North Bay – Mattawa Conservation Authority

Paleolimnology of Callander Bay, Lake Nipissing

Prepared by:

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Project Number:

107389

Date:

October 6, 2009

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October 6, 2009 Project Number: 107389

Francis Gallo
Water Resources Specialist
North Bay – Mattawa Conservation Authority
15 Janey Avenue
North Bay, ON P1C 1N1

Dear Mr. Gallo:

Re: Paleolimnology of Callander Bay, Lake Nipissing

I am very pleased to submit this report regarding the paleolimnological study for Callander Bay. Results from the study indicate that Callander Bay shifted from mesotrophic to eutrophic conditions ~1950 following control of discharge from Lake Nipissing to the French River with the operation of the Portage Dam. The diatom records further suggest that the total phosphorus concentrations have been relatively stable since ~1955 and do not provide evidence of recent eutrophication resulting from human activities in the watershed.

Please do not hesitate to contact me if you would like to discuss the contents of the report or are interested in conducting algal pigment analysis to reconstruct past cyanobacteria production.

I thank the North Bay-Mattawa Conservation Authority for giving me the opportunity to conduct this most interesting study.

Sincerely,
AECOM Canada Ltd.

Tammy Karst-Riddoch, Ph.D.
Tammy.Karst@AECOM.com

TKR:tkr
Encl.

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Revision Log

Revision #	Revised By	Date	Issue / Revision Description
1	TKR	5-Oct-09	Revisions and elaboration of discussion
2	TKR	16-Oct-09	Editorial revisions from NBMCA, addition of recommendations for future study

Signature Page

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Executive Summary

A diatom-based paleolimnological investigation was undertaken to assess long-term changes in trophic state conditions of Callander Bay in Lake Nipissing. Diatoms are a group of unicellular algae with cell walls that are composed of silica and preserve well in the sediments of most aquatic systems. They are abundant in most freshwater environments and are excellent indicators of environmental conditions because they have well defined ecological preferences. Total phosphorus concentrations were reconstructed by applying a model developed from Ontario lakes to the fossil diatom assemblages in a sediment core from Callander Bay to give a reliable record of changes that have occurred over the past ~400 years. Results from this study confirmed that total phosphorus concentrations have remained relatively stable in recent decades, but that a significant increase occurred coincident with the construction of the Portage Dam in 1949-1950 at the outlet of Lake Nipissing. Operation of the dam resulted in an overall decrease in water levels in Lake Nipissing, particularly during the spring melt period, which would have reduced the available volume of water for assimilation of phosphorus loads thereby causing increased phosphorus concentrations. Operation of the dam may have also resulted in a combination of physical changes to Callander Bay including an altered mixing regime, changes in flushing rates and mixing with waters in the main basin of Lake Nipissing, exposure of productive low lying areas, and increased the size of the shallow littoral zone, all of which could contribute to increased phosphorus concentrations. While the exact mechanism of change cannot be determined without further study, phosphorous concentrations in Callander Bay appear to have been sensitive to hydrological changes resulting from operation of the Portage Dam.

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1. Introduction

The North-Bay Mattawa Conservation Authority has been facilitating the completion of technical studies in support of Drinking Water Source Protection Planning under the *Clean Water Act* (2006) for the Municipality of Callander. In the draft report ***Source Water Protection Planning Studies for the Municipality of Callander – Surface Water Vulnerability Analysis*** (Gartner Lee Limited (now AECOM Canada), September 4, 2008) concern was raised regarding the highly productive, or 'eutrophic' condition of Callander Bay of Lake Nipissing, the municipal drinking water source for Callander, and its implications for drinking water quality. Specifically, there have been past reports of algal blooms by local residents and in 2007, phytoplankton monitoring results indicated high levels of cyanobacteria, commonly known as 'blue green algae', with a relatively high proportion of toxin-producing forms. While the levels of cyanobacteria biomass observed in 2007 would be considered to pose "relatively mild and/or low probabilities of adverse health effects" from recreational body contact based on World Health Organization (WHO) guidelines (Chorus and Bartram, 1999), there is concern about potential increases in cyanobacteria production. In addition to potential toxin formation, high algal biomass in Callander Bay may contribute to taste and odour problems of the drinking water source and to elevated dissolved organic carbon (DOC) levels that can cause the formation of trihalomethanes (THMs) in the treated drinking water.

Phosphorus is the nutrient that limits the growth of aquatic plants including algae in most Precambrian Shield lakes. Based on monitoring data collected over the past ~20 years, total phosphorus concentrations have been relatively stable in Callander Bay with a mean concentration of 23 μg/L, which exceeds the Provincial Water Quality Objective of 20 μg/L for the protection against nuisance growth of aquatic plants including algae (GLL, 2008).

