Appendix H

Lake Holiday, Wing Lake, and Lake Rose Sediment Core Analysis

DRAFT
Sediment Phosphorus-Internal Loading Investigation of Rose, Wing and Lake Holidays

Prepared for

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Sediment Investigation of Rose, Wing, and Lake Holidays

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1.1 Introduction

All lakes accumulate phosphorus (and other nutrients) in the sediments from the settling of particles and dead organisms. This reservoir of phosphorus can be reintroduced or recycled to the lake water and be used by plants and algae for growth. The recycling of nutrients from the sediments to the lake water is known as "internal loading". The process of internal loading is complex and can be affected by temperature, oxygen, pH, wind mixing, and bioturbation by organisms such as carp.

This study was initiated by the Nine Mile Creek Watershed District to determine the potential for internal sediment phosphorus loading in Rose, Wing, and Lake Holidays. Sediment cores were collected from each lake to determine the different fractions of phosphorus in the sediment. Some forms of sediment phosphorus contribute to internal loading (mobile and organic phosphorus) while others remain in the sediment (refractory or non-labile phosphorus). With the results of this study, it is possible to calculate the potential for internal phosphorus loading in the sampled lakes. Multiple sediment cores were collected from each lake to help determine if external loading of sediment and phosphorus is causing increased phosphorus accumulation leading to higher internal loading in certain areas each lake. Instead of just roughly estimating internal loading, which has been commonly done in the past, the results from a study like this can be used within a lake model to more accurately determine the internal phosphorus load that is released from the sediment to the water column.

1.1.1 Internal Loading in Lakes

Internal loading is a natural process in lakes and is mainly driven by temperature. Temperature profoundly influences lake chemistry and biology. When the ice melts and air temperature warms in spring, lakes generally progress from being completely mixed to stratified with an upper layer of warm, well-mixed water (epilimnion) and cold temperatures in a bottom layer (hypolimnion). Separating these two layers is a layer of varying depth that has a sharp temperature gradient (thermocline). Because of the density differences between the lighter warm water and the heavier cold water, lake water becomes resistant to mixing and stratifies.

When stratification occurs, oxygen from the air cannot reach the bottom lake water and, if the lake sediments have sufficient organic matter, degradation of the organic matter by biological activity can deplete the remaining oxygen in the hypolimnion. The epilimnion can remain well-oxygenated, while dissolved oxygen supplies can be reduced to low levels in the hypolimnion (anoxic conditions). Loss of oxygen changes the chemical conditions in the water and sediment, allowing phosphorus that would normally remain bound to the sediments to re-enter the water column. Only a portion of this phosphorus reaches the surface water in deep lakes, however, due to diffusion or partial mixing events (storms and/or high wind) during the summer.

In shallow lakes like Rose, Wing, and Holiday, stable, summer long stratification due to temperature differences does not usually occur. Instead, weak temperature gradients are formed during calm periods. This weak stratification can cause small microzones or pockets of low oxygen just above the sediment surface. These microzones are difficult to detect during periodic sampling because they are usually limited to a small water layer just above the sediment surface and exist for short periods.

Oxygen depletion can also occur over night because algae respire (use oxygen) during this period instead of producing oxygen as they do during daylight hours. Phosphorus can then be released from the sediment under these low oxygen conditions in shallow lakes and is immediately available for uptake by algae and plants. In shallower areas, algae will actually grow on the sediment surface and directly uptake nutrients from the sediment. In some cases, pH can increase due to algae and macrophyte growth and phosphorus can be released from the sediment if pH is high enough (greater than 9.5) for an extended period.

Phosphorus released from the sediment through internal loading processes is considered immediately available because it is in a dissolved form that algae and plants can use directly. Watershed phosphorus loading is generally 35-45% dissolved (on average in MN) while the remaining portion is in the form of particles (either soil or organic matter) that become part of lake sediment. The particulate form of phosphorus can not be directly used by algae or plants until it is released from the particles or organic matter.

Phosphorus taken up by organisms in lakes (including algae and plants) is returned to the sediment when the organisms die. Once in the sediment, much of this phosphorus can then be released again after the organic matter breaks down, continuing the internal loading process.

While this is a natural process in all lakes, additional inputs of phosphorus due to human activity have caused increases in both the total amount and the rate of internal phosphorus loading in lakes.

