

APPENDIX E

Princeton Hydro Honeoye Lake Water 'Bench Test' Information



Alum Bench Test Results Honeoye Lake

**PREPARED FOR:
HONEOYE VALLEY ASSOCIATION
HONEOYE, NEW YORK**

Prepared by:

**PRINCETON HYDRO, LLC
SUITE 1, 1108 OLD YORK RD.
P.O. BOX 720
RINGOES, NJ 08551**

**P - 908-237-5660
F - 908-237-5666**

WWW.PRINCETONHYDRO.COM

**30 July 2004
1st Revision 18 November 2004
2nd Revision January 2005**

Executive Summary

In the summer of 2001, Honeoye Lake experienced a mid-summer blue-green algae bloom of a significant proportion. The bloom resulted in clarity, odor and aesthetic impacts, which impaired the use and enjoyment of the lake. Blooms of the nature and magnitude experienced in Honeoye Lake are typically associated with highly productive, eutrophic waterbodies. Although eutrophication is a natural process, its negative affects on water quality and lake aesthetics, especially intense algae blooms, are cause for concern. Human activities, in particular watershed development, can greatly accelerate the process leading to significant water quality and lake user impairments. As most of the problems arising from eutrophication are the result of excessive nutrient loading, especially the influx of biologically available phosphorus, emphasis is placed on the control of phosphorus and the implementation of lake management measures that control the rate and amount of its loading to the affected lake.

The magnitude of the 2001 algae bloom stimulated increased interest in assessing and identifying those factors contributing to the eutrophication of Honeoye Lake. Fortunately, a considerable amount of water quality data have been collected over the past decade as part of studies conducted by the Finger Lake Community College (FLCC) and the New York State Department of Environmental Conservation (NYSDEC), as well as by local volunteer and stakeholder groups, such as the Honeoye Valley Association (HVA). A detailed examination of the Honeoye Lake historic water quality database revealed that the lake at times experiences deep-water anoxia. That is, during the summer, for limited periods of time, the bottom waters of the lake (> 7 meters in depth) become devoid of dissolved oxygen. Although this only affects a small percentage of the overall lake, during these episodes of anoxia significant amounts of phosphorus are released from the lake's sediments. Because the lake does not strongly stratify, this phosphorus-rich water is subsequently re-circulated into the lake's upper layers where it then becomes available for uptake and assimilation by algae. This appears to be the most likely cause of the lake's mid- to late-summer blue-green algae blooms. Although a comprehensive watershed and pollutant loading analysis must be conducted for the lake, the evidence and data thus far developed indicate that control for the lake's internally regenerated phosphorus load must be dealt with immediately. This is best accomplished through the application of alum.

This report provides details of an alum treatment bench test conducted for Honeoye Lake to determine the appropriate alum dose needed to control the internally regenerated phosphorus load. It also discusses the theory of alum lake treatments and the success of such treatments in the control of the eutrophication process in other lakes nationwide. The use of alum in Honeoye Lake is proposed for the purpose of maintaining sediment-bound phosphorus sequestered in the lake's sediments, even during periods of deep water anoxia. By making this source of phosphorus unavailable for algal assimilation, a reduction in mid-summer, intense, nuisance algal blooms is predicted. The proposed treatment of the lake is not intended to strip the entire water column, as is often a technique used to clarify lakes and bind whole water column concentrations of total phosphorus. In Honeoye Lake this is neither necessary nor ecologically

desirable. Rather, alum use in the lake would focus totally on the management of the lake's internal load. This will require the application of alum in such a manner that the alum floc becomes incorporated into the lake's deep-water sediments. This in effect creates what is commonly referred to as an "alum blanket".

Based on the results of the titration tests, the theoretical **appropriate** alum dose for the lake is 1.17 mg alum / L (0.105 mg of Al^{+3} / L) as based on the results of the alum/phosphate titration bench test. This equates to a surface application of 74 gallons/acre. Assuming only 50% efficiency, this yields a projected alum application rate of 150± gallons/acre. Within the report three additional techniques are used to project an alum rate for the lake. The results of these three alternative computational techniques, including a treatment formula developed by a leading alum treatment applicator, are all in relative agreement. Thus the projected application rate of 150 gallons alum/acre appears accurate and reasonable.

There will be the need to obtain permits from the NYSDEC in advance of the alum treatment. Even with the introduction of alum and the control of the lake's internal phosphorus load, the need for watershed management, macrophyte control and other related lake management and restoration activities, including the preparation of a comprehensive watershed management plan will not be eliminated. However, the proposed alum treatment will address the most likely cause of the recently experience nuisance blue-green algae blooms and greatly aid in the overall proper management of the lake's water quality.

1.0 Introduction - The Use of Alum in Lake Restoration

Alum (aluminum sulfate) has been used in the water treatment industry for over five decades to clarify raw drinking water. These applications typically involve the large-scale introduction of aluminum sulfate within a drinking water treatment plant in order to create a flocculent (floc), which as it settles, strips the water column of particulate matter. The ionic binding of fine sediments to the alum molecule causes this stripping effect.

