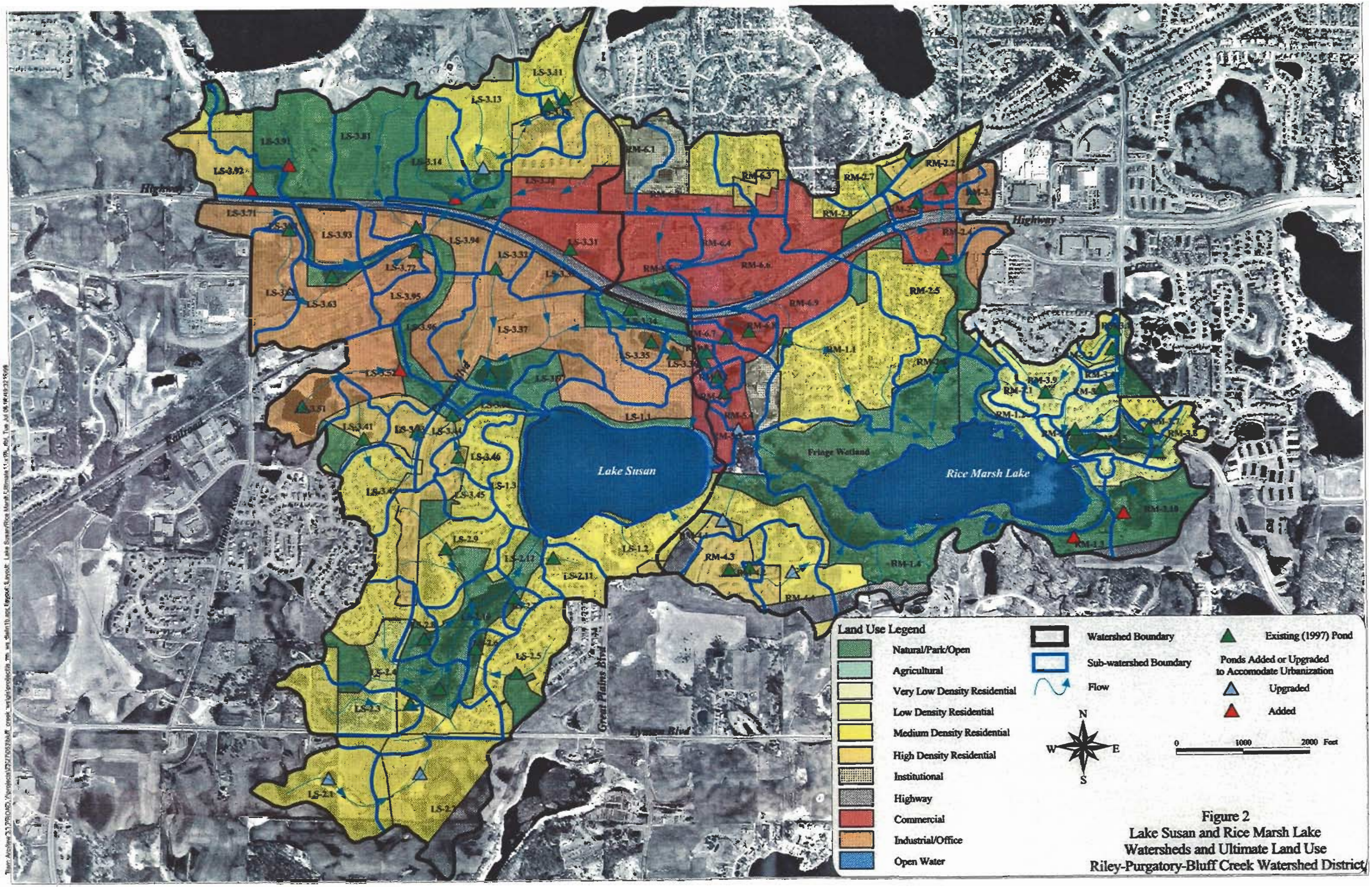


Figure 2
Lake Susan and Rice Marsh Lake
Watersheds and Ultimate Land Use
Riley-Purgatory-Bluff Creek Watershed District

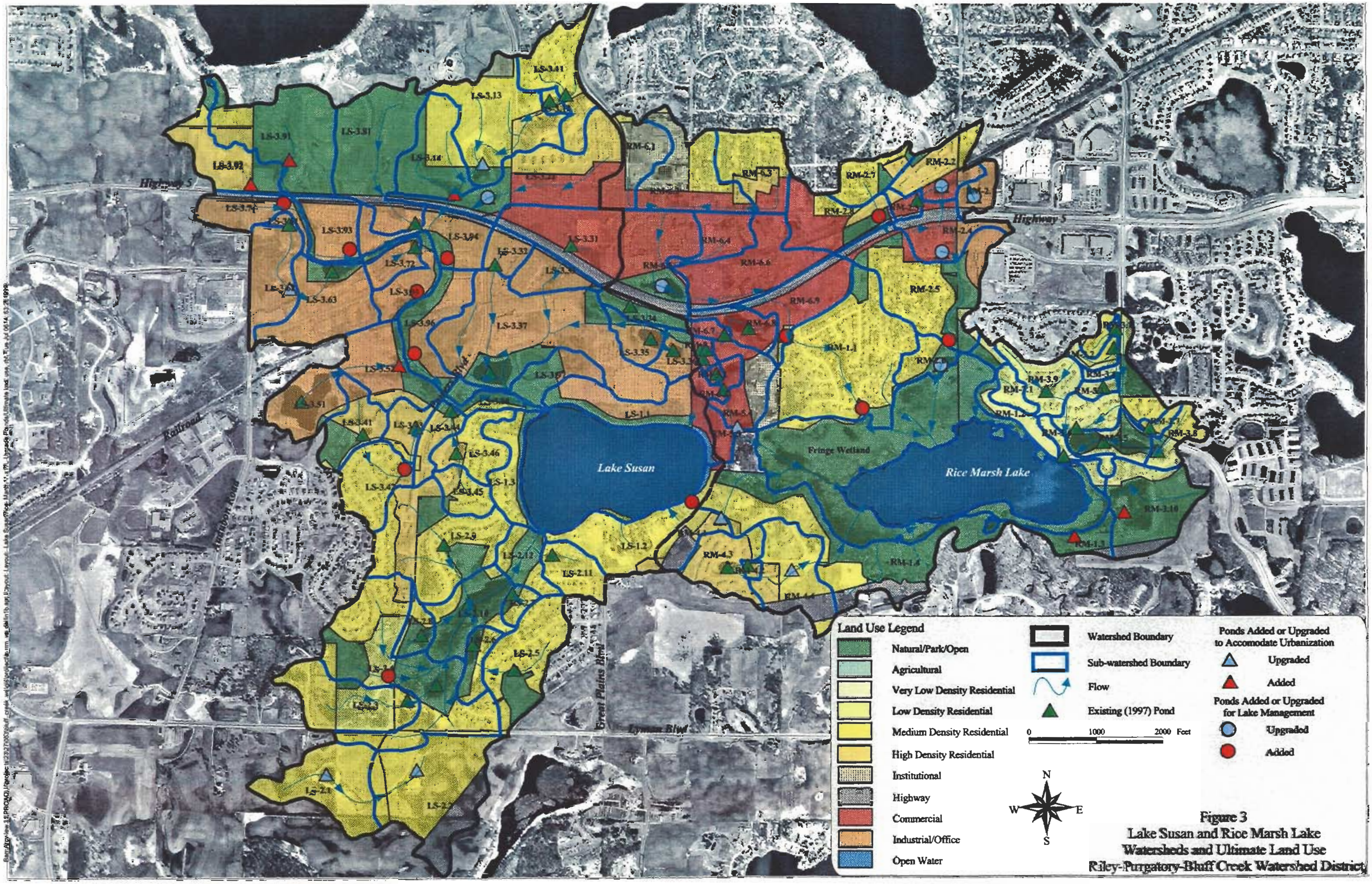
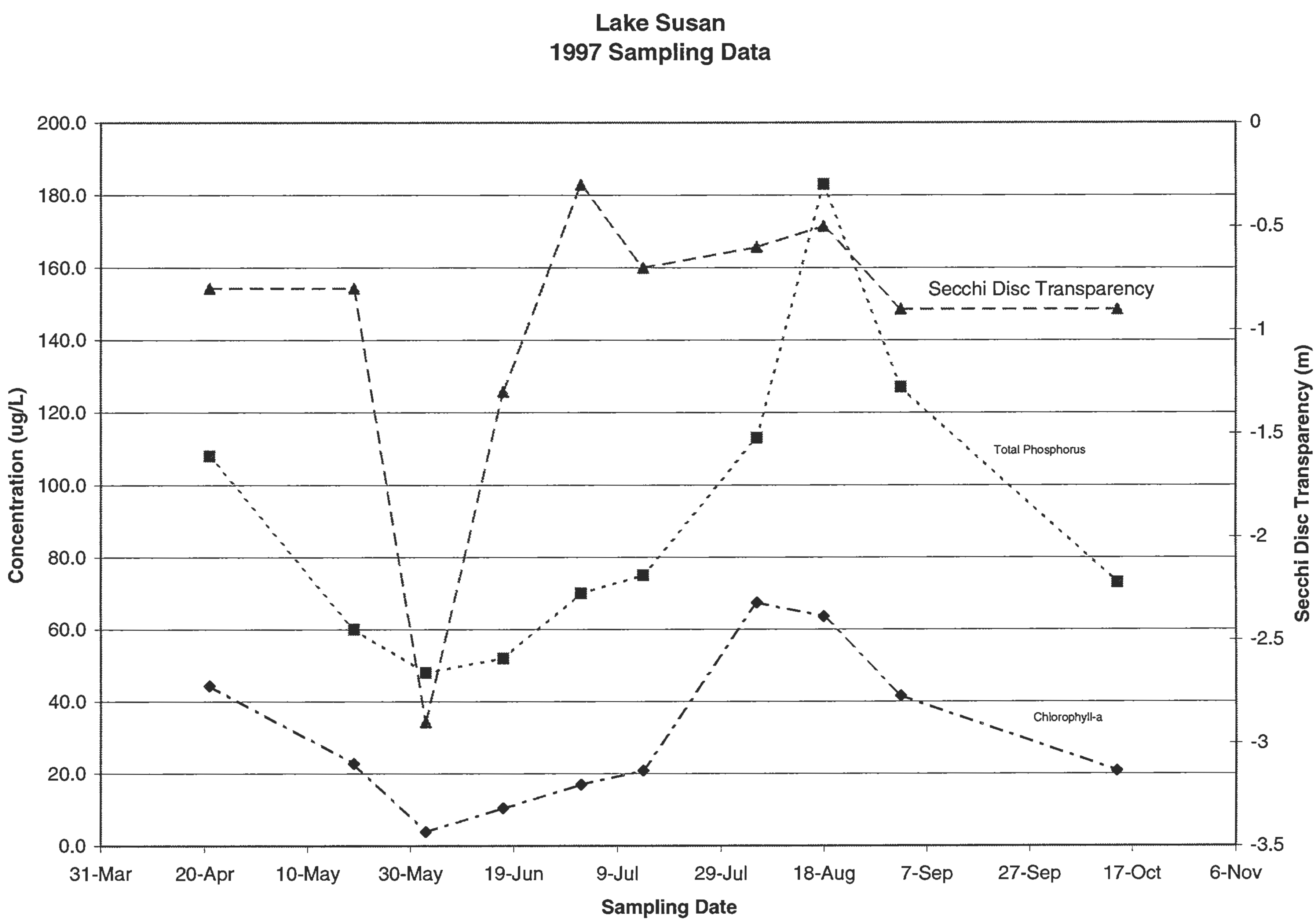
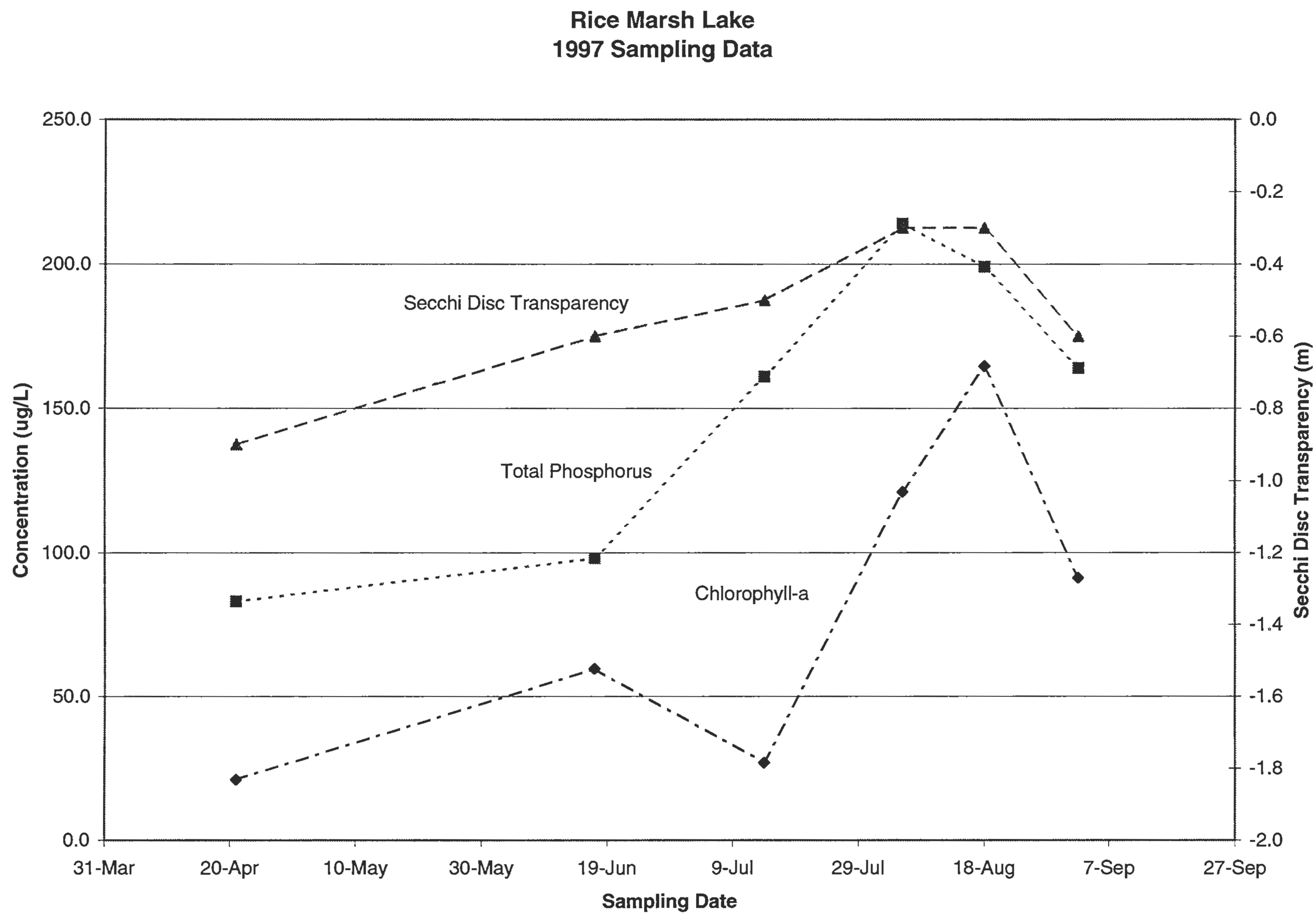


