

6.0 Discussion

6.1 General Discussion of Improvement Options

This section discusses improvement options and general BMPs to remove phosphorus and/or reduce sediment and litter entering a lake. Three types of BMPs were considered during the preparation of this report: structural, nonstructural, and in-lake.

1. Structural BMPs remove a fraction of the pollutants and sediment loads contained in stormwater runoff prior to discharge into receiving waters.
2. Nonstructural BMPs (source control) eliminate pollutants at the source and prevent pollutants from entering stormwater flows.
3. In-Lake BMPs reduce phosphorus already present in a lake, and/or prevent the release of phosphorus from anoxic lake sediments.

6.1.1 Structural BMPs

Structural BMPs temporarily store and treat urban stormwater runoff to reduce flooding, remove pollutants, and provide other amenities (Schueler, 1987). Water quality BMPs are specifically designed for pollutant removal. Their effectiveness is summarized in Table 6-1. Structural BMPs control total suspended solids and total phosphorus loadings by slowing stormwater and allowing particles to settle in areas before they reach the stream. Settling areas can be ponds, storm sewer sediment traps, or vegetative buffer strips. Settling can be enhanced by treatment with a flocculent prior to entering the settling basin (see alum treatment plants below).

When choosing a structural BMP, the ultimate objective must be well understood. The BMP should accomplish the following (Schueler 1987):

1. Reproduce, as nearly as possible, the stream flow before development.
2. Remove at least a moderate amount of most urban pollutants.
3. Require reasonable maintenance.
4. Have a neutral impact on the natural and human environments.
5. Be reasonably cost-effective compared with other BMPs;

Table 6-1 General Effectiveness of Stormwater BMPs at Removing Common Pollutants from Runoff

Best Management Practice (BMP)	Suspended Sediment	Total Phosphorus	Total Nitrogen	Oxygen Demand	Trace Metals	Bacteria	Overall Removal
Wet Pond	5	3	2	3	4	?	4
Infiltration Trench or Basin	5	3	3	4	5	4	4
Porous Pavement	4	4	4	4	4	5	4
Water Quality Inlet (Grit Chamber)	1	?	?	?	?	?	?
Filter Strip	2	1	1	1	1	?	1

Percent Removal	Score
80 to 100	5
60 to 80	4
40 to 60	3
20 to 40	2
0 to 20	1
Insufficient Knowledge	?

Examples of structural BMPs commonly installed to improve water quality include:

- Wet detention ponds
- Infiltration Trenches of Basins
- Vegetative buffer strips
- Oil and grit separators
- Alum treatment plants

Each of the BMPs is described below and their general effectiveness is summarized in Table 6-1.

6.1.1.1 Wet Detention Ponds

Wet detention ponds (sometimes called “NURP” ponds after the Nationwide Urban Runoff Program) are impoundments that have a permanent pool of water and also have the capacity to hold runoff and release it at slower rates than incoming flows. Wet detention ponds are one of the most effective methods available for treatment of stormwater runoff. Wet detention ponds are used to interrupt the transport phase of sediment and pollutants associated with it, such as trace metals, hydrocarbons, nutrients, and pesticides. When designed properly, wet detention ponds can also provide some removal of dissolved nutrients. Detention ponds have also been credited with reducing the amount of bacteria and oxygen-demanding substances as runoff flows through the pond.

During a storm, polluted runoff enters the detention basin and displaces “clean” water until the plume of polluted runoff reaches the basin’s outlet structure. When the polluted runoff does reach the outlet, it has been diluted by the water previously held in the basin. This dilution further reduces the pollutant concentration of the outflow. In addition, much of the total suspended solids and total phosphorus being transported by the polluted runoff and the pollutants associated with these sediments are trapped in the detention basin. A well-designed wet detention pond could remove approximately 80 to 95 percent of total suspended solids and 40 to 60 percent of total phosphorus entering the pond (MPCA, 1989).

As storm flows subside, finer sediments suspended in the pond’s pool will have a relatively longer period of time to settle out of suspension during the intervals between storm events. These finer sediments eventually trapped in the pond’s permanent pool will continue to settle until the next storm flow occurs. In addition to efficient settling, this long detention time allows some removal of dissolved nutrients through biological activity (Walker, 1987). These dissolved nutrients are mainly removed by algae and aquatic plants. After the algae die, the dead algae can settle to the bottom of the pond, carrying with them the dissolved nutrients that were consumed, to become part of the bottom sediments.

The wet detention process results in good pollutant removal from small storm events. Runoff from larger storms will experience pollutant removal, but not with the same high efficiency levels as the runoff from smaller storms. Studies have shown that because of the frequency distribution of storm events, good control for more frequent small storms (wet detention’s strength) is very important to long-term pollutant removal.

6.1.1.2 Infiltration Trenches or Basins

Infiltration is the movement of water into the soil surface. For a given storm event, the infiltration rate will tend to vary with time. At the beginning of the storm, the initial infiltration rate, is the maximum infiltration that can occur because the soil surface is typically dry and full of air spaces. The infiltration rate will tend to gradually decrease as the storm event continues because the soil air spaces fill with water. For long duration storms the infiltration rate will eventually reach a constant value, the minimum infiltration rate (the design infiltration rate). The infiltrated runoff helps recharge the groundwater and mitigate the impacts of development. Stormwater flows in, ponds on the surface, and gradually infiltrates into the soil bed. Pollutants are removed by adsorption, filtration, volatilization, ion exchange, and decomposition. Therefore, infiltration is one of a few BMPs that can reduce the amount of dissolved pollutant in stormwater. Infiltration BMP devices,

such as porous pavements, infiltration trenches and basins, and rainwater gardens, can be utilized to promote a variety of water management objectives, including:

- Reduced downstream flooding
- Increased groundwater recharge
- Reduced peak stormwater discharges and volumes
- Improved stormwater quality

An infiltration basin collects and stores stormwater until it infiltrates to the surrounding soil and evaporates to the atmosphere. Infiltration basins remove fine sediment, nutrients (including dissolved nutrients), trace metals, and organics through filtration by surface vegetation, and through infiltration through the subsurface soil. Deep-rooted vegetation can increase infiltration capacity by creating small conduits for water flow. Infiltration basins are designed as a grass-covered depression underlaid with geotextile fabric and coarse gravel. A layer of topsoil is usually placed between the gravel layer and the grassed surface. Pretreatment is often required to remove any coarse particulates (leaves and debris), oil and grease, and soluble organics to reduce the potential of groundwater contamination and the likelihood of the soil pores being plugged. Infiltration can also be promoted in existing detention ponds by excavating excess sediments (typically the fines that seal the bottom of the pond) and exposing a granular sub-base (assuming one was present prior to the original construction of the detention pond).

Rainwater gardens (a form of bio-retention) are shallow, landscaped depressions that channel and collect runoff. To increase infiltration, the soil bed is sometimes amended, such as with mulch. Vegetation takes up nutrients, and stored runoff is reduced through evapotranspiration. Bio-retention is commonly located in parking lot islands, or within small pockets in residential areas. Bio-retention is primarily designed to remove sediment, nutrients, metals, and oil and grease. Secondary benefits include flow attenuation, volume reduction, and removal of floatables, fecal coliform, and BOD.

6.1.1.3 Vegetated Buffer Strips

Vegetative buffer strips are low sloping areas that are designed to accommodate stormwater runoff traveling by overland sheet flow. Vegetated buffer strips perform several pollutant attenuation functions, mitigating the impact of development. Urban watershed development often involves disturbing natural vegetated buffers for the construction of homes, parking lots, and lawns. When natural vegetation is removed, pollutants are given a direct path to the lake -- sediments cannot settle

out; nutrients and other pollutants cannot be removed. Additional problems resulting from removal of natural vegetation include streambank erosion and loss of valuable wildlife habitat (Rhode Island Department of Environmental Management, 1990).

The effectiveness of buffer strips is dependent on the width of the buffer, the slope of the site, and the type of vegetation present. Buffer strips should be 20-feet wide at a minimum, however 50- to 75-feet is recommended. Many attractive native plant species can be planted in buffer strips to create aesthetically pleasing landscapes, as well as havens for wildlife and birds. When properly designed, buffer strips can remove 30 to 50 percent of total suspended solids from lawn runoff. In addition, well-designed buffer strips will discourage waterfowl from nesting and feeding on shoreland lawns. Such waterfowl can be a significant source of phosphorus to the pond, by grazing turfed areas adjacent to the water and defecating in or near the water's edge where washoff into the pond is probable.

6.1.1.4 Oil and Grit Separators

Oil-grit separators (e.g., StormCeptors) are concrete chambers designed to remove oil, sediments, and floatable debris from runoff, and are typically used in areas with heavy traffic or high potential for petroleum spills such as parking lots, gas stations, roads, and holding areas. A three-chamber design is common; the first chamber traps sediment, the second chamber separates oil, and a third chamber holds the overflow pipe. The three-chambered unit is enclosed in reinforced concrete. They are good at removing coarse particulates, but soluble pollutants probably pass through. In order to operate properly, they must be cleaned out regularly (at least twice a year). The major benefit of a water oil-grit separator is as a pre-treatment for an infiltration basin or pond. They can also be incorporated into an existing stormwater system or included in an underground vault detention system when no available land exists for a surface detention basin. Only moderate removals of total suspended solids can be expected; however, oil and floatable debris are effectively removed from properly designed oil and grit separators.

6.1.1.5 Alum Treatment Plants

In addition to the commonly installed structural BMPs discussed above, alum treatment plants are becoming an option for efficiently removing phosphorus from tributaries, rather than directly treating the lake with alum to remove phosphorus. Alum (aluminum sulfate) is commonly used as a flocculent in water treatment plants and as an in-lake treatment for phosphorus removal. To treat inflows in streams or storm sewers, part of the flow is diverted (e.g., 5 cfs) from the main flow and treated with alum. After the alum is injected in the diverted flow it passes to a detention pond to

allow the flocculent to settle out before the water enters the lake. Alum treatment has been shown to remove up to 90 percent of the soluble and particulate phosphorus from the inflows.

6.1.2 Nonstructural BMPs

Nonstructural (“Good Housekeeping”) BMPs discussed below include:

1. Public Education
2. Ordinances
3. Street Sweeping
4. Deterrence of waterfowl

Good housekeeping practices reduce the pollutant at its source.

6.1.2.1 Public Education

Public education regarding proper lawn care practices, such as fertilizer use and disposal of lawn debris, would result in reduced organic matter and phosphorus loadings to the lake. A public information and education program may be implemented to teach residents within the Crystal Lake watershed how to protect and improve the quality of the lake. The program would include distribution of fliers to all residents in the watershed and placement of advertisements and articles in the city’s newsletters and the local newspapers. Information could also be distributed through organizations such as local schools, Girl Scouts and Boy Scouts, and other local service clubs.

Initiation of a stenciling program to educate the public would help reduce loadings to the storm sewer system. Volunteers could place stenciled messages (i.e., “Dump No Waste, Drains to Crystal Lake”) on all storm sewer catch basins within the Crystal Lake watershed.

6.1.2.2 Ordinances

Legislative methods of addressing water quality include a watershed-wide ban on the use of phosphorus fertilizers or a commercial lawn care ordinance to control content of mixture and ensure that no phosphorus is present in the case of a complete phosphorus ban. This legislated fertilizer phosphorus limitation will become effective in 2004. Exceptions to such a ban would be granted in cases where a resident was able to demonstrate, by means of soil analyses, that phosphorus was required. Other ordinances pertaining to littering, pet feces, and buffer strips adjacent to lakes and other water bodies could be strengthened or created.

6.1.2.3 Street Sweeping

Most often, street sweeping is performed only in the spring, after the snow has melted and in the fall, after the leaves have fallen, to reduce this potential source of phosphorus from entering the storm sewer. For most urban areas, street sweeping has relatively low effectiveness from late-spring (after the streets are cleaned of accumulated loads) until early-fall (prior to the onset of leaf fall) (Bannerman, 1983). In addition, the use of vacuum sweepers is preferred over the use of mechanical, brush sweepers. The vacuum sweepers are more efficient at removing small phosphorus-bearing particles from impervious surfaces within the watershed. Fall street sweeping is particularly important in the watershed directly tributary to the lake, where treatment of stormwater is not available.

6.1.2.4 Deterrence of Waterfowl

The role of waterfowl in the transport of phosphorus to lakes is often not considered. However, when the waterfowl population of a lake is large relative to the lake size, a substantial portion of the total phosphorus load to the lake may be caused by the waterfowl. Waterfowl tend to feed primarily on plant material in or near a lake; the digestive processes alters the form of phosphorus in the food from particulate to dissolved. Waterfowl feces deposited in or near a lake may result in an elevated load of dissolved phosphorus to the lake. One recent study estimated that one Canada goose might produce 82 grams of feces per day (dry weight) while a mallard may produce 27 grams of feces per day (dry weight) (Scherer et al., 1995). Waterfowl prefer to feed and rest on areas of short grass adjacent to a lake or pond. Therefore, shoreline lawns that extend to the water's edge will attract waterfowl. The practice of feeding bread and scraps to waterfowl at the lakeshore not only adds nutrients to the lake, but attracts more waterfowl to the lake and encourages migratory waterfowl to remain at the lake longer in the fall.

Two practices often recommended to deter waterfowl are construction of vegetated buffer strips, and prohibiting the feeding of waterfowl on public shoreline property. As stated above, vegetated strips along a shoreline will discourage geese and ducks from feeding and nesting on lawns adjacent to the lake, and may decrease the waterfowl population.

6.1.3 In-Lake BMPs

In-lake BMPs reduce phosphorus already present in a lake or prevent the release of phosphorus from the lake sediments. Several in-lake BMPs are discussed below.

6.1.3.1 Removal of Benthivorous (Bottom-Feeding) Fish

Benthivorous fish, such as carp and bullhead, can have a direct influence on the phosphorus concentration in a lake (LaMarra, 1975). These fish typically feed on decaying plant and animal matter and other organic particulates found at the sediment surface. The fish digest the organic matter, and excrete soluble nutrients, thereby transforming sediment phosphorus into soluble phosphorus available for uptake by algae at the lake surface. Depending on the number of benthivorous fish present, this process can occur at rates similar to watershed phosphorus loads. Benthivorous fish can also cause resuspension of sediments in shallow ponds and lakes, causing reduced water clarity and poor aquatic plant growth, as well as high phosphorus concentrations (Cooke et al., 1993). In some cases, the water quality impairment caused by benthivorous fish can negate the positive effects of BMPs and lake restoration. Depending on the numbers of fish present, the removal of benthivorous fish may cause an immediate improvement in lake water quality. The predicted water quality improvement following removal of the bottom-feeding fish is difficult to estimate, and will require permitting and guidance from the MDNR. Therefore, it is not included as an option in this report. In addition, using fish barriers to prevent benthivorous fish from spawning may adversely affect the spawning of game fish, such as northern pike.