While some lakes are naturally eutrophic with relatively large natural sources of phosphorus, other lakes may have become more productive due to inputs of phosphorus from human activities (e.g., sewage disposal, agriculture, land-clearance, urban runoff, fertilizer use, etc.). In some situations, phosphorus contained in lake sediments can contribute to a large proportion of the phosphorus in lakes by a process called internal phosphorus loading. Internal phosphorus loading can occur if sediments become resuspended in the water column or if the water column becomes oxygen-deficient (anoxic). Internal phosphorus loading can be enhanced by changes in mixing patterns (i.e., stratification patterns) resulting from climate change and changes in hydrology.

There are several human activities that may have contributed to the currently productive nature of Callander Bay, and there is also evidence for internal phosphorus loading (GLL, 2008). In the absence of monitoring data of sufficient length and/or quality, however, changes in phosphorus concentrations over time and the impacts of human disturbance relative to natural causes (e.g., climate change and variability) remain unknown. This information is critical for setting realistic lake management targets informed by baseline conditions, predicting future changes, and making sound lake management decisions to protect and enhance the water quality of Callander Bay as a drinking water source and valued landscape feature.

When traditional monitoring data are lacking, paleolimnology, the study of past environmental conditions using information contained in the sediment record of water bodies, can provide quality, high-resolution historical records of water quality to address a variety of key lake management issues, such as:

- nutrient enrichment
- acidification
- climate change
- algal blooms
- fish habitat
- flood and drought cycles
- species invasion
- oxygen status
- pollution

In March 2008, the NBMCA retained AECOM Canada (formerly Gartner Lee Limited) to conduct a paleolimnological study of Callander Bay to answer several key questions related to phosphorus concentrations to inform Drinking Water Source Protection studies for Callander Bay:

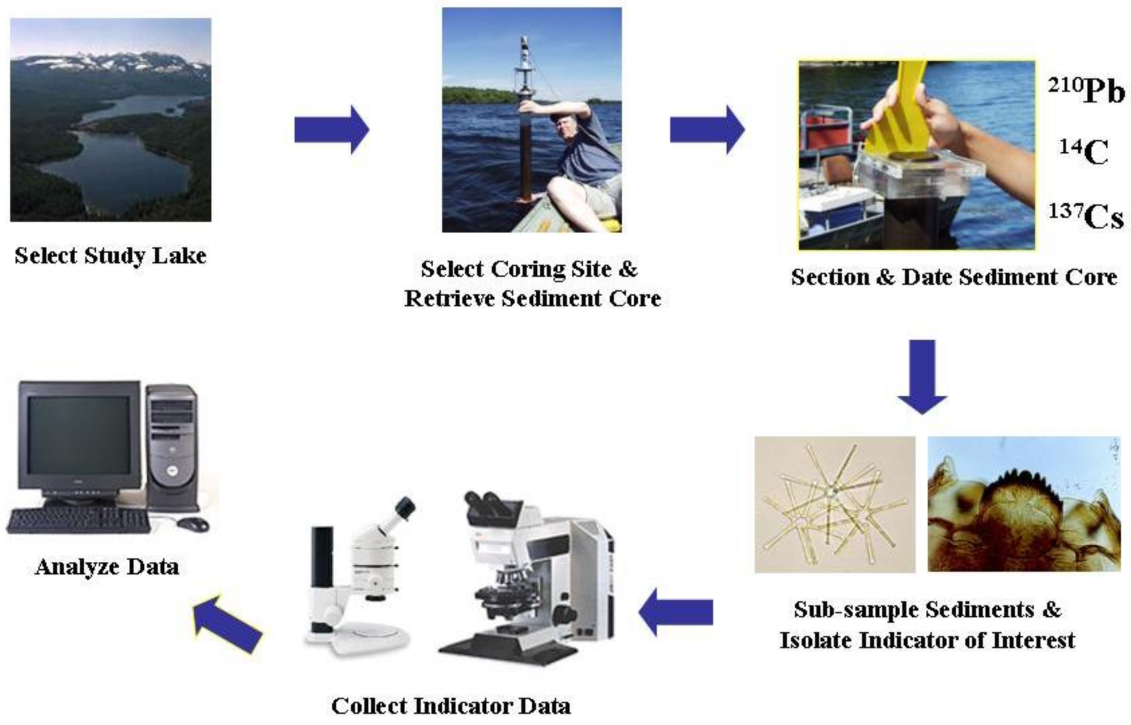
1. What is the natural phosphorus concentration in Callander Bay?
2. Have phosphorus concentrations changed since pre-settlement times?
3. If changes have occurred, when did they occur and what were the causes of those changes?
4. Is there a trend toward increasing phosphorus concentrations in recent years and hence increasing algal production in Callander Bay?
5. What is the role of climate change on phosphorus dynamics in Callander Bay?