1.1.2 Benthic Mixing Effects

Benthic mixing of lake sediments can increase the rate (or speed) of internal loading in lakes. In addition, species like carp can actually increase the depth of sediment mixing in lakes. This means that a greater amount of phosphorus can be transported from the sediment to the water. Because there is little to no oxygen in lake sediment just below the sediment water interface, the pool of phosphorus that might not be available under 'normal' conditions without carp or other mixing drivers is physically pushed out of the sediment due to carp mixing.

1.2 Study Description

Sediment cores were collected in July 2009 from Rose, Wing, and Lake Holidays to determine the buildup and distribution of sediment phosphorus as well as the potential for internal phosphorus loading in these lakes. Sediment from each lake was analyzed for mobile and organic bound phosphorus. Mobile phosphorus is the pool of phosphorus that can be released from the sediment under low oxygen conditions and is the main contributor of internal phosphorus loading. Organic phosphorus can also be released from the sediment after the organic material is broken down through microbial activity. This process usually takes more time but can be accelerated in shallow lakes with higher temperatures at the sediment surface. Organic phosphorus can be the dominant phosphorus pool in shallow lake sediments.

The collected sediment cores were approximately 1 foot (30-40 cm) in depth and were sliced into seven sections to determine the variation of mobile and organic phosphorus by sediment depth. Analyzing sediment by depth allows for the determination of approximate sediment mixing depths and background phosphorus concentrations. Background concentrations (found deeper in the sediment) can be used to evaluate the effectiveness and cost of different internal loading management methods. The sediment cores were collected from multiple locations on each lake to determine spatial differences in phosphorus levels due to external inputs from outside the lake and internal variations due to water depth and sediment accumulation zones.

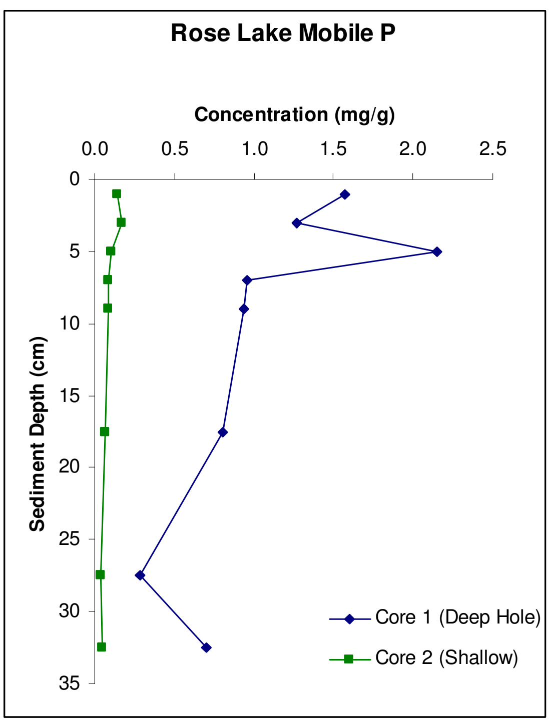
Phosphorus in the sediment cores is quantified in two different ways, phosphorus concentrations and phosphorus mass. Phosphorus concentration is used to show the relative difference of how much phosphorus is contained in different types of soil particles. For example, sediment at the top of a sediment core usually contains more phosphorus for each unit of dry matter because mobile phosphorus migrates from deeper layers to the sediment surface in lakes. However, there is more water at the sediment surface so even though there might be more phosphorus in each particle of sediment, there are less particles and more water at the sediment surface. Therefore, the total mass of phosphorus may be lower in the surface sediment simply due to the fact that there is more water and less sediment near the surface. This is just an example, however, and many times phosphorus concentration and mass will be highest at the sediment surface due to elevated inputs of phosphorus from the watershed.

2.0 Results

Seven sediment cores were collected from the lakes including 3 from Lake Holiday and 2 each from Rose and Wing Lakes. Low water levels prevented core collection in the northern end of both Rose and Wing Lakes. For modeling purposes, sediment phosphorus content was extrapolated for these areas based on the results from cores collected at similar depths in accessible areas of each lake.

2.1 Lake Rose

Lake Rose has both deep and shallow areas within the lake. The deep zone had very high mobile phosphorus, indicating a high potential for internal phosphorus loading (Figure 1). The shallow zone had low mobile phosphorus but higher organic phosphorus content. Much of the phosphorus in organic material, however, can be released due to organic matter breakdown, especially in shallower areas where temperatures are usually higher in comparison to deep areas. This phosphorus then contributes to the overall internal load in the lake.



