Lake Quamichan SOD Summary Report

PREPARED FOR: Shaun Chadburne (Cowichan Municipal District)

PREPARED BY: Paul Gantzer

DATE: May 11, 2024

The following report summarizes the *in-situ* SOD chamber work performed by Gantzer Water, LLC (GW) on Quamichan Lake for the Cowichan Municipal District on April 16 – 17, 2024.

Background

Thermal stratification of eutrophic water-supply reservoirs often accompanies degraded water quality, such as hypolimnetic anoxia. As oxygen demand in the bottom waters exceeds available oxygen stores, anoxia prevails, which in turn can lead to mobilization of nutrients and soluble metals from the sediment to the overlying water column. The density gradient that exists between the epilimnion and hypolimnion dramatically inhibits the oxygen transfer from the atmospheric re-aerated epilimnion to the hypolimnion. Aeration and/or oxygenation systems are designed to supplement the finite oxygen stored in the hypolimnion that is depleted from excessive oxygen demands. Adequate sizing and design criteria depend on understanding the oxygen depleting processes and rates that affect the overall oxygen demand.

Studies have shown that the net hypolimnetic oxygen demand (HOD) observed during stratification is primarily driven by sediment oxygen demand (SOD), with a small water column (WOD) contribution. One method of aeration/oxygenation design is to measure SOD directly and size the hypolimnetic oxygenation systems based on the observed SOD rates during testing. SOD can be measured using cores taken to a lab and incubated or can be measured using *in-situ* SOD chambers. The work performed by GW used the *in-situ* SOD chamber method.

1. Reservoir Sampling and Analysis

Adequate aeration/oxygenation sizing and design criteria depends on understanding the oxygen depleting processes and rates that affect the overall hypolimnion oxygen demand. *In-Situ* sediment oxygen demand (SOD) measurements (Murphy and Hicks, 1980) were conducted to identify the oxygen demands to support the design of an aeration/oxygen maintenance strategy in Quincy Reservoir.

Gantzer Water, LLC works with the same equipment and technology developed by the USEPA, except for upgrading the sensor technology to use fluorescent DO probes that are significantly more stable than the historically used Clark cell probes. Additionally, GW has improved deployment standards that have eliminated the need and use of diver assisted chamber placement. Another upgrade implemented by Gantzer is a long-term (overnight) deployment. This extended deployment provides a more accurate measure and analysis of the deployment for both SOD and WOD analysis.

1.1 *In-Situ* SOD Sampling Materials and Methods

The *in-situ* SOD chambers deployed in Quamichan Lake were the same chambers and components used by Murphy and Hicks (1985) (Figure 1) except for the DO probes, which were InSite IG optical DO probes connected to a GWR Master data logger to record DO readings on a five-minute interval. SOD chambers were also mounted on a 4-ft diameter disc to improve sealing at the sediment water interface (Figure 2).

SOD chambers are designed to circulate the water within the chamber to maximize oxygen uptake rates by sediments without re-suspending sediment particulates. Chambers in contact with the sediments are deployed in triplicate. An oxygen probe is placed in the chamber to track changes in oxygen content over time. A fourth chamber used to determine water column oxygen demand (WOD) is deployed with a sealed bottom that is filled with the same bottom water used to flush and incubate the triplicate SOD chambers. This allows for the extraction of the water column contribution to the observed oxygen depletion rate, resulting in a true measure of SOD.

All data were plotted in Excel and the liner portion of the data set with the highest coefficient of determination (R^2) was used to determine the slope. Once the slope for each data set was determined, the SOD rates were calculated using the observed rates and the known volume and surface area of the chamber (Equations 1).

$$SOD = b\frac{V}{A}0.001 \quad \text{Eq 1}$$

where *SOD* is the sediment oxygen demand in g/m^2 •day, *b* is the slope of the SOD curve in mg/L•d, *V* is the volume of the chamber, *A* is the total surface area of the chamber in m^2, and 0.001 is a conversion for mg to g. The chamber volume was 64.86 L and the surface area was 0.27 m^2.

