9.0 Evaluation of Possible Management Initiatives

Analysis of the existing and future water quality in Lake Holiday, Wing Lake, and Lake Rose (see Section 8.0) indicates that there is potential for water quality improvement in those lakes. Improvements in lake water quality may be achieved by implementing coordinated best management practices (BMPs) within some or all of the lakes and their respective watersheds. The modifications necessary to achieve these improvements were evaluated under three climatic conditions to determine what effect they might have on lake water quality. The modifications, their costs, and benefits are presented in Section 9.2.

9.1 General Discussion of Improvement Scenarios

This section discusses improvement scenarios 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.

9.1.1 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. A qualitative summary of the effectiveness of various structural BMPs is presented in Table 9-1. 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 (e.g. alum treatment). Examples of structural BMPs commonly installed to improve water quality include wet detention ponds, vegetative buffer strips, oil and grit separators, flow through alum treatment plants, and others.

When choosing a structural BMP for implementation, 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 **9-1** **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	?

Source: Schueler 1987

9.1.1.1 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.

9.1.1.2 Infiltration

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 underlain 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 have 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.

9.1.1.3 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.

9.1.1.4 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 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.

9.1.1.5 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. Alum treatment plants are not feasible within the Holiday-Wing-Rose watersheds due to the lack of area to provide a settling basin for flocculent settlement after mixing.

9.1.1.6 Iron-Enhanced Sand Filtration

Sand filtration systems are typically designed to remove particulate matter and phosphorus from stormwater flows. With the addition of steel fiber, steel wool blankets, or other types of iron amendments, additional removal of soluble and non-settleable phosphorus is possible. Pretreatment of the stormwater flow is necessary to ensure proper hydraulics and that infiltration rates are maintained for phosphorus removal. When stormwater flow exceeds the capacity of the filter system, only partial treatment will be possible with higher flows being bypassed around the filter. Because aerobic conditions are required, flow must be diverted from the filter to allow for drainage and drying and, thus, a parallel system or a system with a controlled bypass is recommended.

A sand filter facility in Bellevue, WA receiving stormwater with inflow concentrations of total and soluble phosphorus of 94 and 26 µg/L, reduced loading between 43 and 72 percent (City of Bellevue, Washington, 1999). This facility uses chopped granular steel wool that increased clogging, creating anaerobic conditions within the filter, thereby reducing its effectiveness at removing phosphorus. A column test design by Erickson et al. (2006) provided between 40 and 90 percent removal of soluble phosphorus in a system comprised of C33 sand with granular steel wool or steel wool fabric as an amendment. An iron enhanced sand filter was installed in the Ramsey-Washington Metro Watershed District (RWMWD) using iron filings with a grain size distribution similar to the sand used in the filter (Barr 2009). Using iron filings instead of chopped steel wool provides a number of benefits including less chance for filter plugging and less pollutants that can be associated with steel wool (oil). Testing of the design installed at RWMWD was conducted and phosphorus removal was between 80 and 90% (Erickson et al. 2009). Longevity, based on the testing parameters, was at least 20 years. This will vary between systems however, based on hydraulic loading rate and the concentration of phosphorus in the inflows. Within the Holiday-Wing-Rose watershed, the use of iron-enhanced sand filtration may be limited by the lack of space available to support a reasonable hydraulic loading rate.

9.1.2 Nonstructural BMPs

Nonstructural ("Good Housekeeping") BMPs discussed below include:

1. Public Education
2. City Ordinances
3, Street Sweeping
4. Deterrence of Waterfowl

Good housekeeping practices reduce the pollutant at its source.

9.1.2.1 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 Lake Holiday, Wing Lake, and Lake Rose watersheds how to protect and improve the quality of the lake. The program could 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, lake associations, 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 Lake") on all storm sewer catch basins within the Holiday-Wing-Rose watershed.

Surveys were sent to residents of the Holiday-Wing-Rose Chain of Lakes watershed in the fall of 2008, in an effort to better understand the current and desired uses of these lakes, as well as local residents' perceptions regarding lake water quality. The results of this survey (presented in Section 2.1.1) may be used to inform and guide public education efforts within these watersheds.

9.1.2.2 Ordinances

Water quality problems can be addressed through legislative methods, such as the state-wide ban on the use of phosphorus fertilizers or a commercial lawn care ordinance to limit the use or herbicides or other chemicals that may affect water quality. Other ordinances pertaining to littering, pet feces, and buffer strips adjacent to lakes and other water bodies could be strengthened or created.

9.1.2.3 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. 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.

9.1.2.4 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 form. 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. In general, the areas of short grass adjacent to Lake Holiday, Wing Lake, and Lake Rose are limited. Along Lake Holiday and Wing Lake, trees and other vegetation grow along the water's edge in many areas. The north side of Lake Rose is bordered by wetland vegetation or trees.

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.

9.1.3 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.

9.1.3.1 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 Minnesota Department of Natural Resources (MDNR). 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.

9.1.3.2 Application of Alum (Aluminum Sulfate)

As discussed in Section 7.3.1.3, there is an internal load of phosphorus from the sediments in Lake Holiday, Wing Lake, and Lake Rose. Sediment release of phosphorus to the lake basins occurs during the summer months, when the water overlying the sediments is depleted of oxygen. This internal load of phosphorus is transported to the entire lake during mixing events (in shallow lakes) or in the late-summer, when the surface waters cool sufficiently for wind-mixing to mix the entire lake (often referred to as “fall turnover”) in deeper, dimictic lakes. Phosphorus released from the sediments is typically in a dissolved form, which can be quickly utilized by algae, leading to intense algae blooms. 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). 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).

The benefits of an in-lake alum treatment of a lake include both a temporary and a long-term improvement in the water quality of a lake. The temporary benefit (lasting from 1 to 2 years) results from the alum's ability to remove phosphorus from the water column. The phosphorus removal inhibits algal growth by depriving the algae of phosphorus, a required nutrient. Additionally, temporary improvements in water clarity result from the "cleansing" of the water column that occurs as the alum floc settles and removes suspended particulate matter. Long-term benefits to the lake are expected to result from the alum's ability to bind phosphorus after the alum comes to rest on the lake sediment surface, thus preventing transfer of sediment-bound phosphorus back to the water column (i.e., preventing internal loading).

Over time, the effectiveness of the thin alum blanket on the sediment surface diminishes. Estimates of the effective duration of a single alum treatment in preventing sediment phosphorus release vary from 7 to 10 years. This effective duration can be affected by several factors, including the adequacy of the alum dosage, homogeneity of treatment, wind-driven mixing and sediment resuspension, control of watershed nutrient loads, and changes in the sediment-water chemical exchange dynamics that may result from the treatment itself.

9.1.3.3 Iron Salt Applications with Hypolimnetic Aeration

The application of iron salts (such as ferric chloride or ferric sulfate) can be used to reduce TP concentrations within a lake. In aerobic conditions, the iron salts can be used to precipitate and/or inactivate the TP associated with lake sediments. Application of iron salts alone has not been shown to be effective in the long term. However, when used in combination with hypolimnetic aeration, the results of the treatment have been more effective.

Hypolimnetic aeration involves oxygenation in the hypolimnion of a thermally-stratified lake to raise the dissolved oxygen content within this layer of the lake without disrupting the stratification or temperature. By aerating the hypolimnion, the anoxic conditions that often develop along the sediment-water interface during the summer months in many thermally-stratified lakes can be minimized, reducing the internal phosphorus loading from the lake sediments into the water column. Hypolimnetic aeration can be achieved through a variety of designs and set-ups, which can include mechanical agitation, injection of pure oxygen, and injection of air.

Water quality data collected from Lake Holiday, Wing Lake, and Lake Rose indicate that all lakes are periodically anoxic during the summer. Application of iron salts in these lakes would likely require aeration to be effective. The application of iron salts in conjunction with aeration can achieve reductions in internal loading similar to an alum treatment (see Section 9.1.3.2). Alum treatment may be a more desirable option when compared to the ongoing maintenance and costs of an aeration system.

9.1.3.4 Aquatic Vegetation (Curlyleaf Pondweed) Management

As discussed in Section 7.3.1.2.2, Curlyleaf pondweed is present in high concentrations in Lake Holiday and Wing Lake, and present in moderate concentrations in Lake Rose. When Curlyleaf pondweed dies in the early- to mid-summer, its decay releases phosphorus in to the lake. Curlyleaf pondweed can be a significant source of phosphorus. The in-lake analysis presented in Section 7.3 of this report estimates that Curlyleaf pondweed accounts for as much as 21 percent of the summer phosphorus loading to Lake Holiday and is a significant source of phosphorus in Wing Lake (12 to 16 percent) and Lake Rose (6 to 10 percent). Reducing or eliminating the Curlyleaf pondweed population may improve water quality through the reduction of total phosphorus. In addition, the reduction in Curlyleaf pondweed may result in conditions more favorable to native plant species.

Aquatic vegetation may be managed using a variety of techniques, including mechanical harvesting, chemical treatment, and controlled draw-downs. Any of these management strategies, however, will be a stressor on other, desirable aquatic vegetation (e.g. coontail). Controlling Curlyleaf pondweed may require management over several years, because this species annually produces turions (seeds) which can lie dormant for one or more years before growing. Studies show that each Curlyleaf pondweed plant can produce up to 900 turions (Catling et al., 1985). Continued treatment is necessary prevent the growth of existing turions.

9.1.3.4.1 Application of Herbicides

Controlling Curlyleaf pondweed can be done by herbicide treatments applied from a barge or boat. Herbicide treatment would likely consist of five annual spring herbicide treatments to effectively reduce or eliminate the Curlyleaf pondweed growth. To minimize the impact to native vegetation, herbicide treatment is typically applied early in the spring to remove the Curlyleaf pondweed when native plants are seasonally suppressed. Herbicide treatments are generally more effective at eradicating the plant than mechanical methods but MDNR regulations limit the extent of the lake that can be treated in any year. Unless otherwise approved, the MDNR will currently only permit treatment of 15 percent of the littoral zone of a given lake with herbicides. 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 bio-concentrated (Pullmann, 1992). Examples of two aquatic herbicides appropriate for use in controlling the Curlyleaf pondweed growth in lakes are Reward (active ingredient = Diquat) and Aquathol-K (active ingredient = Endothall).

To treat greater than 15 percent of a lake's littoral zone, it is necessary to get approval from the MDNR through a variance process. MDNR approval generally includes requirements for an extensive pre- and post-treatment monitoring program to evaluate the treatment effectiveness and the potential for new Curlyleaf pondweed growth in subsequent years. Analysis of data and annual reporting is also required to determine the degree of Curlyleaf pondweed control and confirm the positive or neutral effect of the herbicide treatment on the native plant community.

9.1.3.4.2 Mechanical Harvesting

Harvesting of lake macrophytes is typically done 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 consist 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 $500/acre (McComas, 2007).

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 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 pondweed prior to die-back in late-June or early-July.

Mechanical harvesting requires an MDNR permit and provides only temporary benefits. Mechanical harvesting must be repeated annually for several years to achieve lasting reduction of Curlyleaf pondweed, due to the ability of Curlyleaf pondweed turions to remain dormant in the sediment for one or more years. Mechanical harvesting may have significant impacts on other aquatic macrophytes in addition to Curlyleaf pondweed. The MDNR regulations state that the maximum area that can be harvested is 50 percent of the littoral zone.

9.1.3.4.3 Controlled Draw-downs

Controlled draw-downs may be used in the fall and winter to expose Curlyleaf pondweed turions to freezing temperatures and desiccation, preventing their growth the following year (Crowell, 2003). This method was recently applied to Northwest and Southwest Anderson Lakes in Bloomington and Eden Prairie. Draw-downs may be a feasible option in Lake Holiday, Wing Lake, and Lake Rose, owing to the shallow depths and relatively small surface areas of the lakes. This management option, however, will result in reduced water surface elevations as the lakes recover from draw-downs, which may limit recreational use of the lakes and be aesthetically undesirable to residents for a period of time. There are also ecological impacts that must be considered, such as stresses placed on fish and amphibian habitat. A drawdown would require the approval of more than 75% of the lake shore residents and the regulatory review agencies.

9.2 Feasibility Analysis

9.2.1 Statement of Problem

Based on the observed summer-average total phosphorus concentrations, Lake Holiday and Wing Lake fall into the NMCWD’s Level IV classification; Level IV lakes are generally intended for runoff management with no significant recreational use value. Observed summer-average TP values place Lake Rose in the NMCWD’s Level III category, which includes lakes with designated uses of fishing and aesthetic viewing. Using the Trophic State Index based on Secchi depth (TSI_{SD}), however, places all three lakes in the NMCWD’s Level IV category.

Currently, the NMCWD has not established water quality goals for Lake Holiday, Wing Lake, or Lake Rose. Thus, the existing water quality in each lake is not exceeding an applied standard. Wing Lake and Lake Rose, however, are listed on the MPCA’s Draft 2010 Impaired Waters List. Meeting the definition of shallow lakes, Wing Lake and Lake Rose are subject to the MPCA’s shallow lakes criteria of summer-average total phosphorus concentrations less than or equal to 60 µg/L, chlorophyll *a* concentrations less than or equal to 20 µg/L, and Secchi disc transparencies not less than 1.0 m. Although Lake Holiday is not included on the Draft 2010 Impaired Waters List and is not actively managed by the NMCWD, it is likely that water quality in Lake Holiday must improve in order to meet water quality goals in the downstream lakes.

