Bottom Sediment Analysis of Elk Lake, Victoria BC.

Prepared By:
Julio Flores and Queen Esther Nankabirwa

Prepared For:
ENVR 208 Sustainability Research Project
Environmental Technology Program
Camosun College
June 16, 2017

Acknowledgements

Special thanks to our head supervisor, Dr. David Blundon, for his unwavering support throughout this project by helping with the sampling design, collecting and analysing samples, editing the final report and preparing us for our presentations of this study. Our second supervisor, Trisha Jarrett, for initiating contact with the Ministry of Environment analytical laboratory. Biology department laboratory technologists, Dave Thomas and Leslie Glover, for providing the equipment and setting up the lab for us to analyse the samples for texture. Chemistry department laboratory technologists Andrea Fong and Carol Chalmers for helping in the preparation of the samples for loss on ignition method. Big thank you to Steve Gormican (Chair of the Environmental Technology Program and boat keeper of the "Tintanic") and Tony Dorling (Environmental Technology Program, Technologist) for gathering, listening and providing feedback. Geomorphologist, Chris Ayles, for helping us define our project objectives and providing insight about sediment analysis. Instructor Ian Browning for providing the Lamotte Soils kit. Head of the Geoscience and Chemistry Department, Dr.Tark Hamilton, for sharing alternative methods to loss on ignition method. Clive Dawson, head of analytical chemistry at Ministry of Environment, and Joni Borges, for walking us through the loss on ignition method and giving us a tour of the lab. Matthew Killoran, for recommending the use of electric metallic tubing (EMT) as probing poles. To Rebecca (Baby's) for being there for me and providing her love, support and patience throughout this project. To my family for always being supportive along this journey.

Executive Summary

Elk Lake is a glacial lake that has been showing signs of deterioration since the late 1900's. Due to an over production of potassium, nitrogen and phosphorous, the status of the lake has been labeled as eutrophic (CRD, n.d). The purpose of this study is to contribute to the understanding of the eutrophication of Elk Lake. The objectives were to measure the depth and thickness of the lake bottom sediment, create a digital, kriged, map of the bathymetry of the lake, measure the organic matter and classify and characterize the texture of the bottom lake sediment.

Eight transects were created with 97 sampling locations. Seven extra stations were included from a recent study (Yasseri and Goethem, 2016) for comparative purposes. These locations were used to create the digital map that represented the lake's depth. Twelve locations were sampled for sediment thickness which ranged from 0.1 to 4.2 m. A dry sieving method was used as the initial method. This was done by drying the sediment samples under heat lamps for approximately 2 hours. Then each sample was sieved through the descending diameters to classify particle size by percentages. The second method, involved using Sodium hexametaphosphate $(NaPO_3)_6$. Using the dry sieving method, the average organic matter (OM) content was 22% (1 – 44), 1.5% gravel (0 – 2.0), 60% sand (41 – 92), and 16% silt/clay (1 – 27). Seventy-seven percent of these samples were classified as organic sediment (>17% OM), 23% sand (2 – 0.063 mm) and 0% silt clay. A second method produced the results as 76.3% silt and clay and 0% sand. The organic matter and gravel percentages remained consistent.

The following recommendations are made to improve the methodology for this study. Determining the lake sediment thickness using submersible ground penetrating radar. Probing the lake with metal coupling rods was a suitable method in shallow water; however, in deep water it was not because of the difficulty of keeping the probe in a stationary position.

Table of Contents

List of Figures

List of Tables

Introduction

Located in the district of Saanich, British Columbia, Elk/Beaver Lake is a 2.24 km^2 waterbody (Figure 1) used for recreational activities such as swimming, boating, rowing, fishing, sightseeing and enjoyment. There were an estimated 1.48 million visits in 2014 (Cleverly, 2015).

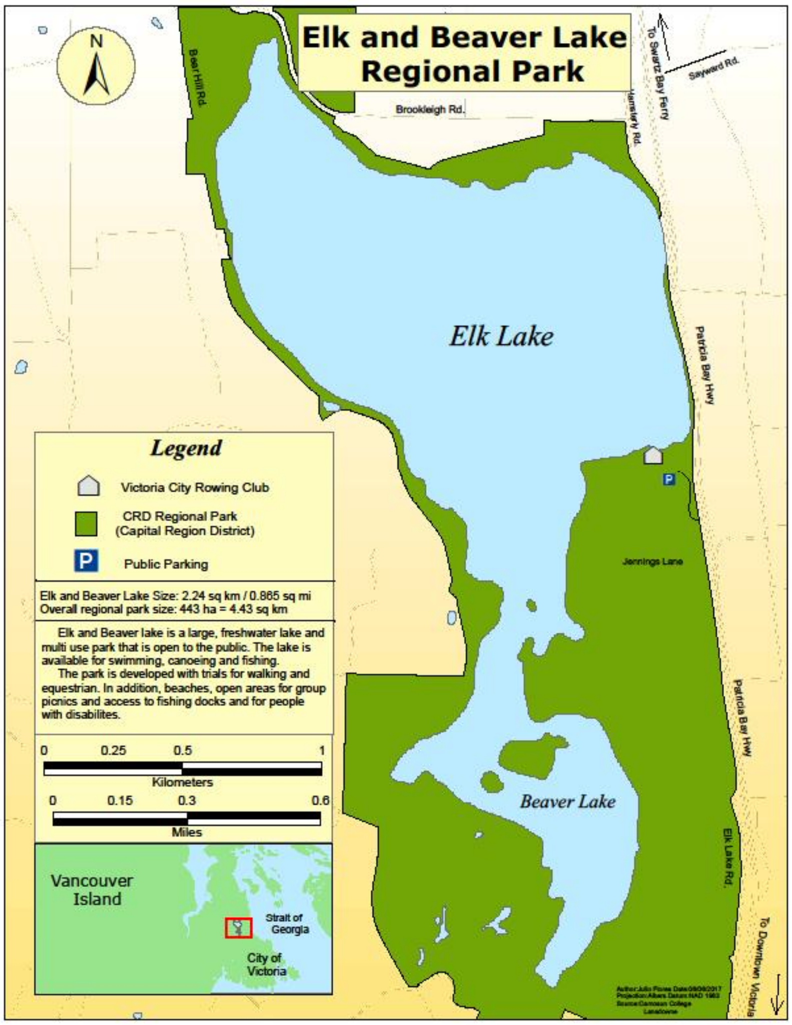

Figure 1. Map of Elk/Beaver Lake Regional Park.

The lake receives water from a 7.82 km^2 upstream drainage that includes O'Donnel Creek and Hamsterly Creek flowing into Elk Lake, and Haliburton Brook and Linnet Creek flowing into Beaver

Lake (Capital Regional District [CRD], n.d.). The lake also receives inflow from a number of stormwater drains under the Pat Bay Highway (Figure 2).

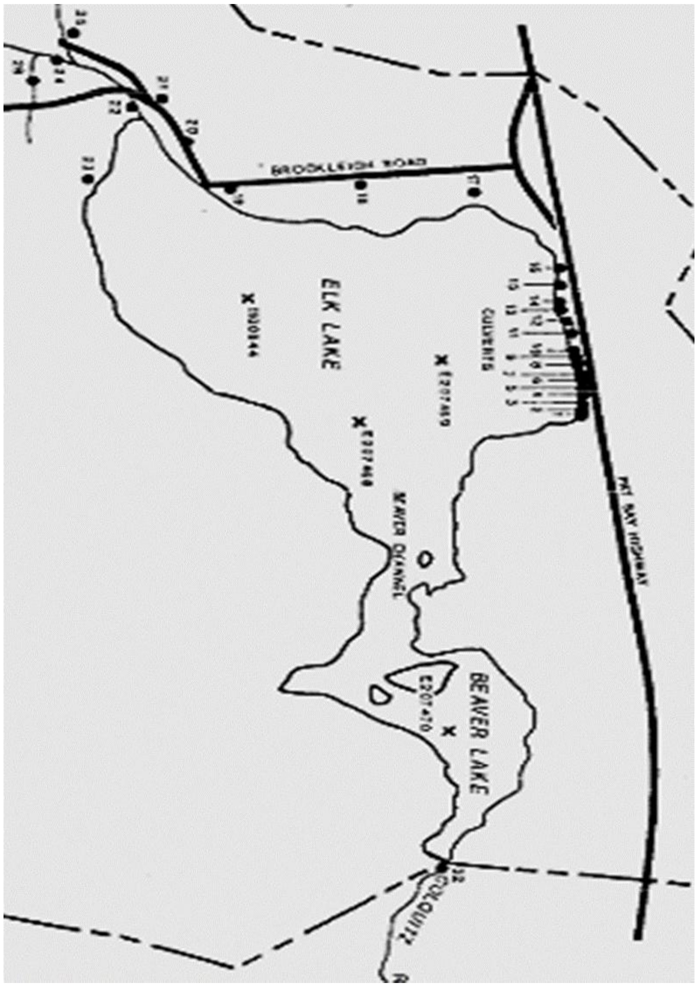

Figure 2. Map of Elk/Beaver Lake showing stormwater drains (culverts) located on the eastern shore of Elk Lake.