6.1.3.2 Application of Alum (Aluminum Sulfate)

As discussed in Section 5.4.3, there is a net internal load of phosphorus from the sediments in the main basin of Crystal Lake. Sediment release of phosphorus to the lake basins occurs during the summer months, when the oxygen in the water overlying the sediments is depleted of oxygen. This internal load of phosphorus is transported to the entire lake during late-summer, when the surface waters cool sufficiently for wind-mixing to mix the entire lake (often referred to as “fall turnover”). Phosphorus released from the sediments is typically in a dissolved form, which can be quickly utilized by algae, leading to intense algae blooms. Areal application of alum has proven to be a highly effective and long-lasting control of phosphorus release from the sediments, especially where an adequate dose has been delivered to the sediments and where watershed sediment and phosphorus loads have been minimized (Moore and Thorton, 1988). Alum will remove phosphorus from the water column as it settles and then forms a layer on the lake bottom that covers the sediments and prevents phosphorus from entering the lake as internal load. An application of alum to the lake sediments will decrease the internal phosphorus load by 80 percent (*Effectiveness and Longevity of*

Phosphorus Inactivation with Alum, Welch and Cook, 1999) and will likely be effective for approximately 10 years, depending on the control of watershed nutrient loads.

6.1.3.3 Application of Alum + Lime (Aluminum Sulfate plus Calcium Hydroxide)

A recent method to reduce aquatic macrophyte densities, which has been researched in Canada over the last 7 years, is by dosing an area with lime. The results of their research suggest that the macrophyte biomass decreased by as much as 80 percent after lime application and remained there for at least 2 years (“Effects of Single Ca(OH)₂ Doses on Phosphorus Concentration and Macrophyte Biomass of Two Boreal Eutrophic Lakes Over 2 Years.”. Reedyk *et al*, 2001). A recent study conducted by Barr Engineering (*Big Lake Protection Grant LPT-67:Big Lake Macrophyte Management Plan Implementation, Volume 1: Report*. Barr Engineering, 2001a) indicated what lime applications appear to be more effective in minimizing curlyleaf pondweed growth than herbicide treatments and that the experimental lime applications had the residual benefits the following year.

David Wright from the MDNR was contacted to ascertain what fraction of the littoral zone could be treated with alum + lime under an MDNR permit. He did not provide a clear answer to the above question but provided the following comments:

- If the purpose of the treatment were to control the growth of nuisance aquatic vegetation, then MDNR’s starting point would be the existing limit when pesticides are used (treatment is limited to 15 percent of the littoral zone). Alum-plus-lime would fall under EPA’s definition of a pesticide if it was advertised to control or limit the growth of nuisance vegetation. However, alum-plus-lime is not registered as a pesticide and the MDNR would not issue an aquatic plant management permit that allows the use of an unregistered pesticide.
- If the purpose of the treatment were to improve alum floc stability and reduce the fertility and internal loading capacity of littoral zone/shallow water sediments, then MDNR’s starting point would be the amount of area that is outlined by the existing management planning effort. The MDNR has written permits for alum-plus-lime treatments that allowed 100 percent of the littoral zone to be treated (Faille Chain of Lakes near Osakis, MN).

6.1.3.4 Application of Herbicides

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. Aquatic herbicides are among the most closely scrutinized compounds known, and must be registered for use by both the U.S. EPA and the State of Minnesota. Registration of an aquatic herbicide requires extensive testing. Consequently, all of the aquatic herbicides currently

registered for use are characterized by excellent toxicology packages, are only bio active for short periods of time, have relatively short-lived residuals, and are not bioconcentrated (*The Lake Association Leader's Aquatic Vegetation Management Guidance Manual*, Pullmann, 1992). Examples of two aquatic herbicides appropriate for use in controlling the curlyleaf pondweed growth in Crystal or Keller Lakes are Reward (active ingredient = Diquat) and Aquathol-K (active ingredient = Endothall). The use of low-level Sonar application has recently been found to selectively control exotic weed species such as Eurasian watermilfoil and curlyleaf pondweed (*Whole-Lake Applications of Sonar for Selective Control of Eurasian Watermilfoil*, Getsinger *et al*, 2001). Due to past history of Sonar applications and the limited research on the new low level applications the use of Sonar is not feasible at this time. It is also important to note that the MDNR will currently only permit 15 percent of the littoral zone of a given lake be treated with herbicides.

6.1.3.5 Application of Copper Sulfate

Copper sulfate applications can be a highly effective algaecides in some cases, but these efforts are always temporary (days) and can have high annual costs. In addition care must be taken to limit the impacts on none target organisms, such as invertebrates, and possible sediment contamination with copper. The primary effects on algae include inhibition of photosynthesis and cell division as a result of the additional cupric ion, the form of copper toxic to algae, present in the water column (Cooke *et al*, 1993). Blue-green algae are particularly sensitive to copper sulfate treatments. As a result, after a copper sulfate treatment is made the blue-green algae concentration is knocked back. However, after a few days the green algae (fast growers) take control and within a few weeks the chlorophyll *a* concentration is back to pretreatment levels (Ed Swain, MPCA). As the algae die and settle out of the water column they take with them the nutrients they used for growth. Therefore, copper sulfate application may temporarily reduce the total phosphorus concentration in a water body by removing the phosphorus that is associated with algal biomass. Once the algae settles out of the water column and starts to decompose, soluble phosphorus is released back into the water column that can be used for future algal growth. As a result, copper sulfate treatments are typically not considered a long-term solution to nutrient loading problems.

6.1.3.6 Mechanical Harvesting

Harvesting of lake macrophytes is typically used to remove plants that are interfering with uses such as boating, fishing, swimming, or aesthetic viewing. Mechanical control involves macrophyte removal via harvesting, hand pulling, hand digging, rotovation/cultivation, or diver-operated suction dredging. Small-scale harvesting may involve the use of the hand or hand-operated equipment such

as rakes, cutting blades, or motorized trimmers. Individual residents frequently clear swimming areas via small-scale harvesting or hand pulling or hand digging.

Large-scale mechanical control often uses floating, motorized harvesting machines that cut the plants and remove them from the water onto land, where they can be disposed. Mechanical harvesters consists of a barge, a reciprocating mower in front of the barge that can cut up to a depth of roughly 8 feet, and an inclined porous conveyer system to collect the cuttings and bring them to the surface. Typically a lake association or homeowner would contract a large scale harvesting operation at an estimated cost of \$450/acre.

Removal of aquatic vegetation through mechanical harvesting has been shown to not be an effective nutrient control method (Cooke et al, 1993). However, none of this research was focused on the internal phosphorus load reduction due to mechanical harvesting of curlyleaf pondweed. Blue Water Science's *2000 Orchard Lake Management Plan* suggests that there is up to 5.5 pounds of phosphorus per acre of curlyleaf pondweed. Additional research mentions that harvesting can reduce the extent of nuisance curlyleaf pondweed growth, if harvesting occurs for several years, and can reduce stem densities by up to 80 percent (McComas and Stuckert, 2000). Therefore, harvesting of curlyleaf pondweed may significantly reduce the phosphorus in the water column of a lake assuming enough biomass can be removed from the lake. This assumes that enough time and equipment would be available to harvest the curlyleaf prior to die-back in early-July.

While mechanical harvesting is more acceptable to the MDNR than chemical methods it would still require an MDNR permit and provide only temporary benefits and must be repeated annually. The MDNR regulations state that the maximum area that can be harvested is 50 percent of the littoral zone.

6.1.3.7 Hypolimnetic Withdrawal

Hypolimnetic withdrawal involves discharging the nutrient-rich waters from the hypolimnion instead of surface waters. This typically results in a reduced hypolimnetic detention time, decreased chance for anaerobic conditions to develop, and reduced phosphorus availability for epilimnetic entrainment. The withdrawal is accomplished by extending a pipe from the lakes outlet along the lake bottom to the deepest part of the lake. This pipe can act as either a siphon or water can be pumped at a predetermined rate. By discharging nutrient-rich water from the hypolimnion the internal phosphorus load available when stratification breaks down can be reduced. A Clean Water Partnership grant through the Minnesota Pollution Control Agency (MPCA) partially funded a

hypolimnetic withdrawal and phosphorus precipitation/inactivation project for Crystal and Keller Lakes and construction of the system was completed in September 1994. However the system did not become fully operational until May 1996 and operations were suspended in July 1998, due to odor complaints.

6.2 Feasibility Analysis

6.2.1 Statement of Problem

Water quality modeling simulations show that the phosphorus load to main basin of Crystal Lake and the various bays will increase as development proceeds within the watershed. As a result, the phosphorus concentration in the lake will increase as well (see Figure 5-20). Most of the stormwater runoff entering Crystal Lake is first detained in wetlands, stormwater runoff detention ponds, or Keller Lake. Therefore, water quality model simulations indicate that much of the particulate phosphorus is removed from stormwater runoff upstream of Crystal Lake (see Figure 5-18). The phosphorus that is discharged to the lake is mainly associated with small particles (with slow settling rates), or is dissolved (i.e., not associated with particles).

6.2.2 Selection and Effectiveness of Alternatives

Three types of BMPs were considered for recommendation in this plan:

1. Structural
2. Nonstructural
3. In-lake

Each of these types are defined and discussed in Section 6.1. Specific BMP alternatives that were considered for the Crystal Lake watershed are discussed below. Not all of the BMP alternatives discussed below are recommended for implementation in the Crystal Lake and Keller Lake watersheds.

6.2.2.1 Site-Specific Structural BMPs

Several site-specific structural BMPs were examined that would reduce the total phosphorus, sediment and floatable material to the lakes. Figure 6-1 shows the location of these potential sites. Estimated “budgeting” costs reflect 2002 dollars and do not include cost to acquire land or easements, obtain permits, or to mitigate wetland loss (detailed cost estimated are provided in Appendix G). The following additional structural BMPs were considered during the preparation of this report:

Figure 6-1 Potential BMPs for Crystal and Keller Lakes (3.68 MB)

6.2.2.1.1 Excavate Additional Storage Volume in Existing Ponds to Meet NURP Standards

Many of the detention basins in Burnsville and Apple Valley were constructed prior to the establishment of current MPCA (i.e., Protecting Water Quality in Urban Areas, 1989) and NURP (Nationwide Urban Runoff Program) design criteria. Current criteria of the MPCA and NURP require a minimum permanent pool or dead storage volume for each pond based upon its watershed size and land use. In addition to ponds that were designed prior to the current MPCA and NURP criteria, sedimentation over time tends to fill in the dead storage volume and reduce the pond water quality treatment effectiveness. As discussed previously, the treatment effectiveness of a pond is directly related to its dead storage volume. The annual phosphorus loading could be reduced if additional wet detention volume was created by upgrading each individual pond or by upgrading one pond to act as a regional detention basin that accounts for multiple subwatershed dead storage deficiencies.

Table 6-2 summarizes the existing dead storage volumes based on field surveys conducted in the summer of 2001 and compares the existing volume to the NURP required dead storage volume. Upgrading the ponds that do not meet MPCA/NURP criteria would result in improved treatment effectiveness and reduced phosphorus loading to Keller and Crystal Lakes. Specifically, detention basins were upgraded to have a wet detention volume from 2.5 inches of runoff over the individual subwatershed (individual pond) for which the pond is designed. It was assumed that if a downstream pond provided enough wet detention volume for its subwatershed and the amount of deficient volume for an upstream pond, no upgrading of the deficient pond was required.

Upgrading of the ponds in the Crystal and Keller Lake watersheds (see Figure 6-1 to identify upgraded ponds) to provide water quality treatment storage based on the criteria established in the National Urban Runoff Program (NURP) for full-development watershed conditions will reduce the annual phosphorus load to Crystal and Keller Lakes by 2 lbs. and 10 lbs., respectively. The 2 lbs. reduction in the Crystal Lake annual load would only reduce the modeled in-lake total phosphorus concentrations slightly (a summer average decrease of 1 µg/L total phosphorus in the main basin of Crystal Lake from 51 µg/L to 50 µg/L; see Table 6-3a). The slight reduction in Crystal Lake total phosphorus concentration would not reduce chlorophyll *a* concentrations or improve water clarity (see Tables 6-3b & c). Keller Lake would exhibit a similar 1 µg/L reduction in total phosphorus concentration and no change in chlorophyll *a* levels or water clarity (see Tables 6-4a,b, & c) even though the annual load would be reduced by about 10 lbs. This BMP scenario is estimated to have a capital cost of \$977,000, with an annual operation and maintenance cost of about \$9,800 and would have no impact of the summer average Secchi disc transparency (see Figures 6-2a and 6-2b). This results in an annualized cost of \$93,000 over a 20-year period.

Table 6-2. Crystal Lake MPCA/NURP Wet Detention Volumes (Required per MPCA/NURP)
(Full Development Watershed Land Use Conditions)

