TETRA TECH

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Subject:	Effectiveness of Alum Treatment Demonstration Projects in Grand Lake St. Mary's
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Introduction

Grand Lake St. Marys has become increasingly enriched over the years because of activities in the watershed that have resulted in significant external and internal loading of nutrients, organics, and sediment to the lake. The result is a lake that is overly productive and displays extremely poor water quality. The poor water quality is illustrated by dense blooms of cyanobacteria (blue-green algae) that regularly occur in the lake. These blooms cause algae scum to appear, they contribute to low dissolved oxygen that stresses the aquatic life, and they are associated with cyanobacteria toxins that have led to postings that limit contact with the water.

Grand Lake St. Marys has an average summer total phosphorus (TP) concentration of approximately 200 µg/L and chlorophyll (chl) concentration of approximately 250 µg/L. The high lake TP concentration is in part due to very high tributary inflow concentrations that range from 300 µg/L to 500 µg/L. Also, the available data indicates that internal TP loading from the lake's bottom sediments represents a substantial contribution of the total load during the summer. The chl concentrations are far in excess of the hypereutrophic criterion of 25 µg/L (Nurnberg, 1996).

Several demonstration projects were tested in Grand Lake St. Marys during the fall of 2010 to evaluate the potential for improving water quality. These demonstration projects occurred in partially, or wholly, enclosed coves/embayments along the shore of the lake. One of the techniques evaluated was the treatment of lake water with alum. Alum, which is aluminum sulfate, forms a floc that sorbs and/or complexes TP and particulate matter while settling from the water column. This aluminum floc continues to inactivate lake bottom sediment P, thus curtailing internal loading. The technique has been used successfully in over 150 lakes worldwide (Welch and Gibbons, 2005; Cooke et al., 2005; and Welch and Cooke, 1999) and this technical memorandum describes the results for the of demonstration of alum treatment in three coves for Grand Lake St. Marys in 2010.

Procedures

Six coves/embayments were considered for the demonstration project and three were eventually selected:

A. Harmon's Channel
B. West Bank Marina
C. Otterbein #2 Channel

Algal mass was too high and dissolved oxygen was too low (fish were dying) in three other coves/embayments to allow for a fair evaluation of alum treatment. However, algal concentrations were very high and dissolved oxygen levels were also low even in the three locations that were selected.

The size and depths of the three demonstration project locations are presented in Table 1. The project locations are shallow (1.2 meters (m) to 2.0 m), which is similar to that of the open lake (1.4 m). Alum along with a buffer (sodium aluminate) was added at 31.6 mg/L Al to each location on September 20, 2010. The dose was determined based on sediment and water column TP content from previously collected samples, and the total dosage is shown in Table 1. Total treatment cost was $61,500.

Table 1. Characteristics of the three demonstration project locations.

Demonstration Project	**Size (ha)**	**Dosage (Kg Al)**	**Depth (m)**
Harmon's Channel (A)	5.3	2,012	1.2
West Bank Marina (B)	3.6	2,083	2.0
Otterbein #2 Channel (C)	3.1	1,449	1.5

The project locations were monitored for TP and chl on a biweekly basis through mid-November, providing five post-treatment data points. Water samples for TP and chl were collected at 0.5 m inside and outside of each location and before and after treatment. Samples were collected from several sites inside the three treated areas and composited producing one sample for analysis.

Results

Initially, the treatments clarified the water column within an hour or so, which was expected. However, the improvement did not persist with unexpectedly high TP and chl observed during the first sample collection (September 27, 2010). At the conclusion of all the sampling, mean TP and chl concentrations were reduced by 50 to 60 percent in locations A and C (Table 2, Figure 1). However, there was no difference in pre- and post-treatment mean TP and chl in location B (West Bank marina).

Multiple control sites were also sampled with mean TP and chl concentrations similar at each site (Table 2). The control sites consisted of the following:

- outside the project locations after the alum treatments
- inside and outside the project locations before the treatments (Otterbein #1 and #2)
- inside an untreated cove (Otterbein #1) after treatments

Mean TP in the five control conditions ranged from 164 ± 20 to 198 ± 51 µg/L (Table 2). Mean chl ranged from 127 ± 22 µg/L to 195 ± 43 in four control conditions, but was much lower (63 ± 17) in the fifth – untreated Otterbein #1. This consistency over five separate control conditions gives credibility to the effect of alum in two of the treated coves. The lack of effectiveness in the third location was unexpected, but is explained in the next section.

Table 2 also includes the ratio of chl to TP, which provides and indication of the rate of primary production in the lake.

Table 2. Means (± SD) of TP and chl in three coves/embayments before and after alum was applied September 20, 2010. Number of samples indicated by ( ) and statistical significance by *.