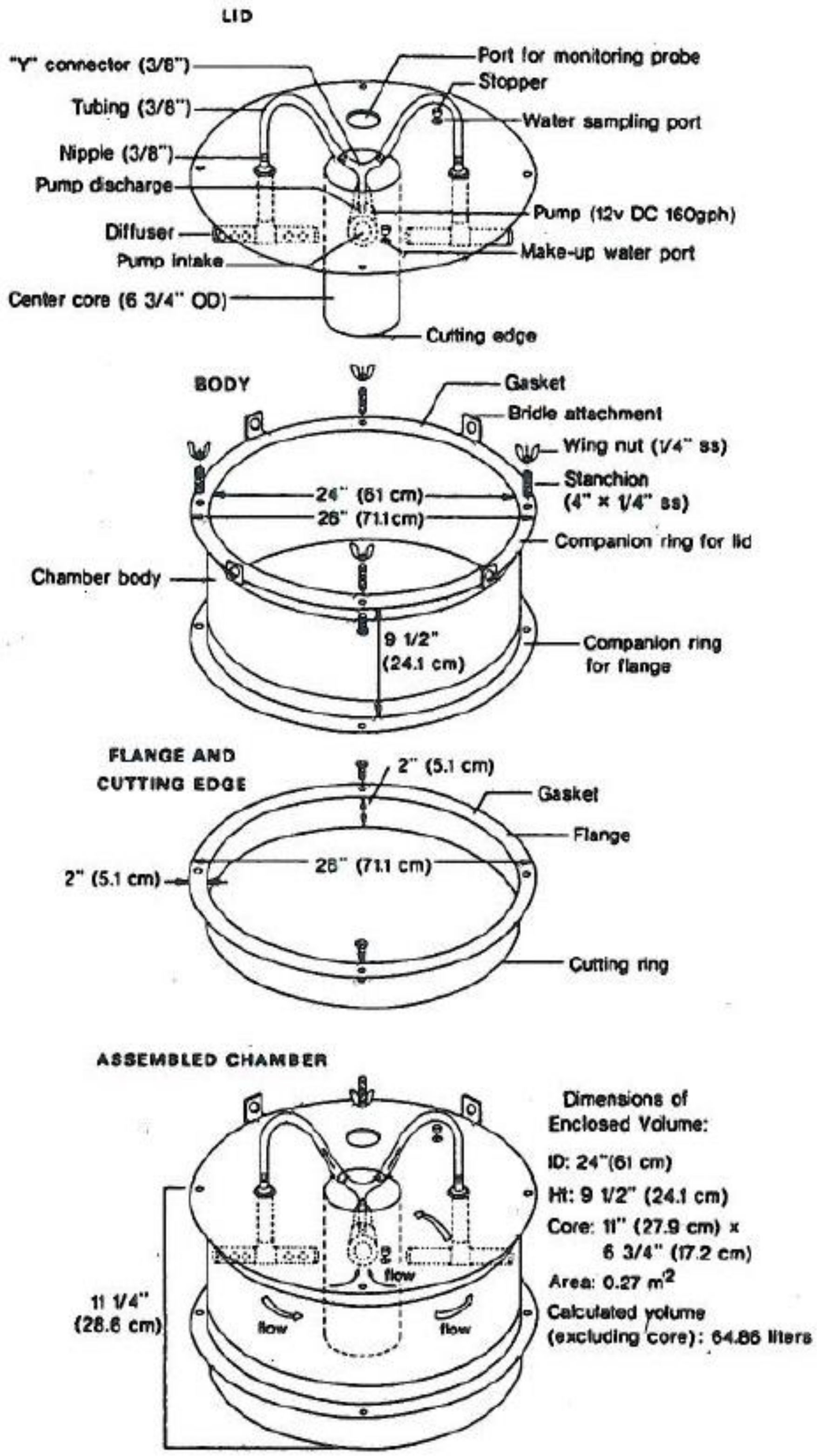


Figure 1: Schematic of in-situ SOD chamber.

