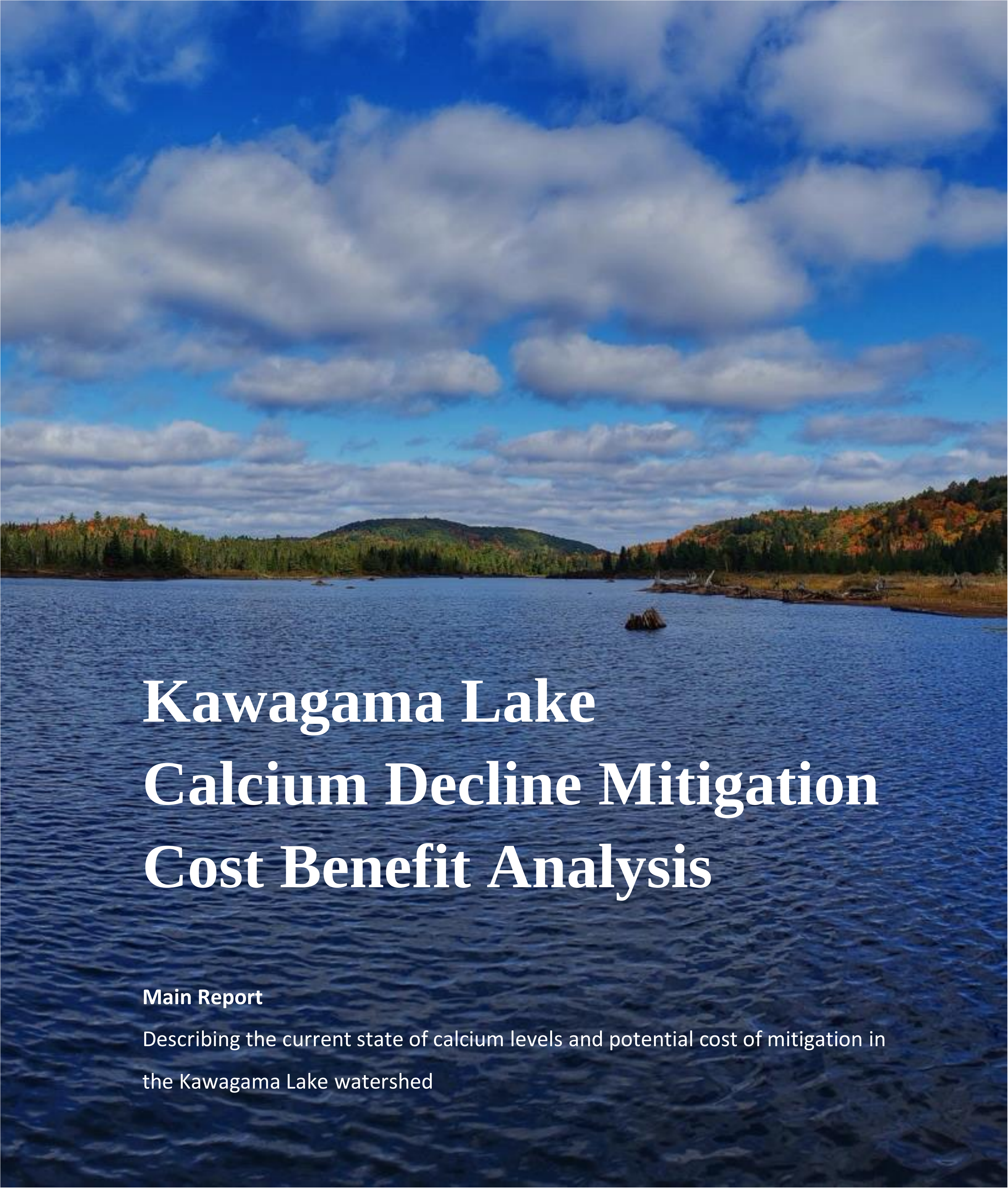

Kawagama Lake Calcium Decline Mitigation Cost Benefit Analysis

Main Report

Describing the current state of calcium levels and potential cost of mitigation in the Kawagama Lake watershed

U-LINKS CENTRE FOR COMMUNITY-BASED RESEARCH

KLCA Kawagama Lake Cottagers' Association

TRENT UNIVERSITY

Kawagama Lake Calcium Decline Mitigation Cost Benefit Analysis

Main Report

Prepared by Samantha Dunlop for the Kawagama Lake Cottagers Association (KLCA) as part of the ERSC 3840 Winter 2020 course at Trent University.

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All photographs of Kawagama Lake were used with permission from Adam Pifko and Alice Brown-Dussault.

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Overview

Calcium is a vital nutrient for plant growth and ecosystem function, both aquatic and terrestrial. The decline of calcium in lakes and soils is occurring in watersheds across the boreal shield, as a result of acid deposition and land use practices such as silviculture. The decline of calcium is concerning because it can cause major changes to food webs and ecosystem functioning. Nutrient contents in catchment soils are connected to the levels seen in lakes through interactions between soil surfaces and surface waters in the riparian zones of watersheds, as well as the biological, geological, and meteorological processes occurring throughout the watershed.

In response to the concerns over calcium decline expressed by members of the KLCA, a literature review was conducted in 2019 to raise awareness for the mechanisms, consequences, and mitigation options of calcium decline. Building on that momentum, this study seeks to assess the current state of calcium pools in the Kawagama Lake watershed and make recommendations for mitigation efforts.

