Background

- In 1985 Lake Campbell was treated with aluminum sulfate (“alum”) to reduce phosphorus in the lake fueling harmful algae blooms.
- Since 2021, the lake has experienced the return of annual toxic blooms, exceeding the Washington State Department of Health guidelines.
- The 2024 Lake Cyanobacteria Management Plan (LCMP), confirmed most phosphorus input to the lake is via sediment release during the summer months.
- Recommended long-term management includes an alum treatment to inactivate phosphorus in the sediments and prevent its release from organic matter and minerals.

Lake Campbell in August 2024.

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Objectives

To conduct a sediment incubation study that includes the following:

- Collect 16 sediment core samples from the deepest part of the lake.
- Collect a vertical-depth profile of temperature, dissolved oxygen, and pH.
- Expose the sediment cores and overlying water to varying oxygen, pH, and alum treatment conditions via an incubation experiment.
- Quantify internal phosphorus content of sediment in the lake.
- Confirm the efficacy of the alum dosage recommended by the Lake Cyanobacteria Management Plan (LCMP).

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Methods

- On August 19, 2024, a vertical depth-profile of temperature, dissolved oxygen, and pH was completed at the deepest part of the lake, to a depth of ~5.0 meters.
- Water subsamples were collected for analysis of total phosphorus (TP) and orthophosphate.
- 16 sediment cores were collected using a hammer corer.

Collecting sixteen sediment cores.

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Methods

- 8 study groups represented a combination of neutral or high pH (7 or 8.5 units), aerobic or anaerobic oxygen conditions, and alum treatment (no treatment or 18.0 g Al/m^2).
- Alum-dosed cores received 0.5 mL of aluminum sulfate (58 mg Al/mL) and 0.25 mL of sodium aluminate pH buffer (146 mg Al/mL).
- The cores' overlying water was sampled at the start of incubation, then ~12 to 18 hours, 46 hours, 70 hours, and 185 hours after beginning incubation.
- Each sample was measured for temperature, dissolved oxygen (DO), and pH, and analyzed for orthophosphate and total phosphorus (TP).

Sediment cores exposed to varying conditions.

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Results-Physical Measurements

- Oxygen levels were lower in the anaerobic than in the aerobic study group.
- The groups receiving the alum treatment were also dosed with sodium aluminate (a pH buffer). The pH of all 8 cores in this treatment group dropped after the alum dose, with more marked decreases in the high pH group. This was expected due to the acidic aluminum hydroxide floc forming from the alum reacting with water.
- In the alum treated, high pH group, the most substantial drop in pH was observed in anaerobic conditions. This demonstrates the importance of properly applying alum with a buffer and monitoring pH to avoid impacts on aquatic biota.
- The temperature of the overlying core water during incubation (averaging 19.4 degrees Celsius (°C) at hour 185) was slightly lower than that of the lake at a depth of ~5.0 meters (20.5 degrees Celsius (°C).

Results-TP and Orthophosphate NOT TREATED

- In the experimental groups not treated with alum, the concentrations of TP and orthophosphate were lower in aerobic conditions than in anaerobic conditions.
- TP decreased and orthophosphate increased, over time, in the anaerobic, neutral pH group, but both parameters increased in the anaerobic, high pH group.

Results-TP and Orthophosphate

- In all alum dosed cores, at the first sampling event post-treatment, concentrations were less than the detection limits, (5.0 µg/L) in 5 of 8 cores, and (3.0 µg/L) 8 of 8 cores, for TP and orthophosphate, respectively.

- In all alum dosed cores, following the initial decline in TP and orthophosphate, concentrations increased slightly through the end of the study. Despite this, TP remained low, with an HR 185 average of 6.9 µg P/L for the aerobic neutral pH group, 13.2 µg P/L for the aerobic high pH group, 13.5 µg P/L for the anaerobic neutral pH group, and 16.7 µg P/L for the anaerobic high pH group.

- In all alum dosed cores, orthophosphate remained low (5 of 8 cores<detection limit at hour 185). Core 15, in the anaerobic, high pH group, core 14, in the aerobic, high pH group, and core 12 in the anaerobic, neutral pH group still had detectible concentrations.

Results-TP Release Rate

Lake Campbell sediments were collected (16 cores) and incubated under various environmental conditions and half were dosed with ALUM.

	Phosphorus Release Rate (Untreated)	Phosphorus Release Rate (Treated)	Release Reduction (%)
Aerated + Neutral pH	**<0**	***<0***	**--**
Low Oxygen + Neutral pH	**0.9 to 1.7**	***<0 to 0.3***	***~90%***
Aerated + High pH	**<0 to 12.9**	***<0 to 0.1***	***~99%***
Low Oxygen + High pH	**1.5 to 4.7**	***<0 to 0.4***	***~94%***

Rate measured in $mg/m^2/day$
Total phosphorus released over 168 hours.

Alum dosed (left) and untreated (right) cores in low oxygen + high pH conditions.

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Conclusions and Recommendations

- Phosphorus concentrations and release rates generally increased under anaerobic conditions and were further elevated in anaerobic conditions with a higher pH (pH 8.5).
- The alum treatment substantially decreased TP and orthophosphate concentration and flux rate.
- Sodium aluminate was used as a pH buffer, but treated groups still experienced a temporary decrease in pH, with more impact on the high pH group.
- If Lake Campbell is treated with alum, the use of a buffer is necessary, and pH should be monitored continuously to avoid ecologically impactful declines in pH.
- During the summer, we expect the sediment of Lake Campbell to be exposed to elevated pH and low oxygen levels. The lake is expected to undergo wind-induced mixing such that the oxygen levels at the sediment-water interface may increase during those events. This study captured and compared Lake Campbell's dynamic summer conditions (aerobic, anaerobic, and neutral and high pH).

Conclusions and Recommendations

- The 2024 LCMP estimated the internal loading to be at least 208 kg per year on average or at least 0.75 mg/m^2/day.

- In this study, the phosphorus release rate ranged from 0.9 to 12.9 mg/m^2/day.
  - These data suggest that the total phosphorus mass released from the sediments in Lake Campbell likely exceeds the minimum estimate of 208 kg per year.

- In agreement with the LCMP, this study confirms that there is substantial release of phosphorus from the sediments during the summer and likely throughout the year during low oxygen and/or elevated pH conditions.

- This study confirms that the internal release rate is a major source of phosphorus to Lake Campbell and that alum would be an effective strategy to reduce the sediment release rate, the lake water phosphorus concentration, and, ultimately, the algae biomass in the lake.