Location A-Harmon

Pre	TP (µg/L)	Chl (µg/L)	Chl/TP
Inside (1)	673	91	0.14
Outside (1)	135	132	0.98
Post			
Inside (5)	83 ± 34*	67 ± 40 *	0.82 ± 0.37
Outside (4)	172 ± 56*	195 ± 43 *	1.31 ± 0.75
% reduction	52	66	

Location B-West Bank

Pre	TP	Chl	Chl/TP
Inside (1)	158	132	0.84
Outside (1)	642	122	0.19
Post			
Inside (5)	159 ± 105	167 ±29	1.49 ± 1.02
Outside (5)	171 ±77	186 ± 29	1.24 ± 0.48

Cove C-Otterbein #2

Pre	TP	Chl	Chl/TP
Inside (2)	162	109	0.67
Outside (2)	137	157	1.14
Post			
Inside (5)	85 ± 33*	92 ± 26*	1.18 ± 0.5
Outside (4)	198 ± 51*	173 ± 32*	0.97 ± 0.51
% Reduction	57	47	

Otterbein #1 and #2

Pre/Control (4)	164 ± 20	127 ± 22	0.79 ± 0.24

Otterbein #1 untreated

Inside (5)	187 ± 40	63 ± 17	0.35 ± 0.11

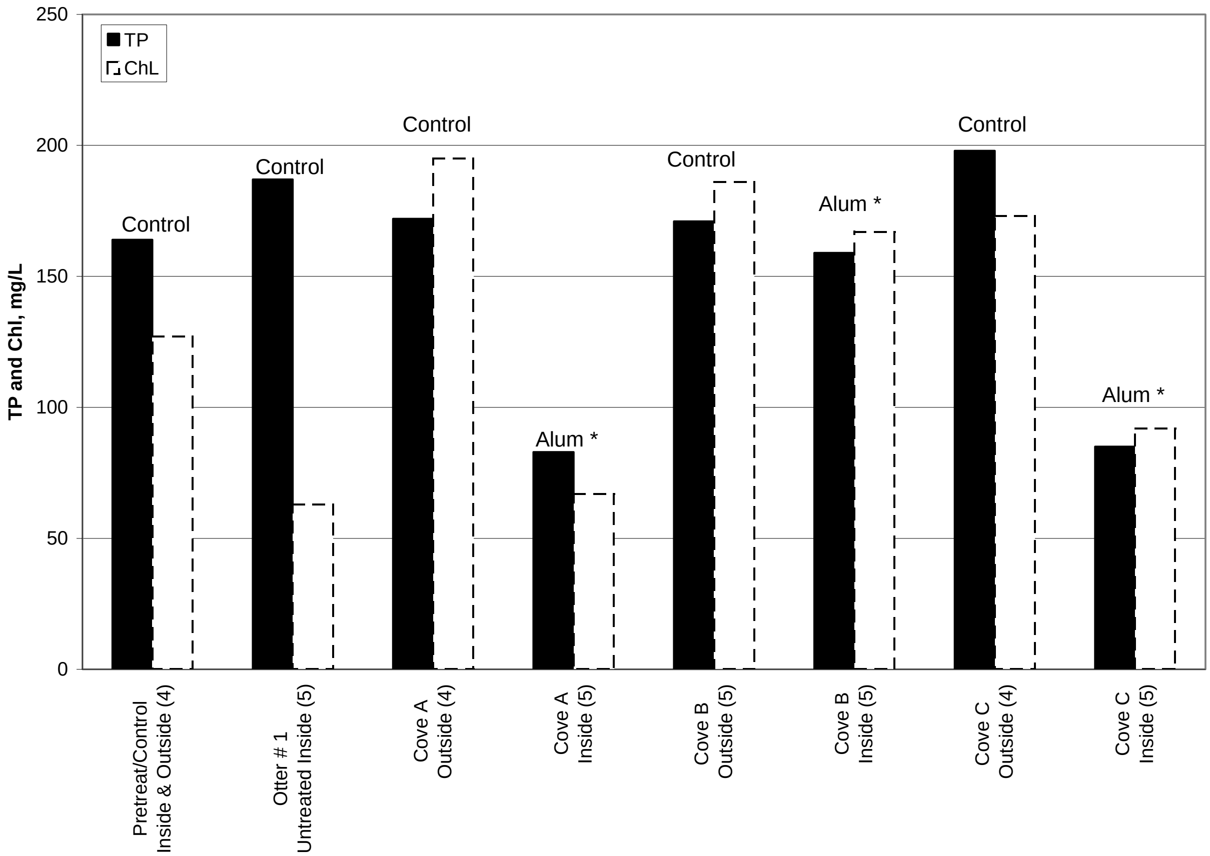

Figure 1. Effectiveness of alum treatment on mean TP and Chl inside three cove/embayments compared to untreated outside and pre/control conditions (Otterbein #1 and #2), as well as inside an untreated cove section (Otterbein #1). Significant effect*.