Watershed	Imp. Fraction	Perv. Fraction	Perv. Curve #	Watershed Composite CN*	Potential Abstraction	Watershed Runoff 2.5" Storm (One-year event)	Watershed Area (acres)	Required NURP Dead Storage Volume (acre-ft)	Existing Dead Storage Volume (ac-ft)	Deficient?	Volume of Deficient Dead Storage (ac-ft)	Comment
A1	0.2589	0.7	64.15	73	3.7	0.6	206.23	9.70	6.49	YES	3.2	
A12a	0.2951	0.7	63.29	74	3.6	0.6	12.38	0.61	0.04	YES	0.6	
A13a	0.384	0.6	55.79	72	3.9	0.5	194.24	8.56	6.94	YES	1.6	
A13b	0.377	0.6	61.44	75	3.3	0.7	23.69	1.30	0.36	YES	0.9	
A13b-2	0.2391	0.8	60.67	70	4.4	0.4	4.73	0.17	0.47	NO	-0.3	
A13b-3	0.2462	0.8	67.59	75	3.3	0.7	5.06	0.28	0.37	NO	-0.1	
A2	0.2348	0.8	64.78	73	3.8	0.6	108.72	4.99	3.78	YES	1.2	
A22a	0	1.0	73.33	73	3.6	0.6	2.61	0.13	3.84	NO	-3.7	
A22b	0.0801	0.9	50.43	54	8.4	0.1	15.22	0.09	48.97	NO	-48.9	
A22c	0.6518	0.3	49.05	81	2.4	0.9	107.79	8.44	0.41	YES	8.0	Buckhill Area - No Room for Ponding
A22c-1	0.6235	0.4	49.61	80	2.5	0.9	6.96	0.51	0	YES	0.5	
A23	0.3024	0.7	52.18	66	5.1	0.3	31.83	0.87	1.65	NO	-0.8	
A24a	0.18	0.8	49.02	58	7.3	0.1	38.7	0.42	2531.8	NO	-2531.4	Crystal Lake
A24b	0.2662	0.7	54.08	66	5.2	0.3	93.93	2.50	159.7	NO	-157.2	Mystic Bay
A24c	0.2646	0.7	48.66	62	6.2	0.2	18.85	0.33	13.9	NO	-13.6	Maple Island Bay
A3	0.4311	0.6	66.47	80	2.5	0.9	57.06	4.24	0.75	YES	3.5	
A35	0.2992	0.7	64.4	74	3.4	0.6	6.23	0.33	0.61	NO	-0.3	
A36	0.2352	0.8	64.72	73	3.8	0.5	5.42	0.25	0.78	NO	-0.5	
A37-38	0.2813	0.7	65.34	75	3.4	0.6	11.3	0.59	0	YES	0.6	
A39a	0.1908	0.8	65.06	71	4.0	0.5	1.49	0.06	2.7	NO	-2.6	
A39b	0.218	0.8	64.87	72	3.9	0.5	6.75	0.30	0.25	YES	0.0	Combined - No Upgrade Required
A40	0.2348	0.8	66.81	74	3.5	0.6	12.11	0.62	0.82	NO	-0.2	
A41a	0.2269	0.8	64.79	72	3.8	0.5	10.43	0.47	0.31	YES	0.2	
A41b	0.2792	0.7	64.37	74	3.6	0.6	0.89	0.04	0	YES	0.0	
A46a	0.3356	0.7	66.54	77	3.0	0.7	45.78	2.84	2.28	YES	0.6	
A46b	0.2571	0.7	64.63	73	3.7	0.6	4.07	0.20	0.27	NO	-0.1	
A46c	0.1932	0.8	65.07	71	4.0	0.5	4.32	0.18	0.06	YES	0.1	
A46d	0.3188	0.7	63.93	75	3.4	0.6	5.06	0.27	1.32	NO	-1.0	
A6a	0.267	0.7	63.43	73	3.8	0.6	98.31	4.54	2.58	YES	2.0	
A6b	0.0454	1.0	62.34	64	5.6	0.3	11.81	0.26	0.88	NO	-0.6	Combined into Single Upgrade of A6a
A6c	0.3391	0.7	65.27	76	3.1	0.7	48.12	2.85	0	YES	2.9	
A7a	0.2398	0.8	64.54	73	3.8	0.6	493.62	22.64	0	YES	22.6	No Existing Pond
A7b	0.2628	0.7	61.51	71	4.1	0.5	147.1	6.07	0	YES	6.1	No Existing Pond
A7c	0.2658	0.7	65.71	74	3.5	0.6	20.77	1.07	0.25	YES	0.8	
A8	0.1878	0.8	63.1	70	4.4	0.4	114.8	4.24	902	NO	-897.8	Lac Lavon
BBBay	0.2383	0.8	61.94	71	4.2	0.5	37.88	1.50	126.3	NO	-124.8	Bluebill Bay
BHBay	0.061	0.9	46.98	50	10.0	0.0	26.21	0.05	98.9	NO	-98.8	Buckhill Bay
CL-10	0.4799	0.5	64.69	81	2.4	0.9	93.16	7.18	0	YES	7.2	
CL-11a	0.4688	0.5	65.16	81	2.4	0.9	15.57	1.19	0	YES	1.2	
CL-12a	0.4403	0.6	61.3	77	2.9	0.8	99.92	6.34	153.3	NO	-147.0	Lee Lake
CL-12a-1	0.3892	0.6	72.13	82	2.2	1.0	15.95	1.34	1.72	NO	-0.4	
CL-13a	0.2834	0.7	64.57	74	3.5	0.6	12.93	0.66	1.48	NO	-0.8	
CL-13b	0.2801	0.7	62	72	3.9	0.5	20.74	0.92	0.63	YES	0.3	
CL-13c	0.2316	0.8	66.81	74	3.5	0.6	5.67	0.29	0.59	NO	-0.3	
CL-13d	0.2386	0.8	64.74	73	3.8	0.6	5.48	0.25	0.21	YES	0.0	Combined
CL-13e	0.3224	0.7	64.65	75	3.3	0.7	14.6	0.81	0.61	YES	0.2	
CL-13f	0.2034	0.8	65	72	3.9	0.5	5.56	0.24	6.2	NO	-6.0	
CL-15	0.2903	0.7	63	73	3.7	0.6	88.77	4.25	6.1	NO	-1.9	
CL-16	0.3999	0.6	72.65	83	2.1	1.0	33.46	2.91	7.9	NO	-5.0	
CL-18	0.2397	0.8	64.79	73	3.7	0.6	114.37	5.32	4.07	YES	1.2	
CL-19	0.2207	0.8	65.9	73	3.7	0.6	19.45	0.92	1.06	NO	-0.1	
CL-20a	0.2899	0.7	65.61	75	3.3	0.7	3.44	0.19	0.12	YES	0.1	
CL-20b	0.1303	0.9	66.21	70	4.2	0.5	3.04	0.12	1.71	NO	-1.6	
CL-20c	0.2864	0.7	68.16	77	3.0	0.7	7.3	0.44	0.04	YES	0.4	Combined - No Upgrade Required
CL-20d	0.1956	0.8	70.37	76	3.2	0.7	4.11	0.23	1.68	NO	-1.4	
CL-20e	0.19	0.8	65.63	72	3.9	0.5	0.82	0.04	0	YES	0.0	
CL-21	0.3497	0.7	60.31	73	3.6	0.6	127.27	6.23	4.39	YES	1.8	Combined into Single Upgrade of CL-21
CL-23	0.2632	0.7	59.39	70	4.4	0.4	9.45	0.35	0	YES	0.3	

Table 6-2. Crystal Lake MPCA/NURP Wet Detention Volumes (Required per MPCA/NURP)
(Full Development Watershed Land Use Conditions)

Watershed	Imp. Fraction	Perv. Fraction	Perv. Curve #	Watershed Composite CN*	Potential Abstraction	Watershed Runoff 2.5" Storm (One-year event)	Watershed Area (acres)	Required NURP Dead Storage Volume (acre-ft)	Existing Dead Storage Volume (ac-ft)	Deficient?	Volume of Deficient Dead Storage (ac-ft)	Comment
CL-25	0.0821	0.9	61.49	64	5.5	0.3	30.15	0.71	2.1	NO	-1.4	
CL-26Aa	0.3969	0.6	75	84	1.9	1.1	12.77	1.20	1.37	NO	-0.2	
CL-26Ab	0.3999	0.6	76.32	85	1.8	1.2	7.03	0.69	1.08	NO	-0.4	
CL-29a	0.3225	0.7	65.85	76	3.1	0.7	4.45	0.26	0.2	YES	0.1	Combined into Single Upgrade of CL-29a
CL-29b	0.3401	0.7	65.43	77	3.1	0.7	6.28	0.38	0.12	YES	0.3	
CL-29c	0.3	0.7	66.29	76	3.2	0.7	1.16	0.07	0.28	NO	-0.2	
CL-29d	0.3158	0.7	64.42	75	3.3	0.7	20.29	1.10	0.85	YES	0.3	
CL-2a	0.1191	0.9	48.19	54	8.5	0.1	7.77	0.05	7.84	NO	-7.8	
CL-2b	0.2557	0.7	44.74	58	7.1	0.1	9.35	0.11	1.25	NO	-1.1	
CL-2c	0.2991	0.7	55.35	68	4.7	0.4	41.17	1.34	12.2	NO	-10.9	
CL-30	0.2352	0.8	63.32	71	4.0	0.5	45.87	1.94	1.68	YES	0.3	
CL-31-2	0.164	0.8	63.48	69	4.5	0.4	13.98	0.50	0	YES	0.5	No Existing Pond
CL-31a	0.1843	0.8	63.93	70	4.2	0.5	13.65	0.53	1.84	NO	-1.3	
CL-31b	0.0582	0.9	62.53	65	5.5	0.3	12.38	0.30	2.08	NO	-1.8	
CL-31c	0.0634	0.9	62.17	64	5.5	0.3	3.02	0.07	0.66	NO	-0.6	
CL-32a	0.3304	0.7	64.79	76	3.2	0.7	27.69	1.58	1.59	NO	0.0	
CL-33a	0.2532	0.7	66.56	75	3.4	0.6	28.73	1.51	0.49	YES	1.0	
CL-33b	0.3007	0.7	65.4	75	3.3	0.7	13.18	0.72	0.58	YES	0.1	
CL-3A	0.2684	0.7	61.37	71	4.0	0.5	74.81	3.11	0	YES	3.1	
CL-3B	0.3011	0.7	57.11	69	4.4	0.4	12.91	0.47	0.07	YES	0.4	No Room for Pond
CL-4A	0.0359	1.0	57.71	59	6.9	0.2	13.37	0.17	0	YES	0.2	
CL-5a	0.2046	0.8	61.44	69	4.5	0.4	9.57	0.33	2.43	NO	-2.1	Combined with CL-7Ca & CL-7Cb
CL-7A1a	0.4364	0.6	58.87	76	3.2	0.7	25.71	1.48	4.2	NO	-2.7	
CL-7B	0.3819	0.6	62.99	76	3.1	0.7	49.17	2.91	2	YES	0.9	
CL-7Ca	0.5856	0.4	58.82	82	2.2	1.0	43.59	3.58	0.42	YES	3.2	
CL-7Cb	0.6881	0.3	48.05	82	2.1	1.0	7.26	0.62	0	YES	0.6	Combined into Single Upgrade of CL-5a
CL-8	0.2609	0.7	54.75	66	5.1	0.3	20.59	0.56	0	YES	0.6	
CL-8Aa	0.5	0.5	48.61	73	3.6	0.6	9.78	0.47	4.74	NO	-4.3	
WVR-43a	0.6471	0.4	64.64	86	1.6	1.3	67.71	7.10	4.79	YES	2.3	

Table 6-3a

**Comparison of Estimated Total Phosphorus Concentrations and Costs for Feasible Lake/Watershed Management Options for Crystal Lake : Main Basin
Assuming Existing or Full Development Watershed Land Use**

Management Option	In-Lake Water Quality Condition: Main Basin Total Phosphorus Concentration (µg/L)				Capital Cost	Annual O&M	Annualized Costs ¹
	Spring (ca. May 1)	Early-Summer Peak (ca. July 1)	Summer Average (ca.15 May - 15 Sept)	Fall Overturn (ca. Mid-Sept.)			
I. Current Watershed Land Use							
A. 1. Observed 2002 Conditions	21	59	42	68	\$0	\$0	\$0
2. Existing Conditions Model Calibration - 2002 Data	24	59	42	68	\$0	\$0	\$0
B. Source Reduction Efforts							
1. Fertilizer P Limitation - Limitation to become Effective 2004 (Assuming NURP 50 Particle Distribution)	20	57	42	67	\$0	\$0	\$0
2. Fertilizer P Limitation - Limitation to become Effective 2004 (Assuming Barten, 1997 P Concentrations)	18	53	38	60	\$0	\$0	\$0
II. Full Development Watershed Land Use							
A. No Action - No BMPs by BDWMO*	25	64	51	85	\$0	\$0	\$0
B. Source Reduction Efforts							
1. Fertilizer P Limitation - Limitation to become Effective 2004 (Assuming NURP 50 Particle Distribution)	25	63	50	83	\$0	\$0	\$0
2. Fertilizer P Limitation - Limitation to become Effective 2004 (Assuming Barten, 1997 P Concentrations)	23	59	46	77	\$0	\$0	\$0
C. Infiltration of Runoff							
1. Regional Infiltration Basins (Valley M.S.- Apple Valley, West Buckhill - Burnsville, Rolling Oaks - Lakeville)*	24	63	50	85	\$160,257	\$1,282	\$15,254
2. Apple Valley's Existing Redwood Upgrade/Expansion into Infiltration Basin*	24	64	51	84	\$105,315	\$843	\$10,024
3. Low Impact Development Retrofits (i.e., Rainwater Gardens)* Assuming 3/4 inch of Impervious Surface Runoff is Infiltrated on 1/3 of the Parcels	17	54	43	80	\$11,661,568	\$93,293	\$1,110,001
D. Runoff Detention Ponding							
1. Existing Ponds Upgraded to NURP*	25	64	51	85	\$977,008	\$7,816	\$92,996
2. Add Ponds into A7a-1 & A7b-1*	25	64	51	85	\$593,828	\$4,751	\$56,523
E. Chemical Treatment of Runoff							
1. 10 cfs Capacity Alum Treatment Plant At CL-2b*	22	57	44	78	\$1,164,874	\$60,000	\$161,559
2. 5 cfs Capacity Alum Treatment Plant At Keller Lake Outlet*	22	58	47	83	\$834,672	\$40,000	\$112,770
F. Inflow Diversion							
1. Route Keller Lake Outflows Directly to Crystal Lake Outlet*	16	53	37	61	\$982,170	\$7,857	\$93,487
G. In-Lake Chemical Treatments							
1. Summer Copper Sulfate Treatment*	25	64	49	84	\$0	\$6,138	\$6,138
2. Alum Treatment of Crystal Lake - Main Basin*	25	64	47	58	\$169,534	\$0	\$14,781
3. In-Lake Alum Treatment of Crystal Lake Main Basin and Alum + Lime Treatments of the Littoral Zone*							
a. Alum + Lime Treatments of 15% of the Littoral Zone*	25	60	47	58	\$210,570	\$0	\$18,358
b. Alum + Lime Treatments of 50% of the Littoral Zone*	25	54	44	57	\$326,253	\$0	\$28,444
c. Alum + Lime Treatments of 100% of the Littoral Zone*	25	40	39	57	\$457,293	\$0	\$39,869
4. Alum + Lime Treatment of Keller Lake's Littoral Zone*							
a. Alum + Lime Treatment of 15% of Keller Lake's Littoral Zone*	25	63	50	83	\$24,807	\$0	\$2,163
b. Alum + Lime Treatment of 50% of Keller Lake's Littoral Zone*	23	62	48	79	\$59,358	\$0	\$5,175
c. Alum + Lime Treatment of 100% of Keller Lake's Littoral Zone*	22	61	45	73	\$108,716	\$0	\$9,478
5. Operate Hypolimnetic Withdrawal / FeCl ₃ Treatment System	20	57	41	64	\$6,563	\$36,520	\$37,092
H. In-Lake Mechanical or Structural Treatments							
1. In-Lake Mechanical Harvesting to Control Curlyleaf Pondweed in Crystal Lake	25	55	47	84	\$0	\$54,600	\$54,600
2. In-Lake Mechanical Harvesting to Control Curlyleaf Pondweed in Keller Lake	25	63	50	84	\$0	\$14,359	\$14,359
3. In-Lake Mechanical Harvesting to Control Curlyleaf Pondweed in Crystal And Keller Lakes	24	54	47	84	\$0	\$68,959	\$68,959