Figure 3
Lake Susan and Rice Marsh Lake
Watersheds and Ultimate Land Use
Riley-Purgatory-Bluff Creek Watershed District



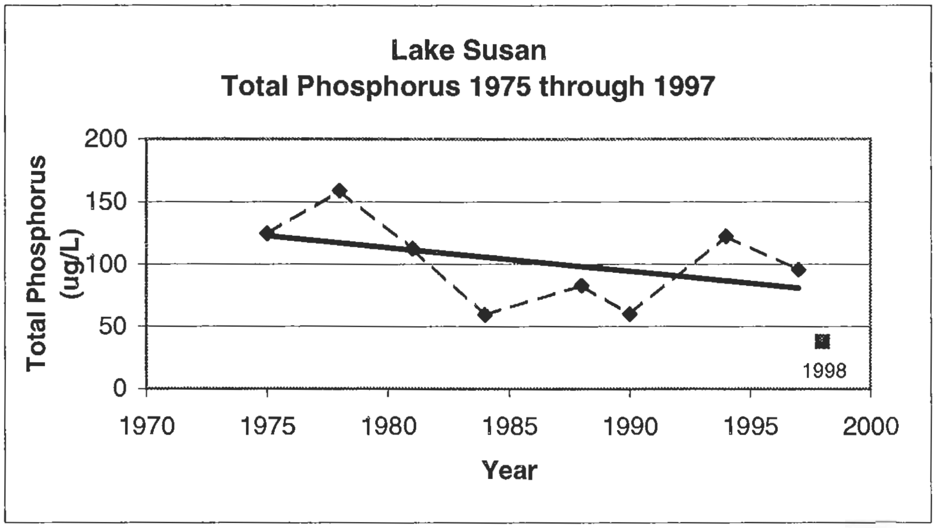
P:\23\27\053\Susan UAA\Lake Data\Suswqsta.xls: 1997 Graph

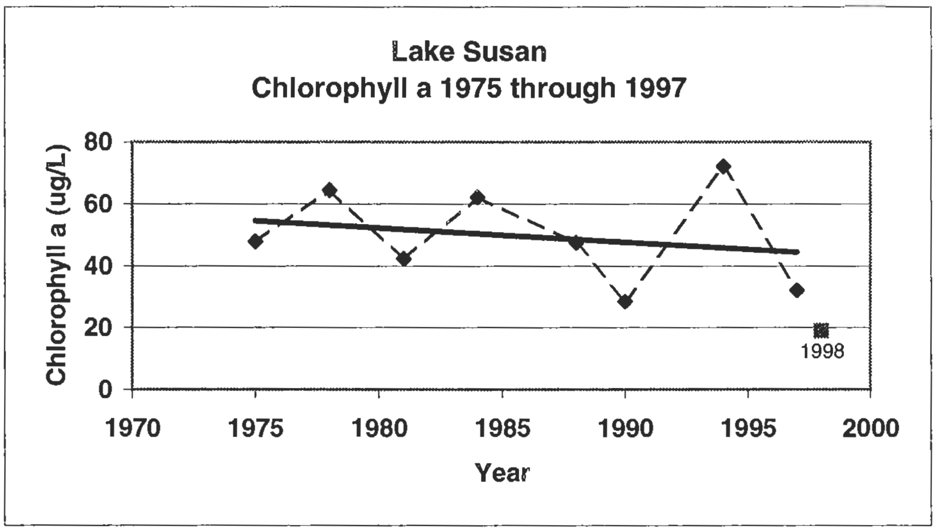
Figure 4

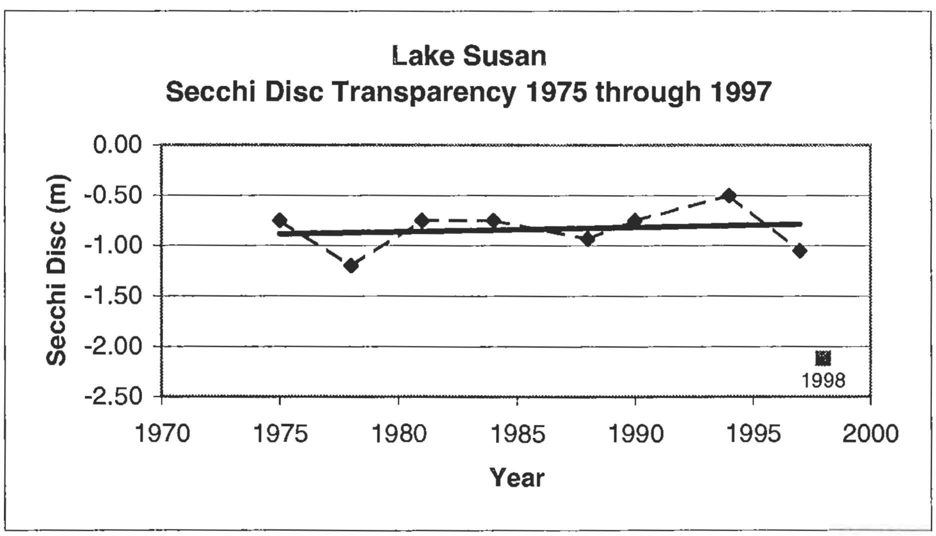


P:\23\27\053\Rice Marsh\RM Lake Data\rmSWQSTA.xls: 1997 Graph

Figure 5

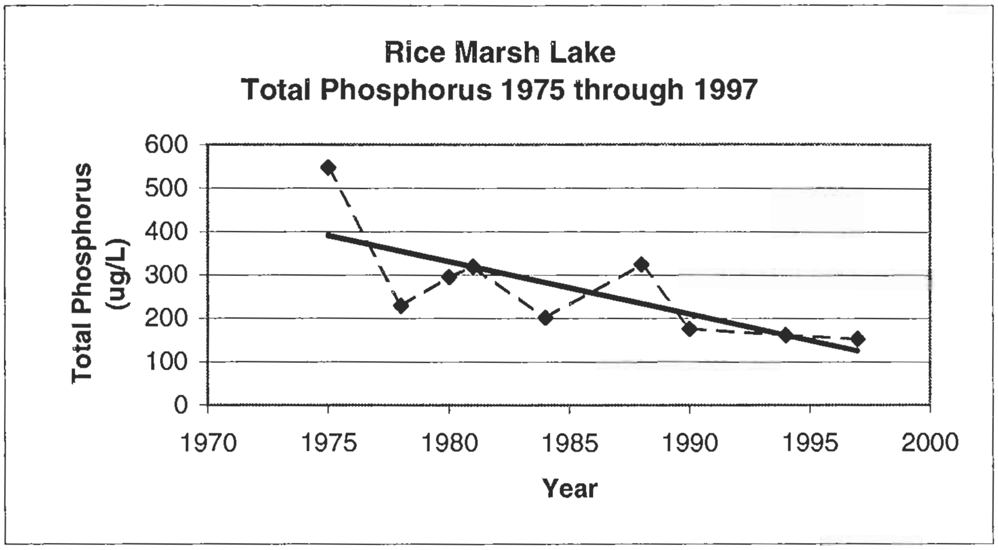


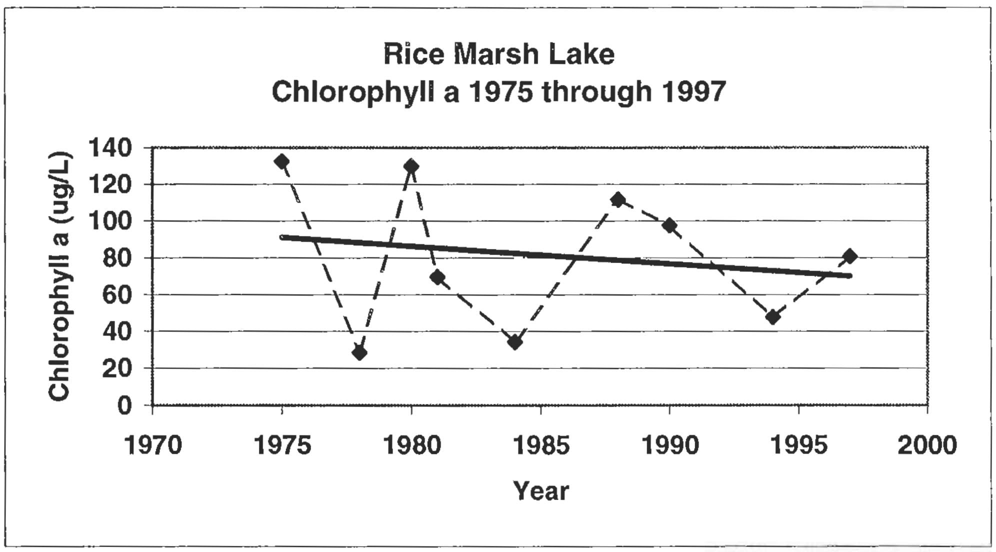




Note: The regression lines do not take into account the 1998 post-alum-treatment summer averages (TP=3
the 1998 summer averages are shown for comparison to years when alum had not been applied.

Figure 6


Rice Marsh Lake
Total Phosphorus 1975 through 1997
Total Phosphorus (ug/L)
600
500
400
300
200
100
0
1970
1975
1980
1985
1990
1995
2000
Year


Rice Marsh Lake
Chlorophyll a 1975 through 1997
Chlorophyll a (ug/L)
140
120
100
80
60
40
20
0
1970
1975
1980
1985
1990
1995
2000
Year

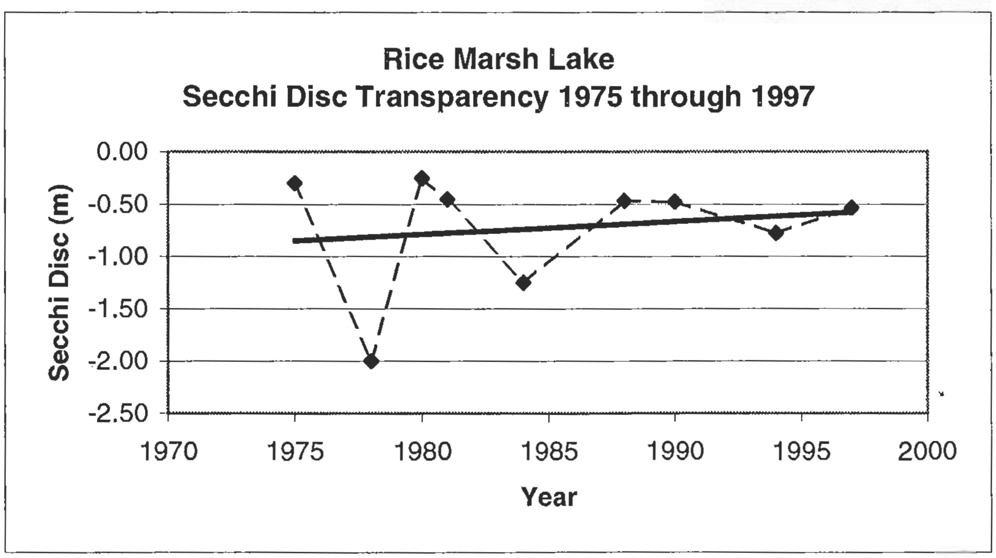
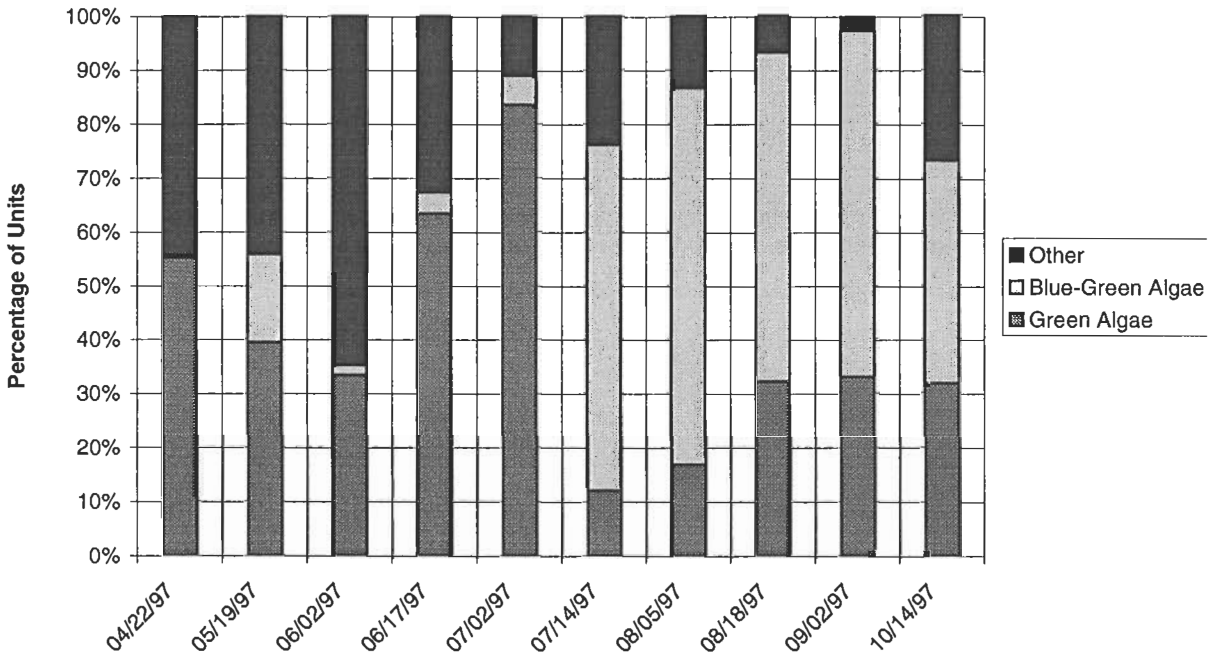
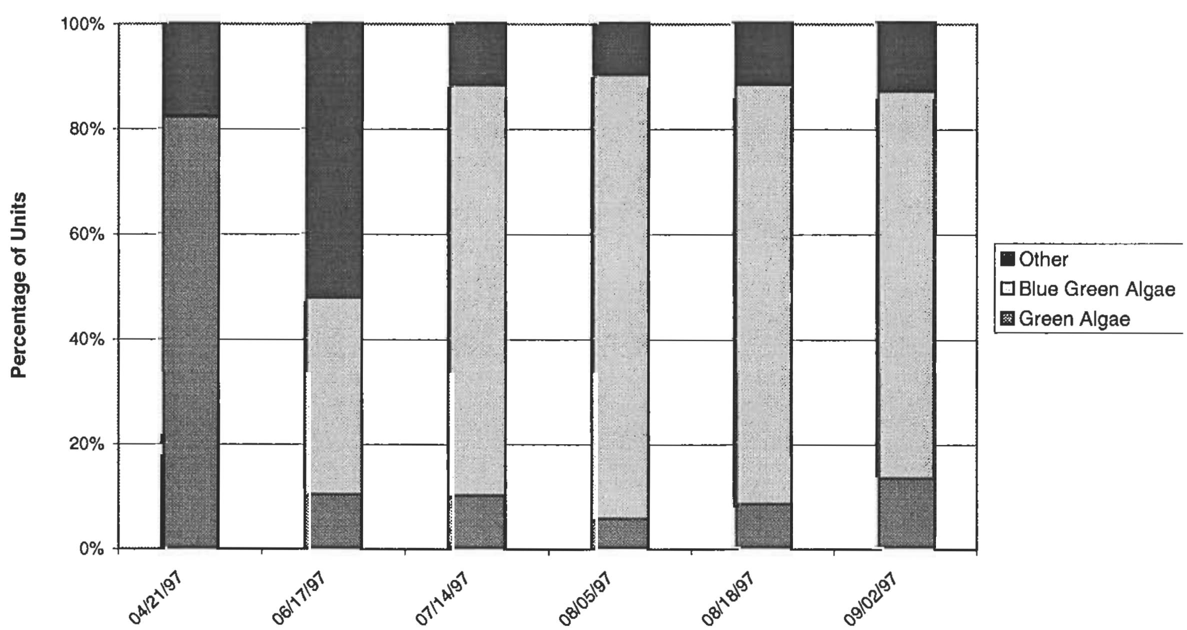

