

*Alum Treatment Facility Feasibility Study
for Muskellunge Creek*

*Prepared for
Little St. Germain Lake Protection and
Rehabilitation District*

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Executive Summary

The feasibility of constructing and operating an alum treatment facility designed to remove phosphorus from Muskellunge Creek was evaluated. The feasibility analysis was performed assuming that the facility would be constructed north east of the intersection of Birchwood Drive and Muskellunge Creek Road (see Figure 1). The criteria for evaluation include capital and operation costs, physical constraints of the site and the capacity of the site to accommodate required treatment facility structures, and the expected in-lake phosphorus levels (East Bay) with a range of potential treatment facility designs and operating conditions. The findings of this study are as follows:

- Proper operation, performance, and cost effectiveness of the treatment facility will be constrained by the limited size of the site that is available for the construction of the facility and the large flow volume in Muskellunge Creek that will need to be treated. The effectiveness of the facility may be compromised by the effect of phosphorus release from the Little St. Germain Lake sediments (see last bullet point on next page).
- A total of twelve alternative plant operating conditions have been evaluated. The conditions evaluated include treatment of 50% (flows <6.6 cfs), 75% (flows <11.1 cfs), and 100% (flows <21 cfs) of Muskellunge Creek flows, alum doses of 3 and 6 mg/L as aluminum, and the use of baffle or mechanical mixing of alum and water.
- The cost of capital, engineering and design, and treatment system optimization is expected to range from \$0.7 to \$1.0 million if a baffle type mixing system is used and from \$0.8 to \$1.1 million if a mechanical mixer is used. Greater treatment performance is expected with the mechanical mixing system. ***Land acquisition costs have not been included in these costs.***
- Annual operation and maintenance costs are expected to range from \$130,000 to \$600,000, depending on the volume of stream flows that are treated and whether alum doses of 3 or 6 mg/L are used. This cost primarily includes the cost of alum, alum sludge removal and disposal, and the part-time and seasonal employment of a technician.
- Because the available treatment site is constrained by its size, treatment of stream flows less than 6.6 cfs is recommended. This would provide the treatment pond with a minimum required residence (settling/alum floc removal) time of 4.4 hours. With the treatment of flows less than 6.6 cfs, the accumulated alum sludge in the pond would need to be excavated annually at the end of each treatment season. If flows greater than 6.6 cfs are treated, the pond would fill up with alum sludge before the end of the treatment season and treatment would need to be prematurely halted.

- There are several physical and chemical constraints that may affect system performance or will require some operational adjustments. According to the study by Foth and Van Dyke (Foth and Van Dyke 2004), the use of an alum dose of 3 mg/L is expected to yield a total phosphorus reduction of 59%. However, performance in a laboratory setting has been shown to be consistently higher than performance in full scale operations. For this reason, a 6 mg/L dose has also been evaluated because a higher dose may be needed to achieve adequate phosphorus reductions. Unfortunately, the use of a 6 mg/L dose may be constrained by the low alkalinity of Muskellunge Creek (expected to range from 35 to 60 mg/L as CaCO₃) and the potential to suppress the pH of water in the creek below 6.0. Hence, the lack of alkalinity in Muskellunge Creek may restrict the treatment system performance (because a lower dose will need to be used) or an alternative coagulant (e.g., polyaluminum chloride) that does not suppress pH will need to be considered.
- Using a calibrated water quality model for the East Bay of Little St. Germain Lake and 2001 monitoring data collected by the USGS, it is estimated that average treatment season (mid-April through September) phosphorus levels would decline from 0.051 mg/L to somewhere within the range of 0.038 to 0.041 mg/L with the treatment of stream flows less than 6.6 cfs (see Figure 6). It is expected that there will be limited additional benefit to treating stream flows above 6.6 cfs.
- The use of the calibrated lake model and the sediment studies conducted by the USGS indicate that phosphorus release from the sediments (internal loading) of the East Bay of Little St. Germain has a significant effect on phosphorus levels in the East Bay. If internal phosphorus loading were reduced by 90%, the average phosphorus level in the East Bay (mid-April through September) would have been 0.036 mg/L in 2001 (see Figure 7). More importantly, the control of internal phosphorus loading would have the effect of reducing phosphorus levels during the mid-July through August period when algal blooms are most often prevalent. It is recommended that serious consideration be given to the control of internal phosphorus loading in Little St. Germain Lake prior to deciding to construct an alum treatment facility on Muskellunge Creek.
- Information is also provided in this report regarding methods that can be used to reduce internal phosphorus loading in Little St. Germain Lake and the additional data gathering steps that would be required to properly implement these methods. The best method is the application of alum (aluminum) directly to the lake sediment. This is called a “whole lake” alum treatment. The aluminum in the alum permanently binds with phosphorus in the lake sediment and inhibits the release of phosphorus (internal loading) during the summer months. This treatment would likely have to be repeated once every 10 years.

1.0 Introduction

Muskellunge Creek has been identified as a significant source of phosphorus loading to Little St. Germain Lake. The USGS estimates that from 53% to 61% of the total phosphorus loading to Little St. Germain Lake is from Muskellunge Creek (USGS 2005). This study also indicated that the water quality of Little St. Germain could be significantly improved with large reductions in phosphorus loading from Muskellunge Creek. The treatment of water from Muskellunge Creek with chemical coagulants such as alum was identified by the Little St. Germain Lake District as a potential means of reducing phosphorus loading to Little St. Germain. Barr Engineering was retained by the Little St. Germain Lake District to evaluate the feasibility of constructing and operating an alum treatment facility on Muskellunge Creek and the corresponding phosphorus reductions in Little St. Germain Lake that could be achieved with its operation.

The primary purpose of this study was to determine the feasibility of constructing and operating a properly functioning alum treatment facility. This study focused on the development of a conceptual but functioning alum treatment design such that the costs to construct and operate a treatment facility could be estimated.

The Association for the Advancement of Cost Engineering (AACE) provides a Cost Estimate Classification System that relates accuracy to the level of information available, the intended end usage, and the methodology employed to produce cost estimates (Recommended Practice 1997). Based on this system, the cost estimates provided in this study are between a Class 3 and Class 4 Cost Estimate. As a result, costs can be reasonably expected to vary by +/- 15% to 40%.

2.0 Site Description

Little St. Germain Lake is located approximately 10 miles west of Eagle River, Wisconsin in Vilas County. The proposed site for the alum treatment facility is located northeast of Little St. Germain Lake near the intersection of Birchwood Drive and Schultz Road. Figure 1 shows the proposed alum treatment facility location. This locations was chosen after a site visit in October, 2006 in which several sites were evaluated.

The proposed site is an open space area slightly under $\frac{3}{4}$ acres in size and owned by Vilas County. The site resides on the northwest bank of Muskellunge Creek (the primary tributary to Little St. Germain Lake) separated by approximately 120-feet of forested land from the creek. Four-foot hand auger samples taken at the site indicate that soils are generally medium sands with some silt and organic content.