Management Option	In-Lake Water Quality Condition: Main Basin Total Phosphorus Concentration (µg/L)				Capital Cost	Annual O&M	Annualized Costs ¹
	Spring (ca. May 1)	Early-Summer Peak (ca. July 1)	Summer Average (ca. 15 May - 15 Sept)	Fall Overturn (ca. Mid-Sept.)			
III. BMP Combinations with Full Development Watershed Land Use							
1. · Fertilizer P Limitation · In-Lake Alum Treatment of Crystal Lake Main Basin · Alum + Lime Treatments of Crystal and Keller Lakes Littoral Zones							
a. Alum + Lime Treatments of 15% of Crystal and Keller Lakes Littoral Zones	25	59	46	56	\$235,377	\$0	\$20,521
b. Alum + Lime Treatments of 50% of Crystal and Keller Lakes Littoral Zones	23	53	41	51	\$385,612	\$0	\$33,619
c. Alum + Lime Treatments of 100% of Crystal and Keller Lakes Littoral Zones	21	37	33	45	\$566,010	\$0	\$49,347
2. · Fertilizer P Limitation · Upgrade Existing Ponds to NURP · Add Ponds A7a-1 & A7b-1	22	58	46	76	\$1,570,835	\$12,567	\$149,519
3. · Management Option III.2 plus · Restore Wetland between Lac Lavon Drive and Crystal Lake Road East	22	58	45	76	\$1,765,916	\$14,127	\$168,088
4. · Management Option III.2 plus · Upgrade Redwood Pond · Add Regional Infiltration Basins	21	57	45	75	\$1,836,407	\$14,691	\$174,798
5. · Management Option III.4 plus · LID Retrofits over 1/3 of Watershed to Infiltrate 3/4 Inch of Impervious Area Surface Runoff	14	47	36	70	\$13,497,976	\$107,984	\$1,284,799
6. · Management Option III.4 plus · Mechanical Harvesting of Curlyleaf Pondweed in Crystal Lake	21	48	41	74	\$1,836,407	\$69,291	\$229,398
7. · Management Option III.6 plus · Mechanical Harvesting of Curlyleaf Pondweed in Keller Lake	21	47	40	74	\$1,836,407	\$83,650	\$243,756
8. · Management Option III.7 plus · In-Lake Alum Treatment of Crystal Lake Main Basin · In-Lake Alum Treatment of Keller Lake	18	46	33	36	\$2,062,863	\$84,105	\$263,955
9. · Management Option III.8 plus · Alum + Lime Treatments of Crystal and Keller Lakes Littoral Zones							
a. Alum+Lime Application to 15% of Littoral Zone	21	52	39	46	\$2,071,784	\$83,650	\$264,278
b. Alum+Lime Application to 50% of Littoral Zone	19	46	35	42	\$2,222,019	\$83,650	\$277,376
c. Alum+Lime Application to 100% of Littoral Zone	18	30	27	36	\$2,402,417	\$83,650	\$293,104
10. · Management Option III.7 (without Pond A7b-1) plus · Resume Operation of Hypolimnetic FeCl ₃ Treatment System	16	40	30	53	\$1,711,142	\$119,115	\$268,301
11. · Management Option III.10 plus · In-Lake Alum Treatment of Crystal Lake Main Basin	16	40	28	26	\$1,880,677	\$119,115	\$283,081
12. · Management Option III.11 plus · Construct a 10 cfs Alum Treatment Plant at CL-2b	13	34	21	21	\$3,045,551	\$179,115	\$444,640
13. · Management Option III.12 plus · Construct a 5 cfs Alum Treatment Plant at Keller Lake Outlet	11	32	19	19	\$3,880,223	\$219,115	\$557,411
14. · Fertilizer P Limitation · Upgrade Select Existing Ponds to NURP (Ponds A1, WVR-43a, A46a, A6a, A7c, & CL-21) · Add Ponds A7a-1 · Upgrade Redwood Pond · Add Regional Infiltration Basins (Valley M.S. and Buckhill West Park) · Mechanical Harvesting of Curlyleaf Pondweed in Crystal Lake · Mechanical Harvesting of Curlyleaf Pondweed in Keller Lake · Resume Operation of Hypolimnetic FeCl ₃ Treatment System	16	41	30	54	\$860,203	\$112,360	\$187,357

*Does not include fertilizer P limitation.

¹ Assumes 20 years with a 6.0% interest rate.

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

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

[TP] = measured or estimated epilimnetic (mixed surface layer) summer average total phosphorus concentration (µg/L)

[Chl] = estimated epilimnetic (mixed surface layer) summer average chlorophyll *a* concentration (µg/L)

SD = estimated summer average Secchi disc transparency (m)

Table 6-3b

Comparison of Estimated Chlorophyll a Concentrations and Costs for Feasible Lake/Watershed Management Options for Crystal Lake : Main Basin
Assuming Existing or Full Development Watershed Land Use

Management Option	In-Lake Water Quality Condition: Main Basin Chlorophyll a Concentration (µg/L)				Capital Cost	Annual C&M	Annualized Costs ¹
	Spring (ca. May 1)	Early-Summer Peak (ca. July 1)	Summer Average (ca. 15 May - 15 Sept)	Fall Overturn (ca. Mid-Sept.)			
I. Current Watershed Land Use							
A. 1. Observed 2002 Conditions	5	24	15	30	\$0	\$0	\$0
2. Existing Conditions Model Calibration - 2002 Data	7	24	15	30	\$0	\$0	\$0
B. Source Reduction Efforts							
1. Fertilizer P Limitation - Limitation to become Effective 2004 (Assuming NURP 50 Particle Distribution)	5	23	15	29	\$0	\$0	\$0
2. Fertilizer P Limitation - Limitation to become Effective 2004 (Assuming Barten, 1997 P Concentrations)	4	21	13	25	\$0	\$0	\$0
II. Full Development Watershed Land Use							
A. No Action - No BMPs by BDWMO*	7	28	20	41	\$0	\$0	\$0
B. Source Reduction Efforts							
1. Fertilizer P Limitation - Limitation to become Effective 2004 (Assuming NURP 50 Particle Distribution)	7	27	19	40	\$0	\$0	\$0
2. Fertilizer P Limitation - Limitation to become Effective 2004 (Assuming Barten, 1997 P Concentrations)	6	24	17	36	\$0	\$0	\$0
C. Infiltration of Runoff							
1. Regional Infiltration Basins (Valley M.S.- Apple Valley, West Buckhill - Burnsville, Rolling Oaks - Lakeville)*	7	27	19	41	\$160,257	\$1,282	\$15,254
2. Apple Valley's Existing Redwood Upgrade/Expansion into Infiltration Basin*	7	27	20	41	\$105,315	\$843	\$10,024
3. Low Impact Development Retrofits (i.e., Rainwater Gardens)* Assuming 3/4 inch of Impervious Surface Runoff is Infiltrated on 1/3 of the Parcels	4	22	15	38	\$11,661,568	\$93,293	\$1,110,001
D. Runoff Detention Ponding							
1. Existing Ponds Upgraded to NURP*	7	28	20	41	\$977,008	\$7,816	\$92,996
2. Add Ponds into A7a-1 & A7b-1*	7	27	20	41	\$593,828	\$4,751	\$56,523
E. Chemical Treatment of Runoff							
1. 10 cfs Capacity Alum Treatment Plant At CL-2b*	6	23	16	37	\$1,164,874	\$60,000	\$161,559
2. 5 cfs Capacity Alum Treatment Plant At Keller Lake Outlet*	6	24	18	40	\$834,672	\$40,000	\$112,770
F. Inflow Diversion							
1. Route Keller Lake Outflows Directly to Crystal Lake Outlet*	4	21	13	26	\$982,170	\$7,857	\$93,487
G. In-Lake Chemical Treatments							
1. Summer Copper Sulfate Treatment*	7	27	18	41	\$0	\$6,138	\$6,138
2. Alum Treatment of Crystal Lake - Main Basin*	7	27	17	24	\$169,534	\$0	\$14,781
3. In-Lake Alum Treatment of Crystal Lake Main Basin and Alum + Lime Treatments of the Littoral Zone*							
a. Alum + Lime Treatments of 15% of the Littoral Zone*	7	25	18	24	\$210,570	\$0	\$18,358
b. Alum + Lime Treatments of 50% of the Littoral Zone*	7	21	16	23	\$326,253	\$0	\$28,444
c. Alum + Lime Treatments of 100% of the Littoral Zone*	7	14	14	23	\$457,293	\$0	\$39,869
4. Alum + Lime Treatment of Keller Lake's Littoral Zone*							
a. Alum + Lime Treatment of 15% of Keller Lake's Littoral Zone*	7	27	19	40	\$24,807	\$0	\$2,163
b. Alum + Lime Treatment of 50% of Keller Lake's Littoral Zone*	6	27	18	37	\$59,358	\$0	\$5,175
c. Alum + Lime Treatment of 100% of Keller Lake's Littoral Zone*	6	26	17	33	\$108,716	\$0	\$9,478
5. Operate Hypolimnetic Withdrawal / FeCl ₃ Treatment System	5	23	14	27	\$6,563	\$36,520	\$37,092
H. In-Lake Mechanical or Structural Treatments							
1. In-Lake Mechanical Harvesting to Control Curlyleaf Pondweed in Crystal Lake	7	22	18	41	\$0	\$54,600	\$54,600
2. In-Lake Mechanical Harvesting to Control Curlyleaf Pondweed in Keller Lake	7	27	19	41	\$0	\$14,359	\$14,359
3. In-Lake Mechanical Harvesting to Control Curlyleaf Pondweed in Crystal And Keller Lakes	7	21	17	40	\$0	\$68,959	\$68,959

Management Option	In-Lake Water Quality Condition: Main Basin Chlorophyll a Concentration (µg/L)				Capital Cost	Annual C&M	Annualized Costs ¹
	Spring (ca. May 1)	Early-Summer Peak (ca. July 1)	Summer Average (ca. 15 May - 15 Sept)	Fall Overturb (ca. Mid-Sept.)			
III. BMP Combinations with Full Development Watershed Land Use							
1. - Fertilizer P Limitation							
- In-Lake Alum Treatment of Crystal Lake Main Basin							
- Alum + Lime Treatments of Crystal and Keller Lakes Littoral Zones							
a. Alum + Lime Treatments of 15% of Crystal and Keller Lakes Littoral Zones	7	25	17	23	\$235,377	\$0	\$20,521
b. Alum + Lime Treatments of 50% of Crystal and Keller Lakes Littoral Zones	6	21	15	20	\$385,612	\$0	\$33,619
c. Alum + Lime Treatments of 100% of Crystal and Keller Lakes Littoral Zones	5	12	11	16	\$566,010	\$0	\$49,347
2. - Fertilizer P Limitation	6	24	17	35	\$1,570,835	\$12,567	\$149,519
- Upgrade Existing Ponds to NURP							
- Add Ponds A7a-1 & A7b-1							
3. - Management Option III.2 plus	6	24	17	35	\$1,765,916	\$14,127	\$168,088
- Restore Wetland between Lac Lavon Drive and Crystal Lake Road East							
4. - Management Option III.2 plus	5	23	16	35	\$1,836,407	\$14,691	\$174,798
- Upgrade Redwood Pond							
- Add Regional Infiltration Basins							
5. - Management Option III.4 plus	3	18	12	31	\$13,497,976	\$107,984	\$1,284,799
- LID Retrofits over 1/3 of Watershed to Infiltrate 3/4 Inch of Impervious Area Surface Runoff							
6. - Management Option III.4 plus	5	18	14	34	\$1,836,407	\$69,291	\$229,398
- Mechanical Harvesting of Curlyleaf Pondweed in Crystal Lake							
7. - Management Option III.6 plus	5	17	14	34	\$1,836,407	\$83,650	\$243,756
- Mechanical Harvesting of Curlyleaf Pondweed in Keller Lake							
8. - Management Option III.7 plus	4	17	11	12	\$2,062,863	\$84,105	\$263,955
- In-Lake Alum Treatment of Crystal Lake Main Basin							
- In-Lake Alum Treatment of Keller Lake							
9. - Management Option III.8 plus							
- Alum + Lime Treatments of Crystal and Keller Lakes Littoral Zones							
a. Alum+Lime Application to 15% of Littoral Zone	5	20	14	17	\$2,071,784	\$83,650	\$264,278
b. Alum+Lime Application to 50% of Littoral Zone	5	17	11	15	\$2,222,019	\$83,650	\$277,376
c. Alum+Lime Application to 100% of Littoral Zone	4	9	8	12	\$2,402,417	\$83,650	\$293,104
10. - Management Option III.7 (without Pond A7b-1) plus	4	14	9	21	\$1,711,142	\$119,115	\$268,301
- Resume Operation of Hypolimnetic FeCl ₃ Treatment System							
11. - Management Option III.10 plus	4	14	8	8	\$1,880,677	\$119,115	\$283,081
- In-Lake Alum Treatment of Crystal Lake Main Basin							
12. - Management Option III.11 plus	3	11	6	5	\$3,045,551	\$179,115	\$444,640
- Construct a 10 cfs Alum Treatment Plant at CL-2b							
13. - Management Option III.12 plus	2	10	5	5	\$3,880,223	\$219,115	\$557,411
- Construct a 5 cfs Alum Treatment Plant at Keller Lake Outlet							
14. - Fertilizer P Limitation	4	14	9	21	\$860,203	\$112,360	\$187,357
- Upgrade Select Existing Ponds to NURP (Ponds A1, WVR-43a, A46a, A6a, A7c, & CL-21)							
- Add Ponds A7a-1							
- Upgrade Redwood Pond							
- Add Regional Infiltration Basins (Valley M.S. and Buckhill West Park)							
- Mechanical Harvesting of Curlyleaf Pondweed in Crystal Lake							
- Mechanical Harvesting of Curlyleaf Pondweed in Keller Lake							
- Resume Operation of Hypolimnetic FeCl ₃ Treatment System							

*Does not include fertilizer P limitation.

¹ Assumes 20 years with a 6.0% interest rate.

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

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

[TP] = measured or estimated epilimnetic (mixed surface layer) summer average total phosphorus concentration (µg/L)

[Chl] = estimated epilimnetic (mixed surface layer) summer average chlorophyll concentration (µg/L)

SD = estimated summer average Secchi disc transparency (m)

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**Table 6-3c Comparison of Estimated Total Phosphorus Concentrations for Feasible
Lake/Watershed Management Options for Crystal Lake: Main Basin Assuming
Existing or Full Development Watershed Land Use**

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Table 6-3c

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**Table 6-4a Comparison of Estimated Total Phosphorus Concentrations for Feasible
Lake/Watershed Management Options for Keller Lake Assuming Existing or Full
Development Watershed Land Use**

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Table 6-4a

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**Table 6-4b Comparison of Estimated Chlorophyll a Concentrations for Feasible
Lake/Watershed Management Options for Keller Lake Assuming Existing or Full
Development Watershed Land Use**

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Figure 6-4b

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**Table 6-4c Comparison of Estimated Total Phosphorus Concentrations for Feasible
Lake/Watershed Management Options for Keller Lake Assuming Existing or Full
Development Watershed Land Use**

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Table 6-4c

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Figure 6-2a Crystal Lake Secchi Disc Transparency and Estimated Costs for the Various BMP Management Options—Modeled Full Development Compared to Existing Conditions

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Figure 6-2b Keller Lake Secchi Disc Transparency and Estimated Costs for the Various BMP Management Options—Modeled Full Development Compared to Existing Conditions

6.2.2.1.2 Construct Water Quality Treatment Ponds A7a-1 and A7b-1

Figure 5-14 illustrates that a significant portion (about 28 percent) of the annual external total phosphorus load to Crystal Lake is from Keller Lake (based on observed in-lake total phosphorus concentration in Keller Lake). Therefore, the impacts of watershed BMPs tributary to Keller Lake were simulated to identify the “hot spots” tributary to Keller Lake and assess the impacts of BMPs on improving Keller Lake water quality and thus reducing the phosphorus loading to Crystal Lake. Reducing the phosphorus loading from Keller Lake would have a direct impact on the main basin of Crystal Lake, and would likely be noticeable in terms of reduced algal bloom frequencies at Crystal Lake Beach.