Elk Lake has a surface area of 1.87 km^2, a maximum depth of 18 m, mean depth of 9.2 m, water residence time of 4.4 yrs., alkalinity of 139 mgL^{-1} as CaCO3, external total phosphorous (TP) load of 0.12 $gm^{-2}yr^{-1}$ and an internal phosphorous (IP) load of 0.71 – 0.94 and is oligotrophic (Nürnberg, 2017). Historically, Elk Lake was the water source for Greater Victoria. Beaver Lake however was originally a separate body of water (swamp), created by beaver dams (CRD, n.d.). The two lakes were later joined when Colquitz Creek was dammed at the south end of Beaver Lake. Human activities starting in the mid19th century, such as land clearing, agricultural activities and increase in impervious surfaces, contributed to the exponential movement of sediment into the lake up to approximately 2000 (CRD, n.d). Early signs of eutrophication (high productivity) were found as a result of water monitoring in 1968 two years after the Elk/Beaver Lake was established as a regional park (CRD, n.d). Vuori (1971) describes the profundal (deep water) sediments of lakes in the Victoria area as unusual compared to lakes in the rest of North America. This difference was attributed to the Mediterranean climate of the Victoria area with its long growing season and high organic matter accumulation. Vuori found that Elk Lake sediment had a whitish-gray residue with high amounts of OM, total P, organic nitrate and plankton and speculated that the lake sediments would have long periods with a lack of oxygen. Elk lake was declared highly eutrophic by 1972 (CRD, n.d.). The first major study on the lake was conducted in 1988 (McKean, 1992). Ten to 30-year trends indicate that phosphorous and nitrogen concentrations in Elk Lake have not changed significantly over time and are in decline or are maintaining at a steady-state (Rogers, 2009). Most nutrient concentration data are not precipitation-dependent, and this, coupled with significant correlations to water temperature and dissolved oxygen, indicate that in-lake processes are the primary influence on lake-nutrient concentrations -- not external Groeneveld (2002) concluded that if the recent settlement of the Greater Victoria area had not occurred, Elk Lake would be less eutrophic and contain fewer heavy metals.

If disturbed, the potential nutrients, within the sediment, can be exposed to the water column, if disturbed. According to Monahan, Levson, Henderson, & Sy**.** (2000), the southern portion of the lake is susceptible to moderate amplification hazard. In addition, O'Donnel and Hamsterly Creeks on the Northern side of the lake are susceptible to moderate to high amplification hazard. In the event of an earthquake, this would release sediment into the overlying water column which would in turn result into the movement of fine sediment into the Colquitz watershed.

Recently, an extensive water quality and sediment sampling of Elk Lake was undertaken, with a focus on the internal loading of nutrients ("legacy" nutrients released from lake bottom sediment), which indicated a continued deterioration of the aquatic environment (Nordin, 2015). Interest in cleaning up the lake have intensified; for example see Lyder, Gray, & Sandborn (2015); Collins & McConnell (2016). In 2016 a CRD Elk/Beaver Lake Initiative Coordinator was established. Most recently and LaZerte (2016) collected bottom sediment samples from seven stations at Elk Lake. Volunteers, from the Vancouver Island's Blue Water Task Force (BWTF), have been monitoring the beaches of Elk Lake since 2014. According to their website, Swim Guide - Elk Lake has met the guidelines (standardized EPA criteria of 235 MPN/100 mL of *E. coli*) for swimming < 60% of the time.

Most lakes in the interior of BC stratify based on temperature during the summer, the hypolimnion (cold water layer) is at the bottom while the epilimnion (warm water layer) floats on top. The lakes maintain this structure for most of the summer because the cold water is denser than the upper warm layer of water therefore inhibiting mixing of the two layers. However in spring and fall, these lakes usually overturn and mix because wind energy overcomes temperature and density differences between surface and bottom waters (Nordin, 2015). Elk Lake is categorised as a monomictic lake meaning it overturns only once a year (Nordin, 2015). Nordin explains that coastal lakes in BC like Elk Lake stratify during the summer, surface temperatures increase throughout the summer months to 23 to 25°C and cools to 10 to 12°C in the fall, the bottom remains at 6 to 8°C. Thermal stratification of Elk Lake results in a condition known as anoxia, that typically occurs throughout the summer months (Nürnberg & LaZerte, 2016), where there is no oxygen supplied to the deeper colder water. The little oxygen that is available in the deep waters, Nordin (2015) explains, is consumed by decomposition and respiration by bacteria, fungi, invertebrates and fish. Fish cannot use the deeper cooler waters and often, low oxygen facilitates the release of nitrogen and phosphorous from rich bottom sediments (Nordin, 2015). The lake water is oxygenated when it mixes from top to bottom, typically in the winter from the end of October to the beginning of March, with temperatures between 4 and 6°C.

The three nutrients required for aquatic plant growth are nitrogen (N), potassium (K) and phosphorus (P). Potassium is usually present in excess and nitrogen is supplemented by fixation (Smith, 1990). Of these, P is the most intimately involved in the eutrophication of freshwater (Smith, 1990). Smith also explains that because P tends to be precipitated in sediments and cannot be supplemented naturally, it is usually limiting. In excess supply, cyanobacteria respond with increased growth rates and blooms that can be toxic to small mammals and harmful to humans (CRD, n.d.). Elk Lake usually experiences these blooms in the winter months of January and February, when the lake has turned over mixing the nutrient rich water from the hypolimnion with the oxygenated epilimnion water (CRD, n.d.), and have been linked to internal phosphorus loading from the bottom sediments in several reports (Nürnberg & LaZerte, 2016; Nordin, 2015). Nordin states that the magnitude of internal loading has doubled over the last 25 years and the concentration of phosphorous appears to have increased by a similar amount. Phosphorous can be divided into total and available, where total P consists of both the releasable and non-releasable P under naturally occurring conditions. Available P, as defined by Yasseri and Goethem (2016), is the amount of P that could be released to the overlying water column, from the active sediment layer (0 – 5 cm), under naturally occurring conditions. The CRD (n.d.) reports the water residence time of water and dissolved substances in Elk/Beaver Lake to be 7 yrs and the primary driver of high lake productivity.

Objectives

The purpose of this sustainable research project was to contribute to the understanding of eutrophication of Elk Lake, in particular the particle composition and extent of these lake bottom sediments. This was accomplished through the following objectives:

- Measure the depth to the bottom sediment.
- Creating a digital map of the bathymetry of the lake via kriging.
- Measure the thickness of the bottom sediment.
- Measure the organic matter in the lake sediment.
- Characterize the texture of the lake bottom sediments.
- Classifying the sediment.

Methodology

Sample Location

The location and waypoints of each Ekman sediment grab-sample and seven stations was determined with a global mobile map viewing instrument (OsmAnd 2.6) used for online and offline open street maps (OSM) maps. This instrument functions like a GPS providing reliable location and tracking movement (latitude and longitude), waypoint flagging and relative bearing. These location and waypoints can then be transferred to GPX files that can be loaded into Arcmap or Google Earth to be viewed. Once the boat is in the vicinity of the sample location a waypoint is marked on the OsmAnd 2.6 device. The waypoint is then used to determine the distance to the sample location. Using this distance and line of sight to a fixed object the boat is steered to the sample location.

Sampling Design

Google Earth provided a base map for a sampling design of Elk Lake. The 10-horsepower marker buoy that was centrally located (48°31'40.12"N, 123°23'41.04"W) was selected as a starting point for transects (Figure 3). Initially, four transects (1 – 4) were established and four more (5 – 8) added to represent the lake. The longest transects (2 and 8) were assigned 100 m intervals, the remaining shorter transects, 1, 3 - 7 were assigned 50 m intervals (Appendix A). Waypoints were then determined for these locations; in addition, seven stations established by Yasseri and Goethem (2016) were included.

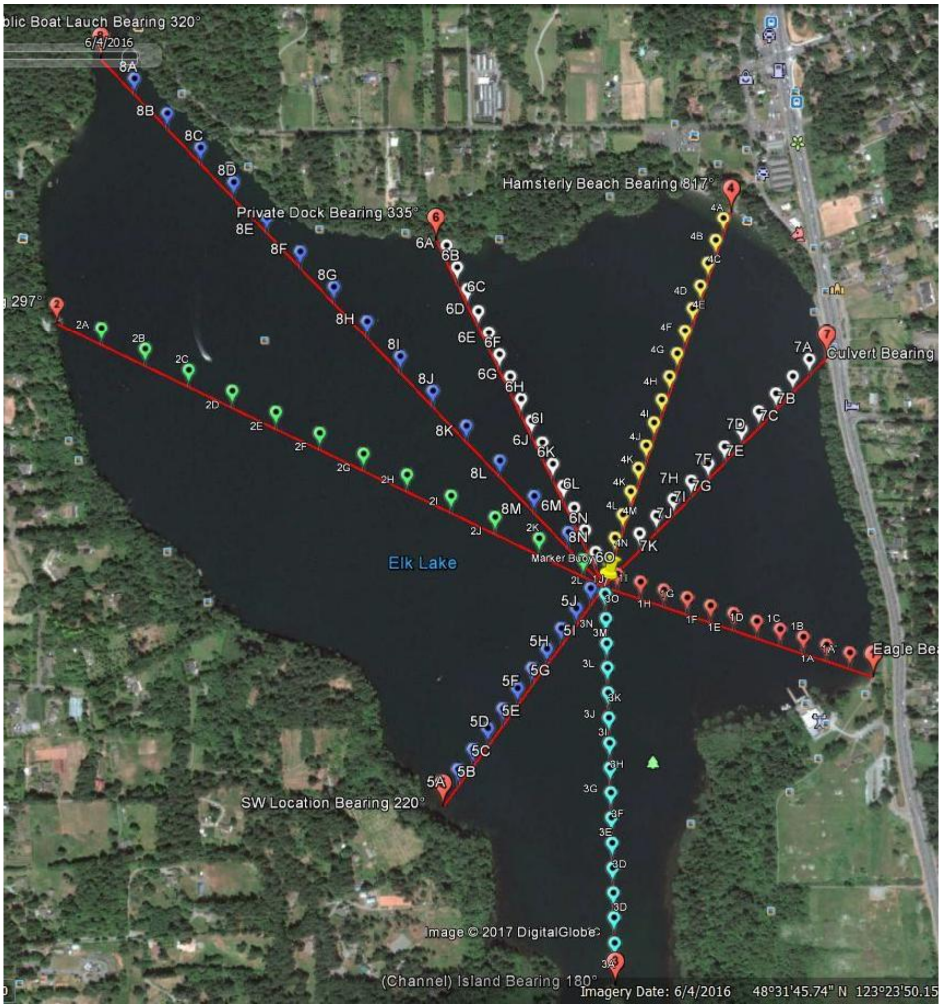

Figure 3. Sampling design showing 8 transects with 97 sample locations for Elk Lake. Note that each transect radiates from a central marker (10 hp) buoy.

