AN EVALUATION OF THE ALUM TREATMENT OF WAPOGASSET AND BEAR TRAP LAKES, POLK CO.

Paul Garrison
WDNR

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Because of the apparent failure of the alum treatment in Wapogasset and Bear Trap lakes in Polk Co., I have reexamined the data in order to determine why the treatment was not successful. Alum treatments have been used as a means of significantly reducing internal phosphorus (P) loading for over 30 years. In fact the first lake to be treated with alum in the United States was Horseshoe Lake in Wisconsin. These treatments generally are effective at reducing internal loading for 5-11 years in unstratified lakes and 4 to 21 years in stratified lakes (Welch & Cooke, 1999). So what happened in these two lakes?

As measured in 1995, the internal P loading from anoxic sediments in the hypolimnion of both lakes was very high. Welch & Jacoby (2001) reported on the internal loading rate for a number of lakes in western Washington. I calculated the internal loading rates the same way as they did. As is evident in the table, the loading rates in Wapogasset and Bear Trap lakes are much higher than the Washington lakes. This indicates that there likely is a large amount of easily mobilized P in the sediments of these lakes.

Table 2.–Annual and summer flushing rates (ρ), annual and summer (June-September unless specified) external (Le) and summer internal (Li) P loading and mean TP concentrations during summer (TPs) and all year (TPy) in 17 western Washington lakes prior to restoration (unless indicated).

Lake	ρ(J-S) 1/y	Mass Balance Le mg·m⁻²y⁻¹	Mass Balance Li mg·m⁻²y⁻¹	Mass Balance Li %[3]	Observed Li mg·m⁻²y⁻¹	Observed TP[4]s mg·m⁻³	Observed TP[4]y mg·m⁻³
Unstratified							
Twelve	2.5(0.33)	256(31)	0	0	0	6	8
Horseshoe	4.8(1.52)	433(124)	97	44	46	30	24
Long-K	3.5(0.49)	477(98)	120	55	101	69	49
	7.9(0.67)	885(151)	167	53	example 91	78	65
Long-T	2.4(0.65)	532(138)	139	50	154	37	38
Pattison	2.2(0.57)	352(92)	149	62	173	54	53
Campbell	1.0(0.25)	209(52)	98	65	106	49	38
Eric	1.2(0.30)	158(40)	435	92	523	115	74
Wapato	4.4(1.1)	ND(592)[5]	113[5]	16	75	86	-
(post diversion)		ND(279)[5]	157[5]	36	134	58	-
Green	0.92(0.27)	159(35)	250	88	260	52	42
Lawrence	0.29(0.014)	148(24)	679	97	646	84	50
			<u>Wapogasset</u>		1550		
Stratified			<u>Bear Trap</u>		1280		
Ballinger	4.1(1.03)	1400				60	37
		840(84)				43	47
Pine	0.44(0.016)[1]	155(5.8)	35[2]	86	114[2]	23	24
(post diversion)	0.31(0.048)[1]	113(8.3)	50[2]	86	131[2]	26	25
Silver	0.42(0.000)[1]	234(59)	0	0	19	14	14
Roesiger	1.3(0.13)	213(37)	50	58	128	8	10
American	0.31(0.10)	360(105)	266	72	214	20	23
Stevens	0.073(0.010)	860(50)	171	77	365	38	23
Phantom	0.42(0.038)	576(89)	447	83	750	116	85

[1]Evaporation>inflow-summer
[2]April-September
[3]% of total summer load (June-September unless specified)
[4]Whole lake means
[5]May-August
ND = no data

Characteristics of the sediments also indicate that there may be a large reservoir of highly mobile P. Welch & Cooke (1999)found in a review of the long-term effectiveness of alum treatments that the ratio of aluminum (Al) to iron (Fe) was important. As a rule of thumb, if the Al:Fe is greater than 1.0 the effectiveness of the alum is much greater. This is because enough Al needs to be added such that the Al binds the P that normally would be present as iron bound phosphorus. While aluminum bound P is not subject to dissolution during anoxic conditions, iron bound P is very susceptible to release from the sediments into the water column under anoxic conditions. This is why internal loading occurs. As is evident in the following table, the Al:Fe is very low in Wapogasset and Bear Trap lakes, even after the alum treatment.

Table 6.–TP content in mg g^{-1} and ratios among P, Al and Fe in surficial (0-6, 0-8 CM) sediment (n = 2 or 1*) of study lakes.