Rice Marsh Lake
Secchi Disc Transparency 1975 through 1997
Secchi Disc (m)
0.00
-0.50
-1.00
-1.50
-2.00
-2.50
1970
1975
1980
1985
1990
1995
2000
Year

Figure 7

1997 Lake Susan Phytoplankton Composition



1997 Rice Marsh Lake Phytoplankton Composition



P:\23\27\053\Susan UAA\Lake Data\Suphyt97.xls: Algae classes

Figure 8

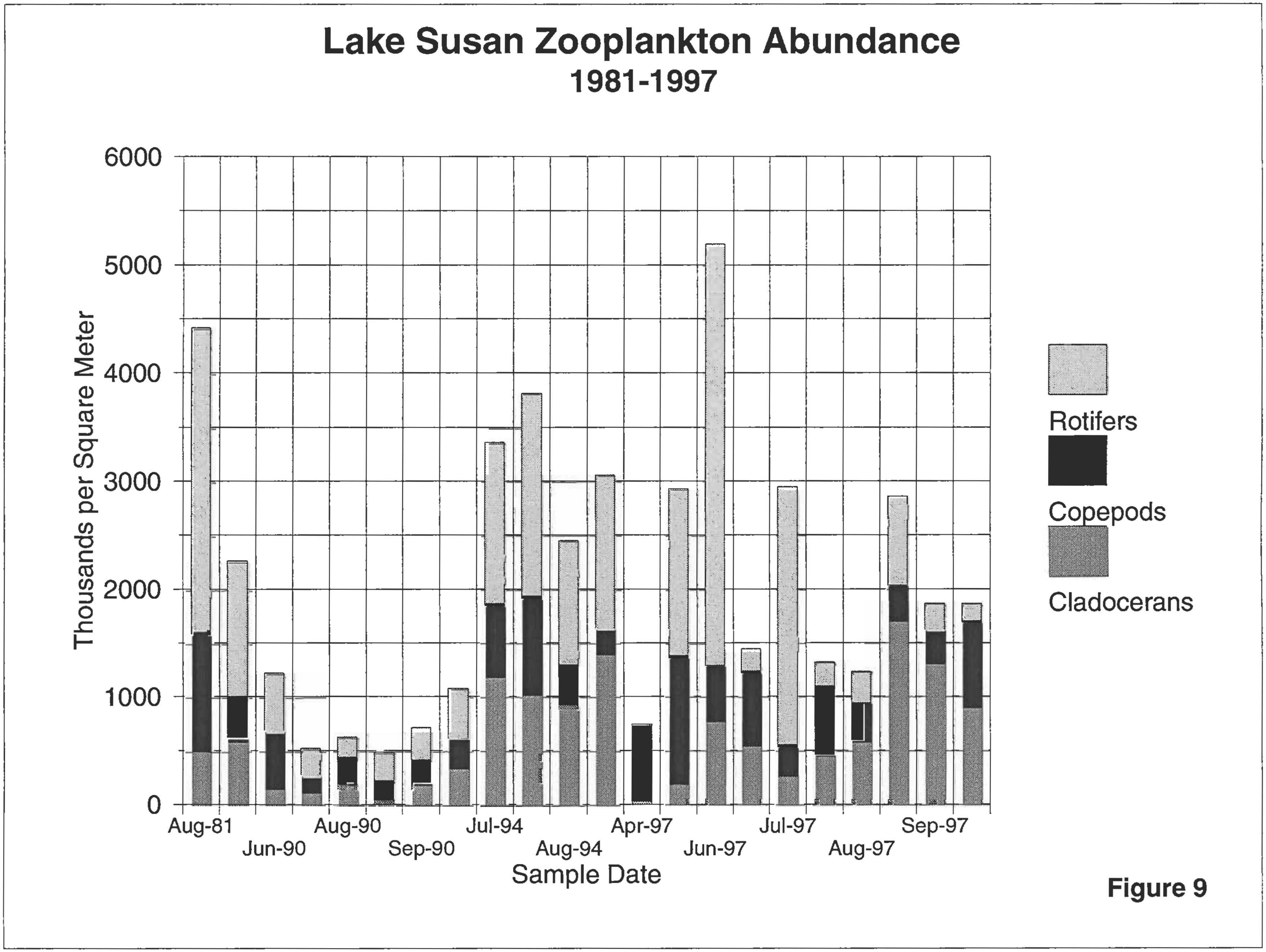


Figure 9

P:\23\27\053\LAKES97\SUSAN\ZP97SU.WB2

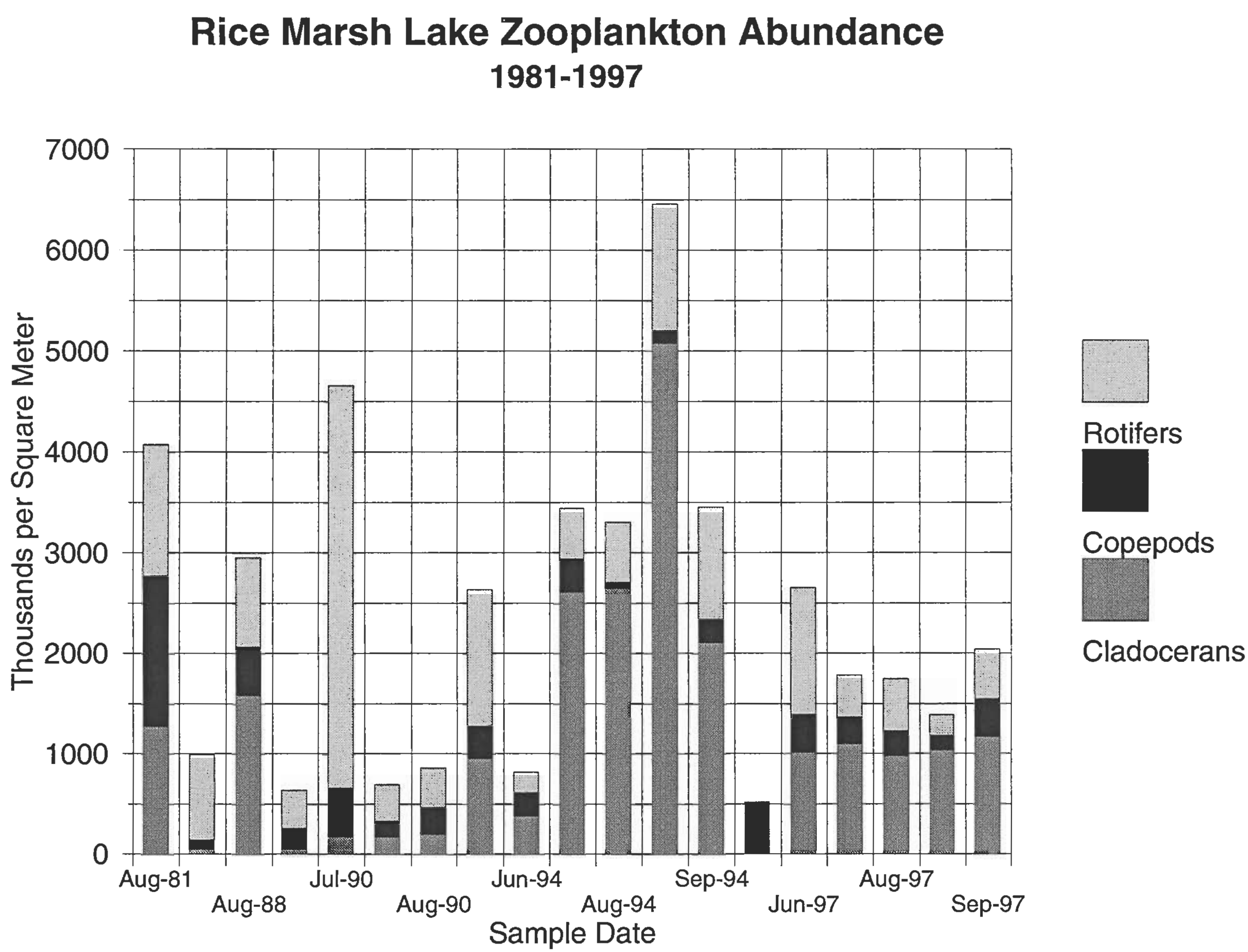
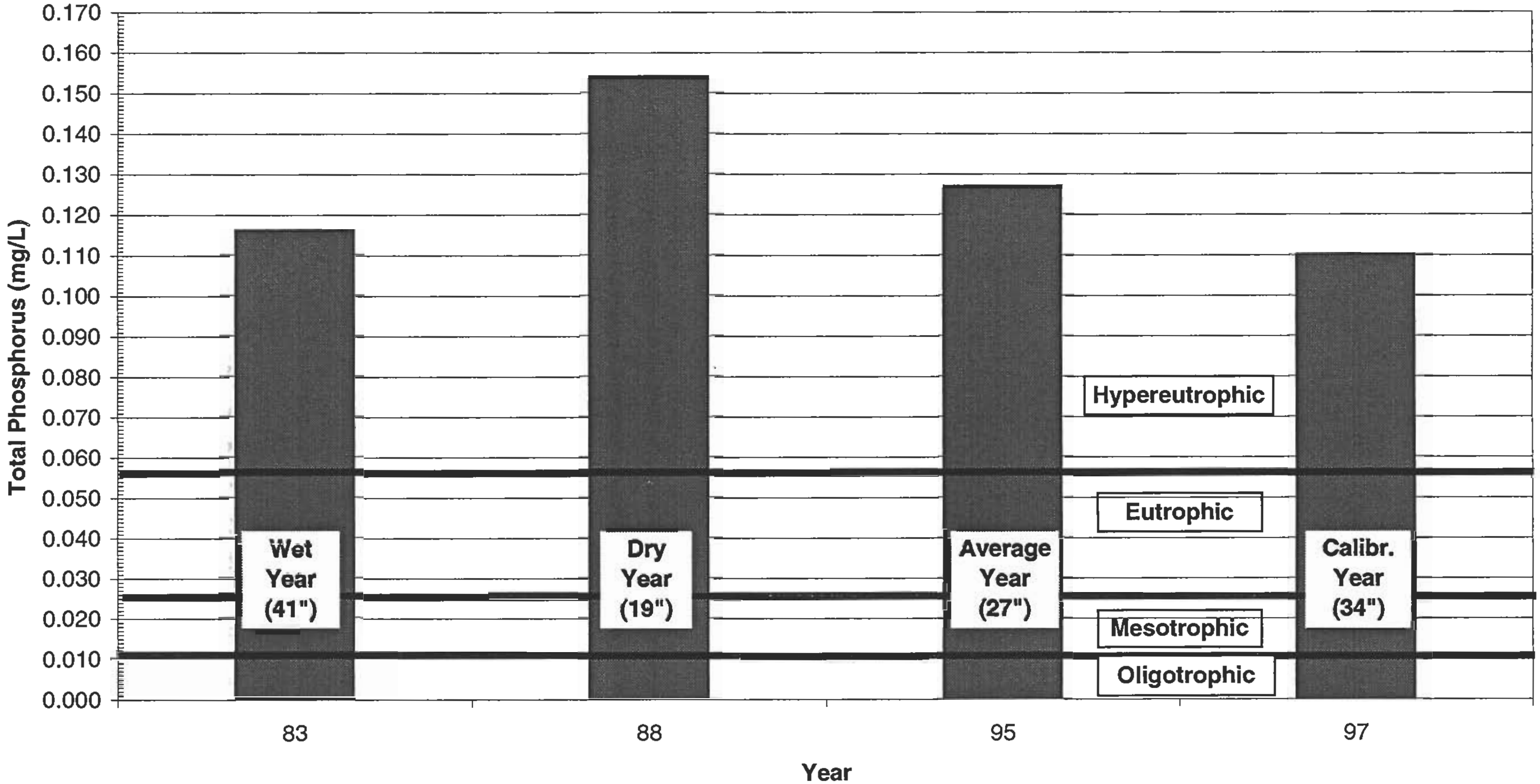


Figure 10

P:\23\27\053\LAKES97\RICEMAR\ZP97RM.WB2

Lake Susan: Estimated Average Summer Total Phosphorus Concentration Under Varying Climatic Conditions

(Ultimate Land Use, No Management Initiatives)