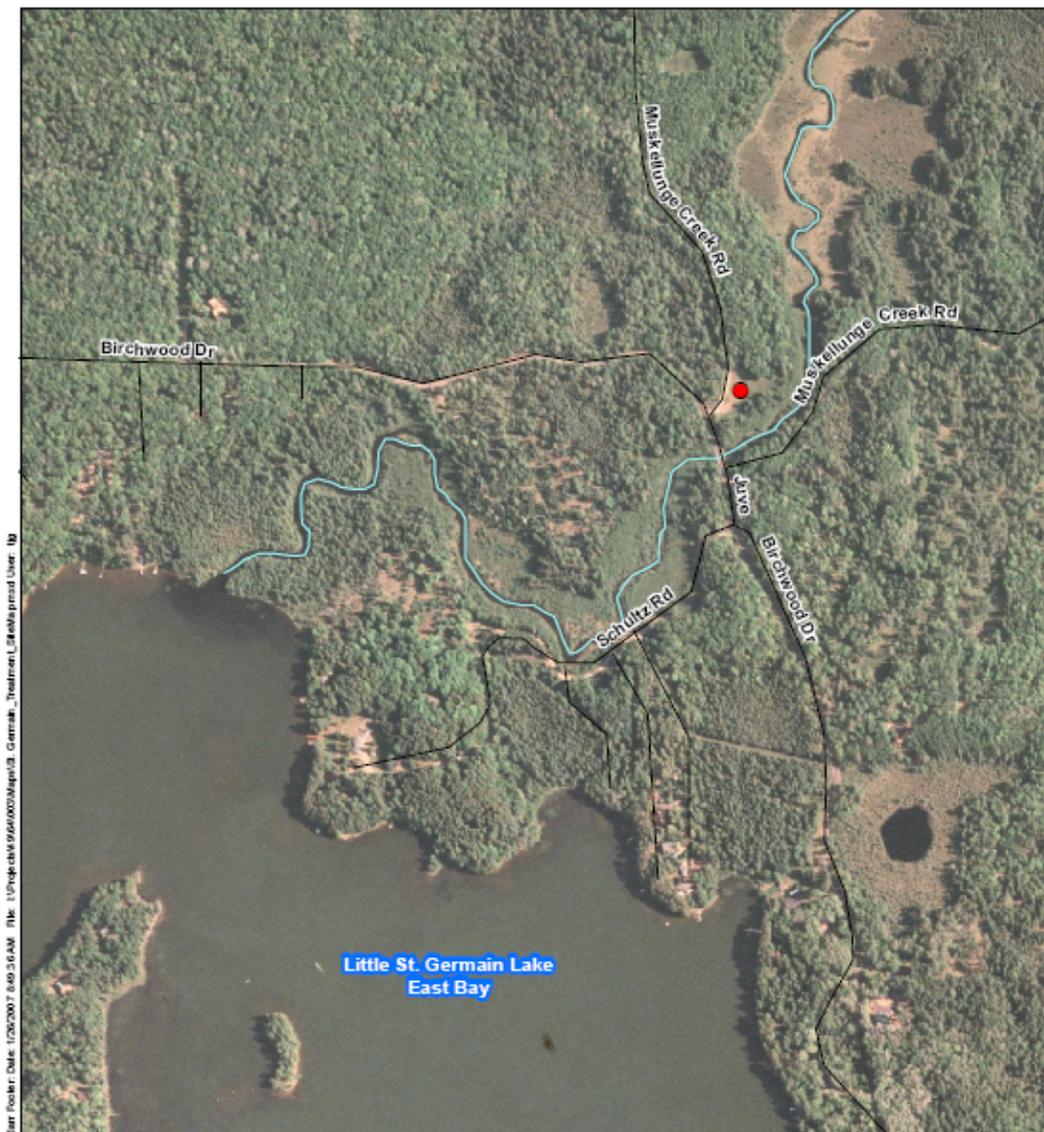


Proposed Alum Treatment Facility Site
(looking south)



Muskellunge Creek, facing upstream from the
Birchwood Drive culvert

Electrical service in this region is provided by Wisconsin Public Service Corporation. The nearest single phase electrical service is located 1,500-feet from the site. The nearest 3-phase electrical service is located $2\frac{1}{2}$ - 3 miles from the site.



- Proposed Facility Location
- Muskellunge Creek
- Roads

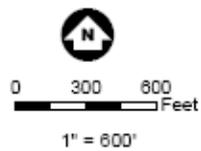


Figure 1
SITE MAP
Little St. Germain Lake
Alum Treatment Facility

Figure 1. Site Map

3.0 Facility Description

3.1 Plant Design

The proposed alum treatment facility would consist of the following basic components:

- Stream diversion weir
- Stream diversion pipes
- Inlet control manhole
- Mixing vault
- Settling pond
- Geotextile curtain
- Outlet control manhole
- Storage building
- Chemical storage tanks
- Chemical feed equipment
- Chemical feed controls

A weir constructed across Muskellunge Creek would force a percentage of creek water into a pipe that would empty into an inlet control manhole. The inlet control manhole would contain a broad crested weir that could be adjusted to stop inflow from the creek during pond maintenance. Water from the inlet control manhole would be routed into a mixing vault. Inside the mixing vault, water would pass over a v-notch weir (see photograph below). A level transducer mounted on the weir plate would be used to instantaneously calculate the flow rate across the weir. In turn, alum would be added to the water based on the flow rate.

Two options were considered for alum and water mixing: (1) a three-phase electric mixer and (2) a vertical baffle system. The use of a mixer will provide thorough mixing of alum and creek water with a relatively small head loss but will require the use of a variable frequency drive (VFD) to convert single phase power to three phase power. A vertical baffle system can also be used to mix water and alum and has the primary benefit of reduced cost. However, mixing using baffles will be less thorough because of dead zones created in the baffles and there will be a relatively significant head loss (meaning, the diversion structure in Muskellunge Creek will need to raise the elevation of the river water in order to force water through the treatment system). Also, the pond water level will need to be lower with the baffle system. If an electronically powered mixer is selected, the vault would be sized to ensure a retention time of 2½ - 3 minutes so that the alum has adequate contact with the inflowing stream water. If a vertical baffle system is selected to provide mixing, the vault should be sized to ensure a Gt (a treatment design parameter: velocity gradient multiplied by retention time) of 8,000.



Tanners Lake Alum Treatment Facility, mixing vault with v-notch weir



Tanners Lake Alum Treatment Facility, chemical feed pumps and controls

Water from the mixing vault would be routed to a pond to settle the alum floc and temporarily store alum sludge. In order to maximize the retention time of water passing through the pond, an impermeable geotextile curtain would be installed to force water to travel across the length of the pond and back before being routed to the outlet control structure. The outlet control structure would contain a broad crested weir that could be adjusted to raise/lower the pond water elevation. Water from the outlet control structure would be routed back to Muskellunge Creek on the downstream side of the stream diversion weir.



Tanners Lake Alum Treatment Facility, outlet control structure with an adjustable broad crested weir

The storage building would house chemical storage tanks, chemical feed equipment, and chemical feed controls. The size of the storage building is dependent upon the size and number of chemical storage tanks needed. Controls housed in the storage building would receive data from the level transducer in the mixing vault and would then adjust variable speed pumps to supply alum from the storage tanks to the mixing vault.



Tanners Lake Alum Treatment Facility, Alum storage tanks with transfer piping and secondary containment

Figure 2 shows the facility layout used to produce cost estimates.



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-  Pond Extents
-  Pond NWL
-  2-ft Pond Contours
-  Geotextile Curtain
-  Control Structures
-  RCP

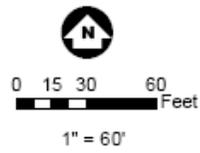


Figure 2
 FACILITY MAP
 Little St. Germain Lake
 Alum Treatment Facility

Figure 2. Facility Map

Figure 3 shows all available USGS discharge data for Muskellunge Creek. The data was sorted such that the flow rate to treat 50%, 75%, and 100% of the creek flow by volume (total volume of flows treated divided by the total volume of flows that discharge from Muskellunge Creek to Little St. Germain Lake) could be estimated. This data was used to determine the size of the treatment facility and pond that would be required for a given maximum treated flow rate. For example, a plant that is designed to treat 50% of the stream flows would divert all flows from Muskellunge Creek that are less than 6.6 cfs. Hence, the plant would need to be designed to treat flows as high as 6.6 cfs. If the plant were to treat 75% of all flow (by total volume), the plant would need to be designed to treat flows up to 11.1 cfs. It can be seen that to capture an additional 25% of the flow volume in Muskellunge Creek, the plant has to be sized much larger (i.e., for 11.1 cfs rather than 6.6 cfs). Cost estimates were developed for three plant sizes designed to treat maximum flow rates of 6.6, 11.1, and 21 cfs to such that cost benefit-type analysis could be performed.

Given the three plant sizes and treatment flow rates, the hydraulic residence time of the settling pond (see Figure 2) is expected to range from 1.4 to 4.4 hours (maximum treatment rates of 21 to 6.6 cfs). To maintain treatment efficiency, the pond residence time should be no less than 4 hours if alum is used. As part of start-up testing (see Section 4.3), it may be necessary to evaluate different coagulants other than alum as there are several specialty coagulants that settle more quickly than alum.

