Summary
To determine the feasibility of rehabilitation of wetlands and ponds in the northwest Moody Lake watershed, the CLFLWD authorized a feasibility analysis in January of 2015. This memo summarizes the results of the feasibility work, recommendations for implementation of wetland rehabilitation to be included in a Clean Water Fund proposal, and expected phosphorus load reductions to Moody Lake. Recommendations for implementation were divided into three phases based on results from the feasibility work and are focused on the northwest portion of Moody Lake's watershed which contributes the majority of the phosphorus load to Moody Lake (Figure 1). Phase 1 will rely on a combination of land acquisition/conservation easement, upland best management practices, and wetland sediment excavation in wetlands A and B (Figure 2). Phase 2 will focus on sediment excavation in wetland C only. Phase 3 will include an alum treatment to immobilize soil phosphorus and prevent phosphorus from leaching downstream if Phase 1 and 2 are not capable of achieving desired phosphorus reductions. Continued coordination with the private landowners will be needed.

Moody Lake requires a total annual watershed phosphorus load reduction of 88% (555lbs/year; EOR, 2010). Water quality monitoring will be conducted after completion of each phase to document progress towards the required phosphorus load reductions and the need for the next phase of implementation (Figure 3).

Alternative Options
A suite of alternative options were also evaluated. Alternative options valued included an engineered solution that involved the re-direction of flow around the nutrient rich portion of wetland A as well as a chemical amendment of the tributary at the outlet of Peterson Wetland with the option of an iron-enhanced sand filter or an alum injection system. These options are not initially recommended for implementation based on a cost-benefit analysis and a preference to address phosphorus source.
Figure 1. Moody Lake phosphorus loads estimated from 2014 monitoring data
Figure 2. Location of Moody Lake wetlands
Figure 3. Moody Lake Wetland Rehabilitation Phases
Data Collection and Analysis

Wetland Delineation and Assessment

Wetlands A, B and C were field delineated on July 21, 2015 by EOR (Jason Naber WDC and Joe Pallardy WDC in-training). A copy of the delineation report is provided in Appendix A. Weather conditions were clear at the time of the delineation; however, site conditions were wetter than normal due to above average precipitation in July. The adjacent upland immediately bordering the wetland was flooded during the site visit. Given the flooded site conditions, the wetland delineation relied heavily on indicators of hydric soils (wetland soils) and wetland vegetation with less emphasis on indicators of wetland hydrology because the presence of hydric soils and wetland vegetation are better indicators of the long term wetland boundary. The methodology of the 1987 Corps of Engineers Wetland Delineation Manual and regional supplements for the Northcentral and Northeast Region were used to delineate wetlands within the project area.

Two sampling transects were established within wetland A, additionally; one sampling transect was established at both wetland B and wetland C (Figure A-1). Three wetland complexes were delineated at the project site (Table A-1). These wetlands were previously mapped by the National Wetlands Inventory (NWI) and classified as shallow emergent marshes (Type 3) wetlands. The site investigation identified the wetland boundary by confirming wetland characteristics (vegetation, soils & hydrology) for each wetland. In wetland A, dominant species included reed canary grass (*Phalaris arundinacea*), rattlesnake grass (*Glyceria canadensis*) and broad leaf cattail (*Typha latifolia*). In wetlands B and C, reed canary grass (*Phalaris arundinacea*), is the dominant plant species.

Hydrological Monitoring

Monitoring wells were installed in wetlands A, B, and C in May of 2015 and were left in the field to collect water level data throughout the duration of the project. Graphs depicting water levels throughout the growing season are shown in Appendix B. Water levels observed within all three wetlands in 2015 suggest that wetland hydrology is present. Furthermore, wetland water levels reacted quickly to precipitation events indicating that the primary source of water to these wetlands is overland runoff from their respective watersheds. However, the presence of hydrology throughout the season suggests there is likely some interaction with groundwater. Precipitation levels during the monitoring period were above normal; therefore it is possible that certain sections of the wetland may dry out in certain years. Water level loggers are currently installed within the monitoring wells to record water levels throughout the season.

Grab Sampling Results

One set of grab samples was collected on 7/6/2015 after the landowner of wetland A & B provided information of highly turbid water entering the wetland from offsite. Results of this grab sample indicated that TP concentrations coming into wetland A are much lower than those observed just downstream of wetland A, providing further support that the eastern portion of wetland A and wetland B are sources of phosphorus.
**Soil Sampling**

Soil samples were collected from the small easterly basin (B in Figure 2) and the larger westerly basin in the 250th wetland (A in Figure 2) and in the main basin of the Peterson wetland (C in Figure 2) to determine phosphorus content and soil stratigraphy. Consistencies in overall wetland characteristics (hydrology, vegetation, soils) indicated that additional samples were not needed. Secondly, soil cores were collected from the pond upstream of the Lofton monitoring site to determine the depth of accumulated sediment within the pond.

Two soil cores were collected from wetland A, one from the western portion of wetland A and one from the eastern portion of wetland A (Figure 4). One soil core was collected at wetland B, wetland C, and at Lofton Pond (Figure 4). Analysis of the soil cores included one sample for total phosphorus (TP) concentration and moisture content from within the top layer of soil. Following is a discussion of each site sampled.

