Memorandum

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

From: Greg Wilson

Subject: Final Technical Memorandum #3--Feasibility Analysis for Controlling Internal Phosphorus Loads in Spring Lake

Date: February 27, 2004

Project: 23/70-158 GJW 003

This technical memorandum, the third of three technical memoranda, has been prepared to discuss our feasibility analysis for controlling internal phosphorus loads in Spring Lake. This analysis is based on our review of the available literature, as well as monitoring data, previous assessments, and modeling completed for Spring Lake. This memorandum is intended to:

- Summarize conclusions from previous studies that discuss measures for controlling internal phosphorus loads in Spring Lake
- Present the results of the feasibility analysis to consider and evaluate the expected cost, feasibility and benefits of several in-lake treatment options
- Provide recommendations for further evaluation and/or implementation of specific in-lake treatment options

Results of Previous Studies

This section discusses three previous studies pertaining to controlling internal phosphorus loads in Spring Lake. A diagnostic-feasibility study for Prior and Spring Lakes (*Montgomery Watson, 1993*), concluded the following about Spring Lake:

- Internal loading contributes approximately one-third of the phosphorus load to Spring Lake
- 60% of the phosphorus in Spring Lake is soluble and readily available for algal uptake

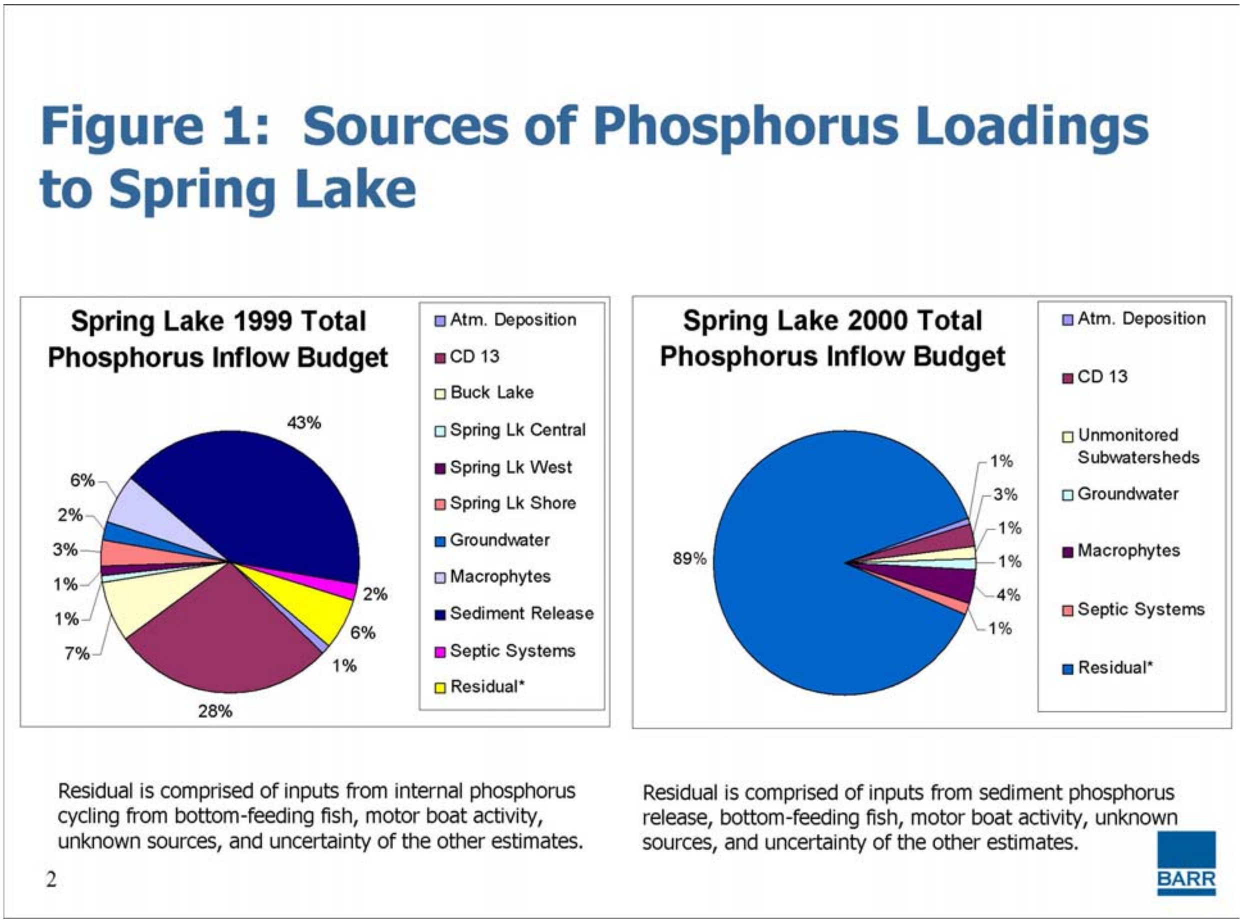
The Watershed Restoration Action Strategy for the Second Implementation Phase of the Prior-Spring Lake Improvement Project (*Prior Lake-Spring Lake Watershed District*), discussed the following results from more recent studies:

- 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

- 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 FLUX Model was used to develop the phosphorus budget for Spring Lake during 1999 (wet conditions with above average rainfall), and the BATHTUB Model was used to develop the phosphorus budget using the second order decay function for phosphorus sedimentation. The resulting phosphorus budget indicate the following:
  - 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 microcosm experiments conducted on sediment cores collected in 1999 indicate an anoxic sediment phosphorus release rate of 17 mg/m^2/day for Spring Lake. The Spring Lake rate is within the 95% confidence interval for hypereutrophic lakes, indicating that internal phosphorus recycling plays an important role in the nutrient and algae dynamics of the lake.
- 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
  - 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

Final Technical Memorandum #2—Spring and Upper Prior Lakes External and Internal Phosphorus Load Modeling (*Wilson, 2003*), discussing updated FLUX and BATHTUB modeling results from 1999 and 2000 (shown in Figure 1), indicates the following about the 1999 phosphorus budget:

- 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 phosphorus budget can be made from referring to the memorandum and Figure 1:

- 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 were 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 contributions to 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

In summary, sediment phosphorus release and recycling accounts for approximately 43 to 78% of the total phosphorus load for Spring Lake. As a result, significant water quality improvements will require implementation of lake improvement options that would greatly minimize the potential for sediment phosphorus release. To a lesser degree, senescing curlyleaf pondweed macrophytes and bottom-feeding fish also affect the water quality of Spring Lake, since each of them contribute approximately 5 to 10% of the total phosphorus load to the lake.

Evaluation of Expected Cost, Feasibility and Benefits of In-Lake Treatment Options

This section presents the evaluation of the expected cost, feasibility and benefits of several in-lake treatment options for Spring Lake. The results of the BATHTUB modeling, discussed in the previous section, will be used to evaluate the benefits of various in-lake treatment options. This feasibility analysis will consider and evaluate the feasibility and expected cost of the following in-lake treatment options:

- Hypolimnetic aeration
- Artificial destratification (i.e., mixing)
- Chemical treatment of anoxic sediments using
  - Alum
  - Lime
  - Alum plus lime
  - Ferric chloride, both with and without aeration
  - Calcium carbonate (spent lime)
  - Calcium nitrate (i.e., RIPLOX)
- Lake sediment covering (sealing) using
  - Geosynthetic clay liners
  - Plastic liners
  - Bentonite
- Removal of benthivorous fish (e.g., carp and bullheads) using Rotenone and/or netting
- Management of scenescing aquatic plants (e.g., Curlyleaf pondweed) using:
  - Dredging
  - Herbicides
  - Harvesting
  - Water level drawdown
  - Lime slurry
- Hypolimnetic withdrawal
- Biomanipulation

The Prior Lake-Spring Lake Watershed District (PLSLWD) has been conducting the following in-lake treatment options, on an annual basis, during the last few years:

- Benthivorous fish (e.g., carp & bullheads) removal with netting
- Management of scenescing aquatic plants (primarily Curlyleaf pondweed) using:

- Herbicide treatment with Endothall
- Harvesting

This past year, the PLSLWD funded mechanical harvesting on 50 acres of Spring Lake for $21,000, herbicide treatment on 40 acres of the lake for $15,467, and removal of 25,000 lbs. of benthivorous fish for $6,000. The current permit, obtained by PLSLWD from the Minnesota Department of Natural Resources (MDNR), limits the area of Spring Lake that can be managed for aquatic plants to 45 acres each for harvesting and herbicide treatment. Some limited surveys have been done to observe the difference in the stem density of curlyleaf pondweed, but no large-scale, quantitative evaluations have been done to document the current effectiveness of these treatment options in Spring Lake.