Sediment Sampling

A standard 15.24 x 15.24 x 15.24 cm Ekman grab was used to collect sediment samples from the bottom of the lake. This unit was attached to a tether and lowered to the bottom of the lake. Once the Ekman grabbed a sediment sample, it was slowly pulled to the surface. The tether was measured as it was pulled into the boat to determine the depth. For each sample location, waypoints were taken and the sample placed in a labeled Ziploc bag and stored in a refrigerator. In addition, the seven sample stations that Yasseri and Goethem (2016) established were sampled as described above. A total of 104 samples were collected.

Lake Depth

The Environmental Technology aluminum boat was fitted with a Humminbird Wide-eyed 1993 series depth finder. The narrow cone transducer beam was selected. The depth finder was calibrated to a sensitivity of -5 which would register objects that have the most density. The sensitivity setting increases or reduces the amount of detail that may be within the water column. Six probing poles of ¾” Electric Metallic Tubes (EMT) measuring 10’ (3.05 m) were calibrated in 1” (2.54 cm) sections.

Sediment Thickness

The probing poles were designed to be joined together with coupling, 10” (25.4 cm) sectional poles of smaller diameter and reinforced with screws. At each sample location the tethered poles were coupled together in the boat as they were lowered to the lake bottom. Once the pole reached the bottom, the water depth was noted and the probe was then forced into the sediment until it could not be pushed any further. The difference between these measurements was the sediment thickness.

Sediment classification

Thirty one of the 97 sediment samples collected were analysed for texture. Samples were selected based on their transect location and their visually assessed texture. One sample was taken from transect 7, two from transect 6, three from transect 3, four each from transects 1, 2 and 4, five from transect 8 and eight from transect 5.

Dry sieving was the initial method used to classify the sediment samples. The samples were prepared by drying them in an oven overnight at 105°C. A heat lamp was also used to accelerate the drying process. Samples were then crushed into fine particles using a mortar and pestle as well as a coffee grinder. They were then sieved with U.S.A. standard test sieves of 4, 2, 1, 0.5, 0.25, 0.125 and 0.063 mm. The sediment from each sieve was weighed with an analytical balance and recorded. These sample were categorised into three mineral texture classes based on gravel (> 2mm), sand (2 – 0.063 mm) and silt clay (< 0.063) mm particle sizes (University College London Department of Geography, 2017). Their classification was based on the above texture analysis and their organic matter content. A sediment sample with (> 17% C was defines an organic soil (Soil Classification Working Group. (1998). Organic matter content was determined by loss on ignition (LOI) analysis. The LOI procedure, from Simon Fraser University (SFU) Soil Science Lab, compiled by Robertson (2011) was followed. In addition, six in-house controls from the BC Ministry of Environment were used to ensure accuracy of results.

A 10.75 g sample from transect 2B was further analyzed using sodium hexametaphosphate, to breakdown hard sediment amalgamations, > 0.125 mm - >0.063mm and then wet sieve the solution (Kettler, Doran & Gilbert, 2001). A 3:1 (45ml : 15 g) solution of 3% $(NaPO_3)_6$ was mixed with 15 g of dry sample in a 125 ml Erlenmeyer flask and placed into a reciprocating shaker overnight for approximately 16 hours. Following the 16 hr marker, the solution was wet sieved using only, the >0.063mm sieve. Any particles that did not go through, were separated and dried for sand composition. The remaining solution was collected into a 600 ml beaker and let sit for approximately >6 hours <12 hours. The clay was decanted and the silt fraction was dried at 105 ℃.

Results

Sample Location

The planned transects and sample and actual sample locations are shown in Figure 4.

Figure 5, on the following page, details the actual transects and sampled locations.

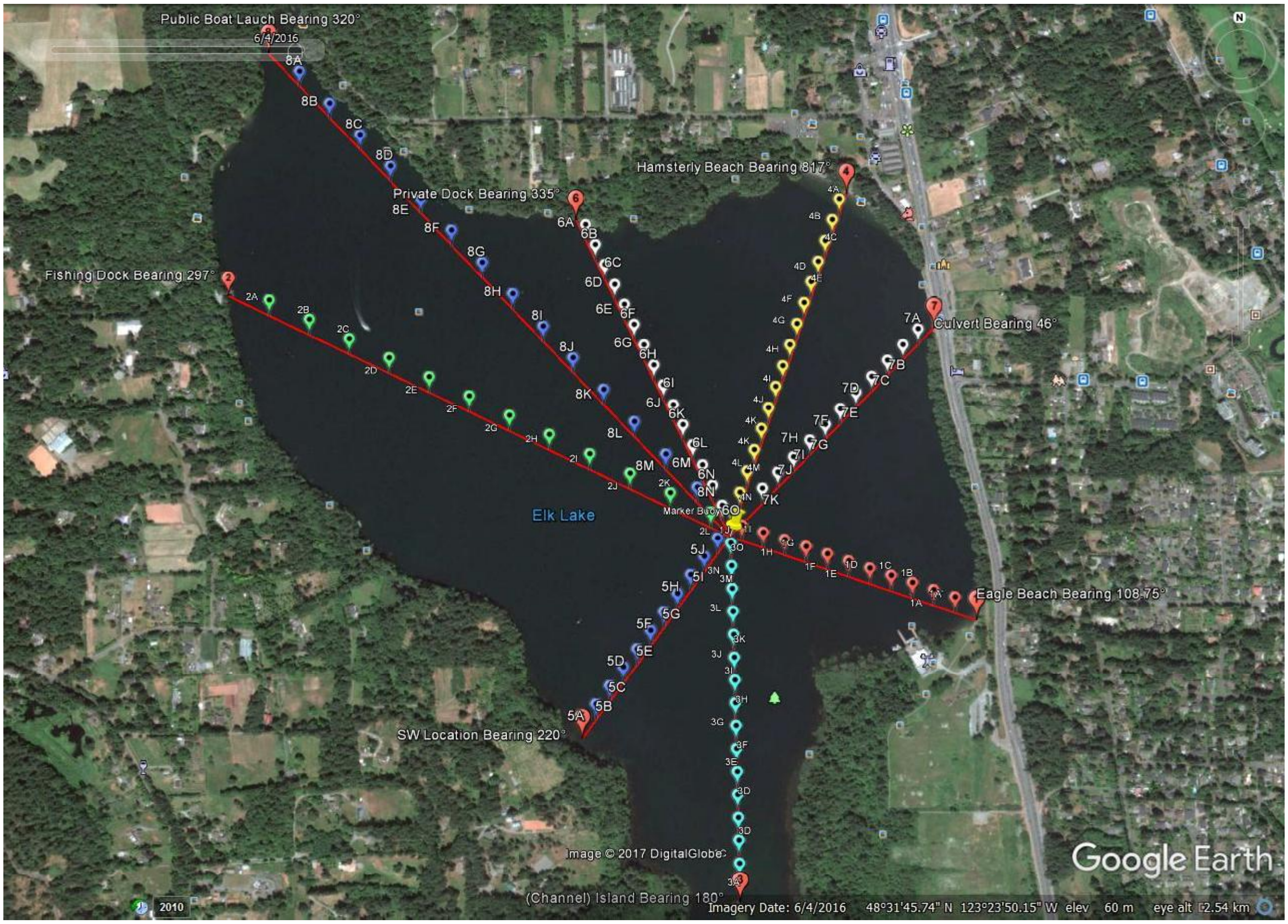

Figure 4 Intended transects and sampling locations using Google Earth.

Sampling Design

Transects 1, 2, 6 and 8 were successfully navigated whereas transects 3, 4, 5 and 7 were not (Figure 4). The coordinates of the seven stations that Yasseri and Goethem (2016) sampled were approximately located (Figure 5)