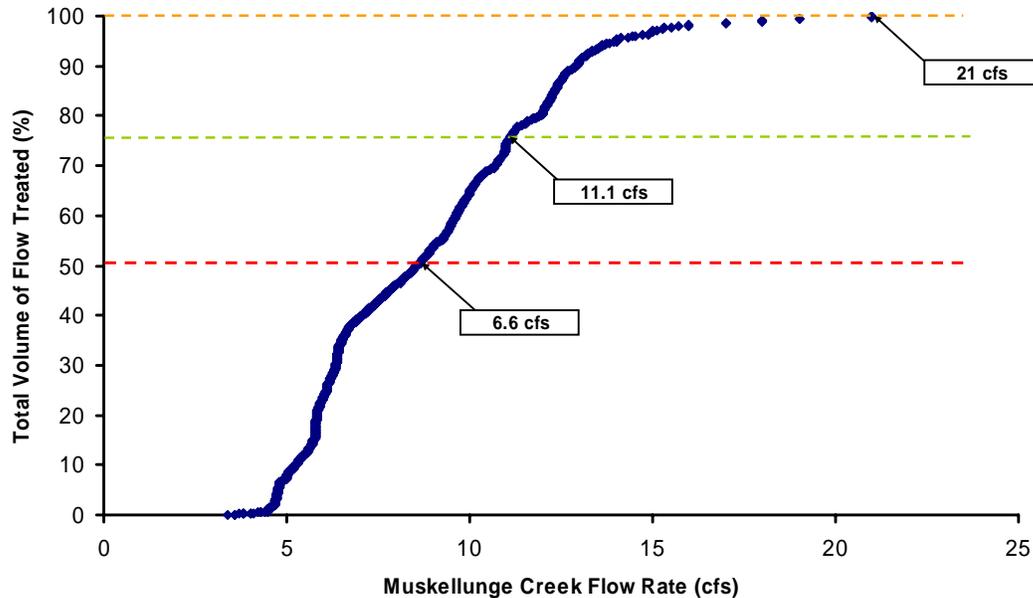


Figure 3. Muskellunge Creek Flows

4.0 Cost Estimate

The following provides a detailed discussion of the cost estimates that have been developed for the Little St. Germain Lake alum treatment facility. The discussion includes the resources used, assumptions made, and items that were included to estimate the following costs (organized by category):

- Capital
- Engineering and Design
- Start-up/System Optimization
- Maintenance and Operations

Each of the above costs were evaluated for treatment of 50%, 75%, and 100% of stream flows (by volume) at alum dosing rates of 3 mg/L and 6 mg/L as aluminum. Table 1 shows a summary of the costs.

Table 1. Alum Treatment Facility Cost Estimate Summary

Costs		Alum Dosing Rate of 3 mg/L			Alum Dosing Rate of 6 mg/L		
		Percentage of Stream Flow Treated			Percentage of Stream Flow Treated		
		50%	75%	100%	50%	75%	100%
Capital ⁽¹⁾	Mech. Mixer	\$649,600	\$692,200	\$743,000	\$696,400	\$775,700	\$853,600
	Baffle	\$622,750	\$665,350	\$716,150	\$669,550	\$748,850	\$826,750
Engineering & Design ⁽¹⁾		\$153,500	\$153,500	\$153,500	\$153,500	\$153,500	\$153,500
Start-up/System Optimization ⁽¹⁾		\$11,220	\$11,220	\$11,220	\$11,220	\$11,220	\$11,220
Maintenance & Operations ⁽²⁾	Mech Mixer	\$132,376	\$215,528	\$316,301	\$247,338	\$413,642	\$615,188
	Baffle	\$129,963	\$213,115	\$313,888	\$244,925	\$411,230	\$612,776
Annualized Cost⁽³⁾	Mech Mixer	\$173,092	\$258,374	\$361,687	\$290,394	\$460,663	\$666,104
	Baffle	\$169,337	\$254,619	\$357,932	\$286,639	\$456,908	\$662,349

⁽¹⁾ 2007 Dollars

⁽²⁾ Annualized cost over a 20 year period assuming 3% inflation

⁽³⁾ Annualized cost over a 20 year period assuming 3% inflation for maintenance and operations costs and payment for Capital, E&D, and Start-up costs in 2007

General assumptions that affect many of the above costs include:

1. The pond normal water level will be at an elevation approximately 4-feet below existing ground surface
2. Generally sandy soil conditions exist below the 4-foot depth (sandy soil conditions confirmed with hand auger sampling from 0 to 4-feet)
3. Building and pond construction will be permitted within the 75-foot from the center of road setback requirements
4. Stream diversion structures will not need to permit fish migration upstream or downstream
5. There are no existing site utilities within the proposed pond, building, or stream diversion system footprints

Detailed costs and other supplemental data are located in the following appendices:

- Appendix A – Capital Costs
- Appendix B – Start-up/System Optimization Costs
- Appendix C – Maintenance and Operations Costs
- Appendix D – Contact Information and Quotes

4.1 Capital Costs

Capital costs include all expenses incurred to construct the proposed alum treatment facility. The following costs were considered:

1. Mobilization/Demobilization
2. Site Preparation and Erosion Control
3. Storage Building (alum treatment facility)
4. Equipment
5. Earthwork and Ponding Facilities
6. Site Restoration
7. Electric Service

Land acquisition and/or easement costs were not considered in the capital cost estimate.

Only the storage building (alum treatment facility) and equipment costs were assumed to vary based on the treatment conditions selected (i.e., volume of creek flows treated and alum doses). These costs will vary because the chemical storage tanks and the building will need to be sized to accommodate the treatment of greater stream flows (50, 75, and 100 of flow volumes) and the used of different alum doses. However, since the settling pond area is limited, the pond size will need to be as large as is feasible regardless of the treatment conditions selected. Changes in the remaining capital costs were assumed be negligible.

Detailed cost information for all capital costs is included in Appendix A. Costs were generally estimated using one of the following:

1. Bid tabs for similar work adjusted to reflect 2007 dollars
2. 2007 RSMeans Building and Construction Cost Data Book (Means)
3. Direct quotes/cost estimates from manufactures, vendors, or service providers

4.1.1 Mobilization/Demobilization

Mobilization/demobilization costs generally include: performing all operations as are necessary for mobilization and demobilization of supervision, labor, materials, and equipment; the Contractor's premium for any special insurance; and furnishing temporary facilities.

Mobilization/demobilization costs were estimated from a collection of bid tabs for similar work scopes as a percentage of the total bid price. On most occasions, mobilization/demobilization constituted 10% - 12% of the total bid price.

4.1.2 Site Preparation and Erosion Control

Site preparation and erosion control cost estimates included the following:

- Silt fence
- Rock construction entrance
- Street sweeping
- Clearing and grubbing
- Stripping and stockpiling topsoil
- Utility locate

All site preparation and erosion control costs were estimated using Means and a collection of bid tabs for similar types of work adjusted to 2007 dollars.

Silt fence costs include furnishing and installing 3-foot high silt fence at the eastern and southern construction limits. Rock construction entrance costs include furnishing and installing 2'-3" rock, 1-foot deep, for 50-feet. Street sweeping cost were based upon forty-five minutes of sweeping per day following the days in which trucks are hauling soil from the site.

Clearing and grubbing costs include removal of all brush and/or trees as necessary to perform the work. The lump sum cost for clearing and grubbing was estimated by combining cost per acre rates for dense brush with 24-inch diameter tree removal costs and assumes that culvert alignment will be designed to minimize tree removal. Stripping and stockpiling topsoil costs assume that there are on average 8-inches of existing topsoil on-site. Utility locating costs include potholing and protecting existing site utilities assuming there are utilities that run in the easement along Muskellunge Creek Road.

4.1.3 Storage/Treatment Facility Building

Storage building costs were estimated using Means. The building cost was estimated using a per square foot rate for warehouses and storage buildings. This cost generally includes site work, masonry, and building services (HVAC, plumbing, electrical). It also includes the contractor's overhead and profit but it does not include land costs or the cost of extending utility service to the site location (see Land Acquisition/Easements & Electric Service). The size of the storage building was assumed to vary based on the treatment criteria selected. As the percentage of the stream flows treated or the alum dosing rate increase, the building size was increased to accommodate larger chemical storage tanks.

Other associated building costs include an entry door, footings/foundation, and paving. The entry door cost includes furnishing and installing a general overhead commercial door (20-foot wide, 16-foot tall). The footings/foundation cost includes construction and materials for a 5½-foot deep continuous footing (directly poured) with four (4) spread footings and #5 rebar spaced 1-foot on center (assuming a frost line of 5.5-feet). Paving costs include materials, delivery, and construction for a 200 square foot asphalt parking area (6" stone base, 2" binder course, 1" topping).

4.1.4 Equipment

Equipment costs include furnishing the following:

- Controls
- Chemical storage tanks
- Chemical feed equipment
- Level transducer
- Mixer

Installation costs for these items are accounted for in the Storage Building cost estimate. The cost for controls was estimated from the Tanner's Lake Alum Treatment Facility that was constructed in Oakdale, Minnesota, with adjustment to 2007 dollars. Chemical storage tanks were priced from several manufacturers including Hawkins Chemical, Diverse Plastic Groups, and American Tank. A unit cost of \$1.24 per gallon was estimated from the manufacturer prices for tanks ranging in size from 10,000 to 15,000 gallons. The size and number of chemical storage tanks required varies based on the percentage of flows treated and the dosing rate. Table 2 shows the relationship between treatment criteria, chemical storage, and the storage building footprint.