Runoff from a large portion (roughly 641 acres) of the areas tributary to Keller Lake enters the lake with little or no water quality treatment. Therefore, two regional water quality treatment ponds, designed to MPCA and NURP criteria, were simulated to treat a portion of the untreated tributary area (runoff from 69 percent of the untreated areas were routed to the two proposed ponds). One pond (Pond A7b-1) would be located in the open space north of the Crystal Beach Park parking lot to intercept the trunk storm sewer under Crystal Lake Road (See Figure 6-1). This pond would be designed to have 4.8 acre-feet of dead storage, an average depth of 5 feet, and a surface area of roughly 1 acre. The other proposed pond (Pond A7a-1) would be located in Lac Lavon Park at the southeast corner of Keller Lake. This 15.7-acre-foot water quality pond, which could be designed to have an average depth of 5 feet and a surface area of about 3.1 acres, would treat runoff currently being conveyed to the lake through the 60-inch storm sewer under Whitney Drive.

Model simulation indicates that the construction of these two ponds would reduce the annual watershed total phosphorus load by 78 lbs. and, therefore, the Keller Lake spring total phosphorus concentration by an estimated 13 µg/L (from 59 to 46 µg/L). Due to the continued watershed load and large internal phosphorus load from curlyleaf pondweed and anoxic sediment release the two regional ponds would have an insignificant impact on Keller Lake early-summer peak, summer average, and fall overturn phosphorus concentration (see Table 6-4a) or on the total phosphorus load to Crystal Lake (only a 6 lb. total phosphorus load reduction was predicted). As a result, the proposed pond would not significantly impact Crystal Lake water quality (see Tables 6-3a, b, & c). However, these basins would reduce the external nutrient loading to Keller Lake and help increase the longevity of annual in-lake treatment. The estimated construction cost for the two water quality treatment ponds is \$594,000, with an annual operations and maintenance cost of \$4,800. This results

in an annualized cost of \$57,000 to cover the capital project cost and future excavation and facility maintenance.

6.2.2.1.3 Route Keller Lake Outflows Directly to Crystal Lake Outlet

Another option to limit the impacts of Keller Lake water on Crystal Lake would be to route the Keller Lake outflows around Crystal Lake. One method would be to submarine a large polyethylene pipe in Crystal Lake from Keller Lake directly to the Crystal Lake outlet structure. Keller Lake water quality would remain unchanged under this scenario. This would significantly reduce both the annual water and total phosphorus load to Crystal Lake (annual reductions of about 753 acre-feet and 223 lbs., assuming 2002 climatic conditions). As a result the Crystal Lake spring total phosphorus concentration would be reduced by 10 µg/L while the summer average total phosphorus concentration would be reduced by 15 µg/L. While the total phosphorus concentration reductions are significant only the summer average in-lake total phosphorus concentration, 37 µg/L, would achieve BDWMO's total phosphorus goal. The estimated capital cost of this BMP scenario is \$982,000, with an annual operation and maintenance cost of about \$7,900. The resulting annualized cost is about \$93,000.

One disadvantage of this option is that routing the water around Crystal Lake could simply be pushing the phosphorus load downstream to the next water body (Twin Lakes). This could severely impact the water quality of Twin Lakes. In addition to the water quality concerns, there are water quantity or storm sewer capacity concerns. The existing system downstream of Crystal Lake may not have enough capacity to handle the added flows from Keller Lake. Due to these disadvantages this BMP option is not recommended.

6.2.2.1.4 Construct a Stormwater Alum Treatment Plant at CL-2b (Design Flow 10 cfs)

Another significant source of phosphorus enters Mystic Bay from storm sewers conveying runoff from subwatershed CL-2a and upstream areas. Due to the Lakeville's stringent policy regarding wetland preservation, most of the stormwater entering the Mystic Bay is first detained in either upstream wetlands or stormwater detention ponds. As a result, water quality modeling simulations indicate that the phosphorus load entering the lake at this point (roughly 22 percent of the annual loading to Crystal Lake for full-development conditions; see Figure 5-14) is primarily associated with small particles (with slow settling rates), or is not associated with particles (i.e., soluble phosphorus) as illustrated by Figure 5-18 (roughly 80 percent of the phosphorus entering the lake at

this location is in the dissolved form). Therefore additional ponds to promote settling will have little, if any impact on reducing the annual loading to Mystic Bay and thus the main basin of Crystal Lake.

In addition to the commonly installed structural BMPs (water quality treatment basins), runoff alum treatment plants are a new option for efficiently removing phosphorus from tributaries, rather than directly treating the lake with alum to remove phosphorus. Alum (aluminum sulfate) is commonly used as a flocculent in water treatment plants and as an in-lake treatment for phosphorus removal. A possible alternative to increase phosphorus removal from CL-2a is the construction of an in-line alum treatment plant at the outlet from subwatershed CL-2b. Such a plant would divert and treat a set fraction of the total runoff flow (e.g., 10 cfs). Alum would be injected into the diverted flow, which would then be discharged into a settling basin (e.g., the existing pond in subwatershed CL-2a could potentially be used for this purpose). Alum floc would form and settle within the basin. Both soluble and particulate phosphorus would adsorb onto the floc as it settled, and would, therefore, be removed from the runoff. Effluent from the settling pond would effectively be free of phosphorus.

Construction of an alum treatment plant designed to treat 10 cfs of runoff would cost approximately \$1,165,000 to construct, and an additional \$60,000 per year to operate and maintain (based on experience at the Tanners Lake alum treatment facility in the Ramsey-Washington Watershed District). This result in an annualized cost of \$162,000 to cover the capital cost and annual cost associated with future excavation and facility maintenance. Treating 10 cfs would result in treating 75 percent of the flows (see Figure 6-3) entering the lake through subwatershed CL-2a. As a result the phosphorus load entering the lake through subwatershed CL-2a would be reduced to 63 lbs., assuming 80 percent of the phosphorus would be removed via alum treatment. Modeling results indicate this BMP scenario would significantly reduce the summer average in-lake phosphorus concentration in Mystic Bay from 66 µg/L for full-development to 29 µg/L (see Table F-1a in Appendix F). In addition to providing a drastic improvement in the Mystic Bay water quality, the alum treatment plant would also reduce the summer average total phosphorus concentration in the main basin of Crystal Lake to 44 µg/L. This total phosphorus concentration would likely result in a Secchi disc transparency of about 1.5 meters which is slightly below the goal specified in the *BDWMO Water Management Plan* (see Figure 6-2).

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**Figure 6-3 Pond CL-2b Outflows—Percent of Annual Flows Treated as a Function of Alum
Treatment Plant Design Flow Rate**

6.2.2.1.5 Stormwater Alum Treatment Plant at Keller Lake Outlet (Design Flow 5 cfs)

Another alum treatment facility was modeled to treat the outflows from Keller Lake. If a 5 cfs capacity treatment facility was constructed at the Keller Lake outfall, only 24 percent of the outflows (see Figure 6-4) from Keller Lake would receive treatment. In order to treat greater than 75 percent of the flows the facility would have a capacity of about 55 cfs, thus significantly increase the cost. In addition, this treatment facility would be difficult to construct and operate due to the low hydraulic head difference between Crystal and Keller Lakes and provide no substantial benefit to Keller Lake or the bays of Crystal Lake.

Because the majority of flows would bypass the 5 cfs facility, this alum treatment plant would not have a significant impact on the early-summer peak or fall overturn Crystal Lake total phosphorus concentrations. However, it would reduce the summer average concentration to 47 µg/L (a 4 µg/L reduction for full-development conditions). This total phosphorus concentration is estimated to result in a Secchi disc transparency of 1.5 meters which is below the BDWMO's goal. Construction of an alum treatment plant designed to treat 5 cfs of runoff would cost approximately \$835,000 to construct, and an additional \$40,000 per year to operate (based on experience at the Tanners Lake alum treatment facility in the Ramsey-Washington Watershed District). The resulting 20-year annualized cost for this management option would be approximately \$113,000.

6.2.2.1.6 Restore Wetland between Crystal and Keller Lakes (South of Crystal Beach)

The restoration of the wetland between Lac Lavon Drive and Crystal Lake Road East was analyzed in connection to BMP combination Management Option III.3 because only treated runoff could be directed to the wetland to restore the system's hydrology. Review of historical topography indicates that the wetland was likely connected directly to Keller Lake and, if the water levels fluctuated in Keller Lake, it would impact the hydrology of the wetland prior to overflowing into Crystal Lake. Assuming the conditions that currently exist at the west end of Keller Lake represent natural conditions, the area to be restored was likely a cattail wetland. Simply connecting the area to Keller Lake may not result the system's hydrology because of the Keller Lake outlet structure. Therefore, it was assumed that an 18-inch pipe would convey flows from the proposed pond A7a-1 to the wetland area. The water would be allowed to leave the wetland area through two 12-inch pipes connecting the wetland to Keller Lake. Restoration of this wetland complex would require a detailed wetland assessment and a hydrologic and hydraulic analysis to make certain that the existing homes to the west of the wetland would not be impacted.

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Figure 6-4 Keller Lake Outflows—Percent of Annual Flows Treated as a Function of Alum Treatment Plant Design Flow Rate

Comparing BMP combinations Management Options III.2 and III.3 results in the assessment of the impacts the restored wetland would have on water quality in Crystal and Keller Lakes. As shown in Tables 6-3a, 6-3b, 6-3c, and 6-4a 6-4b, and g-4c, there would be no impact on Crystal Lake water quality (total phosphorus concentration, chlorophyll *a* concentration, or Secchi disc transparency) and only a slight reduction in summer average total phosphorus concentration in Keller Lake (1 µg/L). Restoring this wetland complex was estimated to have a capital cost of \$195,100 (see Table G-24 in Appendix G).

6.2.2.1.7 Upgrade Existing Pond in Redwood Park, Apple Valley into an Infiltration Basin

After a through review of the cities' storm sewer systems in relation to public open space areas and soil survey data, four locations appear to be possible locations to promote regional infiltration (two in Apple Valley, one in Burnsville, and one in Lakeville). The first location is in Redwood Park. Discussions with City of Apple Valley staff indicate that the existing pond could potentially be excavated down to granular material, thus increasing the basins infiltration capacity. The analysis of this BMP assumed that the existing Redwood Pond (Pond A1) would be excavated to meet NURP criteria and in doing so the infiltration rate for water levels below the normal pool would be increased to 0.12 in/hr (half the rate for hydrologic soil group B due to potential excavation limitations and future bottom siltation).

Implementation of this BMP option would reduce the annual external phosphorus load to Keller Lake by 27 lbs. due to infiltration. The reduced phosphorus load impact on Keller Lake water quality is partially offset by a water load reduction to the lake of 81 acre-feet. As a result, the spring and summer average in-lake total phosphorus concentrations are only reduced by 1 µg/L and there is no impact on chlorophyll *a* concentrations and Secchi disc transparency (see Tables 6-4a, 6-4b, and 6-4c).

While the in-lake total phosphorus concentrations in Keller Lake are not predicted to change significantly, the reduced water loading to the lake results in less runoff and phosphorus being discharged to Crystal Lake. The phosphorus load to Crystal Lake is predicted to decrease by about 24 lbs. annually. As a result there would be only a slight reduction (1 µg/L) in spring and fall overturn total phosphorus concentration in Crystal Lake (see Table 6-3a). Table 6-3a also shows that the estimated capital cost for this option is \$105,000, with an annual operation and maintenance cost of \$843. This results in an annualized cost of roughly \$10,000 to cover the capital cost and the annual cost associated with future excavation and maintenance of the facilities.

6.2.2.1.8 Construction of Regional Infiltration Basins (Valley Middle School - Apple Valley, West Buckhill Park - Burnsville, Rolling Oaks Park- Lakeville)

Other locations that were identified to promote infiltration are north of Valley Middle School in Apple Valley (A7a-2), within West Buckhill Park in Burnsville (A13a-1), and within Rolling Oaks Park (CL-3A-1 & CL-4A) in Lakeville. Surface runoff tributary to the intersection of Gardenview and Baldwin Drives would be directed to a grit chamber (e.g., a StormCeptor) prior to entering proposed infiltration basin A7a-2. The storm sewer under 187th Street West was assumed to be redirected to the infiltration basin located in Rolling Oaks Park. This infiltration basin would also receive runoff from the entire park area. Stormwater flows in the existing 27-inch storm sewer were redirected to the surface and convey via overland flow to the proposed infiltration basin in Buckhill Park. Figure 6-1 illustrates the areas tributary to the proposed infiltration basins. The individual basins were each sized to infiltrate 1 inch of runoff in 72 hours from the impervious areas within the respective watershed. As a result, infiltration basins A7a-2, A13a-1, and CL-4A were modeled with storage volumes of 0.50 acre-feet, 0.42 acre-feet, and 0.51 acre-feet, respectively and a maximum depth of 17 inches (assuming an infiltration rate of 0.23 in/hr for hydrologic soil group B).

Model simulations with all three of the proposed infiltration basin in place indicate that the phosphorus loads to Crystal Lake would be reduced by 34 lbs. while the load to Keller Lake would be reduced by 4 lbs. In addition to reducing the phosphorus loads to the lakes the infiltration basins would also reduce the water loads by 107 acre-feet for Crystal Lake and 8 acre-feet for Keller Lake. The reduction in phosphorus loading to the lakes is essentially offset by the reduction in the water loading and thus the reduction in flushing through the lakes. Therefore, the summer average total phosphorus concentration in Crystal Lake is only predicted to decline by 1 µg/L while Keller Lake's summer average concentration is not estimated to change. The estimated capital cost for this option is \$160,000, with an annual operation and maintenance cost of \$1,282. This results in an annualized cost of roughly \$15,300 to cover the capital cost and the annual cost associated with future excavation and maintenance of the facilities.

6.2.2.1.9 Retrofit Watershed with Rainwater Gardens to Promote Infiltration

Retrofitting the entire Crystal Lake watershed with rainwater gardens (at an estimated \$10 per square foot) would be extremely expensive and difficult because the majority of the watershed is nearing full-development conditions. However, several model simulations were performed to assess the impacts on in-lake water quality assuming various amounts of runoff from the impervious areas were infiltrated. The results of the analysis are summarized in Figure 6-5. This figure illustrates the relationship between in-lake total phosphorus and infiltration storage volume throughout the watershed. Based on the analysis results it is clear that the greater the impervious area infiltration volume, the greater the impact on in-lake phosphorus concentrations. Prior studies conducted by Barr Engineering determined that optimal infiltration volume was equivalent to 3/4-inch from impervious surfaces. If only one-third of the watershed could be retrofit with rainwater gardens (assuming twice as many people decline as accept the opportunity) the Crystal and Keller Lake total phosphorus loads would be reduced by 215 lbs. and 179 lbs. annually and result in summer average total phosphorus concentrations of 43 µg/L and 123 µg/L, respectively (see Tables 6-3a and 6-4a). This is a significant improvement for Crystal Lake and only a minor improvement for Keller Lake. There would be no noticeable improvement in Keller Lake's water clarity while Crystal Lake's water clarity was estimated to improve by about 0.2 meters (from 1.3 to 1.5 meters). The estimated capital cost to retrofit one-third of the entire Crystal Lake watershed with rainwater gardens is \$11,662,000, with an annual operation and maintenance cost of \$93,293. This results in an annualized cost of roughly \$1,110,000 to cover the capital cost and the annual cost associated with future excavation and maintenance of the facilities.