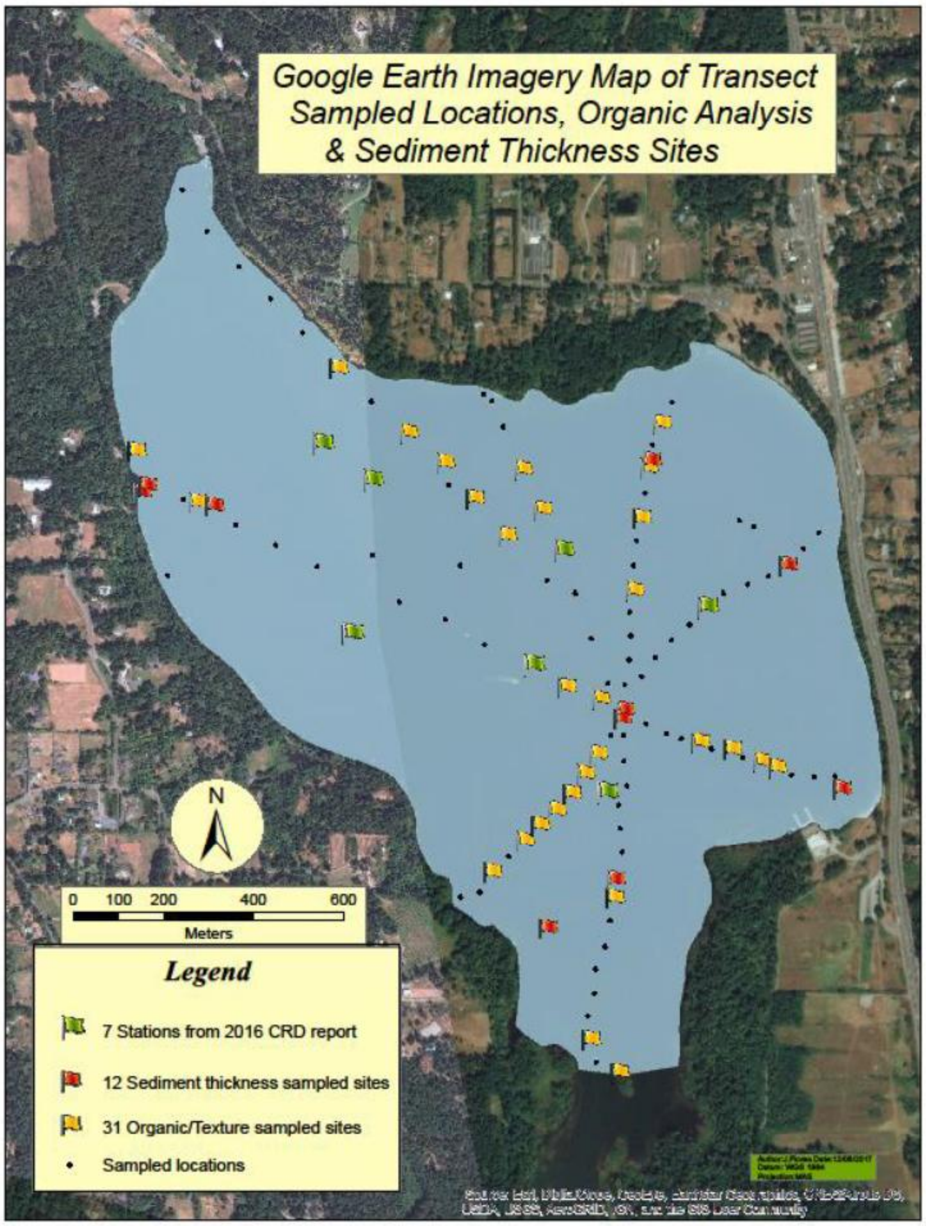

Figure 5. A Google Earth map showing transects, sample locations used for sediment texture and organic matter analysis, probed depth (sediment thickness) and seven stations established by Yasseri and Goethem (2016).

Sediment Sampling

Percent organic matter (%OM) content for Station 1, established by Yasseri and Goethem (p.7, 2016), was 26.8 compared to 3.7 for our closest sample location (8F). For Station 2, %OM was 25.4 compared to 1.0 for our closest sample location (8F). For Station 3, %OM was 20.9 compared to 24.0 and 24.8 for our closest sample locations (8K, 5I), respectively. For Station 4, %OM was 26.4 compared to 22.5 for our closest sample location (4I). For Station 5, %OM was 23.9 compared to 23.7 for our closest sample locations (5H). For Station 6, %OM was 26.6 compared to 3.0 and 21.8 for our closest sample locations (2K, 2J), respectively. There were no transects in the vicinity of Yasseri and Goethem's Station 7. We were unable to compare the percent dry weight to that of Yasseri and Goethem (2016) because of the difference in sampling techniques (Mondsee corer versus Ekman sediment grab-sampler).

Lake Depth

The depth finder provided electronic images of the depth of Elk Lake. However, there was inconsistency in recording images at certain lake depths; for example, there was no image recorded at 42' (12.8m) but one was recorded at 52' (15.85m). The depth finder readings were then used to create a kriged map representing the 116 (97 Ekman grabs + 7 Stations + 12 depths) sampled locations (Figure 6).

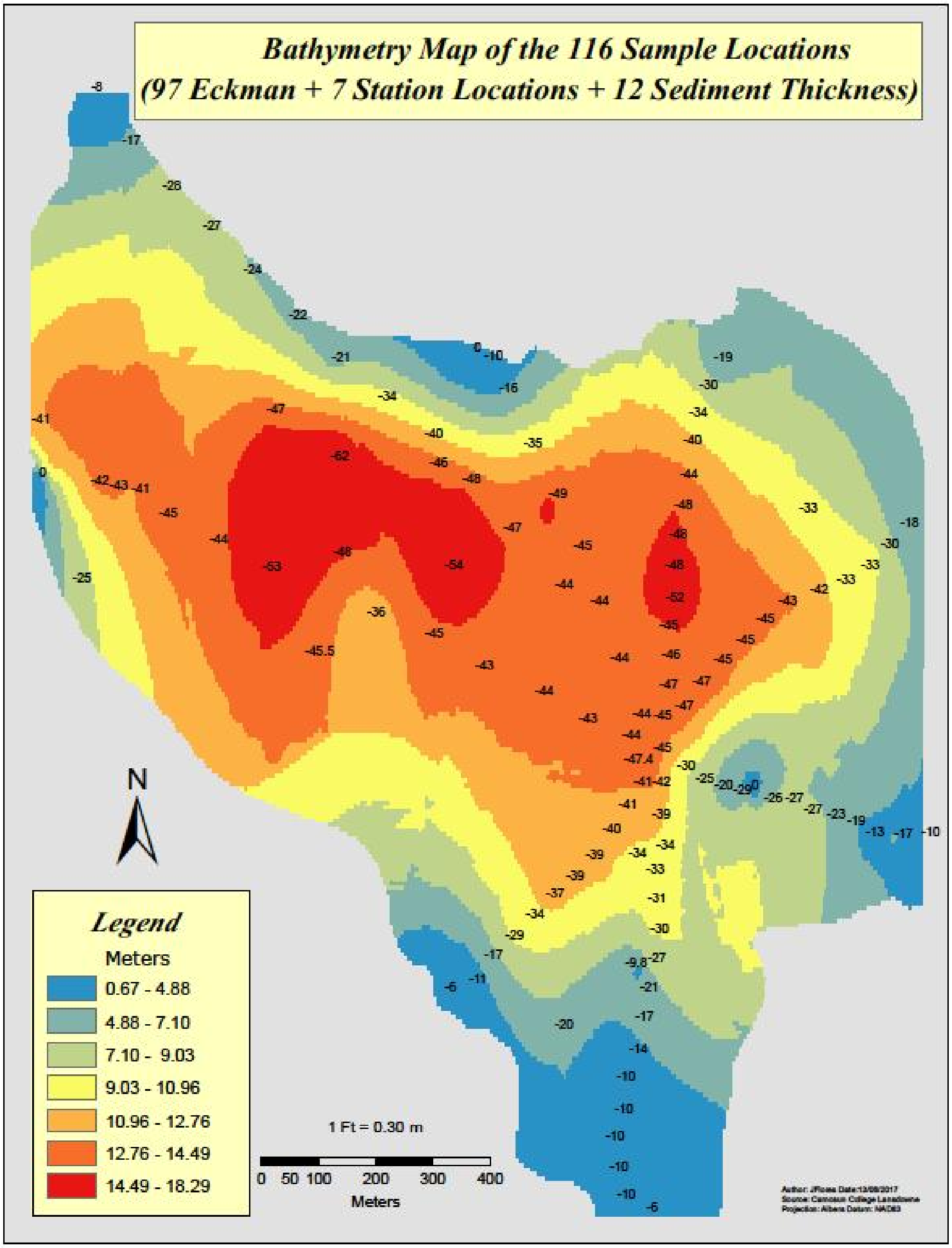

Figure 6. Kriged Bathymetry Map of 116 sampled locations.

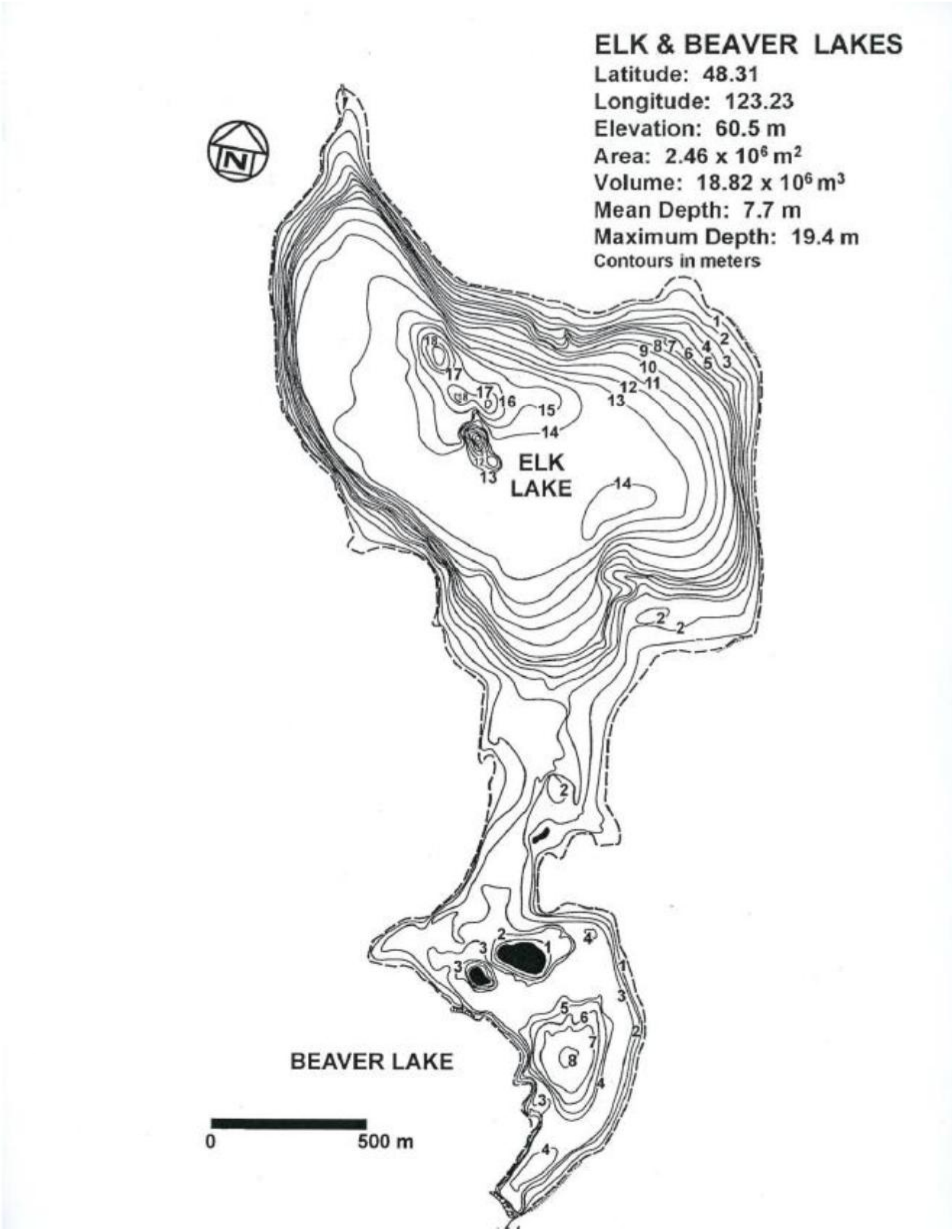

Figure 7. Bathymetry map from Spafard et al 2002 found in Nordin 2015. Comparative with the kriged bathymetry map in Figure 6.

