BARR

Memorandum

To: Shannon Lotthammer and Paul Nelson, Prior Lake-Spring Lake Watershed District (PLSLWD)

From: Greg Wilson

Subject: Final Technical Memorandum #2--Spring and Upper Prior Lakes External and Internal Phosphorus Load Modeling

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This technical memorandum, the second of three technical memoranda, has been prepared to discuss our data analysis for modeling Spring and Upper Prior Lakes external and internal phosphorus loads. This analysis is based on our review of 1999 and 2000 monitoring data and modeling, previously completed by the PLSLWD for each lake. This memorandum is intended to:

- Summarize conclusions from previous studies of Spring and Upper Prior Lakes
- Describe the methodology used to update or evaluate the existing BATHTUB modeling and complete an analysis of the internal and external phosphorus loadings for each lake
- Discuss the results of this analysis

Results of Previous Studies

This section discusses four previous studies pertaining to in-lake monitoring, and hydrologic and nutrient budget analyses completed on Spring and Upper Prior Lakes. A diagnostic-feasibility study of Spring Lake (*Metropolitan Council; September 1983; Publication No. 10-83-093F*), concluded that:

- Spring Lake is a large, relatively shallow and very fertile lake, receiving nutrients from runoff and internal sources causing nuisance blue-green algae blooms
- The lake’s dominant algae, Aphanizomenon, resist efforts at nutrient reduction in the lake and may actually increase in abundance following nutrient reductions
- Improving the water quality of Spring Lake requires both that the character of the algal community be changed and that phosphorus in the lake be substantially reduced
- Improvements in water quality may occur if phosphorus from all sources is reduced by greater than 1,500 kilograms per year (kg/yr)

A diagnostic-feasibility study for Prior and Spring Lakes (*Montgomery Watson; August 1993; for the Prior Lake-Spring Lake Watershed District*), concluded the following about Spring and Upper Prior Lakes:

- Algae blooms restrict the desired uses of Spring and Upper Prior Lakes, with chlorophyll-a concentrations averaging 45 μg/L and 35 μg/L, respectively
- The lakes are dominated by blue-green algae
- Internal loading contributes approximately one-third of the phosphorus load to Spring Lake
- More than 40% of the phosphorus load to Spring Lake comes from 23% of the direct watershed, possessing highly erodible soils
- 60% of the phosphorus in Spring Lake is soluble and readily available for algal uptake
- Upper Prior Lake receives approximately 55% of its phosphorus load from Spring Lake, so controlling phosphorus in Spring Lake is particularly important for improving the water quality of Upper Prior Lake
- Thirty-five percent of the remaining phosphorus load comes from the direct highly developed, drainage area to Upper Prior Lake

The Watershed Restoration Action Strategy for the Second Implementation Phase of the Prior-Spring Lake Improvement Project (*Prior Lake-Spring Lake Watershed District*), discussed the following results from more recent studies:

- The lakes are hypereutrophic and suffer from shoreline habitat loss and a lack of aquatic plant diversity
- Submerged aquatic plant surveys completed in 2000 showed that:
  - Curlyleaf pondweed is about the only species present in Spring Lake during early summer, with an estimated 180 acres of total areal coverage and 87 acres of nuisance growth
  - Eight other species were observed at low densities in Spring Lake
  - Curlyleaf pondweed, Eurasian watermilfoil, and low occurrences of sago pondweed were found in Upper Prior Lake during the early summer, while milfoil was still the dominant plant and diversity was low later in the summer
- Monitoring data from the deepest portion of the lakes indicates that both lakes are dimictic; however, Upper Prior Lake and the shallow western end of Spring Lake probably do not strongly stratify and likely mix intermittently
- Late summer algae growth in Spring Lake appears to be limited by light availability, while phosphorus appears to limit algal growth in both lakes during the rest of the year
- Large increases in Spring Lake phosphorus concentrations during periods of little or no flow indicate that internal phosphorus loading played an important role during 2000
- The calculated TSI values for Spring and Upper Prior Lakes from the 1999 and 2000 data indicate significantly better water quality by comparing the Secchi depth measurements against the phosphorus and chlorophyll-a readings, based on the Carlson TSI relationships. This could be due to the fact that large particulates, such as Aphanizomenon algae flakes, dominate the water column.
- The FLUX Model was used to develop phosphorus budgets for Spring and Upper Prior Lakes during 1999 (wet conditions with above average rainfall), and the BATHTUB Model was