1. Introduction to Calcium Decline

Calcium (Ca^{2+}) is an important nutrient, essential for plant growth and ecosystem health. Calcium decline can result in negative changes to ecosystem structure and function (Chan et al., 2019). Most literature and research has focused on lake chemistry, but little information is available concerning the state of soils in the Kawagama Lake watershed. The previous study from 2019 covered Ca^{2+} decline, the impacts of such, and potential mitigation efforts for the Kawagama Lake watershed (Chan et al., 2019). This study aims to assess the soil characteristics of the Kawagama Lake watershed, with specific focus on the state of Ca^{2+} decline in this region, as well as whether mitigation methods are needed and what the potential cost could be. The information provided by this report is intended to guide future decisions regarding mitigation and further research.

1.1 SOIL-TO-LAKE LINKAGES

Soils and lakes of a catchment basin, or watershed, are connected through their biota, their geology, and meteorological activities (Likens and Bormann, 1974). Different pathways transfer energy and materials, such as nutrients, throughout ecosystems via animals and their activities, movement of dissolved and particulate substances, movement of gases, and precipitation (Likens and Bormann, 1974).

Nutrient concentrations in soil are influenced by absorption, atmospheric deposition, erosion, fixation, leaching, transformation, and plant uptake (Luke et al., 2007). For example, sulphate (SO_4^{2-}) concentrations decrease as they are leached from the soils, causing the concentration of Ca^{2+} and magnesium (Mg^{2+}) to decrease too (Houle et al., 2006). Calcium, Mg^{2+}, and potassium (K^+) are common nutrients (exchangeable base cations) found in catchment soils and surface waters (Houle et al., 2006).

The riparian zone along the edges of waterbodies is the area that connects the terrestrial forest ecosystem to the aquatic ecosystem of the lake or river. In this zone, the interactions between vegetation, soils, and runoff waters influences the chemistry and hydrology of the watershed (Luke et al., 2007). Water chemistry is impacted by the potential oxidization-reduction reactions that occur along the runoff path (Luke et al., 2007). For example, reduction reactions can release phosphorous (P) from Ca^{2+} and Mg^{2+} compounds (Luke et al., 2007). High pH levels impact the solubility and concentration of elements such as Ca^{2+}, Mg^{2+}, and K^+ (Luke et al., 2007). When pH is neutral to basic, P tends to bind and form insoluble compounds, such as calcium phosphates (Luke et al., 2007). The retention of P is important because of the way it impacts Ca^{2+} availability (Luke et al., 2007).

In addition to their role as a direct link between soils and lakes, riparian zones act as a buffer zone between the two (Luke et al., 2007). Buffer zones are important to ecosystems because they help to maintain a state of equilibrium. Base cations such as Ca^{2+}, Mg^{2+}, and K^+, and various others, aid in buffering pH levels in the soils and waters of aquatic ecosystems, helping prevent further acidification (Lucas et al., 2011). A landscape with little human influence is able to buffer nutrient losses from terrestrial to aquatic ecosystems (Likens and Bormann, 1974). Soils with higher organic matter content have a greater capacity to hold moisture and prevent sediment loading into streams (Luke et al., 2007). Low buffering capacity against acidic deposition in surface waters is directly related to the size of base cation reservoirs in forest soils (Houle et al., 2006).

Sources of base cation soils include atmospheric deposition and weathering (Ouimet and Duchesne, 2005). Base cations can be deposited to watersheds through atmospheric transport and deposition of particles such as aluminum (Al), Ca^{2+}, Mg^{2+}, and K^{+}, and soidium (Na) (Watmough et al., 2014). Weathering of minerals in soils is also a process that releases base cations into catchment soils (Koseva, 2010; Ouimet and Duchesne, 2005).

While weathering and atmospheric deposition provide base cations for watershed soils, these processes cannot always balance the loss of base cations occurring through forestry harvesting, nutrient leaching, nitrogen (N) fertilizer application, and acidic sulphur (S) deposition (Houle et al., 2006; Jeziorski et al., 2008). This decrease in base cation availibilty has resulted in an increase in soil acidity (Houle et al., 2006; Lucas et al., 2005; Ouimet and Duchesne, 2005). Studies have shown that soils in Ontario's boreal region have acidified (Aherne et al., 2003; Jeziorski et al., 2008; Miller and Watmough, 2009; Watmough, et al., 2005).

There are a number of mitigation options for catchment soils. A study by McLaughlin (2014) suggests that by examining the Ca^{2+} levels in forest stands and catchments, sensitive areas can be identified, which is useful for conducting forest management planning at the landscape scale. Application of lime and wood ash additions promotes tree health and growth (Reid and Watmough, 2014). Articles argue in favour of liming over wood ash application due to cost and access regulations (Hannam et al., 2018; Homan et al., 2015).

1.2 REGIONAL CALCIUM LEVELS

The Kawagama Lake watershed is located near Dorset within Haliburton county, in south-central Ontario. In order to assess the state of Ca^{2+} in this watershed, we compared our data to that of another study which sampled soil at sites throughout central and southern and Ontario (McDonough, 2011). Our study location was in the Kawagama Lake watershed, with eight six on the north shores of Kawagama Lake and two sites on the north side of Bear Lake, which is just east of Kawagama (Figure 1, Appendix A).