Of the intended 104 sample locations only 97 were sampled (Appendix A). Transects 2, 6 and 8 on the Northwestern side of the lake are the deepest (Figure 6 and 7). Transects 4 and 7 start off deep at the marker buoy and make a steep incline towards the shore. Transects 5 and 3 begin off relatively deep and then gradually maintain a shallow plateau towards the channel. Transect 1 undulates between the buoy and the shore (Figure 8).

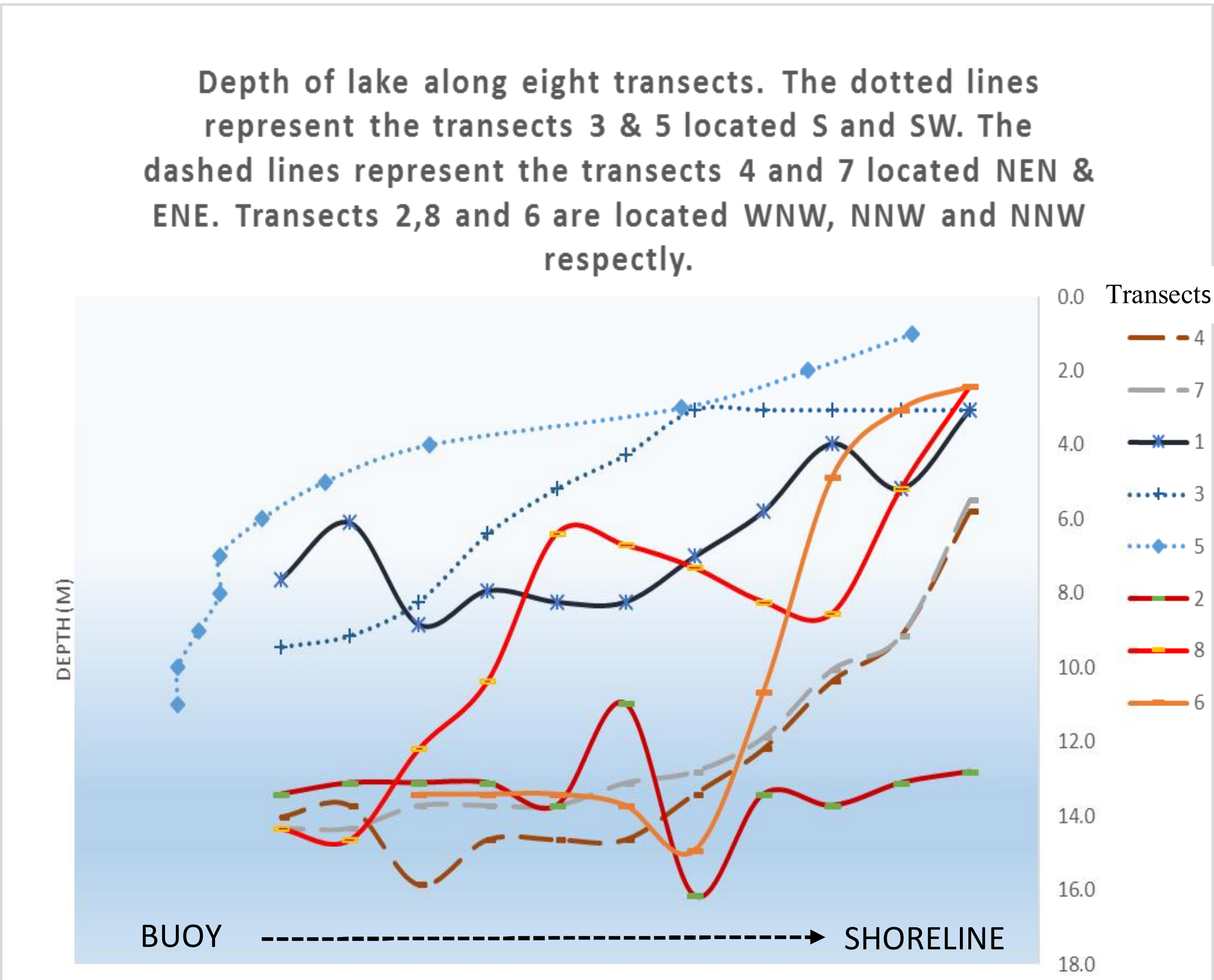

Figure 8. Depth of Elk Lake along eight transects starting at the 10 hp marker-buoy and ending near the shoreline (Figure 2).

Sediment Thickness

From the 12 locations the average sediment thickness was estimated to be 5.42 m and ranged from a low of 0.37 to a high of 13.72 m (Table 1).

Table 1. Location (Figure 3), latitude, longitude, bottom sediment depth (Top) from depth finder, probe depth (Bottom) from probing poles and sediment thickness (m) for 12 sample locations.

Transect	Latitude	Longitude	Top (m)	Bottom (m)	Thickness
A'	48°31'24.84"N	123°23'49.43"W	6.10	7.01	0.91
B'	48°31'28.33"N	123°23'42.15"W	2.99	3.35	0.37
C'	48°31'18.55"N	123°23'45.01"W	3.51	3.87	0.37
D'	48°31'58.39"N	123°23'38.45"W	11.28	14.33	3.05
E'	48°31'54.11"N	123°23'28.89"W	10.97	14.02	3.05
Near Eagle B	48°31'34.65"N	123°23'17.98"W	3.05	5.33	2.29
Pt A (Buoy)	48°31'39.87"N	123°23'41.47"W	14.45	21.34	6.89
Pt B	48°31'45.84"N	123°24'10.91"W	13.87	21.34	7.47
Pt C	48°31'45.08"N	123°23'56.38"W	12.65	21.34	8.69
Pt D	48°31'54.98"N	123°24'25.74"W	12.50	21.34	8.84
Pt E	48°31'55.43"N	123°24'29.09"W	11.89	21.34	9.45
Pt F	48°31'49.93"N	123°24'30.69"W	7.62	21.34	13.72

Sediment Classification

The average water loss of the 31 sediment samples was 33.6% and varied from a low of 20.7 to a high of 41.8% (Table 2; Appendix C). From the dry sieving method, the average and range of particle composition for the samples was 22.2% (1.0 - 44.0) OM, 1.5% (0 – 20.2) gravel (>2 mm), 59.7% (41.4 to 92.0) sand (2 – 0.063 mm) and 16.6% (1.1 to 27.5) silt clay (< 0.063 mm). The majority ($\bar{x}$ = 73.7%) of the sand particles were very fine sand (0.125 – 0.063 mm) followed by 20.0% fine sand (0.25 – 0.125 mm). Classification of these sediment samples resulted in 77.4% of them being classified organic (> 17% C), 22.6% sandy and 0% silt-clay.

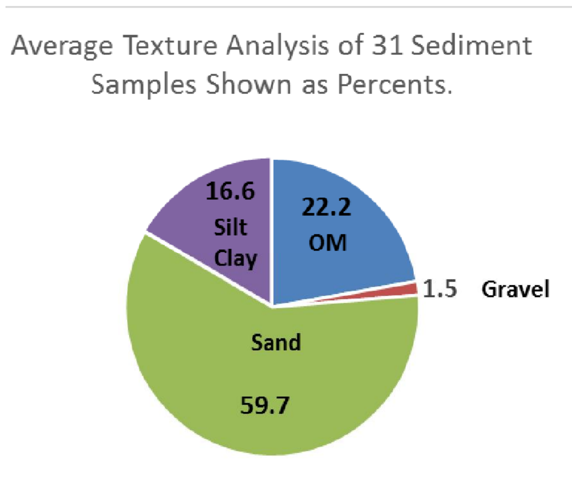

Figure 9. Average texture analysis of 31 sediment sample shown in percentages.

Table 2. Percent water loss, particle size and sediment classification for the 31 selected from a total of 97 Ekman sediment grab-samples.