used to develop the phosphorus budgets using the second order decay function for phosphorus sedimentation. The resulting phosphorus budgets indicate the following:
  - Watershed management efforts should continue to focus on the County Ditch 13 and Buck Lake subwatersheds
  - Internal recycling of phosphorus is significant in Spring Lake, and meaningful phosphorus reductions are unlikely to occur until internal recycling is addressed
  - Sediment phosphorus release is a significant portion of the 1999 budget for Upper Prior Lake
- Sediment phosphorus release microcosm experiments conducted on sediment cores collected in 1999 indicate anoxic sediment phosphorus release rates of 17 and 36 $mg/m^2/day$ for Spring and Upper Prior Lakes, respectively. The Spring Lake rate is within, while the Upper Prior Lake rate is well above, the 95% confidence interval for hypereutrophic lakes, indicating that internal phosphorus recycling plays an important role in the nutrient and algae dynamics of both lakes.
- Additional sediment cores were collected from Spring Lake in 2001 to determine the "releasable" phosphorus from the lake sediment and the necessary alum dose rates from Rydin and Welch (1999) ranged from 40 to 45 $g\ Al/m^2$ for the two samples analyzed
- The following project goals and objectives have been set for Spring Lake:
  - Reduce Spring Lake phosphorus concentration to 70-90 μg/L, consistent with the MPCA's goal for the WCBP ecoregion
  - Reduce the soluble reactive fraction of total phosphorus to 15%
  - Control internal recycling of phosphorus
  - Reduce watershed total phosphorus loads by 900 kg/yr
  - Control current infestations of Curlyleaf Pondweed from 180 to 90 acres, and nuisance condition coverage area from 90 to 40 acres or less; and manage probable future infestations of Eurasian Water Milfoil and enhance native plant coverage area to 30 to 40% of the lake area
- The following project goals and objectives have been set for Upper Prior Lake:
  - Reduce nutrient loading and improve winter dissolved oxygen concentrations
  - Reduce Upper Prior Lake phosphorus concentration to 50 μg/L, with ultimate goal of 40 μg/L, consistent with the recently proposed nutrient standard
  - Control internal recycling of phosphorus
  - Control current infestations of Curlyleaf Pondweed and manage infestations of Eurasian Water Milfoil; and increase native plant diversity from 1 species to 4 or more

The 2001 Annual Report (*Prior Lake-Spring Lake Watershed District*), discussing the CAMP monitoring results from 2001, indicates that:

- The water quality of Spring and Upper Prior Lakes is hypereutrophic and each lake received an MCES lake grade of D

- The calculated TSI values for Spring and Upper Prior Lakes from the data indicate significantly better water quality by comparing the Secchi depth measurements against the phosphorus and chlorophyll-a readings, based on the Carlson TSI relationships. This could be due to the fact that large particulates, such as Aphanizomenon algae flakes, dominate the water column.

Methodology for Evaluation of the Internal and External Phosphorus Loadings

For our evaluation of the internal and external phosphorus loadings, Barr was supplied with BATHTUB models for Spring Lake from 1999 and 2000, and for Upper Prior Lake from 1999. Our approach for this portion of the project began with a review of the assumptions and available monitoring data used to construct these models.