**Wetland A**

The observed TP concentration within the western portion of wetland A was lower than TP concentrations reported for undisturbed wetland soils (550 mg TP/kg of sediment; Mukherjee et al., 2009). Observed TP concentrations in the eastern portion of wetland A had elevated nutrient concentrations in the top (1250 mg TP/kg of sediment) and bottom (1210 mg TP/kg of sediment) of the soil core indicating a thick layer of nutrient rich sediment is present (Table 1). In wetland A, the top soil layer was approximately 3 inches thick and consisted of a fibric peat layer in both soil samples. In the western portion of wetland A, the fibric peat layer transitioned to a secondary soil layer that had a clay-loam texture that was interspersed with decayed peat. In the eastern portion of wetland A, this fibric peat layer continued throughout the entire soil core (Table 1).

**Wetland B**

The observed TP concentration within the top soil layer in wetland B was more than two times as high as TP concentrations reported for typical wetland soils. The TP concentration of the bottom sample collected from wetland B was lower in comparison with the top sample; however, TP concentrations in the bottom sample were still higher than those reported for typical wetland soils (Table 1). In wetland B, the top soil layer was approximately 4 inches thick and consisted of a fibric peat/muck layer. The fibric peat/muck layer transitioned to a secondary soil layer that had a silt-loam texture.

**Wetland C**

The observed TP concentration within the top soil layer in wetland C was nearly two times as high as TP concentrations reported for typical wetland soils. The TP concentration observed within the bottom layer in wetland C was close to typical wetland soil conditions. The difference in observed TP concentrations between the top and bottom samples in wetland C was greater than the difference between the top and bottom samples observed in wetlands A and B; however the top layer sediment was not as phosphorus-rich in wetland C in comparison with wetlands A and B. In wetland C, the top soil layer was approximately 2.5 inches thick and consisted of a muck layer. The muck layer transitioned to a secondary soil layer that had a peat/muck texture.
Figure 4. Location of sediment cores with total phosphorus concentrations (mg TP/gram of sediment) depicted for the top 8 inches (black numbers) and bottom 8 inches (red numbers) of the soil core.
Lofton Pond

The observed TP concentration within the top soil layer in Lofton Pond was only slightly above TP concentrations reported for typical wetland soils. Observed TP concentrations in the bottom layer were the lowest of any soil sample collected and were below reference conditions (Table 1). In Lofton Pond, the top soil layer was approximately 2.5 inches thick and consisted of a muck layer. The muck layer transitioned to a secondary soil layer that had a fibric peat texture.

Table 1. Wetland A, B, and C sediment sample layer depth, texture, total phosphorus concentrations and percent moisture

<table>
<thead>
<tr>
<th>Site</th>
<th>Core Depth</th>
<th>Depth of Layer (in.)</th>
<th>Texture</th>
<th>TP [mg/kg]</th>
<th>% Moisture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wetland A West</td>
<td>Top</td>
<td>3</td>
<td>Fibric Peat</td>
<td>238</td>
<td>65.5</td>
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<tr>
<td></td>
<td>Bottom</td>
<td>7</td>
<td>Decayed Peat/Clay-Loam</td>
<td>304</td>
<td>66.2</td>
</tr>
<tr>
<td>Wetland A East</td>
<td>Top</td>
<td>3</td>
<td>Fibric Peat</td>
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<tr>
<td></td>
<td>Bottom</td>
<td>5</td>
<td>Fibric Peat</td>
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<td>74.5</td>
</tr>
<tr>
<td>Wetland B</td>
<td>Top</td>
<td>4</td>
<td>Fibric Peat/Muck</td>
<td>1,240</td>
<td>68.1</td>
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<tr>
<td></td>
<td>Bottom</td>
<td>6</td>
<td>Silt Loam</td>
<td>880</td>
<td>53.4</td>
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<tr>
<td>Wetland C</td>
<td>Top</td>
<td>2.5</td>
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<tr>
<td></td>
<td>Bottom</td>
<td>7</td>
<td>Peat/Muck</td>
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<td>62.5</td>
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<tr>
<td>Lofton Pond</td>
<td>Top</td>
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<td>Muck</td>
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<tr>
<td></td>
<td>Bottom</td>
<td>10</td>
<td>Fibric Peat</td>
<td>237</td>
<td>77.9</td>
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</table>

Recommended Implementation Approach

**Phase 1: Land Acquisition/ Easement, BMP Placement, and Sediment Excavation**

Below natural background TP concentrations in the wetland A west soil core compared to high TP concentrations in the wetland A east and wetland B soil cores suggest a localized source of phosphorus to the eastern portion of wetland A and wetland B. That is to say, if the 250th wetland had high phosphorus concentrations due to phosphorus enriched runoff originating from throughout the watershed, we would expect high TP concentrations in the wetland A west and east cores. Based on this finding, the highest priority for reducing watershed TP loads to Moody Lake is to focus on reducing this localized phosphorus source to the eastern portion of wetland A and wetland B. The eastern portion of wetland A and wetland B have historically been and are currently used as a water source for cattle. A history of direct access to the wetlands has allowed nutrient rich runoff to flow directly into the wetlands and eventually downstream to Moody Lake. Over time, a nutrient rich layer of sediment has accumulated within the eastern portion of wetland A and wetland B that acts as a source of phosphorus. Consequently, best management practices (BMPs) that reduce sources of phosphorus that are already present within wetlands A and B will be required in addition to BMPs that reduce contributions from the watershed. Best management practices aimed at reducing phosphorus sources within wetlands A/ B and watershed sources are discussed below.
**Land Acquisition/Conservation Easement**

We recommend acquiring or obtaining a conservation easement on approximately 10 acres of land that includes wetland B, the eastern portion of wetland A and some portion of nearby upland to the north and east (Figure 5). Actual acreage will vary and is dependent on landowner consent and desires of the Comfort Lake Forest Lake Watershed District.