Table 2. Chemical Storage Tank and Treatment Criteria Relationship

Percent of Total Flows Treated ⁽¹⁾	Alum Use (gallons)		# of Tanks	Tank Volume gallons	Tank Dia. feet	Tank Height feet	
	annually	monthly					
3 mg/L dose	50	58,620	11,720	2	6,100	8.5	16.3
	75	101,020	20,200	2	10,300	12.0	14.3
	100	152,410	30,480	3	10,300	12.0	14.3
6 mg/L dose	50	117,240	23,450	2	12,150	12.0	16.7
	75	202,040	40,410	4	10,300	12.0	14.3
	100	304,810	60,960	5	12,250	12.0	17.1

⁽¹⁾This is the total volume of flows treated divided by the total volume of flows that discharge from Muskellunge Creek to Little St. Germain Lake

Quotes for variable speed chemical feed pumps were obtained from Hawkins Chemical assuming a total maximum alum delivery rate of 0.5 gallons per minute. Additional chemical feed equipment including piping, valves, and couplers were assumed to be approximately 10% of the equipment costs. Level sensor and communication cord quotes were received from Geokon Pressure. Mixer quotes were received from Philadelphia Mixers and Midwest Mixing assuming a maximum operating volume of 12,650 gallons and that three-phase power would be accessible. The quote prices were increased to account for delivery and installation costs.

4.1.5 Earthwork and Ponding Facilities

Earthwork and ponding facilities cost estimates considered the following:

- Pond excavation
- Pond lining
- Floating baffle curtain
- Piping
- Mixing vault
- Control structures
- Pond and trench dewatering
- Stream diversion/dewatering
- Stream weir
- Soil hauling and disposal

Pond Excavation and Lining

The ponding area was assumed to occupy the remaining open space surface area after allotting space for the storage building at the proposed site. The volume of the pond was estimated by generally assuming a 3:1 side slope to an elevation 16-foot below ground surface. The resulting total pond volume with these assumptions was approximately 7,100 cubic yards (4.4 acre-feet). However, the outlet in the pond will need to be placed four feet below the ground surface based on a visual estimate of the ground surface with respect to the water level of Muskellunge Creek. The resulting dead storage capacity of the pond was approximated to be 3,900 cubic yards (2.4 acre-feet). Pond excavation costs were estimated using a collection of bid tabs for similar sized pond excavations adjusted to 2007 dollars.

Based on the sandy site conditions and the need to restrict ground water inflows during alum sludge excavation (to limit the volume of material that needs to be excavated or pumped), a pond liner was added to the cost estimate. The cost includes furnishing, placing, compacting, and grading 1-foot of clay on the pond bottom below the approximate normal water line. Assumptions for the clay liner include a clay source within fifteen (15) miles of the site and a material rate of no more than \$20 per cubic yard delivered. Alternatively, a geosynthetic clay liner could be utilized. Accounting for the additional pond excavation for the clay liner, the total pond excavation was estimated to be 7,650 cubic yards (4.7 acre-feet). Costs include excavation and placement into quad axel dump trucks for off-site disposal.

Floating Baffle Curtain

In order to prevent short circuiting in the pond the use of an impermeable floating baffle curtain is required and was added to the costs. A cost estimate from Environetics was solicited for 150-feet of curtain at a depth of 8-feet. The estimate included \$7,000 for materials and delivery and an additional \$3,500 for installation and accessories.

Piping

It was calculated that a 24-inch reinforced concrete pipe (RCP) would be adequate to route water from Muskellunge Creek to the pond. The 24-inch RCP costs include furnishing and installing the pipe, trench excavation, and backfill of the pipe. Backfill includes 1-foot of sand over/under the pipe compacted in 6" - 12" lifts and the use of excavated materials for all other backfill. Assumptions with these costs include an excavation depth of less than 6-feet, peaty soils near the creek, and sandy soils on the remainder of the site. The 24-inch flared end section (FES) costs include furnishing and installing four FES's over 12-inches of compacted sand fill and non-woven geotextile fabric, assuming that 24-inch pipe is adequately sized. RCP and FES costs were estimated using Means.

Mixing Vaults

Costs were estimated for two types of mixing vaults with v-notch weirs. If single phase power is extended to the site and converted to three phase power an electric mixer could be used to mix alum with stream water. A vault was sized to permit 180 seconds of retention time for average flows of nearly 8 cubic feet per second. To meet these criteria a quote for a pre-cast structure was obtained from County Materials Corporation for a vault with a 12-foot x 14-foot base and 14-foot height. Due to the large size of the structure, material costs alone approached \$40,000. As a result, the cost to construct a similar structure in-place was estimated using Means. Costs for the in-place structure included: excavation; sub-grade preparation; forming; #5 re-bar reinforcement spaced 1-foot on center; concrete; furnishing and installing a v-notch steel weir plate; a spring loaded access hatch; and backfill.

The vertical baffle mixing vault was sized using the relationships shown in Appendix A, Table A15. It would consist of thirteen (13) baffles 3-feet wide by 4-feet tall, spaced 1.5-feet apart, with a 2.5-foot opening between the baffle and vault surface. Based on the dimensions of the vault and the number of baffles, the cost to construct the structure in-place was estimated using Means. Costs included: excavation; sub-grade preparation; forming; #5 re-bar reinforcement spaced 1-foot on center; concrete; furnishing and installing a v-notch steel weir plate; furnishing and installing thirteen 3-foot by 4-foot steel baffles; a steel sided hinged access door; and backfill.

Control Structures

The cost for water control structures were estimated from a collection of bid tabs for similar pre-cast structures adjusted to 2007 dollars. A 5-foot diameter structure, 6 to 8-foot high with an adjustable broad crested weir, and spring loaded access hatch was assumed to be adequately sized for the site conditions. The costs include furnishing, excavation, installation, and backfill of the structures.

Pond and Trench Dewatering

Pond and trench dewatering costs were estimated using Means. The cost estimate assumes that a 4-inch diaphragm pump with 20-feet of suction hose and 100-feet of discharge hose operated twelve hours per day for 25 days will be sufficient for management of surface and groundwater infiltration to permit pond construction and installation of all RCP and associated inland structures.

Stream Weir and Dewatering/Diversion

The cost to construct a stream weir and manage surface water and groundwater to permit construction was estimated using Means. Cost estimates were based upon a stream weir consisting of sheet pile that spans the width of the stream and is capped with concrete. Costs for the weir include furnishing and installing: sheet pile; concrete forms; #5 re-bar 1-foot on center; high early strength concrete (pumped); backfill; and stream bank restoration. Assumptions for stream weir construction include a stream width of 40-feet, sheet pile depth of 10-feet, and a concrete cap 2-foot high by 3-foot wide. Stream diversion, dewatering, and/or ice management costs include management of all water sources to facilitate construction of the stream weir. Assumptions include that the use of a 6-inch diaphragm pump and sand bags for five days work will be sufficient for managing surface and groundwater sources and that stream weir construction will take place during stream low flow conditions.

Soil Hauling and Disposal

Cost estimates for soil hauling and disposal were obtained from Pitlick and Wick. Pitlick and Wick provided an estimate of approximately \$75 per hour for quad axel dump trucks (approximately 15 loose cubic yards per truck). The total number of hauling hours was estimated for hauling just over 9,000 in place cubic yards from the site assuming a 1-hour round trip for each truck and a soil swell factor of 20%. Excavated soils were assumed to

be non-hazardous and disposal costs were assumed to be approximately \$3.20 per cubic-yard.

4.1.6 Site Restoration

Site restoration cost estimates considered the following:

- Topsoil placement
- Geotextile fabric
- Geogrid mat
- Rip Rap, Class III
- Seeding
- Mulching

All site restoration costs were estimated using Means and a collection of bid tabs for similar types of work adjusted to 2007 dollars.

Topsoil placement costs include placing and grading salvaged topsoil across all disturbed surfaces where vegetation reestablishment is to take place. Geotextile fabric and Geogrid mat costs include furnishing and installing these materials on steep slopes and drainage pathways to prevent erosion. Rip rap costs include furnishing and installing Class III rip rap on the downstream side of the stream weir, at the flared end sections, and where stream bank restoration is to take place.