However, alum is capable of achieving more than the simple clarification of water and the binding of particulate matter. In natural lake environments, alum has been used to reduce the amount of phosphorus in the water column. Phosphorus is recognized as the nutrient present in limiting amounts in most freshwater lake ecosystems. This means, the amount of phosphorus available for uptake and assimilation by primary producers, in particularly phytoplankton (algae), will dictate the overall productivity of the lake. Simply stated, as phosphorus levels increase, lake productivity can be expected to increase. Because lake productivity is largely a function of algal photosynthesis, the more phosphorus present in a lake, the greater the amount of algal biomass. Although algae are essential to the maintenance of a healthy, balanced lake ecosystem, in excessive amounts, algae can create water quality impacts, especially reductions in lake clarity and aesthetics that impair recreational use of the lake.

Since the early 1980's, alum has been used in the management of recreational lakes and drinking water reservoirs to "inactivate" biologically available inorganic phosphorus. As noted above, reducing phosphorus concentrations in lake water decreases the availability of this vital nutrient for uptake and utilization by phytoplankton. A reduction in phytoplankton production leads to an increase in the clarity of the lake. Because phosphorus may enter a lake ecosystem from external (stormwater runoff, septic tank effluent, atmospheric deposition, waterfowl) and internal (decaying aquatic vegetation, phosphorus released from bottom sediments) simply treating the water column alone may not result in sufficient phosphorus controls to achieve adequate control of lake productivity and the desired water quality and lake aesthetic benefits. In addition, because treatment of lake involves the introduction of large quantities of alum in a natural environment, it is imperative to investigate and assess whether the alum treatment will elicit negative impacts on the biota and chemistry of the treated lake.

As noted above, in every lake ecosystem some of the phosphorus utilized by algae and phytoplankton is internally generated. Of particular concern, because of the potential magnitude associated with this source, is the phosphorus released from the lake's sediments. When there is ample dissolved oxygen in the water column (even concentrations as little as 1.0 mg/L) phosphorus is relatively stable in the sediments, remaining bound to iron. However, under anoxic conditions (when dissolved oxygen levels are at or close to zero) the phosphorus-iron is disrupted resulting in the liberation of sedimentary phosphorus back into the water column. Anoxic conditions may occur on a regular basis in lakes that even weakly undergo thermal stratification. Thermal stratification is a natural process caused by the seasonal warming of the

water column. This phenomenon is common for lakes with maximum depths exceeding 10 feet. When a lake stratifies, the density of the water column is no longer uniform. The warmer, upper layers of the lake are “lighter” (less dense) than the cooler “heavier” (more dense) deeper layers. When the density difference between layers becomes significant, these layers can no longer freely mix. In the summer, this results in the deeper portions of the lake becoming segregated from the upper layers. This inability of the water column to freely mix impairs the reoxygenation of the lakes deeper layers. Bacteria quickly utilize the limited available oxygen in the lake’s deeper layers, resulting in the onset of anoxia. Phosphorus is then released from the sediments at higher than normal rates. The destratification of the water column results in its free mixing and the subsequent circulation or “up welling” of the phosphorous rich water from the lake’s dark depths, to the sunlit surface. Once in the sunlit portions of the lake, where algal photosynthesis occurs, this phosphorus becomes available for biological assimilation. If this internally regenerated phosphorus load is significant, an algae bloom will likely be experienced. Control of this internal phosphorus recycling is therefore critical.

Initially alum was used in the restoration of lakes and ponds as simply a stripping or floccing agent, similar in effect to the manner it is used in water treatment plants. These applications of alum were discovered to readily clarify the treated waterbody, decreasing the amount of suspended material present in the water column. This included inorganic sediment and fine debris as well as algae and phytoplankton. In the late 1970s and early 1980s, alum became used increasingly in natural lake systems for the control of deep-water phosphorus released from under anoxic conditions. These treatments essentially capitalized on alum’s ability to bind phosphorus. In these applications, the applied alum was utilized for more than simply water column stripping; it was used for nutrient management. Alum utilized in this manner decreased the amount of phosphorus available in the lake for algal and phytoplankton assimilation. Thus, although these treated lakes remained anoxic and stratified, the released phosphorus was not available for uptake and utilization by algae and phytoplankton.

The use of alum for nutrient management purposes increased in frequency following a series of carefully executed deep-water alum applications conducted by Kent State under the direction of Dr. Dennis Cooke. Those projects demonstrated that when properly administered, alum could sequester the released phosphorus, resulting in lower overall lake productivity, which translated to lakes less prone to algae blooms. This practice of deep-water alum treatments, for the purpose of controlling phosphorus released from anoxic hypolimnetic sediments, was colloquially termed the creation of an “alum blanket”. Essentially the “blanket” is the resulting alum floc and sludge, which has settled from the water column and has become integrated into the lake’s sediments. It does not create a discernable cap or “plastic” barrier. Rather, it results in the integration of active alum into the lake’s sediment, with this alum being responsible for the binding of the majority of the phosphorus released from the sediments under periods of anoxia. Cooke’s research demonstrated that this alum could remain in an active form, effectively fixing the released phosphorus for ten years or more in certain situations (Welsh and Cooke, 1995).

More recent work conducted by Drs. Stephen Souza and Fred Lubnow of Princeton Hydro has shown that alum “blankets” can be successfully used to control the internal phosphorus load of relatively shallow, polymictic lakes such as Honeoye Lake. Similar successful applications of alum for relatively shallow lake ecosystems have been reported by Pilgrim (2004). Given the data collected over the past decade by Finger Lake Community College, under the direction of Dr. Bruce Gilman, and data compiled by NYSDEC, it appears the lake’s internal phosphorus load is significant. Interest has thus been raised regarding the use of an alum blanket to control the lake’s internal phosphorus load.