**BMP Placement: Buffer Strips, Livestock Exclusion**

A concentrated flow path is visible via aerial photography that appears to route runoff directly from the adjacent uplands to the eastern portion of wetland A (Figure 6). Implementation of a grassed waterway along the concentrated flow path combined with a 50 foot buffer strip to the north and east of wetlands A and B can help to infiltrate and filter runoff.

Implementing a 50 foot wide buffer along 850 feet of upland adjacent to wetlands A and B would achieve an estimated 68% phosphorus reduction from the immediate drainage area (approximately 25 acres; Figure 6). The immediate drainage area that would be treated by the buffer represents approximately 5% of the total drainage area to wetlands A and B. The total cost to implement a 50 foot wide buffer along 850 feet of riparian land is estimated to cost between $5,000-$6,000 for the entire 1 acre buffer. This cost includes $3,000-$4,000 in seeding costs and an additional $1,000-$2,000 in construction and design costs.

Excluding livestock from grazing within this area would have multiple water quality benefits including reducing soil compaction, reducing runoff, and eliminating nutrients and bacteria associated with animal waste deposited in or near the wetland boundary. Construction costs for electric livestock fencing are estimated at $1,000. Cost savings may be achieved by repositioning electric fencing already in place.

**Sediment Excavation & Wetland Restoration.**

Following the buffer strip implementation and permanent cattle removal, a wetland excavation of accumulated nutrient rich sediment will be required from wetlands A and B. Analysis of the soil cores indicated high TP concentrations were present in both the top and bottom samples within the eastern portion of wetland A as well as within wetland B. Based on this analysis; an average of 12 inches of sediment should be excavated from both wetlands. The wetland excavation will focus on creating deeper cells of open water in the areas of wetland A and wetland B identified as having the highest TP concentrations with shallower excavation occurring along the wetland edge (Figure 7). Additionally, creating deeper excavation cells will help to create a ponding effect on wetland flow that will increase residence time which will allow for a greater proportion of sediment and attached nutrients to settle out before being transported downstream.

Removing an average of 12 inches of nutrient rich sediment from within the targeted areas in wetlands A and B would result in a removal of 60 acre-inches of sediment; equivalent to 8,067 cubic yards of sediment. A review of average sediment excavations costs suggested $10/cubic yard was an accurate estimate as long as the excavated sediment could be land applied to a nearby field. Therefore, the cost estimate for the sediment excavation is estimated at $80,667. Sediment removal
Figure 5. Proposed general location for land acquisition based on soil core results with total phosphorus concentrations (mg TP/gram of sediment) depicted for the top 8 inches (black numbers) and bottom 8 inches (red numbers) from wetland A and wetland B.
Figure 6. Location of 50 foot buffer along 850 feet of riparian land adjacent to wetlands A and B
Figure 7. Sediment excavation areas within wetlands A and B
via excavation from a type 3 wetland requires replacement and/or restoration under the Wetland Conservation Act. Permitting costs associated with mitigation requirements following sediment removal were estimated at $10,000. Site restoration and mitigation will take place on site and will cost $30,000 for a total construction cost of $120,667. Engineering, design, and legal contingency costs will add an additional 35% of the total construction cost, bringing the total project cost to $162,900 (Table 2). Observed TP concentrations were significantly lower in the northeast tributary at 256th street in comparison with the northwest tributary at 250th street (Figure 8) despite having similar land use, soil type, and drainage area (EOR, 2014). Assuming the implementation of buffer strips, livestock exclusion and removal of nutrient rich sediment allows wetland A to function as a nutrient sink rather than as a source, mean TP concentrations are expected to be similar to concentrations observed in the tributary at 256th street (0.19 mg/L). Multiplying the mean TP concentration observed for the tributary at 256th street by the flow volume observed at 250th street results in a potential annual TP load of 348 pounds/year. This is equivalent to a cumulative reduction of 434 pounds per year or 78% of the needed annual phosphorus load reduction of 555lbs/year.

Table 2. Phase 1 Cost-Benefit Analyses.