Figure 2: Photo SOD equipment deployed. Small white buoys indicate chamber locations and large orange buoy is the data logger/telemetry hub.

1.2 *In-Situ* SOD Sampling Field Work

Water column profiles were collected at the SOD sample site using a Seabird Electronics SBE 19PlusV2 high resolution profiler (CTD). The CTD collects water column temperature, conductivity, DO and pressure (depth) at a 4 Hz rate, resulting in centimeter resolution discrete depth profile. Water column profiles were used to determine temperature and DO conditions to ensure bottom waters were oxic prior to the start of SOD measurements. Based on the discrete depth profiles, Quamichan Lake was thermally stratified and had a 1.5° C temperature difference between top and bottom. The discrete depth profile resembled a typical stratified water body with a decrease in DO at the bottom. DO was observed to be near 12.0 mg/L at the surface down to 5-meter depth and then decreasing to 3.5 mg/L at the bottom (Figure 3).

SOD chambers were deployed in triplicate and programed to circulate water through them for 60 minutes before being placed in incubation mode. The chambers were configured to withdraw water from two meters above the chamber, to make sure the chambers were flushed with water undisturbed by the sediments and having higher DO than during deployment. All chambers were placed into incubation mode by isolating the water in the chamber and then circulating the chamber for the duration of the deployment. Dissolved oxygen in the chambers was observed to be around 5.5 mg/L at the onset of incubation. Chambers were left in place to incubate overnight. Data from the chambers were plotted and a trend line analysis was used to identify the slope through the data and the corresponding coefficient of determination (R^2).

1.3 SOD Results

Only data from SOD chamber 3 and the WOD chamber are summarized in Table 1. Chamber 2 had malfunctioned on the data logger and kept switching off. Despite checking, and re-starting the data logger, it was determined that it could not be field repaired. Despite having a successful deployment of chamber 1, the discharge tubing to circulate the chamber disconnected from the chamber. This is evident in the data not changing during the deployment period. Chamber 3 was deployed successfully and had a very reliable data set.

The data collected was typical of SOD testing for lakes with soft flocculant sediment. This is evident from the data not being observed to be perfectly linear, a slight curve in the data. The part of the data that was most linear following incubation was used to determine the SOD rates and is noted in the data presented below. In general, overnight deployments result in R^2 values of 0.99 or greater, which was only observed in one chamber. For Quamichan Lake, R^2 values were observed to be 0.998. All data are presented with each data set graph (Figure 4) and in summary Table 1. A measurable water column demand was observed, which was subtracted from the measured SOD rates to determine the true SOD rate.

Final analysis and subsequent reporting used chamber 3, which resulted in a calculated SOD rate of 0.977 g/m^2 day at 11°C. The rate is shown at *in-situ* temperature as well as corrected to 15 and 20°C. 20 °C was calculated based on estimates of bottom conditions from the July 2018 data set. The resulting oxygen demand at 20°C was calculated to be 1.48 g/m^2-day, and when applied to the surface area below 5.5 m (17 ft) depth (~462 acres) this translates to an oxygen demand just over 2,500 kg/d.