Several lake management scenarios to maintain and/or improve the water quality of Lake Holiday, Wing Lake, and Lake Rose were explored. Table 9-2 summarizes the different BMP scenarios considered. Table 9-3 presents the predicted summer-average total phosphorus concentrations, chlorophyll *a* concentrations, Secchi disc transparencies, and TSI_{SD} for Lake Holiday for existing conditions and all management alternatives analyzed. Tables 9-4 and 9-5 contain similar information for Wing Lake and Lake Rose. Several lake management scenarios are discussed below.

Table 9-2 **Summary of BMP Scenarios Evaluated for Lake Holiday, Wing Lake, and Lake Rose**

Scenario Number	All Lakes	Lake Holiday					Wing Lake			Lake Rose			Estimated BMP Scenario Cost[1]
	Future land use, watersheds, and stormwater system	Infiltration (residential rainwater gardens) in watershed	In-lake alum treatment	In-lake vegetation treatment	Iron-enriched sand filtration of outflow to Wing Lake	Bypass of Wing Lake and Lake Rose	Infiltration (residential rainwater gardens) in watershed	In-lake alum treatment	In-lake vegetation treatment	Infiltration (residential rainwater gardens) in watershed	In-lake alum treatment	In-lake vegetation treatment	
0													--
1	X												--
2	X	X					X			X			$ 270,000
3	X		X										$ 23,600
4	X		X					X					$ 48,700
5	X		X					X			X		$ 152,800
6	X		X	X									$ 207,600
7	X		X	X				X					$ 232,700
8	X		X					X	X		X		$ 347,800
9	X		X	X				X	X				$ 427,700
10	X		X	X				X	X		X		$ 531,800
11	X		X	X				X	X		X	X	$ 752,800
12	X	X	X				X	X		X	X		$ 422,800
13	X	X	X	X			X	X	X	X	X		$ 801,800
14	X	X	X	X				X	X		X		$ 639,800
15	X			X	X			X	X		X		$ 1,293,200
16	X				X			X			X		$ 914,200
17	X					X							--[2]

[1] Estimated costs in 2010 dollars. Appendix G includes cost estimate for individual BMPs.

[2] BMP deemed infeasible prior to cost estimation.

Table 9-3 Modeled Water Quality in Lake Holiday under Varying Climatic Conditions and BMP Scenarios (refer to Table 9-2)

Scenario Number	Wet Climatic Conditions (1992-1993) Summer Average				Average Climatic Conditions (1998-1999) Summer Average				Dry Climatic Conditions (2007-2008) Summer Average			
	TP µg/L	Chl a µg/L	SD m	TSI_{SD} --	TP µg/L	Chl a µg/L	SD m	TSI_{SD} --	TP µg/L	Chl a µg/L	SD m	TSI_{SD} --
0	204	110	0.41	73	192	103	0.43	72	338	198	0.26	79
1	203	110	0.41	73	191	102	0.43	72	337	197	0.26	79
2	204	110	0.41	73	190	102	0.43	72	339	198	0.26	79
3	161	84	0.50	70	161	83	0.50	70	177	93	0.46	71
4	161	84	0.50	70	161	83	0.50	70	177	93	0.46	71
5	161	84	0.50	70	161	83	0.50	70	177	93	0.46	71
6	140	71	0.56	68	136	69	0.57	68	144	74	0.55	69
7	140	71	0.56	68	136	69	0.57	68	144	74	0.55	69
8	161	84	0.50	70	160.5	83	0.50	70	177	93	0.46	71
9	140	71	0.56	68	136.4	69	0.57	68	144	74	0.55	69
10	140	71	0.56	68	136.4	69	0.57	68	144	74	0.55	69
11	140	71	0.56	68	136.4	69	0.57	68	144	74	0.55	69
12	161	84	0.50	70	160.0	83	0.50	70	177	93	0.46	71
13	130	65	0.60	67	135.0	68	0.58	68	144	73	0.55	69
14	130	65	0.60	67	135.2	68	0.58	68	144	73	0.55	69
15	182	97	0.45	72	167	87	0.48	70	302	174	0.29	78
16	203	110	0.41	73	191	102	0.43	72	337	197	0.26	79
17	203	110	0.41	73	191	102	0.43	72	337	197	0.26	79

Table 9-4 Modeled Water Quality in Wing Lake under Climatic Conditions and Varying BMP Scenarios (refer to Table 9-2)

Scenario Number	Wet Climatic Conditions (1992-1993) Summer Average				Average Climatic Conditions (1998-1999) Summer Average				Dry Climatic Conditions (2007-2008) Summer Average			
	TP µg/L	Chl a µg/L	SD m	TSI_{SD} --	TP µg/L	Chl a µg/L	SD m	TSI_{SD} --	TP µg/L	Chl a µg/L	SD m	TSI_{SD} --
0	114	52	0.77	64	136	72	0.68	66	100	41	0.85	62
1	112	51	0.78	64	119	57	0.74	64	93	36	0.90	62
2	111	51	0.78	64	134	71	0.68	66	97	39	0.87	62
3	104	45	0.82	63	125	62	0.72	65	91	35	0.91	61
4	74	24	1.07	59	73	23	1.08	59	57	15	1.31	56
5	74	24	1.07	59	73	23	1.08	59	57	15	1.31	56
6	101	42	0.85	62	122	60	0.73	65	89	34	0.93	61
7	71	22	1.11	59	71	22	1.11	59	56	14	1.33	56
8	66	20	1.16	58	62	17	1.23	57	42	9	1.63	53
9	63	18	1.21	57	59	16	1.27	57	41	8	1.68	53
10	63	18	1.21	57	59	16	1.27	57	41	8	1.68	53
11	63	18	1.21	57	59	16	1.27	57	41	8	1.68	53
12	71	22	1.10	59	76	25	1.05	59	52	13	1.40	55
13	57	15	1.30	56	62	17	1.22	57	40	8	1.70	52
14	58	16	1.28	56	58	15	1.28	56	40	8	1.70	52
15	43	9	1.61	53	46	10	1.53	54	38	7	1.77	52
16	52	13	1.40	55	59	16	1.27	57	48	11	1.48	54
17	--[1]	--[1]	--[1]	--[1]	--[1]	--[1]	--[1]	--[1]	--[1]	--[1]	--[1]	--[1]

[1] - Impacts to Wing Lake water levels make this BMP scenario unfavorable

Table 9-5 Modeled Water Quality in Lake Rose under Varying Climatic Conditions and BMP Scenarios (refer to Table 9-2)

Scenario Number	Wet Climatic Conditions (1992-1993) Summer Average				Average Climatic Conditions (1998-1999) Summer Average				Dry Climatic Conditions (2007-2008) Summer Average			
	TP µg/L	Chl a µg/L	SD m	TSI_{SD} --	TP µg/L	Chl a µg/L	SD m	TSI_{SD} --	TP µg/L	Chl a µg/L	SD m	TSI_{SD} --
0	114	53	0.77	64	88	33	0.94	61	88	33	0.94	61
1	106	46	0.81	63	85	31	0.96	61	86	31	0.96	61
2	107	47	0.81	63	85	31	0.96	61	87	32	0.95	61
3	107	47	0.81	63	86	31	0.96	61	83	30	0.98	60
4	99	41	0.86	62	84	30	0.97	60	83	30	0.98	60
5	58	15	1.28	56	50	12	1.44	55	45	10	1.56	54
6	106	46	0.81	63	85	31	0.96	61	85	31	0.97	60
7	98	40	0.86	62	75	25	1.06	59	83	30	0.98	60
8	56	15	1.31	56	49	11	1.46	55	36	6	1.86	51
9	97	39	0.87	62	74	24	1.07	59	82	29	0.99	60
10	56	14	1.32	56	49	11	1.47	54	36	6	1.86	51
11	50	12	1.43	55	44	9	1.59	53	33	6	1.97	50
12	56	14	1.32	56	48	11	1.48	54	35	6	1.88	51
13	53	13	1.38	55	47	11	1.51	54	35	6	1.88	51
14	54	14	1.35	56	49	11	1.47	54	36	6	1.86	51
15	51	12	1.42	55	47	11	1.51	54	35	6	1.88	51
16	51	12	1.42	55	48	11	1.48	54	36	6	1.84	51
17	--[1]	--[1]	--[1]	--[1]	--[1]	--[1]	--[1]	--[1]	--[1]	--[1]	--[1]	--[1]

[1] - Impacts to Lake Rose water levels make this BMP scenario unfavorable

9.2.2 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 9.1. Specific BMP alternatives that were considered for the Lake Holiday, Wing Lake, and Lake Rose watersheds are discussed below. Not all of the BMP alternatives discussed below are recommended for implementation in these watersheds. Figure 9-1 shows the location of these potential sites. Estimated "budgeting" costs reflect 2010 dollars and do not include costs to acquire land or easements or obtain permits (concept level cost estimates are provided in Appendix G).

9.2.2.1 Site-Specific Structural BMPs

The Lake Holiday, Wing Lake, and Lake Rose watersheds are fully developed. Therefore, there is little room within these watersheds for additional structural BMPs such as stormwater ponds. In addition, the storm sewer system surrounding these lakes is arranged such that water enters each lake at several locations, making it difficult to treat a high percentage of the stormwater runoff to each lake without multiple structural BMPs.

9.2.2.1.1 Localized Infiltration (Rainwater Gardens) in the Lake Holiday, Wing Lake, and Lake Rose Watersheds

In light of the limited space available within the Holiday-Wing-Rose watersheds for centralized structural BMPs, localized infiltration BMPs (e.g. residential rainwater gardens) provide the best opportunity for structural BMPs upstream of the lakes. Rainwater gardens improve water quality by infiltrating stormwater runoff (and the associated phosphorus) prior to the stormwater reaching a downstream waterbody. Rainwater gardens in the Metro Area have been reported to reduce runoff volume by as much as 90 percent (Barr, 2006). Rainwater gardens may also enhance natural beauty and promote public involvement in water quality issues.

A field survey of the Holiday-Wing-Rose watersheds identified 30 sites in the Lake Holiday watershed, 30 sites in the Wing Lake watershed, and 15 sites in the Lake Rose watershed that could support rainwater gardens. These locations are shown on Figure 9-1. For modeling purposes, only those rainwater gardens directly upstream of Woodgate Pond, Lake Holiday, Wing Lake, or Lake Rose were considered; this includes 62 of the 75 total sites. Each rainwater garden was assumed to provide 300 cubic feet of storage based on average dimensions of 30 feet long by 10 feet wide by 1 foot deep. These BMPs were included in the P8 model for each lake by dividing the storage by 1 inch of rainfall and the watershed percent impervious area to determine the total watershed area that could be effectively infiltrated by the rainwater gardens, and removing that area from the lake's tributary watershed.

The rainwater gardens impact water quality in each lake by reducing the amount of runoff to each lake. Table 9-6 shows the reduction in summer total phosphorus loading to each lake achieved through infiltration BMPs. Despite the reductions, the implementation of these rainwater gardens may actually worsen water quality in these lakes; this is because surface runoff to these lakes acts to dilute the phosphorus load from internal loading sources. If the internal loading rates in these lakes are reduced (via alum treatment or some other means), then the impact of the infiltration BMPs is an improvement to in-lake water quality. Table 9-6 shows the impact of infiltration BMPs on summer-average total phosphorus in each lake without any other BMPs and with an alum treatment applied to each lake. When the internal load in each lake is reduced, the infiltration BMPs generally reduce the total phosphorus concentration.

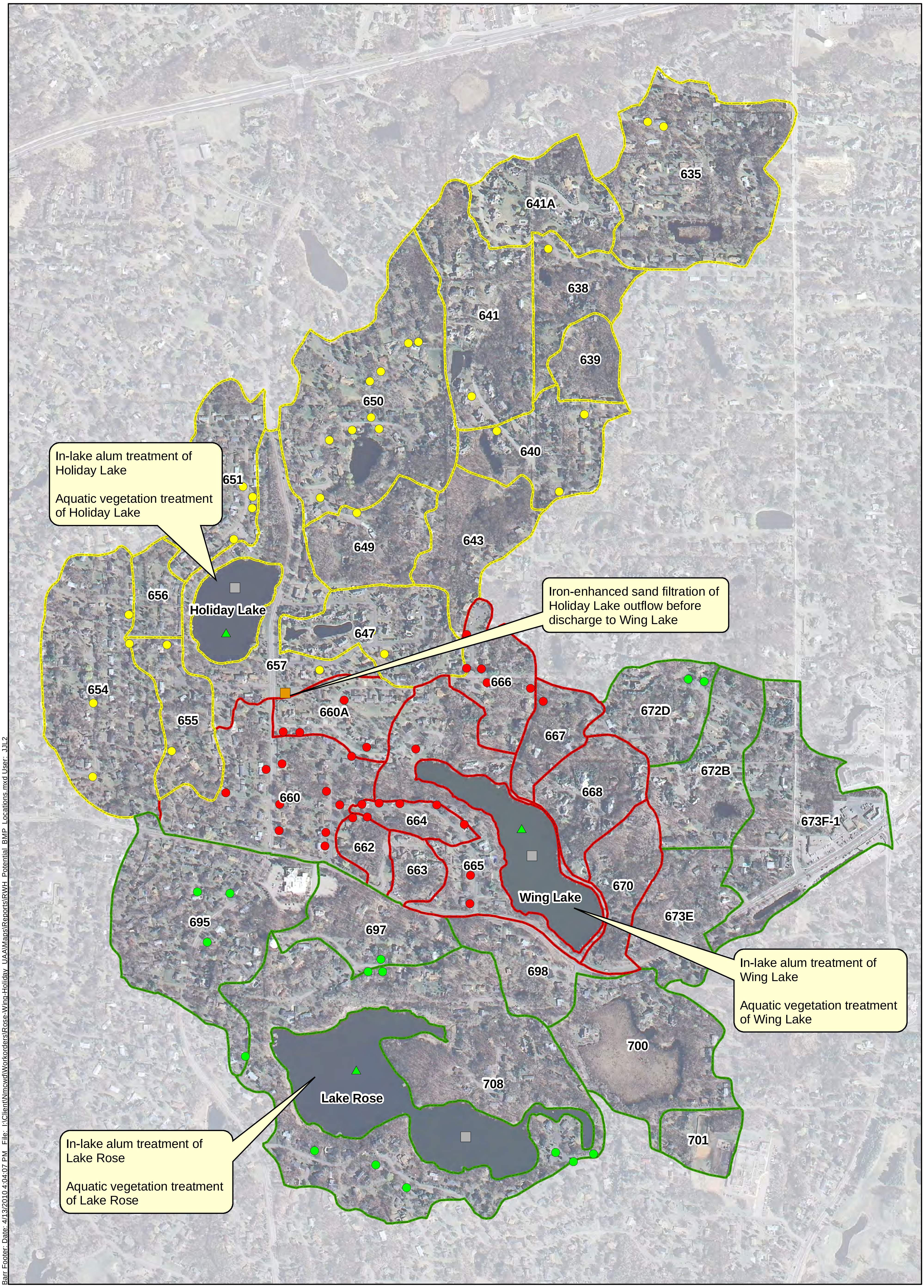
Table 9-6 Impact of Watershed Infiltration BMPs on Summer-average Total Phosphorus Concentrations in Lake Holiday, Wing Lake, and Lake Rose under Varying Climatic Conditions