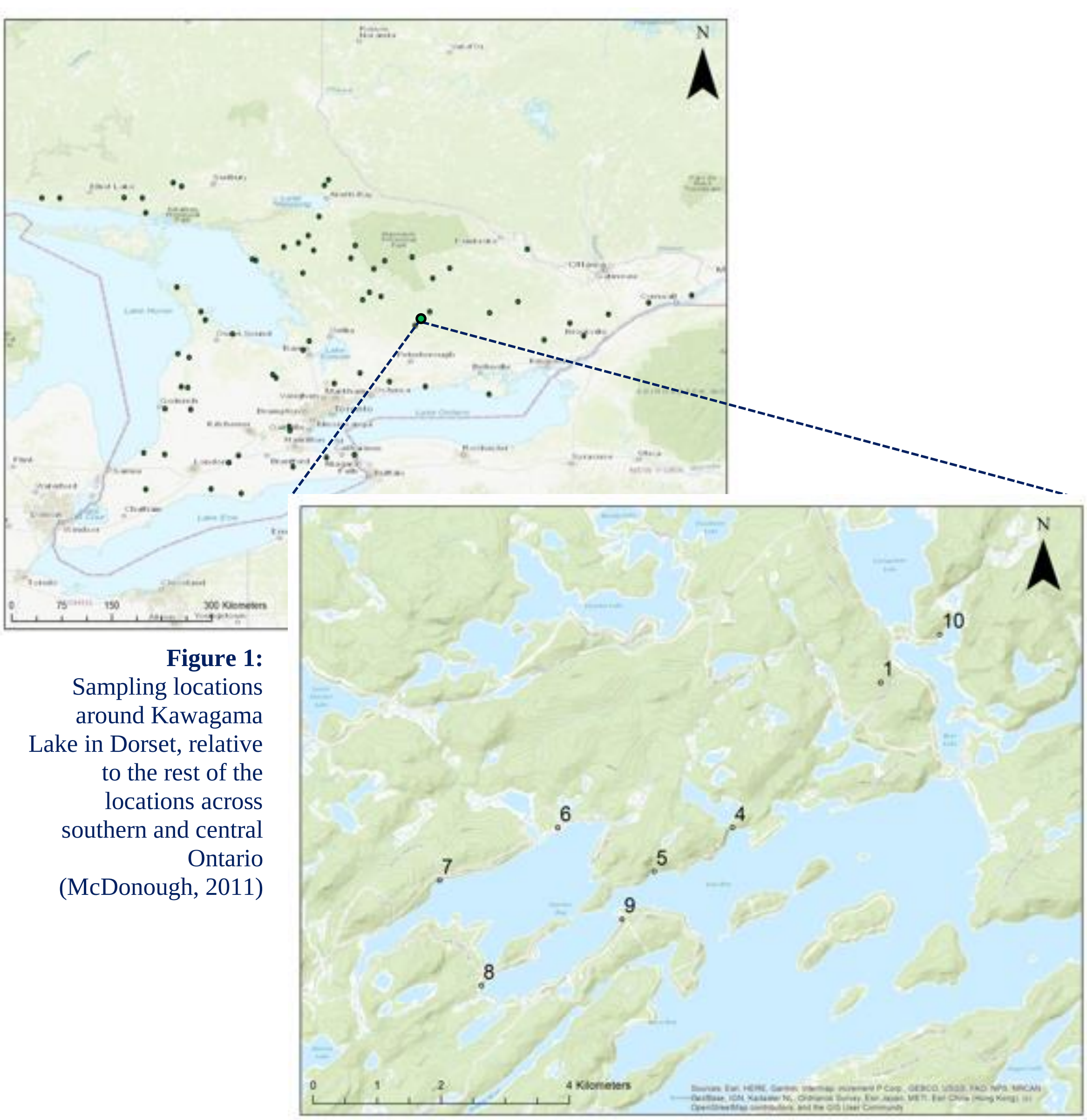

Figure 1: Sampling locations around Kawagama Lake in Dorset, relative to the rest of the locations across southern and central Ontario (McDonough, 2011)

The maps to the right indicate that the Kawagama Lake watershed is located in an area of low soil Ca^{2+} and Mg^{2+} concentrations (Figure 2).

Ca^{2+} levels are consistently low across the boreal shield region and down through Hastings to Peterborough county. Conversely, the easternmost arm of the province, as well as the corridor from the Bruce Peninsula to Niagara region are comparatively high in Ca^{2+}.

In contrast to the Ca^{2+} and Mg^{2+} levels, the K^{+} concentration is within the range of regional averages.