	TP	Al/P	Fe/P	Al/Fe
Campbell	2.3	7.4	6.8	1.09
Erie	1.6	8.0	7.7	1.04
Long (north)	1.5	7.5	8.1	0.93
Long (south)	1.6	6.5	8.7	0.75
Pattison (north)	2.3	5.2	10.0	0.52
Pattison (south)	1.9	4.8	7.2	0.67
Long (Kitsap-pretreat)	1.8	21.6	16.3	1.33
Wapato	2.6	12.2	11.2	1.09
Mirror	2.1	6.0	6.2	0.97
Shadow	2.5	5.8	3.1	1.87
Horseshoe	2.6	4.7	2.6	1.81
Eau Galle	4.1	4.8	4.8	1.00
West Twin	1.7	12.3	17.4	0.71
East Twin (untreated)	1.4	10.2	20.8	0.49
Dollar	2.4	17.5	18.3	0.95
Kezar*	1.3	15.7	10.2	1.54
Annabessacook*	2.8	6.8	11.3	0.60
Morey*	0.6	27.5	44.0	0.63
Delevan*	0.8	10.0	12.1	0.82
Cochnewagon*	1.0	22.6	24.1	0.94
Irondequoit*	1.0	14.4	18.4	0.78

Pretreatment (post)

	TP	Al/P	Fe/P	Al/Fe
Wapogasset	2.1	5.0 (5.7)	22.5	0.22 (0.30)
Bear Trap	3.3	2.3 (3.6)	13.1	0.18 (0.27)

It seems to me that the reason the alum treatment in Wapogasset and Bear Trap lakes was not successful is most likely because not enough alum was added to inactivate the easily mobilized P in the sediments. It is likely that these lakes contain much more of this type of P than typically has been present in other Wisconsin lakes that have been treated with alum in the past. This is in part because most of these lakes are possess hard water with high amounts of calcium. Because of the calcium, much of the sedimented P is complexed with calcium and thus becomes generally unreactive, even in the absence of oxygen. In contrast Wapogasset and Bear Trap lakes contain much lower concentrations of Ca and therefore most of the sediment P is complexed with iron, which is much more likely to be mobilized in the absence of oxygen. In a paper by Rydin & Welch (1999) they found that for 3 Wisconsin hard water lakes, the application rate should be 75-150 g Al m^{-2}. The rate in Wapogasset and Bear Trap lakes was 40-50 g Al m^{-2}. This rate was determined by past experience where the amount of alum to be applied was targeted at 10-12 mg L^{-1} of treated lake volume. It now appears that this method of calculating dosing rates is not adequate for lakes that possess reduced Ca levels. Instead, a much better technique is one proposed by Rydin & Welch (1999). This technique measures the amount of mobile inorganic sediment P in the top 4 cm of the lake sediments. Since the purpose of alum is to immobilize sediment P as opposed to the removal of P from the water column, this dosing technique should be more reliable.

Additional evidence of the enhanced amount of mobile sediment P in low Ca lakes is work done by Asplund (1996). He assayed sediments from high and low Ca lakes in order to determine their potential to release P as a result of motorboat activity. He found that little P was released from high Ca sediments but a significant amount was released from low Ca sediments.

In summary, it is my opinion that the reason the alum treatment in these lakes was not successful was that not enough alum was applied. This was because of the large of amount of mobile P in the sediments. While the method we have used in the past has been adequate for hard water lakes it does not seem to work for soft water lakes. If it is decided that another alum treatment should be done, the first treatment will not have been wasted. The alum added has immobilized a portion of the P but there is a significant amount left. I would recommend that in the future dosing for alum treatments are determined by measuring the amount of mobile inorganic P in the sediments. In the case of Wapogasset and Bear Trap lakes this likely will dramatically increase the cost of an alum treatment. I plan to analyze the amount of mobile sediment P this winter so we will be able to determine how much alum would need to be added to significantly reduce the internal loading in these lakes.