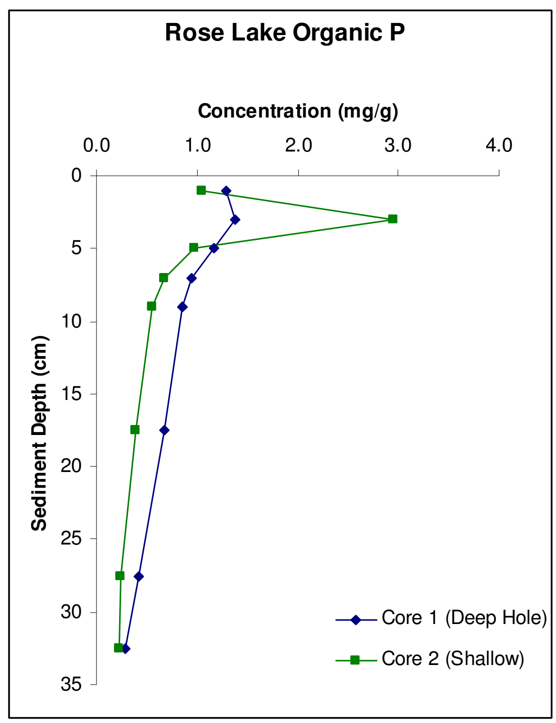


Figure 1. Mobile and organic phosphorus in the sediment of Lake Rose

Table 1 shows the potential internal phosphorus loading rates based on both mobile and organic phosphorus content of the sediment in Lake Rose. The lowest potential for internal loading was found in the shallower areas of the lake and the highest was found in the deep hole.

Table 1. Potential internal phosphorus loading ranges and lake-wide averages based on mobile and labile organic phosphorus in the sediment of Lake Rose

Lake Rose Average Internal Loading Rates ($mg/m^2/d$)		
Mobile P Only	Mobile + Organic P	Range
2.6	4.9	2.3-10.6

2.2 Wing Lake

Wing Lake had low mobile phosphorus in all areas of the lake (Figure 2). Organic phosphorus, however, was elevated in the upper part of the sediment. This is likely due to the shallow nature of the lake where any available phosphorus is used quickly and incorporated into organic matter (mainly dead algae, plants, and bacteria). Some types of algae will grow on the sediment surface where the can utilize phosphorus directly from the sediment. Much of the phosphorus in the sediment organic matter is considered labile and will be released once the organic matter breaks down.

Potential internal loading rates based on mobile phosphorus were 0 mg/m2/day (Table 2). However, when labile organic phosphorus is included, average, lake wide internal loading potential is 2.2 mg/m2/day.

Table 2. Potential internal phosphorus loading ranges and lake-wide averages based on mobile and labile organic phosphorus in the sediment of Wing Lake

Wing Lake Average Internal Loading Rates ($mg/m^2/d$)		
Mobile P Only	Mobile + Organic P	Range
0	2.2	0.0-2.9