2. Approach

2.1 General Paleolimnological Approach

Paleolimnology is conceptually simple. As sediments accumulate at the bottom of a lake basin, so do physical, chemical and biological indicators of environmental conditions that exist at the time of deposition. Assuming that the sediments containing these indicators are deposited in an orderly fashion, indicators can be isolated from the sediment matrix at increasing depths to provide a record of environmental conditions going back in time, from years to millennia. Figure 1 illustrates the basic approach for paleolimnological assessments.

Figure 1. The paleolimnological approach to environmental assessment.

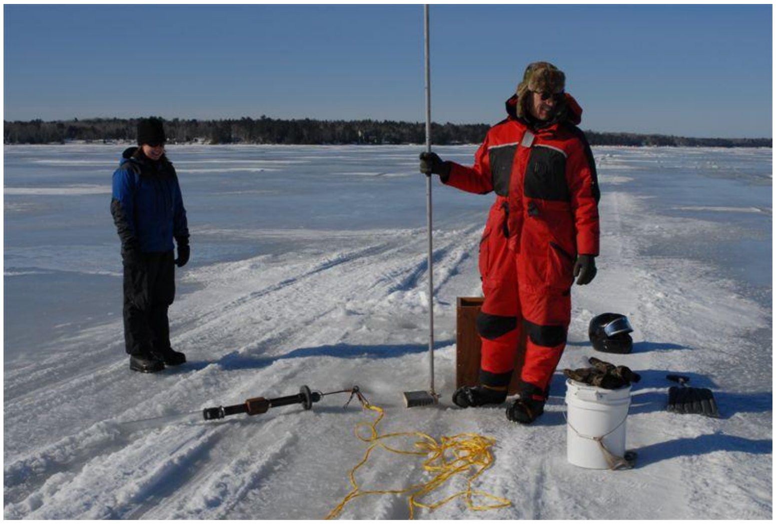


Photos courtesy of B. Cumming, I. Walker, Dell & Leica

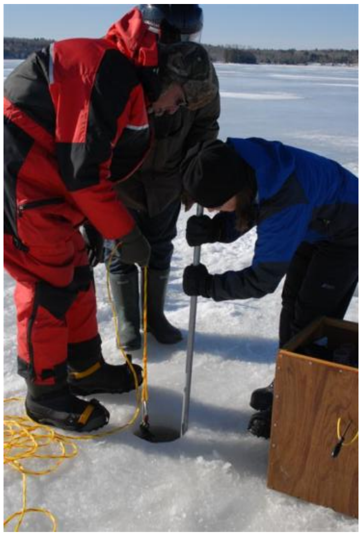
Each step of the paleolimnological approach relies on specific standard methods that have been published extensively in the scientific literature (e.g., Last and Smol (2001), Smol (2008), Smol et al. (2001)). The following sections provide only an overview of the methods used and specific details related to the Callander Bay study.

2.2 Sediment Collection

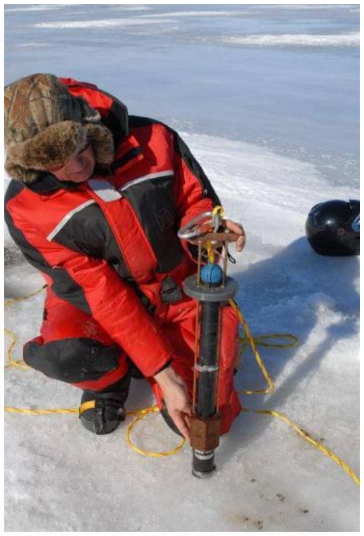
An 84-cm long sediment core was retrieved through ice cover from near the centre of Callander Bay on March 25, 2008 by NBMCA staff and a local resident, Mr. Jean-Marc Filion. The coring apparatus was constructed by Mr. Filion, and consisted of a push-rod type end-filling corer fitted with a 2.5-cm diameter core tube. The sediment core was extruded by pushing sediments up from the bottom of the core tube, and sectioned at 1-cm intervals. Sediment samples were placed in plastic bags and shipped to Queen's University (Drs. Brian Cumming and Kathleen Laird) for physical analyses (loss-on-ignition, water content, dry weight), dating, and preparation for diatom analysis. Unused sediments are stored at the Paleoecological Environmental Assessment and Research Laboratory (P.E.A.R.L.) in the biology department at Queen's University.



Coring apparatus with push rod, corer and core tube.



The corer and core tube are lowered through the ice and the core tube is manually pushed into the sediments to the desired depth using the push rod.



The top of the core tube is sealed to create suction and is lifted to the surface.