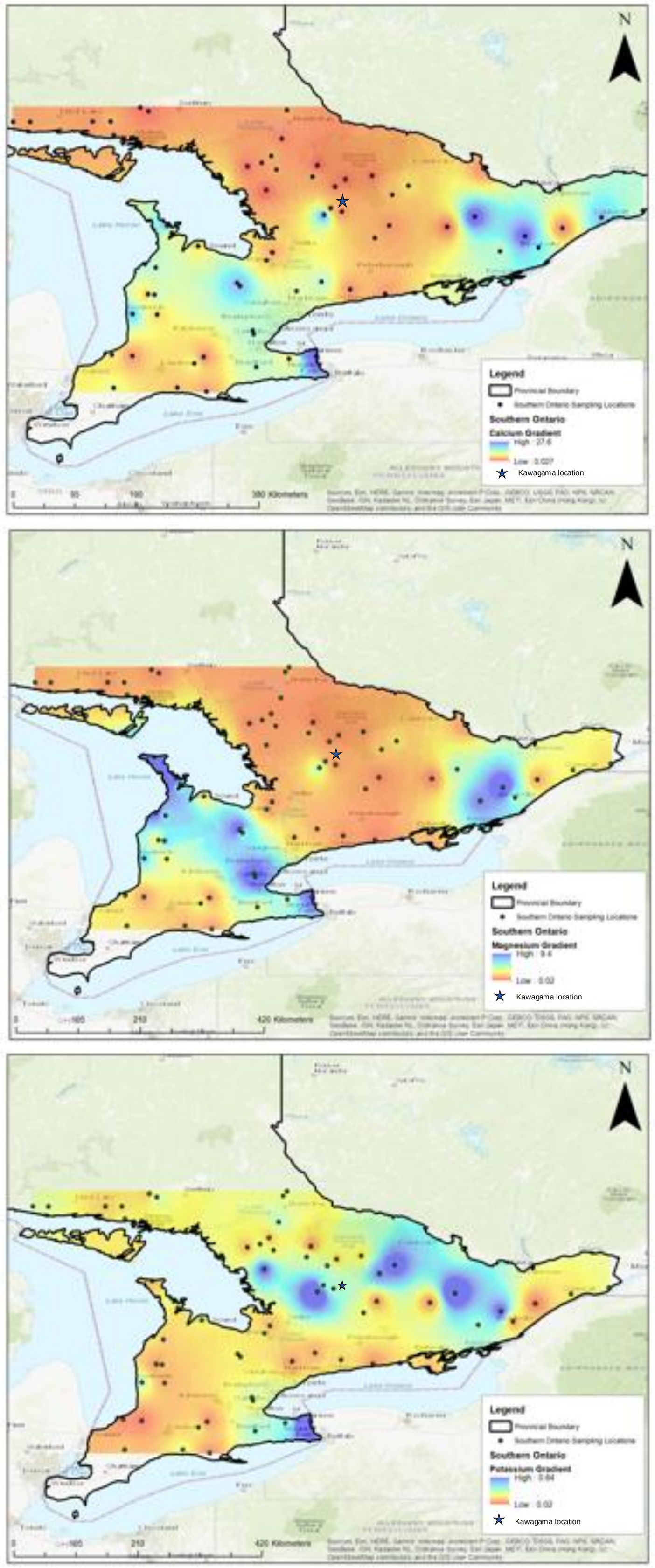

Figure 2: Soil calcium, foliar calcium, soil magnesium, and soil potassium concentration (meq/100g soil) gradients of southern and central Ontario (McDonough, 2011)

2. Assessing the State of Calcium in the Kawagama Lake Watershed

2.1 METHODOLOGY

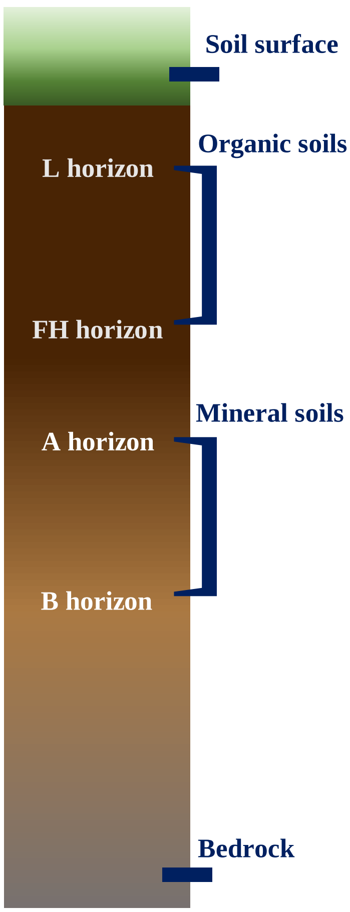

Figure 3: Diagram of a soil profile, indicating the horizons

Field Sampling

Soils and lakes of watersheds are hydrologically and chemically connected, so sampling and analysis of soil characteristics can help develop a better understanding of lake health.

Soil samples from the L, FH, A, and B horizons were collected. The L (litter) and FH (fibric and humus) horizons are organic soils, while the A and B horizons are upper and lower mineral soils, respectively (Figure 3).

Figure 2 indicates the eight sites travelled to in early October of 2019. The sampling sites for this study were located within the region of Crown Land surrounding Kawagama Lake in Dorset, Ontario.

The sites were travelled to by aluminium boat and then the study group hiked to the sample locations. Alice Brown-Dussault from Trent University was accompanied by Adam Pifko from the KLCA and Brendan Martin of U-links while collecting the samples. The samples were gathered by digging with a garden trowel.

Laboratory Analysis

The soil samples were sifted and ground before being analyzed for pH levels, exchangeable base cations, and organic matter content. Each of these indices are important abiotic (non-living) factors that influence the biological activity in the ecosystem. These soil properties were analyzed because they help describe the chemical composition of the watershed, as organic matter content relates to the binding of exchangeable base cations, while loss-on-ignition tests for moisture and is related to plant health.

The pH is a chemical factor describing the level of acidity. This was tested with a pH meter which has an electrode calibrated for measuring the acidity of the soil-and-water solution.

Exchangeable base cation measurements are chemical factors describing nutrient availability for plant uptake, which is related to plant health and growth. Soil solutions were diluted with ammonium chloride (NH_4Cl) and then the nutrient concentrations were measured using spectrometry.

Percent of organic matter in the soil is a biological factor assessed with loss-on-ignition testing. Soil sample weights were recorded before and after being heated in an oven and then in a furnace. The differences in weights were used to calculate the percent of organic matter present in the sample.

Data Analysis

The data produced in the laboratory testing was averaged for each of the soil horizons. Along with averages, standard deviations were calculated too (Appendix B). Averages are the sum of the values from a category divided by the total number of samples. Standard deviation is the amount of variation seen between samples.