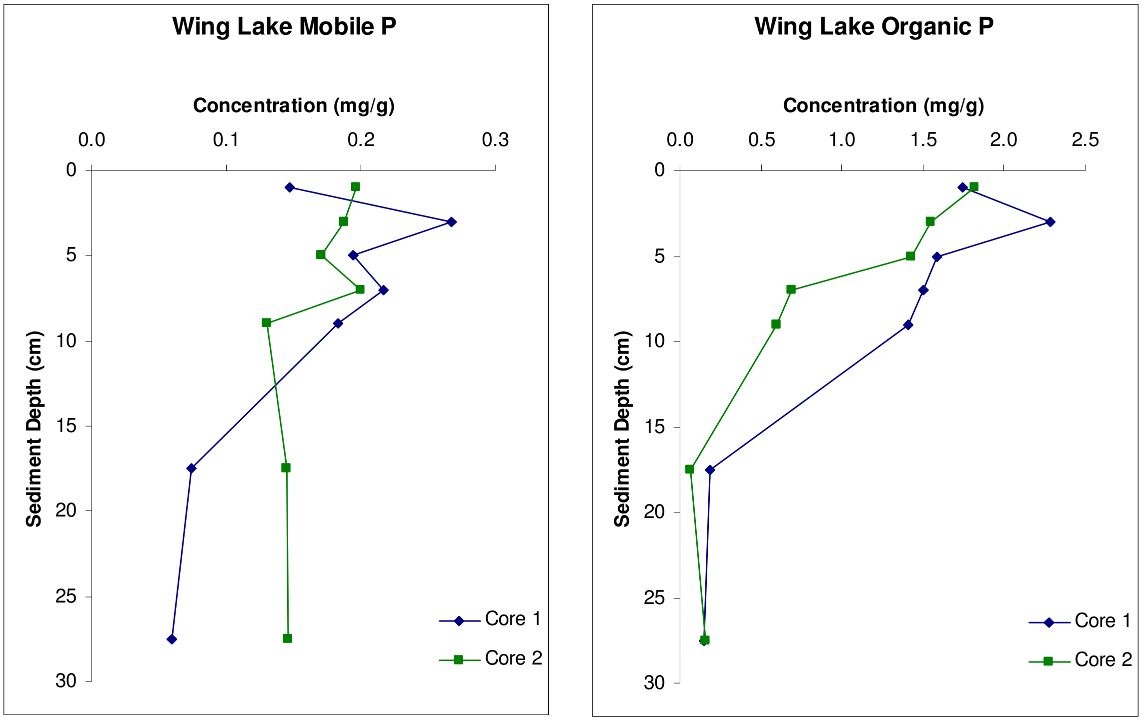


Figure 2. Mobile and organic phosphorus in the sediment of Wing Lake

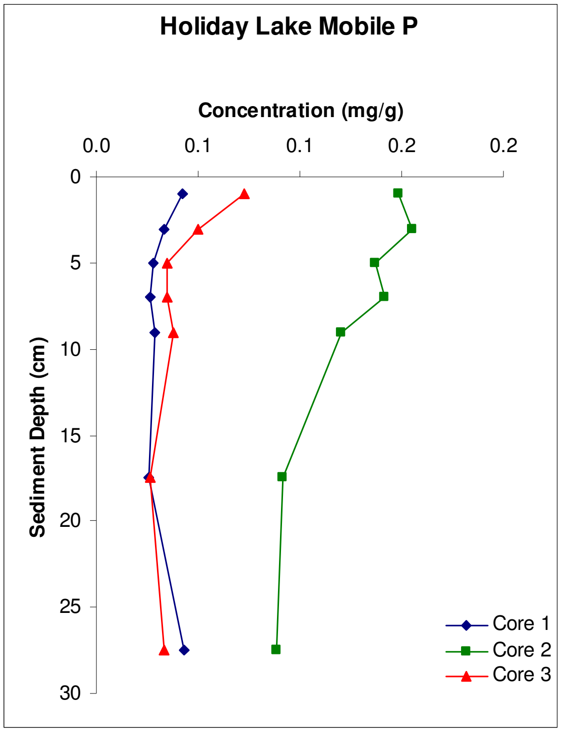
2.3 Lake Holiday

Similar to Rose and Wing Lakes, Lake Holiday had relatively low amounts of mobile phosphorus but elevated amounts of labile organic phosphorus in the upper sediment across the lake (Figure 3).

As was seen in Wing Lake, Lake Holiday had low amounts of mobile phosphorus in the sediment resulting in an estimated internal loading rate of 0 mg/m2/day. When labile organic phosphorus was included, the potential internal phosphorus loading rate across the lake increased to 3.7 mg/m2/day (Table 3).

Table 3. Potential internal phosphorus loading ranges and lake-wide averages based on mobile and labile organic phosphorus in the sediment of Lake Holiday

Lake Holiday Average Internal Loading Rates ($mg/m^2/d$)		
Mobile P Only	Mobile + Organic P	Range
0.1	3.7	0.0-6.0