Climatic Condition	Modeled Summer-average TP (µg/L) [1]				Summer[1] Total Phosphorus Load Reduction from Infiltration BMPs (lbs)
	Future Conditions (no BMPs)	With Infiltration BMPs	With In-Lake Alum Treatment	With Infiltration BMPs and In-Lake Alum Treatment	
Lake Holiday					
Wet (1992-1993)	203	204	161	161	0.9
Average (1998-1999)	191	190	161	160	0.8
Dry (2007-2008)	337	339	177	177	0.5
Wing Lake					
Wet (1992-1993)	112	111	74	71	1.3
Average (1998-1999)	119	134	73	76	1.2
Dry (2007-2008)	93	97	57	52	1.0
Lake Rose					
Wet (1992-1993)	106	107	58	56	0.6
Average (1998-1999)	85	85	50	48	0.6
Dry (2007-2008)	86	87	45	35	0.5

---

1 – Based on June 1 – September 30

It should be noted that the analysis described in this section assumes that residential rainwater gardens will be constructed on 62 of the 75 potential locations. In reality, it is often difficult to obtain high percentages of public participation. Intensive public education and involvement efforts are necessary to achieve the support necessary to successfully implement and maintain rainwater gardens, as the maintenance is often the responsibility of the property owner. Recent projects place the average cost of residential rainwater gardens at about $10 to $14 per square foot (based on residential rainwater gardens constructed in Burnsville, Minnesota). Approximately two thirds of that cost is construction, with the remaining cost going towards homeowner education, design, and construction supervision. Based on the 62 rainwater gardens included in the P8 modeling, the total cost for this BMP would range from $190,000 to $260,000. The cost range increases to $225,000 to $315,000 if all 75 sites are included.



In-lake alum treatment of Holiday Lake

Aquatic vegetation treatment of Holiday Lake

Iron-enhanced sand filtration of Holiday Lake outflow before discharge to Wing Lake

In-lake alum treatment of Wing Lake

Aquatic vegetation treatment of Wing Lake

In-lake alum treatment of Lake Rose

Aquatic vegetation treatment of Lake Rose

Potential BMPs Evaluated

- ▲ Aquatic Vegetation Treatment
- ■ In-Lake Alum Treatment
- ■ Iron-Enriched Sand Filter
- ● Infiltration (Holiday)
- ● Infiltration (Wing)
- ● Infiltration (Rose)

Subwatersheds

- 🟩 Lake Rose
- 🟥 Wing Lake
- 🟨 Lake Holiday

0 250 500 1,000
Feet

Figure 9-1

LOCATION OF POTENTIAL BMPS
WITHIN HOLIDAY-WING-ROSE WATERSHED

Holiday, Wing and Rose UAA
Nine Mile Creek Watershed District
Minnetonka, MN

9.2.2.1.2 Iron-Enhanced Sand Filtration between Lake Holiday and Wing Lake

Wing Lake receives between 13 and 34 percent of its summer total phosphorus loading from Lake Holiday (see Figure 6-10). Several scenarios were evaluated in which an iron-enhanced sand filter was used to treat the pumped outflow from Lake Holiday prior to its discharge to Wing Lake. Adding the iron-enhanced sand filter will reduce the external phosphorus load to Wing Lake, and ultimately, Lake Rose. These phosphorus loading reductions to Wing Lake translate into improvements in the summer-average total phosphorus, chlorophyll *a* concentrations, and Secchi disc transparency in the lake. Table 9-7 presents the reduction in summer phosphorus loading to Wing Lake from Lake Holiday due to the implementation of an iron-enhanced sand filter between the two lakes. The benefits are increased when additional BMPs are implemented in Lake Holiday. In addition, the iron-enhanced sand filter reduces the springtime phosphorus concentration in Wing Lake. This BMP was included in BMP Scenarios 15 and 16 (see Table 9-2).

This analysis assumes 0.5 acres of area is available for the sand filter. Currently, there is an empty residential lot between Lake Holiday and Wing Lake (see Figure 9-1). The city or NMCWD would need to purchase this parcel to construct a sand filter. Based on a 0.5 acre area, the sand filter may treat up to 3.5 cfs before bypassing the filter. The outflow from Lake Holiday is rarely above 3.5 cfs, allowing a 0.5 acre filter to treat over 90 percent of the outflow from Lake Holiday under wet climatic conditions. This BMP is estimated to have a capital cost of approximately $785,000 including engineering, design, and a 25 percent contingency (see Appendix G). Actual cost for the iron-enhanced sand filter would depend on the unique conditions at the site and a more precise determination of those costs would be necessary.

Table 9-7 Impact of Iron-enhanced Sand Filtration of Lake Holiday Outflow on Summer Total Phosphorus Loading to Wing Lake under Varying Climatic Conditions

Climatic Condition	Modeled Summer TP Load from Lake Holiday (lbs) [1]		Reduction in Summer[1] Total Phosphorus Load from Lake Holiday (lbs)
	Future Conditions without Additional BMPs (Scenario 1)	With Iron-enhanced sand Filtration (Scenario 16)	
Wing Lake			
Wet (1992-1993)	26.0	8.2	17.8
Average (1998-1999)	13.5	4.1	9.5
Dry (2007-2008)	11.0	3.3	7.7

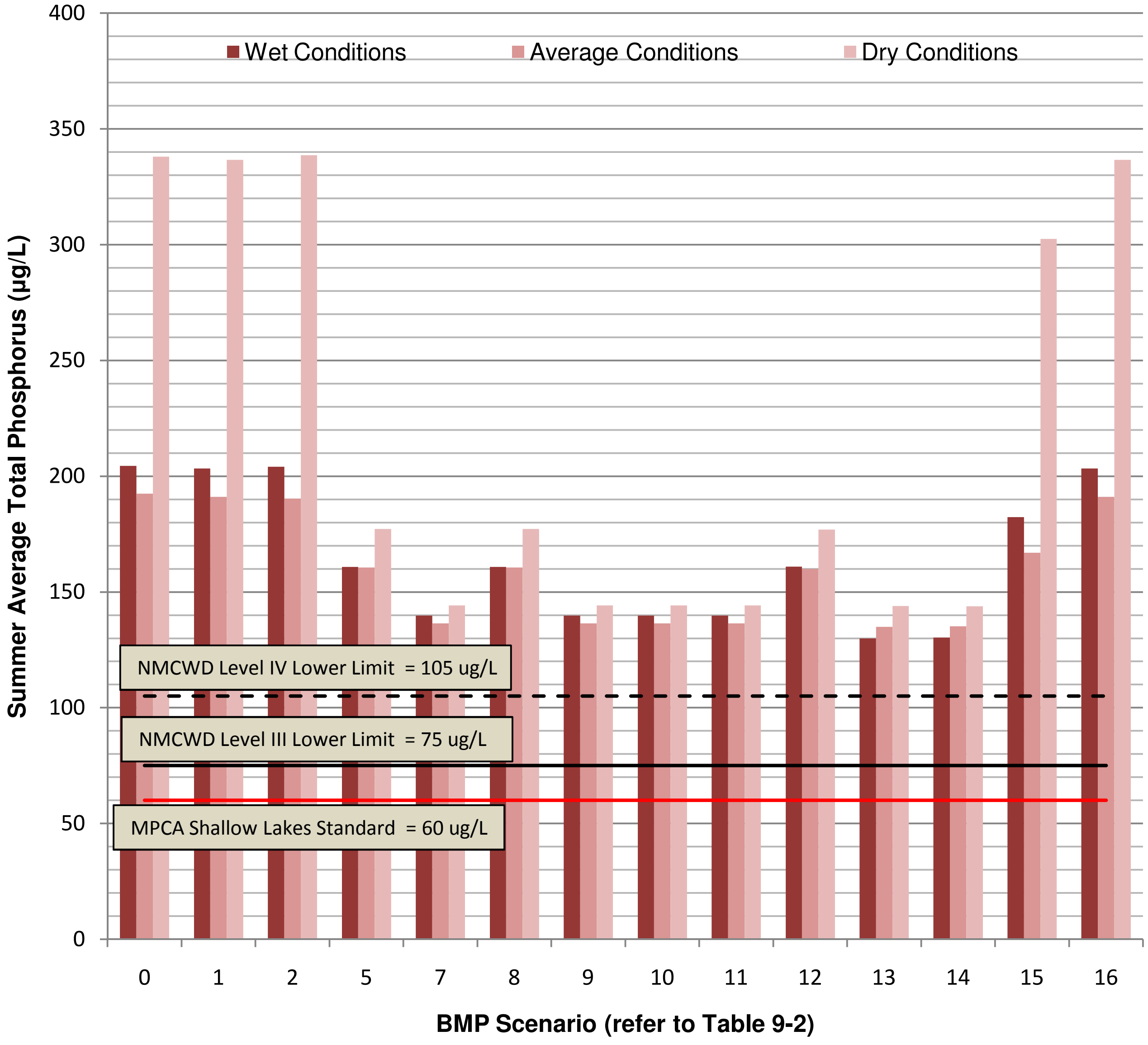
---

1 – Based on June 1 – September 30

8.2.2.1.2 Lake Holiday Outflow Bypass of Wing Lake and Lake Rose

Wing Lake receives between 13 and 34 percent of its summer total phosphorus loading from Lake Holiday (see Figure 6-10). It is possible that diverting flow from Lake Holiday away from Wing Lake and Lake Rose would improve water quality in the downstream lakes (BMP Scenario 17 in Table 9-2). This BMP was considered infeasible due to the negative impact on water surface elevations in Wing Lake and Lake Rose. Water levels in Lake Rose have been below average in recent years, and it is anticipated that there would be little support for management options that would further lower the average water surface elevation.

Figure 9-2
Modeled Summer-average Total Phosphorus in Lake Holiday under Varying BMP Scenarios and Climatic Conditions



Scenario 0: Existing Conditions

Scenario 1: Future Conditions

Scenario 2: Watershed Infiltration in Holiday-Wing-Rose watersheds

Scenario 5: Alum treatment in Holiday , Wing, and Rose

Scenario 7: Alum treatment in Holiday and Wing ; vegetation treatment in Holiday

Scenario 8: Alum treatment in Holiday, Wing, and Rose; vegetation treatment in Wing

Scenario 9: Alum treatment in Holiday and Wing; vegetation treatment in Holiday and Wing

Scenario 10: Alum treatment in Holiday, Wing, and Rose; vegetation treatment in Holiday and Wing

Scenario 11: Alum treatment in Holiday, Wing, and Rose; vegetation treatment in Holiday, Wing, and Rose

Scenario 12: Watershed Infiltration in Holiday-Wing-Rose watersheds; alum treatment in Holiday, Wing, and Rose

Scenario 13: Watershed Infiltration in Holiday-Wing-Rose watersheds; alum treatment in Holiday, Wing, and Rose; vegetation treatment in Holiday and Wing