Based on our prior experience, and consultation with Curlyleaf Pondweed: New Management Ideas for an Old Problem (*Crowell, 2003*) and Managing Lakes and Reservoirs (*Holdren et al., 2001*), the other in-lake treatment options (from above) were considered for feasibility and their limitations with regard to cost or effectiveness. Based on this initial assessment, some of these in-lake treatment options are not recommended for further consideration. The following discussion summarizes the in-lake treatment options that are not recommended, along with the basis for excluding them from further consideration:

- Hypolimnetic aeration and artificial destratification
  - Both have the potential to increase sediment resuspension and lake productivity
  - Results are not always predictable, may not prevent phosphorus release from sediments (Gachter and Wehrli, 1998; Gachter and Muller, 2003)
- Chemical treatment of anoxic sediments using
  - Lime and Spent Lime
    - Not as effective as alum
  - Ferric chloride, both with and without aeration
    - Would not work as well as alum without aeration and would have increased cost associated with aeration (estimated range of $850,000 to $1,400,000 in additional long-term [20 years] costs associated with aeration)
  - Calcium nitrate (i.e., RIPLOX)
    - Limited experience, longevity unknown
- Lake sediment covering (sealing)
  - Concern about benthic organisms and cost
- Dredging
  - Cost prohibitive
- Hypolimnetic withdrawal
  - Discharging phosphorus-rich water has impact on downstream lakes
- Biomanipulation
  - Potential for limited long-term success and would likely require fishing restrictions

After excluding the above treatment options from further conderation, the following in-lake treatment options warranted further consideration and evaluation:

- Chemical treatment of anoxic sediments using
  - Alum
  - Alum plus lime
- Benthivorous fish (e.g., carp & bullheads) removal with netting
- Management of scenescing aquatic plants (e.g., Curlyleaf pondweed) using:
  - Herbicides
  - Harvesting
  - Water Level Drawdown
  - Lime Slurry

The following sections are intended to discuss each of these in-lake improvement options in more detail.

1. Chemical Treatment of Anoxic Sediments Using Alum

Phosphorus release, from the mobile phosphorus sediment fraction, occurs when sediments become anoxic. The mobile P sediment fraction consists of iron bound and loosely sorbed phosphorus. Alum works to control phosphorus release because the aluminum in alum exchanges with the iron bound and loosely sorbed phosphorus, creating a bond that is stable under anaerobic conditions. Alum reacts with both phosphorus and solids in the water column and removes them by creating a sweeping floc. Alum will reduce the alkalinity and pH of the lake water following its application, so one permit condition may be that the applied dose needs to be low enough that the pH is maintained at or above 6.0. As a result, more than one application of alum to the lake may be needed to achieve the desired dose for the sediment phosphorus release, yet ensure that the pH does not drop below 6.0. It is also likely that another permit condition will require ongoing monitoring for pH during the alum application to verify that the lake pH is not dropping below 6.0.

The alum should be applied to all of the lake sediments that are more than five feet deep. The long-term success of in-lake alum treatment is mostly dependent on the following factors:

- Adequate dose determination
- Good application technique
- Proper control of watershed phosphorus loadings to prevent phosphorus-rich sediments from re-accumulating