6.2.2.1.10 Replace Culvert between Mystic and Maple Island Bays

Neighborhood residents have expressed concerns about the existing 36-inch RCP culvert under Maple Island Road. Their main issue is that this culvert, which connects Maple Island and Mystic Bays and was roughly 75 percent full of sediment in 2002, does not have enough capacity to allow mixing between the two bays. Given the topography surrounding Maple Island Bay, its watershed characteristics, its small size, and connection to the main lake, it appears that very little water could be flushed from Maple Island Bay into Mystic Bay. One could speculate that given the higher phosphorus concentrations in Maple Island Bay and the resulting concentration gradient between the two bays, phosphorus would generally tend to move into Mystic Bay (i.e., down gradient). Therefore no detailed modeling of potential culvert improvements was completed as part of this study.

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Figure 6-5 Predicted Summer Average Total Phosphorus Concentrations for Various Amounts of Impervious Area Runoff Infiltration Volumes

6.2.2.2 In-Lake Treatments

6.2.2.2.1 Application of Copper Sulfate to Crystal Lake

The first in-lake treatment method investigated was a mid-summer application of copper sulfate. Historically a copper sulfate treatment was made to Crystal Lake in 1999, 2000, and 2002. Observed water quality data indicated that immediately following the treatments both the total phosphorus and chlorophyll *a* concentrations decreased while the Secchi disc transparency increased. The impacts of copper sulfate are generally short lived and cause a shift in the algae present in the water column from blue-green algae to green algae. While possibly temporarily improving water clarity, model simulations indicate that a copper sulfate application would not significantly impact in-lake total phosphorus concentrations in Crystal Lake (see Table 6-3a) and have no impact on Keller Lake water quality. If the dose rate were similar to the rate used in 2002, a copper sulfate treatment to the entire Crystal Lake water surface area would cost roughly \$6,200 annually.

6.2.2.2.2 Application of Alum to the Main Basin of Crystal Lake

In-lake application of alum (aluminum sulfate) to prevent sediment phosphorus release in the main lake basin during the summer and fall months is another BMP scenario analyzed. 2002 monitoring data and water quality modeling simulations indicate that sediment-released phosphorus severely affects the late-summer water quality in Crystal Lake's main basin, Maple Island Bay, and Buckhill Bay. During late-fall it was estimated that sediment-released phosphorus accounts for up to 34 µg/L. Modeling simulations indicate that following an alum treatment of the main basin of Crystal Lake, the total phosphorus concentrations for summer (average) and fall overturn will be reduced from 51 µg/L and 85 µg/L (respectively) to 47 µg/L and 58 µg/L (respectively), for full-development conditions (see Table 6-3a). This assumes that application of alum to the lake sediments will decrease the internal phosphorus load by 80 percent and be effective for up to 10 years (*Effectiveness and Longevity of Phosphorus Inactivation with Alum*, Welch and Cook, 1999). Approximate capital cost of an in-lake alum application in the main Crystal Lake basin is \$170,000 and would improve Crystal Lake's summer average Secchi disc transparency to 1.4 meters. To maximize the longevity of the alum treatment, application should be made to the lake sediments after the external phosphorus loadings from watershed runoff are reduced through construction of structural BMPs.

Based on correspondence with Ken Wagner, a researcher on boat traffic impacts on lake mixing, boat traffic would have the following impacts.

- Boats in freshwater (typically <200 hp) will not stir below 15 feet, 100 hp engines reach about 10 feet, 10 hp engines reach about 5 feet; engine type, angle, prop size, and hull configuration all make a difference, but these are reasonable estimates.
- Alum will react with phosphorus and not let it resolubilize, despite changes in pH, oxygen, or resuspension. The issue with resuspension is exposure of new, non-treated sediment to the water column for later release of phosphorus.
- Wind is more likely to cause issue in shallow water than boats, given impact over a larger area, but the wind can't be controlled. In shallow water with adequate oxygen, phosphorus release is likely to be low (<2 mg/m²/day) and rapid precipitation back to the sediment is likely if there is adequate iron. In deeper water with low or no oxygen, release rates up to 20 mg/m²/day are possible. It may not even be necessary to treat the shallower waters, and may not be very effective if there is a lot of wind.

A fall application or a no wake zone of 200 feet (or whatever is needed to give 10 feet depth) from shore for a minimum of 1 year would allow the floc to stabilize in the top layer of sediment, where the effect would be minimized.

6.2.2.2.3 Application of Alum to Crystal Lake and Alum + Lime Application to the Various Percentages of the Lake's Littoral Zone

Correspondence with David Wright, MDNR, failed to establish the fraction of the littoral zone that could be treated with alum + lime. Based on these correspondences the treatable area could range from 0-100 percent of the littoral zone (see Section 6.1.3.3). The permissible treatment area would depend on the underlying purpose of the treatment, whether it is for macrophyte control or floc stability and reduced sediment phosphorus release. Therefore, three different management options involving alum + lime application to various percentages of Crystal Lake's littoral zone were investigated. The various percentages selected were 15 percent (the maximum area permitted to be treated with herbicides), 50 percent (the maximum area permitted to be mechanically harvested), and 100 percent (the maximum area that has been permitted to improve floc stability and reduce internal loading). All three of these options included the application of alum to the main basin of Crystal Lake.

The first option assumes the MDNR would only permit alum + lime application to 15 percent of the lake's littoral zone. The acreages that would be treated and the estimated reduction in curlyleaf pondweed coverage are summarized in Table 6-5. The reductions are based on an estimated biomass decrease of 80 percent after lime application ("Effects of Single Ca(OH)₂ Doses on Phosphorus Concentration and Macrophyte Biomass of Two Boreal Eutrophic Lakes Over 2 Years." Reedyk *et al*, 2001). This management option could possibly reduce the summer average phosphorus concentration in the main basin of Crystal Lake by to 47 µg/L (see Management Option II.G.3.a in Table 6-3a). The resulting in-lake Secchi disc transparency would only improve by 0.1 meters over the no BMP option. Therefore this management option would not achieve the BDWMO's goal for Crystal Lake. Recent alum + lime application to a small pond in Apple Valley cost about \$1,375 per acre (\$725/acre for lime and \$650/acre for alum). The estimated capital cost of a 31.2-acre lime application combined with an alum application to reduce the anoxic sediment release of soluble phosphorus in the main basin of Crystal Lake is roughly \$211,000. The alum + lime application would also have a significant impact on the summer average and early-summer peak total phosphorus concentrations in the various bays (see Appendix F).

Table 6-5 Alum + lime Treatment Acreages for Application to 15 percent of the Littoral Zone

Lake	No Curlyleaf Growth Area (ac)	Nuisance Curlyleaf Coverage (ac)	Non-Nuisance Curlyleaf Coverage (ac)	Assumed Area of Alum+Lime Application (ac)	Estimated Curlyleaf Coverage after Alum+Lime (ac)	Estimated Curlyleaf Reduction (percent)
Crystal Lake -Main Basin	87.4	28	71.3	17.9	85	14 percent
Mystic Bay	1	34	4.8	5.1	35	11 percent
Bluebill Bay	0	30	10.3	4.5	37	9 percent
Maple Island Bay	0	0	3.7	3.7	1	80 percent
Buckhill Bay	0	8	13.9	0	22	0 percent
Crystal Lake (Total)	88.3	100	104	31.2	179	12 percent
Keller Lake	0	54.7	0	8.2	48	12 percent

If the MDNR were to permit the application of alum + lime similar to mechanical harvesting 50 percent of the littoral zone could be treated. Table 6-6 summarizes the acreages that would be treated and the estimated reduction in curlyleaf pondweed coverage for lime application to 50 percent of the littoral zone. This management option would reduce the in-lake summer average total phosphorus concentration by an additional 3 µg/L over only treating 15 percent of the littoral zone which would result in an estimated Secchi disc transparency of 1.5 meters. The estimated capital cost of a 104-acre lime application combined with an alum application to reduce the anoxic sediment release of soluble phosphorus in the main basin of Crystal Lake is roughly \$326,000.

Table 6-6 Alum + lime Treatment Acreages for Application to 50 percent of the Littoral Zone

Lake	No Curlyleaf Growth Area (ac)	Nuisance Curlyleaf Coverage (ac)	Non-Nuisance Curlyleaf Coverage (ac)	Assumed Area of Alum+Lime Application (ac)	Estimated Curlyleaf Coverage after Alum+Lime (ac)	Estimated Curlyleaf Reduction (percent)
Crystal Lake -Main Basin	87.4	28	71.3	36.3	70	29 percent
Mystic Bay	1	34	4.8	34	12	70 percent
Bluebill Bay	0	30	10.3	30	16	60 percent
Maple Island Bay	0	0	3.7	3.7	1	80 percent
Buckhill Bay	0	8	13.9	0	22	0 percent
Crystal Lake (Total)	88.3	100	104	104	120.8	41 percent
Keller Lake	0	54.7	0	27.4	32.8	40 percent

The third option involves the management of the curlyleaf pondweed and anoxic sediment release of phosphorus in Crystal Lake could possibly reduce the summer average phosphorus concentration in the main basin of Crystal Lake by up to 12 µg/L if the entire littoral zone was treated with lime plus alum (see Management Option G.3.c in Table 6-3a). This phosphorus reduction would improve the Secchi disc transparency to 1.7 meters thus achieving the BDWMO’s water clarity goal. The estimated capital cost of a 208-acre lime application (the entire littoral zone) combined with an alum application to reduce the anoxic sediment release of soluble phosphorus to the main basin of Crystal Lake is roughly \$457,000. The alum + lime application would also have a significant impact on the summer average and early-summer peak total phosphorus concentrations in the various bays (see Appendix F).

6.2.2.2.4 Application of Alum to Keller Lake and Alum + Lime to the Various percentages of the Lake's Littoral Zone

The next set of management options simulated involved the application of alum to all of Keller Lake and alum + lime to various portions of the lake's littoral zone. These management options are similar to those previously discussed in connection with alum + lime application to Crystal Lake. Alum + lime applied to various portions of the lake's littoral zone would reduce the internal phosphorus load caused by curlyleaf die-back to Keller Lake. As a result of the improved Keller Lake water quality Crystal Lake water quality would also improve.

The first option assumes the MDNR would only permit alum + lime application to 15 percent of the lake's littoral zone. The acreages that would be treated and the estimated reduction in curlyleaf pondweed coverage are summarized in Table 6-5. This management option could possibly reduce the summer average phosphorus concentration in the Keller Lake to 88 µg/L (see Management Option G.4.a in Table 6-4a). The resulting in-lake Secchi disc transparency would only improve by 0.2 meters over the no BMP option. The improvement in Keller Lake water quality would also improve the predicted total phosphorus concentrations, chlorophyll *a* concentrations, and Secchi disc transparencies in Crystal Lake (see Management Option G.4.a in Table 6-3a, b, & c). However, the improvement in Crystal Lake is not substantial enough to achieve the BDWMO's water clarity goal for Crystal Lake. The estimated capital cost of an 8.2-acre alum + lime application is roughly \$25,000. This results in an annualized cost of \$2,163 over a 20-year period.

If the MDNR were to permit the application of alum + lime to 50 percent of the littoral zone roughly 27.4 acres could be treated. As a result of the alum + lime treatment curlyleaf pondweed coverage could be reduced by 40 percent (see Table 6-6). This management option would reduce the in-lake summer average total phosphorus concentration by an additional 4 µg/L in Keller Lake over only treating 15 percent of the littoral zone. This would result in an estimated summer average Secchi disc transparency of 1.2 meters. The additional alum + lime treatment area (19.2 acres) would not substantially improve the water quality in Crystal Lake (Management Option G.4.a vs. G.4.b in Table 6-3a, b, & c). The estimated capital cost of a 27.4-acre alum + lime application is roughly \$60,000 (\$5,175 annually for 20 years).

Similarly, an alum + lime application to 100 percent of Keller Lake was modeled to determine the impacts of managing curlyleaf pondweed in Keller Lake. Table 6-4a illustrates that there would be a substantial reduction in the summer-peak and summer average total phosphorus concentrations in Keller Lake (26 µg/L and 49 µg/L, respectively). A large but not quite as substantial reduction was also predicted in the fall overturn concentration (26 µg/L). This reduction in Keller Lake total

phosphorus concentration cascades downstream into the main basin of Crystal Lake, which is predicted to have a 6 µg/L reduction in summer average total phosphorus concentration. Crystal Lake spring, early-summer and fall overturn concentrations are also predicted to decrease after the Keller Lake alum + lime application. The capital cost of this BMP alternative is estimated to cost \$109,000 and improve the clarity of both Keller Lake and Crystal Lake (see Tables 6-3c & 6-4c and Figure 6-2). This capital cost translates into an annualized cost of \$9,478 over a 20-year period.

6.2.2.2.5 Mechanical Macrophyte Harvesting to Control Curlyleaf Pondweed

While mechanical harvesting is more acceptable to the MDNR than chemical methods it will still require an MDNR permit, provide only temporary benefits, and must be repeated annually. The MDNR regulations state that the maximum area that can be harvested is 50 percent of the littoral zone.

Three management options involving mechanical harvesting were simulated for this UAA study. The first option assumes mechanical harvesting of curlyleaf pondweed in Crystal Lake. The areas that would be harvested and the estimated reduction in curlyleaf pondweed coverage are summarized in Table 6-7. The reductions are based on an estimated biomass decrease of 75 percent after harvesting (McComas and Stuckert, 2000). This management option could possibly reduce the summer average phosphorus concentration in the main basin of Crystal Lake to 47 µg/L (see Management Option H.1 in Table 6-3a). The resulting in-lake Secchi disc transparency would only improve by 0.1 meters over the no BMP option. Therefore, this management option would not achieve the BDWMO’s goal for Crystal Lake. The estimated annual cost of harvesting 104 acres of curlyleaf pondweed is roughly \$54,600. Harvesting in Crystal Lake would only impact the areas harvested and would have no impact on Keller Lake.

Table 6-7 Estimated Curlyleaf Pondweed Reduction Resulting from Mechanical Harvesting

Lake	Assumed Area Harvested (ac)	Estimated Curlyleaf Coverage after Harvesting (ac)	Estimated Curlyleaf Reduction (percent)
Main Basin	36.3	72	27 percent
Mystic Bay	34	13	66 percent
Bluebill Bay	30	18	56 percent
Maple Island Bay	3.7	1	75 percent
Buckhill Bay	0	22	0 percent
Crystal Lake (Total)	104	126	38 percent
Keller	27.4	34.2	38 percent

The second scenario involves harvesting about 27.4 acres of curlyleaf pondweed in Keller Lake. This would result in a 38 percent reduction in curlyleaf pondweed. As a result, Keller Lake's early-summer total phosphorus concentration would be reduced to 90 µg/L (a 12 µg/L reduction) while the summer average concentration would be reduced to 120 µg/L (a 6 µg/L reduction). It is estimated that there would be no noticeable improvement in Keller Lake's summer average water clarity (see Table 6-4c). Model simulations also indicate that there would be no noticeable impact on the predicted water quality in Crystal Lake (see Tables 6-3a, b, & c). Because mechanical harvesting does not kill the aquatic plant, it would have to be conducted on an annual basis. Therefore the annualized cost of harvesting is estimated to be \$14,359.