Mean TP and chl concentrations inside the treatment areas were compared to the means outside the treatment areas for the five sampling dates (September 27 to November 27). Pretreatment levels inside and outside locations A and B were not used, because of unusually high TP concentrations exceeding 600 µg/L (Table 2). These two extreme TP concentrations also produced unusually low chl/TP ratios (0.14 and 0.19), compared to the other data, which averaged about 1.0 (Table 2). While a ratio of 1.0 was typical of treated and untreated areas alike in Grand Lake St. Marys, it is unusually high compared to other lakes, which frequently average about 0.35. This speaks to the extremely high rate of primary production in Grand Lake St. Marys.

While alum was significantly effective in two of the three coves, the degree of effectiveness was poorer than expected (i.e., the percent reduction was lower than expected and the residual TP concentration was higher than expected). Typically, alum treatments reduce residual TP concentrations to 30 µg/L or less (Cooke et al., 2005). The residual concentrations observed in locations A and C (as high as 80 µg/L) are highly unusual, if not unprecedented. Furthermore, the lack of effectiveness in location B was unexpected. Extenuating circumstances, such as extremely high concentrations of buoyant algae, may explain some of these unexpected results, as discussed in the following section.

Discussion

Several factors led to the less-than-expected effectiveness of alum in project locations A and C and the total lack of effectiveness in location B. First, the extremely high biomass of the cyanobacteria probably interfered with the ability of the alum to inactivate sediment P – the primary goal of the technique. This is because alum floc sorbs to particulate and dissolved organic matter as well as P. The high particulate organic matter in the algal cells therefore utilized some of the binding capacity of the floc, reducing its effectiveness once it reached the sediment.

Perhaps even more importantly, the settled algal cells undoubtedly became buoyant once they were in the lower light conditions on the bottom of the lake. Under these conditions, the gas vesicles of the algae expanded and they rose in the water column, which is normal behavior. This phenomenon would account for the higher-than-expected residual TP concentrations in the treated coves and the high variability of the mean TP (± 30-66%) and chl (± 17-60%). That variability is believed to have been caused by temporal and patchy distribution patterns of the algae, not sampling techniques, because four successive (within one hour) pre-treatment samples inside and outside Otterbein #2 (n=4) produced variability of mean TP and chl of only 13 and 17 percent, respectively.

An extreme example of variability occurred in project location B. TP was relatively low for the first two samples: 71 and 62 µg/L. However, TP was 309 and 220 µg/L for the next two sample dates. Buoyant cyanobacteria can create patchy distributions of chl and TP that could account for such variability, although some of the variability should have been minimized by the composite-sampling approach.

The second possibility is that the barrier curtains were ineffective at preventing lake water from entering the treatment areas. That was especially the case for location B where an unknown amount of water was observed to exchange between the secluded treatment areas and the open lake. Also, location B received an uneven distribution of alum due to extremely windy conditions. A failure to evenly apply alum floc has been observed to be an important factor in the inactivation of sediment P in other lake treatments (e.g., Green Lake in 1991).

In summary, the failure of the demonstration projects to lower TP to the expected concentrations is considered to be due primarily to treating during a period with high in-lake algae conditions. Spring is the optimal time to treat because cyanobacterial concentrations are low and the alum floc can therefore sorb dissolved and non-algal particular P in the water column and still retain sufficient binding capacity when it reaches the sediment. Based on conditions in Grand Lake St. Marys in 2010, April and May would be the best time to apply alum because cyanobacterial biomass did not begin to increase until June.

Summary

1) Alum application to three demonstration locations at 31.6 mg/L Al initially cleared the water, but over the following two months TP and chl were only reduced approximately 50 to 60 percent in two of the treatment areas. No reduction was observed in the third treatment area.

2) The residual TP concentrations in the two treatment areas displaying some effectiveness were more than double those observed in other treated shallow-lakes.
3) The principal cause for the high residual TP concentrations is believed to be the high concentrations of buoyant cyanobacteria, which compromised the binding capacity of the alum floc and led to the re-suspension of floc. A secondary cause is believed to be the likely encroachment of outside water with high TP and chl water into the treatment areas.
4) The failure of the alum to have any long-term effect in treatment area B is believed to be due to both the uneven distribution of the alum during application (due to high winds), as well as the exchange of outside lake water.

Recommendations

Based on the results of these demonstration projects and previous analysis of conditions within Grand Lake St. Marys, the following recommendations are made:

1) The alum demonstration should be repeated with application occurring just after ice out or early spring when algal concentrations are low. With less algal present, low DO should not be a problem and the effectiveness of the alum should be greatly increased.
2) Much of the internal P loading may come from the previous year's decaying algal mass on the sediment surface. To effectively tie up that source of P, one or two treatment areas should be pre-treated with hydrogen peroxide to solubilize that organic P for inactivation by Al.
3) A potential whole lake alum treatment should be designed based on the results of the spring demonstration project, and needs to take into account the algal biomass at the time of treatment and the rate of application of the alum. It is critical that the available P for bio-utilization be inactivated throughout the lake as quickly as possible to allow for the inactivation of sediment P.

References

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