In-lake alum treatments, properly applied, will typically reduce rate of sediment phosphorus release by 90 percent for several years. Welch and Cooke (1995) concluded that in-lake alum treatments were highly effective and long lasting in stratified lakes. They also found that higher alum dosages were positively correlated to phosphorus control longevity. Another consideration in the management of sediment phosphorus release from Spring Lake is the potential role of the labile organic/polyphosphate fraction of sediment phosphorus since Rydin and Welch (1998, 1999) found that alum additions did not directly impact this source of sediment phosphorus. Bacterial mineralization of this fraction of sediment phosphorus could be an important source of phosphorus after an alum treatment, especially when the alum layer becomes buried by new sediment (Gachter et al., 1988; Jensen and Andersen, 1992; Gachter and Meyer, 1993; James and Barko, 2003). Sediment microcosm testing should be conducted to further evaluate how well various alum dosages might address sediment phosphorus release in Spring Lake. In addition, submersed aquatic macrophytes (such as curlyleaf pondweed) play an important role in directly recycling phosphorus from the sediment via root uptake and subsequent senescence (die-off) and indirectly recycling phosphorus by increasing pH in the water column through photosynthetic activities (James et al., 2001). James et al. (2001) suggests that percentage removals of plant biomass by mid-June could decrease phosphorus flux from decomposing plants by the corresponding percentage because more phosphorus is removed from the system prior to curlyleaf pondweed senescence.

Since sediment phosphorus release and recycling accounts for approximately 43 to 78% of the total phosphorus load, an in-lake alum treatment would dramatically improve the water quality in Spring Lake. In-lake alum treatment is the most reliable and cost-effective control measure for minimizing sediment phosphorus release. Table 1 provides a matrix of factors for consideration as improvement options for addressing sediment phosphorus release and controlling curlyleaf pondweed are being compared. There is a description of each improvement option along with its benefits, limitations, estimated costs and other considerations. Table 1 presents the estimated capital and annualized costs associated with an in-lake alum application to Spring Lake. The annualized cost is based on the cost associated with making payments on the upfront capital cost (assuming 20 year term at 6% interest), combined with the annual operation and maintenance costs for any potential in-lake improvement options. As shown in Table 1, the estimated total capital cost is $522,000 for an in-lake alum application to Spring Lake. The capital cost includes the costs associated with contractor mobilization/demobilization, application and sediment microcosm testing, final dose determination, engineering specifications, permitting and a 25 percent contingency included for all of the costs. For the purposes of the cost estimate, a volume of 487,500 gallons of alum, recommended previously, was assumed with a unit cost of $1 per gallon and a mobilization/demobilization cost of $10,000.

Table 1 Estimated Cost of Potential Improvement Options for Spring Lake

Potential In-Lake Improvement Options	Benefits	Limitations	Other Considerations	Estimated Capital Cost ($)	Estimated Annual Operation & Maintenance Cost ($)	Total Annualized Cost Estimate ($)
1. Alum Treatment	▪ Proven control option ▪ Cost-effective	▪ Longevity influenced by watershed runoff treatment	▪ Implementation should follow control of other sources ▪ Sediment microcosm testing should be done ▪ Requires MPCA, MDNR permitting	$522,000	---	$45,000
2. Alum Plus Lime Treatment	▪ Lime improves efficiency of alum application ▪ Limits macrophyte density	▪ Longevity influenced by watershed runoff treatment ▪ Non-selective removal of plants	▪ Implementation should follow control of other sources ▪ Sediment microcosm testing should be done ▪ Requires MPCA, MDNR permitting	$662,000	---	$58,000
3. Benthivorous Fish Removal	▪ Addresses sediment phosphorus recycling ▪ Improves effectiveness of alum application	▪ Not an effective long-term control option without effective fish barriers	▪ Requires MDNR permit	---	$13,000	$13,000
4. Whole-Lake Curlyleaf Pondweed Herbicide Treatment	▪ Effective control option ▪ Low capital cost	▪ Potential for on-going treatment costs	▪ Requires MDNR permit	$25,000	$70,000	$72,000
5. Whole-Lake Curlyleaf Pondweed Harvesting	▪ Removes biomass from the system	▪ Not effective long-term control option	▪ Requires MDNR permit	$25,000	$76,000	$78,000
6. Water Level Drawdown for Curlyleaf Pondweed Control	▪ Effective control option ▪ Low operation and maintenance costs ▪ Flood control benefits	▪ High capital cost ▪ Significant potential for public opposition	▪ Requires MDNR permit ▪ Would require extensive coordination/public education	$298,000	---	$26,000
7. Lime Slurry Application for Curlyleaf Pondweed Control	▪ Effective for all plant species	▪ Non-selective removal of plants ▪ Not well-documented	▪ Requires MDNR permit ▪ Pilot study should be completed	$166,000	---	$14,000