Seeding costs include application and post-care of seed mixes to restore existing vegetation types assuming applicable seed mixes will include a wet prairie seed mix and an emergent zone seed mix. Tree replacement costs include planting minimum 2” diameter trees and post-care assuming existing tree types are similar to River Birch or White Oak and that up to fifteen (15) trees will require replacement. Mulching costs include furnishing and placing shredded hardwood mulch around planted trees assuming one (1) cubic yard of mulch will be sufficient for each replaced tree.

4.1.7 Electric Service

Wisconsin Public Service Corporation provided a cost estimate of just over \$14,100 to extend single-phase power that currently exists 1,500 feet from the site. A detailed estimate to extend three-phase power 2 ½ - 3 miles was not provided. However, Wisconsin Public Service Corporation did indicate that the cost would likely exceed \$500,000. As a result, it would be more cost-effective to convert single-phase to three-phase power through the use of a VFD if an impeller mixer is used.

Mixing with a baffle type system was considered as an optional treatment system design because of the additional costs associated with providing three phase power installation. Although in this assessment the treatment efficiency of the impeller mixer and the baffle mixer were considered the same, it is expected that the baffle system will not perform as well as the impeller mixing system.

4.2 Engineering and Design

Engineering and Design costs were estimated as 15 – 20% of the total project cost. These costs include the following:

1. Surveying
2. Project planning
3. Design, plans, and specifications
4. Construction observation

The cost estimate for these items is \$123,500. An additional \$30,000 was added to this estimate for permitting work associated with anticipated floodplain and fisheries/wildlife permit requirements. The total Engineering and Design cost is estimated to be \$153,500.

4.3 Start-up/System Optimization

Following the construction of the alum treatment facility, field testing will be needed to determine the optimal alum dosing rate and impeller speed. Field testing will also include assessments of pH effects. Costs for these items generally include staff time, equipment, lab fees, travel, and lodging. Table B1, in Appendix B, shows an estimate of these costs. In total, start-up/system optimization costs are expected to be approximately \$11,200.

Phosphorus removal estimates and alum costs have been developed for alum doses of 3 and 6 mg/L as aluminum (chosen in accordance with the work performed by Foth and Van Dyke 2004, and Pilgrim and Brezonik 2005a). Because alkalinity in Muskellunge Creek is low and likely ranges from 35 to 60 mg/L, it is possible that the alum dose that can be safely used will be restricted to 3 mg/L. Alum is an acid, and when it is added to water the pH of water drops. The pH of the water should not be allowed to drop below 6.0 because of potential aquatic life affects (Pilgrim and Brezonik 2005b). Hence, field testing will need to be conducted to determine the appropriate alum dose and whether a different coagulant many need to be considered.

4.4 Maintenance and Operations

General maintenance and operations costs considered the following:

- Sludge Removal
- Mixing Chamber Cleaning
- Alum Replenishment
- Utilities

4.4.1 Sludge Removal

Alum sludge will need to be removed regularly from the settling pond in order to maintain adequate sludge storage capacity within the pond and to maintain treatment efficiency. As storage capacity decreases so too does the retention time of water moving through the pond. As a result, the overall volume for floc storage and the nutrient removal efficiency decrease. To develop cost estimates, this study assumes that alum sludge removal will be required for every 3,100 cubic yards of sludge produced (80% of dead storage capacity). The frequency of sludge removal depends upon the percentage of the flow treated and the alum dosing rate. Approximately 0.75 cubic feet of alum sludge is generated for every gallon of alum used.

Figure 4 below shows the anticipated frequency that sludge removal would need to occur for different treatment conditions.

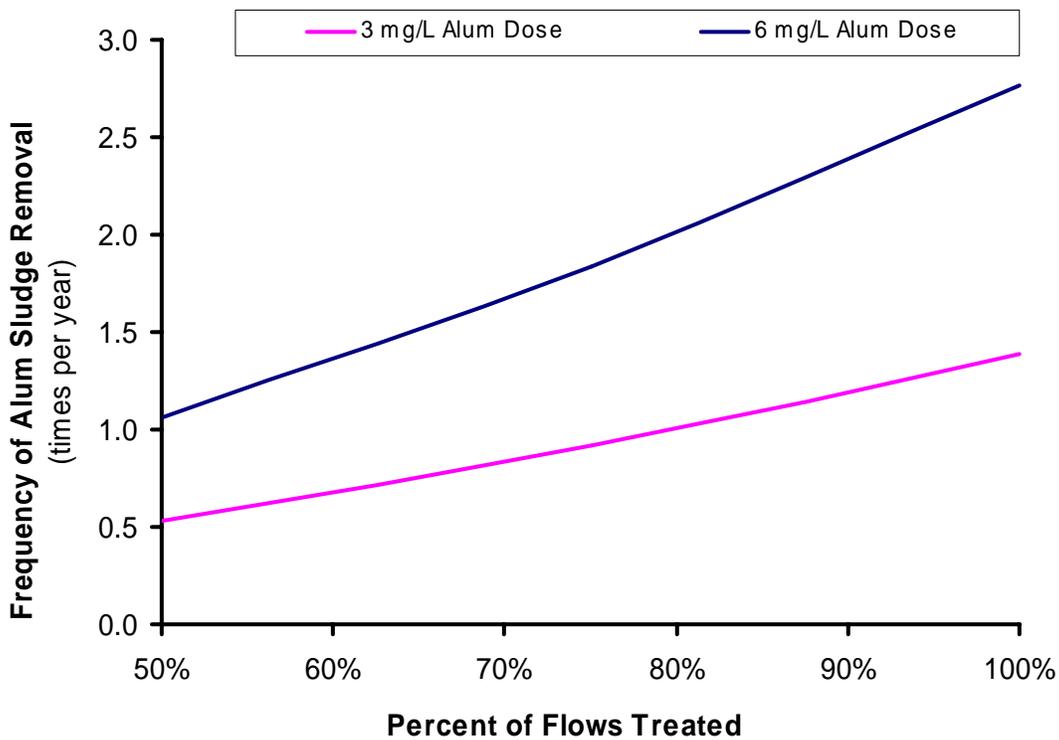


Figure 4. Sludge Removal Frequency and Treatment Criteria Relationship

Solidify and Excavate

Two sludge removal methods were considered. The first method involves solidifying the sludge with fly ash, excavating the material, and hauling/disposing of the material off-site. The fly ash is needed so that the material can be solidified to the point that it is accepted by a landfill. Based upon sludge removal experience at the Tanner's Lake Alum Treatment pond in Oakdale, Minnesota, approximately 1-cubic yard of fly ash is needed to solidify 100-gallons of alum sludge. Also, for every cubic yard (or 200-gallons) of alum sludge that was generated, 1-ton of solidified waste was produced. When the pond is 80% full of alum sludge (approximately 3,100-cubic yards of alum sludge), 3,100-tons of solidified waste will need to be disposed.



Tanners Lake Alum Treatment Facility, alum sludge removal using fly-ash to solidify the sludge (2003)

County G Landfill was contacted to determine the cost for disposal at that facility. Disposal rates are approximately \$50/ton. At this rate, disposal costs would be around \$155,000 (for a full pond). Including material/delivery cost of fly-ash, excavation, hauling, dewatering, and engineering; costs would likely exceed \$350,000.

Pump-out

The second method, which was used to estimate total annual operating costs, involves pumping the pond contents into large tankers that would haul the material to an approved land-application area. A local contractor, Mike's Septic Pumping, was contacted and provided an estimate of approximately \$135 per hour per tanker for hauling with 4,000 and 5,000 gallon tankers. He indicated that he has access to 7,500 gallon tankers which are the maximum sized tankers that can be used in the area (road limitations). Costs for hauling with the 7,500 gallon tankers were approximated at \$185/hour.

The total hauling hours were approximated assuming that a total of one million gallons would need to be pumped from the pond (including infiltration) over a nine day period with three 7,500-gallon tankers hauling 11.5 hours per day. Other costs included: contractor mobilization/demobilization; sludge removal; the use of a 6-inch dewatering system; minor excavation; and site restoration. The costs do not include permitting for land-application disposal and assume that there would be no landowner charge for application of the material to their land.

Tables C3 and C8, in Appendix C, provide additional cost details for alum sludge removal using this method.