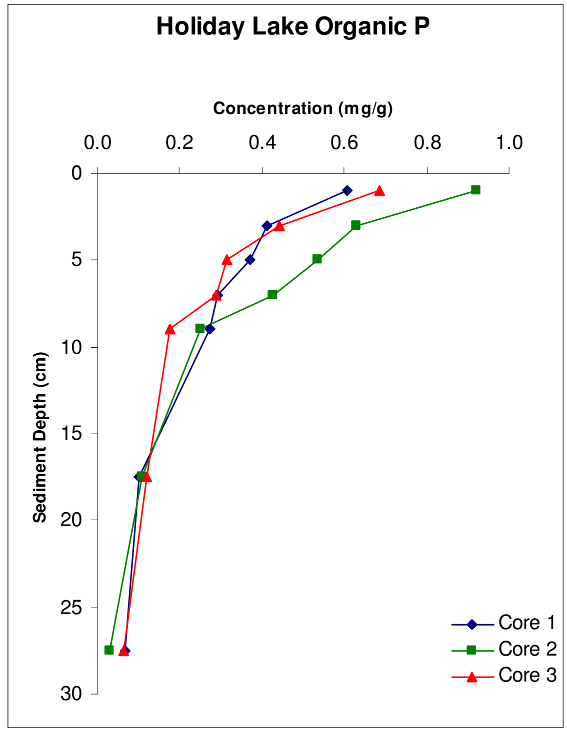


Figure 3. Mobile and organic phosphorus in the sediment of Lake Holiday

3.0 Summary

3.1 Study Results

All lakes accumulate phosphorus (and other nutrients) in the sediments from the settling of particles and dead organisms. This reservoir of phosphorus can be reintroduced or recycled to the lake water and be used by plants and algae for growth. The recycling of nutrients from the sediments to the lake water is known as "internal loading". The process of internal loading is complex and can be affected by temperature, oxygen, pH, wind mixing, and bioturbation by organisms such as carp.

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Multiple sediment cores were collected from each lake to help determine if external loading of sediment and phosphorus is causing increased phosphorus accumulation leading to higher internal loading in certain areas of each lake. Instead of just roughly estimating internal loading, which has been commonly done in the past, the results from a study like this can be used within a lake model to more accurately determine the internal phosphorus load that is released from the sediment to the water column.

Potential internal phosphorus loading rates (lake wide) for all lakes in the sediment phosphorus study were based on spatial modeling of mobile and organic phosphorus and are shown in Table 4.

Table 4. Internal phosphorus loading rates based on sediment phosphorus composition

Lake/Bay	Internal Phosphorus Loading	
	Mobile P Model	Mobile+Organic P Model
	(mg/m^2/day)	
Lake Rose	2.6	4.9
Lake Holiday	0.1	3.7
Wing Lake	0.0	2.2

Mobile phosphorus was relatively low in both Holiday and Wing Lakes, resulting in low estimated internal loading rates in each lake (Table 4). In Lake Rose, mobile phosphorus was high in the deep hole and lower in the shallow areas of each lake (Figures 4-6). This is likely due to the shallow nature of the lake where any available phosphorus is used quickly and incorporated into organic matter (mainly dead algae, plants, and bacteria). Some types of algae will grow on the sediment surface (benthic algae) where they can utilize phosphorus directly from the sediment. Much of the phosphorus in the sediment organic matter is considered labile and will be released once the organic matter breaks down.

When labile organic phosphorus was included in the estimation of internal loading, the potential release rates increased for all lakes. Because all of the lakes in the study are shallow, the potential contribution of labile organic phosphorus to the overall internal load can be significant, as seen in the table above.