2. Chemical Treatment of Anoxic Sediments Using Alum Plus Lime Slurry

This improvement option is identical to the first improvement option, with the exception that lime slurry would be applied to the shallow or littoral portions of the lake along with the alum. There are several potential benefits of adding lime slurry with the alum, as discussed below:

- It holds the alum floc in place, preventing wind movement and scour from motor boats
- It reduces aquatic plant density, non-selectively
- It adds capacity for binding phosphorus, which controls filamentous and planktonic algae growth, and
- Lime slurry neutralizes pH

Table 1 presents the estimated capital and annualized costs associated with an in-lake alum and lime slurry application to Spring Lake. As shown in Table 1, the estimated total capital cost is $662,000. For the purposes of the cost estimate, a lime slurry treatment area of 180 acres was assumed with a unit cost of $625 per acre to go along with all of the alum treatment costs (described above).

3. Benthivorous Fish Removal

As previously described, the PLSLWD funded the removal of 25,000 lbs. of benthivorous fish in 2002 for $6,000. Benthivirous fish represent approximately 5 to 10 percent of the phosphorus budget in Spring Lake. Removing or limiting reproduction of benthivorous fish would reduce the internal phosphorus load, improve the balance of fisheries, and improve the effectiveness of an alum and/or lime slurry treatment. As discussed previously, no quantitative evaluation has been done to document the current water quality treatment effectiveness of this improvement option in Spring Lake. The PLSLWD should continue seining and work with the MDNR to identify locations where fish barriers should be constructed on the inlets to the lake to minimize the reproduction of benthivorous fish. Without fish barrier construction, seining will likely be required every year to keep benthivorous fish populations in check.

Table 1 presents the estimated annual cost of $13,000 associated with benthivorous fish removal in Spring Lake. For the purposes of the cost estimate, it was assumed that 100,000 lbs. of fish would be removed with a $1,000 mobilization/demobilization cost. Costs for construction of fish barriers will need to be included in the analysis following consultation with MDNR and design of the barriers.

4. Curlyleaf Pondweed Control With Herbicide Treatments

As discussed before, decay of curlyleaf pondweed represents approximately 5 to 10 percent of the Spring Lake phosphorus budget. The load associated with this source of phosphorus is more significant since all of it is released within a few weeks during the middle of the summer. Addressing curlyleaf pondweed is important since it reduces internal load, restores the balance of native plants, and improves the effectiveness of an in-lake alum treatment. The PLSLWD funded herbicide treatment on 40 acres of the Spring Lake for $15,467, this past year. The current permit, obtained by PLSLWD from the MDNR, limits the area of Spring Lake that can be managed for aquatic plants to 45 acres for treatment using the herbicide endothall (Aquathol® K). Current studies indicate that there is good control and selectivity for curlyleaf pondweed with endothall (Crowell, 2003). In addition to endothall, diquat and fluridone are herbicides that are being used for control of curlyleaf pondweed. Initial studies indicate that diquat works long-term, but is nonselective in that it kills several species of plants. Fluridone, which requires a whole-lake treatment, has not worked long-term and is also nonselective.

As previously described, some limited surveys have been done to observe the difference in the stem density of curlyleaf pondweed, but no large-scale, quantitative evaluations have been done to document the current effectiveness of these treatment options in Spring Lake. The U.S. Army Engineer Research and Development Center (USAERDC) is currently working on a study of the long-term effectiveness of endothall to see if the herbicide needs to be applied every year, or if a few years of application alone will eliminate turion production enough to provide longer-term control. Table 1 presents the estimated annual cost of $70,000 associated with application of endothall to Spring Lake. For the purposes of the cost estimate, it was assumed that 180 acres would be treated at the same unit cost of $387 per acre, from this past year. An aquatic plant management plan was prepared in March, 2001. This plan provided information about the available aquatic plant surveys and provided recommendations for potential curlyleaf pondweed management options, but the report content does not reflect the current knowledge about which curlyleaf pondweed management options have been successful on Spring Lake and should be updated with recommendations for the whole lake. An estimated capital cost of $25,000 is included for this option to update the current plan and obtain a new permit from the MDNR to apply endothall to Spring Lake. The annualized cost, shown in Table 1, assumes that endothall will have to be applied every year.