The third harvesting option simulated was a combination harvesting in Crystal and Keller Lake. Based on the above discussions, it is evident that harvesting of curlyleaf pondweed would only impact the individual lake where harvesting occurs. There would be no significant benefit of the combined harvesting efforts in terms of water quality (see Management Option II.H.3). However, harvesting would improve the recreational-use and aesthetic-uses for the lakes. Harvesting in Crystal and Keller Lakes would have an annual cost of \$68,959.

6.2.2.2.6 Resume Operation of the Ferric Chloride (FeCl₃) Treatment System

A Clean Water Partnership grant through the Minnesota Pollution Control Agency (MPCA) partially funded a hypolimnetic withdrawal and phosphorus precipitation/inactivation project for Crystal and Keller lakes. The project consisted of hypolimnetic withdrawal from Crystal Lake, phosphorus precipitation/inactivation with ferric chloride (FeCl₃), and discharge to Keller Lake via the storm sewer along the north side of the lake. A 12-inch pipe was installed along the bottom of Crystal Lake to its deepest location (approximately 37 feet deep). Water was pumped via a wet well on shore, dosed with ferric chloride, and discharged to the storm sewer at a rate of 1.5 cubic feet per second (cfs). The storm sewer empties into Keller Lake, where the ferric hydroxide floc settles out of the water column. Phosphate adsorbs to the insoluble ferric hydroxides and also forms ferric-phosphate complexes, which settle out of the water. Iron to phosphorus ratios (Fe:P) exceeding three are desired to promote iron phosphate precipitation (Stauffer, 1981; cited in Walker et al., 1989).

The original design specified a pumping rate of 4.5 cfs (2,000 gallons per minute), which was expected to pump a volume equal to the hypolimnion (325 acre-feet) in 30 to 40 days. At this pumping rate, the expectation for phosphorus concentration was a reduction of 50 percent in Keller Lake and at least 25 percent in Crystal Lake. The final design, however, had to be reduced to 1.6 cfs (720 gpm) to provide sufficient room in the receiving storm sewer for stormwater runoff.

The Crystal Lake withdrawal and treatment system was designed to accommodate the following operating alternatives (Figure 6-6):

- Alternative 1** Hypolimnetic intake—discharge to Keller Lake
- Alternative 2** Near surface intake—discharge to Keller Lake
- Alternative 3** Near surface intake—discharge to hypolimnetic outlet
- Alternative 4** Hypolimnetic intake—discharge to surface outlet

The first configuration was the selected operational design for Crystal Lake in 1996. The hypolimnetic intake consists of a 12-inch pipe along the bottom at the deepest point in the lake to collect hypolimnetic lake water. Hypolimnetic water was pumped to a wet well on shore, where FeCl_3 was added and pumped to a storm sewer that discharges to Keller Lake. The FeCl_3 solution was stored in a pair of 700-gallon tanks within a locked shed, equipped with appropriate secondary containment. After entering Keller Lake, ferric hydroxide-phosphate complexes settle out before Keller Lake water discharges to Crystal Lake.

Crystal Lake had an infestation of the Eurasian watermilfoil, a nuisance aquatic plant, but it has not been detected in Keller Lake. To prevent Eurasian watermilfoil plant fragments from entering Keller Lake, a screen (2 mm mesh size) was installed as part of the project.

Construction of the hypolimnetic withdrawal and treatment system was completed in September 1994, but did not become fully operational until May 1996. Water was pumped at a constant flow of 720 gallons per minute (1.6 cubic feet per second). In 1996, water was pumped from May 21 through August 29; the pump operated for 94 days out of the 102 calendar days. The 8 days when the pump was not operating occurred in the first week of August and was caused by corrosion of the electrical system. In 1997, water was pumped from June 5 through September 10; the pump operated for 95 out of 97 days. The pump was shut off for two days in mid-August because of odor complaints. The system began operating on May 28, 1998 and ran continuously until July 23, 1998, when it was stopped because of odor problems, and was not restarted for the remainder of 1998. An odor complaint prompted an increase in the ferric chloride dosing on July 8, 1998. A second complaint on July 17 prompted a second increase in the ferric chloride dose rate. With the third odor complaint, the system was shut down. As previously described, the ferric chloride dose varied from year-to-year and in some instances within a given year. As shown on Figure 6-7, the higher the FeCl_3 dose the lower the summer average total phosphorus concentration in Keller Lake.

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Figure 6-6 Crystal Lake Hypolimnetic Withdrawal and Chemical Treatment System Operating Alternatives

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Figure 6-7 Impacts of Iron Dosing on Keller Lake Summer Average Total Phosphorus Concentration

Resuming the operation of the hypolimnetic withdrawal system would require a new system configuration be selected. The ideal configuration would involve a near surface intake with discharge to Keller Lake (Alternative 2 listed in 6.2.2.2.6 above). This would reduce the likelihood of odor problems because the water being discharge would not have low oxygen levels. Assuming past operation of the system was responsible for the macrophyte shift from curlyleaf pondweed to stringy pondweed and a FeCl_3 dose of 8.8 mg Fe/L, resumed operation would significantly reduce the summer average total phosphorus concentration in Keller Lake to 50 $\mu\text{g/L}$ (see Table 6-4a). This phosphorus concentration translates to a 1.5 meter summer average Secchi disc transparency in Keller Lake (an 0.6 meter improvement for full-development conditions). The predicted water quality is a long-term estimate and assumes continued operation every summer.

As the result of improved water quality in Keller Lake, the water quality in Crystal Lake would also improve. Simulation results indicate that the summer average total phosphorus concentration in Crystal Lake would be reduced by 10 $\mu\text{g/L}$ (from 51 $\mu\text{g/L}$ to 41 $\mu\text{g/L}$) while the water clarity improves by 0.4 meters. The resulting summer average phosphorus concentration and water clarity (41 $\mu\text{g/L}$ and 1.6 meters) would surpass the BDWMO's goals for Crystal Lake. Table 6-3a shows that the estimated capital cost for this option is \$13,125 to convert the system to a near surface intake, with an estimated annual operation and maintenance cost of \$36,520. This results in an annualized cost of \$37,664 to cover the capital cost and the annual cost associated with chemicals and maintenance of the facility.

6.2.2.3 Nonstructural BMP Alternatives

As stated previously, most of the stormwater runoff entering Crystal Lake is first retained and treated by upstream wet detention basins or wetlands. Water quality modeling simulations show that the upstream basins are effective at removing most coarse particulates and phosphorus associated with coarse particles. However, wet detention basins may not be highly effective at removing soluble phosphorus, or phosphorus associated with extremely small particles. Therefore, source control becomes extremely important in reducing the amount of phosphorus contained in stormwater runoff. Nonstructural BMPs are effective at reducing the amount of phosphorus on-site, prior to transport into stormwater runoff. Examples of effective nonstructural BMPs that would be appropriate for the Crystal and Keller Lake watersheds include:

1. Public education programs to inform the residents of the Crystal and Keller Lake watersheds of ways to reduce phosphorus loading through proper handling of yard wastes, fertilizers, pet wastes, soaps and detergents.

2. Encourage industrial/commercial areas to institute good housekeeping practices, including appropriate disposal of yard wastes, appropriate disposal of trash and debris, appropriate storage and handling of soil and gravel stockpiles.
3. Discourage the feeding of waterfowl at shoreline areas around Crystal and Keller Lakes.
4. Encourage vegetated buffers between yards and wetlands and ponds.
5. Require vegetated buffers between yards and the shore of Crystal and Keller Lakes.
6. Perform regular street sweeping, especially in high-density residential areas, 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 and was included in the calibration process.

It is not possible to model the effects of all nonstructural BMPs accurately, but studies have shown that they are moderately effective at reducing phosphorus loads. As part of this study the impact of fertilizer P limitation was modeled using P8.

6.2.2.3.1 Fertilizer P Limitation

The State of Minnesota has recently passed legislation placing a limitation on the use of fertilizers containing phosphorus in the seven-county metro area. This legislation is set to become effective in 2004 and will allow the use of fertilizers containing phosphorus if a soils test indicates warrant it.

Two methods were used to provide a range of resulting in-lake water quality estimates as a result the fertilizer phosphorus limitation. The first method simply involved reducing the pervious runoff concentrations in the particle file used in P8. The concentrations for the various particle classes were simply reduced by 23 percent based on personal conversations with John Barten and research papers (Barten, 1995; Barten, 1997; and Garn 2002). The estimated in-lake total phosphorus concentration in Crystal Lake for existing land use conditions is not estimated to improve while the Keller Lake total phosphorus concentration would improve by only 3 µg/L (see Options A.2 & B.1 in Tables 6-3a and 6-4a). Similar reductions were estimated for full-development land use conditions (1 µg/L and 3 µg/L reductions for Crystal and Keller Lakes respectively).

The second analysis method required the following assumptions to estimate the impacts of the fertilizer phosphorus limitation on in-lake water quality of Crystal and Keller Lakes.

- 75 percent of homeowners apply fertilizer to their lawns annually (Barten, 1995).
- 67 percent of lawns have very high levels of phosphorus prior to fertilization (Barten, 1995).
- 16.5 percent of lawns have high levels of phosphorus prior to fertilization.
- 16.5 percent of lawns have medium levels of phosphorus prior to fertilization.

Typical suburban phosphorus runoff concentrations without and with phosphorus fertilizer application were estimated by combining the above assumptions with the mean pervious area runoff phosphorus concentrations (total phosphorus and soluble reactive phosphorus) determined by Barten, 1997 for the various lawn fertility types. Total phosphorus concentrations in typical lawn runoff were estimated to be reduced from 1.68 mg/L with application of fertilizers containing phosphorus to 1.39 mg/L without phosphorus fertilizer application (a 17.3 percent reduction). The soluble reactive phosphorus concentration in lawn runoff was estimated to decline by 8.4 percent once the phosphorus fertilizer limitation becomes effective (1.11 mg/L with fertilizers containing phosphorus to 1.01 mg/L without phosphorus fertilizer application).

Applying the above phosphorus concentration reductions to the pervious area runoff estimated from the P8 model for existing land use conditions indicates that the summer average in-lake phosphorus concentrations in Crystal and Keller Lakes could be reduced by 4 µg/L and 12 µg/L, respectively (see Options A.2 & B.2 in Tables 6-3a and 6-4a). Under full-development conditions similar reductions in summer average in-lake phosphorus concentrations were estimated (5 µg/L and 12 µg/L reductions for Crystal and Keller Lakes, respectively). This reduction in total phosphorus concentrations translates into reduced chlorophyll *a* concentrations and improved Secchi disc transparencies of 0.1 meters.

Based on the above modeling results the legislative limitation on the use of fertilizers containing phosphorus would reduce the summer average phosphorus concentration in Crystal Lake by 1 to 5 µg/L and 3 to 12 µg/L for Keller Lake under full-development conditions. The cost associated with this management option (changes in fertilizer costs) will be paid for by the individual homeowner.

6.3 Combination of BMP Options

In order to cost effectively achieve the BDWMO's water quality goals for Crystal and Keller Lakes it was necessary to combine several of the individual BMPs previously discussed. Therefore, 18 different combinations of the individual BMPs were developed and analyzed as part of this UAA. The elements making up the 18 BMP combinations and their associated costs are summarized in Table 6-8. The table also contains the modeled summer average in-lake water quality predictions for Crystal and Keller Lakes. Figures 6-8 and 6-9 present the predicted summer average Secchi disc transparencies, for Crystal and Keller Lakes respectively, relative to the BDWMO's and City of Burnsville's water clarity goals. Summer average total phosphorus concentrations and 20-year annualized BMP costs are also shown on these figures.

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Table 6-8 Summary of BMP Combinations and Resulting Crystal and Keller Lakes' Summer Average Water Quality

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Figure 6-8 Crystal Lake Secchi Disc Transparencies, Total Phosphorus Concentrations and Annualized Costs Estimated for BMP Combination Options—Modeled Full Development

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Figure 6-9 Keller Lake Secchi Disc Transparencies, Total Phosphorus Concentrations and Annualized Costs Estimated for BMP Combination Options—Modeled Full Development

The first combination of options (Management Options III.1) involves: Fertilizer P Limitation, In-Lake Alum Treatment of the main basin of Crystal Lake and Alum + lime Treatments to Various Portions of Crystal and Keller Lakes Littoral Zones. The combinations analyzed applying alum to the entire lake surface and alum + lime to 15 percent, 50 percent, and 100 percent of each lake's littoral zone. This management option would address to internal loading of phosphorus and not significantly manage the external load of phosphorus to the lakes.

- **Treating 15 percent of the littoral zones** to control the recycle of sediment-bound phosphorus and manage curlyleaf pondweed in both Crystal and Keller Lakes would not only benefit the main basin of the Crystal Lake but would also significantly reduce the in-lake phosphorus concentration in Keller Lake, Mystic Bay, Maple Island Bay, Bluebill Bay, and Buckhill Bay, all of which have exhibited algal bloom problems. Assuming 15 percent of each lake's littoral zone was treated with lime in addition to alum, the summer average total phosphorus concentrations would be 46 µg/L and 107 µg/L for Crystal and Keller Lakes, respectively. The resulting water clarity in Crystal and Keller Lakes (1.5 meters and 1.0 meters respectively) would achieve the BDWMO's goals for both lakes. Table 6-8 shows that the estimated capital cost for this option is \$235,000. This results in an annualized cost of \$20,521 over a 20-year period.
- **Expanding the littoral zone treatment area from 15 percent to 50 percent** would reduce Crystal Lake summer average total phosphorus concentration by an additional 5 µg/L (see Management Option III.1.b). Treating 50 percent of both lakes' littoral zone will also achieve Crystal Lake's summer average Secchi disc transparency goal (1.6 meters versus 1.6 meters; see Figure 6-8). This management option would also substantially improve the water quality in the various bays and Keller Lake (e.g., Keller Lakes summer average total phosphorus concentration would be reduced by an additional 17 µg/L). The capital cost of the combined BMPs is about \$386,000 (see Table 6-8). This results in an annualized cost of \$33,619 over a 20-year period.
- **Expanding the littoral zone treatment area from 50 percent to 100 percent** would reduce Crystal Lake summer average total phosphorus concentration by an additional 8 µg/L resulting in a concentration of 33 µg/L. This is significantly below the BDWMO's total phosphorus goal for Crystal Lake. Treating 100 percent of both lake's littoral zone will result in a Crystal Lake summer average Secchi disc transparency of greater than the specified goal (1.9 meters versus 1.6 meters; see Figure 6-8) as well has substantially improve the water quality in the various bays and Keller Lake. The capital cost of the combined BMPs is about \$566,000 (see Table 6-8). This results in an annualized cost of \$49,347 over a 20-year period.

Management Option III.2, shown in Table 6-8, consists of the fertilizer P limitation, upgrading of existing ponds to NURP, and adding Ponds A7a-1 & A7b-1. Based on the water quality analysis of

these BMP options, this combination will provide some water quality improvement to both Crystal and Keller Lakes by reducing the annual external phosphorus loads by 88 lbs. and 19 lbs., respectively. The resulting summer average Secchi disc transparency will not meet the BDWMO's water clarity goal for Crystal Lake. Table 6-8 show that the estimated capital cost for this BMP combination is \$1,571,000, with an annual operation and maintenance cost of \$12,600. This results in an annualized cost of roughly \$150,000 over a 20-year period to cover the capital cost and the annual cost associated with operation and maintenance of the facilities (future excavation).