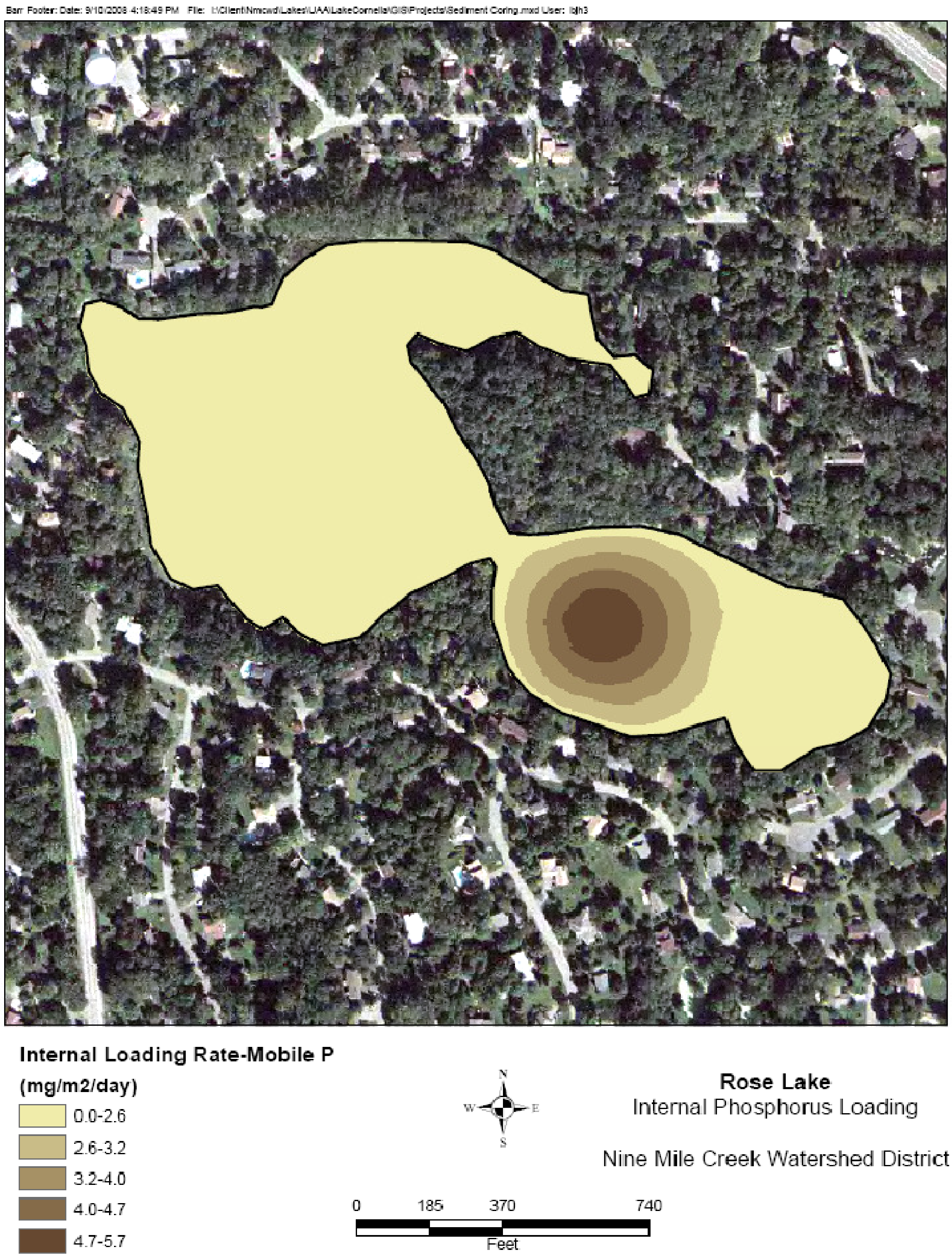

Figure 4. Spatial model of internal phosphorus loading, based on mobile sediment phosphorus in Lake Rose

Figure 5. Spatial model of internal phosphorus loading, based on mobile sediment phosphorus in Lake Holiday