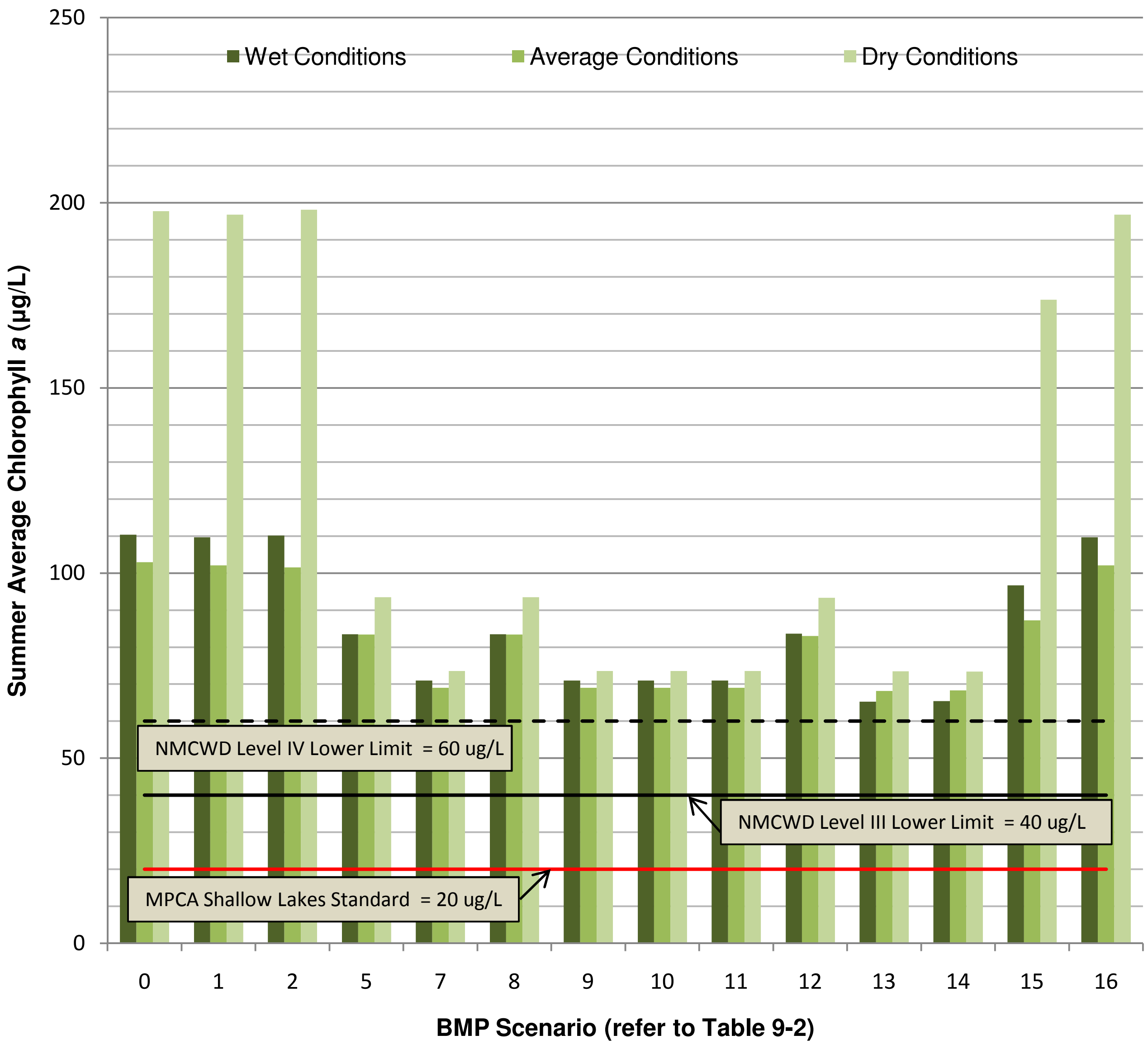
Scenario 14: Watershed Infiltration in Holiday watersheds; alum treatment in Holiday, Wing, and Rose; vegetation treatment in Holiday and Wing

Scenario 15: Iron-enhanced sand filtration of Holiday outflow; alum treatment in Wing and Rose; vegetation treatment in Holiday and Wing

Scenario 16: Iron-enhanced sand filtration of Holiday outflow; alum treatment in Wing and Rose

Figure 9-3

Modeled Summer-average Chlorophyll-*a* in Lake Holiday under Varying BMP Scenarios and Climatic Conditions



Scenario 0: Existing Conditions

Scenario 1: Future Conditions

Scenario 2: Watershed Infiltration in Holiday-Wing-Rose watersheds

Scenario 5: Alum treatment in Holiday , Wing, and Rose

Scenario 7: Alum treatment in Holiday and Wing ; vegetation treatment in Holiday

Scenario 8: Alum treatment in Holiday, Wing, and Rose; vegetation treatment in Wing

Scenario 9: Alum treatment in Holiday and Wing; vegetation treatment in Holiday and Wing

Scenario 10: Alum treatment in Holiday, Wing, and Rose; vegetation treatment in Holiday and Wing

Scenario 11: Alum treatment in Holiday, Wing, and Rose; vegetation treatment in Holiday, Wing, and Rose

Scenario 12: Watershed Infiltration in Holiday-Wing-Rose watersheds; alum treatment in Holiday, Wing, and Rose

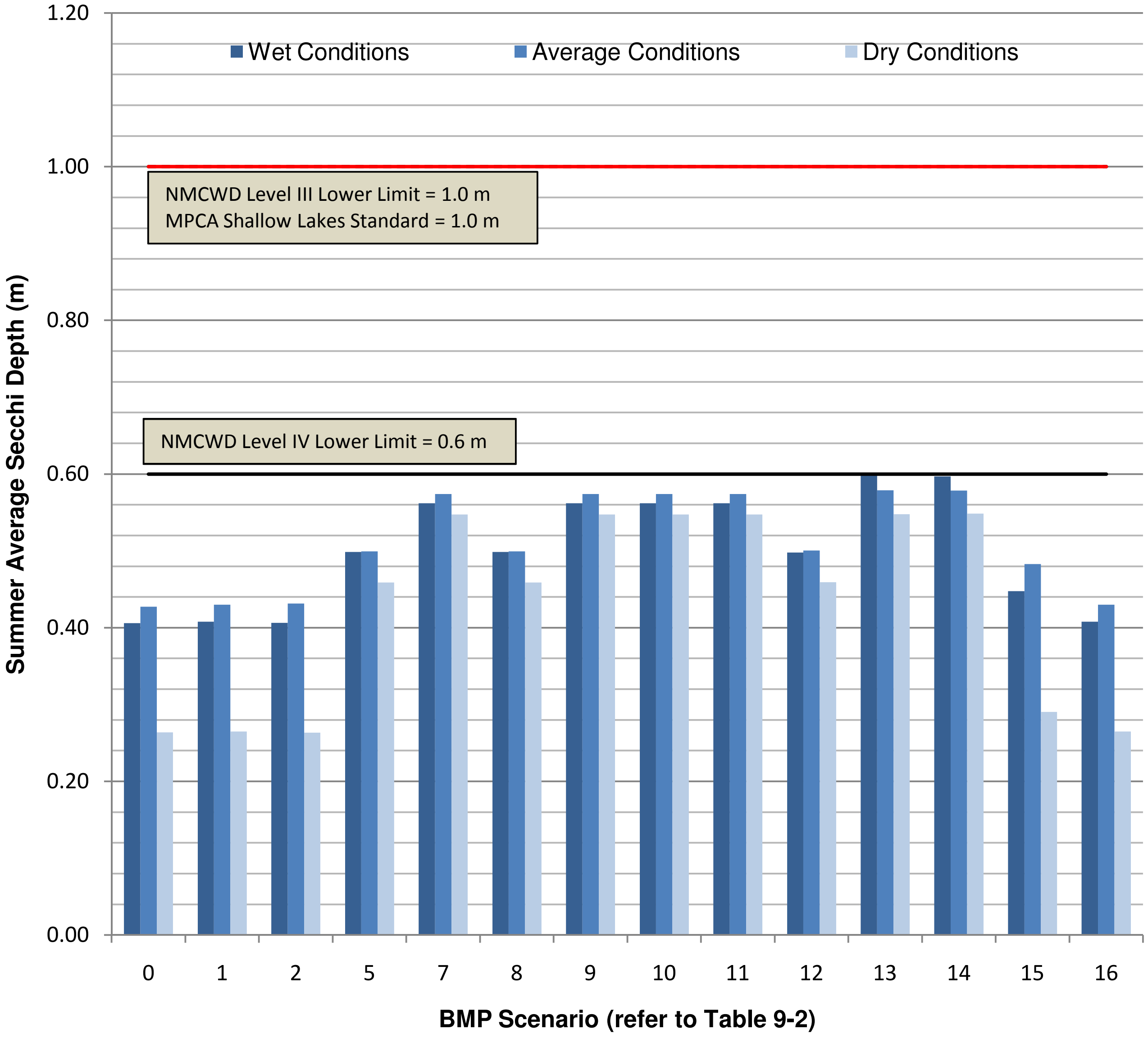
Scenario 13: Watershed Infiltration in Holiday-Wing-Rose watersheds; alum treatment in Holiday, Wing, and Rose; vegetation treatment in Holiday and Wing

Scenario 14: Watershed Infiltration in Holiday watersheds; alum treatment in Holiday, Wing, and Rose; vegetation treatment in Holiday and Wing

Scenario 15: Iron-enhanced sand filtration of Holiday outflow; alum treatment in Wing and Rose; vegetation treatment in Holiday and Wing

Scenario 16: Iron-enhanced sand filtration of Holiday outflow; alum treatment in Wing and Rose

Figure 9-4
Modeled Summer-average Secchi Disc Transparency in Lake Holiday under Varying BMP Scenarios and Climatic Conditions



Scenario 0: Existing Conditions

Scenario 1: Future Conditions

Scenario 2: Watershed Infiltration in Holiday-Wing-Rose watersheds

Scenario 5: Alum treatment in Holiday , Wing, and Rose

Scenario 7: Alum treatment in Holiday and Wing ; vegetation treatment in Holiday

Scenario 8: Alum treatment in Holiday, Wing, and Rose; vegetation treatment in Wing

Scenario 9: Alum treatment in Holiday and Wing; vegetation treatment in Holiday and Wing

Scenario 10: Alum treatment in Holiday, Wing, and Rose; vegetation treatment in Holiday and Wing

Scenario 11: Alum treatment in Holiday, Wing, and Rose; vegetation treatment in Holiday, Wing, and Rose

Scenario 12: Watershed Infiltration in Holiday-Wing-Rose watersheds; alum treatment in Holiday, Wing, and Rose

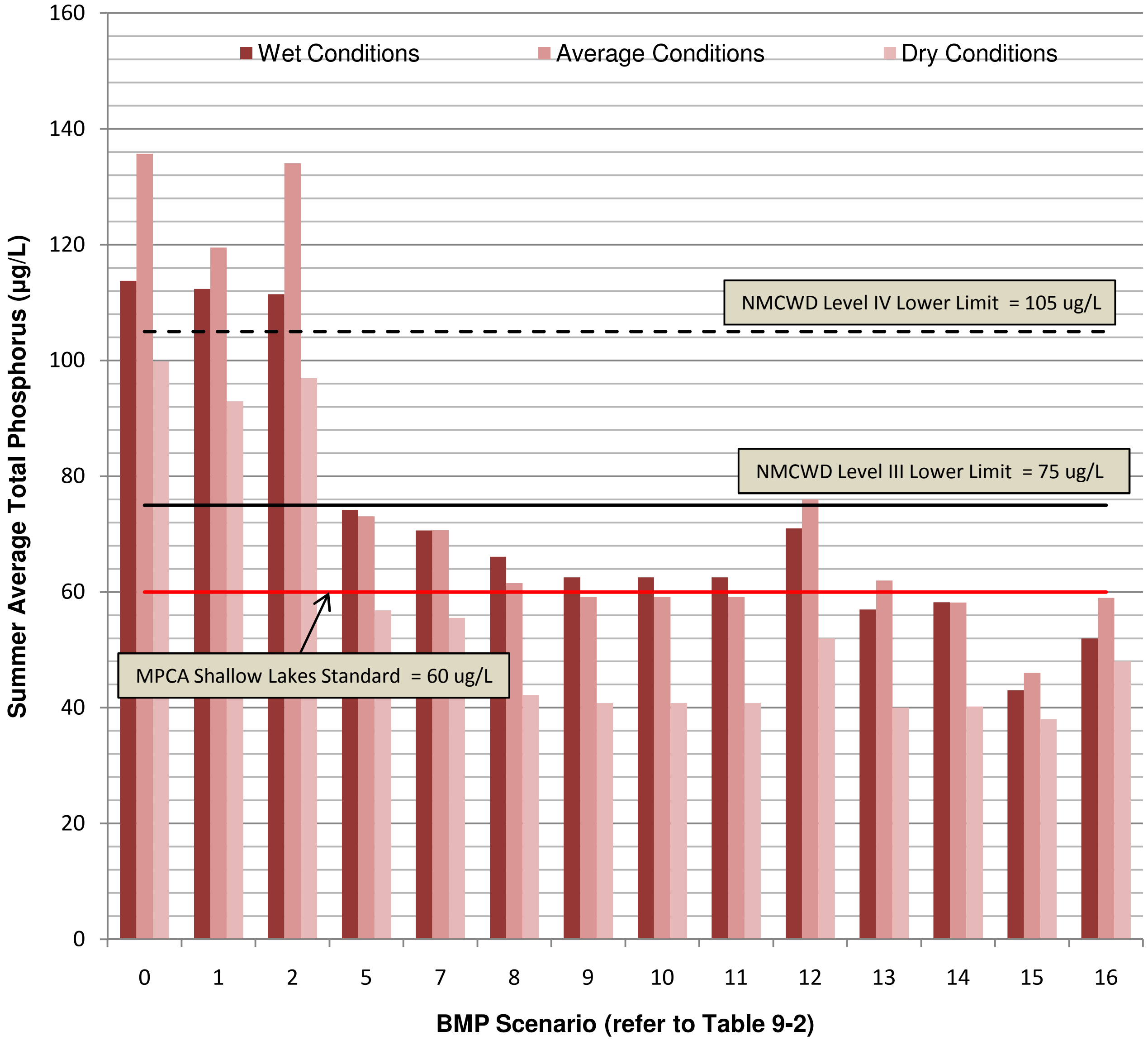
Scenario 13: Watershed Infiltration in Holiday-Wing-Rose watersheds; alum treatment in Holiday, Wing, and Rose; vegetation treatment in Holiday and Wing

Scenario 14: Watershed Infiltration in Holiday watersheds; alum treatment in Holiday, Wing, and Rose; vegetation treatment in Holiday and Wing

Scenario 15: Iron-enhanced sand filtration of Holiday outflow; alum treatment in Wing and Rose; vegetation treatment in Holiday and Wing