2.0 How Alum Works

Whether alum is used to strip and clarify a lake’s water column or to control internally released and recycled sedimentary phosphorus, the process of creating the alum floc is responsible for the subsequent results. On contact with water, alum forms a “fluffy” amorphous aluminum hydroxide precipitate. This precipitate is the result of the dissociation of the alum and liberation of aluminum ions which are immediately hydrated, and through a progressive series of hydrolyzes, form aluminum hydroxide. Aluminum hydroxide is the principle ingredient in many common antacids. The resulting colloidal amorphous floc also has high coagulation and phosphorus adsorption and binding properties. Because the floc is heavier than water, it settles out of the water column. As the floc slowly settles out of the water column, phosphorus, especially inorganic phosphorus, binds to the alum floc and becomes, in effect, inactivated or unavailable for biological uptake by algae and phytoplankton. The resulting aluminum-phosphorus compounds are insoluble in water. Unlike the phosphorus-iron bond, the aluminum-phosphorus bond is extremely strong. Of particular importance, is phosphorus will not be released from the aluminum even under anoxic conditions. As noted above, once the alum floc settles on the bottom of the lake it becomes integrated into the sediments and subsequently reacts with phosphorus released from the sediments. This binding of sediment-released phosphorus further decreases the overall availability of phosphorus for uptake and utilization by algae and phytoplankton. The overall effect of the alum treatment is a reduction in lake productivity. With less algae present in the water column, the lake is clearer and more transparent.

3.0 Eliciting Care When Applying Alum in Natural Lake Ecosystems

Concerns are often raised regarding the impact of alum treatments on lake biota. These concerns tend to arise due to:

1. The potential “smothering” of benthic fauna, especially aquatic insect larvae, attributable to the settled floc, and
2. The potential acute toxicity to fish caused by elevated concentrations of dissolved aluminum in the water column.

With respect to impacts to benthic fauna, one of the most comprehensive studies on this matter, Narf, 1990, reported that alum treated lakes showed no long term negative effects on the diversity or assemblage of benthic infauna. Although not published, data collected by Princeton Hydro at Lake Mohawk show the same results.

With respect to dissolved aluminum toxicity, the proper use of alum dictates that the amount applied to a lake be sufficient to control phosphorus availability, but not so great to cause the pH to shift below 6.0. The control of pH shifts is critical because the solubility of aluminum in water is directly related to pH. The relationship is such that increased dissolution of aluminum occurs at pH levels below 5.5 and above 9.0. It is the lower pH though that is typically of concern, because alum (aluminum sulfate) is acidic. The introduction of large quantities of alum, over a short period of time, as occurs during a lake treatment, has the potential to cause a major depression of the lake's pH. As the lake's pH declines below 5.5, an increasing proportion of the aluminum contained in the applied alum becomes present in a dissolved, rather than in a particulate state. As noted above, this is problematic as dissolved aluminum, at high enough concentrations, is toxic to aquatic biota, in particular fish. On the basis of continuous flow bioassays conducted to evaluate the toxicity of dissolved aluminum on trout and other fish, Freeman and Everhart (1971) concluded that concentrations of dissolved aluminum below 52 µg Al/L have no negative impacts on fish.

This is an extremely low concentration and is evidence of the potential toxicological impacts of improper alum use on aquatic life. However, because the solubility of aluminum in water is a function of not only dose, but also of baseline pH and alkalinity, a simple upper threshold concentration is not in itself a suitable means of predicting or avoiding impact to aquatic life. As such, guidance developed for the use of alum (largely based on the studies of Cooke) conclude that measures must be taken to ensure the pH of the treated lake system remains in a range of 6.0 to 9.0 during and immediately following application of the alum. Doing so avoids the situation where aluminum is present largely in a dissolved state, thus circumventing dissolved aluminum impacts to the lake's fish community (Cooke, et al, 1978).

The most appropriate way to determine the degree and extent of the effect of alum on a lake's pH is to conduct controlled, laboratory scaled assessments, commonly referred to as "bench tests". Such a bench test was conducted for Honeoye Lake for the specific purpose of assessing the affects of the introduction of alum on the pH of the lake and the feasibility of an alum treatment for the control, through inactivation, of available phosphorus.

4.0 Honeoye Lake Alum Treatment Bench Scale Test

To ascertain both the **appropriate dose** (the amount needed to effectively inactivate available phosphorus) and the **safe dose** (the amount below which no impact will result to the lake's biota), an alum bench test was conducted for Honeoye Lake. The remainder of this report

discusses the results of that test and addresses the feasibility of using alum to inactivate a large portion of the lake's internal phosphorus load. Specifically, this report discusses:

1. Whether alum [the salt aluminum sulfate ($\text{Al}_2(\text{SO}_4)_3 \cdot 14\text{H}_2\text{O}$)] can be safely used to bind biologically active phosphorus,
2. Determine the appropriate safe dose of alum needed to treat and inactivate the lake's deep water internal load,
3. Develop initial estimates for the cost of such an alum treatment.