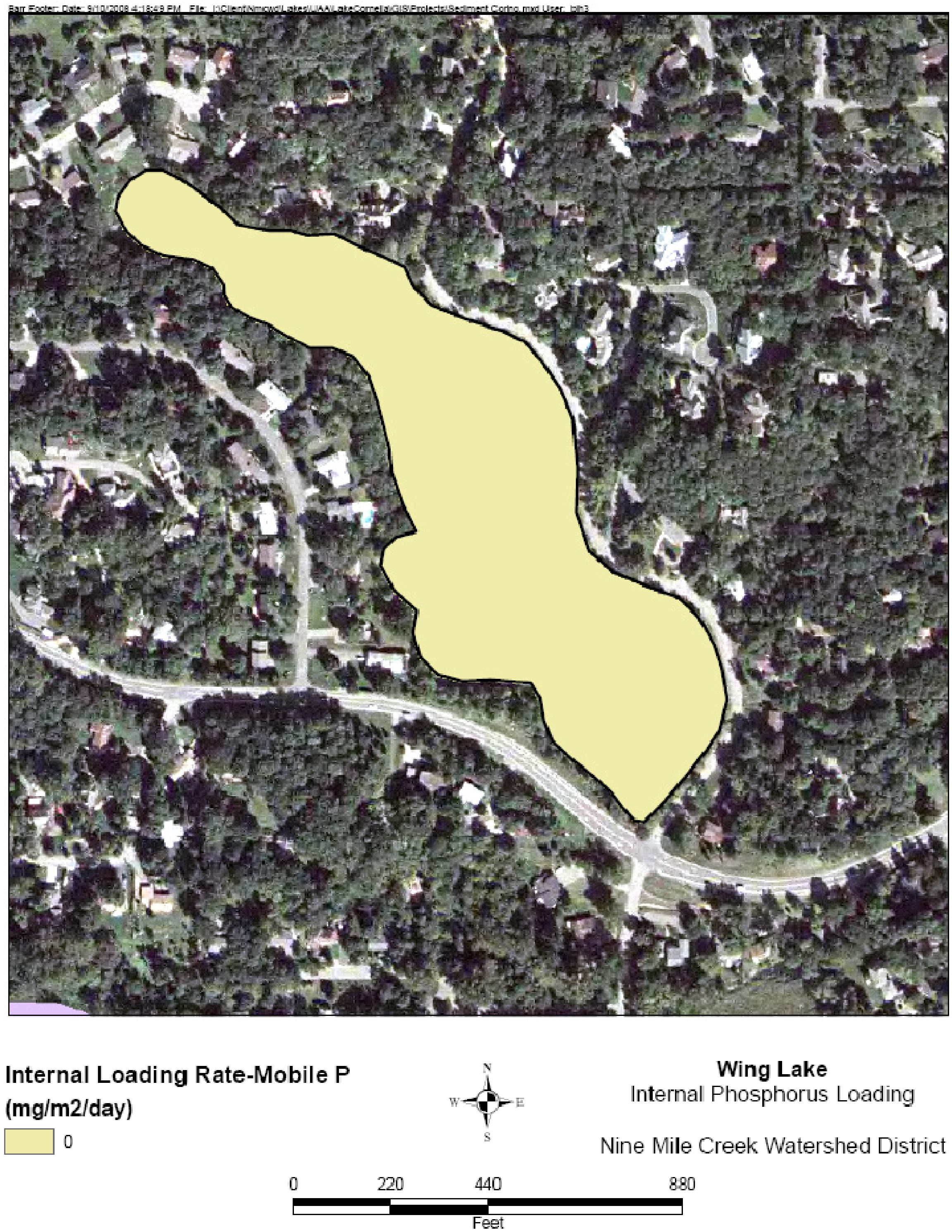

Figure 6. Spatial model of internal phosphorus loading, based on mobile sediment phosphorus in Wing Lake

The degradation of organic matter is mainly dependent upon temperature and the type of organic material present (labile, non-labile, or refractory). Shallow lakes generally have much higher temperatures near the sediment surface in comparison to deep lakes which means organic matter degradation rates are usually higher. However, while mobile phosphorus is immediately available under low oxygen conditions, it takes time for labile organic phosphorus to break down and be converted to mobile phosphorus.

Benthic species can affect internal phosphorus loading in lakes. Carp mainly feed on organic matter in the sediment and are known to excrete high amounts of soluble phosphorus in lake water which can add a significant amount of phosphorus to a lake budget. However, the physical mixing action of carp while they feed can also contribute to direct internal loading from the sediment. Carp have the ability to not only accelerate internal phosphorus loading, but increase the amount of loading from sediments in lakes.

3.2 Management Methods and Costs

Based on this study, internal phosphorus loading in Rose, Wing and Lake Holidays can be expected to contribute to low water quality during the summer months. There are a number of management methods available that can help reduce internal loading in these lakes, including (but not limited to):

- Benthic rough fish removal (if needed)
- Dredging
- Sediment phosphorus inactivation (alum treatment, iron addition and aeration, etc.)

However, external loads to each of these lakes should be controlled to the best extent possible before reductions to internal loading are attempted. Phosphorus in lakes is generated in the watershed and if external phosphorus sources are elevated, they can quickly overwhelm any attempts at in-lake phosphorus management. Lake response modeling (beyond simple BATHTUB type models) can help determine the relative impacts of external and internal loading and can be used to estimate the beneficial effects different management options can have in lakes like Rose, Wing, and Lake Holidays.

3.2.1 Sediment Nutrient Inactivation (Alum)

Because Rose, Wing and Holiday are shallow lakes, a buffered alum treatment would be necessary due to the limited amount of alkalinity (buffering capacity) available in each lake. The costs for buffered alum treatment in each lake are shown below and are based on lake area and the amount of phosphorus (both mobile and labile organic) in the sediment of each lake.

Table 5. Buffered alum doses (based on mobile and labile organic phosphorus) for Rose, Wing and Lake Holidays

Lake	Surface Area (acres)	Total Cost
Rose	26.9	$104,100
Wing	13.8	$25,100
Holiday	8.1	$23,600

Applying the above alum doses will achieve a 90% reduction in internal phosphorus loading in each lake.