Tanners Lake Alum Treatment Facility, alum sludge removal via pump-out (2006)



Tanners Lake Alum Treatment Facility,
cleaning debris from the floating intake screen



Tanners Lake Alum Treatment Facility,
mixing pond contents to facilitate pumping

4.4.2 Mixing Vault Cleaning

The mixing vault would likely need to be cleaned annually. Sediment and precipitate films will accumulate in and on the vault. A general cleaning cost was estimated assuming a two man crew working eight hours at a combined rate of \$120 per hour and an equipment cost of \$740 for a total of \$1,700 annually.

4.4.3 Alum Usage Costs

The cost to refill the alum storage tanks will vary with the treatment criteria selected. General Chemical provided a material cost estimate of \$0.64 per gallon of alum (includes delivery). Table C5, in Appendix C, shows the anticipated annual cost for alum related to treatment criteria in 2007 dollars.

4.4.4 Utilities

The annual utility costs were estimated by approximating the electrical requirements for the following items at a rate of \$0.1067 per kWh:

- Heating/cooling
- Lighting
- Controls
- Chemical feed pumps
- Mixer

Heating and cooling requirements were estimated assuming temperatures in the building were to range between 50° and 70° F. The mixer was assumed to have an efficiency of approximately 85% and lighting was assumed to be nearly negligible. In addition to these costs, a monthly base fee is assessed by WI Public Service Co. for single and three-phase power.

5.0 Anticipated In-Lake Results

An in-lake water quality model was developed for the East Bay of Little St. Germain Lake to evaluate the expected change in phosphorus levels in the lake with the treatment of Muskellunge Creek water. The water quality model was calibrated using water quality and flow monitoring data collected for Muskellunge Creek, groundwater inputs to the Lake, and the water column of the East Bay of Little St. Germain Lake (USGS 2005). The calibrated model was then used to determine the expected change in the average in-lake total phosphorus concentration given two alum doses (3 and 6 mg/L as aluminum) and the treatment of 50%, 75%, and 100% of the stream flows (by total volume).

5.1 Model Calibration

The water quality model used in this assessment is provided below.

$$P = \frac{L + R_p A_s}{Q + V_p A_{tot}} \left\{ 1 - \exp\left[-\frac{t}{V / (Q + V_p A_{tot})} \right] \right\} + P_o \exp\left[-\frac{t}{V / (Q + V_p A_{tot})} \right]$$

where:

Q = inflow and outflow rate (Muskellunge Creek, Groundwater, and Precipitation),

P = average in-lake concentration of P,

L = external P loading (Muskellunge Creek, Groundwater, and Precipitation)

V_p = P settling rate (e.g. m/d),

t = time,

P_o = initial in-lake P concentration,

V = lake volume,

A_{tot} = lake surface area,

A_s = sediment area contributing to P release,

R_p = P release rate from sediment

The USGS monitoring data collected from January through October of 2001 were used to calibrate the model. The calibration was performed by adjusting two parameters: (1) the phosphorus settling rate (V_p), and (2) the phosphorus release rate (R_p). Figure 5 shows the results of the calibration. It compares the model-predicted phosphorus levels in the East Bay of Little St. Germain Lake to the actual monitored phosphorus levels.

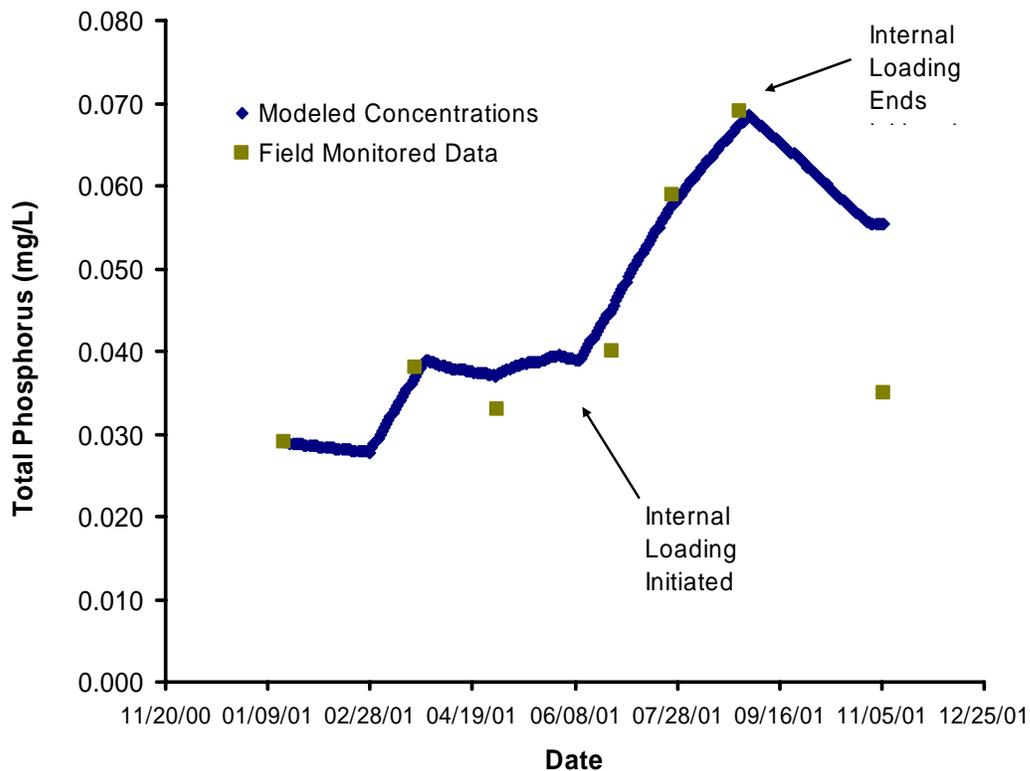


Figure 5. Results of the total phosphorus model calibration for the East Bay of Little St. Germain

Calibration consisted of setting the phosphorus settling rate to 4 meters per year and the internal phosphorus loading rate to 1.25 mg per square meter of lake-bottom area per day. Internal phosphorus loading was input into the model starting in mid-June and finishing at the end of August (loading was also input for the month of March). The phosphorus settling rate used in this model was comparable to settling rates in the published literature and studies (Dillon and Rigler 1974, Barr Engineering 2005, Pilgrim 2005a). The phosphorus release rate used in this model is comparable to the positive release rate of $0.9 \text{ mg P m}^{-2} \text{ d}^{-1}$ measured by the USGS with anaerobic microcosms and Upper East Bay sediment. Although the rate of phosphorus release from sediment is in the low range when compared to other eutrophic lakes, it is significant because the East Bay is shallow and the total volume of the East Bay is low compared to the sediment surface area. Also, with shallow lakes even low rates of internal loading can be significant because all of the internal phosphorus release is often transported to the photic zone where algae can use it.

5.2 In-Lake Phosphorus Levels with Treatment of Muskellunge Creek

Using the calibrated in-lake model, expected average phosphorus levels in the East Bay of Little St. Germain Lake with the treatment of Muskellunge Creek with alum were calculated using the 2001 monitoring data. Average in-lake phosphorus levels were determined from the date that treatment is expected to start each year, mid-April, to the date that treatment is expected to cease, September 30. The start and end date were chosen because alum is not an effective coagulant in cold water.

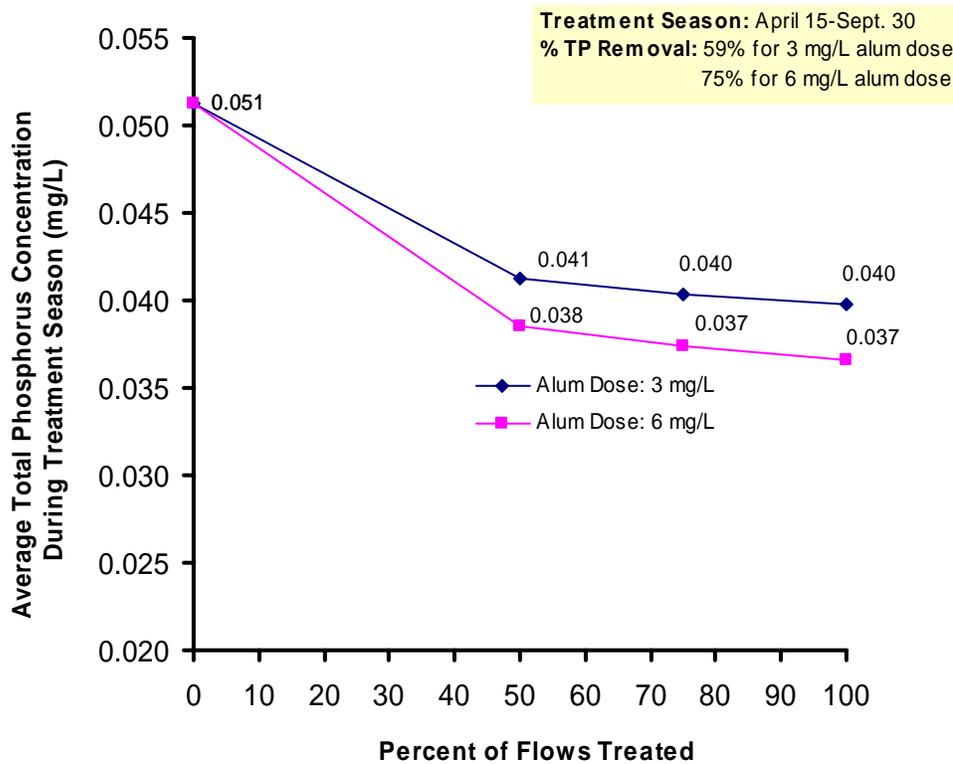


Figure 6. Average total phosphorus levels in the East Bay of Little St. Germain Lake in 2001 without and with the treatment of Muskellunge Creek inflows