Sampling of Honeoye Lake was conducted by Princeton Hydro staff on 20 July 2004. A variety of physical, chemical and biological water quality data was collected as part of the sampling effort. All sampling was conducted at a single sampling station (Figure 1) located along the lake's east central shoreline in an area recognized to be the deepest portion of the lake. *In-situ* sampling of temperature, dissolved oxygen (DO), pH and conductivity was conducted at 1.0 meter intervals from the surface to the bottom of the lake. Discrete water samples were collected at 0.5 meters, mid-depth (approximately 4 meters) and near the lake's bottom at a depth of approximately 8.5 meters. These samples were analyzed for total phosphorus, soluble reactive phosphorus, dissolved aluminum, hardness and alkalinity (as CaCO_3). Finally, approximately 10 gallons of water were collected from the mid depth and bottom depth stations and utilized to conduct the alum bench test.

On 20 July, the *in-situ* data documented that Honeoye Lake was well mixed (only weakly thermally stratified). It was fairly well oxygenated from the surface to approximately 8 meters, but anoxic near the bottom. The lake, at the time of sampling had a pH of 7.6. Alkalinity from surface to bottom was fairly uniform ranging from 65.0 mg/L at the surface to 69.5 mg/L at the bottom. Likewise, the lake displayed relatively uniform hardness values from surface to bottom ranging from 79.6 mg/L at the surface to 80.6 mg/L at the bottom. Dissolved aluminum was non-detectable at all sampled depths.

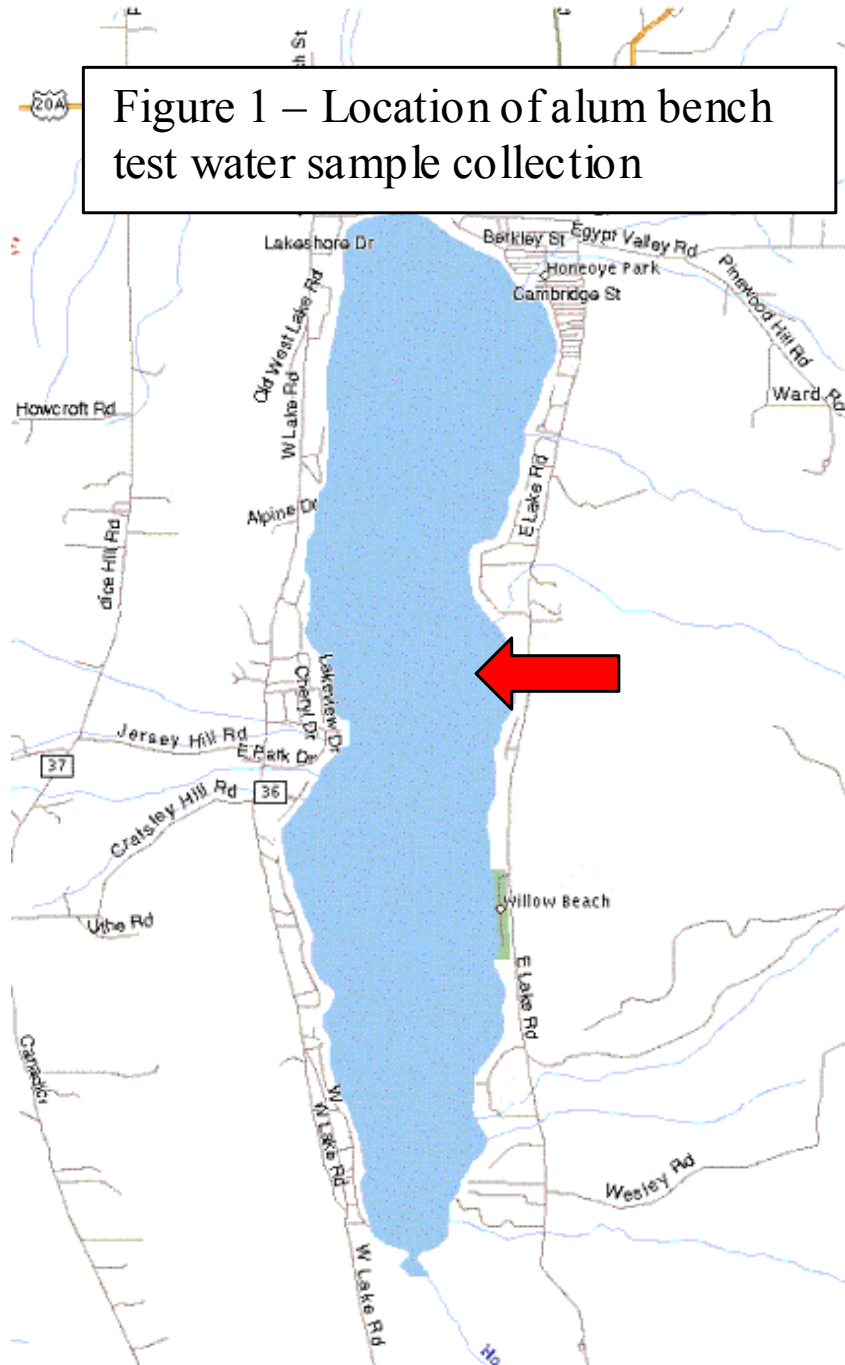
The lake's total phosphorus (TP) concentration was 0.02 mg/L at the surface, 0.03 mg/L at mid-depth and 0.05 mg/L at the bottom. This suggests active release of phosphorus from the lake's deep-water sediments. The lake's soluble reactive phosphorus (SRP) concentrations were 0.004 mg/L at the surface, 0.005 mg/L at mid-depth, and 0.029 mg/L near the bottom. This again indicates active phosphorus release from the lake's deep-water sediments. In addition, these data indicate that a large fraction (approximately 60-70%) of the total phosphorus measured near the lake bottom was in a dissolved, soluble form. Such forms of phosphorus are readily available for algal and phytoplankton uptake and assimilation.