5. Curlyleaf Pondweed Control With Harvesting

As previously discussed, the PLSLWD funded mechanical harvesting on 50 acres of Spring Lake for $21,000. The current permit, obtained by PLSLWD from the MDNR, limits the area of Spring Lake that can be managed for aquatic plants to 45 acres for harvesting. As described before, some limited surveys have been done to observe the difference in the stem density of curlyleaf pondweed, but no large-scale, quantitative evaluations have been done to document the current effectiveness of this treatment option in Spring Lake. It appears as though annual cutting is required with this improvement option, but more study of the long-term effectiveness is needed for lakes, in general (Crowell, 2003).

Table 1 presents the estimated annual cost of $76,000 associated with harvesting macrophytes from Spring Lake. For the purposes of the cost estimate, it was assumed that 180 acres would be harvested at the same unit cost of $420 per acre, from this past year. An estimated capital cost of $25,000 is included for this option to update the current plan and obtain a new permit from the

MDNR to harvest macrophytes from Spring Lake. The annualized cost, shown in Table 1, assumes that harvesting will have to be done every year.

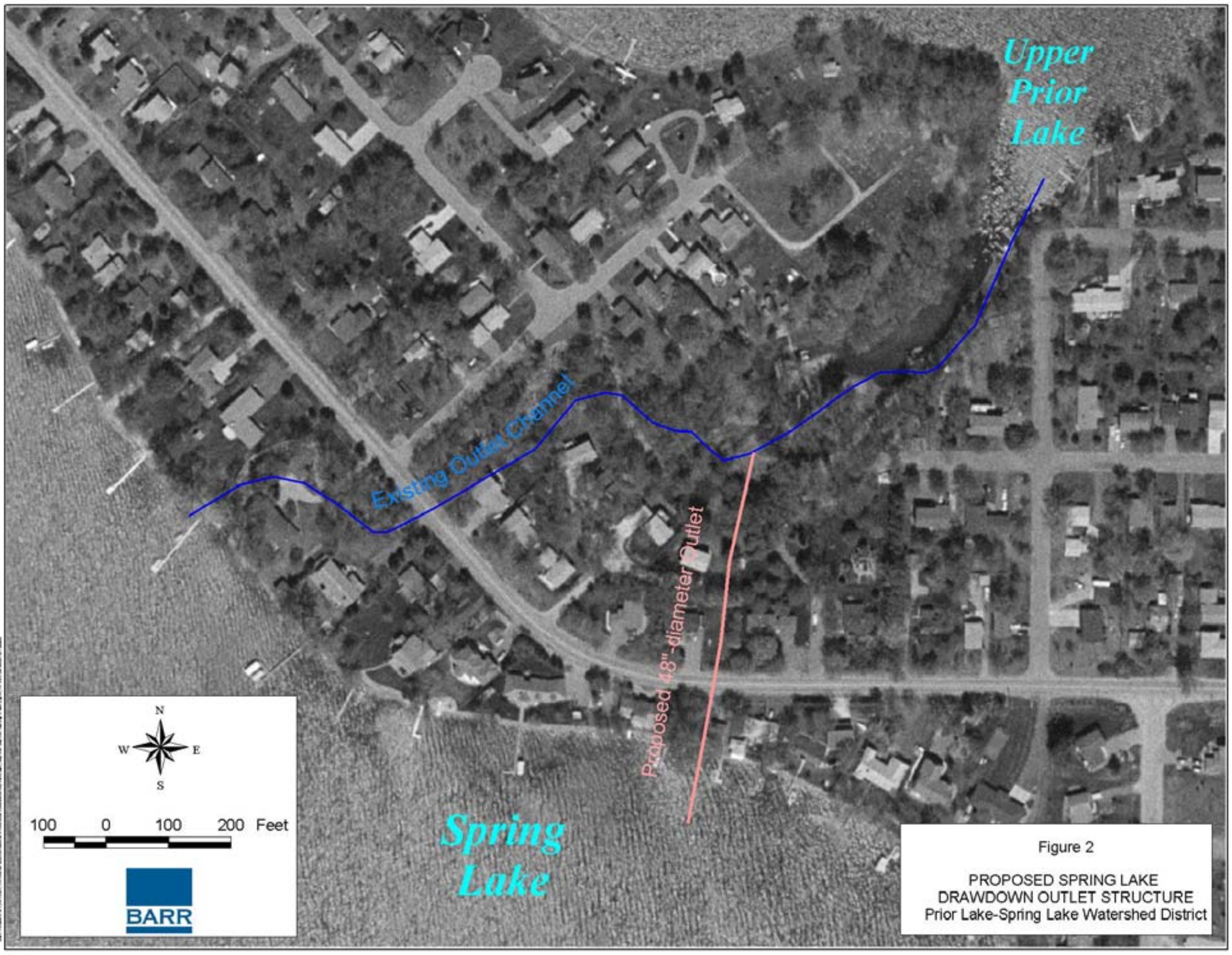
6. Curlyleaf Pondweed Control Using Water Level Drawdown