The milliequivalents (meq) were calculated for the average concentrations of Ca^{2+}, Mg^{2+}, and K^{+}. Milliequivalents are a unit of measurement that describes concentrations to the thousandth chemical equivalent. This type of measurement is used to make comparisons between different elements and compounds that would otherwise be difficult to discern.

The Ca^{2+} pool was calculated by averaging the Ca^{2+} concentrations from the A and B horizons. This average was then multiplied by the estimated mineral soils mass (600 kg/m^2).

2.2 RESULTS & ANALYSIS

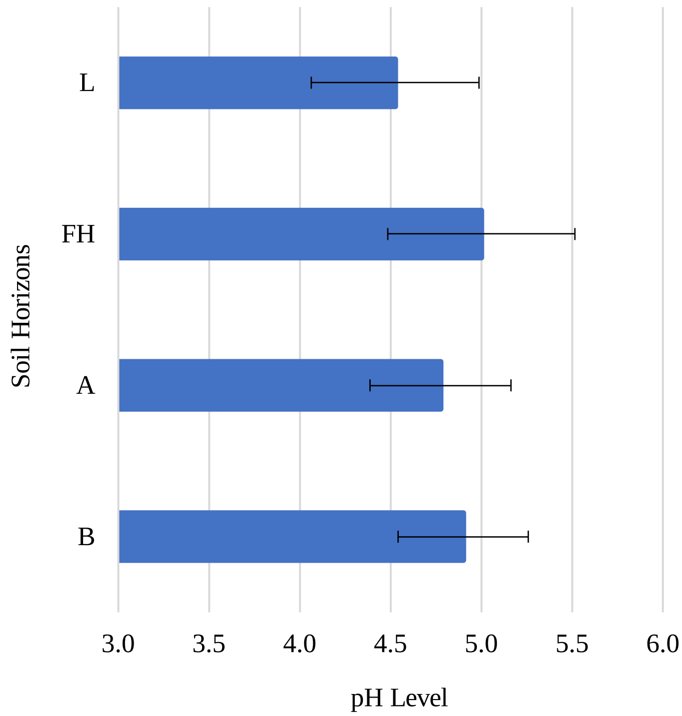

Figure 4: Average pH level at each soil horizon

There was very little variation in pH through all of the soil horizons sampled at the sites in the Kawagama Lake watershed. The lowest average pH was 4.5 and the highest was 5. Since the soil pH was less than 7, the samples were overall acidic. The increase from the L to FH horizons was greater than the following decrease to the mineral soil horizons. The pH increased with sampling depth.

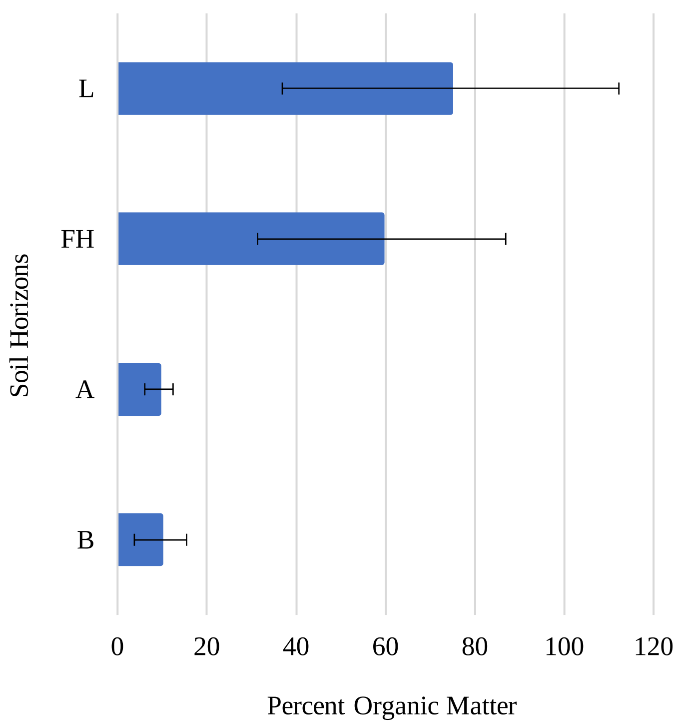

Figure 5: Average percent organic matter at each soil horizon

The percentage of organic matter in soil samples around Kawagama Lake decreased as sampling depth increased. The decreasing trend is steepest from the L horizon to the A horizon, from 74.6% to 9.3%, respectively. In contrast, there was little difference between the A and B horizons, at 9.3% and 9.6%, respectively.