The core is sectioned into discrete intervals by pushing the sediments up from the bottom of the core tube and removing the sediments from the surface of the core.

2.3 Physical Sediment Characteristics

Wet sediment weight was determined for each sediment interval, and subsamples from 18 selected sediment intervals were analyzed for % water, and organic and carbonate content (by loss-on-ignition at 550ºC and 925ºC, respectively).

2.4 Dating

Subsambles from the 18 sediment intervals used for physical analyses (Section 2.3) were analyzed for radioisotopes of lead (^{210}Pb) and caesium (^{137}Cs) by gamma spectrometry for dating. Sedimentation rates and the age-depth profile of the sediment core were determined from changes in the activity of ^{210}Pb in the sediments using the Constant Rate of Supply (CRS) dating model (Appleby and Oldfield, 1978). Sediment samples older than 150 years were interpolated based on linear extrapolation of the mean CRS-modeled sedimentation rate. The ^{210}Pb dates were verified against the ^{137}Cs-derived date of 1968. In the Northern Hemisphere, peak ^{137}Cs activity levels in lake sediments generally coincide with 1968, the year of maximum nuclear testing. Corroboration of these two dating methods lends confidence to the age-depth profile.

2.5 Diatom Analysis

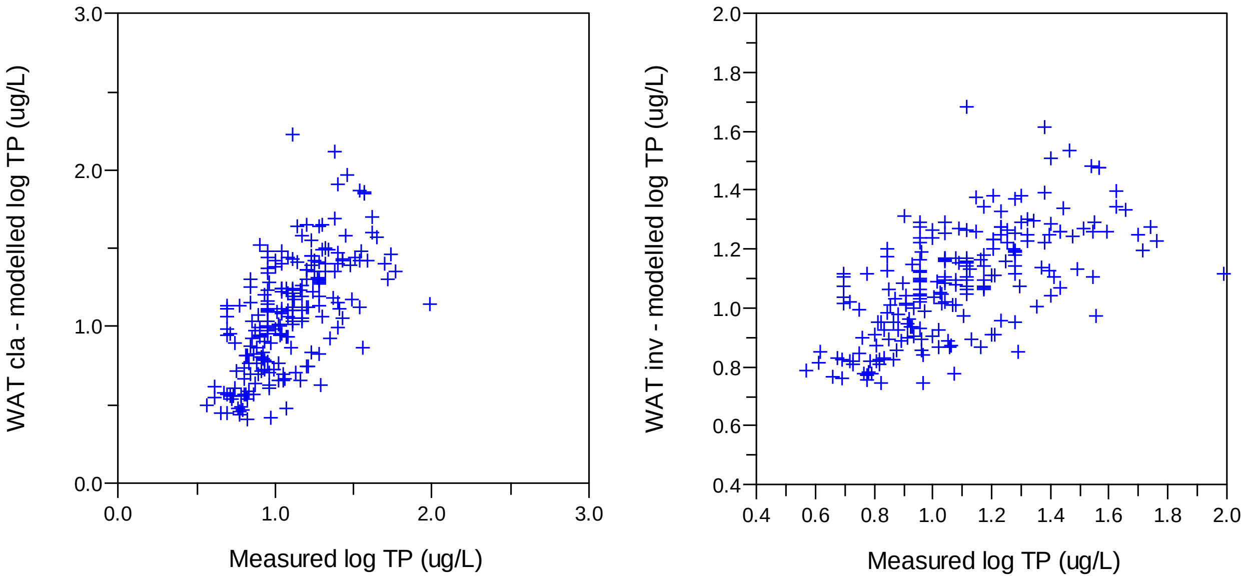
Diatom samples from 22 sediment intervals were prepared using standard strong-acid digestion techniques and mounted on glass microscope slides with Naphrax®, a highly refractive mounting medium. A minimum of 250 diatom valves from 22 sediment intervals was identified to the lowest taxonomic level possible at 1,500 times magnification using a Nikon light microscope with differential interference optics. Diatom enumeration was performed by Dr. Karst-Riddoch using primarily the taxonomy of Kramer and Lange-Bertalot (1986-1991). Diatom data were expressed as taxon relative abundances (%) of the total sum of the diatom valves in each sample. Changes in water quality conditions in Callander Bay were assessed qualitatively based on known ecological preferences of the dominant diatom taxa.

2.6 Total Phosphorus Reconstruction

Total phosphorus concentrations were inferred for Callander Bay using a diatom-based weighted-averaging transfer function developed by Dr. Dörte Köster (Gartner Lee Limited, 2008). This type of empirical model relates the composition of modern diatom algae data from a group of lakes to their present-day total phosphorus concentrations. Using the mathematical relationship between the algae and phosphorus, historical phosphorus concentrations can then be inferred from the fossil diatom assemblages in the sediment core.