Drawdown (lowering water in a lake) can sometimes control weeds by exposing them to drying or freezing. Exposing the littoral zone may also result in shrinkage of soft muck, thus deepening the lake without expensive dredging. Drawdown can also be useful in encouraging growth of plants beneficial to waterfowl. According to MDNR, fall drawdown for the winter works well at controlling curlyleaf pondweed if the water level is drawn down far enough to expose all plant roots and sediments are dried and exposed in the fall. The freezing temperatures will kill curlyleaf pondweed turions. This proposed improvement option will require that the water level in Spring Lake be drawn down approximately eight feet in the fall and kept at that level throughout the winter. Groundwater flow and spring and early summer runoff from the Spring Lake watershed during the following year would restore the water level of the lake.

Currently, there is approximately an eight-foot difference between the normal levels of Spring and Upper Prior Lakes. Figure 2 shows the existing outlet channel for Spring Lake, along with the alignment for a proposed 48-inch diameter pipe outlet that would tie into the existing channel at a level that is approximately eight feet lower than the current level of the lake. The proposed outlet pipe would also include a control structure, with stop-logs, intended to maintain the current normal level of the Spring Lake. During the drawdown period, the stop logs would be removed and the lake would be drawn down by gravity flow. This system would also ensure that the water level will remain at the desired level throughout the winter, even if there is groundwater or other tributary baseflow entering Spring Lake. This would be especially important to ensure that the lake sediments dry out and the curlyleaf pondweed turions become exposed to freezing temperatures.

The proposed outlet structure also provides the added benefit that it can be used in conjunction with any future plans for flood control or water management planning, in that the lake can be drawn down to a lesser extent in the fall to provide the desired storage volume to manage runoff from a 100-year snowmelt runoff event, for example. The MDNR indicated that this project would require a special permit and coordination that would involve input from lake users, managers and every division of the MDNR regarding the permit conditions (Crowell, 2003). There would be several considerations required to minimize the negative effects that a drawdown can have on the fisheries and lake use. Implementation of this improvement option would likely draw significant opposition due to concerns about the Spring Lake fishery, recreational use and downstream lake levels and water quality. But careful planning, design and public education would improve the practical feasibility of this option and should be able to address the concerns of the MDNR and lakeshore residents.

Table 1 presents the estimated capital cost of $298,000 associated with the design, construction, permitting, easement, legal and contingency costs for the Spring Lake drawdown outlet structure. The annualized cost of $26,000, shown in Table 1, assumes that no other operation or maintenance costs will be incurred each year.