<table>
<thead>
<tr>
<th>Wetland</th>
<th>BMP</th>
<th>Quantity</th>
<th>Construction/Excavation Costs</th>
<th>Design/ Legal Contingency Costs</th>
<th>Total Cost</th>
<th>TP Removal (lbs/yr)</th>
<th>Total Cost per pound of TP Removed</th>
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<tr>
<td>Wetlands AB</td>
<td>Land Acquisition/Easement</td>
<td>10 acres</td>
<td>NA</td>
<td>NA</td>
<td>*</td>
<td>NA</td>
<td>NA</td>
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<tr>
<td>Wetlands AB</td>
<td>Grassed Waterway/Buffer</td>
<td>1 acre</td>
<td>$3,000-$4,000</td>
<td>$1,000-$2,000</td>
<td>$5,000-$6,000</td>
<td>53.2</td>
<td>$94-113</td>
</tr>
<tr>
<td>Wetlands AB</td>
<td>Livestock Exclusion</td>
<td>10 acres</td>
<td>$1,000</td>
<td>NA</td>
<td>$406</td>
<td>42-84</td>
<td>$5-10</td>
</tr>
<tr>
<td>Wetlands AB</td>
<td>Sediment Excavation</td>
<td>8,067 CY</td>
<td>$120,667</td>
<td>35%</td>
<td>$162,900</td>
<td>434</td>
<td>$375</td>
</tr>
</tbody>
</table>

*Total costs for land acquisition/conservation easement have not yet been determined.

Phase 1b Monitoring

Flow and water quality samples will be collected at two locations in the Moody Watershed in 2017 (Figure 9). These sites were chosen to quantify the phosphorus load reductions to Peterson Wetland and ultimately to Moody Lake as a result of implementing Phase 1. Continuous flow data will be collected in 2017 using a level logger. Instantaneous flow measurements will be collected at both sites using a Marsh McBirney flow meter. A rating curve will be developed for both sites using instantaneous flow measurements collected during water quality grab sampling events.

Water quality samples collected during grab sampling events will be analyzed for total phosphorus (TP), ortho-phosphorus (OP), total iron (Total Fe), total suspended solids (TSS), pH, and alkalinity. These data will be used as inputs to the FLUX32 model to characterize the reactivity and availability of those phosphorus loads for algal growth, and ultimately to determine the phosphorus load reductions to Moody Lake as a result of implementing phase 1.
Figure 8. Moody Lake Watershed Flow, Total Phosphorus Concentration, and Total Phosphorus Loads
Figure 9. Proposed monitoring locations for phase 1b in 2017.
Phase 2 Wetland C Sediment Excavation

The northwest tributary stream leaving Peterson wetland contributes 640lbs of TP per year to Moody Lake despite receiving inputs of 782lbs of TP per year from the wetlands at 250th street. Therefore, the Peterson wetland is currently serving as a sink for phosphorus. Sediment cores collected from Peterson Wetland indicated the nutrient rich sediment layer was confined to the first 3 inches of the sediment core (Table 1.). Scraping some sediment from the entire wetland with deep excavation areas (greater than 6 inches) occurring in the center of the wetland and shallow excavation areas (less than 6 inches) occurring along the wetland edge will remove nutrient rich sediment (Figure 10) and will allow for a greater proportion of sediment and attached nutrients to settle out by increasing residence time. Removing an average of 6 inches of sediment from the entire 6.1 acre surface area of wetland C would result in a removal of 36 acre-inches of sediment; equivalent to 4,840 cubic yards of sediment. A review of average sediment excavations costs suggested $10/cubic yard was an accurate estimate as long as the excavated sediment could be land applied to a nearby field.

Therefore, the cost estimate for the sediment excavation is estimated at $48,400. Permitting costs associated with mitigation requirements following sediment removal were estimated at $5,000. Site restoration and mitigation will take place on site and will cost an additional $15,000 for a total construction cost of $68,400. Engineering, design, and legal contingency costs will add an additional 35% of the total construction cost, bringing the total project cost to $60,210 (Table 3).

Observed TP concentrations were significantly lower in the northeast tributary at 256th street in comparison with the northwest tributary at the wetland C outlet (Figure 7) despite having similar land use, soil type, and drainage area (EOR, 2014). Assuming the removal of nutrient rich sediment from wetlands A, B, and C allows wetland C to enhance its nutrient sink functionality, mean TP concentrations are expected to be similar to concentrations observed in the tributary at 256th street (0.19 mg/L). Multiplying the mean TP concentration observed for the tributary at 256th street by the flow volume observed at the wetland C outlet results in an annual TP load of 195 pounds/year. This equates to a cumulative reduction (phase 1 and phase 2) of 445 pounds per year in comparison with existing conditions or 80% of the necessary annual phosphorus load reduction (555 lbs/year).

Table 3. Phase 2 Cost-Benefit Analyses.

<table>
<thead>
<tr>
<th>Wetland C</th>
<th>BMP</th>
<th>Quantity</th>
<th>Construction /Excavation Costs</th>
<th>Design/ Legal Contingency Costs</th>
<th>Total Cost</th>
<th>TP Removal (lbs/yr)</th>
<th>Total Cost per pound of TP Removed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sediment Excavation</td>
<td>4,840 CY</td>
<td>$68,400</td>
<td>35%</td>
<td>$92,340</td>
<td>445</td>
<td>$208</td>
<td></td>
</tr>
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</table>

Phase 2b Monitoring

Flow and water quality samples will be collected at the Peterson outlet in 2019 following implementation of Phase 2 to quantify the phosphorus load reductions to Moody Lake as a result of implementing Phase 1. Continuous flow data will be collected in 2019 using a level logger. Instantaneous flow measurements will be collected using a Marsh McBirney flow meter. A rating
Figure 10. Sediment excavation areas within Wetland C
curve will be developed for using instantaneous flow measurements collected during water quality grab sampling events.