Scenario 16: Iron-enhanced sand filtration of Holiday outflow; alum treatment in Wing and Rose

Figure 9-5
Modeled Summer-average Total Phosphorus in Wing Lake under Varying BMP Scenarios and Climatic Conditions



Scenario 0: Existing Conditions

Scenario 1: Future Conditions

Scenario 2: Watershed Infiltration in Holiday-Wing-Rose watersheds

Scenario 5: Alum treatment in Holiday , Wing, and Rose

Scenario 7: Alum treatment in Holiday and Wing ; vegetation treatment in Holiday

Scenario 8: Alum treatment in Holiday, Wing, and Rose; vegetation treatment in Wing

Scenario 9: Alum treatment in Holiday and Wing; vegetation treatment in Holiday and Wing

Scenario 10: Alum treatment in Holiday, Wing, and Rose; vegetation treatment in Holiday and Wing

Scenario 11: Alum treatment in Holiday, Wing, and Rose; vegetation treatment in Holiday, Wing, and Rose

Scenario 12: Watershed Infiltration in Holiday-Wing-Rose watersheds; alum treatment in Holiday, Wing, and Rose

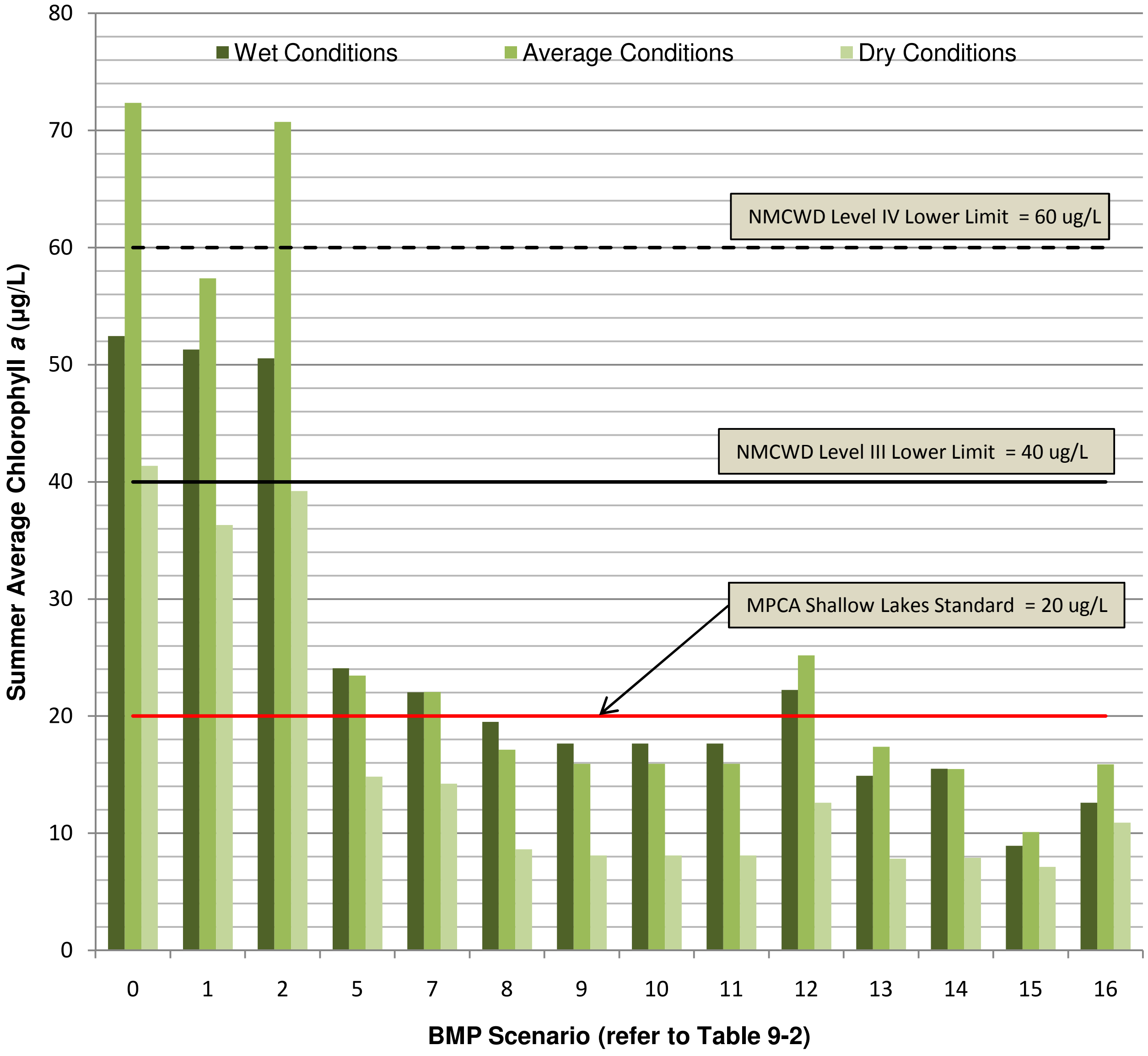
Scenario 13: Watershed Infiltration in Holiday-Wing-Rose watersheds; alum treatment in Holiday, Wing, and Rose; vegetation treatment in Holiday and Wing

Scenario 14: Watershed Infiltration in Holiday watersheds; alum treatment in Holiday, Wing, and Rose; vegetation treatment in Holiday and Wing

Scenario 15: Iron-enhanced sand filtration of Holiday outflow; alum treatment in Wing and Rose; vegetation treatment in Holiday and Wing

Scenario 16: Iron-enhanced sand filtration of Holiday outflow; alum treatment in Wing and Rose

Figure 9-6
Modeled Summer-average Chlorophyll-*a* in Wing Lake under Varying BMP Scenarios and Climatic Conditions



Scenario 0: Existing Conditions

Scenario 1: Future Conditions

Scenario 2: Watershed Infiltration in Holiday-Wing-Rose watersheds

Scenario 5: Alum treatment in Holiday , Wing, and Rose

Scenario 7: Alum treatment in Holiday and Wing ; vegetation treatment in Holiday

Scenario 8: Alum treatment in Holiday, Wing, and Rose; vegetation treatment in Wing

Scenario 9: Alum treatment in Holiday and Wing; vegetation treatment in Holiday and Wing

Scenario 10: Alum treatment in Holiday, Wing, and Rose; vegetation treatment in Holiday and Wing

Scenario 11: Alum treatment in Holiday, Wing, and Rose; vegetation treatment in Holiday, Wing, and Rose

Scenario 12: Watershed Infiltration in Holiday-Wing-Rose watersheds; alum treatment in Holiday, Wing, and Rose

Scenario 13: Watershed Infiltration in Holiday-Wing-Rose watersheds; alum treatment in Holiday, Wing, and Rose; vegetation treatment in Holiday and Wing

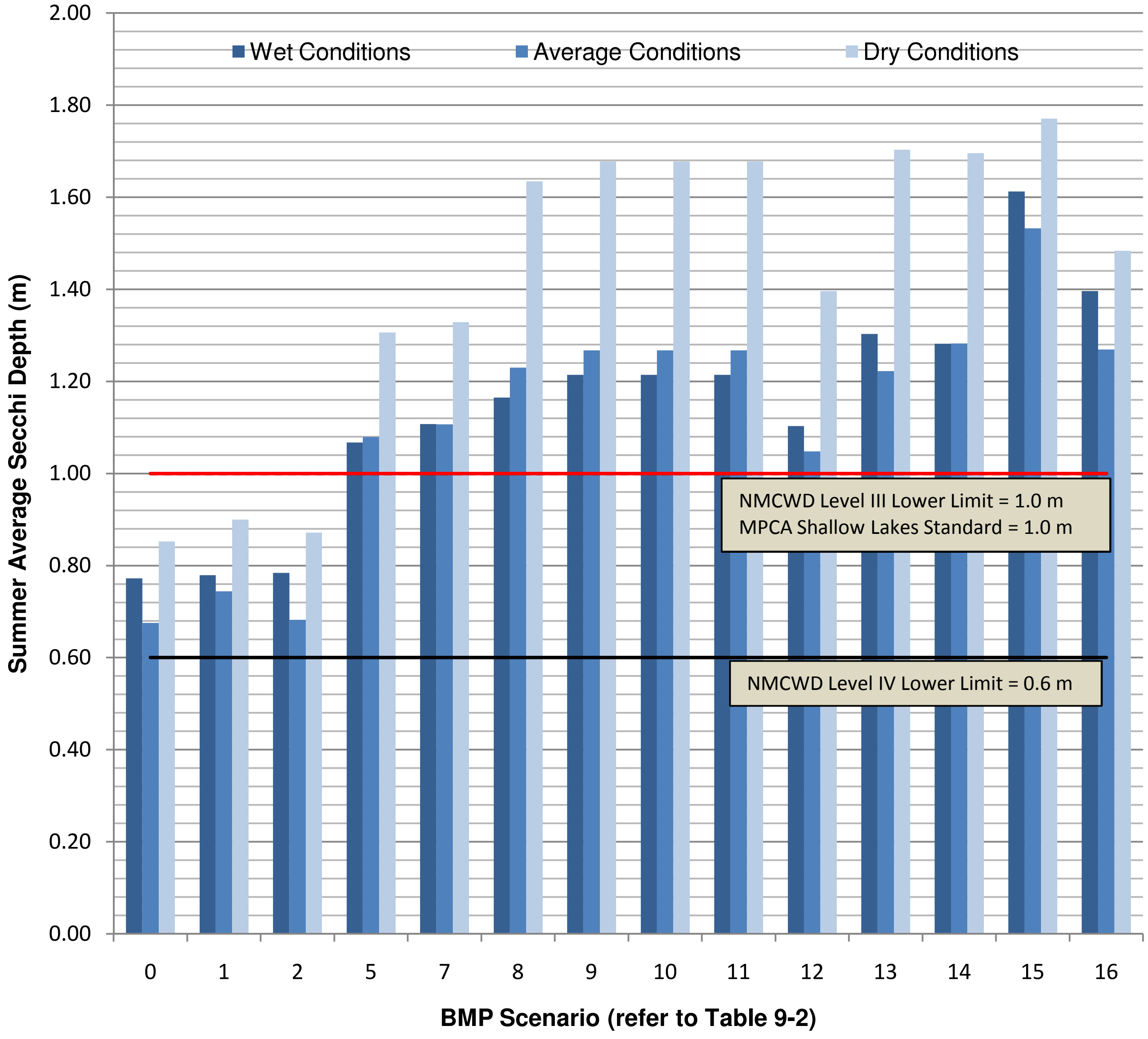
Scenario 14: Watershed Infiltration in Holiday watersheds; alum treatment in Holiday, Wing, and Rose; vegetation treatment in Holiday and Wing

Scenario 15: Iron-enhanced sand filtration of Holiday outflow; alum treatment in Wing and Rose; vegetation treatment in Holiday and Wing

Scenario 16: Iron-enhanced sand filtration of Holiday outflow; alum treatment in Wing and Rose

Figure 9-7

Modeled Summer-average Secchi Disc Transparency in Wing Lake under Varying BMP Scenarios and Climatic Conditions



NMCWD Level III Lower Limit = 1.0 m
MPCA Shallow Lakes Standard = 1.0 m

NMCWD Level IV Lower Limit = 0.6 m

Scenario 0: Existing Conditions

Scenario 1: Future Conditions

Scenario 2: Watershed Infiltration in Holiday-Wing-Rose watersheds

Scenario 5: Alum treatment in Holiday , Wing, and Rose

Scenario 7: Alum treatment in Holiday and Wing ; vegetation treatment in Holiday

Scenario 8: Alum treatment in Holiday, Wing, and Rose; vegetation treatment in Wing

Scenario 9: Alum treatment in Holiday and Wing; vegetation treatment in Holiday and Wing

Scenario 10: Alum treatment in Holiday, Wing, and Rose; vegetation treatment in Holiday and Wing

Scenario 11: Alum treatment in Holiday, Wing, and Rose; vegetation treatment in Holiday, Wing, and Rose

Scenario 12: Watershed Infiltration in Holiday-Wing-Rose watersheds; alum treatment in Holiday, Wing, and Rose