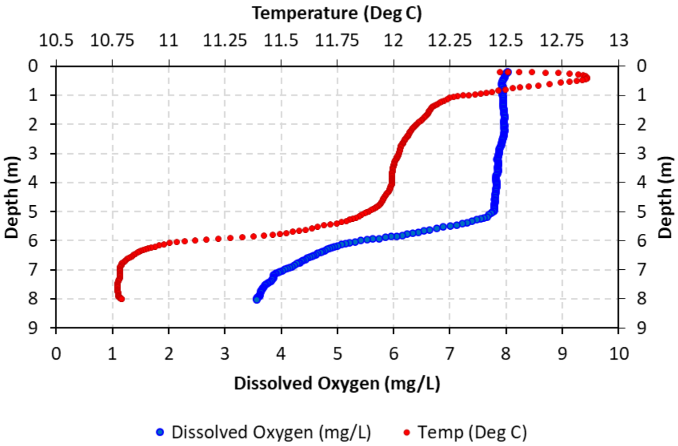
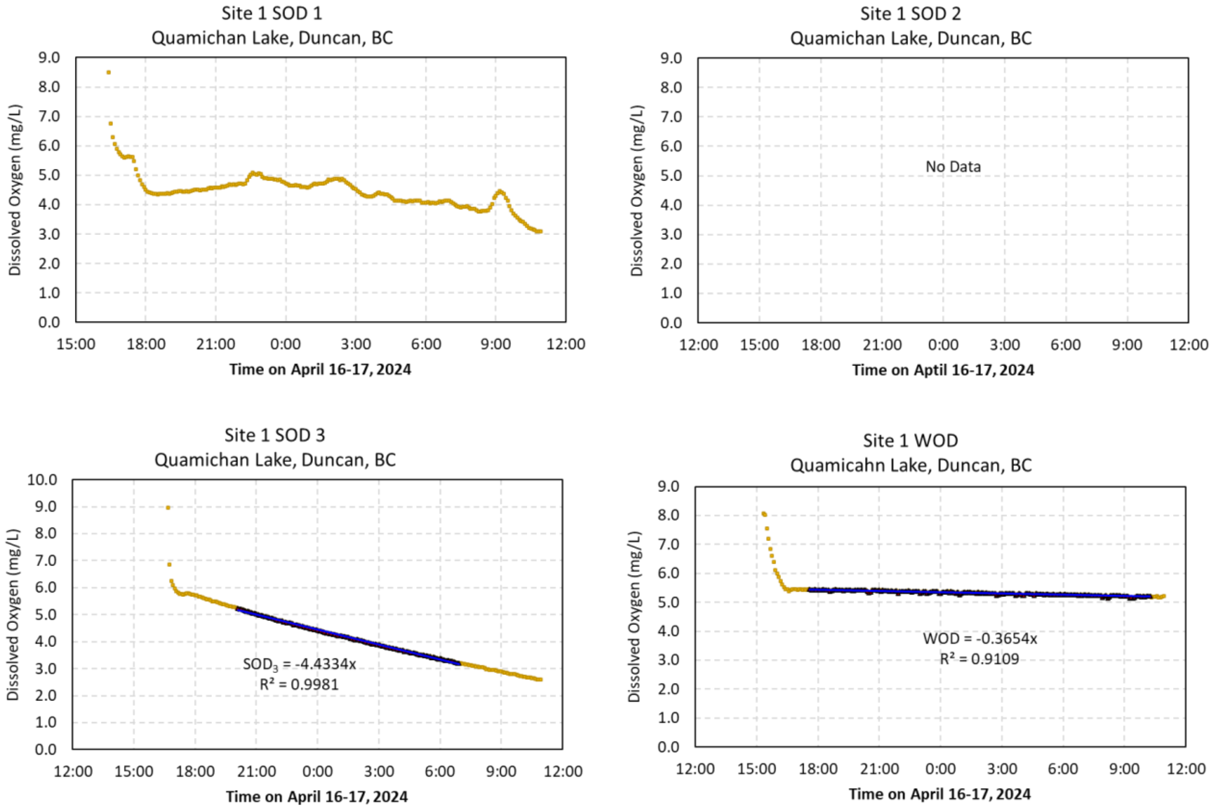


Figure 3: Water column profile data collected on Quamichan Lake on November 28, 2023, showing dissolved oxygen and temperature conditions throughout the water column at the SOD site location.



Site 1 SOD 1
Quamichan Lake, Duncan, BC

Site 1 SOD 2
Quamichan Lake, Duncan, BC

Site 1 SOD 3
Quamichan Lake, Duncan, BC

Site 1 WOD
Quamicahn Lake, Duncan, BC

Figure 4: Dissolved oxygen data collected from chambers deployment in Quamichan Lake.

Table 1: Sediment Oxygen Demand (SOD) rates, replicas and means for Quamichan Lake.