Water quality samples collected during grab sampling events will be analyzed for total phosphorus (TP), ortho-phosphorus (OP), total iron (Total Fe), total suspended solids (TSS), pH, and alkalinity. These data will be used as inputs to the FLUX32 model to characterize the reactivity and availability of those phosphorus loads for algal growth, and ultimately to determine the phosphorus load reductions to Moody Lake as a result of implementing phases 1 and 2.

**Phase 3 Wetland Alum Application**

High TP concentrations within the top and bottom of the wetland A east soil core and the wetland B soil core suggests that an alum treatment may be required if excavation is not capable of removing all of the nutrient rich sediment. The goal of an alum treatment is to immobilize soil phosphorus and prevent phosphorus from leaching downstream. Monitoring efforts following implementation of Phases 1 and 2 will help to guide the areas where application of alum is required. Application of alum is a well-known practice to control phosphorus in lake environments; however, application of alum to wetland environments is considered experimental. Potential methods for application of alum in wetland environments were discussed with John Holz PhD, a nationally recognized alum application scientist and co-owner of HAB Aquatic Solutions. Several potential options for alum application were explored; the top two options with the highest likelihood of success are presented below. Implementation of either option is dependent on water levels within the targeted areas identified as needing treatment following phase 2b.

**Dry Alum Treatment with Tillage to 6 inches**

A one-acre area surrounding the wetland A east soil core was used as a study area to better understand alum dosing and cost estimates associated with a partial alum treatment. Targeting the first six inches of sediment represents a conservative estimate for depth of alum incorporation if water levels within a targeted portion of wetland A are low enough to allow tractors and tillage implements to access and maneuver within the wetland. Dosing calculations were based on targeting six inches of sediment within the targeted 1 acre area, equivalent to a sediment volume of six acre-inches or 806.67 cubic yards. Other factors that were included in the calculation include alum to phosphorus binding ratio, distribution efficiency of the alum itself, and the molecular weight of alum in comparison with phosphorus. Assuming a concentration of 1,250 mg of TP per kilogram of sediment, calculations suggest 738 lbs of total phosphorus are contained within this sediment layer. Calculations based on binding efficiency and treatment duration suggest 43,372 lbs of dry alum would be required to properly inactivate this amount of phosphorus source from within the top 6 inches of sediment in the 1 acre area for a 5 year time period. HAB Aquatic Solutions has quoted a price of $149,071 for purchasing, applying, and incorporating the alum to a depth of 6 inches using appropriate tillage equipment. Engineering, design, and legal contingency costs will add an additional 15% of the total application cost, bringing the total project cost to $171,430. Extrapolating the cost estimate for the 1 acre test area to the entire 5 acre area of wetlands A and B that were targeted for sediment excavation would have an alum purchasing, application, and incorporation cost of $745,355. Engineering, design, and legal contingency costs would add an additional 15%, bringing the total project cost to $857,160. Extrapolating the cost
estimate to the entire 6.1 acre area within wetland C that was targeted for sediment excavation would have an alum purchasing, application, and incorporation cost of $909,333. Engineering, design, and legal contingency costs would add an additional 15%, bringing the total project cost to $1,045,733.

**Liquid Alum Treatment with Incorporation into the First Inch**

Water levels observed within wetland A in 2015 suggest that a pool of water is consistently present that may restrict the ability of tractors and associated tillage implements to access the wetland. A second option involves the use of a high injection spray nozzle mounted on to a small boat used to float the equipment through the wetland. It is likely the vegetation would need to be burned to facilitate access by boat. This method relies on applying alum as liquid slurry and is anticipated to be able to incorporate the alum into the first inch of sediment. This method is very similar to techniques used in lake environments in which the alum floc settles to the top of the sediments. The presence of alum on the wetland sediment surface will also intercept phosphorus that migrates upwards in the soil profile during periods of time when the wetland goes anoxic. Calculations are based on the total amount of alum needed to treat the first inch of sediment within the targeted 1 acre area, equivalent to a sediment volume of one acre-inch or 134.44 cubic yards. Assuming a concentration of 1,250 mg of TP per gram of sediment, calculations suggest 123 lbs of total phosphorus are contained within this sediment layer. Calculations based on binding efficiency and treatment duration suggest 6,547 gallons of liquid alum would be required to properly inactivate this phosphorus source from within the first inch of the sediment for a 5 year time period. HAB Aquatic Solutions has quoted a price of $49,164 for purchasing and spraying an alum slurry using high injection spray nozzles. Engineering, design, and legal contingency costs will add an additional 15% of the total application cost, bringing the total project cost to $56,540. Extrapolating the cost estimate for the 1 acre test area to the entire 5 acre area of wetlands A and B that were targeted for sediment excavation would have an alum purchasing, application, and incorporation cost of $245,820. Engineering, design, and legal contingency costs would add an additional 15%, bringing the total project cost to $282,693. Extrapolating the cost estimate to the entire 6.1 acre area within wetland C that was targeted for sediment excavation would have an alum purchasing, application, and incorporation cost of $299,900. Engineering, design, and legal contingency costs would add an additional 15%, bringing the total project cost to $344,885.