References

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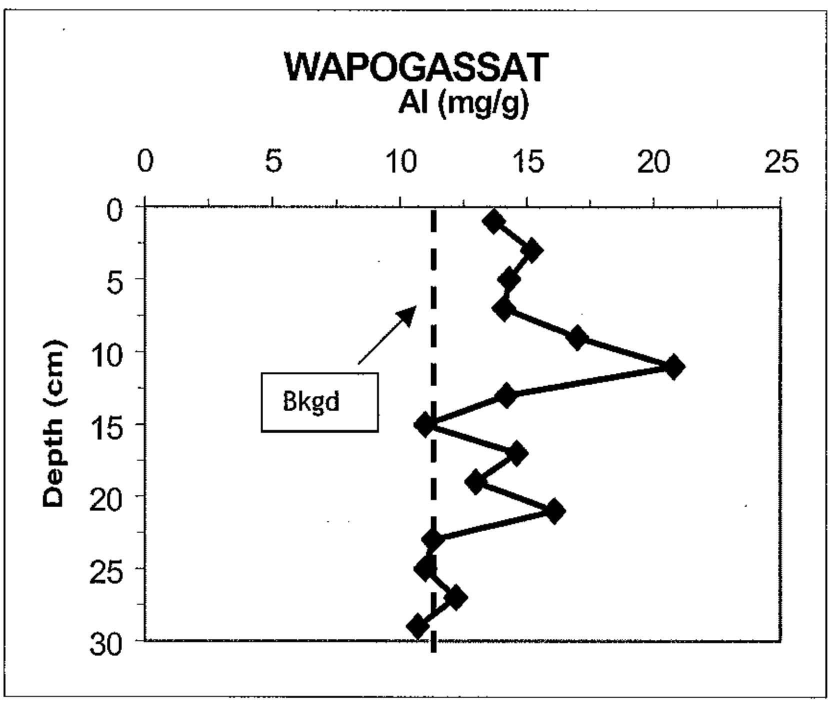
FURTHER UPDATE ON WAPOGASSET AND BEAR TRAP LAKES

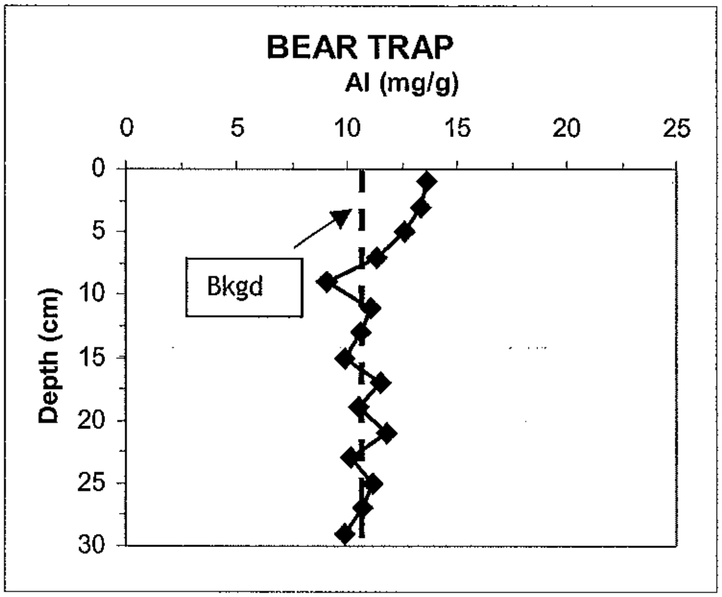
I have received the results from the lab for the aluminum (Al) analysis from the cores from both lakes. In general the results are not too dissimilar from the coring results of June 2000 with the exception of a peak in aluminum at 10-12 cm in Wapogasset. From the cores it appears that in Bear Trap Lake, nearly all of the added Al is in the upper 8 cm of the sediment. The amount of added Al (from the alum treatment) that was recovered in the sediments is surprisingly low. It would appear that much of the Al wasn't retained in the lake.

In Wapogasset, the Al was distributed over a greater depth in the sediment core. In fact the added Al appears to be distributed throughout the upper 22 cm. The peak at 10-12 cm undoubtedly is from the alum treatment. It is likely that the alum has penetrated to a deeper depth in Wapogasset Lake because of its larger size, soft sediments, and relatively shallow depth. In practical terms, this means that more alum needs to be applied in a lake similar to Wapogasset because the alum does not stay in the upper few centimeters.

I have included a figure in a paper by Rydin et al. (2000) which shows Al profiles from 6 Washington lakes. Five of the lakes have low alkalinity similar to Wapogasset and Bear Trap lakes. Medical Lake is the only high alkalinity lake. In none of these lakes, is the Al peak as deep as in Wapogasset Lake.

Based upon the Al distribution in Wapogasset Lake, it does not appear that this lake was a good candidate for alum. The sediment characteristics and lake size result in much of the Al moving into the sediments up to a depth of about 20 cm. This means that an exorbitant amount of alum must be added to this lake for it to be effective. On the other hand, Bear Trap Lake appears a much better candidate for alum. So far, the alum has been retained in the upper 8 centimeters.