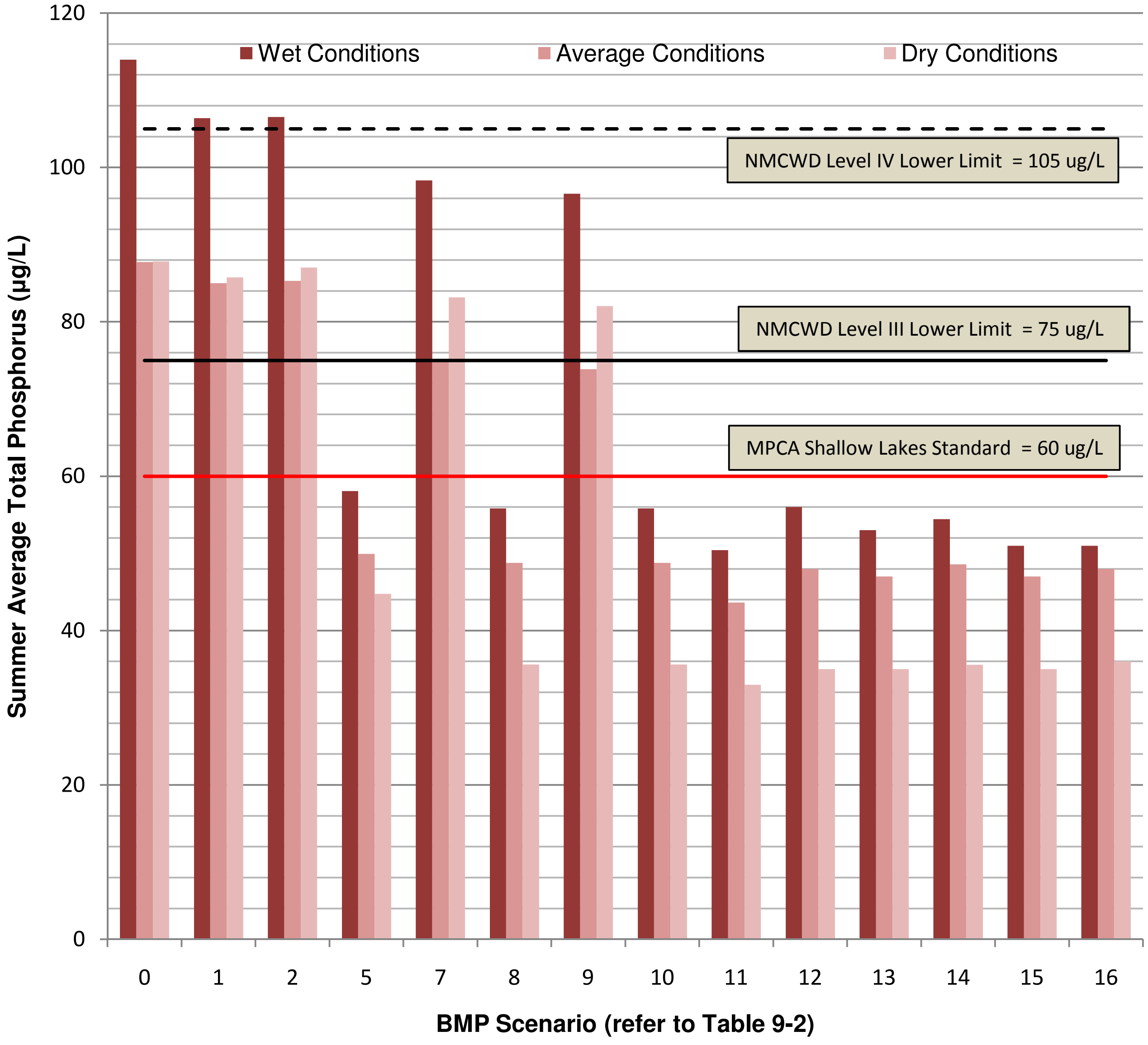
Scenario 13: Watershed Infiltration in Holiday-Wing-Rose watersheds; alum treatment in Holiday, Wing, and Rose; vegetation treatment in Holiday and Wing

Scenario 14: Watershed Infiltration in Holiday watersheds; alum treatment in Holiday, Wing, and Rose; vegetation treatment in Holiday and Wing

Scenario 15: Iron-enhanced sand filtration of Holiday outflow; alum treatment in Wing and Rose; vegetation treatment in Holiday and Wing

Scenario 16: Iron-enhanced sand filtration of Holiday outflow; alum treatment in Wing and Rose

Figure 9-8
Modeled Summer-average Total Phosphorus in Lake Rose under Varying BMP Scenarios and Climatic Conditions



Scenario 0: Existing Conditions

Scenario 1: Future Conditions

Scenario 2: Watershed Infiltration in Holiday-Wing-Rose watersheds

Scenario 5: Alum treatment in Holiday , Wing, and Rose

Scenario 7: Alum treatment in Holiday and Wing ; vegetation treatment in Holiday

Scenario 8: Alum treatment in Holiday, Wing, and Rose; vegetation treatment in Wing

Scenario 9: Alum treatment in Holiday and Wing; vegetation treatment in Holiday and Wing

Scenario 10: Alum treatment in Holiday, Wing, and Rose; vegetation treatment in Holiday and Wing

Scenario 11: Alum treatment in Holiday, Wing, and Rose; vegetation treatment in Holiday, Wing, and Rose

Scenario 12: Watershed Infiltration in Holiday-Wing-Rose watersheds; alum treatment in Holiday, Wing, and Rose

Scenario 13: Watershed Infiltration in Holiday-Wing-Rose watersheds; alum treatment in Holiday, Wing, and Rose; vegetation treatment in Holiday and Wing

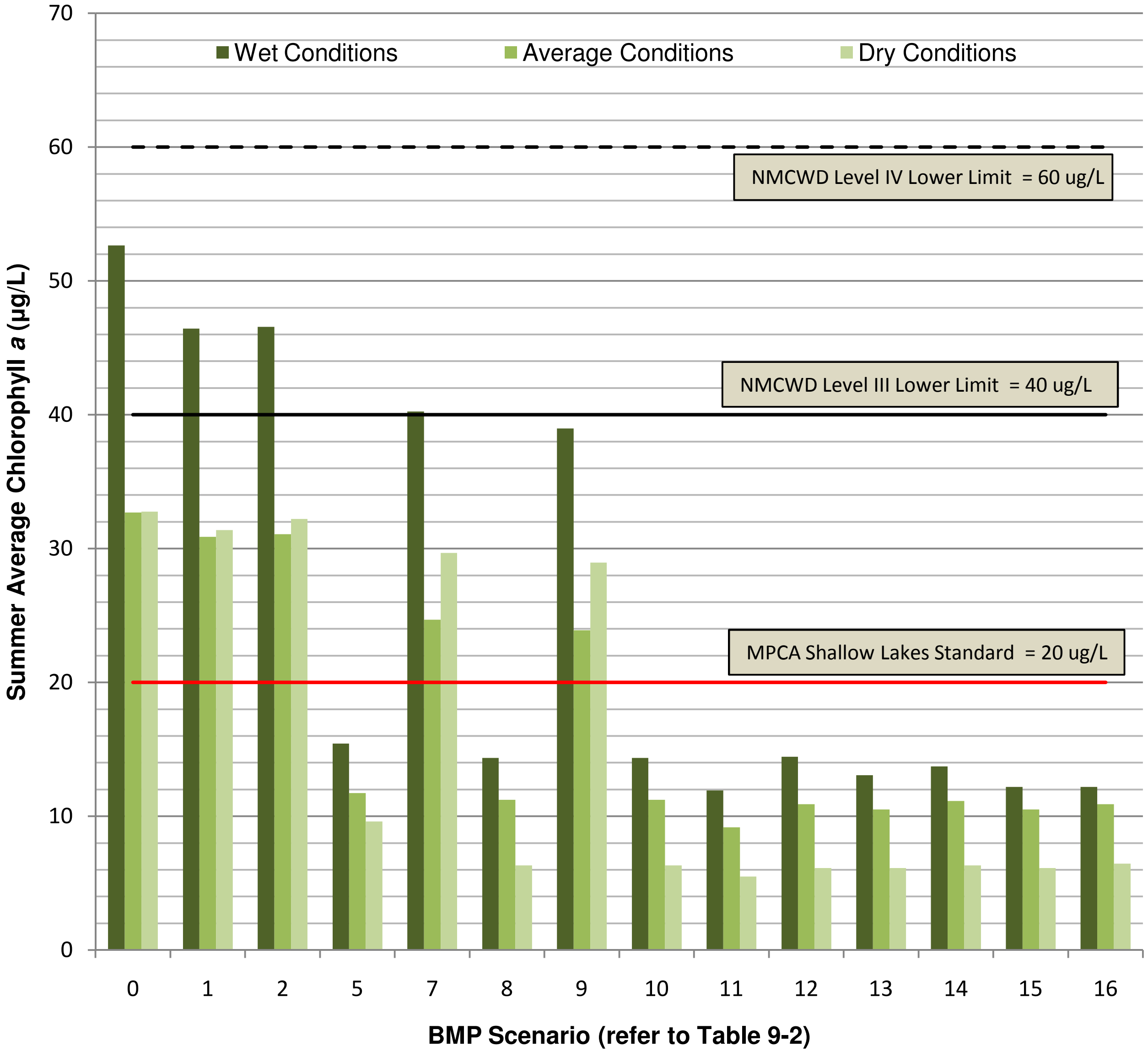
Scenario 14: Watershed Infiltration in Holiday watersheds; alum treatment in Holiday, Wing, and Rose; vegetation treatment in Holiday and Wing

Scenario 15: Iron-enhanced sand filtration of Holiday outflow; alum treatment in Wing and Rose; vegetation treatment in Holiday and Wing

Scenario 16: Iron-enhanced sand filtration of Holiday outflow; alum treatment in Wing and Rose

Figure 9-9

Modeled Summer-average Chlorophyll-*a* in Lake Rose under Varying BMP Scenarios and Climatic Conditions



Scenario 0: Existing Conditions

Scenario 1: Future Conditions

Scenario 2: Watershed Infiltration in Holiday-Wing-Rose watersheds

Scenario 5: Alum treatment in Holiday , Wing, and Rose

Scenario 7: Alum treatment in Holiday and Wing ; vegetation treatment in Holiday

Scenario 8: Alum treatment in Holiday, Wing, and Rose; vegetation treatment in Wing

Scenario 9: Alum treatment in Holiday and Wing; vegetation treatment in Holiday and Wing

Scenario 10: Alum treatment in Holiday, Wing, and Rose; vegetation treatment in Holiday and Wing

Scenario 11: Alum treatment in Holiday, Wing, and Rose; vegetation treatment in Holiday, Wing, and Rose

Scenario 12: Watershed Infiltration in Holiday-Wing-Rose watersheds; alum treatment in Holiday, Wing, and Rose

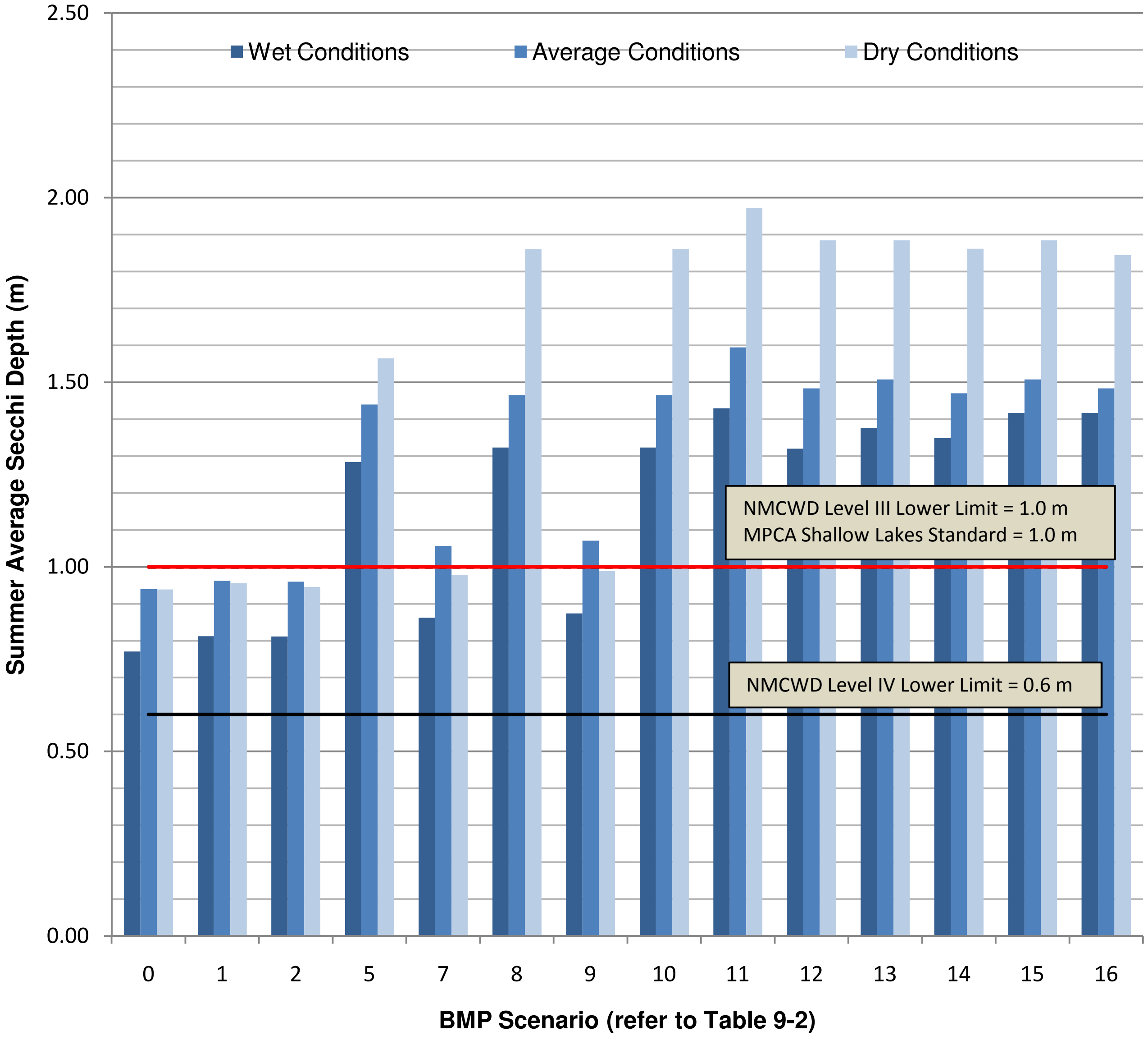
Scenario 13: Watershed Infiltration in Holiday-Wing-Rose watersheds; alum treatment in Holiday, Wing, and Rose; vegetation treatment in Holiday and Wing

Scenario 14: Watershed Infiltration in Holiday watersheds; alum treatment in Holiday, Wing, and Rose; vegetation treatment in Holiday and Wing