**Lofton Pond Alum Treatment**

Lofton Pond contributes 65 lbs of TP per year to Moody Lake (Figure 2). Sediment cores collected from Lofton Pond indicated the nutrient rich sediment layer was between 4.5-8 inches deep (Figure 11). Alum dosing calculations were based on the amount of alum needed to inactivate the phosphorus present within the first 8 inches of sediment, the maximum observed thickness of the nutrient rich sediment layer. Assuming a concentration of 655 mg of TP per gram of sediment, calculations suggest 208 lbs of total phosphorus are contained within this sediment layer. Alum dosing based on binding efficiency and treatment duration suggests 10,832 gallons of liquid alum are needed to inactivate this phosphorus source for a 5 year time period. The cost for purchasing and applying this amount of alum is between $35,021 and $60,035. Alum treatments conducted on the Minneapolis Chain of Lakes demonstrated a 30-58% reduction in observed TP concentrations. A
Figure 11. Depth (inches) of Targeted Nutrient Rich Sediment Layer within Lofton Pond.
30-58% reduction in TP concentrations for Lofton Pond equates to an annual TP load reduction of 20 to 28lbs/year (Table 4).

**Table 4. Phase 3 Cost-Benefit Analyses**

<table>
<thead>
<tr>
<th>Wetland</th>
<th>BMP</th>
<th>Quantity</th>
<th>Construction /Excavation Costs</th>
<th>Design /Legal Contingency Costs</th>
<th>Total Cost</th>
<th>TP Removal (lbs/yr)</th>
<th>Total Cost per pound of TP Removed</th>
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</thead>
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<tr>
<td>Wetlands A,B</td>
<td>Dry Alum Treatment</td>
<td>4,033 CY</td>
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<td>15%</td>
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<td>Wetland A,B</td>
<td>Liquid Alum Treatment</td>
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<td>Wetlands C</td>
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<td>20-28lbs</td>
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*Estimated total phosphorus reductions are contingent upon reductions achieved in Phase 1 and 2.

**Phase 3b Monitoring**

Flow and water quality samples will be collected at the same two locations in the Moody Watershed that were monitored following Phase 1 (Figure 9) to determine the cumulative load reduction following implementation of all 3 Phases. Continuous flow data will be collected in 2020 using a level logger. Instantaneous flow measurements will be collected at both sites using a Marsh McBirney flow meter. A rating curve will be developed for both sites using instantaneous flow measurements collected during water quality grab sampling events.

Water quality samples collected during grab sampling events will be analyzed for total phosphorus (TP), ortho-phosphorus (OP), total iron (Total Fe), total suspended solids (TSS), pH, and alkalinity. These data will be used as inputs to the FLUX32 model to characterize the reactivity and availability of those phosphorus loads for algal growth, and ultimately to determine the need for alternative best management practices.

**Summary of Recommended Approach**

Recommendations for implementation were divided into three phases based on results from the feasibility work and a cost-benefit analysis of best management practices aimed at reducing total phosphorus export to Moody Lake. A summary and cost-benefit analysis for each phase is provided in Table 5.
Table 5. Cost-Benefit Summary of Phased Approach

<table>
<thead>
<tr>
<th>Wetland</th>
<th>BMP</th>
<th>Quantity</th>
<th>Construction/Excavation Costs</th>
<th>Design/Legal Contingency Costs</th>
<th>Total Cost</th>
<th>TP Removal (lbs/yr)</th>
<th>Total Cost per pound of TP Removed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase 1 Wetland A &amp; B</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wetlands AB</td>
<td>Land Acquisition</td>
<td>10 acres</td>
<td>NA</td>
<td>NA</td>
<td>*</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Wetlands AB</td>
<td>Grassed Waterway/Buffer</td>
<td>1 acre</td>
<td>$3,000-4,000</td>
<td>$1,000-$2,000</td>
<td>$5,000-$6,000</td>
<td>53.2</td>
<td>$94-$113</td>
</tr>
<tr>
<td>Wetlands AB</td>
<td>Livestock Exclusion</td>
<td>10 acres</td>
<td>$406</td>
<td>NA</td>
<td>$406</td>
<td>42-84</td>
<td>$5-$10</td>
</tr>
<tr>
<td>Wetlands AB</td>
<td>Sediment Excavation</td>
<td>8,067 CY</td>
<td>$120,667</td>
<td>35%</td>
<td>$162,900</td>
<td>434</td>
<td>$375</td>
</tr>
<tr>
<td>Phase 2 – Wetland C</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wetland C</td>
<td>Sediment Excavation</td>
<td>4,840 CY</td>
<td>$68,400</td>
<td>35%</td>
<td>$92,340</td>
<td>445**</td>
<td>$208</td>
</tr>
<tr>
<td>Phase 3 – Wetland Alum Application</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wetlands AB</td>
<td>Dry Alum Treatment</td>
<td>4,033 CY</td>
<td>$745,355</td>
<td>15%</td>
<td>$857,160</td>
<td>TBD***</td>
<td>TBD***</td>
</tr>
<tr>
<td>Wetland AB</td>
<td>Liquid Alum Treatment</td>
<td>672 CY</td>
<td>$245,820</td>
<td>15%</td>
<td>$282,693</td>
<td>TBD***</td>
<td>TBD***</td>
</tr>
<tr>
<td>Wetlands C</td>
<td>Dry Alum Treatment</td>
<td>4,840 CY</td>
<td>$909,333</td>
<td>15%</td>
<td>$1,045,733</td>
<td>TBD***</td>
<td>TBD***</td>
</tr>
<tr>
<td>Wetland C</td>
<td>Liquid Alum Treatment</td>
<td>807 CY</td>
<td>$299,900</td>
<td>15%</td>
<td>$344,885</td>
<td>TBD***</td>
<td>TBD***</td>
</tr>
<tr>
<td>Wetland D</td>
<td>Liquid Alum Treatment</td>
<td>1,075 CY</td>
<td>$35,021-$60,035</td>
<td>NA</td>
<td>$35,021-$60,035</td>
<td>20-28lbs</td>
<td>$1,751-$2,144</td>
</tr>
</tbody>
</table>