BEAR TRAP
Al (mg/g)
0
5
10
15
20
25
Depth (cm)
0
5
10
15
20
25
30
Bkgd

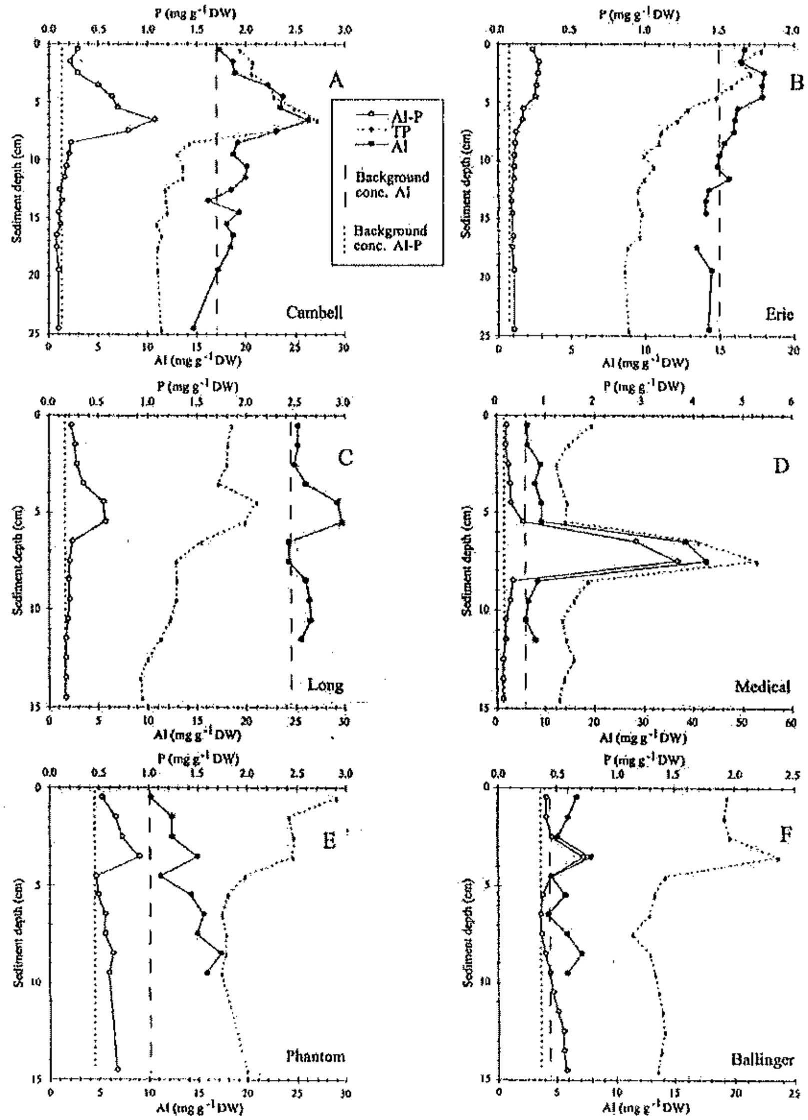


Fig. 1. Concentrations of aluminum (Al), aluminum bound phosphate (Al-P), and total phosphorus (TP) concentrations in sediment profiles from six Washington lakes. In the unstratified lakes (A, B, and C) Al is measured as the total concentration, and in the stratified lakes (D, E, and F) Al is measured as Al extracted together with Al-P; *see Methods*. The vertical dotted lines indicate assumed background concentrations of Al and Al-P.

FURTHEST UPDATE ON WAPOGASSET AND BEAR TRAP LAKES

Some more work has been completed for the evaluation of the alum. This additional work involved collecting 2 cores in Wapogasset and 1 core from Bear Trap lakes last winter. These cores were delivered to Bill James of the Army Corps of Engineers in Spring Valley. They added sequential amounts of alum to the sediments in order to determine how much additional alum would need to be added to these lakes to significantly reduce the release of phosphorus from the sediments.

The amount of alum that should have been added initially was calculated last fall and presented at the December meeting. At that time I estimated that we should have added considerably more alum than was applied in 1999. The work done by Bill James was an attempt to directly determine the proper dosage rate.

The figure below gives the result of sequential addition of alum to the deep hole core from Wapogasset Lake. The results for the other cores were very similar. In all three cores when the added alum concentration was about 20-25 mg g^{-1}, most of the mobile phosphorus (Fe-P + loose-P) was inactivated. This mobile P is the form that is released from the sediments when there is no oxygen present.