Transect	H_2O lost	OM	Gravel	Sand	Silt Clay	Class
1C	29.93	43.8	0.0	41.1	15.1	Organic
1D	30.77	38.1	0.0	50.2	11.6	Organic
1F	27.27	18.9	6.9	66.1	8.1	Organic
1H	20.71	5.9	0.5	92.0	1.6	Sand
2A'	39.92	23.9	0.0	50.3	25.8	Organic
2B	35.69	26.2	0.0	50.7	23.1	Organic
2J	39.75	21.8	0.0	63.2	15.0	Organic
2K	35.44	23.7	0.0	51.9	24.4	Organic
3A'	34.36	42.6	0.0	41.4	16.0	Organic
3B	36.68	44.0	0.3	44.7	11.0	Organic
3H	32.50	1.7	0.4	95.5	2.3	Sand
4E	38.35	24.0	0.0	59.9	16.1	Organic
4G	41.81	25.5	0.0	51.4	23.1	Organic
4I	32.25	22.5	0.0	50.0	27.5	Organic
4L	36.63	14.3	0.0	63.2	22.5	Sand
5C	31.98	27.8	0.7	67.3	4.1	Organic
5E	38.27	16.7	0.0	50.1	33.2	Sand
5F	41.20	20.1	0.1	55.3	24.5	Organic
5G	39.27	22.0	0.0	53.1	25.0	Organic
5H	33.47	23.7	0.0	59.3	17.0	Organic
5I	33.17	24.8	0.0	52.5	22.7	Organic
5J	33.27	24.9	0.0	50.1	25.0	Organic
5K	31.30	25.9	0.1	56.4	17.6	Organic
6F	24.91	1.7	20.2	77.3	0.8	Sand
6G	40.41	24.0	0.0	54.3	21.8	Organic
7E	32.95	24.6	0.0	47.9	27.5	Organic
8F	21.64	3.7	3.3	91.9	1.1	Sand
8H	21.12	1.0	13.6	74.7	10.6	Sand
8I	35.04	23.1	0.2	68.8	7.9	Organic
8J	37.05	23.5	0.0	55.8	20.7	Organic
8K	36.75	24.0	0.0	64.7	11.3	Organic

Results from wet sieving are shown in Figure 9.

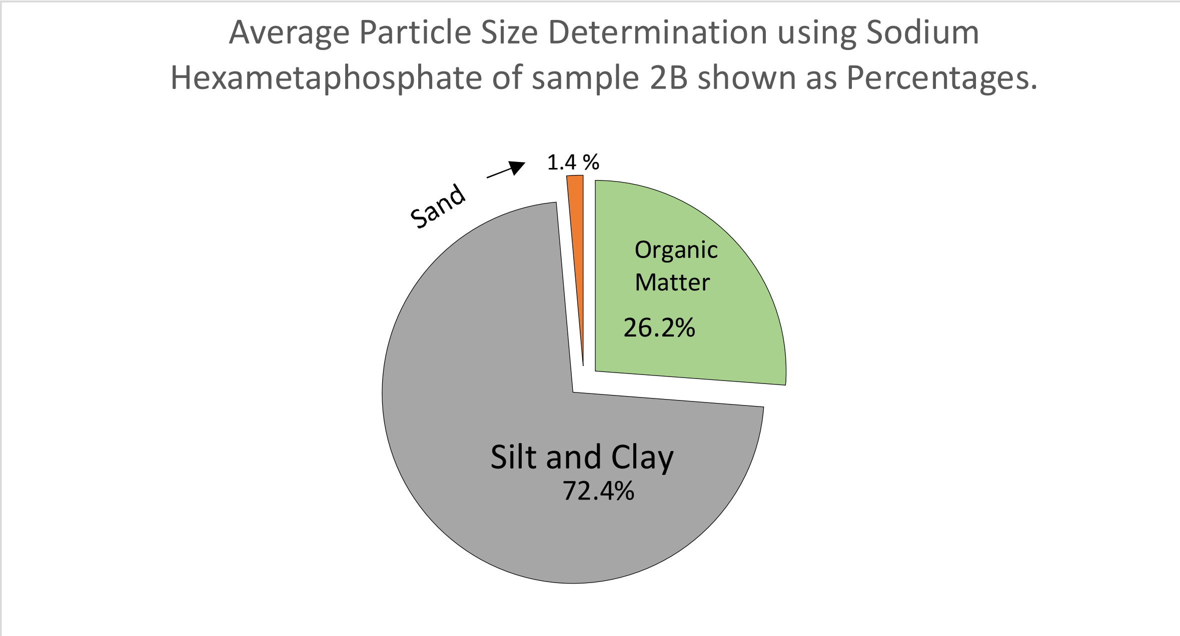

Figure 10. Wet sieve analysis of sample 2B using $(NaPO_3)_6$.

Discussion

Roughly half the sample sites were accurately located the remaining samples site were in close proximity to the original locations (Figure 4). Lake conditions varied considerable which made it difficult to sample at the intended locations. A kriged Arcmap of Elk Lake was created that closely resembles the Elk Lake portion of a previously made bathymetry map of Elk/Beaver Lake (Spafard, Nowlin, Davies and Mazumder, 2002, as cited in Nordin, 2017). We were unable to locate the Spafard et al (2002) article and the source of the map.

From the 12 sample locations (Figure 5) the average sediment thickness was 5.42 m and ranged from a low of 0.1m to a high of 13.72 m. To our knowledge sediment depth measurements of Elk Lake have not been done or published.

Of the six stations established by Yasseri and Goethem (2016), four of their %OM were comparable to our estimates; for example, 26.6 compared to our 21.8%. Two were not similar for example, 25.4 compared to our 1.0%. The latter could be attributed to the fact that the samples were not taken in the exact location. Even though we were in the proximity of these two stations, this highlights the heterogeneity in the sediment bottom of Elk Lake.

The dry and wet sieving results were inconsistent because $(NaPO_3)_6$ broke down the sediment pedzols that were originally classified as coarse sand particles in the dry sieving method. The wet sieving method is more accurate for determining particle size compared to the dry sieving method.

Conclusion

Elk Lake is a eutrophic lake that is plagued by cyanobacteria blooms that have deteriorated its health. The blooms have been linked to internal phosphorous loading from the bottom sediments. The lake also undergoes an anoxic condition because it overturns once a year (monomictic) resulting into a shortage of oxygen for fish and other invertebrates. The Kriged map (Figure 6) and hard copy map from Nordin (2015) appeared quite similar because there are areas in the lake that do not vary (Figure 7). However, this can only be verified by more depth finder measurements. The importance of determining sediment thickness is to estimate the potential amount of phosphorous that could be locked in the sediment. The poles was not a suitable method at depths < 10 m due to the difficulty of handling and maintaining the boat in a stationary position. Other methods that would determine the sediment thickness would be recommended. Determining the texture and classification of sediments proved to be inconsistent with the results. The average percent of water loss from the sediment samples was 33.67%. The dry sieving method average percent of organic matter in the sediment was 22.21%. 77.4% of the sediment samples were classified as organic and the rest as sand. The wet sieving method of one samples results were inverted with an average of 72.4% for silt & clay, and 1% sand. The remaining organic matter remained the same.

Recommendations

These recommendations could prove a better understanding of the eutrophication of Elk Lake.

- Add more transects and decrease the distance between sample locations to better represent the bathymetry of the lake.
- Reanalyse the mineral fraction of the 31 benthic samples using the pipette method to improve texture analysis.
- Do a complete texture analysis which includes loss on ignition and pipette method on the remaining 67 sediment samples.
- Analyse the remaining 67 sediment samples for loss on ignition to determine organic matter and use the wet sieving method to determine particle size.
- Use submersible ground penetrating radar to determine thickness of the sediment.
- Core the lake to determine whether the sediment is homogenous.
- Determine the available phosphorous using our dry weights and the calculations provided by Yasseri and Goethem (2016).

References

Capital Regional District. (n.d.). History & uses. Retrieved June 5, 2017, from: http://www.crd.bc.ca/education/our-environment/watersheds/featured-watersheds/elk-beaver-lake-watershed/history-uses

Collins, M. & McConnell, R. (2016). A strategic approach for improving ecosystem health in Elk /Beaver Lake Capital Regional District Park. Co-Chairs Elk/Beaver Lake Initiative, Victoria Golden Rods and Reels Fishing and Social Club. Retrieved from http://colquitzcoalition.com/publications-and-data/

Cleverley, B. (2015). Elk Lake cleanup gets green light from CRD parks committee. Retrieved from http://peninsulastreams.ca/wp-content/uploads/2012/07/TC-Oct-22-2015-Elk-Lake-cleanup-gets-green-light-from-CRD-parks-committee.pdf

Groeneveld, R. (2002). Paleolimnological study of Elk Lake: 150 – 500 Years of inferred water quality developments. Aquatic Ecology & Water Quality Management Group, Wageningen University, Environmental Management of Drinking Water Group, University of Victoria. Retrieved from http://colquitzcoalition.com/publications-and-data/

Kettler, T. A., Doran, John W, & Gilbert, T. L. (2001). Simplified Method for Soil Particle-Size Determination to Accompany Soil-Quality Analyses. Retrieved from http://digitalcommons.unl.edu/usdaarsfacpub/305

Lyder, R., Gray, E. & Sandborn, C. (2015). Cleaning up Elk Lake and Beaver Lakes: What can be learned from other lakes. Retrieved from http://colquitzcoalition.com/wp-content/uploads/2015/06/FINAL-ELK-LAKE-REPORT-SENT-TO-CLIENTfromELC.pdf

McKean, C.J.P. (1992) Ambient Water Quality Assessment and Objectives for Elk and Beaver Lakes Saanich Peninsula. ISBN 0-7726-1663-9. Retrieved from http://www.env.gov.bc.ca/wat/wq/objectives/elkbeaver/saanich.html

Monahan, P.A., Levson, V.M., Henderson, P. & Sy, A. (2000). Relative Amplification of Ground Motion Hazard Map of Greater Victoria - Expanded Map Legend. Retrieved from http://www.empr.gov.bc.ca/Mining/Geoscience/NaturalHazards/VictoriaEarthquakeMaps/Pages/Liquefaction.aspx

Nordin, R. (2015, June 18). *Water quality sampling program for Elk Lake 2014-2015: Overview, status and phosphorous budget*. Retrieved from http://colquitzcoalition.com/wp-ontent/uploads/2015/06/Elk-Lake-R-Nordin-Final-June-18.pdf

Nürnberg, G. (2017). Attempted management of cyanobacteria by Phoslock (lanthanum-modified clay) in Canadian lakes: water quality results and predictions. Lake and Reservoir Management, 33:163–170, DOI: 10.1080/10402381.2016.1265618 Retrieved from http://www.tandfonline.com/doi/full/10.1080/10402381.2016.1265618

Nürnberg GK, LaZerte BD. (2016). Evaluation of remediation options of Elk/Beaver Lake, Victoria BC. Report for the British Columbia Ministry of Environment, Nanaimo, BC. Baysville (ON): Freshwater Research. Available from: http://colquitzcoalition.com/wp-content/uploads/2015/06/ Nurnberg-Elk-Lake-Remediation-Report-2016_03_01. pdf

Robertson, S. (2011). *Direct estimation of organic matter by loss on ignition: Methods*. Retrieved from https://www.sfu.ca/soils/lab_documents/Estimation_Of_Organic_Matter_By_LOI_.pdf

Rogers, L. (2009). Synthesis of Water Quality Data and Modeling Non-Point Loading in Four Coastal B.C. Watersheds: Implications for Lake and Watershed Health and Management. Master of Science in the Department of Biology, B.Sc., Humboldt State University. Retrieved from http://colquitzcoalition.com/publications-and-data/

Smith, R.L. (1990). Biogeochemical cycling. In *Ecology and field biology* (pp. 274-277). New York, NY: Harper and Row.