Based on the FLUX modeling results from our previous task (discussed in *Memorandum #1-- County Ditch 13 Wetland and Ferric Chloride System Sediment and Phosphorus Removal Performance Assessment; Greg Wilson; February 25, 2003*), Barr updated the existing BATHTUB modeling with changes to the County Ditch 13 external loadings that were previously entered into the models. We also changed the assumptions about the runoff volumes of the other unmonitored subwatersheds so that their respective runoff coefficients corresponded well with what would be expected, given the observed runoff from County Ditch 13 during 1999 and 2000. In addition, the Buck Lake subwatershed runoff phosphorus concentrations were changed to match the total and dissolved phosphorus concentrations from the 1999 monitoring results. We then reviewed the results of the sediment phosphorus release core testing, along with the alum treatment calculations, to determine the expected contribution of sediment phosphorus release to the internal load. Using the available aquatic plant surveys and published data (from Carpenter, 1980 and *Watershed Restoration Action Strategy, Prior Lake-Spring Lake Watershed District*) on the contribution of these plants to the observed internal load, Barr estimated the expected contribution of phosphorus from this source. Using the available septic system and groundwater data, we estimated the expected phosphorus load from these sources. We then combined the computed internal phosphorus loads from sediment phosphorus release, aquatic plants, septic systems and groundwater, and entered that loading into the updated BATHTUB model, along with the residual loading, such that the predicted in-lake phosphorus concentration in the updated BATHTUB model was the same as the observed phosphorus concentration for each modeling scenario. The residual total phosphorus loading from the BATHTUB model that would be required to obtain a match between the predicted and observed in-lake phosphorus concentrations was attributed to uncertainty and other sources of internal loading, such as carp and motor boat activity. The respective internal loading contributions due to carp and motor boat activity were compared with published data from Lamarra (1975) and James et al. (2001).

The loading contribution from each source was presented in pie charts showing the hydrologic and phosphorus inflow components for both Spring (during 1999 and 2000) and Upper Prior Lakes (during 1999). Since detailed water quality monitoring data existed for Spring Lake during 1999, the residual loading from the BATHTUB model was broken down, and the individual components were estimated based on the available monitoring data and other study results. Due to limited monitoring data, the residual loading from the BATHTUB models for Spring Lake in 2000 and Upper Prior Lake in 1999 was not presented with the individual components explicitly expressed, due to the difficulty in separating the sediment phosphorus release contribution from the other sources of internal loading.

The second-order decay rate function phosphorus balance model was used in BATHTUB to provide the best fit to the observed data from Spring Lake during 1999 and 2000, while the second-order fixed phosphorus balance model provided the best fit to the observed data from Upper Prior Lake in 1999. In addition, individual unique group numbers were assigned to each of the three segments of Upper Prior Lake for the calibration since each basin has its own unique set of morphological, flushing rate and nutrient loading characteristics.

Results of Internal and External Phosphorus Loadings Evaluation

This section discusses the results of our internal and external phosphorus loadings evaluation, based on the updated BATHTUB modeling from 1999 and 2000. The BATHTUB modeling results for Spring Lake are presented in Table 1 and Figures 1 and 2 (attached).

Table 1: 1999 and 2000 Spring Lake Budgets (Estimated Coefficient of Variation)

Hydrologic Inflows, hm3/yr	1999	2000
CD 13	6.575 (0.2)	1.22 (0.2)
Direct Precipitation	2.117 (0.05)	1.66(0.05)
Buck Lake	1.971 (0.12)	0.37 (0.11)
Spring Lk Central	0.191 (0.18)	0.02 (0.16)
Spring Lk West	0.202 (0.16)	0.02 (0.13)
Spring Lk Shoreline	0.606 (0.11)	0.10 (0.10)
Groundwater	3.56[3] (0.3)	2.8[4] (0.3)
Total	15.222	6.19

Inflow Phosphorus Budget, kg/yr	1999	2000
Atmospheric Deposition	75.6 (0.2)	75.6 (0.2)
CD 13	1774.2 (0.22)	257.6 (0.22)
Buck Lake	473.0 (0.19)	87.7 (0.17)
Spring Lk Central	62.1 (0.25)	6.6 (0.24)
Spring Lk West	68.6 (0.22)	7.5 (0.2)
Spring Lk Shore	207.8 (0.16)	27.6 (0.14)
Groundwater	148.0 (0.5)	116.3 (0.5)
Macrophytes	392.0 (0.5)	392.0 (0.5)
Sediment Release	2666.7 (0.5)	-------------
Septic Systems	124.0 (0.5)	124.0 (0.5)
Residual	402.4[1]	8136.0[2]
Total	6394.4	9230.9