TP represents the sum of all phosphorus, including dissolved fractions, particulate forms incorporated in the biomass of algae and other aquatic organisms, inorganic particulate forms associated with soil particles and other solids, polyphosphates from detergents, and soluble

(dissolved) orthophosphates. SRP is the dissolved, inorganic portion of the total phosphorus pool and the form most easily bioassimilated by algae, bacteria and plants.

Alkalinity represents the buffering capacity of a waterbody, or the quantitative measure of water's capacity to neutralize acids. Numerically, it is expressed as the concentration of calcium carbonate that has an equivalent capacity to neutralize strong acids. The higher the alkalinity, the more "acid" that is required to depress, or lower, the pH of the waterbody. The alkalinity (as CaCO₃) of the surface and bottom waters of Honeoye Lake was 65.0 mg/L and 69.5 mg/L, respectively. The alkalinity of natural aquatic ecosystems usually ranges from 20 to 200 mg CaCO₃ /L. As such, the alkalinity of Honeoye Lake can be considered moderate, suggesting that it should be possible to safely use alum to manage the lake's internal phosphorus load. As described above, when alum is added to a lake it forms aluminum hydroxide. This process releases H⁺ ions. Unless adequately buffered, a lake could experience a substantial shift in the pH following the introduction of the amount of alum typically used to blanket a lake's sediments. If the pH declines to far below 6.0, a large proportion of the aluminum can shift to a dissolved form that could have a toxicological impact on the lake's fishery. This potential for aluminum toxicity is one of the reasons for the alum bench test and this assessment.

Table 1 - Discrete Water Quality Data for Honeoye Lake			
Water Quality Parameter	Surface (0.5 m)	Mid (~ 4.0 m)	Bottom (>8.0 m)
Alkalinity (mg CaCO ₃ / L)	65.0	63.5	69.5
Total Phosphorus TP (mg / L)	0.02	0.03	0.05
Soluble Reactive Phosphorus SRP (mg / L)	0.004	0.005	0.029
Hardness	79.6	69.4	80.6



5.0 Feasibility Assessment of Alum Treatments

Introduction

For the past decade, Honeoye Lake has been the subject of studies conducted by the NYSDEC, Finger Lake Community College (FLCC), the Honeoye Valley Association and others engaged in the restoration and management of the lake. This extensive dataset has focused mostly on the quantification and characterization of in-lake conditions, encompassing the lake's biology, water chemistry and physical attributes. Princeton Hydro had an opportunity to review these data and discuss our findings with the HVA and Dr. Bruce Gilman of FLCC.

The results of Princeton Hydro's 2003 introductory assessment of Honeoye Lake suggested that a significant internal phosphorus load exists in the lake, and that this load, because of the polymictic nature of the lake (i.e., weakly stratified), can be a primary cause for major mid- to late-summer algae blooms. Because of the magnitude and effect of this internal load, an appropriate management measure would be the control of this internally regenerated and recycled phosphorus.

There are various means of accomplishing this, ranging from the installation of aeration and water column mixing equipment to the dredging and removal of the nutrient rich sediments. However, the most feasible solution is the application of alum. Specifically, based on the historic data and the data thus far developed by Princeton Hydro, an alum treatment is the most cost-effective and technically sound means to control the phosphorus liberated from the lake's deep-water sediments during periods of hypolimnetic anoxia. The proposed alum application would not be conducted for the purpose of stripping or clarifying the water column or for the purpose of inactivating the watershed (external) generated phosphorus load. Rather the introduction of alum would be for the purpose of controlling the lake's internal phosphorus load. The application of alum for this purpose, and in the manner proposed herein, is commonly referred to as the creation of an alum, sediment "blanket".

This project, the Alum Bench Test, was conducted to further evaluate the environmental and economic feasibility of applying alum to deep-water anoxic sediments appears. As proposed herein, this form of alum application would involve the introduction of alum at a rate of at least 150 gallons per acre to that portion of the lake at least eighteen feet (18 feet) deep. As discussed below, there is no need to apply alum in the shallower sections of the lake. First, these shallow areas do not experience anoxia, and therefore are not major sources of internally recycled phosphorus. Second, it is within these shallow areas of the lake (which includes the littoral zone) where the majority of the lake's biota live. Avoiding the application of alum in these areas reduces the likelihood of environmental impact. Finally, not applying alum in these shallower areas will negate the chance that the alum blanket will be disturbed or circulated to the lake's surface.

The primary consideration in determining the ecological feasibility of such an alum application for Honeoye Lake is to ensure no toxicological or other deleterious environmental side effects will occur. This was the primary reason for conducting the alum bench test. Specifically, the potential for aluminum toxicity, caused by a rapid, sustained decline in lake pH must be evaluated in advance of any proposed alum treatment. This was accomplished by conducting a laboratory bench test to determine the maximum amount of alum that could be safely applied to Honeoye Lake.