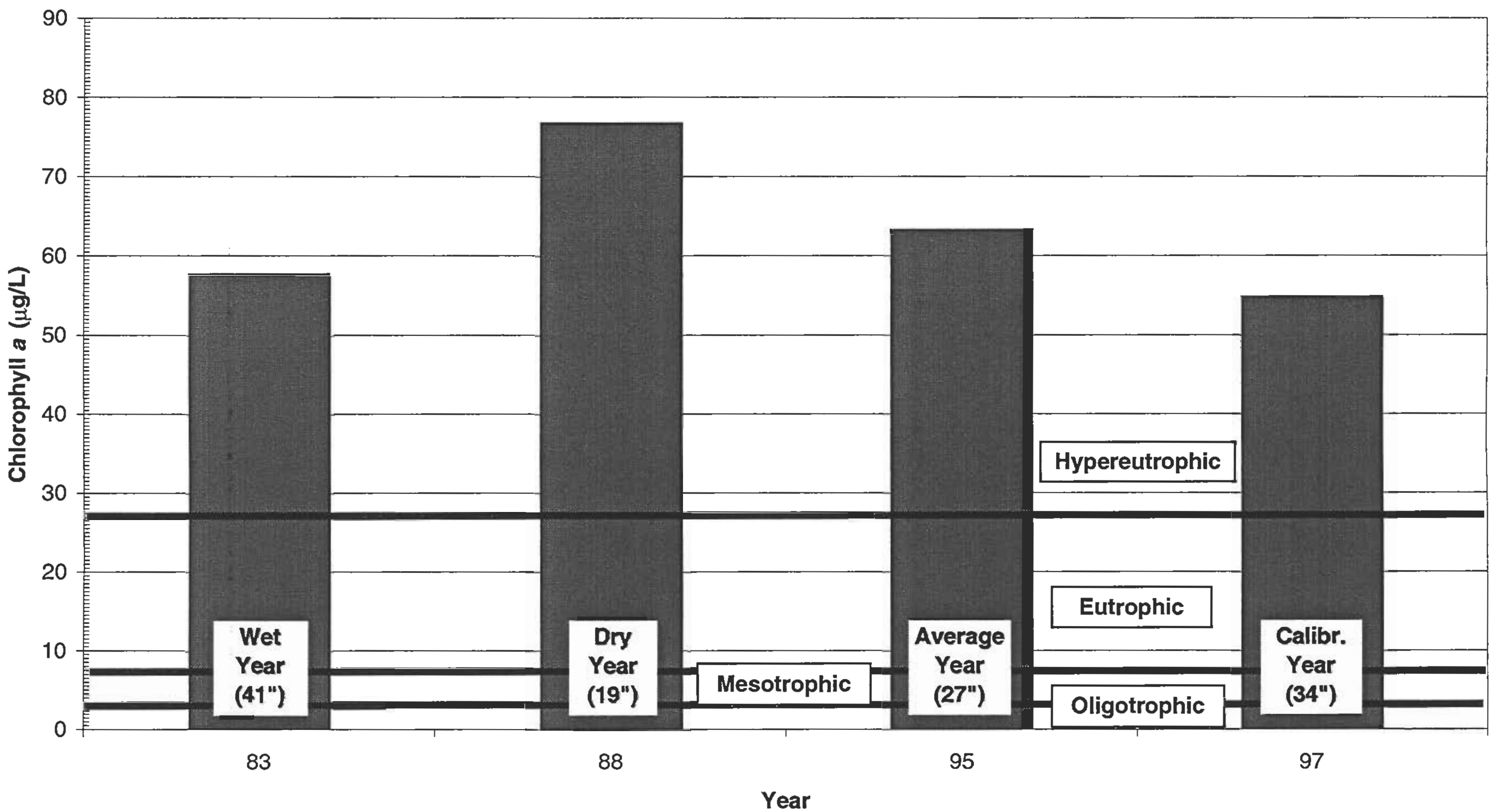


P:\23\27\053\Susan UAA\Model Results\Report Graphs.xls:Figure 11

Figure 11

Lake Susan: Estimated Average Summer Chlorophyll *a* Concentration Under Varying Climatic Conditions

(Ultimate Land Use, No Management Initiatives)



P:\23\27\053\Susan UAA\Model Results\Report Graphs.xls:Figure 12

Figure 12

Lake Susan: Estimated Average Summer Secchi Disc Transparency
Under Varying Climatic Conditions
(Ultimate Land Use, No Management Initiatives)

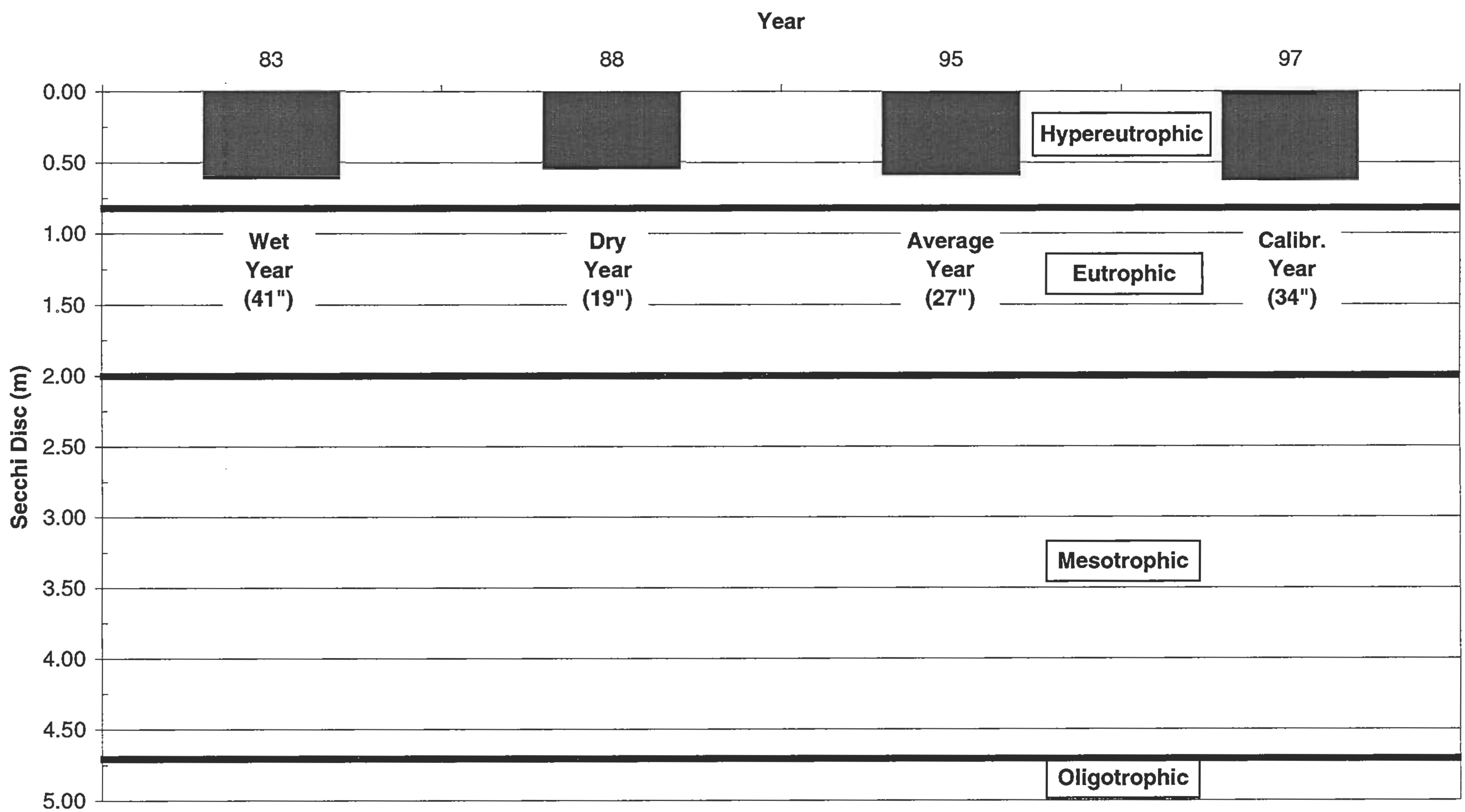
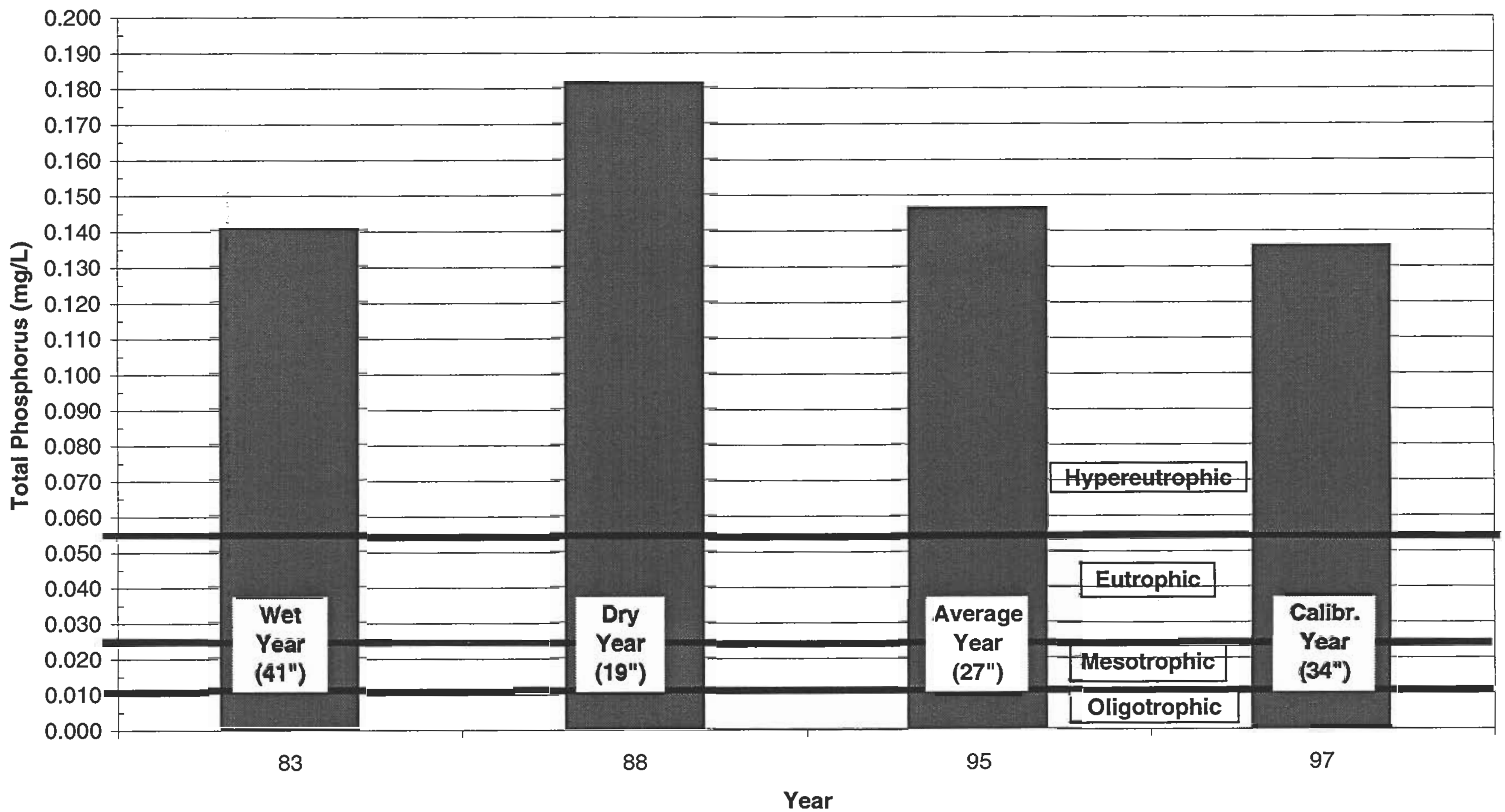


Figure 13

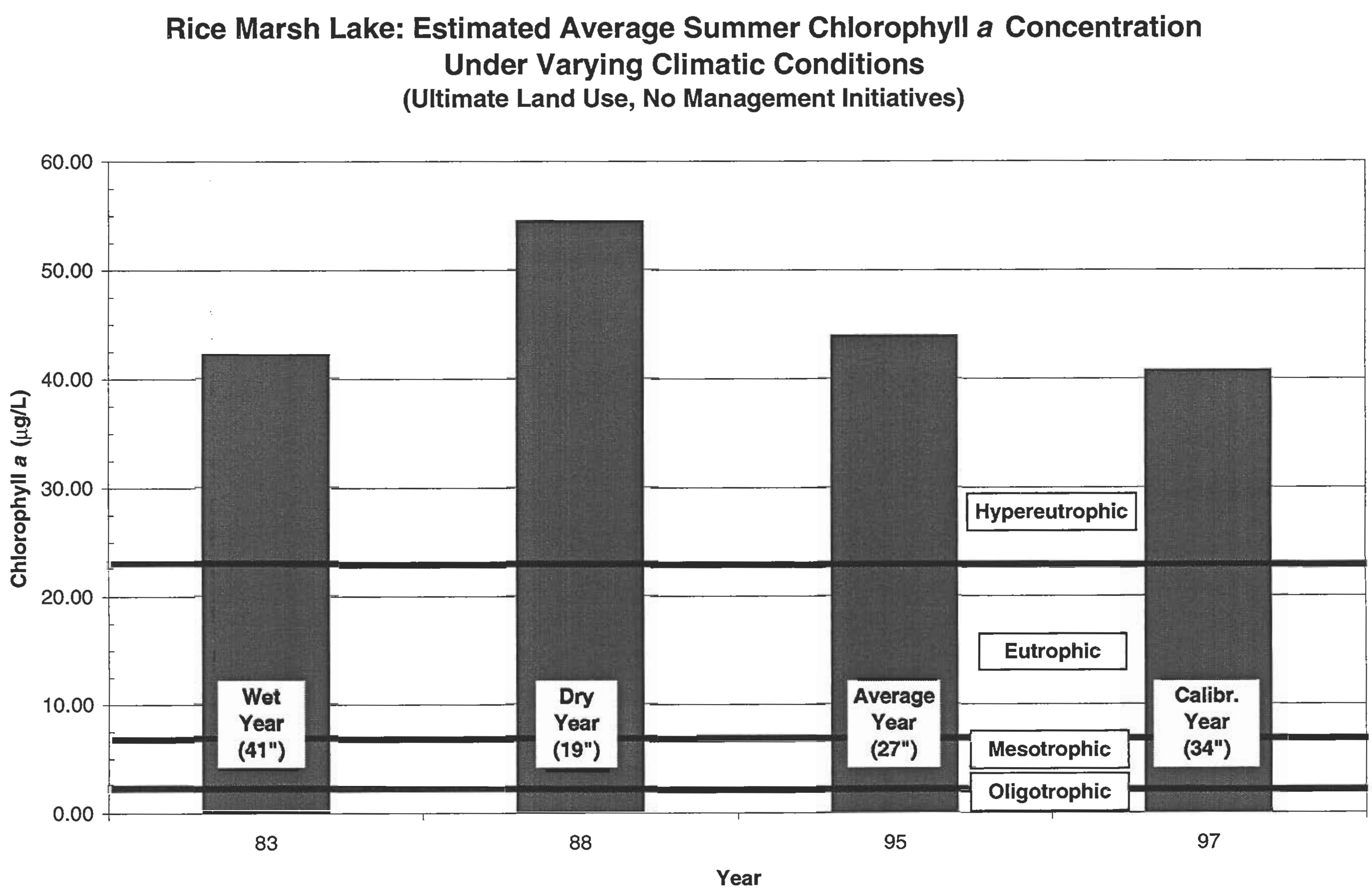
Rice Marsh Lake: Estimated Average Total Phosphorus Concentration Under Varying Climatic Conditions

(Ultimate Land Use, No Management Initiatives)