Location	Sample	Observed Rate of Change (mg/L day)	R^2	SOD (g/m^2 day)	Average (g/m^2 day)	Std Dev	Coeficient of Variation (%)	Water Temp (°C)	SOD @ 15° C (g/m^2 day)	SOD @ 20° C (g/m^2 day)
Quamichan Lake	[1]SOD_1				0.977			11.0	1.17	1.48
	[2]SOD_2									
	SOD_3	4.434	0.998	1.065						
	WOD	0.365	0.911	0.088						

[1] *SOD_1 chamber integrity was observed to be compromised by the discharge tubing that disconnected from the chamber.*

[2] *SOD_2 data logger was observed to have failed.*

1.4 Oxygen Demand Requirements and OST

2018 temperature data was used to identify the hypolimnion boundary by drawing a straight line through the lower temperature and thermocline region. The intersection was used to mark the hypolimnion boundary. In June 2018, the hypolimnion boundary was observed to be approximately 3.5 meters deep and was observed to progress deeper to approximately 5.4 meters deep in July (Figure 5). The volume table (Table 2) created from the topographical map indicates the surface area at 5.4 m depth is approximately 426 acres. Applying the 1.48 g/m^{2}day to the area corresponding to the 17 – 18-ft (5.4 m) depth contour (426 acres), the predicted oxygen demand is 2,500 kg/d as previously stated.

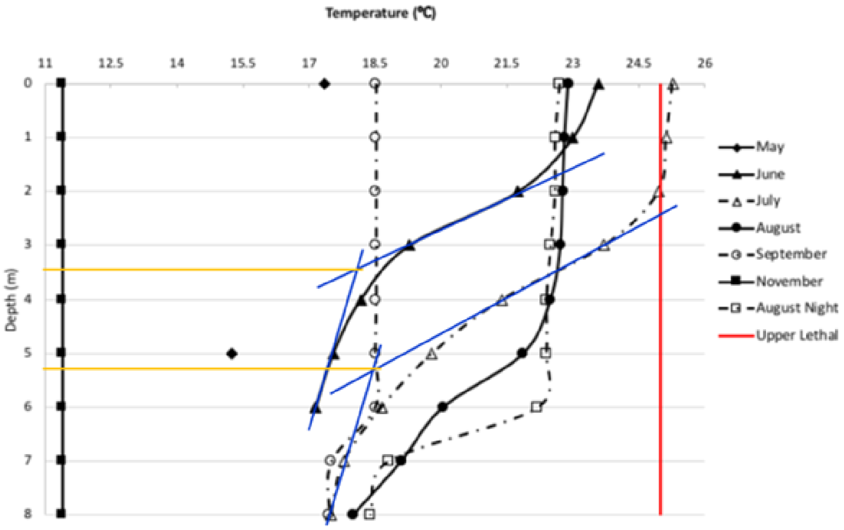


Figure 5: 2018 Temperature data from "Quam L BCIT Thesis - Moore 2019.pdf", showing (blue) lines through the data to determine the hypolimnion boundary (gold lines).

Table 2: Area versus depth table

AREA (Acres)	Depth (ft)	Depth (m)
746.3	0.2	0.1
729.1	0.7	0.2
719.5	1.7	0.5
712.4	2.7	0.8
705.2	3.7	1.1
698.7	4.7	1.4
691.6	5.7	1.7
682.8	6.7	2.1
672.4	7.7	2.4
658.2	8.7	2.7
641.3	9.7	3.0

621.2	10.7	3.3
599.3	11.7	3.6
576.6	12.7	3.9
550.9	13.7	4.2
523.7	14.7	4.5
492.2	15.7	4.8
458.9	16.7	5.1
426.1	**17.7**	**5.4**
392.2	18.7	5.7
355.5	19.7	6.0
318.0	20.7	6.3
285.5	21.7	6.6
250.9	22.7	6.9
213.4	23.7	7.2
165.1	24.7	7.5
106.0	25.7	7.8
33.0	26.7	8.1
0.0	27.7	8.5