The bench test was also conducted to determine the appropriate dose of alum needed to inactivate the lake's soluble reactive phosphorus (SRP) load and inactivate other available forms of phosphorus. If done correctly, this could result in at least four to five years, and perhaps even greater, control of the lake's internal phosphorus load. The key to successful selection of the dose rate is to introduce alum in the amount needed to inactivate the measured and/or projected internal load, yet not introduce more alum than is actually necessary. In doing so, the application can be conducted in a cost-effective, ecologically responsible manner.

Alum Treatments for the Control of Internal Phosphorus Loading

Sediments usually release phosphorus into the overlying water; however, this process substantially increases when the overlying waters are anoxic. Under oxic conditions the net flux of phosphorus is into the sediments, primarily in the form of HPO_4^{-2} . Under anoxic conditions, the net flux of phosphorus, as phosphate (HPO_4^{-2}) is from the sediments into the overlying water, with this flux being largely the result of the dissolution of iron bound phosphorus. The rate is typically one to two orders of magnitude (10 – 100 times) greater under anoxic versus oxic conditions, reaching rates as great as 200 mgP/M²/d. As such, a significant amount of phosphorus can be liberated from the sediments into the overlying water column even during periods of short-term anoxia. Because a large proportion of the sediment stored phosphorus is contained in the upper 10 cm of the sediment (Want, et. al., 2004) it is not necessary for anoxic conditions to persist for an extended period in order for such conditions to have dire consequences. In addition, the release occurs over a relatively short time frame. As reported by Armstrong (1979), approximately 50% of the phosphorus released from anoxic sediments occurs within a few hours of the onset of anoxia. Thus, even short-term, sporadic periods of anoxia can result in a major phosphorus load to the lake.

It is widely recognized that phosphorus readily binds with a variety of cations, including Calcium (Ca^{+2}), Iron (Fe^{+3}) and aluminum (Al^{+3}). While a variety of phosphorus-inactivating compounds were initially considered for Honeoye Lake, the aluminum-based products were considered over others such as iron and calcium salts. Funk and Gibbons (1979) provides a thorough overview of the history and applicability of nutrient inactivation techniques. Although some of the first in-lake nutrient control measures were conducted using ferric chloride and other iron-based products, the most effective and large-scale nutrient inactivation projects have focused on the use of alum, aluminum hydroxide. Unlike the other compounds, aluminum-based

products remain bound to phosphorus over a relatively wide range of pH (6.0 to 9.0) and under both oxic (with oxygen) and anoxic (no or very little dissolved oxygen) conditions. For Honeoye Lake, the only technically feasible nutrient inactivation project is one involving the introduction of alum.

It was concluded, based on the initial data collected and analyzed by Princeton Hydro in 2003 that an appropriate alum dose for Honeoye Lake should be in the range of 100 to 175 gallons/acre, with the alum applied to approximately 800 acres of the lake's total surface area. This essentially equates to that portion of the lake greater than 18 feet in depth. Treatment of sections of the lake less than 8 feet in depth is greatly discouraged, and in fact is not required. As noted above, the application of alum in shallow, to even moderately deep, sections of the lake is strongly discouraged. The most serious likely problem to occur following shallow water alum applications is the resurfacing of the alum floc. This happens because of wind and wave related turbulence, as well as turbulence attributable to boating, all of which act to circulate the settled alum floc to the surface of the lake. The resurfaced floc in turn causes significant aesthetic impacts. However, more importantly, there is little need to treat these areas because they contribute little to the overall internal phosphorus recycling dynamics of the lake. Thus, there is no need to treat the shallow, oxic sediments of the lake.

When compared to the scientific literature, the projected application rates of 100- 175 gallons/acre of alum range from low to average. Thus, given the lake's alkalinity and baseline pH it was concluded that the introduction of alum would not have an environmental impact on the Honeoye Lake ecosystem. Nonetheless, additional testing was required to confirm that this dosage range would have no significant effects on the lake's pH shift, especially a shift great enough to result in the dissolution of aluminum. As noted above, alum is acidic, and unless a lake has adequate alkalinity (the lake's natural capacity to neutralize acids), an alum treatment could depress the pH to a point where concentrations of dissolved aluminum toxic to aquatic biota are present in the lake. It is therefore critical that substantial and extended declines in pH, especially below 6.0, be avoided to minimize the risk of aluminum toxicity.

Alum Bench Test and Computation of Alum Treatment Dose

A bench test was conducted of Honeoye Lake water to determine how much alum could be safely added to the lake without producing aluminum toxicity. Some of the basic data utilized in assessing the lake's safe and effective alum doses are provided below. As noted, the introduction of alum in Honeoye Lake is limited to the anoxic hypolimnetic reaches of the lake. In our analysis, a cut-off depth of 18 feet (5.5 meters) was utilized to define the treatment zone. It was also assumed, for the purpose of dose computations, that the hypolimnion of the lake remains anoxic for 90 days. This is an obvious over assumption given the lake's polymictic nature.