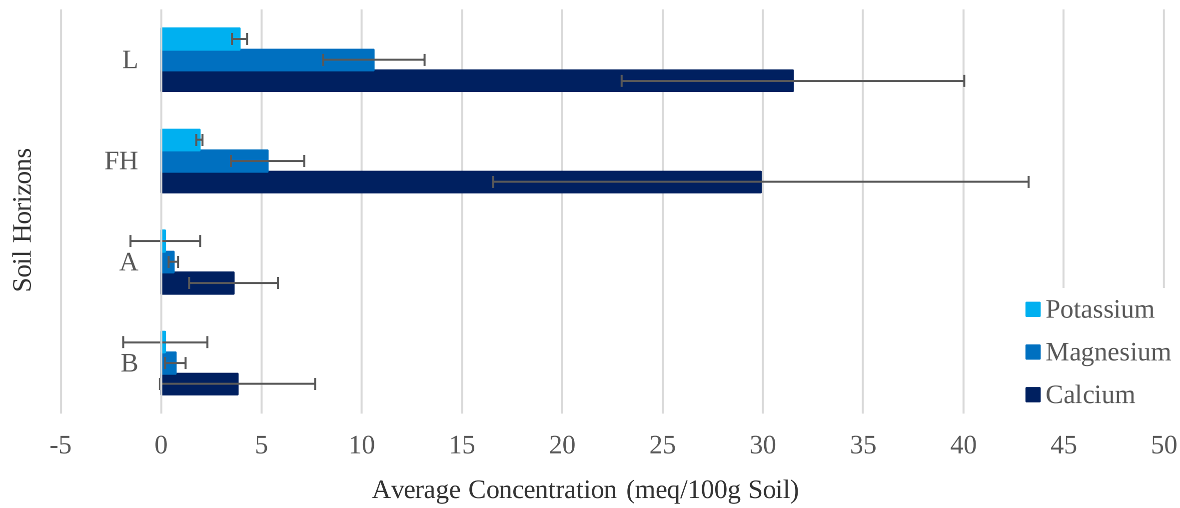

Figure 6: Average nutrient concentrations at each soil horizon

Average soil nutrients concentrations decreased as sampling depth increased (Figure 6). Calcium concentration was most variable in the L and FH horizons. The difference between the organic and mineral soils was much greater than the difference seen within the organic (L and FH) and mineral (A and B) soils. The concentration of soil Ca^{2+} was greater than that of K^{+} and Mg^{2+}. The L horizon, primarily comprised of leaf litter, had the average concentration of Ca^{2+}, Mg^{2+}, and K^{+}, at 31.5, 10.6, and 3.9 meq/100g soil, respectively.

The average Ca^{2+} concentration between the A and B horizons sampled around Kawagama Lake was about 3.7 meq/100g soil. Based on this average, the Ca^{2+} pool in the watershed was approximately 0.45 kg/m^2.

A study by Miller and Watmough (2009) measured nutrient concentrations from soil samples across southern Ontario, within the hardwood plains and boreal shield. Their study established a critical threshold for soil Ca^{2+} concentrations at 2 meq/100g soil where decreasing soil Ca^{2+} concentrations correlates with significant foliar Ca^{2+} decrease (Miller and Watmough, 2009). The Ca^{2+} pool at the critical threshold was estimated to be 0.24 kg/m^2 (Miller and Watmough, 2009).

Although the average Ca^{2+} levels around Kawagama were above the critical threshold, two of the sampling sites were recorded at this threshold and two other sites were approaching this critical value.

Focusing in on the samples taken from the Kawagama Lake watershed, one can see the spatial variation in nutrient concentrations around the northern shorelines (Figure 7).

The maps to the right show the range of nutrient concentrations from the A horizon at each of the sampling sites around Kawagama Lake.

The sampling locations at the southwestern side of our study region exhibited the lowest concentration for all nutrients, including Ca^{2+}, Mg^{2+}, and K^{+}.