For the model used in our study, the data from three previously published diatom models in Ontario (Hall and Smol 1996; Reavie and Smol 2001; Werner and Smol 2005) and one unpublished dataset (Prévost, unpublished) were compiled into one large set of Ontario lakes (210 lakes). This procedure has the advantage that information contained in all of these datasets is combined, thereby encompassing a wider range of lake conditions and improving model performance. The numerical methods we used were weighted averaging with inverse and classical deshrinking, respectively, as well as tolerance down-weighting, as these methods resulted in the best model performance. The historical total phosphorus concentrations that we present are an average of the results of both methods, in order to provide a "consensus" reconstruction, as recommended by Birks (1995). The models had a statistical performance that is similar to the previously published models, with an R^2_{jack} (jackknifed[1] coefficient of determination) of the correlation between measured and modelled total phosphorus concentrations of 0.40 and 0.41, respectively (as compared to Hall and Smol: 0.41, Reavie and Smol: 0.47, Werner and Smol: 0.44) (Figure 2).

Figure 2. Measured versus modeled total phosphorus concentrations in 210 Ontario lakes, using a weighted averaging diatom inference model with classical (left panel) and inverse (right panel) deshrinking.



The fossil diatom species found in the Callander Bay sediment core were very well represented in the model. Between 90 and 99% of the diatoms found in the sediment samples were present in the model. This indicates that the model is appropriate for use in the Callander Bay paleolimnological study.

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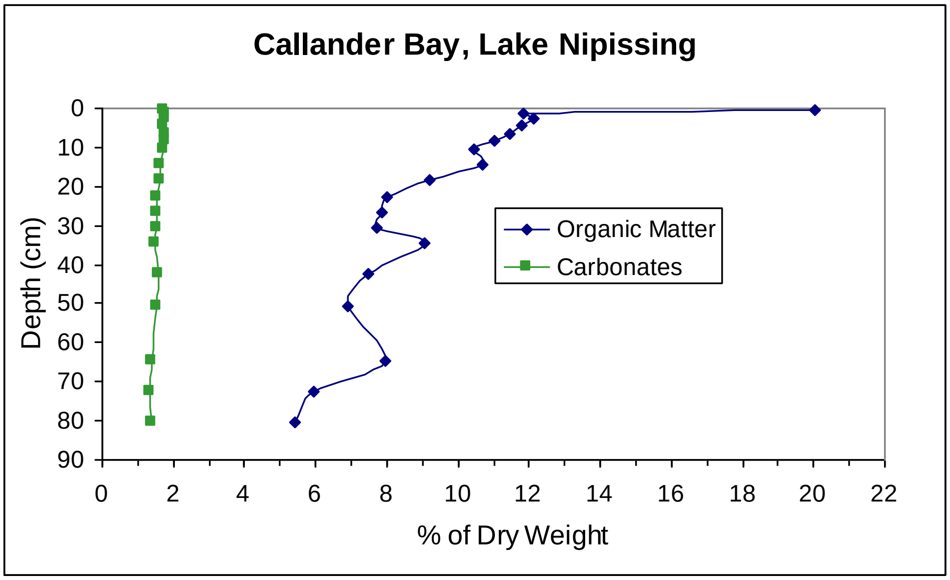
[1] *The jackknife algorithm re-samples from the original dataset by eliminating one of the sites each time, builds the model with the data from the remaining sites and applies the model to the data from the excluded site. This removes the circularity that would occur when data from a site are compared with data produced by a model that includes the same site.*

3. Results

3.1 Physical Sediment Characteristics

Percent organic matter in the sediment core varied from approximately 5 to 12% then increased to more than 20% in the topmost sediment interval (Figure 3). Overall, there is an increase in organic matter content of the sediments over time. Increases in organic matter can be attributed to several factors including increased in-lake production of organic matter, increased influx of organic matter, or decreases in the load of inorganic matter to the lake. Additionally, increases in organic matter in the upper most sediment intervals may be due to taphonomic processes, such that complete decomposition of organic matter has not yet occurred. Carbonate content of the sediments remain stable throughout the core indicating that there have been no major changes in the flux of carbonate materials to the lake. Physical sediment data are provided in Appendix A.

Figure 3. Organic matter and carbonate profiles for the Callander Bay sediment core.



3.2 Chronology and Sedimentation Rates

^{210}Pb activity in lake sediments is comprised of 1) ‘supported’ ^{210}Pb (also called background ^{210}Pb), which originates from ^{222}Rn decay that occurs in the sediment and 2) ‘unsupported’ ^{210}Pb, which originates from the ^{222}Rn decay that occurs in the atmosphere and the water column. The half life of ^{210}Pb is 22.3 years, and so, unsupported ^{210}Pb should decline exponentially reaching supported levels in ~150 years.