NOTES:

[1] – Residual is comprised of inputs from internal phosphorus cycling from bottom-feeding fish, motor boat activity, unknown sources, and uncertainty of the other estimates. Internal recycling estimated from measured sediment release rates and period of anoxia (low oxygen) is about 1,600 Kg for the 1999 summer season. Assuming winter DO depletion lasts about two-thirds as long, phosphorus release gives an annual recycling estimate of about 2,667Kg (I.e., 87% of the residual and sediment release estimate or 43% of the total budget.)

[2] – Residual is comprised of inputs from sediment phosphorus release, bottom-feeding fish, motor boat activity, unknown sources, and uncertainty of the other estimates. Water column phosphorus and dissolved oxygen measurements were not available for 2000, but bottom-feeding fish and motor boat activity could account for 857 kg and 96 kg, respectively, of the residual load, with the difference in the residual load likely due to sediment phosphorus release and recycling (I.e., 7,183 kg or 88% of the residual estimate, or 78% of the total budget).

[3] – Assumed groundwater flow was comparable to estimate in diagnostic-feasibility study of Spring Lake (Metropolitan Council, 1983).

[4] – Assumed groundwater flow estimates, based on proportion of annual precipitation compared to estimated groundwater flow in diagnostic-feasibility study of Spring Lake (Metropolitan Council, 1983).

The following points about the 1999 Spring Lake budgets can be made from referring to Table 1 and Figure 1:

- CD13, Buck Lake, Precipitation and Groundwater account for 94% of inflows
- CD13, Buck Lake, Macrophytes, Sediment Release and Residual Loading account for most (84%) of the phosphorus loading

- Residual is comprised of inputs from bottom-feeding fish, motor boat activity, unknown sources, and uncertainty
- Sediment P Release estimated from measured sediment release rates and period of anoxia (low oxygen) was about 1,600 Kg for the 1999 summer season
- Assuming winter DO depletion lasts about two-thirds as long, phosphorus release gives an annual recycling estimate of about 2,667Kg (i.e., 87% of the residual and sediment release estimate or 43% of the total budget)
- The sediment phosphorus release percentage compares well with the 33% estimate from the 1983 phosphorus budget that the Met Council attributed to internal mechanisms in Spring Lake

The following points about the 2000 Spring Lake budgets can be made from referring to Table 1 and Figure 2:

- CD13, Direct Precipitation and Groundwater account for 92% of inflows
- The Residual Loading accounts for most (89%) of the phosphorus loading
- Unlike 1999, the Residual also includes sediment phosphorus release, along with inputs from bottom-feeding fish, motor boat activity, unknown sources, and uncertainty
- Since, with the exception of epilimnetic surface-water samples, water column phosphorus and dissolved oxygen measurements were not available for 2000
- Bottom-feeding fish and motor boat activity estimated to account for 860 kg and 100 kg, respectively, of residual load
- The difference in the residual load would likely be due to sediment phosphorus release and recycling (i.e., 7,180 kg or 88% of residual estimate, or 78% of the total budget)
- The primary reason for the large difference between the 1999 and 2000 sediment phosphorus release and recycling total Spring Lake load contributions of 43 to 78%, respectively, is that 1999 was a much wetter year, with significantly more of the total phosphorus load coming from watershed sources

The BATHTUB modeling results for Upper Prior Lake are presented in Table 2 and Figure 3 (attached).