P:\23\27\053\Rice Marsh UAA\Model Results\RM Report Graphs.xls:Figure 14

Figure 14

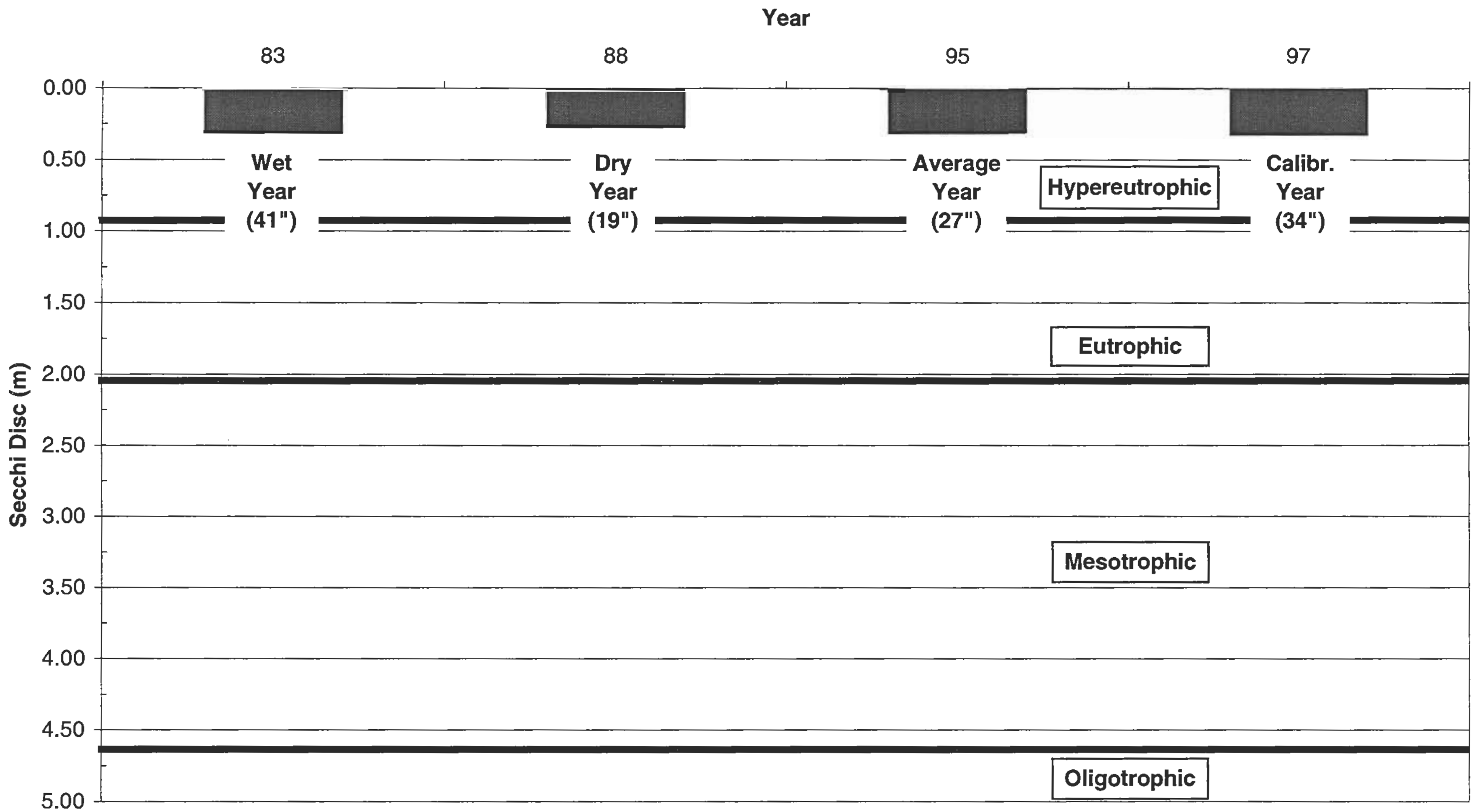


P:\23\27\053\Rice Marsh UAA\Model Results\RM Report Graphs.xls:Figure 15

Figure 15

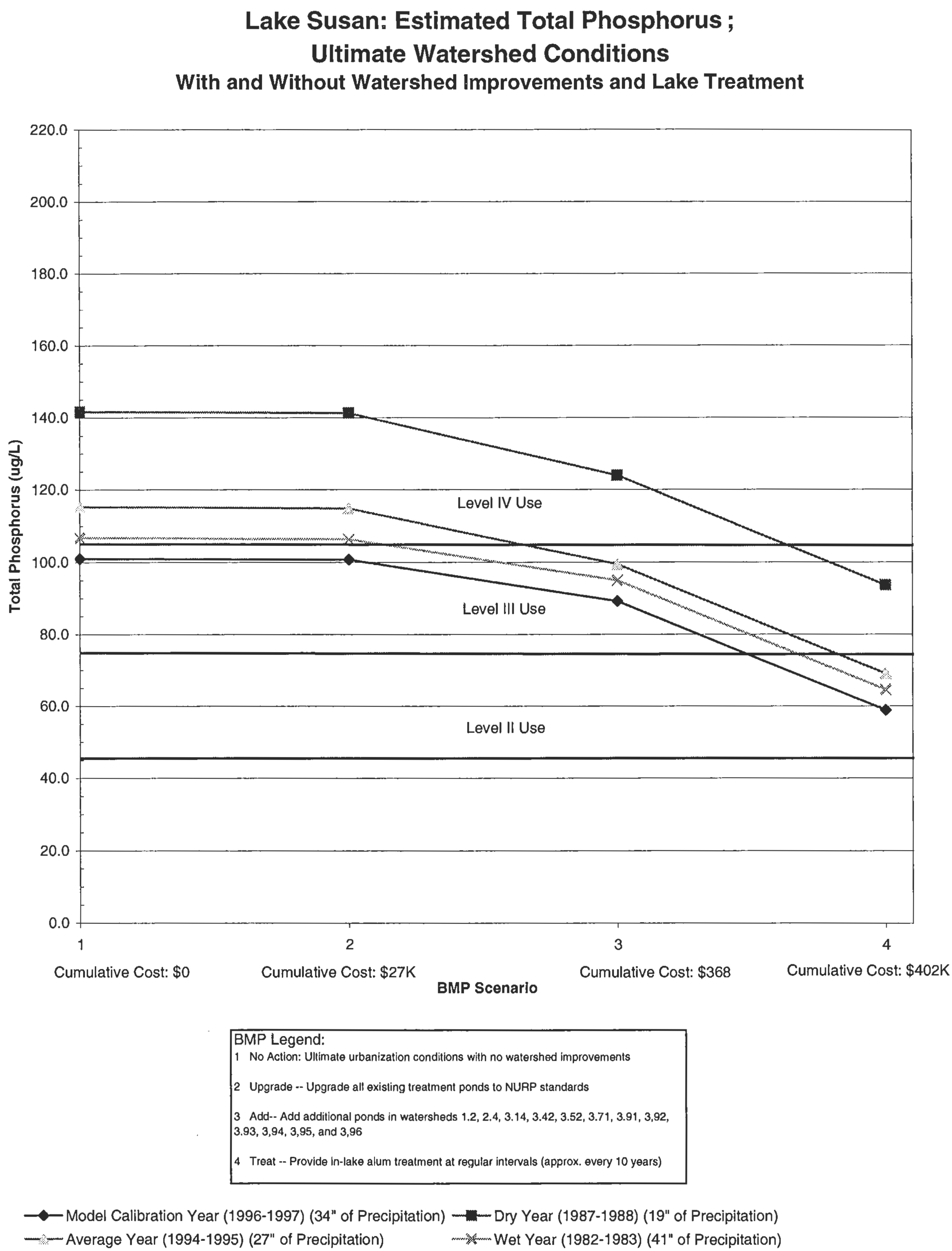
Rice Marsh Lake: Estimated Average Summer Secchi Disc Transparency Under Varying Climatic Conditions

(Ultimate Land Use, No Management Initiatives)



P:\23\27\053\Rice Marsh UAA\Model Results\RM Report Graphs.xls:Figure 16

Figure 16



P:\23\27\053\Susan UAA\Model Results\Report Graphs.xls:TP Results Figure

Figure 17

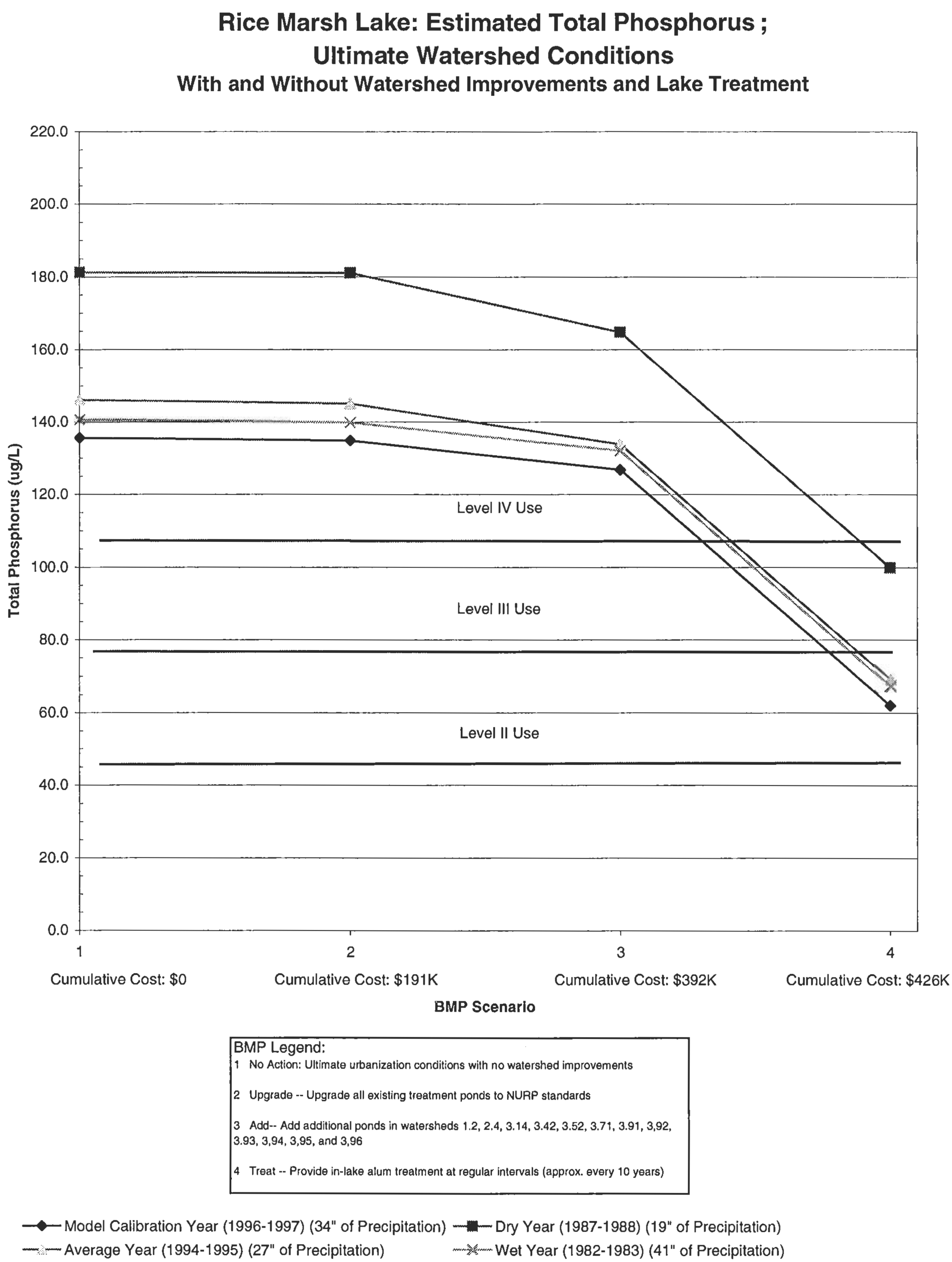

Rice Marsh Lake: Estimated Total Phosphorus ;
Ultimate Watershed Conditions
With and Without Watershed Improvements and Lake Treatment
Total Phosphorus (ug/L)
220.0
200.0
180.0
160.0
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
Level IV Use
Level III Use
Level II Use
1
2
3
4
Cumulative Cost: $0
Cumulative Cost: $191K
Cumulative Cost: $392K
Cumulative Cost: $426K
BMP Scenario
BMP Legend:
1 No Action: Ultimate urbanization conditions with no watershed improvements
2 Upgrade -- Upgrade all existing treatment ponds to NURP standards
3 Add-- Add additional ponds in watersheds 1.2, 2.4, 3.14, 3.42, 3.52, 3.71, 3.91, 3,92, 3.93, 3,94, 3,95, and 3,96
4 Treat -- Provide in-lake alum treatment at regular intervals (approx. every 10 years)
Model Calibration Year (1996-1997) (34" of Precipitation)
Dry Year (1987-1988) (19" of Precipitation)
Average Year (1994-1995) (27" of Precipitation)
Wet Year (1982-1983) (41" of Precipitation)

Figure 18

Appendices

Appendix A

General Concepts in Lake Water Quality

Appendix A
General Concepts in Lake Water Quality

There are a number of concepts and terminology that are necessary to describe and evaluate a lake's water quality. This section is a brief discussion of those concepts, divided into the following topics:

- Eutrophication
- Trophic states
- Limiting nutrients
- Nutrient recycling and internal loading
- Stratification

To learn more about these five topics, one can refer to any text on limnology (the science of lakes and streams).

Eutrophication

Eutrophication, or lake degradation, is the accumulation of sediments and nutrients in lakes. As a lake naturally becomes more fertile, algae and weed growth increases. The increasing biological production and sediment inflow from the lake's watershed eventually fill the lake's basin. Over a period of many years, the lake successively becomes a pond, a marsh and, ultimately, a terrestrial site. This process of eutrophication is natural and results from the normal environmental forces that influence a lake. Cultural eutrophication, however, is an acceleration of the natural process caused by human activities. Nutrient and sediment inputs (i.e., loadings) from wastewater treatment plants, septic tanks, and stormwater runoff can far exceed the natural inputs to the lake. The accelerated rate of water quality degradation caused by these pollutants results in unpleasant consequences. These include profuse and unsightly growths of algae (algal blooms) and/or the proliferation of rooted aquatic weeds (macrophytes).

Trophic States

Not all lakes are at the same stage of eutrophication; therefore, criteria have been established to evaluate the nutrient "status" of lakes. Trophic state indices (TSIs) are calculated for lakes on the basis of total phosphorus, chlorophyll *a* concentrations, and Secchi disc transparencies. A TSI value is obtained from any one of these three parameters. TSI values range upward from 0, describing the condition of the lake in terms of its trophic status (i.e., its degree of fertility). Four trophic status designations for lakes are listed below with corresponding TSI value ranges:

1. ***Oligotrophic*** – **[TSI ≤ 37]** Clear, low productivity lakes with total phosphorus concentrations less than or equal to 10 µg/L.

2. ***Mesotrophic*** – **[38 ≤ TSI ≤ 50]** Intermediate productivity lakes with total phosphorus concentrations greater than 10 µg/L, but less than 25 µg/L.

3. ***Eutrophic*** – **[51 ≤ TSI ≤ 63]** High productivity lakes generally having 25 to 60 µg/L total phosphorus.

4. ***Hypereutrophic*** – **[64 ≤ TSI]** Extremely productive lakes which are highly eutrophic, disturbed and unstable (i.e., fluctuating in their water quality on a daily and seasonal scale, producing gases, off-flavor, and toxic substances, experiencing periodic anoxia and fish kills, etc.) with total phosphorus concentrations above 60 µg/L.

Determining the trophic status of a lake is an important step in diagnosing water quality problems. Trophic status indicates the severity of a lake's algal growth problems and the degree of change needed to meet its recreational goals. Additional information, however, is needed to determine the cause of algal growth and a means of reducing it.

Limiting Nutrients

The quantity or biomass of algae in a lake is usually limited by the water's concentration of an essential element or nutrient—the "limiting nutrient". (For rooted aquatic plants, the nutrients are derived from the sediments.) The limiting nutrient concept is a widely applied principle in ecology and in the study of eutrophication. It is based on the idea that plants require many nutrients to grow, but the nutrient with the lowest availability, relative to the amount needed by the plant, will limit plant growth. It follows then, that identifying the limiting nutrient will point the way to controlling algal growth .