Therefore, to conservatively add this amount of oxygen, there are two potential configurations to consider, four large (D-48) OST units (10’ x 10’ x 15’) or five slightly smaller (D-36) OST units (8’ x 8’ x 12’). Both configurations would use the same oxygen supply; two AS-N industrial oxygen generators rated at 1,400 kg/d oxygen delivery capacity supplied with feed air from two 100 Hp compressors. Also, both configurations would require shallow water adapters on each discharge header to dilute the discharge concentration to prevent degassing of oxygen at each discharge location. The D-48 OST units would need a 1250-gpm (main) pump with a 300-gpm shallow water adapter pump. The D-36 OST units would require a 750-gpm (main) pump with a 500-gpm shallow water adapter pump. Figure 6 shows the hypolimnion boundary outlined in yellow overlaid on the topographical map and an example layout showing the five D-36 OST units.

This information is provided to start the discussion if installing OST is feasible.

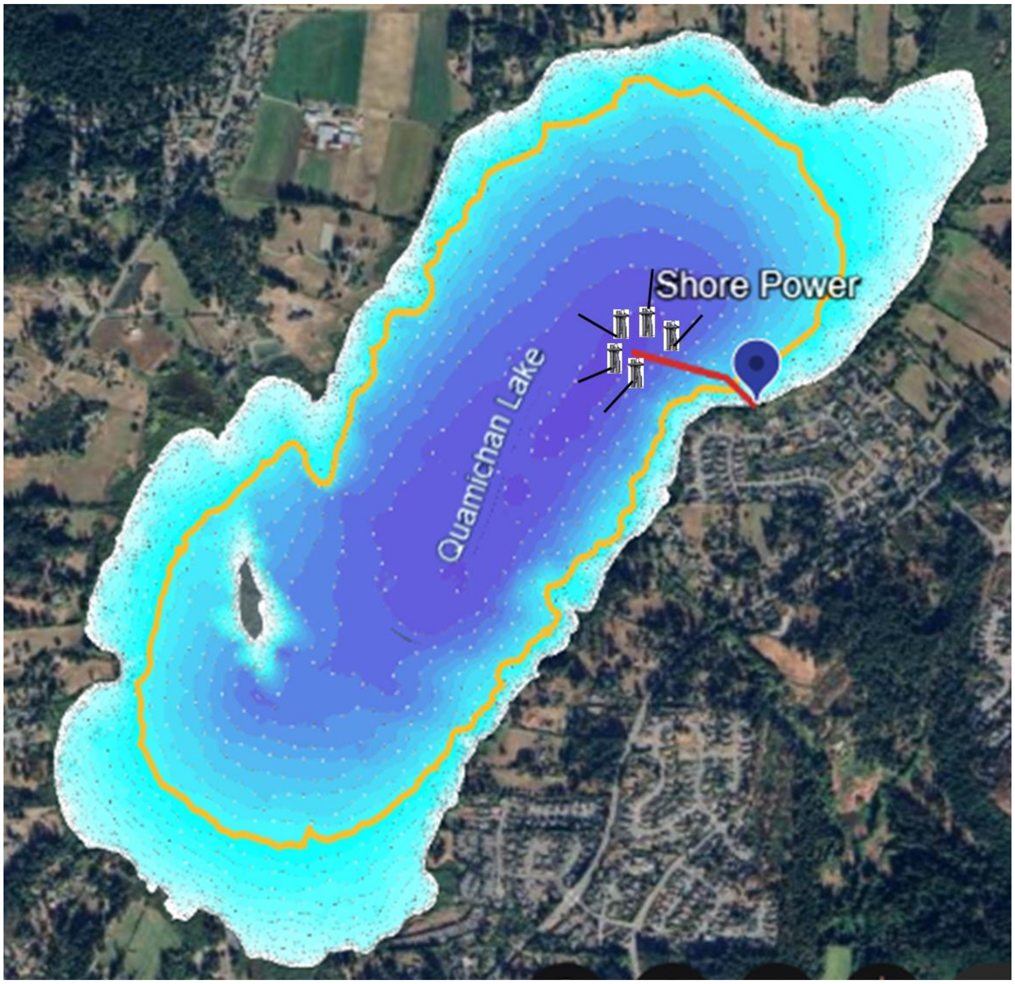


Figure 6: Topographical map showing the approximate hypolimnion boundary in yellow, which corresponds to 17 ft (5.4 m) depth, shore power location, ~1200 ft distance to the deep part of the lake, and an example layout of five D-36 OST units. Black lines on the OST units shows the example discharge piping alignment to each OST unit.