Spafard, M.A., Nowlin, W.A., Davies. J-M & Mazumder, A. (2002). A morphometric atlas of selected lakes in southern British Columbia: Vancouver Island, Saltspring Island and the Kootenay region. Department of Biology, University of Victoria. Industrial Research Chair Program, Environmental Management of Drinking Water. 52 p.

Soil Classification Working Group. (1998). *The Canadian System of Soil Classification*. Ottawa, ON: NRC Research Press.

Swim Guide. Retrieved from https://www.theswimguide.org/beach/7030

University College London Department of Geography. (2017). Particle size analysis (for soils/sediments). Retrieved from http://www.geog.ucl.ac.uk/resources/laboratory/laboratory-methods/particle-size-analysis/particle-size-analysis-for-soils-sediments

Yasseri, S. & Goethem, P.V. (2016). *Elk Lake sediment analysis*. *A summary of results and implications for Phoslock treatment.* Retrieved from http://colquitzcoalition.com/wp-content/uploads/2015/06/Elk-Lake-Sediment-Report-110816-FINAL.pdf

Victoria Golden Rods & Reels (2017). Status Report Elk Lake Enhancement Project (Spring 2015). Retrieved from http://www.goldenrodsandreels.com/news/

Vuori, E. (1971). A preliminary survey and comparison of eight southern Vancouver Island lakes at various altitudes. Retrieved from http://a100.gov.bc.ca/appsdata/acat/documents/r6839/00214vict_c_1145998345943_476_15ea68d904b69904dbade353d1e39.pdf

Appendix A

The coordinates of the 97 sample locations shown in Figure 3.

Transect	Latitude	Longitude	Depth (m)		Transect	Latitude	Longitude	Depth (m)
1A'	48°31'35.81"N	123°23'18.34"W	3.0		5A	48°31'26.96"N	123°23'58.80"W	1.8
A	48°31'35.77"N	123°23'20.62"W	5.2		B	48°31'27.34"N	123°23'56.76"W	3.4
B	48°31'35.86"N	123°23'23.06"W	4.0		C	48°31'28.78"N	123°23'55.47"W	5.2
C	48°31'36.42"N	123°23'24.68"W	5.8		D	48°31'29.88"N	123°23'53.69"W	8.8
D	48°31'36.84"N	123°23'26.36"W	7.0		E	48°31'31.09"N	123°23'51.96"W	10.4
E	48°31'37.11"N	123°23'28.34"W	8.2		F	48°31'32.22"N	123°23'50.28"W	11.3
F	48°31'37.68"N	123°23'29.57"W	8.2		G	48°31'33.27"N	123°23'48.55"W	11.9
G	48°31'37.71"N	123°23'31.74"W	7.9		H	48°31'34.47"N	123°23'46.90"W	11.9
H	48°31'38.19"N	123°23'33.04"W	8.8		I	48°31'35.91"N	123°23'45.48"W	12.2
I	48°31'38.40"N	123°23'34.98"W	6.1		J	48°31'37.30"N	123°23'44.10"W	12.5
J	48°31'38.77"N	123°23'36.63"W	7.6		K	48°31'38.61"N	123°23'42.62"W	12.5
K	48°31'39.49"N	123°23'38.86"W	9.1		6C	48°32'3.05"N	123°23'56.63"W	2.4
2A'	48°31'58.84"N	123°24'34.25"W	12.5		D	48°32'2.58"N	123°23'55.72"W	3.0
A	48°31'55.21"N	123°24'27.61"W	12.8		E	48°32'0.71"N	123°23'54.46"W	4.9
B	48°31'53.60"N	123°24'23.38"W	13.1		F	48°31'57.68"N	123°23'52.34"W	10.7
C	48°31'52.17"N	123°24'19.04"W	13.7		G	48°31'54.81"N	123°23'50.23"W	14.9
D	48°31'50.65"N	123°24'14.54"W	13.4		H	48°31'51.88"N	123°23'48.08"W	13.7
E	48°31'49.26"N	123°24'10.14"W	16.2		I	48°31'48.78"N	123°23'46.60"W	13.4
F	48°31'48.10"N	123°24'5.61"W	11.0		J	48°31'45.58"N	123°23'44.84"W	13.4
G	48°31'46.90"N	123°24'0.67"W	13.7		K	48°31'42.39"N	123°23'42.98"W	13.4
H	48°31'45.08"N	123°23'56.38"W	13.1		7A	48°31'53.27"N	123°23'20.23"W	5.5
I	48°31'43.68"N	123°23'51.27"W	13.1		B	48°31'52.11"N	123°23'21.94"W	9.1
J	48°31'42.12"N	123°23'47.54"W	13.1		C	48°31'50.92"N	123°23'23.61"W	10.1
K	48°31'41.25"N	123°23'43.83"W	13.4		D	48°31'50.08"N	123°23'25.65"W	11.9
3A'	48°31'14.52"N	123°23'41.58"W	1.8		E	48°31'49.50"N	123°23'27.92"W	12.8
A	48°31'15.21"N	123°23'44.05"W	3.0		F	48°31'48.83"N	123°23'30.59"W	13.1
B	48°31'16.85"N	123°23'44.71"W	3.0		G	48°31'47.87"N	123°23'32.51"W	13.7
C	48°31'18.55"N	123°23'45.01"W	3.0		H	48°31'46.62"N	123°23'34.19"W	13.7
D	48°31'20.13"N	123°23'44.30"W	3.0		I	48°31'45.51"N	123°23'36.11"W	13.7
E	48°31'21.89"N	123°23'44.16"W	3.0		J	48°31'44.27"N	123°23'37.87"W	14.3
F	48°31'23.49"N	123°23'43.11"W	4.3		K	48°31'42.89"N	123°23'39.35"W	14.3
G	48°31'25.35"N	123°23'42.62"W	5.2		8A	48°32'17.59"N	123°24'29.34"W	2.4
H	48°31'27.01"N	123°23'42.21"W	6.4		B	48°32'14.61"N	123°24'26.68"W	5.2
I	48°31'28.62"N	123°23'41.60"W	8.2		C	48°32'12.11"N	123°24'23.21"W	8.5
J	48°31'30.28"N	123°23'41.38"W	9.1		D	48°32'9.79"N	123°24'19.75"W	8.2
K	48°31'31.98"N	123°23'41.60"W	9.4		E	48°32'7.39"N	123°24'16.26"W	7.3
L	48°31'33.66"N	123°23'41.77"W	10.1		F	48°32'4.84"N	123°24'12.42"W	6.7
M	48°31'35.04"N	123°23'40.89"W	10.4		G	48°32'2.47"N	123°24'8.74"W	6.4
N	48°31'36.80"N	123°23'41.27"W	11.9		H	48°32'0.27"N	123°24'4.76"W	10.4
O	48°31'38.63"N	123°23'41.27"W	12.8		I	48°31'58.14"N	123°24'0.77"W	12.2
4D	48°32'2.55"N	123°23'36.22"W	5.8		J	48°31'55.59"N	123°23'57.56"W	14.6
E	48°32'1.01"N	123°23'37.40"W	9.1		K	48°31'52.92"N	123°23'54.07"W	14.3
F	48°31'59.48"N	123°23'38.31"W	10.4		L	48°31'49.72"N	123°23'49.65"W	13.4
G	48°31'57.86"N	123°23'38.77"W	12.2					
H	48°31'55.99"N	123°23'39.08"W	13.4					
I	48°31'54.23"N	123°23'39.52"W	14.6					
J	48°31'52.61"N	123°23'39.96"W	14.6					
K	48°31'50.81"N	123°23'40.29"W	14.6					
L	48°31'49.03"N	123°23'40.23"W	15.8					
M	48°31'47.49"N	123°23'40.70"W	13.7					
N	48°31'45.80"N	123°23'40.53"W	14.0					
O	48°31'44.09"N	123°23'40.70"W	14.3					
P	48°31'42.30"N	123°23'41.19"W	13.7					

Appendix B

Latitude, longitude and depth of 31 selected Ekman sediment grab-samples			
Transect	Latitude	Longitude	Depth
1C	48°31'36.42"N	123°23'24.68"W	19
1D	48°31'36.84"N	123°23'26.36"W	23
1F	48°31'37.68"N	123°23'29.57"W	27
1H	48°31'38.19"N	123°23'33.04"W	29
2A'	48°31'58.84"N	123°24'34.25"W	41
2B	48°31'53.60"N	123°24'23.38"W	43
2J	48°31'42.12"N	123°23'47.54"W	43
2K	48°31'41.25"N	123°23'43.83"W	44
3A'	48°31'14.52"N	123°23'41.58"W	6
3B	48°31'16.85"N	123°23'44.71"W	10
3H	48°31'27.01"N	123°23'42.21"W	21
4E	48°32'1.01"N	123°23'37.40"W	30
4G	48°31'57.86"N	123°23'38.77"W	40
4I	48°31'54.23"N	123°23'39.52"W	48
4L	48°31'49.03"N	123°23'40.23"W	52
5C	48°31'28.78"N	123°23'55.47"W	17
5E	48°31'31.09"N	123°23'51.96"W	34
5F	48°31'32.22"N	123°23'50.28"W	37
5G	48°31'33.27"N	123°23'48.55"W	39
5H	48°31'34.47"N	123°23'46.90"W	39
5I	48°31'35.91"N	123°23'45.48"W	40
5J	48°31'37.30"N	123°23'44.10"W	41
6F	48°31'57.68"N	123°23'52.34"W	35
6G	48°31'54.81"N	123°23'50.23"W	49
7E	48°31'49.50"N	123°23'27.92"W	42
8F	48°32'4.84"N	123°24'12.42"W	22
8H	48°32'0.27"N	123°24'4.76"W	34
8I	48°31'58.14"N	123°24'0.77"W	40
8J	48°31'55.59"N	123°23'57.56"W	48
8K	48°31'52.92"N	123°23'54.07"W	47