Nitrogen (N) and phosphorus (P) are generally the two growth-limiting nutrients for algae in most natural waters. Analysis of the nutrient content of lake water and algae provides ratios of N:P. By comparing the ratio in water to the ratio in the algae, one can estimate whether a particular nutrient may be limiting. Algal growth is generally phosphorus-limited in waters with N:P ratios greater than 12. Laboratory experiments (bioassays) can demonstrate which nutrient is limiting by growing the algae in lake water with various concentrations of nutrients added. Bioassays, as well as fertilization of in-situ enclosures and whole-lake experiments, have repeatedly demonstrated that phosphorus is usually the nutrient that limits algal growth in freshwaters. Reducing phosphorus in a lake, therefore, is required to reduce algal abundance and improve water transparency. Failure to reduce phosphorus concentrations will allow the process of eutrophication to continue at an accelerated rate.

Nutrient Recycling and Internal Loading

Phosphorus enters a lake from either runoff from the watershed or direct atmospheric deposition. It would, therefore, seem reasonable that phosphorus in a lake can decrease by reducing these external loads of phosphorus to the lake. All lakes, however, accumulate phosphorus (and other nutrients) in the sediments from the settling of particles and dead organisms. In some lakes this reservoir of phosphorus can be reintroduced in the lake water and become available again for plant uptake. This resuspension or dissolution of nutrients from the sediments to the lake water is known as "internal loading." The relative amounts of phosphorus coming from internal and external loading varies with each lake. The amount of phosphorus released from internal loading can be estimated from depth profiles (measurements from surface to bottom) of dissolved oxygen and phosphorus concentrations.

Stratification

The process of internal loading is dependent on the amount of organic material in the sediments and the depth-temperature pattern, or "thermal stratification," of a lake. Thermal stratification profoundly influences a lake's chemistry and biology. When the ice melts and air temperature warms in spring, lakes generally progress from being completely mixed to stratified with only an upper warm well-mixed layer of water (epilimnion), and cold temperatures in a bottom layer (hypolimnion). Because of the density differences between the lighter warm water and the heavier cold water, stratification in a lake can become very resistant to mixing. When this occurs, generally in mid-summer, oxygen from the air cannot reach the bottom lake water and, if the lake sediments has sufficient organic matter, biological activity can deplete the remaining oxygen in the hypolimnion. The epilimnion can remain well-oxygenated, while the water above the sediments in the hypolimnion becomes completely devoid of dissolved oxygen (anoxic). Complete loss of oxygen changes the chemical conditions in the water and allows phosphorus that had remained bound to the sediments to reenter the lake water.

As the summer progresses, phosphorus concentrations in the hypolimnion can continue to rise until oxygen is again introduced (recycled). Dissolved oxygen concentration will increase if the lake sufficiently mixes to disrupt the thermal stratification. Phosphorus in the hypolimnion is generally not available for plant uptake because there is not sufficient light penetration to the hypolimnion to allow for growth of algae. The phosphorus, therefore, remains trapped and unavailable to the plants until the lake is completely mixed. In shallow lakes this can occur throughout the summer, with sufficient wind energy (polymixis). In deeper lakes, however, only extremely high wind energy is sufficient to destratify a lake during the summer and complete mixing only occurs in the spring and fall (dimixis). Cooling air temperature in the fall reduces the epilimnion water temperature, and consequently increases the density of water in the epilimnion. As the epilimnion water density approaches the density of the hypolimnion water very little energy is needed to cause complete mixing of the lake. When this fall mixing occurs, phosphorus that has built up in the hypolimnion is mixed with the epilimnion water and becomes available for plant growth.

Appendix B

1998 Lake Susan Water Quality Data

1998 Lake Susan Water Quality Sampling Data

(Alum treatment applied April 15)

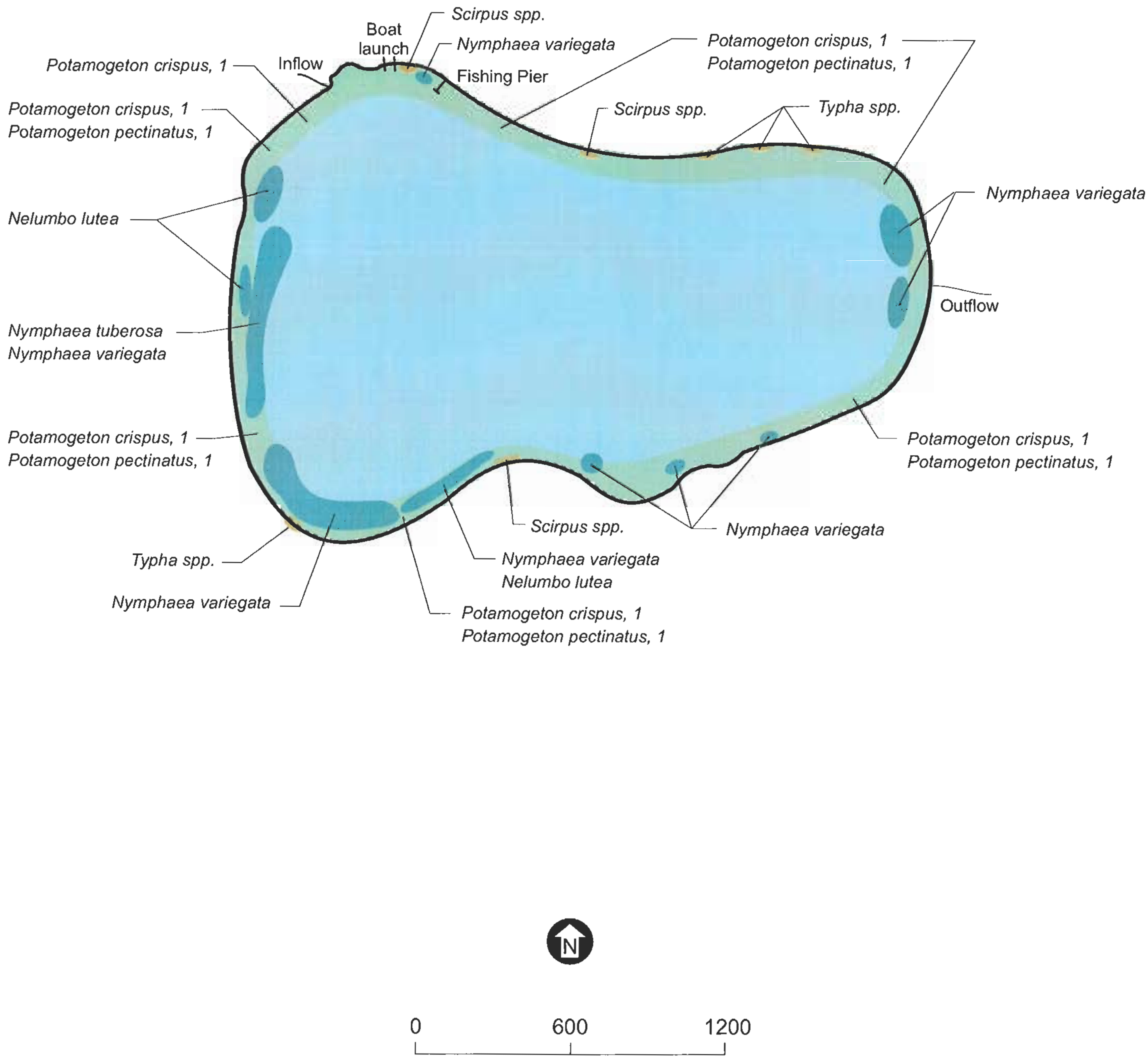
Sample Date	Chl a (ug/L)	TP (ug/L)	Transparency (meters)
4/13/98	49.8	100	0.76
4/21/98	15.9	32	4.85
5/8/98	10.0	20	3.33
5/21/98	11.4	23	1.97
6/16/98	18.4	37	3.42
7/13/98	16.4	33	3.12
7/27/98	16.9	34	1.21
8/18/98	22.9	46	1.52
8/28/98	19.4	39	1.33
9/19/98	16.4	33	0.79
9/30/98	30.9	62	0.76
10/24/98	22.9	46	0.91

Notes: Chl a values were not measured as a part of the 1998 sampling, therefore listed Chl a values are estimates based on Chl a - TP regression analysis for the lake.

All measured TP and transparency values were reported in "Lake Susan Restoration Evaluation for 1998", February 1999, Blue Water Science, Prepared for the City of Chanhasse

Appendix C

Lake Susan and Rice Marsh Lake Macrophyte Data



LAKE SUSAN
June 19, 1997

P:2327053/LAKEMAPS/SUSAN/1997 JUNE97.CDR

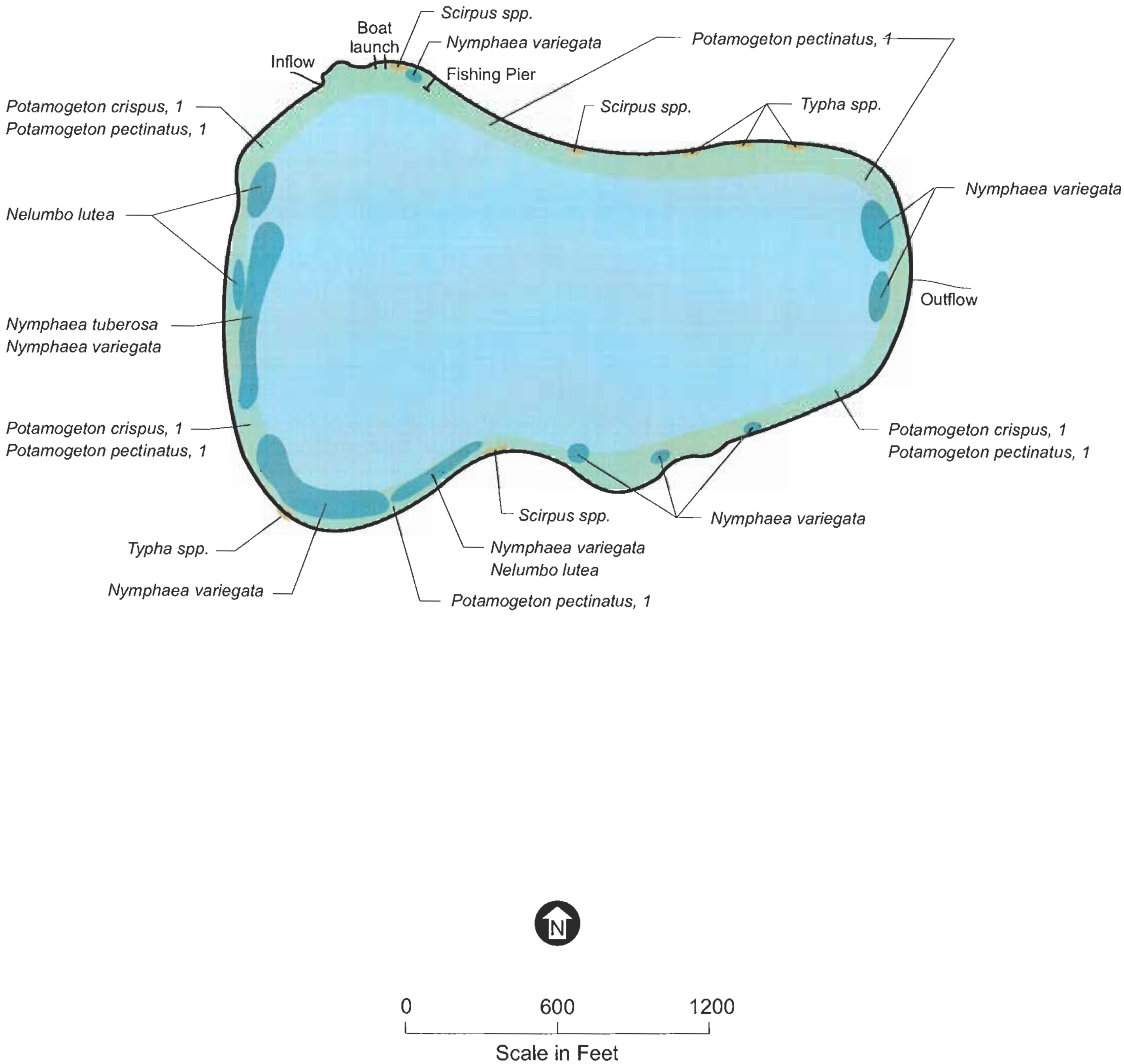
LAKE SUSAN MACROPHYTE SURVEY
June 19, 1997

- No macrophytes found in water > 3-4 feet
- Macrophyte densities estimated as follows: 1=light; 2=moderate; 3= heavy

	Common Name	Scientific Name
Submerged Aquatic Plants:	Curly leaf pondweed	*Potamogeton crispus*
	Sago pondweed	*Potamogeton pectinatus*
	Lotus	*Nelumbo lutea*
Floating Leaf:	White waterlily	*Nymphaea tuberosa*
	Yellow waterlily	*Nymphaea variegata*
Emergent:	Bulrush	*Scirpus spp.*
	Cattail	*Typha spp.*
No Aquatic Vegetation Found:		

Comments: Potamogeton crispus and Potamogeton pectinatus were observed sporadically along shoreline in less than two feet of water.