Thank you for the opportunity to work with Cowichan Municipal District on this project. Please contact me if you have any questions regarding this report.

Regards,

Paul A. Gantzer

References

Murphy, P.J., and D.B. Hicks 1985. In-situ Method for Measuring Sediment Oxygen Demand. “Sediment Oxygen Demand, Processes, Modeling, and Measurement”, Institute of Natural Resources, Athens, GA.

Sediment Phosphorus Speciation Results

Internal phosphorus (P) loading can represent a major driving force behind harmful algal blooms (HABs) within many lake systems. Understanding when, where, and how much internal P loading is occurring from the sediments is key to addressing water clarity and HAB issues long term. This information, paired with external P load estimates, provides the foundation for developing a P budget and water quality model that can be used to determine how restoration efforts will impact water quality.

The process of internal P re-cycling from lake sediments is complex and is influenced by many factors. These factors can include biological (e.g., bacterial activity, mineralization processes, and bioturbation), chemical (e.g., redox conditions, pH, iron, and nitrate availability), and physical factors such as resuspension and sediment mixing. Estimating the amount of internal P loading occurring per area was performed by collecting surficial sediments from the "active" P layer of sediment (typically the top 10 cm or 4 inches of sediment) and then determining the amount of P bound to different forms in sediment. This provides a direct estimate of P release under different conditions and the mass of P that has deposited over time. For example, the amount of iron bound P can provide estimates of P release once oxygen has been depleted.

Sediment Phosphorus Sampling Methods

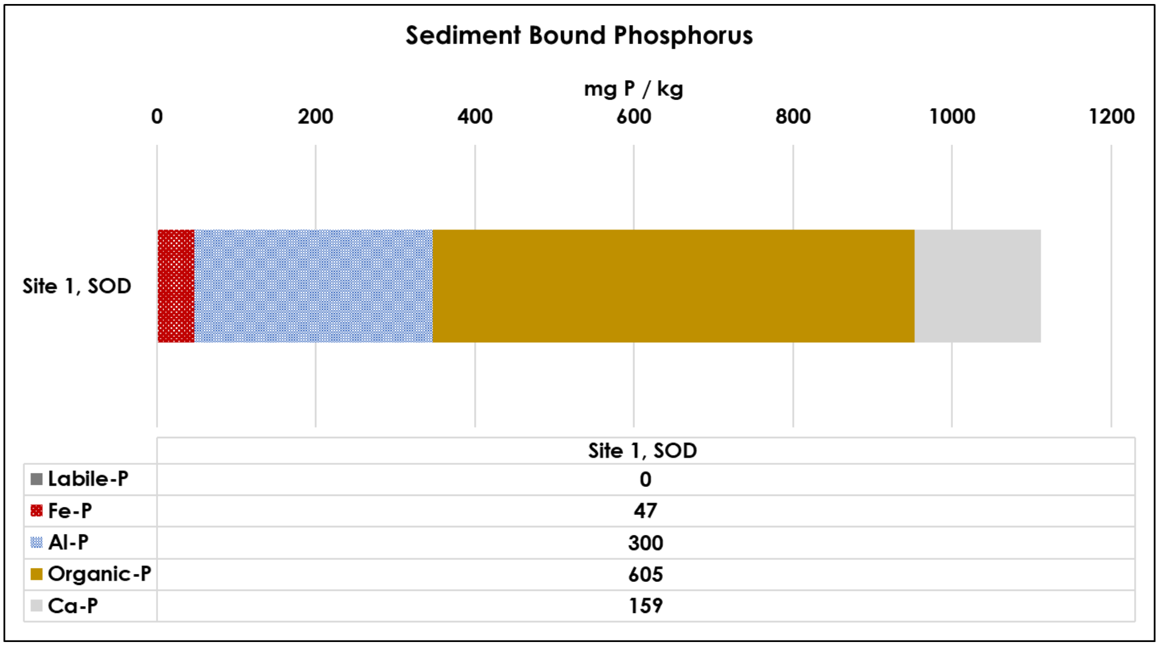
Surficial sediments were collected that represent the "active" sediment layer (top ~10 cm). The samples were sent the same day in a cooler to an EPA-certified analytical lab for analysis.