For the Callander Bay core, ^{210}Pb activity declines about exponentially with depth from 1 cm to the bottom of the core (Figure 4). In the topmost sediment interval, ^{210}Pb levels are lower than expected. This pattern is common in the uppermost sediment intervals because of incomplete taphonomic processes, which is supported by the increase in organic matter content at the top of the sediment core. Background ^{210}Pb activity of 1.37 dpm/g is reached between 31 and 34 cm downcore[2]. The resulting age-depth profile for Callander Bay based on the Constant Rate of Supply model is illustrated in Figure 5. Using linear extrapolation for sediment depths where unsupported ^{210}Pb is zero, the Callander Bay core dates back to between 1667 and 1625 encompassing the entire post-European settlement history of the Callander area.

A distinct ^{137}Cs peak provides an estimate for 1964, the year of maximum testing of nuclear weapons and fallout of ^{137}Cs. For Callander Bay, the peak in ^{137}Cs occurs at 6.5 cm in the core, but due to sampling resolution, the peak could exist anywhere between 5 and 8 cm in the core, corresponding to a ^{210}Pb date between ~1991 and ~1968. In addition, the caesium peak is not well-defined, with activity levels remaining relatively constant from 8.5 cm to the top of the core. This indicates that there has been some post depositional upward movement of caesium in the core, and so the 1964 peak most likely occurs deeper in the sediment core (closer to 8 cm).

Sedimentation rates in Callander Bay have varied considerably over the past ~400 years (Figure 6). Notably, sedimentation rates increased consistently from the turn of the 20th century reaching maximum rates between 1933 and 1956. Rates then declined by 1968 and remained constant to 2007. The increase in sediment rate in the topmost sediment interval is most likely an artefact due to incomplete taphonomic processes as described previously.

All radioisotope data and chronology calculations are provided in Appendix A for reference.

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[2] *Background ^{210}Pb was calculated as the mean of 1) mean ^{214}Bi activity, and 2) mean ^{210}Pb activity of the bottom 6 ^{210}Pb values.*

Figure 4. Radioisotope profiles (^{210}Pb, ^{214}Bi and ^{137}Cs) for the Callander Bay sediment core.

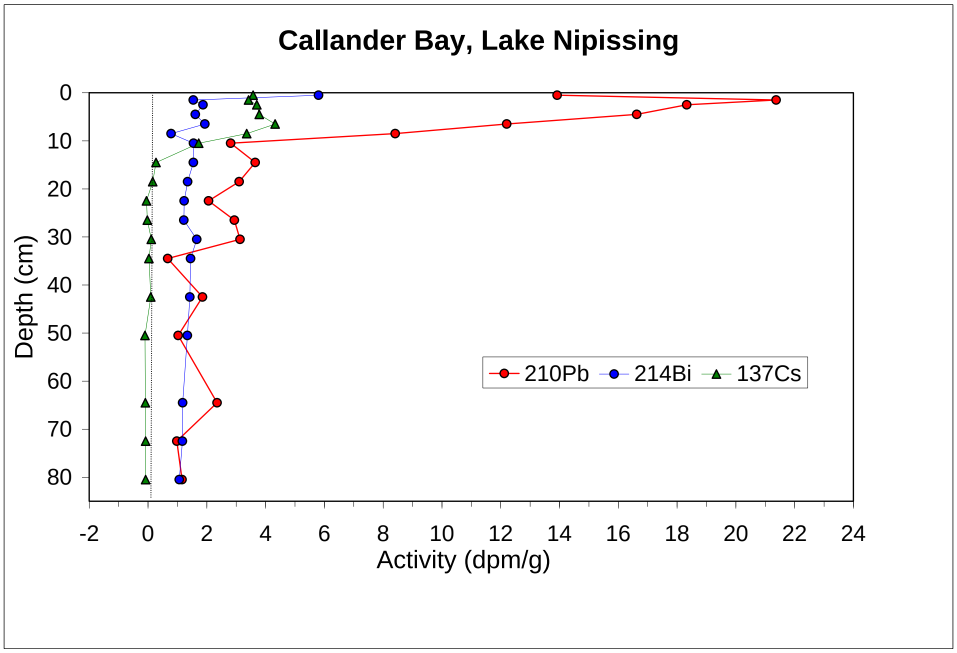


Figure 5. Age-depth profile for the Callander Bay sediment core.