7. Curlyleaf Pondweed Control With Lime Slurry

This improvement option is essentially the same as the second improvement option without the application of alum to the lake sediments. As previously described, the lime slurry would be applied to the shallow or littoral portions of the lake. The benefits of applying lime slurry include the following:

- Reduces aquatic plant density
- Adds capacity for binding phosphorus, which controls filamentous and planktonic algae growth

Studies indicate good control, but lime slurry is probably not selectively removing curlyleaf pondweed. More quantitative study of the long-term effectiveness of lime slurry is needed before this improvement option should be considered for Spring Lake. An alternative would be to complete a pilot study with lime slurry application to treatment plots within Spring Lake. This pilot study could be done in conjunction with the harvesting and herbicide applications that have been done on Spring Lake over the last few years. This would allow a quantitative, side-by-side comparison of three potential treatment options for control of curlyleaf pondweed. The estimated cost of a pilot study is $5,000 to $10,000, depending on permitting requirements and the scale of assessment.

Table 1 presents the estimated capital and annualized costs associated with an in-lake lime slurry application to Spring Lake. As shown in Table 1, the estimated total capital cost is $166,000. In addition, the capital cost includes the costs associated with contractor mobilization/demobilization, pilot study testing, engineering specifications, permitting and a 25 percent contingency included for all of the costs. For the purposes of the cost estimate, a lime slurry treatment area of 180 acres was assumed with a unit cost of $625 per acre.

Recommendations for Implementation and Further Evaluation of In-Lake Improvement Options

This section is intended to provide recommendations for implementation or further evaluation of specific in-lake treatment options. This feasibility analysis, along with several previous studies, indicates that there are three sources of internal phosphorus loading to Spring Lake: sediment release, benthivorous fish and senescing curlyleaf pondweed. The results of this feasibility analysis indicate that, at a minimum, an in-lake alum treatment should be applied to Spring Lake at depths greater than 5 feet to address the sediment phosphorus release from anoxic sediments. The results also indicate that seining, along with construction of fish barriers at Spring Lake inlets, should be continued to address the phosphorus contributions from benthivorous fish in Spring Lake. As previously discussed, curlyleaf pondweed plays an important role in directly recycling phosphorus from the sediment via root uptake and subsequent senescence (die-off) and indirectly recycling phosphorus by increasing pH in the water column through photosynthetic activities. As a result, additional control of curlyleaf pondweed prior to an in-lake alum treatment would be beneficial.

It is a little less clear which of the five remaining improvement options should be implemented to control phosphorus release from curlyleaf pondweed. The annualized cost column in Table 1 was intended to provide a way of comparing both one-time capital and annual projects to each other. The costs presented in Table 1 assume that treatments would need to occur every year for improvement options 3, 4 and 5. Based on the assumptions used to develop the annualized cost estimates in Table 1, it would appear as though a lime slurry application would be the least expensive improvement option for control of curlyleaf pondweed (based on an annualized cost of $14,000). Unfortunately, lime slurry appears to be nonselective and its long-term effectiveness has not been documented.

The second least-expensive improvement option in Table 1, based on an annualized cost of $26,000, is water level drawdown. In comparison, the annualized cost for herbicide treatment with endothall is $72,000. The primary difference between these two improvement options, as it relates to annualized cost, is due to the assumption that endothall treatments would need to continue once a year, every year. As previously discussed, the USAERDC is currently working on a study of the long-term effectiveness of endothall to see if the herbicide needs to be applied every year, or if a few years of application alone will eliminate turion production enough to provide longer-term control of curlyleaf pondweed. If this study or the results of a quantitative study of the current practice within Spring Lake shows that long-term control can attained without continued annual applications, then the annualized cost for this option is likely inline with the cost to provide water level drawdown. However, if endothall does not provide long-term control, or requires five or more applications during the next 20 years, then water level drawdown should be considered as the preferred option for curlyleaf pondweed control. This is with the water management benefits of a drawdown outlet structure notwithstanding and recognizing that drawdown would likely have significant opposition due to concerns about the Spring Lake fishery, recreational use and downstream lake levels and water quality. As previously discussed, careful planning, design and public education would improve the practical feasibility of drawdown and should be able to address the concerns of the MDNR and lakeshore residents.

Based both on cost (annualized cost of $78,000) and long-term effectiveness, harvesting should not be considered as a viable improvement option for controlling curlyleaf pondweed.

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