Basic Morphometric Properties of Honeoye Lake and P Loading Input Parameters Used in Alum Dose Computation		
Parameter	English	Metric
Proposed Treatment Zone	800 acres	$3.24 \times 10^6 \text{M}^2$
Volume of lake above treatment area (assuming average depth of 23.1 ft (7M))	18,480 acre-ft	22,663,200 M ³
Daily P release rate under anoxic conditions	N/A	6 mg/M ² /D
Projected load based on 90 days of anoxia	3,850 lbs P	1,750 kg P
Projected dose to control hypolimnetic P load (assuming 50% efficiency)	N/A	2,625 kg Alum = 63,525 gallons 79 gallons/acre
Instantaneous measured maximum P concentration in hypolimnion	N/A	0.07 g/M ³
Maximum instantaneous measured P load in entire water column of treatment zone	3,491 lbs P	1,586,424 g P = 1,587 kg P
Projected Alum dose (assuming 50% efficiency)	N/A	2,380 kg Alum = 57,608 gallons or 72 gallons/acre

The maximum **safe dosage** was determined by titrating unfiltered and unpreserved Honeoye Lake water with alum until the pH within the treatment vessel declined to 6.0. This test concluded at a titrated concentration of 52.6 mg of alum / L, which equates to 4.7 mg of Al⁺³ / L. This converts to a total treatment volume of 296,456 gallons, for the treatment of the entire 800 acre target area. This equates to a per acre treatment rate of 370 gallons of Al⁺³/acre. Alum is 4.4% aluminum, thus dividing by 0.044 yields a theoretical maximum per acre dose of 8,422 pounds of alum. The weight of liquid alum is 11 pounds per gallon. The theoretical maximum per acre dose is therefore 765 gallons alum/acre. As noted above, the projected amount of alum needed to treat the lake's measured *in-situ* P load and the computed internally regenerated P load are also in the range of 150 gallons alum/acre. These application rates are well below the safe dose concentration arrived at by means of the bench test titration.

Sweetwater Technology, a leading applicator of alum in lake ecosystems, has developed an alum treatment computational formula based on a variety of lake and treatment in-put parameters. This basic equation is as follows:

$$W_a = P_L \times ((K_a \times K_r)/(K_d \times K_i)) \times Y$$

- W_a = Treatment amount of aluminum in pounds per acre
- P_L = Estimated or measured annual P load lbs/yr
- K_a = Ratio of molecular Al to molecular P = 0.89
- K_d = Distribution efficiency, that is the consistency of the alum application = 0.95 for GPS barge type applications
- K_i = In-situ efficiency of the treatment accounting for binding of Al to particulate material, which for Honeoye Lake was tested at a 0.5 and 0.8 level of efficiency
- K_r = Cooke average sediment release rate 2.5
- Y = Five year longevity of treatment

Starting with the projected internal P load of 3,850 lbs, as determined by the combination of measured, reported and literature values for P recycling under anoxic sediment conditions. The resulting computed dose in pounds of aluminum is 90,171. Applied over 800 acres this translates to a per acre dose rate of 112 lbs Al^{+3} /acre. Converting from aluminum to alum, and then from a dry application to a liquid application, results in a treatment dose of 232 gallons/acre at 50% efficiency and 145 gallons/acre at 80% efficiency. Substituting the computed instantaneous load of 3,491 lbs P in place of the projected internally recycled load, results in similar, but slightly lower application rates. As the appropriate treatment application doses are well below the projected maximum safe dose, the introduction of alum at a rate of 150 gallons/acre should result in no deleterious impact to the lake.

An alternative means of computing alum dose requirements can be achieved by using a very simplified computation based on the molar relationship of aluminum and phosphorus. Again, using the actual field data, but extrapolating to a maximum measured in-lake concentration of 0.07 mg/L P (or g/M^3), the equivalent amount of required aluminum, at 50% binding efficiency, to inactivate this phosphorus is $1.17 g/M^3 Al^{+3}$. Applying this P concentration over the entire proposed treatment volume ($22,663,200 M^3$) results in a required treated load of 1,586,424 g/M^3 . Applying the required treatment dose to this volume yields a computed total application of 1,856,116 $g Al^{+3}$. Converting to liquid alum translates to a total application volume of 8,436 gallons, which is only 10 gallons/acre.

As previously noted, Princeton Hydro has successfully treated polymictic waterbodies, with phosphorus dynamics similar to those reported for Honeoye Lake, using treatment doses on the order of 150 gallons per acre alum. We are confident based on these documented successful treatments that Honeoye Lake's internal phosphorus load can also be controlled at similar application rates. The data presented above substantiate this conclusion.

6.0 Conclusions

There are two primary techniques used to determine alum dose rates (Cooke and Kennedy 1981; Cooke et al. 1993):

1. The alkalinity/pH method whereby the proposed dose is determined in part by the lake's buffering capacity as determined by a decreasing decline in pH crested through the progressive introduction of alum, by titration to raw lake water, until a pH of 6.0 is achieved,
2. The phosphorus loading method whereby the proposed dose is calculated on the basis of the measured or modeled phosphorus load. For the most part, emphasis is placed on the internal load in cases where alum blanket formation for the purpose of sequestering internal phosphorus recycling from anoxic sediments is the project goal. The applicable alum dose is typically computed as being equal to the measured or modeled phosphorus load.

For Honeoye Lake the alkalinity/pH technique was used to compute the maximum **safe dose**, while a direct analysis of alum titration to the point where soluble reactive phosphorus was inactivated, was used to compute the **appropriate dose**. The Sweetwater Technology alum application formula was also used to compute the **appropriate dose** under differing levels of alum treatment efficiency.