Management Option III.3 builds on III.2 by adding the restoration of the wetland between Lac Lavon Drive and Crystal Lake Road East. The addition of this wetland would not significantly impact the water quality in either Keller or Crystal Lakes. It would, however, help restore wildlife habitat back to a more natural state. The estimated capital cost of this BMP combination is \$1,765,000, with an annual operation and maintenance cost of \$14,100. This results in an annualized cost of roughly \$168,000 to cover the capital cost and the annual cost associated with future excavation and maintenance of the facilities.

Management Option III.4 also builds on III.2 by adding the regional infiltration basins. Modeling simulations indicate that the addition of these infiltration basins will slightly reduce the spring steady-state phosphorus concentrations in Crystal and Keller Lakes. Overall, the addition of these infiltration basins would not significantly impact the water quality in either Keller or Crystal Lakes. However, they will reduce the volume of runoff entering the water body that will help with some of the water quantity concerns and reduce the amount of dissolved nutrients entering the lakes. It would also help restore wildlife habitat back to a more natural state. The estimated capital cost of this BMP combination is \$1,836,000, with an annual operation and maintenance cost of \$14,700. This results in an annualized cost of roughly \$175,000 to cover the capital cost and the annual cost associated with future excavation and maintenance of the facilities.

Another combination of options, Management Option III.5, was evaluated to determine the added benefits of retrofitting one-third of the Crystal Lake watershed with rainwater gardens, sized to infiltrate $\frac{3}{4}$ -inch of runoff from the impervious surfaces. As shown in Table 6-8, the summer average total phosphorus concentration would be reduced to 36 $\mu\text{g/L}$ in Crystal Lake (a 9 $\mu\text{g/L}$ reduction over Management Option III.4) while Keller Lake would likely exhibit a summer average total phosphorus concentration reduction of about half that expected in Crystal Lake (4 $\mu\text{g/L}$). The resulting Crystal Lake water clarity (1.8 meters) would surpass the BDWMO's goal. As previously discussed, retrofitting the rainwater gardens would be extremely difficult and expensive. The capital costs for

this BMP combination are estimated to be \$13,498,000 with an annual operation and maintenance cost of \$108,000. This results in an annualized cost of roughly \$1,285,000 to cover the capital cost and the annual cost associated with future excavation and maintenance of the facilities. Because of the extreme costs of retrofitting rainwater gardens, this BMP combination is likely cost-prohibited and, therefore, no further analysis of rainwater gardens was completed as part of this UAA study.

Mitigation of the external phosphorus loading by the watershed BMPs in Management Option III.4 will not fully achieve the BDWMO's goals. Therefore, the internal loading also requires remedial measures. The first combination involving internal load mitigation measures builds on Management Option III.4 by adding mechanical harvesting of curlyleaf pondweed in Crystal Lake (Management Option III.6). This option would reduce the summer average phosphorus concentration in Crystal Lake to 41 µg/L (a 4 µg/L reduction over Management Option III.4; see Table 6-8). This in-lake phosphorus concentration translates to an estimated Secchi disc transparency of 1.6 meters, thus meeting the BDWMO's goal. Because this combination did not involve an in-lake BMPs for Keller Lake, its' water quality would not change over Management Option III.4. The estimated capital cost of this BMP combination is \$1,836,000, with an annual operation and maintenance cost of \$69,300. This results in an annualized cost of roughly \$229,400 to cover the capital cost and the annual cost associated with future excavation, annual curlyleaf harvesting, and maintenance of the facilities.

The next Management Option (III.7) analyzed builds on Management Option III.6 by assuming mechanical harvesting of curlyleaf in Keller Lake as well. While this would provide little benefit to Crystal Lake's water quality, it would significantly reduce the early-summer phosphorus peak in Keller Lake resulting in a phosphorus concentration of 74 µg/L (a 12 µg/L reduction over Management Option III.4). The summer average phosphorus concentration would be reduced by an estimated 6 µg/L. These reductions, however, would not have a major impact on Keller Lakes' water clarity but they may reduce the magnitude of an early-summer algal bloom. The estimated capital cost of this BMP combination is \$1,836,000, with an annual operation and maintenance cost of \$83,700. This results in an annualized cost of roughly \$243,800 to cover the capital cost and the annual cost associated with future excavation, annual curlyleaf harvesting, and maintenance of the facilities.

If in-lake alum applications were made to the main basin of Crystal Lake and all of Keller Lake in addition to the elements of Management Option III.7, model simulations indicate the summer average phosphorus concentration in Crystal and Keller Lakes would be 33 µg/L and 70 µg/L, respectively. This management option (III.8) results in significant water quality improvements over Management

Option III.7 and would result in Crystal Lake summer average water clarity of 1.9 meters, meeting the BDWMO's goal. Since an alum application would also be made to all of Keller Lake, the internal load from the anoxic release of phosphorus would be significantly reduced for up to 10 years. The summer average phosphorus concentration in Keller Lake would surpass the BDWMO's phosphorus goal. In fact, all of the water quality goals established by the BDWMO for both lakes will be met with this option. The watershed BMP that were included in this management option would significantly extend the longevity of the in-lake alum applications. The estimated capital cost of this BMP combination is \$2,142,000, with an annual operation and maintenance cost of \$86,100. This results in an annualized cost of roughly \$272,900 to cover the capital cost and the annual cost associated with future excavation, annual curlyleaf harvesting, and maintenance of the facilities.

The next BMP combination simulated, Management Option III.9, utilizes alum + lime for macrophyte control and floc stability in various portions of the littoral zones of the lakes. This management option, which builds on Management Option III.4, would address the internal and external phosphorus loads to the lakes through conventional watershed BMPs and in-lake chemical treatments.

- **Treating 15 percent of the littoral zones** to control the recycle of sediment-bound phosphorus and manage curlyleaf pondweed in both Crystal and Keller Lakes would benefit both Crystal Lake and Keller Lake. Treating 15 percent of each lake's littoral zone with lime in addition to alum would reduce Crystal and Keller Lakes summer average total phosphorus concentrations to 39 µg/L and 104 µg/L, respectively. The resulting water clarity in Crystal and Keller Lakes (1.7 meters and 1.0 meters respectively) would achieve the BDWMO's goals for both lakes. Table 6-8 show that the estimated capital cost for this option is \$2,072,000. In addition to the capital cost, annual costs of \$83,700 would be required to maintain and operate the various facilities. This results in an annualized cost of roughly \$264,278 to cover the capital cost and the annual cost associated with future excavation and maintenance of the facilities.
- **Expanding the littoral zone treatment area from 15 percent to 50 percent** would reduce Crystal Lake summer average total phosphorus concentration by an additional 4 µg/L (see Management Option III.1.b). Treating 50 percent of both lakes' littoral zone will also achieve Crystal Lake's summer average Secchi disc transparency goal (1.8 meters versus 1.6 meters; see Table 6-8 and Figure 6-8). This management option would also substantially improve the water quality in the various bays and Keller Lake (e.g., Keller Lakes summer average total phosphorus concentration would be reduced by an additional 17 µg/L, see Figure 6-9). The capital costs for this BMP combination are estimated to be \$2,222,000 with

an annual operation and maintenance cost of \$83,700. This results in an annualized cost of roughly \$277,376 (see Table 6-8).

- **Expanding the littoral zone treatment area to 100 percent** would reduce Crystal Lake summer average total phosphorus concentration by an additional 8 µg/L resulting in a concentration of 27 µg/L. This is significantly below the BDWMO's total phosphorus goal for Crystal Lake. Treating 100 percent of both lake's littoral zone will result in a Crystal Lake summer average Secchi disc transparency of greater than the specified goal (2.3 meters). This is only 0.3 meters less than the City of Burnsville's water clarity goal for Crystal Lake (2.6 meters). The capital costs for this BMP combination are estimated to be \$2,402,000 with an annual operation and maintenance cost of \$83,700. This results in an annualized cost of approximately \$293,104 (see Figure 6-8).

Management Option III.10 also builds on Management Option III.7 by resuming the operation of the FeCl₃ treatment system. Proposed Pond A7b-1 would not be necessary to treat runoff with the resumed operation of the FeCl₃ treatment system. In fact, construction of this pond would result in the iron floc settling in the pond rather than in Keller Lake where the iron floc will help immobilize the sediment bound phosphorus. Therefore, this option does not include proposed Pond A7b-1. This would reduce the summer average total phosphorus concentration in Keller Lake by 69 µg/L over Option III.7, resulting in concentration of only 37 µg/L. As a result of the improved phosphorus concentration, the chlorophyll *a* concentration and Secchi disc transparency would improve to 8 µg/L and 1.7 meters, respectively. The improved water quality in Keller Lake would cascade downstream and improve the water quality of Crystal Lake. This management option would result in summer average total phosphorus concentration, chlorophyll *a* concentration and Secchi disc transparency of 31 µg/L, 10 µg/L, and 2.1 meters, respectively. All of the water quality goals established by the BDWMO for both lakes will be met with this option. In addition to improving summer average conditions, this combination of BMPs would also improve the spring, early-summer peak, and fall overturn conditions (see Tables 6-3a, b & c, 6-4a, b, & c, and Appendix F). The estimated capital cost of this BMP combination is \$1,718,000, with an annual chemical, operation and maintenance cost of \$119,100. This results in an annualized cost of roughly \$268,873 to cover the capital cost and the annual cost associated with future excavation, annual aquatic plant management (curlyleaf harvesting), annual FeCl₃ additions, and maintenance of the facilities.

The addition of an in-lake alum treatment to Management Option III.10 for Crystal Lake was simulated in Management Option III.11. This alum treatment would provide no benefit to Keller Lake water quality (see Figure 6-9) but would benefit Crystal Lake and its various bays (see Tables 6-3a, b, & c, and Appendix F). This alum treatment would reduce the Crystal Lake's summer

average and fall overturn total phosphorus concentrations to 28 µg/L and 27 µg/L, respectively. Because curlyleaf would still be present in the lake there would still be an internal load early in the summer. As a result, the early-summer peak phosphorus concentration would only be reduced to 41 µg/L. Crystal Lake water clarity would improve to 2.3 meters on a summer average basis. The Crystal Lake alum treatment would add about \$170,000 to the capital cost of Management Option III.10, resulting in a capital cost of approximately \$1,887,000. This results in an annualized cost of roughly \$283,653 to cover the capital cost and the annual cost associated with future excavation, annual curlyleaf harvesting, annual FeCl₃ additions, and maintenance of the facilities.

Management Option III.12 combines Management Option III.11 with an alum treatment plant to treat up to 10 cfs of stormwater runoff leaving Pond CL-2b. The addition of the alum treatment facility would have significant water quality impacts on Mystic Bay and the main basin of Crystal Lake for the various time periods reported in Tables 6-3a, b, & c and Appendix F. As Table 6-8 shows, the summer average total phosphorus concentration in Crystal Lake would be reduced to 21 mg/L. This would place the lake firmly in the mesotrophic status category and result in summer average water clarity of 2.8 meters. This average water clarity greatly surpasses the BDWMO's goal and even exceeds the goal established by the City of Burnsville (2.6 meters). Table 6-8 and Figure 6-8 show that the estimated capital cost for this option is \$3,052,000 to convert the system to a near surface intake, with an estimated annual operation and maintenance cost of \$179,000. This results in an annualized cost of \$445,213 to cover the capital cost and the annual cost associated with future excavation, chemicals (FeCl₃ and Alum) and maintenance of the facilities.

If a second alum treatment facility, constructed at the Keller Lake outlet (sized to treat 5 cfs), were combined with the watershed and in-lake BMP of Management Option III.12 the summer average water clarity in Crystal Lake would be about 3.1 meters. All of the water quality goals for both lakes are achieved with this option, including Burnsville's 2.6 meter water clarity goal, but it would be extremely expensive. The significant improvement in clarity over existing conditions would be the results of summer average total phosphorus and chlorophyll *a* concentrations of 19 µg/L and 5 µg/L respectively. No added benefits above those identified in Management Option III.10 to Keller Lake would be expected. This management option (III.13) has an estimated capital cost of \$3,887,000 to convert the system to a near surface intake, with an estimated annual operation and maintenance cost of \$219,000. This results in an annualized cost of \$557,983 to cover the capital cost and the annual cost associated with future excavation, chemicals (FeCl₃ and Alum) and maintenance of the facilities.

The final BMP combination management option (Management Option III.14) was developed with extensive input from the BDWMO Board, city staffs, and neighborhood residents. This management option is an enhancement of Management Option III.10. The following elements were combined to form this management option:

- Phosphorus Fertilizer Limitation.
- Upgrade ponds A1, WVR-43a, A46a, A6a, A7a, and CL-21 to provide sufficient water quality treatment storage volume to meet NURP criteria.
- Add Pond A7a-1 designed to meet NURP criteria as a regional water quality treatment basin.
- Enhance Redwood Pond (Pond A1) to act as an infiltration basin.
- Add a regional infiltration basin north of Valley Middle School and in West Buckhill Park.
- Resume operation of the FeCl₃ treatment system withdrawing near surface water.
- Manage aquatic macrophytes, primarily curlyleaf pondweed, in both Crystal and Keller Lakes by mechanical harvesting.

Model simulations indicate that this BMP combination (Management Option III.14) would result in summer average total phosphorus concentrations of 30 µg/L and 32 µg/L in Crystal and Keller Lakes, respectively (see Figures 6-8 and 6-9). These concentrations would translate into summer average Secchi disc transparencies of 2.1 meters and 1.8 meters respectively, thus achieving the BDWMO's goal for both lakes. The capital cost of this management option (\$860,000) combined with annual operations and maintenance costs (\$112,400) results in a 20-year annualized cost of \$187,357.

6.4 Cost Allocation

Two different methods of allocating the various BMP costs are presented in this section. The first method utilizes the existing method in the joint powers agreement. This method apportions the project costs to all the municipalities within the BDWMO based 50 percent on land area and 50 percent on property valuation. Each municipality would be responsible for the following percentages of the total project costs. The allocation of BMP costs using this method is shown in Table 6-9.

- Apple Valley (7.7 percent)
- Burnsville (78.2 percent)
- Eagan (0.4 percent)
- Lakeville (18.9 percent)
- Savage (0.3 percent)

The second cost allocation method is based on the source of the phosphorus loading. Using this method means that the municipalities would be proportionally responsible for BMP cost based on the quantity of nutrients they contribute to the water body. Each municipality would be responsible for the following percentages of the total project costs. The allocation of BMP costs using this method is shown in Table 6-10.

- Apple Valley (26.6 percent)
- Burnsville (43.4 percent)
- Lakeville (30.0 percent)

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**Table 6-9 Allocation of Costs for Lake/Watershed Management Options for Crystal Lake,
based on the Joint Powers Agreement**

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**Table 6-10 Allocation of Costs for Lake/Watershed Management Options for Crystal Lake,
based on the Source of the Total Phosphorus Loads**

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Table 6-10

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