Scenario 15: Iron-enhanced sand filtration of Holiday outflow; alum treatment in Wing and Rose; vegetation treatment in Holiday and Wing

Scenario 16: Iron-enhanced sand filtration of Holiday outflow; alum treatment in Wing and Rose

Figure 9-10
Modeled Summer-average Secchi Disc Transparency in Lake Rose under Varying BMP Scenarios and Climatic Conditions



Scenario 0: Existing Conditions

Scenario 1: Future Conditions

Scenario 2: Watershed Infiltration in Holiday-Wing-Rose watersheds

Scenario 5: Alum treatment in Holiday , Wing, and Rose

Scenario 7: Alum treatment in Holiday and Wing ; vegetation treatment in Holiday

Scenario 8: Alum treatment in Holiday, Wing, and Rose; vegetation treatment in Wing

Scenario 9: Alum treatment in Holiday and Wing; vegetation treatment in Holiday and Wing

Scenario 10: Alum treatment in Holiday, Wing, and Rose; vegetation treatment in Holiday and Wing

Scenario 11: Alum treatment in Holiday, Wing, and Rose; vegetation treatment in Holiday, Wing, and Rose

Scenario 12: Watershed Infiltration in Holiday-Wing-Rose watersheds; alum treatment in Holiday, Wing, and Rose

Scenario 13: Watershed Infiltration in Holiday-Wing-Rose watersheds; alum treatment in Holiday, Wing, and Rose; vegetation treatment in Holiday and Wing

Scenario 14: Watershed Infiltration in Holiday watersheds; alum treatment in Holiday, Wing, and Rose; vegetation treatment in Holiday and Wing

Scenario 15: Iron-enhanced sand filtration of Holiday outflow; alum treatment in Wing and Rose; vegetation treatment in Holiday and Wing

Scenario 16: Iron-enhanced sand filtration of Holiday outflow; alum treatment in Wing and Rose

9.2.2.2 In-Lake Best Management Practices

9.2.2.2.1 In-Lake Alum Treatment of Lake Holiday

The results of the sediment core analysis and in-lake model calibration suggest that internal loading may be impacting summer-average TP concentrations in Lake Holiday. Due to its position in the watershed, internal loading in Lake Holiday can have a cascade effect on summer-average TP concentrations in Wing Lake and Lake Rose. Alum (aluminum sulfate) treatment of Lake Holiday is expected to diminish the extent of the internal loading, resulting in significant long-term declines in summer-average TP concentrations. Alum removes 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. Over time, the effectiveness of the thin alum blanket on the sediment surface diminishes. It is reasonable to assume that for Lake Holiday, an alum treatment would be conducted at approximately 10-year intervals. If necessary, the treatment interval could be adjusted based on the results of ongoing water quality monitoring.

An in-lake alum treatment of Lake Holiday was considered in several of the BMP scenarios analyzed (see Table 9-2). Following an in-lake application of alum, a reduction in internal loading rates of 80 percent was assumed (Welch and Cook, 1999). This reduction in internal phosphorus release would reduce the summer phosphorus loading to Lake Holiday by 13 to 32 lbs (depending upon climatic conditions). In addition, the summer phosphorus loading to Wing Lake from Lake Holiday would be reduced by up to 4 lbs in wet conditions (see Table 9-8). Associated with the total phosphorus reductions would be a decline in the chlorophyll *a* levels and improvement in the water clarity.

Table 9-8 Impact of In-lake Alum Treatment of Lake Holiday Outflow on Summer Total Phosphorus Loading to Lake Holiday and Wing Lake under Varying Climatic Conditions

Climatic Condition	Modeled Summer[1] TP Load (lbs)		Reduction in Summer[1] Total Phosphorus Load (lbs)
	Future Conditions without Alum Treatment (BMP Scenario 1)	With Lake Holiday Alum Treatment (BMP Scenario 2)	
Internal Loading in Lake Holiday			
Wet (1992-1993)	21.0	2.5	18.5
Average (1998-1999)	14.8	2.0	12.8
Dry (2007-2008)	39.2	7.4	31.7
Upstream Loading to Wing Lake from Lake Holiday			
Wet (1992-1993)	25.9	21.6	4.3
Average (1998-1999)	11.8	11.8	0.1
Dry (2007-2008)	7.5	6.2	1.2

1 – Based on June 1 – September 30

Based on the sediment core analysis for Lake Holiday and the lake's surface area, the estimated cost of a whole-lake alum treatment is approximately $24,000. The alum treatment may need to be repeated in the future to maintain the predicted water quality.

9.2.2.2.2 In-Lake Alum Treatment of Wing Lake

Calibration of the Wing Lake in-lake models for varying climatic conditions demonstrate that internal loading contributes approximately 24 to 29 lbs of TP during the summer months, or about 32 to 43 percent of the total summer phosphorus load to the lake. Alum (aluminum sulfate) treatment of Wing Lake is expected to diminish the extent of the internal loading, resulting in significant long-term declines in summer-average TP concentrations. Alum removes 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. Over time, the effectiveness of the thin alum blanket on the sediment surface diminishes. It is reasonable to assume that for Wing Lake, an alum treatment would be conducted at approximately 10-year intervals. If necessary, the treatment interval could be adjusted based on the results of ongoing water quality monitoring.

An in-lake alum treatment of Wing Lake was considered as a potential BMP in several of the BMP scenarios analyzed (see Table 9-2). Following an in-lake application of alum, a reduction in internal loading rates of 80 percent was assumed for this analysis (Welch and Cook, 1999). This reduction in internal phosphorus release would reduce the summer phosphorus loading to Wing Lake by 13 to 32 lbs depending upon climatic conditions (see Table 9-9). Associated with the total phosphorus reductions would be a decline in the chlorophyll *a* levels and improvement in the water clarity.

Table 9-9 Impact of In-lake Alum Treatment of Wing Lake on Summer Total Phosphorus Loading

Climatic Condition	Modeled Summer[1] TP Load (lbs)		Reduction in Summer[1] Total Phosphorus Load (lbs)
	Future Conditions without Alum Treatment (BMP Scenario 1)	With Wing Lake Alum Treatment	
Internal Loading in Wing Lake			
Wet (1992-1993)	24.4	4.9	19.6
Average (1998-1999)	29.2	5.8	23.4
Dry (2007-2008)	25.4	5.5	20.0

---

1 – Based on June 1 – September 30

Based on the sediment core analysis for Wing Lake and the lake's surface area, the estimated cost of a whole-lake alum treatment is approximately $25,000. This cost is similar to the cost estimate for

Lake Holiday, owing to a slightly larger lake size, but lower required alum dose. The alum treatment may need to be repeated in the future to maintain the predicted water quality. In addition, the presence of benthivorous fish, such as carp and bullhead, may reduce the effectiveness and longevity of an in-lake alum treatment because of their tendency to stir up the lake bottom. It is unknown to what extent these fish may inhabit Wing Lake.

9.2.2.2.3 In-Lake Alum Treatment of Lake Rose

Sediment core data indicates that internal loading is a significant source of phosphorus to Lake Rose. This was verified during the calibration of the Lake Rose in-lake models, which demonstrate that internal loading contributes up to 91 lbs of TP during the summer months, or up to 75 percent of the total summer phosphorus load to the lake. Alum (aluminum sulfate) treatment of Lake Rose is expected to diminish the extent of the internal loading, resulting in significant long-term declines in summer-average TP concentrations. Similar to Lake Holiday and Wing Lake, it is reasonable to assume that for Lake Rose, the alum treatment would be conducted at approximately 10-year intervals. If necessary, the treatment interval could be adjusted based on the results of ongoing water quality monitoring.

An in-lake alum treatment of Lake Rose was considered as a potential BMP in several of the BMP scenarios analyzed (see Table 9-2). Following an in-lake application of alum, a reduction in internal loading rates of 80 percent was assumed for this analysis (Welch and Cook, 1999). This reduction in internal phosphorus release would reduce the summer phosphorus loading to Wing Lake by 13 to 32 lbs depending upon climatic conditions (see Table 9-10). Associated with the total phosphorus reductions would be a decline in the chlorophyll *a* levels and improvement in the water clarity.

Table 9-10 Impact of In-lake Alum Treatment of Lake Rose on Summer Total Phosphorus Loading

Climatic Condition	Modeled Summer[1] TP Load (lbs)		Reduction in Summer[1] Total Phosphorus Load (lbs)
	Future Conditions without Alum Treatment (BMP Scenario 1)	With Lake Rose Alum Treatment	
Internal Loading in Lake Rose			
Wet (1992-1993)	48.0	9.6	38.4
Average (1998-1999)	33.2	6.7	26.6
Dry (2007-2008)	91.3	18.9	72.4

---

[1] – Based on June 1 – September 30

Based on the sediment core analysis for Lake Rose and the lakes surface area, the estimated cost of a whole-lake alum treatment is $104,000. This cost is greater than Lake Holiday and Wing Lake due to higher required alum dosing and the larger lake surface area. The alum treatment may need to be repeated in the future to maintain the predicted water quality. In addition, the presence of benthivorous fish, such as carp and bullhead, may reduce the effectiveness and longevity of an in-lake alum treatment because of their tendency to stir up the lake bottom. It is unknown to what extent these fish may inhabit Lake Rose.

9.2.2.2.4 Aquatic Vegetation Treatment of Lake Holiday

In Lake Holiday, Curlyleaf pondweed is present in high concentrations. Calibration of the in-lake models suggest Curlyleaf pondweed contributes 8 lbs of phosphorus to Lake Holiday during the summer or 13 to 26 percent of summer phosphorus loading depending upon climate conditions. Reducing the coverage of Curlyleaf pondweed in Lake Holiday is expected to have a benefit on phosphorus concentrations in Lake Holiday and downstream. Aquatic vegetation treatment of Lake Holiday was considered in several of the BMP scenarios analyzed (see Table 9-2).

Controlling Curlyleaf pondweed can be done by herbicide treatments, mechanical harvesting, or controlled fall and winter draw-downs (see Section 9.1.3.4). Herbicide treatments are generally more effective at eradicating the plant than mechanical methods. MDNR regulations limit the extent of the lake that can be treated in any year to 15 percent of the littoral area unless otherwise approved by the MDNR. A survey of residents who live on or near Lake Holiday (see Section 2.1.1) indicated that the majority of respondents are not opposed to the use of chemicals to control aquatic vegetation in Lake Holiday. Mechanical harvesting could be used to control aquatic vegetation in Lake Holiday, and may be applied to as much as 50 percent of the littoral area in a given year. However, mechanical harvesting in Lake Holiday is not recommended due to limited lake access, the potential to disrupt lake bottom sediments with high phosphorus release rates, and the general ineffectiveness of the method for eliminating Curlyleaf pondweed from the lake. Controlled fall and winter draw-downs inhibit Curlyleaf pondweed growth by freezing and desiccating Curlyleaf pondweed turions. Controlled draw-downs may not be favorable to residents due to the temporary impacts on downstream water levels in Wing Lake and Lake Rose.

The in-lake model analysis of these BMPs assumed a 50 percent reduction in Curlyleaf pondweed areal coverage within Lake Holiday achieved by chemical treatment. Reducing the coverage of Curlyleaf pondweed by 50 percent reduces the summer total phosphorus loading by 4 lbs (see Table 9-11). If aquatic vegetation management is applied to Lake Holiday, repeated treatment over several years will likely be necessary to achieve a significant reduction in Curlyleaf pondweed populations. The five year cost of repeated chemical treatments is estimated to be $184,000, which includes costs for obtaining permits from the MDNR and the extensive monitoring program required to evaluate the effectiveness of the treatments (see Appendix G). The majority of the estimated cost is related to the pre- and post-treatment water quality monitoring, biological monitoring, and reporting required by the MDNR.

Table 9-11 Impact of Aquatic Vegetation Treatment on Summer Total Phosphorus Loading to Lake Holiday, Wing Lake, and Lake Rose under Varying Climatic Conditions

Climatic Condition	Modeled Summer[1] TP Load (lbs) from Aquatic Vegetation		Reduction in Summer[1] Total Phosphorus Load (lbs)
	Future Conditions without Vegetation Treatment (BMP Scenario 1)	Future Conditions With Vegetation Treatment	
Lake Holiday			
Wet (1992-1993)	8.1	4.0	4.0
Average (1998-1999)	8.1	4.0	4.0
Dry (2007-2008)	8.1	4.0	4.0
Wing Lake			
Wet (1992-1993)	9.2	4.6	4.6
Average (1998-1999)	9.2	4.6	4.6
Dry (2007-2008)	9.2	4.6	4.6
Lake Rose			
Wet (1992-1993)	7.8	3.9	3.9
Average (1998-1999)	7.8	3.9	3.9
Dry (2007-2008)	7.7	3.9	3.9

---

1 – Based on June 1 – September 30

9.2.2.2.5 Aquatic Vegetation Treatment of Wing Lake

In Wing Lake, Curlyleaf pondweed contributes about 9 lbs of phosphorus to the lake during the summer (or 12 to 16 percent of summer phosphorus loading depending upon climate conditions). Reducing the coverage of Curlyleaf pondweed in Wing Lake will benefit summer phosphorus concentrations in the lake and have residual benefits in Lake Rose. Aquatic vegetation treatment of Wing Lake was considered in several of the BMP scenarios analyzed (see Table 9-2).

Controlling Curlyleaf pondweed can be done by herbicide treatments applied from a barge or boat, mechanical harvesting, or controlled fall and winter draw-downs (see Section 9.1.3.4). Mechanical harvesting is not recommended due to the potential impacts on ecologically-beneficial species present in Wing Lake (including coontail and waterlily). Draw-downs may also be impractical due to impacts on Lake Rose and the need to redirect the outflow from Lake Holiday. The in-lake model analysis of these BMPs assumed a 50 percent reduction in Curlyleaf pondweed areal coverage within Wing Lake by chemical treatment. Reducing the coverage of Curlyleaf pondweed by 50 percent reduces the summer total phosphorus loading by 4.6 lbs (see Table 9-11).