Without treatment, average total phosphorus levels would have been approximately 0.051 mg/L in 2001 (during the treatment season). Treatment of 50% of the flow volume would have resulted in a decrease in the in-lake concentrations to approximately 0.038 to 0.041 mg/L, depending upon the alum dose. It is notable that the treatment of more than 50% of the stream volume did not result in noticeably greater reductions in lake phosphorus levels. Hence, it is recommended that the plant, if constructed, treat no more than 50% of Muskellunge Creek flows. The reason that more treatment does not result in

lower in-lake phosphorus levels is because the concentration of phosphorus that leaves the treatment plant begins to approach the equilibrium in-lake phosphorus level and because flows were generally lower in 2001.

On an average basis, the treatment of lake inflows appear to have a notable effect on in-lake levels, however, mid to late summer phosphorus peaks are still expected to occur. Figure 7 shows the daily phosphorus concentrations that would have been expected to occur in the East Bay of Little St. Germain Lake in 2001 with the treatment of Muskellunge Creek inflows. It can be seen that although phosphorus levels are lower throughout the treatment season, the mid to late summer peak in phosphorus would remain.

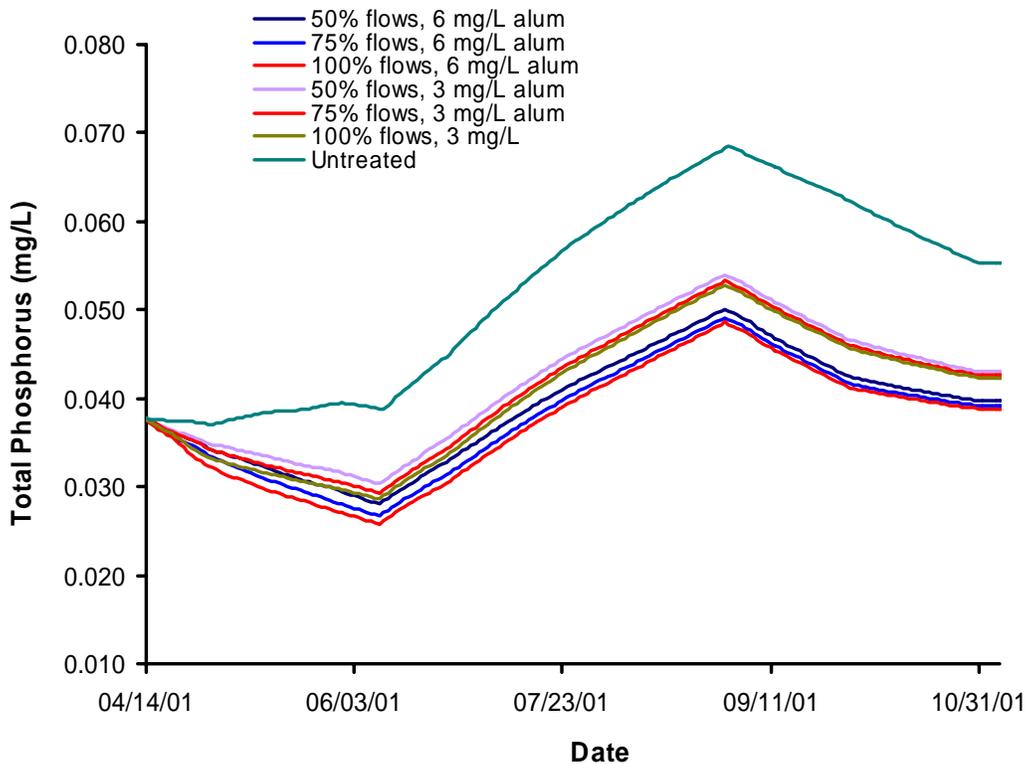


Figure 7. Expected daily phosphorus concentrations in the East Bay of Little St. Germain Lake with the treatment of Muskellunge Creek inflows

5.3 In-Lake Phosphorus Levels With Internal Load Reductions

Using the calibrated lake model, the effect of reducing internal phosphorus loads was also estimated. Figure 8 shows the estimated in-lake phosphorus levels with an internal phosphorus load reduction of 90%. The effect of an internal phosphorus load reduction on in-lake phosphorus levels is also compared to expected in-lake phosphorus levels with the treatment of 50% of the Muskellunge Creek inflows with an alum dose of 6 mg/L as aluminum. Average summer total phosphorus levels are expected to be lower with internal load reduction when compared to the treatment of Muskellunge Creek inflows, but more importantly, the summer phosphorus peak, which is often responsible for summer algal blooms, is reduced to a greater extent with the reduction of internal loading.

One way to reduce the release of phosphorus from lake sediment (internal phosphorus loading) is through the application of alum to the lake sediments. This procedure is commonly used to reduce internal phosphorus loading. This method will be significantly cheaper than the construction and operation of an alum treatment facility on Muskellunge Creek.

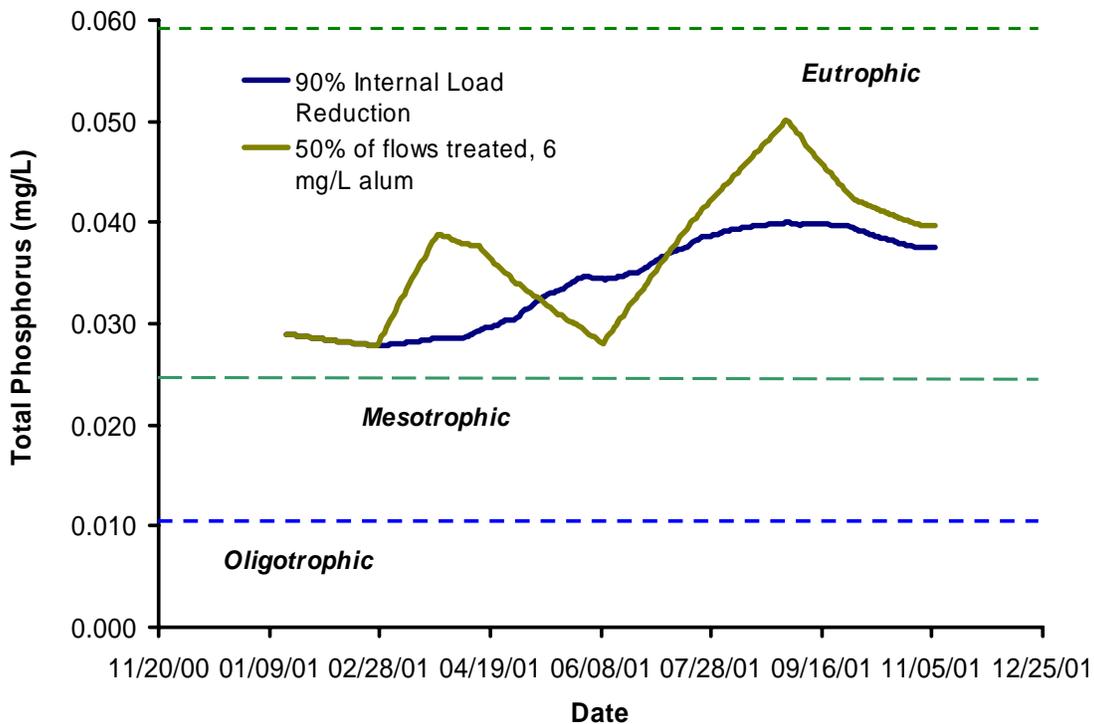


Figure 8. Comparison of the expected daily phosphorus concentration in the East Bay of Little St. Germain Lake with the treatment of Muskellunge Creek and the treatment of lake sediments to reduce internal phosphorus loading

6.0 Internal Phosphorus Loading Reduction

When oxygen levels are reduced to low levels in the water column and the sediment of lakes, a process known as internal phosphorus loading is triggered. The chemical characteristics of the lake sediment change such that phosphorus is no longer tightly held by sediment and is then able to diffuse upward into the water column. Internal loading can be a significant source of phosphorus loading to a lake and is often responsible for the late summer algal blooms that occur in lakes. However, internal loading can be significantly reduced by adding phosphorus binding elements to the lake sediment. The two elements that are typically used are calcium and aluminum. Calcium is added in the form of calcium hydroxide and aluminum is added as aluminum sulfate (same as alum). Alum has been successfully added to lakes since the 1970s with the purpose of reducing internal phosphorus loading.