P:2327053LAKEMAPS/SUSAN/1997/MACJUN97.CDR



LAKE SUSAN
August 21, 1997

P:2327053/LAKEMAPS/SUSAN/1997 AUGUST97.CDR

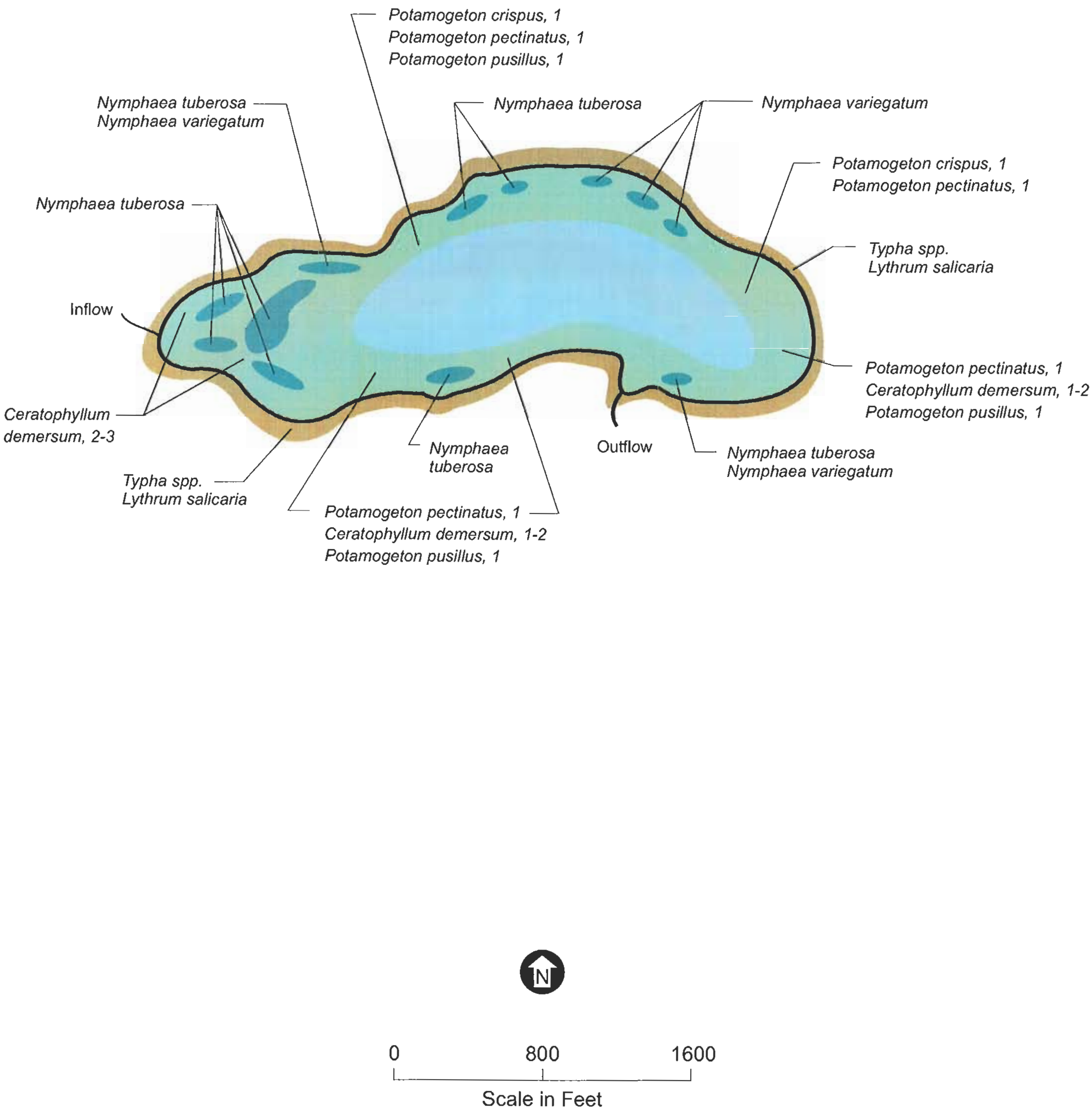
LAKE SUSAN MACROPHYTE SURVEY
August 21, 1997

- No macrophytes found in water > 3-4 feet
- Macrophyte densities estimated as follows: 1=light; 2=moderate; 3= heavy

	Common Name	Scientific Name
Submerged Aquatic Plants:	Sago pondweed Lotus	*Potamogeton pectinatus* *Nelumbo lutea*
Floating Leaf:	White waterlily Yellow waterlily	*Nymphaea tuberosa* *Nymphaea variegata*
Emergent:	Bulrush Cattail	*Scirpus spp.* *Typha spp.*
No Aquatic Vegetation Found:		

Comments: Potamogeton pectinatus were observed sporadically along shoreline in less than two feet of water.

P:2327053LAKEMAPS/SUSAN/1997/MACAUG97.CDR



P:2327053/LAKEMAPS/RICEMARSH/1997 JUNE97.CDR

RICE MARSH LAKE
June 19, 1997

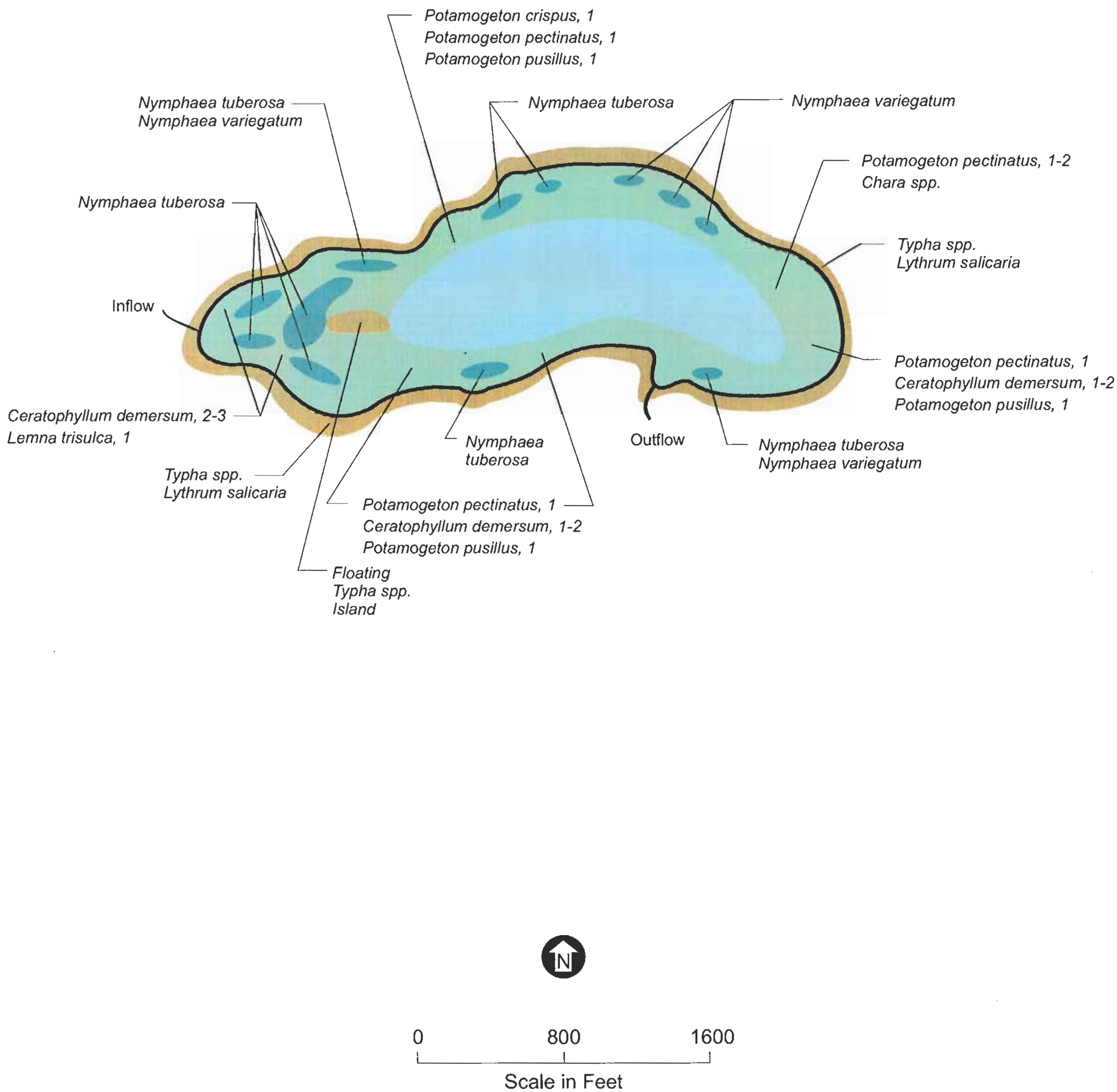
RICE MARSH LAKE MACROPHYTE SURVEY
June 19, 1997

- No macrophytes found in water > 4-5 feet
- Macrophyte densities estimated as follows: 1=light; 2=moderate; 3= heavy

	Common Name	Scientific Name
Submerged Aquatic Plants:	Pondweed	*Potamogeton pusillus*
	Curly leaf pondweed	*Potamogeton crispus*
	Sago pondweed	*Potamogeton pectinatus*
	Coontail	*Ceratophyllum demersum*
Floating Leaf:	White waterlily	*Nymphaea tuberosa*
	Yellow waterlily	*Nymphaea variegata*
Emergent:	Cattail	*Typha spp.*
	Purple loosestrife	*Lythrum salicaria*
No Aquatic Vegetation Found:		

Comments:

P:2327053/LAKEMAPS/RICEMARSH/1997/MACJUN97.CDR



RICE MARSH LAKE
August 20, 1997

P:2327053/LAKEMAPS/RICEMARSH/1997 AUGUST97.CDR

RICE MARSH LAKE MACROPHYTE SURVEY
August 20, 1997

- No macrophytes found in water > 4-5 feet
- Macrophyte densities estimated as follows: 1=light; 2=moderate; 3= heavy

	Common Name	Scientific Name
Submerged Aquatic Plants:	Pondweed	*Potamogeton pusillus*
	Curly leaf pondweed	*Potamogeton crispus*
	Sago pondweed	*Potamogeton pectinatus*
	Coontail	*Ceratophyllum demersum*
	Muskgrass	*Chara spp.*
	Star duckweed	*Lemna trisulca*
Floating Leaf:	White waterlily	*Nymphaea tuberosa*
	Yellow waterlily	*Nymphaea variegata*
Emergent:	Cattail	*Typha spp.*
	Purple loosestrife	*Lythrum salicaria*
No Aquatic Vegetation Found:		

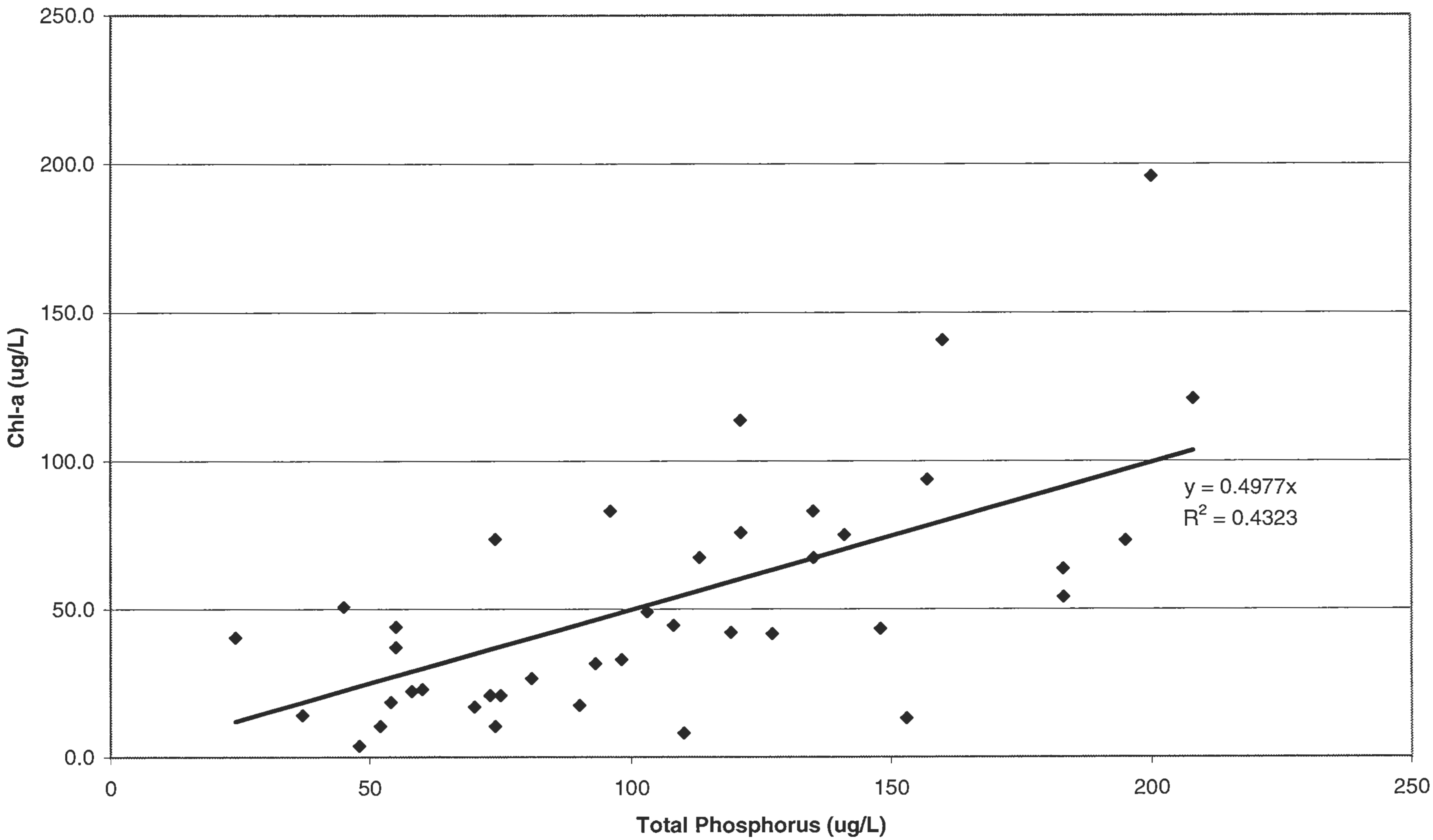
Comments:

P:2327053/RICEMARSH/1997/MACAUG97.CDR

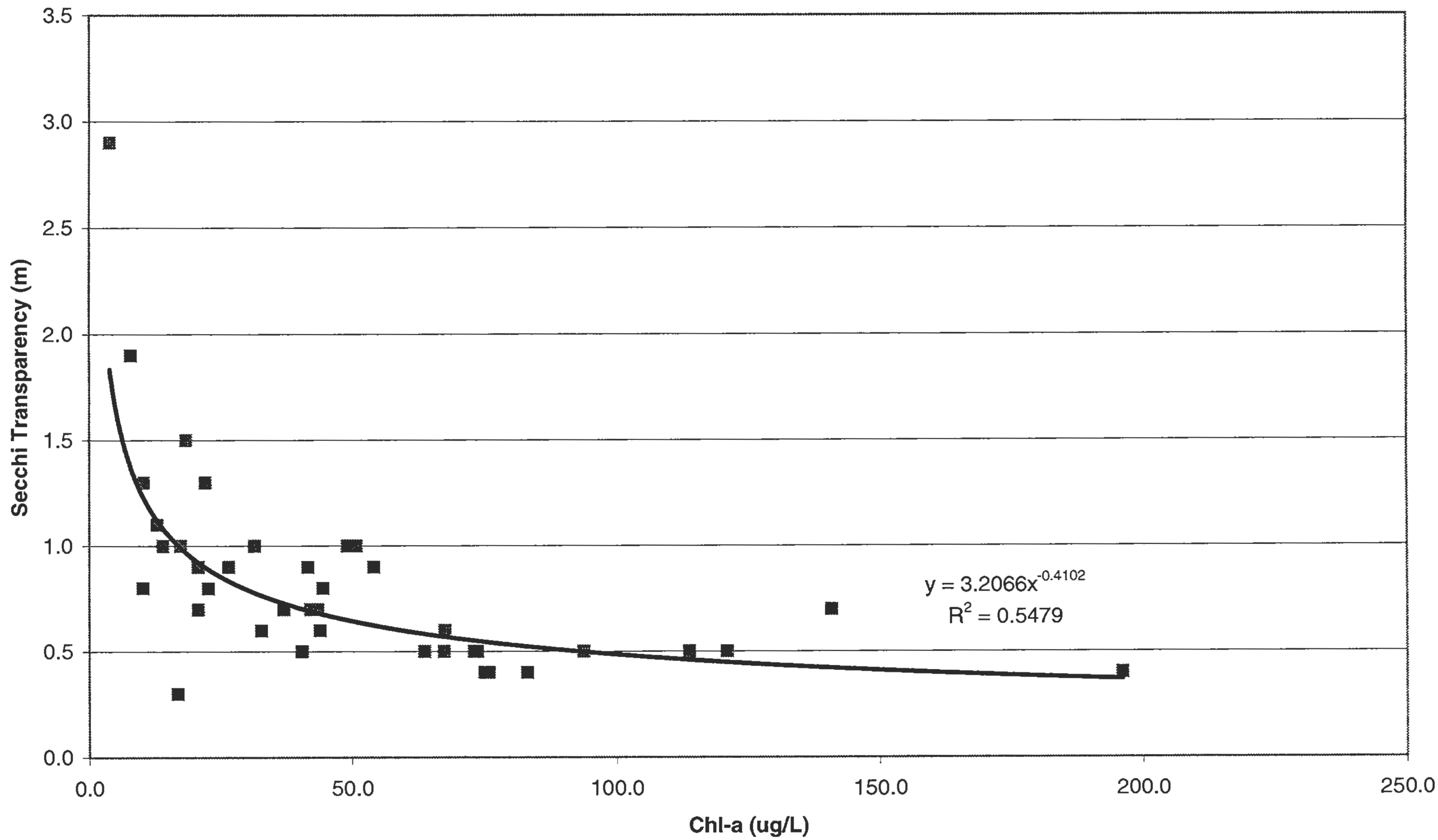
Appendix D

Chl a and Transparency Regression Analyses

Chl-a vs. Total Phosphorus
Lake Susan; all data 1971-1997



Secchi Transparency vs. Chl-a
Lake Susan - All Barr Data 1971-1997



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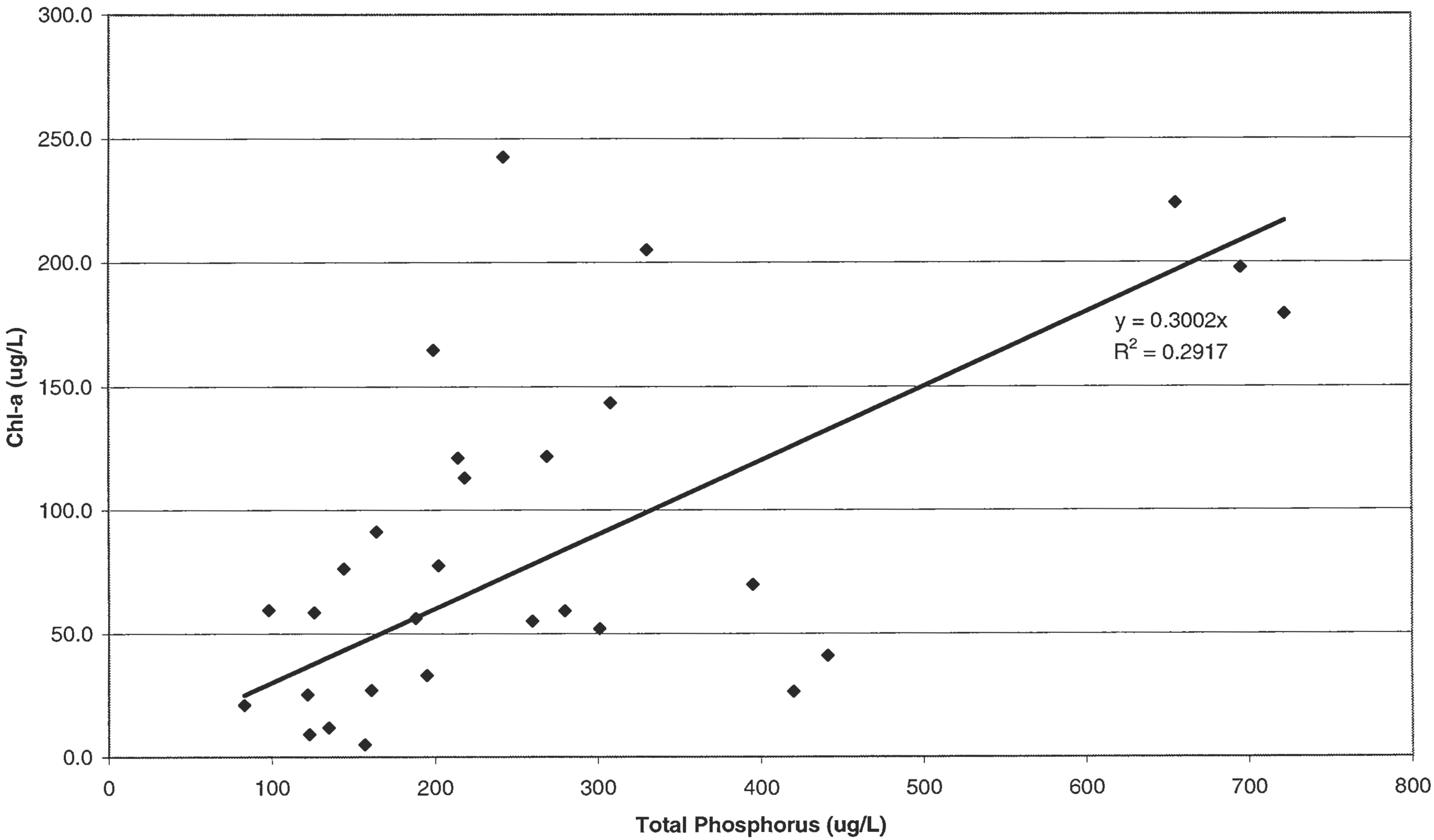
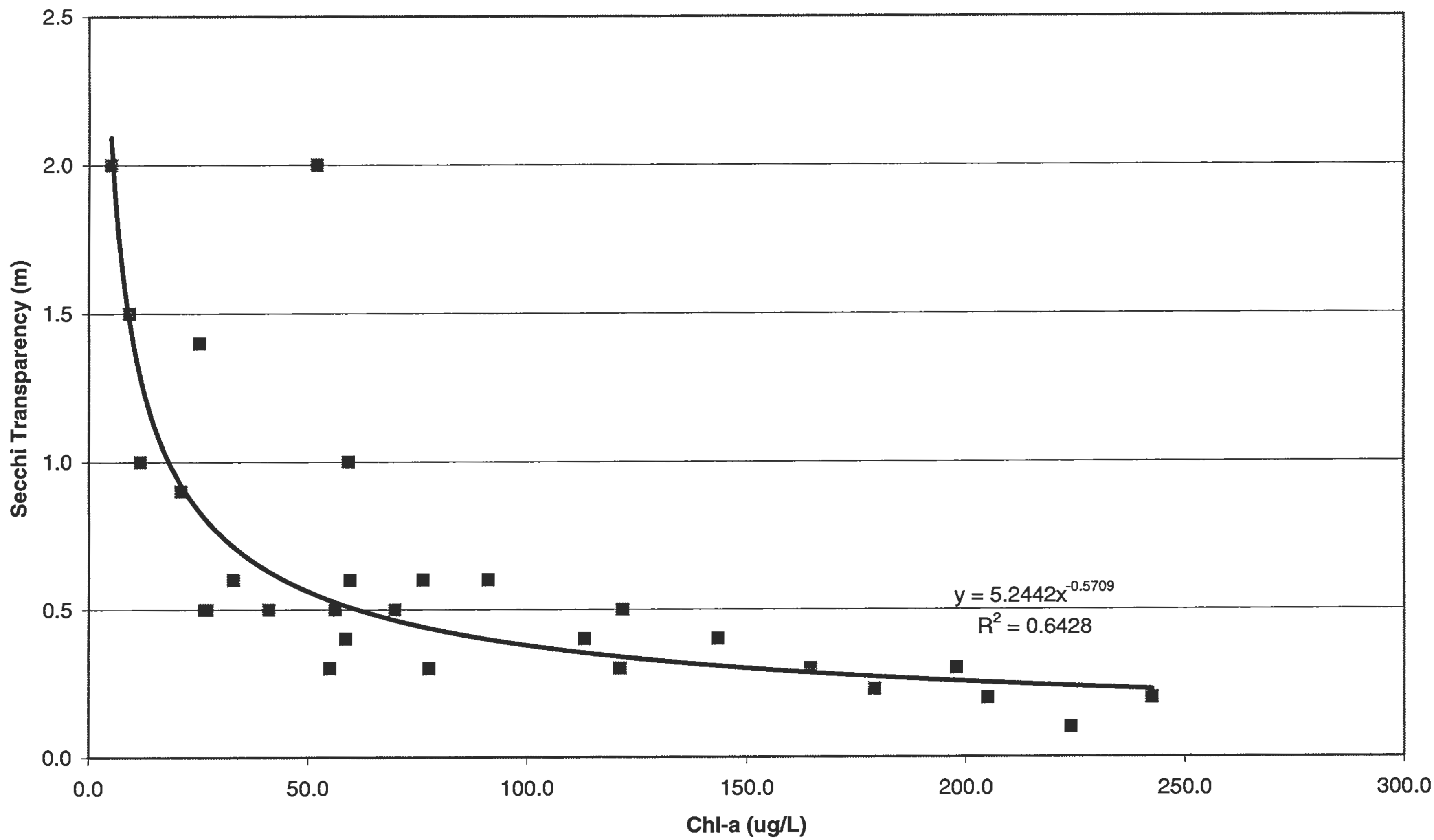
10:52 AM 5/31/99

Chl-a vs. Total Phosphorus
Rice Marsh Lake; all data 1972-1997



Secchi Transparency vs. Chl-a
Rice Marsh Lake - All Data 1972-1997



Appendix E

Cost Calculations

Rice Marsh Lake pond upgrade and additions cost estimates
Spreadsheet originated 6/1/99 -cjh

All estimates based on the assumption that excavation costs will predominate,
and excavation costs, for this analysis, are taken as: $ 8.00 per cu. Yd.

Volume added times cost per c.y. = cost for upgrade or addition
In cases where existing live storage was greater than planned live storage, no excavation costs were assessed for live storage.
In some cases, pond volumes may be augmented simply by adjusting the outlet; this was not accounted for in the following calculations.

Pond	Upgrade or Add	Orig Dead Storage Vol. (A-F)	Orig Live Storage Vol. (A-F)	Final Dead Storage Vol. (A-F)	Final Live Storage Vol. (A-F)	Change in Volume (cu. Yds.)	Excavation Cost	Pond Costs to be Borne by Developer? (Y or N)	Remaining Cost		
2.1	U	0.2	1.44	1	1.44	1,291	$ 10,325	**N**	$ 10,325		
2.2	U	0.3	1.12	1	1.12	1,129	$ 9,035	**N**	$ 9,035		
2.4	U	0.62	0.3	1	1	1,742	$ 13,939	**N**	$ 13,939		
2.6	U	5	0.5	6	0.5	1,613	$ 12,907	**N**	$ 12,907		
4.1	U	0.1	0.4	1	0.4	1,452	$ 11,616	Y	$ -		
4.4	U	1.6	0.67	3	1	2,791	$ 22,329	Y	$ -		
6.5	U	3.8	5	15	5	18,069	$ 144,555	**N**	$ 144,555		
5.4	U	0.1	0.52	1.7	1.4	4,001	$ 32,009	Y	$ -		
									Subtotal:	**$**	**191,000**
1.1	A	0	0	4.9	4	14,359	$ 114,869	**N**	$ 114,869		
1.3	A	0	0	0.45	0.35	1,291	$ 10,325	Y	$ -		
2.5	A	0	0	1	1	3,227	$ 25,813	**N**	$ 25,813		
2.8	A	0	0	1.5	1.2	4,356	$ 34,848	**N**	$ 34,848		
3.10	A	0	0	2.3	1.9	6,776	$ 54,208	Y	$ -		
6.9	A	0	0	1	1	3,227	$ 25,813	**N**	$ 25,813		
									Subtotal:	**$**	**201,000**
									Total:	**$**	**392,000**

It is assumed that the developer will bear the cost for providing additional storage (either by upgrading existing ponds or adding new ponds) in cases where the extra storage volume to be provided is required principally because of future development within the subwatershed.

Where space permits, upgraded pond dead storage volumes are as required to meet NURP criteria.
Added ponds, by contrast, have dead and live storage volumes as required by the proposed new (1999) RPBCWD rules.

Lake Susan pond upgrade and additions cost estimates
Spreadsheet originated 6/1/99 -cjh

All estimates based on the assumption that excavation costs will predominate,
and excavation costs, for this analysis, are taken as $ 8.00 per cu. Yd.

Volume added times cost per c.y. = cost for upgrade or addition
In cases where existing live storage was greater than planned live storage, no excavation costs were assessed for live storage.
In some cases, pond volumes may be augmented simply by adjusting the outlet; this was not accounted for in the following calculations.

Pond	Watershed Section: N or S	Upgrade or Add	Orig Dead Storage Vol. (A-F)	Orig Live Storage Vol. (A-F)	Final Dead Storage Vol. (A-F)	Final Live Storage Vol. (A-F)	Change in Volume (cu. Yds.)	Excavation Cost	Pond Costs to be Borne by Developer? (Y or N)	Remaining Cost	
2.1	S	U	1.7	2.94	2.5	2.94	1,291	$ 10,325	Y	$ -	
2.2	S	U	0.2	0.1	3	1	5,969	$ 47,755	Y	$ -	
3.13	N	U	0.17	3	3.5	3	5,372	$ 42,979	Y	$ -	
3.62	N	U	0.52	4	3.5	4	4,808	$ 38,462	Y	$ -	
3.21	N	U	2.87	5	5	5	3,436	$ 27,491	**N**	$ 27,491	
										Subtotal:	**$ 27,000**
1.2	S	A	0	0	1.23	0.95	3,517	$ 28,137	**N**	$ 28,137	
2.4	S	A	0	0	2.6	2	7,421	$ 59,371	**N**	$ 59,371	
3.14	N	A	0	0	3	2.5	8,873	$ 70,987	Y	$ -	
3.42	N	A	0	0	1.7	1.4	5,001	$ 40,011	**N**	$ 40,011	
3.52	N	A	0	0	2.5	2.1	7,421	$ 59,371	Y	$ -	
3.71	N	A	0	0	2	1.7	5,969	$ 47,755	**N**	$ 47,755	
3.91	N	A	0	0	1.3	0.9	3,549	$ 28,395	Y	$ -	
3.92	N	A	0	0	2	1.7	5,969	$ 47,755	Y	$ -	
3.93	N	A	0	0	2.1	1.8	6,292	$ 50,336	**N**	$ 50,336	
3.94	N	A	0	0	2.6	2.24	7,809	$ 62,468	**N**	$ 62,468	
3.95	N	A	0	0	0.87	0.7	2,533	$ 20,263	**N**	$ 20,263	
3.96	N	A	0	0	1.4	1.12	4,066	$ 32,525	**N**	$ 32,525	
										Subtotal:	**$ 341,000**
										Total:	**$ 368,000**

It is assumed that the developer will bear the cost for providing additional storage (either by upgrading existing ponds or adding new ponds) in cases where the extra storage volume to be provided is required principally because of future development within the subwatershed.

Where space permits, upgraded pond dead storage volumes are as required to meet NURP criteria.
Added ponds, by contrast, have dead and live storage volumes as required by the proposed new (1999) RPBCWD rules.