If aquatic vegetation management is applied to Wing Lake, repeated treatment over several years may be necessary to achieve a significant reduction in Curlyleaf pondweed populations. The five year cost of repeated herbicide treatments is estimated to be $195,000, which includes costs for obtaining permits from the MDNR and monitoring the effectiveness of treatments (see Appendix G). The majority of the estimated cost is related to the extensive pre- and post-treatment monitoring and reporting program required by the MDNR when conducting a whole lake treatment.

9.2.2.2.6 Aquatic Vegetation Treatment of Lake Rose

In Lake Rose, Curlyleaf pondweed contributes about 8 lbs of phosphorus to the lake during the summer (or 6 to 10 percent of summer phosphorus loading depending upon climate conditions). Reducing the coverage of Curlyleaf pondweed in Lake Rose will benefit summer phosphorus concentrations in the lake. Aquatic vegetation treatment of Lake Rose was considered in several of the BMP scenarios analyzed (see Table 9-2).

Controlling Curlyleaf pondweed can be done by herbicide treatments applied from a barge or boat, mechanical harvesting, or controlled fall and winter draw-downs (see Section 9.1.3.4). Mechanical harvesting is not recommended due to the potential impacts on ecologically-beneficial species present in Lake Rose (including coontail and waterlily) and limited lake access. Draw-downs may also be impractical due to the desire of residents to maintain higher water levels in Lake Rose. The in-lake model analysis of these BMPs assumed a 50 percent reduction in Curlyleaf pondweed areal coverage within Lake Rose achieved via chemical treatment. Reducing the coverage of Curlyleaf pondweed by 50 percent reduces the summer total phosphorus loading by about 4 lbs (see Table 9-11).

If aquatic vegetation management is applied to Lake Rose, repeated treatment over several years may be necessary to achieve a significant reduction in Curlyleaf pondweed populations. The five year cost of repeated chemical treatments is estimated to be $221,000. This cost includes obtaining permits from the MDNR and monitoring the treatments (see Appendix G). The majority of the estimated cost is related to the extensive pre- and post-treatment monitoring and reporting program required by the MDNR when conducting a whole lake treatment.

9.3 BMP Scenarios

Several of the potential BMPs listed in Section 9.2 were combined into the BMP scenarios presented in Table 9-2. The in-lake models were used to predict summer-average total phosphorus, summer-average chlorophyll *a*, and summer-average Secchi disc transparency in Lake Holiday, Wing Lake, and Lake Rose under varying climatic conditions. The results of that analysis are presented in Figures 9-2 through 9-10 for selected BMP scenarios. Those combinations of BMPs which result in modeled water quality in Wing Lake and Lake Rose that meet the MPCA's shallow lakes criteria are discussed in this section along with the associated costs of those BMP scenarios.

9.3.1.1 BMP Scenario 8 – Alum Treatment in Lake Holiday, Wing Lake, and Lake Rose; Aquatic Vegetation Treatment in Wing Lake

This scenario includes in-lake alum treatments in Lake Holiday, Wing Lake, and Lake Rose, as well as five years of chemical treatment of aquatic vegetation in Wing Lake. Based on the water quality analysis of the BMP Scenario 8, this combination will provide significant water quality improvement to all three lakes. As shown in Table 9-12, this combination of BMPs would reduce loading to Lake Holiday by 8 to 30 lbs depending upon climate conditions. Summer loading to Wing Lake would be reduced by about 30 lbs for all modeled climatic conditions. Summer total phosphorus loads in Lake Rose would be reduced by between 32 and 77 lbs depending upon climatic conditions. The reduced phosphorus load would result in a reduction in summer-average total phosphorus concentration of approximately 40-170 µg/L for Lake Holiday, 40-90 µg/L for Wing Lake, and approximately 40-50 µg/L for Lake Rose (see Figures 9-2 through 9-10). The estimated total capital cost for this BMP combination is approximately $348,000.

Table **9-12** **Summer Total Phosphorus Loading Reduction in Lake Holiday, Wing Lake, and Lake Rose with BMP Scenario 8 under Varying Climatic Conditions**

Climatic Condition	Modeled Summer Total Phosphorus Load (lbs)		Load Decrease (lbs)	Percent Decrease (%)
	Future Conditions (no additional BMPs)	BMP Scenario 8		
Lake Holiday				
Wet (1992-1993)	48.3	38.4	9.9	20.5
Average (1998-1999)	38.7	30.8	7.9	20.4
Dry (2007-2008)	61.7	32.0	29.7	48.1
Wing Lake				
Wet (1992-1993)	76.4	47.8	28.6	37.4
Average (1998-1999)	67.0	37.3	29.7	44.3
Dry (2007-2008)	60.3	29.5	30.8	51.1
Lake Rose				
Wet (1992-1993)	98.6	51.6	47.0	47.7
Average (1998-1999)	78.6	46.6	32.0	40.7
Dry (2007-2008)	137.1	60.1	77.0	56.2

---

1 – Based on June 1 – September 30

9.3.1.2 BMP Scenario 10 – Alum Treatment in Lake Holiday, Wing Lake, and Lake Rose; Aquatic Vegetation Treatment in Lake Holiday and Wing Lake

This scenario is identical to BMP Scenario 8, with the addition of five years of chemical aquatic vegetation treatment in Lake Holiday. This additional BMP improves water quality in Lake Holiday and has residual water quality benefits on Wing Lake and Lake Rose. The impacts of this BMP scenario on summer total phosphorus loading are presented in Table 9-13. As shown in Table 9-13, this combination of BMPs would reduce loading to Lake Holiday by another 2 to 4 lbs above BMP Scenario 8. Summer loading to Wing Lake would be reduced by another 1 to 2 lbs, while summer total phosphorus loads in Lake Rose would be reduced by less than 1 lb. The reduced phosphorus load would result in a further 21-27 µg/L reduction from BMP Scenario 8 for Lake Holiday. In Wing Lake, the improvement in summer-average TP concentration would be less than 3 µg/L better than under BMP Scenario 8. The reduction in TP concentrations in Lake Rose would be negligible compared to BMP Scenario 8 (see Figures 9-2 through 9-10). The estimated total capital cost for this BMP combination is approximately $532,000.

Table 9-13 Summer Total Phosphorus Loading Reduction in Lake Holiday, Wing Lake, and Lake Rose with BMP Scenario 10 under Varying Climatic Conditions

Climatic Condition	Modeled Summer Total Phosphorus Load (lbs)		Load Decrease (lbs)	Percent Decrease (%)
	Future Conditions (no additional BMPs)	BMP Scenario 10		
Lake Holiday				
Wet (1992-1993)	48.3	34.4	9.9	20.5
Average (1998-1999)	38.7	26.7	7.9	20.4
Dry (2007-2008)	61.7	28.0	29.7	48.1
Wing Lake				
Wet (1992-1993)	76.4	45.8	28.6	37.4
Average (1998-1999)	67.0	36.3	29.7	44.3
Dry (2007-2008)	60.3	28.7	30.8	51.1
Lake Rose				
Wet (1992-1993)	98.6	51.1	47.5	47.7
Average (1998-1999)	78.6	46.5	32.1	40.7
Dry (2007-2008)	137.1	60.0	77.1	56.2

---

1 – Based on June 1 – September 30

9.3.1.3 BMP Scenario 11 – Alum Treatment in Lake Holiday, Wing Lake, and Lake Rose; Aquatic Vegetation Treatment in Lake Holiday, Wing Lake, and Lake Rose

This scenario is identical to BMP scenario 10 with the addition of five years of chemical aquatic vegetation treatment in Lake Rose. This additional BMP improves water quality in Lake Rose, but has no additional benefits for Lake Holiday or Wing Lake. The summer-average TP concentrations in Lake Rose would be lowered by 3-5 µg/L relative to BMP Scenario 9 and by 3-6 µg/L relative to BMP Scenario 8 (see Figures 9-2 through 9-10). The additional cost added by five years of chemical treatment of Lake Rose would be approximately $221,000, raising the total BMP cost to $753,000.

9.3.1.4 BMP Scenario 13 – Watershed Infiltration in the Holiday-Wing-Rose Watersheds; Alum Treatment in Lake Holiday, Wing Lake, and Lake Rose; Aquatic Vegetation Treatment in Lake Holiday and Wing Lake,

This scenario is identical to BMP Scenario 10 with the addition of watershed infiltration (rainwater gardens) at various locations within the Lake Holiday watershed, Wing Lake watershed, and Lake Rose watershed. This scenario is presented to quantify the additional benefit of watershed infiltration when other BMPs are in place (in this case, alum treatments and vegetation treatments). The summer phosphorus loading under this scenario is presented in Table 9-14 and compared to BMP Scenario 10.

Table 9-14 Summer Total Phosphorus Loading Reduction in Lake Holiday, Wing Lake, and Lake Rose with BMP Scenario 13 under Varying Climatic Conditions

Climatic Condition	Modeled Summer Total Phosphorus Load (lbs)		Load Decrease (lbs)	Percent Decrease (%)
	BMP Scenario 10	BMP Scenario 10 + Watershed Infiltration (BMP Scenario 13)		
Lake Holiday				
Wet (1992-1993)	34.4	28.8	5.6	16.3
Average (1998-1999)	26.7	25.9	0.8	3.0
	28.0	27.4	0.6	2.1
Wing Lake				
Wet (1992-1993)	45.8	39.5	6.3	13.8
Average (1998-1999)	36.3	34.8	1.5	4.1
Dry (2007-2008)	28.7	27.6	1.1	3.8
Lake Rose				
Wet (1992-1993)	51.1	48.1	3.0	5.9
Average (1998-1999)	46.5	45.4	1.1	2.4
Dry (2007-2008)	60.0	59.9	0.1	0.2

---

1 – Based on June 1 – September 30

As shown in Table 9-14, this combination of BMPs provides additional load reductions during wet years (by reducing runoff), but has less impact in average and dry years. In average and dry years, the average reduction in phosphorus loading relative to BMP Scenario 10 is about 1 lb. The reduced TP load results in a 10 μg/L decrease in summer-average TP concentrations in Lake Holiday under wet conditions relative to BMP Scenario 10; the decrease is less than 2 μg/L in Lake Holiday for average and dry conditions. Similarly, the summer-average TP concentrations under wet conditions in Wing Lake and Lake Rose decrease by 4 μg/L and 3 μg/L, respectively, relative to BMP Scenario 10. The benefits to summer-average TP concentrations in Wing Lake and Lake Rose under average and dry climatic conditions are similar to those observed for Lake Holiday.

The rainwater gardens included in this BMP scenario include 62 locations throughout the Lake Holiday watershed, Wing Lake watershed, and Lake Rose watershed (in total there are 75 potential locations rainwater garden locations, see Section 9.2.2.1.1). The added cost of implementing 62 rainwater gardens included in this analysis would range from $190,000 to $260,000. The cost range increases to $225,000 to $315,000 if all 75 sites are included. Including the average cost of 75 rainwater gardens, the total cost of BMP scenario 13 would be approximately $802,000.

9.3.1.5 BMP Scenario 16 – Iron-enhanced Sand Filtration of Lake Holiday Outflow; Alum Treatment in Wing Lake and Lake Rose

This scenario includes treatment of the outflow from Lake Holiday through a half-acre iron-enhanced sand filter prior to discharge to Wing Lake, as well as in-lake alum treatments in Wing Lake and Lake Rose. Based on the water quality analysis of the BMP Scenario 8, this combination will provide significant water quality improvement to Wing Lake and Lake Rose, but would provide no benefit to water quality in Lake Holiday. As shown in Table 9-15, this combination of BMPs would reduce loading to Wing Lake by 30 to 39 lbs depending upon climatic conditions. Summer total phosphorus loads in Lake Rose would be reduced by between 33 and 77 lbs depending upon climate conditions. The reduced phosphorus load would result in a 45-60 µg/L reduction for Wing Lake relative to future conditions with no BMPs and a 37-55 µg/L reduction for Lake Rose relative to future conditions without additional BMPs. The estimated total capital cost for this BMP combination is approximately $914,000. Over 80 percent of this cost is associated with the iron-enhanced sand filter between Lake Holiday and Wing Lake. This estimate does not include any land acquisition costs that may be necessary to place the sand filter.

Table 9-15 Summer Total Phosphorus Loading Reduction in Lake Holiday, Wing Lake, and Lake Rose with BMP Scenario 16 under Varying Climatic Conditions

Climatic Condition	Modeled Summer Total Phosphorus Load (lbs) Future Conditions (no additional BMPs)	Modeled Summer Total Phosphorus Load (lbs) BMP Scenario 16	Load Decrease (lbs)	Percent Decrease (%)
Lake Holiday				
Wet (1992-1993)	48.3	48.3	0.0	0.0
Average (1998-1999)	38.7	38.7	0.0	0.0
Dry (2007-2008)	61.7	61.7	0.0	0.0
Wing Lake				
Wet (1992-1993)	76.4	37.4	39.0	51.0
Average (1998-1999)	67.0	33.5	33.5	50.0
Dry (2007-2008)	60.3	30.3	30.0	49.8
Lake Rose				
Wet (1992-1993)	98.6	48.9	49.7	50.4
Average (1998-1999)	78.6	45.4	33.2	42.2
Dry (2007-2008)	137.1	59.7	77.4	56.5

---

1 – Based on June 1 – September 30