Alum is added to lakes with the use of an alum treatment barge (see photographs below). The barge has a holding tank that contains the alum and arms are extended from the barge that inject the alum into the lake water column. When the alum reacts with the water it creates a fluffy white floc material (now called aluminum hydroxide) that then settles to the bottom of the lake within a 24 hour period. The barge travels back and forth across the lake distributing the alum until the lake bottom surface is covered with a thin layer of aluminum. Through forces such as wave action and biotic activity, the aluminum (aluminum hydroxide) then begins to mix with the sediment and react with phosphorus in the sediment. It can be expected that a single alum treatment can control internal loading for approximately 10 years.



Alum treatment barge and tanker trucks with alum



Alum floc (aluminum hydroxide) visible minutes after the alum barge has applied alum to the water column of Lake McCarrons.

6.1 Planning Needed for a Whole Lake Alum Treatment

There are essentially three steps that need to be taken before an alum treatment can proceed, they are: (1) sediment cores need to be taken at several locations in the lake to determine the concentration of phosphorus in the sediment and to determine appropriate alum doses, (2) some simple lake modeling will need to be performed to demonstrate to the Wisconsin Department of Natural Resources the expected benefit to the lake with the application of alum, and (3) a decision will need to be made regarding what the type of aluminum-based material (alum, sodium aluminate) will need to be used in the treatment.

Sediment cores will need to be taken at several (approximately 25) different locations in the lake to identify where phosphorus is high in the lake sediment. From these cores, appropriate alum doses would be identified and a map would be developed to direct the applicator where to apply the alum and at what dose. The dose and lake area for application is expected to vary for each bay.

With the application of the appropriate alum dose, it can be expected that internal loading can be reduced by 90 percent. It will be necessary to demonstrate to the Wisconsin Department of Natural Resources what the expected benefit to Little St. Germain Lake will be with the alum treatment. Some simple modeling, using data previously gathered by the USGS, will need to be performed to demonstrate that a reduction in internal phosphorus loading can be expected to lower phosphorus levels in the lake, and that the reduction will lead to an improvement in trophic state.

Finally, alkalinity will need to be measured in Little St. Germain during the year prior to treatment so that the appropriate aluminum compound is chosen for addition to the lake sediments. Alum is a weak acid, and it has the potential to lower the pH of a lake to unacceptable levels if alkalinity is low. Some simple chemical modeling will need to be conducted to determine whether another aluminum compound, sodium aluminate, should be used instead of alum.

7.0 Summary

The feasibility of constructing and operating an alum treatment facility designed to remove phosphorus from Muskellunge Creek was evaluated. The feasibility analysis was performed assuming that the facility would be constructed north east of the intersection of Birchwood Drive and Muskellunge Creek Road (see Figure 1). The criteria for evaluation included capital and operation costs, physical constraints of the site and the capacity of the site to accommodate required treatment facility structures, and the expected in-lake phosphorus levels with a range of potential treatment facility designs and operating conditions.

The conceptually designed alum treatment system would consist of a stream water diversion structure, a manhole control structure, a weir, mixing chamber, and treatment facility building that houses alum holding tanks, pumps, and a control unit, an alum floc settling pond, and an outlet structure. The system would be designed to divert water from Muskellunge Creek at flows less than 6.6 cfs, flows less than 11.1 cfs, and flows less than 21 cfs. Alum doses of 3 and 6 mg/L were considered. From previous studies, total phosphorus removal rates of 59 to 75% were assumed achievable with these doses.

Proper operation, performance, and cost effectiveness of the treatment facility will be constrained by the size of the site that is available for the construction of the facility and the large flow volume in Muskellunge Creek that will need to be treated.

A total of twelve alternative plant operating conditions were evaluated in this study. The conditions evaluated include treatment of 50% (flows <6.6 cfs), 75% (flows <11.1 cfs), and 100% (flows <21 cfs) of Muskellunge Creek flows, alum doses of 3 and 6 mg/L as aluminum, and the use of baffle or mechanical mixing of alum and water. For several reasons that described below, it is recommended that if a facility were built, flows less than 6.6 cfs should be treated by the facility and flows greater than 6.6 cfs should be allowed to pass over the diversion structure. For example, if stream flows are 10 cfs, 6.6 cfs of water would be diverted to the treatment system while 3.4 cfs would spill over the diversion structure.

The cost of capital, engineering and design, and treatment system optimization is expected to range from \$0.7 to \$1.0 million if a baffle type mixing system is used and from greater than \$0.8 to \$1.1 million if a mechanical mixer is used (three phase electric power is required for the mechanical mixer). Land acquisition costs have not been included in these costs.

Annual operation and maintenance costs are expected to range from \$130,000 to \$600,000, depending on the volume of stream flows that are treated and whether alum doses of 3 or 6 mg/L are used. This cost includes, among other items, the cost of alum, sludge removal and disposal, and the part-time and seasonal employment of a technician.

Because the available treatment site is constrained by its size, treatment of stream flows less than 6.6 cfs is recommended. This would provide the treatment pond with a minimum required residence (settling or alum floc removal) time of 4.4 hours. With the treatment of flows less than 6.6 cfs, the accumulated alum sludge in the pond would need to be excavated annually at the end of each treatment season. If flows greater than 6.6 cfs are treated, the pond would fill up with alum before the end of the treatment season and treatment would need to be prematurely halted.

There are several physical and chemical constraints that may affect system performance or will require some operational adjustments. According to a study by Foth and Van Dyke (Foth and Van Dyke 2004), the use of an alum dose of 3 mg/L is expected to yield a total phosphorus reduction of 59%. However, performance in a laboratory setting has been shown to be consistently higher than performance in full scale operations. For this reason, a 6 mg/L dose has also been evaluated because a higher dose may be needed to achieve adequate phosphorus reductions. The use of a 6 mg/L dose may be constrained by the low alkalinity of Muskellunge Creek (expected to range from 35 to 60 mg/L as CaCO₃) and the potential to suppress the pH of water in the creek below 6.0. Hence, the lack of alkalinity in Muskellunge Creek may hinder treatment system performance (because a lower dose would need to be used) or an alternative coagulant (e.g., polyaluminum chloride) will need to be considered.

Using a calibrated water quality model for the East Bay of Little St. Germain Lake and 2001 monitoring data collected by the USGS, it is estimated that average treatment season (mid-April through September) phosphorus levels would decline from 0.051 mg/L to 0.038 to 0.041 mg/L with the treatment of stream flows of 6.6 cfs or lower (see Figure 6). It is expected that there will be limited additional benefit to treating stream flows above 6.6 cfs.

The use of the calibrated lake model and the sediment studies conducted by the USGS indicate that phosphorus release from the sediments (internal loading) of the East Bay of Little St. Germain has a significant effect on phosphorus levels in the East Bay. If internal phosphorus loading were reduced by 90%, the average phosphorus level in the East Bay (mid-April through September) would have been 0.036 mg/L in 2001 (see Figure 7). More importantly, the control of internal phosphorus loading would have had the effect of reducing phosphorus levels during the mid-July through August period when algal blooms are most often prevalent. It is recommended that serious consideration be given to the control of internal phosphorus loading in Little St. Germain Lake prior to deciding to construct an alum treatment facility on Muskellunge Creek.

With the application of alum to lake sediments to control internal loading, additional data would need collected and modeling would need to be completed. This data would be used to identify how much alum (aluminum) should be applied and how much it would cost, where it should be applied, and what the expected benefit would be to Little St. Germain Lake with application.

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