*Total costs for land acquisition/easement has not yet been determined.

**This is a cumulative reduction under the assumption that Phase I has been implemented.

***Estimated total phosphorus reductions are contingent upon reductions achieved in Phase 1 and 2.
References


EOR, 2010. Comfort Lake-Forest Lake Watershed District Six Lakes Total Maximum Daily Load Study


Orning, George., and Michael Wietecki. 2007. Regional Parks for Minnesota's Outstate Urban Complexes. Prepared by the Department of Forest Resources University of Minnesota for the Legislative Citizen Commission on Minnesota Resources.
APPENDIX A: WETLAND DELINEATION

Introduction
Three wetland complexes were identified for rehabilitation in the December 11, 2014 Moody Lake Sequential Diagnostic final technical memorandum: Wetland A) upstream of the 250th monitoring site, Wetland B) north of the 250th monitoring site culvert, and Wetland C) upstream of the Peterson monitoring site (Figure A-1). This report uses the methodology of the 1987 Corps of Engineers Wetland Delineation Manual and regional supplements for the Northcentral and Northeast Region to delineate the wetland boundary for the three wetland complexes.

Figure A-1. Recommended rehabilitative actions in the northwest Moody Lake watershed

Purpose of Review
The purpose of this report is to document the boundaries of three wetland complexes within the Moody Lake watershed. This report has been prepared to facilitate a wetland boundary and type determination by the wetland regulatory agencies.

Review Team and Contact Information
The wetland delineation was performed by Jason Naber and Joe Pallardy of Emmons & Olivier Resources, Wetland Delineation Certification #1254, #5166 respectively.

Site Location and Description
The project is located in Sections 29, 30, and 32, T33N, R20W between Chisago City to the North and Forest Lake to the South. The Comfort Lake Forest Lake Watershed District is the Local Governing Unit for the Wetland Conservation Act.
Methodology

Preliminary Investigation
Prior to conducting the field wetland delineation, existing data and available maps were compiled and reviewed. Topographic maps, National Wetland Inventory (NWI), and MN DNR Protected Waters (PWI) maps were reviewed to determine likely locations of existing wetlands. Two NWI-mapped wetlands occur within the project area. NRCS SSURGO soils were compiled using the Web Soil Survey site to determine potentially hydric soils in the project area). Lastly, precipitation data from the Minnesota Climatology Working Group was reviewed to determine how current precipitation at or near the site compares to normal conditions.

Wetland Delineation Methods
The methodology of the 1987 Corps of Engineers Wetland Delineation Manual and regional supplements for the Northcentral and Northeast Region were used to delineate wetlands within the project area. The wetland delineation was conducted on July 21, 2015. Error! Reference source not found. shows locations of sampling points.

Four wetland-upland transects were conducted on the site. Wetland observation and upland observation points were established, and the Wetland Determination Data Form – Northcentral and Northeast Region was completed. All sample points were recorded for map preparation using a submeter differential Global Positioning System (GPS) and transferred to ArcMap v. 10.1 Geographic Information System (GIS). Photos for the sample points are in Appendix D.

Vegetation
Two sampling points were established within the wetland plant communities encountered at wetland A, additionally; two sampling points were established within the upland plant communities at wetland A. One sample point was established within the wetland plant communities encountered at both wetland B and wetland C and a second sample point was established within the upland plant communities in both wetlands (Figure A-2). At the pit locations, all observable species were assigned scientific names to allow for wetland indicator status determination. Literature used for nomenclature and identification are listed in References. The wetland probability indicator status of dominant plant species was determined using the 2014 National Wetland Plant List v3.2.

Soils
Soil samples were collected using a soil auger and were dug to a minimum of 24 inches. Soil colors were determined using the Munsell Soil Color Charts. Primary and secondary indicators followed the Natural Resources Conservation Service Field Indicators of Hydric Soils. Soils were described to include those hydric indicators immediately below the A-horizon. The hydric soil determination was then made based upon soil pit characterization, soil order, ponding, and flooding.

Hydrology
As required in the 1987 Manual, the presence of subsurface hydrology or indicators thereof was characterized in the rooting zone. Comments are on data sheets about any absence or marginal presence of hydrology on the date of delineation and the professional judgment used to make a hydrology determination at the point.
Delineation Boundary Determination
The boundary was determined after taking into consideration the parameters of soil, hydrology, vegetation, topography, and professional judgment at paired upland and wetland sample points. Boundary point locations were field-flagged at sufficient intervals, depending on curvature.