Alum, in liquid form, is 9% aluminum by composition ($\text{Al}_2(\text{SO}_4)_3 \cdot 14\text{H}_2\text{O}$). The per gallon weight of liquid alum is 11 pounds. Numerous alum applications conducted on lakes across the country over the past 20 years have typically involved the introduction of alum at dose rates on the order of 8 to 20 mg Al/L. The variability in treatment dose appears to be a function of a variety of factors including the purpose of the application (stripping, alum injection, bottom sealing, etc.), prevailing pH and alkalinity, and the water column concentrations of TP and SRP at the time of the application.

The amount of aluminum required to inactivate Honeoye Lake's water column phosphorus load was determined to be approximately 52 mg/L of alum as per the results of the SRP inactivation titration results. This is approximately equivalent to a dose of 5 mg Al/L. This is considered the **appropriate dose** for the lake. At this titrated concentration, SRP was non-detectable in waters collected from with the mid-depth or bottom of the lake (as compared to 0.005 and 0.029 mg/L as measured before the introduction of the alum). This concentration is well below the maximum **safe dose**. This means that enough alum can be safely added to Honeoye Lake to inactivate the lake's internal phosphorus load without causing aluminum toxicity problems. Based on the alkalinity and bench test data for Honeoye Lake, the use of an alum blanket is a feasible management measure and one that should be conducted.

The duration of effectiveness for such a treatment will be strongly dependent upon the lake's hydraulic retention time and the prevailing weather conditions that follow in the years following the treatment. These data have not been fully developed, but would be following the completion of the lake's comprehensive watershed study. However, based on the data reviewed to date, we anticipate, as derived from the magnitude of the lake's internal load, the lake's average flushing rate and the well mixed and relatively well oxygenated nature of all but the deepest portions of the lake, that an a single alum treatment should be effective for at least five years

If an alum treatment is conducted, liquid alum should be used as opposed to solid alum. The application of a liquid product would allow for a more even distribution of the product through the water column. Although additional data must be collected, as based on the results of this alum bench test, we expect a total of 70,000 to 120,000 gallons of alum will need to be applied in order to create an effective alum blanket. The estimated cost of a 120,000 gallon application is in the range of \$125,000, based on a material cost of \$50,000 and an applicator cost of \$75,000. Again this is consistent with our past alum treatment projects. However, this is a preliminary estimate and could likely change subject to the additional data and analysis of the lake (nutrient model) that should be conducted in advance of the actual alum treatment. It does though appear to be a reasonable price based on our experience and the data available in the scientific literature. As noted above, this price includes the cost of the alum, the transport of the product to the lake, and the labor and equipment associated with the application of the alum. It does not however include the cost of NYSDEC permitting (SEQR), pre and post-treatment monitoring and associated public notices and meetings. Should the HVA wish to account for these additional costs, a total project fee on the order of \$150,000-\$175,000 appears appropriate.

In conclusion, we recommend that HVA proceed with an alum treatment for the lake, conducted for the expressed purposes of controlling the lake's internal phosphorus load. The bench test results show that such a treatment could be conducted safely and without undue environmental impact to the lake's biota.

7.0 References

Cooke, Dennis G. *Restoration and Management of Lakes and Reservoirs*, Second Edition. Lewis Publishers, 1993.

Freeman, R.A. and W.H. Everhart. 1971. Toxicity of Aluminum Hydroxide Complexes in neutral and basic media to rainbow trout. *Transactions of the American Fisheries Society* 100: 644-658.

Holz, J.C. and K.D. Hoagland. 1998. Effects of phosphorus reduction on water quality: Comparison of alum-treated and untreated portions of a hypereutrophic lake. *Lake and Reservoir Management* 15(1): 70-82.

Kennedy, R. and Cooke, G. 1982 . Control of Lake Phosphorus with Aluminum Sulfate: Dose Determination and Application Techniques". *Water Resources Bulletin* 18:389-395.

Narf, R.P. 1990. Interaction of Chironomidae and Chaoboridae (Diptera) with aluminum sulfate treated lake sediments. *Lake Reservoir Management*. 6: 33-42.

Sweetwater Technology Corp. 1997. Aluminum Dose Calculations,
<http://teemarkcorp.com/sweetwater/cacall.htm>.

Welch, E.B. and G.D. Cooke. 1999. Effectiveness and longevity of phosphorus inactivation with alum. *J. Lake and Reservoir Management*. 15:5-27.

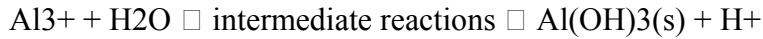
APPENDIX F

Explanation Of The Chemical Processes Involved With An Alum Treatment

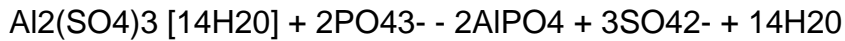
On contact with water, alum forms a “fluffy” amorphous aluminum hydroxide precipitate:



This precipitate is the result of the dissociation of the alum and liberation of aluminum ions which are immediately hydrated, and through a progressive series of hydrolyzes, form aluminum hydroxide ($\text{Al}(\text{OH})_3$).



Aluminum hydroxide is the principle ingredient in many common antacids. The resulting colloidal amorphous floc also has high coagulation and phosphorus adsorption and binding properties. Because the floc is heavier than water, it settles out of the water column. As the floc slowly settles out of the water column, phosphorus, especially inorganic phosphorus, binds to the alum floc and becomes, in effect, inactivated or unavailable for biological uptake by algae and phytoplankton. The Chemical reaction of the aluminum hydroxide with phosphorus is as follows:



Resulting in the ultimate formation of: AlPO_4 .