Table 2: 1999 Upper Prior Lake Budgets (Estimated Coefficient of Variation)

Hydrologic Inflows, hm3/yr	1999
Spring Lake	7.918 (0.2)
Direct Precipitation	1.186(0.05)
East Rice/Crystal Lake Subwatershed	1.2 (0.2)
Unmonitored Subwatersheds	1.119 (0.16)
Total	11.423

Inflow Phosphorus Budget, kg/yr	1999
Atmospheric Deposition	42.4 (0.2)
Spring Lake	1095.1 (0.14)
East Rice/Crystal Lake Subwatershed	57.0 (0.28)
Unmonitored Subwatersheds	419.7 (0.24)
Residual	2406.2[1]
Total	4020.4

NOTES: [1] – Residual is comprised of inputs from sediment phosphorus release, bottom-feeding fish, motor boat activity, macrophytes, groundwater, unknown sources, and uncertainty of the other estimates. Internal recycling estimated from measured sediment release rates and period of anoxia (low oxygen) is about 1,990 Kg for the summer season. The following best estimates, for the more significant components of the residual loading, show that the total estimated internal load will more than account for the residual load (and does not equal the residual load because the individual estimates are based on literature export rates):

Sediment Release	1990 kg	68%
Macrophytes	315 kg	11%
Bottom-Feeding Fish Activity	523 kg	18%
Motor Boat Activity	113 kg	4%
Total	2941 kg	100%

The following points about the 1999 Upper Prior Lake budgets can be made from referring to Table 2 and Figure 3:

- Spring Lake outflow accounts for most (69%) of the inflows, with remaining subwatersheds accounting for about 21%
- Spring Lake represents 27%, while the Residual Loading accounts for significant fraction (61%), of the phosphorus loading
- Residual Loading includes inputs from sediment phosphorus release, bottom-feeding fish, motor boat activity, macrophytes, groundwater, unknown sources, and uncertainty
- Internal recycling estimated from measured sediment release rates and period of summer anoxia (low oxygen) is about 1,990 Kg (or 83% of the residual estimate, or 49% of the total phosphorus budget)
- Combining sediment phosphorus release with other significant components of internal loading results in 535 kg (2941 minus 2406 kg) more than the modeled Residual Loading, which is 13% of the total phosphorus load
- Difference between sum of significant components of internal loading estimates and modeled Residual Loading is likely due to uncertainties in all of the inflow phosphorus budget

estimates for Upper Prior Lake and may also imply that one or more of the internal loading components are over-estimated

In summary, sediment phosphorus release and recycling accounts for approximately 43 to 78% of the total phosphorus load for Spring Lake and 49% of the total phosphorus load for Upper Prior Lake. As a result, significant water quality improvements in each lake will require implementation of lake improvement options that would greatly minimize the potential for sediment phosphorus release. In addition, significant reductions in phosphorus from County Ditch 13 and Spring Lake should result in significant water quality improvements in Spring Lake and Upper Prior Lake, respectively. To a lesser degree, senescing macrophytes and bottom-feeding fish also affect the water quality of Spring and Upper Prior Lakes, since each of them contribute approximately 5 to 15% of the total phosphorus load to each lake.

The in-lake water quality (Bathtub) model and watershed pollutant loading (FLUX) model were used for this analysis to estimate the magnitude and effect of the various sources of phosphorus to Spring and Upper Prior Lakes. As indicated by the coefficient of variation estimates in Tables 1 and 2, there are varying degrees of uncertainty associated with the individual sources of watershed loading, as well as the model error and uncertainty inherent in the empirical in-lake water quality modeling done for this project. It is my opinion that the model error and uncertainty associated with this analysis is low enough so that it does not preclude anyone from making informed decisions, so long as the lake managers and stakeholders take this uncertainty into account when considering management actions. For example, according to the FLUX modeling results, the absolute phosphorus loading to Spring Lake from County Ditch #13 may be 22% higher or lower than the corresponding estimates shown in Table 1. As a result, a 30% total phosphorus load reduction targeted for County Ditch #13 may have to be adjusted upward to provide a “factor of safety” that will overcome the uncertainty associated with the original pollutant load estimates and modeling done for the County Ditch #13 watershed data.

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