Appendix C

Analysis steps for percent water lost for the 31 selected samples out of a total 97.							
Transect	Al weight (g)	Wet weight (g)	Wet weight only (g)	Dry weight + Al pack (g)	Dry weight only (g)	Total dry weight (g)	% H_2O lost
1C	1.31	36.20	34.89	3.39	2.08	4.96	29.93
1D	1.32	36.93	35.61	3.67	2.35	4.84	30.77
1F	1.31	38.11	36.80	8.34	7.03	9.53	27.27
1H	1.32	47.34	46.02	24.31	22.99	25.31	20.71
2A'	1.31	45.71	44.40	3.23	1.92	4.48	39.92
2B	1.31	41.97	40.66	3.76	2.45	4.97	35.69
2J	1.32	46.36	45.04	4.01	2.69	5.29	39.75
2K	1.32	41.50	40.18	3.52	2.20	4.74	35.44
3A'	1.31	39.64	38.33	3.31	2.00	3.97	34.36
3B	1.31	39.94	38.63	1.34	0.03	1.95	36.68
3H	1.31	62.09	60.78	27.06	25.75	28.28	32.50
4E	1.32	44.02	42.70	3.12	1.80	4.35	38.35
4G	1.32	47.74	46.42	3.32	2.00	4.61	41.81
4I	1.32	40.01	38.69	5.15	3.83	6.44	32.25
4L	1.31	46.19	44.88	6.93	5.62	8.25	36.63
5C	1.32	37.63	36.31	3.06	1.74	4.33	31.98
5E	1.32	40.50	39.18	1.33	0.01	0.91	38.27
5F	1.32	48.28	46.96	4.50	3.18	5.76	41.20
5G	1.32	45.61	44.29	3.84	2.52	5.02	39.27
5H	1.31	38.47	37.16	2.48	1.17	3.69	33.47
5I	1.31	37.92	36.61	2.20	0.89	3.44	33.17
5J	1.32	38.65	37.33	2.71	1.39	4.06	33.27
5K	1.33	36.09	34.76	2.25	0.92	3.46	31.30
6F	1.31	51.58	50.27	23.82	22.51	25.36	24.91
6G	1.31	46.45	45.14	3.44	2.13	4.73	40.41
7E	1.32	38.57	37.25	3.07	1.75	4.30	32.95
8F	1.32	56.20	54.88	31.83	30.51	33.24	21.64
8H	1.31	51.15	49.84	27.52	26.21	28.72	21.12
8I	1.32	41.09	39.77	3.43	2.11	4.73	35.04
8J	1.32	42.97	41.65	3.37	2.05	4.60	37.05
8K	1.31	42.35	41.04	3.10	1.79	4.29	36.75

Appendix D

Particle size breakdown of the 31selected samples out of a total 97.								
Transect	Gravel		Sand					Silt Clay
	> 4.0 mm	4.0 - 2.0 mm	2.0 - 1.0 mm	1.0 - 0.5 mm	0.5 - 0.25 mm	0.25 - 0.125 mm	0.125 - 0.063 mm	< 0.063 mm
1C	0.0	0.0	0.0	0.0	0.0	0.0	41.1	15.1
1D	0.0	0.0	0.0	0.0	0.0	0.0	50.2	11.6
1F	0.5	6.4	14.7	11.5	14.7	17.6	7.6	8.1
1H	0.1	0.4	2.1	4.6	26.5	44.6	14.1	1.6
2A'	0.0	0.0	0.0	0.0	0.0	0.0	50.3	25.8
2B	0.0	0.0	0.0	0.0	0.0	0.0	50.7	23.1
2J	0.0	0.0	0.0	0.0	0.0	0.0	63.2	15.0
2K	0.0	0.0	0.0	0.0	0.0	0.0	51.9	24.4
3A'	0.0	0.0	0.0	0.0	0.0	0.0	41.4	16.0
3B	0.3	0.0	0.0	0.0	0.0	0.0	44.7	11.0
3H	0.4	0.0	0.0	0.0	0.0	83.5	12.1	2.3
4E	0.0	0.0	0.0	0.0	0.0	0.0	59.9	16.1
4G	0.0	0.0	0.0	0.0	0.0	0.0	51.4	23.1
4I	0.0	0.0	0.0	0.0	0.0	0.0	50.0	27.5
4L	0.0	0.0	0.0	0.0	0.0	0.0	63.2	22.5
5C	0.7	0.0	0.0	0.0	0.0	56.4	10.9	4.1
5E	0.0	0.0	0.0	0.0	0.0	0.0	50.1	33.2
5F	0.1	0.0	0.0	0.0	0.0	0.0	55.3	24.5
5G	0.0	0.0	0.0	0.0	0.0	0.0	53.1	25.0
5H	0.0	0.0	0.0	0.0	0.0	0.0	59.3	17.0
5I	0.0	0.0	0.0	0.0	0.0	0.0	52.5	22.7
5J	0.0	0.0	0.0	0.0	0.0	0.0	50.1	25.0
5K	0.1	0.0	0.0	0.0	0.0	0.0	56.4	17.6
6F	20.2	0.0	0.0	0.0	0.0	70.4	6.9	0.8
6G	0.0	0.0	0.0	0.0	0.0	0.0	54.3	21.8
7E	0.0	0.0	0.0	0.0	0.0	0.0	47.9	27.5
8F	3.3	0.0	0.0	0.0	0.0	87.9	4.0	1.1
8H	13.6	0.0	0.0	0.0	0.0	0.0	74.7	10.6
8I	0.0	0.2	7.9	16.4	12.1	11.4	20.9	7.9
8J	0.0	0.0	0.0	0.0	0.0	0.0	55.8	20.7
8K	0.0	0.0	0.0	0.0	0.0	0.0	64.7	11.3

Appendix E

Loss on ignition analysis steps for the 31 selected samples out of a total 97.							
Transect	Weight of crucible (g)	Weight of crucible + sample before heating (g)	Weight of crucible + sample after heating (g)	Weight of sample before heating (g)	Weight of sample after heating (g)	LOI (g)	% Organic matter
1C	15.39	18.27	17.01	2.88	1.62	1.26	43.77
1D	16.23	18.72	17.77	2.49	1.54	0.95	38.15
1F	15.85	18.36	17.88	2.50	2.03	0.47	18.91
1H	15.70	18.03	17.89	2.32	2.18	0.14	5.93
2A'	15.10	17.65	17.04	2.56	1.95	0.61	23.89
2B	15.93	18.44	17.78	2.52	1.86	0.66	26.23
2J	14.69	17.30	16.73	2.60	2.03	0.57	21.84
2K	15.36	17.90	17.30	2.54	1.94	0.60	23.68
3A'	15.85	17.82	16.98	1.97	1.13	0.84	42.61
3B	15.11	17.03	16.19	1.92	1.08	0.85	43.97
3H	15.38	17.92	17.87	2.53	2.49	0.04	1.73
4E	16.19	18.74	18.13	2.55	1.94	0.61	24.01
4G	16.11	18.72	18.05	2.61	1.94	0.66	25.49
4I	15.25	17.86	17.28	2.61	2.03	0.59	22.47
4L	16.12	18.75	18.37	2.63	2.25	0.38	14.30
5C	14.38	16.97	16.25	2.59	1.87	0.72	27.82
5E	15.02	15.92	15.77	0.90	0.75	0.15	16.73
5F	15.67	18.24	17.73	2.58	2.06	0.52	20.11
5G	15.56	18.07	17.52	2.50	1.95	0.55	21.96
5H	14.71	17.23	16.63	2.52	1.92	0.60	23.75
5I	15.55	18.11	17.47	2.55	1.92	0.63	24.81
5J	16.04	18.71	18.04	2.67	2.00	0.66	24.90
5K	15.32	17.85	17.20	2.54	1.88	0.66	25.92
6F	15.31	18.16	18.12	2.85	2.81	0.05	1.69
6G	14.66	17.27	16.64	2.60	1.98	0.62	23.96
7E	15.17	17.72	17.09	2.55	1.92	0.63	24.62
8F	15.25	17.98	17.88	2.73	2.63	0.10	3.69
8H	16.18	18.69	18.66	2.51	2.48	0.03	1.05
8I	15.22	17.84	17.23	2.62	2.01	0.60	23.09
8J	14.83	17.38	16.78	2.55	1.95	0.60	23.50
8K	15.95	18.45	17.85	2.50	1.90	0.60	23.98
blank-1	15.76	15.76	15.76	0.00	0.00	0.00	-150.00
blank-2	15.77	15.77	15.77	0.00	0.00	0.00	175.00
FS0F 1	15.83	16.81	16.07	0.99	0.25	0.74	74.92
FS0F 2	15.54	16.54	15.81	0.99	0.27	0.73	73.24
KMB14M 1	15.55	18.12	17.95	2.57	2.40	0.17	6.44
KMB14M 2	15.17	17.76	17.59	2.58	2.42	0.16	6.32