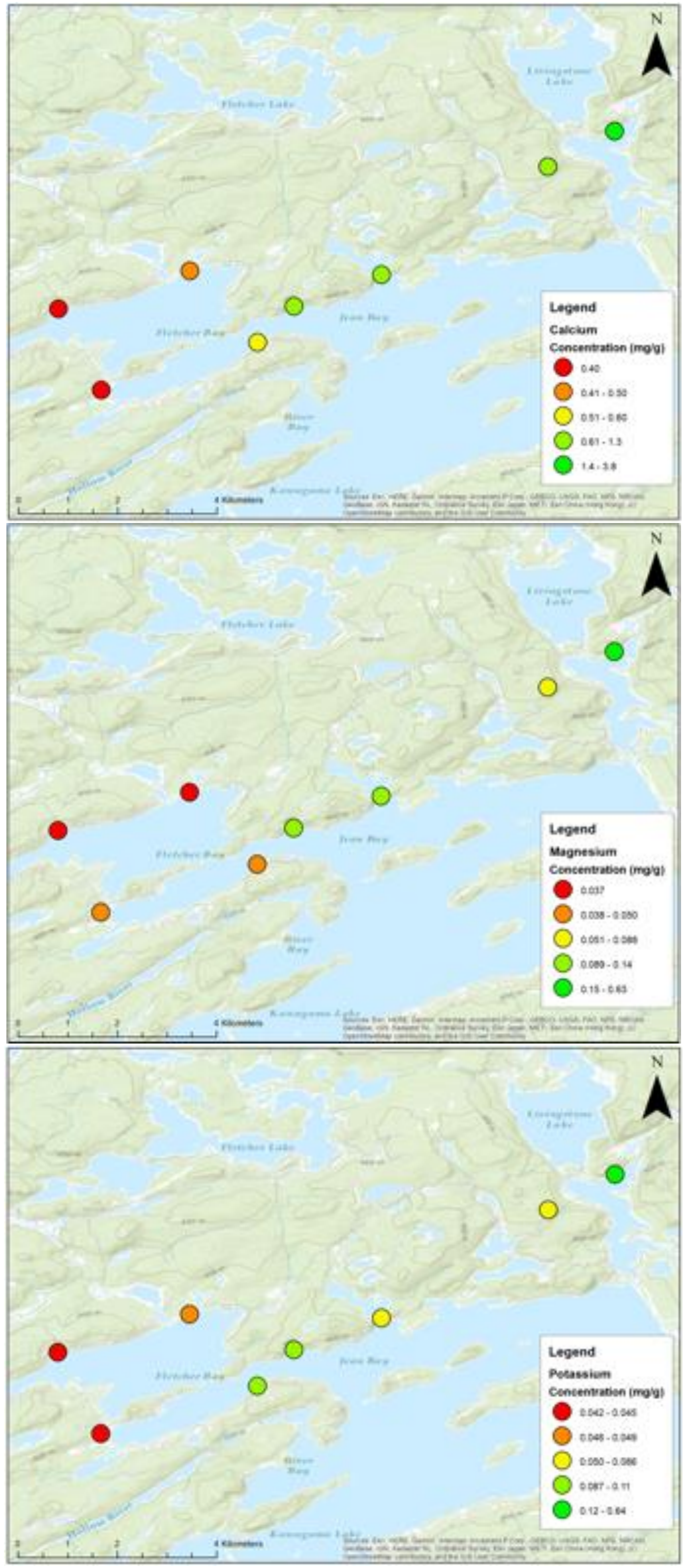

Figure 7: Calcium, magnesium, and potassium concentrations in the A horizon

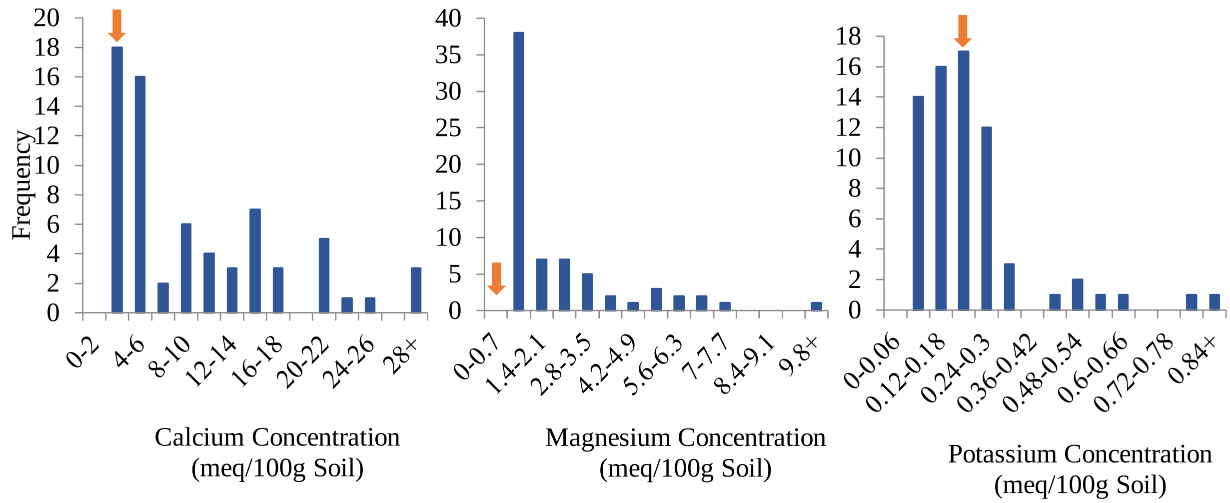

Figure 8: Distribution of calcium, magnesium, and potassium concentrations (meq/100g soil) in the A horizon of soil samples from southern and central Ontario (McDonough, 2011); the arrows indicate the range in which the Kawagama Lake watershed fits

Calcium decline is occurring in lakes across the boreal shield region, including both Kawagama Lake and Bear Lake (Figure 7 & 8). The regional data set from McDonough (2011) suggests that Ca^{2+}, Mg^{2+}, and K^{+} concnetrations are low in central and southern Ontario (Figure 8). It is apparent that the soils in the Kawagama Lake watershed have Ca^{2+} and Mg^{2+} concentrations at the lower range of values across the province, measured at 3.6 and 0.6 meq/100g soil, respectively (Figure 8, Appendix B). Conversely, the K^{+} concentration is within the provincial averages (Figure 8).

Furthermore, a study by Bal et al. (2014) reviewed the data from numerous studies concerning the interactions between forest health and nutrient status, with particular focus on sugar maples (*Acer saccharum*) in Ontario. Using historical records of sugar maple mortality and nutrient deficiency, the authors created a map depicting zones of nutrient deficiency observed across southern Ontario, Canada, and into the neighbouring states in the United States of America (Bal et al., 2014). Based on the information from Bal et al. (2014), Dorset is in a region of Ca^{2+} deficiency.

The findings from both Bal et al. (2014) and McDonough's (2011) Ca^{2+} samples from the mineral soil horizons indicate that Ca^{2+} levels in this region are near the critical threshold of 2 meq/100g soil (Miller and Watmough, 2009)

3. Mitigation Efforts

3.1 MITIGATION METHODS

The previous study covered the potential Ca^{2+} mitigation methods in depth (Chan et al., 2019). The report discussed methods for minimizing and supplementing the loss of Ca^{2+} from the ecosystem (Chan et al., 2019). Possible methods included catchment-based forest management, retention of timber harvest residues, applying wood ash and lime, liming in streams and lakes, and applying dust suppressants (Chan et al., 2019). For this sake of this cost benefit analysis, only the application of lime to catchment soils will be discussed, as it can be calculated with respect for the critical threshold and desired Ca^{2+} pool levels.

3.2. COST BENEFIT ANALYSIS

The current state of the Ca^{2+} pool in Kawagama Lake watershed is comparatively lower than the provincial average (Figure 8). The ideal Ca^{2+} level for the watershed is equal to or greater than the threshold of 2 meq/100g soil. Therefore, mitigation efforts such as applying lime or wood ash, could be beneficial to help reach this goal at the four low level sites.