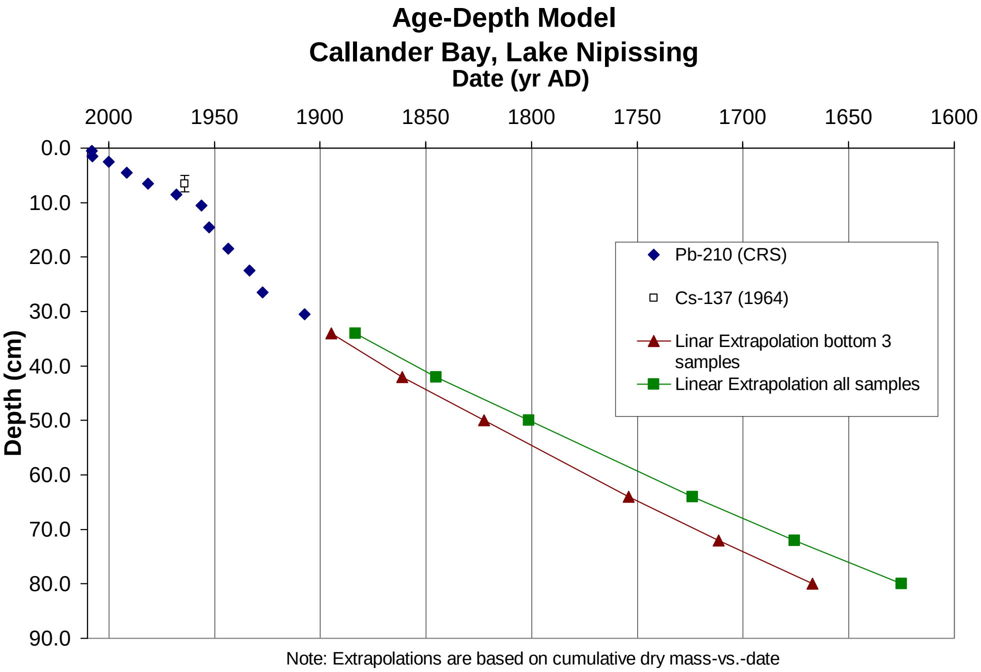
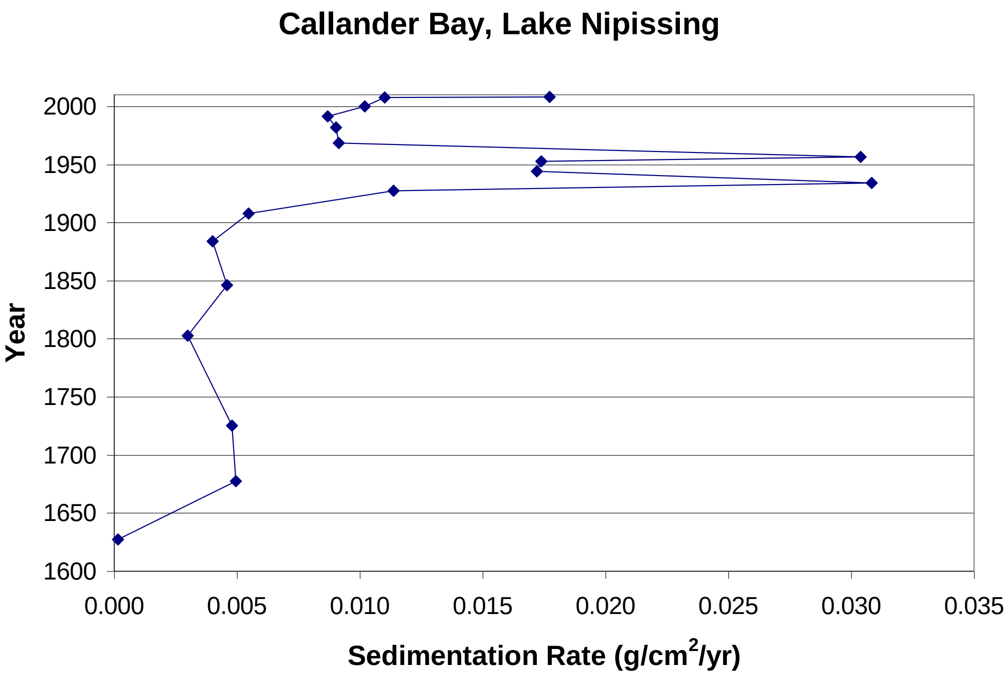


Figure 6. Sedimentation rates for the Callander Bay sediment core.