Description of Field Conditions
The delineation was performed July 21, 2015. Weather conditions were clear at the time of the delineation; however, site conditions were wetter than normal due to above average precipitation in July. The previous three months during the growing season included one month with above normal precipitation and two months with normal precipitation totals. The adjacent upland immediately bordering the wetland was either inundated or saturated during the site visit. See Appendix E for precipitation information.

Topography within the vicinity of the project is comprised of a series of flow through depressional wetlands isolated between moderately sloped upland areas. Vegetation within the project area is comprised of native and non-native species.

The upland soils within the project area are comprised primarily of loams, fine sandy loam, and loamy fine sand. The parent soil within the wetlands is properly classified as muck (Table 1).

Table 1. Soils within project vicinity

<table>
<thead>
<tr>
<th>Soil symbol</th>
<th>Wetland/Upland</th>
<th>Soil Name</th>
<th>Surface texture</th>
<th>Depth to Water Table</th>
<th>Slope</th>
</tr>
</thead>
<tbody>
<tr>
<td>540</td>
<td>Wetland</td>
<td>Seelyville</td>
<td>Muck</td>
<td>0</td>
<td>Level</td>
</tr>
<tr>
<td>544</td>
<td>Wetland</td>
<td>Cathro</td>
<td>Muck</td>
<td>0</td>
<td>Level</td>
</tr>
<tr>
<td>40B 40C 40D</td>
<td>Upland</td>
<td>Nebish</td>
<td>Loam</td>
<td>&gt;20 cm</td>
<td>2-25%</td>
</tr>
<tr>
<td>169B 169C</td>
<td>Upland</td>
<td>Braham</td>
<td>Loamy fine sand</td>
<td>&gt;20 cm</td>
<td>2-12%</td>
</tr>
<tr>
<td>346</td>
<td>Upland</td>
<td>Talmoon</td>
<td>Fine sandy Loam</td>
<td>0-10 cm</td>
<td>Level</td>
</tr>
</tbody>
</table>

Wetlands
Three wetland complexes were delineated at the project site (Error! Reference source not found.); each is described below (Error! Reference source not found.). In wetland A, Reed Canary Grass (Phalaris arundinacea), Rattlesnake grass (Glyceria canadensis) and Kentucky bluegrass (Poa pratensis) are the dominant plant species within the wetland areas while Kentucky bluegrass (Poa pratensis) and Reed Canary Grass (Phalaris arundinacea) are the most
dominant species on the adjacent uplands. In wetland B, Reed Canary Grass (*Phalaris arundinacea*), was the dominant plant species within the wetland areas while Alsike Clover (*Trifolium hybridum*), and Red Clover (*Trifolium pratense*) are the most dominant species on the adjacent uplands. In wetland C, Reed Canary Grass (*Phalaris arundinacea*), was the dominant plant species within the wetland areas while Smooth Brome (*Bromus inermis*) was the most dominant species on the adjacent uplands.

At wetland A, wetland hydrology was met through Hydrology Indicator “Surface water (A1)” at both wetland pits. Primary Indicators of wetland hydrology were not identified at either of the upland pits within wetland A. At wetland B, wetland hydrology was met through Hydrology Indicator “Surface water (A1)” at the wetland pit, Primary Indicators of wetland hydrology were not identified at the upland pit. At wetland C, wetland hydrology was met through Hydrology Indicator “Surface water (A1)” at the wetland pit, Primary Indicators of wetland hydrology were not identified at the upland pit.

Hydric soil indicators were met within wetland A and C, the wetland soil pit in wetland B was flooded; therefore, a soil sample was not taken. In wetland A, pit #4 contained a loamy gleyed matrix, meeting Hydric Soil Indicator “F2” while pit #6 met Hydric Soil Indicator “A3”. In wetland C, pit #6 contained a black histic soil and met Hydric Soil Indicator “A3”.

**Table 2. Wetland Types**

<table>
<thead>
<tr>
<th>Wetland ID</th>
<th>Wetland Type</th>
<th>Acres Delineated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wetland A</td>
<td>Type 3 / PEMFd Shallow Marsh</td>
<td>14.29</td>
</tr>
<tr>
<td>Wetland B</td>
<td>Type 3 / PEMFd Shallow Marsh</td>
<td>0.86</td>
</tr>
<tr>
<td>Wetland C</td>
<td>Type 3 / PEMFd Shallow Marsh</td>
<td>6.11</td>
</tr>
<tr>
<td><strong>Total area of wetland delineated</strong></td>
<td></td>
<td><strong>21.26</strong></td>
</tr>
</tbody>
</table>
APPENDIX B: WATER LEVEL MONITORING

Wetland A

Wetland A Stage 2015
Chisago County, MN

--- Stage --- BM Check --- Precipitation

Precipitation [in.]
Stage [ft.]

Wetland B

Wetland B Stage 2015
Chisago County, MN

--- Stage --- BM Check --- Precipitation

Precipitation [in.]
Stage [ft.]
PROPOSED EXCAVATION OF SEDIMENT IN WETLAND - SCRAPE 8" AVERAGE

DELINATE WETLAND

PRIVATE DRIVE

LOFTEN AVENUE

WEITLANC

WETLAND C

SCALE IN FEET

0 30 60 120