Impacts of Sulfur Loading Following Alum Treatment of Waughop Lake, Pierce County, Washington

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Introduction

- Waughop lake is a small kettle lake in Lakewood Washington (~33 acres)
- The lake has had a long history of hazardous algal blooms (HAB's)
- In the summer of 2020, the lake was treated twice with aluminum sulfate (alum)
- Since the treatments, there has been a large increase in the concentrations of both Na and S.
- Consequences of increased sulfate in the water column have been an increase in hydrogen sulfide in the pore water causing the loss of rooted vegetation in the lakebed.

Alum Treatment

- Waughop lake has been treated twice with alum in 2020.
- The first treatment was on March 25, 2020, and the Second dose began the week of July 13, 2020.
- Each treatment was a dose of 40 mg/L, adding around 16,000 kg S.
- Since the two treatments, elevated levels of sulfur and sodium have been measured.
- While the treatment has been effective in preventing HAB's, there is also evidence that a great deal of plant life may have been removed as a result of the alum treatment.

Figure 1. Alum application process at Waughop Lake. The barge drives around the lake spraying alum and buffer together.

Waughop's History & Background

Figure 2. Waughop Lake, located in Fort Steilacoom Park Lakewood, Washington.

Figure 3. Photo of Waughop Lake showing hazardous green algae.

- Originated as a kettle ~14,000 BP
- Has no surface outflow stream.
- Until the 1960's Fort Steilacoom Park contained a farm worked by patients from the adjoining mental hospital.
- Agricultural waste was dumped directly into Waughop Lake.
- As a result, the bottom sediment is highly enriched in P.
- Storm water runoff as well as septic leaks from the nearby college have also contributed to elevated nutrient levels.
- Nutrient loading has fueled numerous HABs and lake closures.
- During the summer of 2020, the lake was treated with alum twice to reduce the impact of HABs.

Water Column Chemistry

- Alum application profoundly changed to the chemistry of the lake from Ca bicarbonate dominated to Na sulfate dominated.
- This change persists 16 months later.

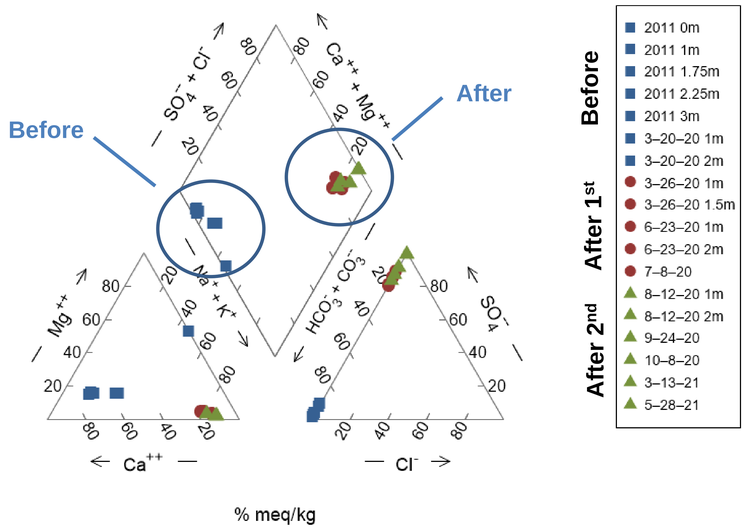


Figure 4. Piper diagram showing chemistry of Waughop Lake before and after 2020 alum treatments.

Possible Fates of Sulfur

There are several possible fates of sulfur in this closed basin. The fates which are most likely are highlighted in blue.

- Stays in the water column as SO_4*
- Converted to H_2S
  - Stays in pore water
  - Escapes as gas
  - Precipitates as sulfide bearing mineral (Pyrite)
- Precipitates as gypsum: $Ca(SO_4)\ 2H_2O$
- Escapes as groundwater outflow*

Sulfur Persists in the Water

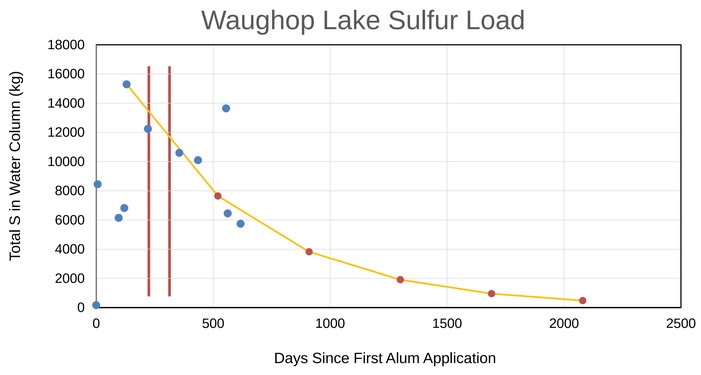
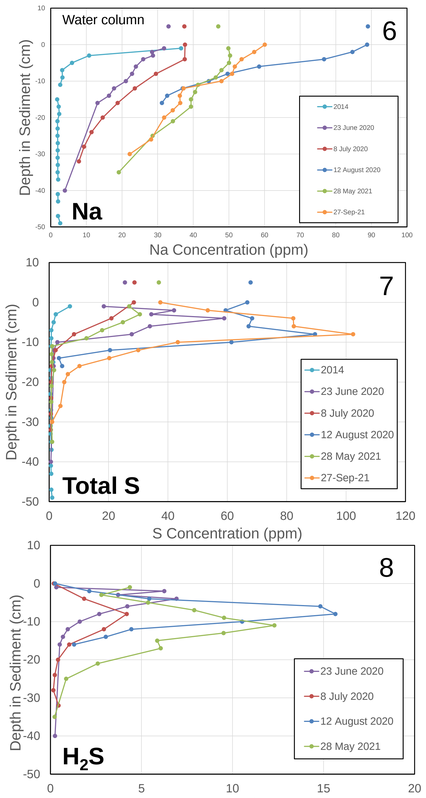


Figure 5. Plot of total S in Waughop water column vs. time. Note spike in S content following each alum application (vertical red lines). Blue dots are measured values of S. Yellow line represents calculated S levels assuming a half life of 13 months (residence time = 19 months). At this rate, it will take ~16 years for S to return to pre-treatment levels.

Pore Water Chemistry



Significant points to note:

- Lake water affects pore water to 20 cm.
- Month to month changes in water column chemistry are reflected in pore water chemistry (fig. 6,7).
- Both concentration and amount of H_2S, S, Na is higher than pre-treatment levels.
- Max H_2S levels exceed toxicity cap for aquatic plants (Myrbo, et. al., 2017)

Environmental Effects

- Dramatic decrease in rooted vegetation (fig. 9).
- Absence of waterfowl this past winter and spring.

Figure 9. Image of Waughop Lake bottom showing the lack of rooted aquatic plant life. Craters in the sediment are from gas escape, likely carbon dioxide, methane, and/or hydrogen sulfide.

Further Work

- Continue to sample the water and sediment at Waughop lake to get a detailed analysis on the effects of alum over a longer period.
- Conduct experiments with a variety of aquatic plants and sediment samples to quantify the effect of elevated sulfur levels on plant growth.

Acknowledgments

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