Sediment Quality Results

The solids content was measured to be 6.6%, meaning that 93.4% of the sediment pulled from the lake was water.

Total phosphorus (TP) was measured to be 1111 mg/kg. Values >500 mg/kg are considered high, but the availability of that P cannot be known from total P concentrations. Iron-bound P, the dominant available fraction, is considered elevated when >50 mg/kg and is very high when >500 mg/kg. Values for Quamichan Lake were measure just below the threshold of being high with 47.2 mg/kg Fe-P. This means that there is not a significant amount of P in the sediment that can be acted upon if low oxygen events occur. The amount released to the lake for plant and algae growth can be estimated by using the area of anoxia and the corresponding hypolimnetic volume.

Organic and calcium-bound P can represent sources of internal P cycling in a lake. Organically-bound P is released during bacterial decomposition, while calcium-bound P is released during low pH events. For Quamichan Lake, the organically bound P was measured to be high and appears to be a significant contributor of P to the water column compared to the iron bound fraction. The decomposition of organic matter could pose a source of P release. Calcium-bound P was not observed to be elevated and represented the smallest fraction. Some P release can be expected at times (pH < 5 or pH > 8); however, this fraction is likely a P sink rather than a source. In general, calcium will bind to P between pH 5-8. Aluminum-bound P cannot dissociate unless subjected to extremely low pH events (<2) and therefore is not a fraction of concern.



	Site 1, SOD
Labile-P	0
Fe-P	47
Al-P	300
Organic-P	605
Ca-P	159

Figure 1: Sediment results for bound P (mg P/kg) for Labile or loosely bound phosphorus (Labile-P), Ironbound phosphorus (Fe-P), Aluminum bound P (Al-P), Organically bound phosphorus (Organic-P), and Calcium bound phosphorus (Ca-P).

The total mass of available P that could be potentially acted upon can be calculated by taking the percent solids in the upper 10 cm (4 inches) of sediment times a specific gravity (typically 1.2), times the fraction of interest, *i.e.* $6.6 \times 1.2 \times 1111 \times (47.2/1111)/1000 = 0.4$. Table 2 below provides a summary of calculations for the Iron-bound P concentrations, the fraction that will become available for uptake by algae under low oxygen conditions.

In addition to measuring phosphorus speciation in the sediment, an analysis was conducted to measure iron (Fe) content. These results are then used in comparison to total phosphorus data to determine efficacy of internal P control using an oxygen management strategy. Per Jensen et al., 1992 it was identified that a Fe:P ratio of 15 was the threshold of success to control internal P loading via an oxygenation strategy. Quamichan Lake Fe:P ratio was measured to be 18 (Table 3), indicating that an oxygenation strategy for Quamichan Lake is on the threshold of successfully being able to control internal P cycling. With the Fe-bound fraction being so low and the Fe:P ratio being just above 15, there is a possibility that an additional P-binding strategy may be necessary.

Table 1: Example calculations of phosphorus release from the Iron-bound fraction under low oxygen conditions.

Location	Solids	Total Phosphorus	Iron Bound Phosphorus	Mass of P to be Treated
	%	mg/kg dry weight	mg/kg dry weight	g/m2
Site 1	6.6	1111	47.2	0.4

Table 2: Summary of iron (Fe) and phosphorus (P) ratios for sediment samples collected in Swartswood Lake. Note: depths are approximate.

Location	Iron (Fe) (mg/kg)	Total P (mg/kg)	Fe:P
Site 1	20,500	1,111	18