Although the average Ca^{2+} concentration around Kawagama Lake and Bear Lake is above the critical threshold of 2 meq/100g soil, two of the sites were approaching this threshold and two were below this threshold (Figure 7). To raise the Ca^{2+} pool above the threshold by increasing it by 2 meq/100g soil in areas with low concentrations would require about 400 kg/ha of lime.

On average, a 20 kg bag of ground or pelleted limestone from a local agricultural co-op should cost about \$10 each. Common store locations where lime can be found include TSC Store, Canadian Tire, and RONA. Most bags of dolomitic limestone are sold in weights of either 15 kg or 18 kg and cost between \$0.46/kg to \$0.6/kg, with an average of \$0.5/kg (Canadian Tire, 2020; RONA, 2020; TSC Stores, 2020). Assuming that liming costs an average of \$0.5/kg per hectare, it would cost approximately \$200/ha to increase soil Ca^{2+} levels by 2 meq/100g soil in areas where soil Ca^{2+} is low.

Larger scale projects could reach out to quarries such as Nelson Aggregates (Ministry of Agriculture, Food and Rural Affairs, 2020). The Uhthoff quarry of Nelson Aggregates is based out of Orillia, about one hour and 15 minutes from Dorset (Nelson Aggregates, 2018b). It is the only quarry in the area and services towns from Muskoka to Simcoe county (Nelson Aggregates, 2018b). However, their minimum order requirement is 22 metric tons, which costs \$500 (Nelson Aggregates, 2018a).

Despite how much cheaper it is to order in bulk, this project would not need more than 0.4 metric tons of limestone per hectare to apply to the watershed all at once, so this type of purchase is out of the question. For the spatial and temporal scale that the KLCA is working within, purchasing bags of dolomitic limestone from local co-ops or hardware stores is much more feasible.

In addition to the cost of lime itself, the KCLA may need to consider the cost of labour, assuming that liming would be contracted. If not, and liming applications are the responsibility of each property owner, this additional cost is negated.

Moreover, this cost estimate does not include the potential monitoring and reapplication costs in future years. Since changes in soils occur slowly, monitoring should be conducted every five to ten years to reassess the state of calcium pools in the watershed and determine the frequency and quantity of reapplication.

4. Conclusion

As Ca^{2+} continues to decline in watersheds across central and southern Ontario, the Kawagama Lake watershed will experience biochemical changes in its soils and surface waters. Based on the analysis of soil samples, the Kawagama Lake watershed is approaching the critical threshold for Ca^{2+} pools.

Nevertheless, the negative impacts associated with Ca^{2+} decline can be mitigated by a number of different liming application techniques. The application of dolomitic limestone in areas of low Ca^{2+} concentrations would assist in raising the Ca^{2+} pool for the catchment soils and surface waters. Next steps may include ongoing monitoring of the state of Ca^{2+} pools in the watershed and investigating the impact of lime application to the ecosystem.

By understanding the dynamic characteristics of this special ecosystem and selecting appropriate mitigative actions, the passion for stewardship in the KLCA community can help preserve beautiful shores and waters of Kawagama.

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Appendix A

The following summary table contains the geographic positioning system (GPS) coordinates of the eight sample sites around Kawagama Lake in Dorset, Ontario.

The latitude describes the north-south positioning of a point on the globe, while the longitude is the description of point's east-west position on the globe.

***Table 1**: Average calcium concentration, in milligrams per gram and milliequivalents, as well as standard deviation*

Sample Site	Latitude	Longitude
1	45.34239	-78.72183
4	45.32285	-78.75205
5	45.31712	-78.7679
6	45.32353	-78.78683
7	45.3167	-78.81066
8	45.30198	-78.80291
9	45.31064	-78.77455
10	45.3488	-78.70972

Appendix B

The following summary tables contain the average values and standard deviation for the samples at each of the soil horizons at the eight sites around Kawagama Lake in Dorset, Ontario.

Table 1: *Average calcium concentration, in milligrams per gram and milliequivalents, as well as standard deviation*

Soil Horizon	Average Concentration (mg/g)	Average Concentration (meq/100g soil)	Standard Deviation
L	6.323	31.5	8.5
HF	6.001	29.9	13.4
A	0.727	3.6	2.2
B	0.766	3.8	3.9

Table 2: *Average magnesium concentration, in milligrams per gram and milliequivalents, as well as standard deviation*

Soil Horizon	Average Concentration (mg/g)	Average Concentration (meq/100g soil)	Standard Deviation
L	1.283	10.6	2.5
HF	0.643	5.3	1.8
A	0.068	0.6	0.2
B	0.084	0.7	0.5

Table 3*: Average potassium concentration, in milligrams per gram and milliequivalents, as well as standard deviation*

Soil Horizon	Average Concentration (mg/g)	Average Concentration (meq/100g soil)	Standard Deviation
L	1.536	3.9	0.4
HF	0.728	1.9	0.2
A	0.066	0.2	1.7
B	0.071	0.2	2.1

Table 4: *Average pH, as well as standard deviation*

Soil Horizon	Average pH	Standard Deviation
L	4.5	0.5
HF	5.0	0.5
A	4.8	0.4
B	4.9	0.4

Table 5: *Average percentage of organic matter, as well as standard deviation*

Soil Horizon	Average Percent Organic Matter	Standard Deviation
L	74.5580	37.6780
HF	59.1340	27.7727
A	9.2650	3.1660
B	9.6123	5.8516