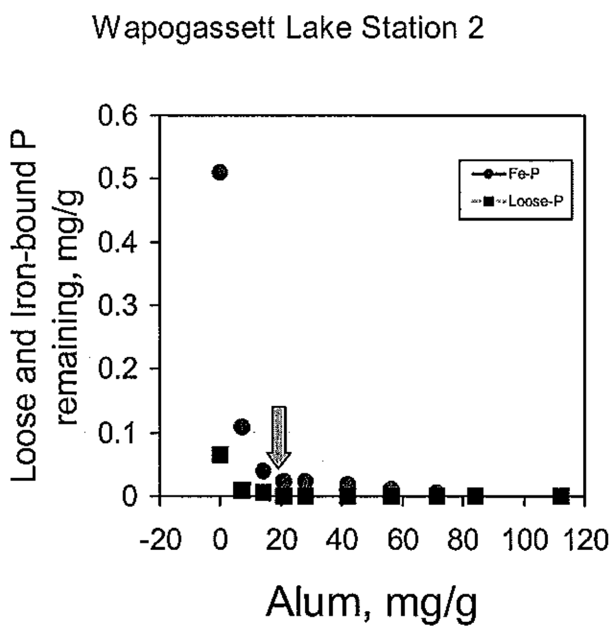


Figure 0. Results of sequential alum dosage to the deep hole core. The arrow denotes the Al concentration that should be added to significantly reduce release of P from the sediments.

This information gives part of the answer as to how much alum should have been added. Additional information that is needed is how deep the alum floc will be distributed in the sediments after the alum is applied. This information was obtained from the cores collected last fall. In a previous report I presented profiles of aluminum in these cores. In Bear Trap Lake, the alum did not penetrate settle beyond 6 cm while in Wapogasset it went much deeper, to about 22 cm. This depth is important because all of the mobile P above this depth needs to be inactivated to prevent phosphorus from being released from the sediments. Consequently the deeper the alum sinks the more that needs to be applied.

Using the amount of alum that is needed to immobilize the P and the depth of sediment where the alum sinks I estimate that 5 times as much alum needs to be added compared with the original application. This means that while the original application rate was 40 g m^{-2} it should have been 200 g m^{-2}. This additional alum would increase the cost considerably.

Although much more alum should have added, it still may not be as effective as desired. This may be especially true in Wapogasset Lake since most of the alum settled to 12 cm (Figure 2). This could mean that mobile phosphorus in the sediment above 12 cm would be released into the overlying water. Perhaps if a greater concentration of alum were initially added much of the sediment P would be inactivated since the aluminum concentration following the 1999 treatment is above background levels. This has not been investigated so I can not be sure that additional alum would in fact remove this phosphorus. Given our current knowledge, it seems that alum may not be appropriate in relatively large, shallow lakes with deep soft bottom sediments such as Wapogassat. Because Bear Trap Lake is smaller an alum treatment would have a greater chance of success if the proper amount were added.

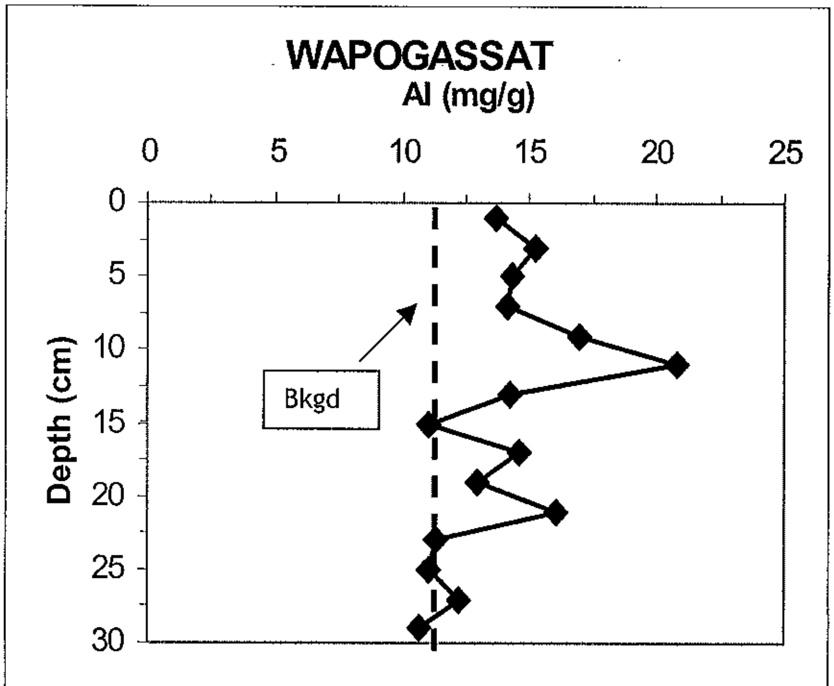


Figure 2. Aluminum concentration in the core from the deep hole. The Al peak at 12 cm is where the most of the alum has settled.