3.3 Diatom Assemblages and Total Phosphorus Reconstructions

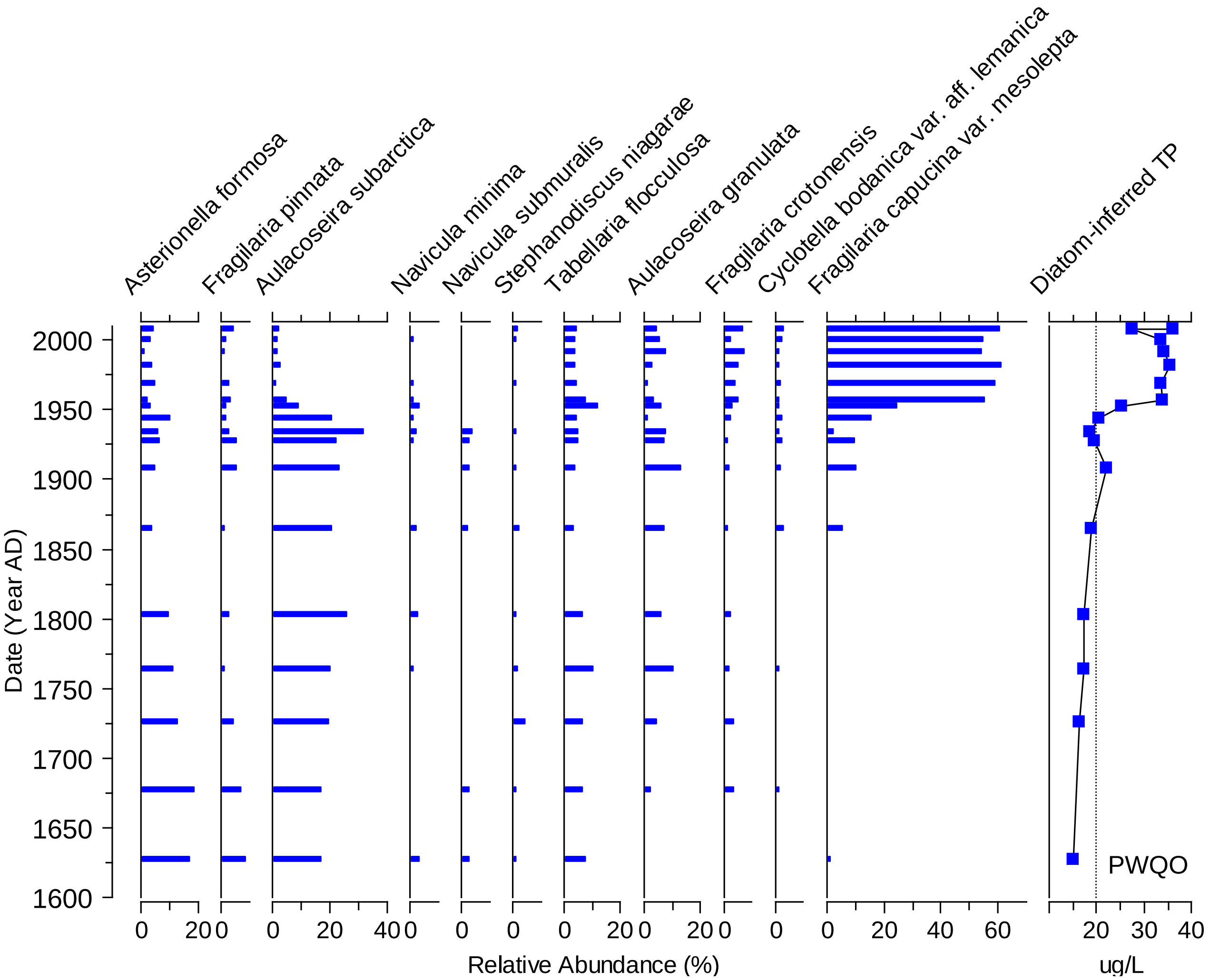
A total of 107 diatom taxa were identified in the Callander Bay sediment core. The full list of taxa and their relative abundances are provided in Appendix B. Figure 7 summarizes the changes in relative abundance of the dominant diatom taxa and the diatom-inferred total phosphorus concentrations in Callander Bay over the past ~400 years.

From the early 1600s to the late 1800s, the diatom assemblages were dominated by planktonic diatoms that are indicative of moderately productive (mesotrophic conditions), including *Asterionella formosa*, and *Aulacoseira subarctica*. Small benthic *Fragilaria pinnata* also dominated the assemblages, representing up to 10% of the total abundance of diatoms. This taxon is considered a generalist, but is commonly found in relatively alkaline environments and is tolerant of low light conditions associated with extended periods of ice cover, or turbidity. Small epiphytic *Navicula minima* and *N. submuralis* were also common. Diatom-inferred total phosphorus concentrations were relatively stable over this ~300-year period and ranged between 15.2 and 17.3 μg/L with a mean concentration of 16.6 μg/L.

Subtle changes in the diatom assemblages occurred beginning in the late 1800s. Most notable was an increase in the eutrophic diatom indicator, *Fragilaria capucina* var. *mesolepta*, from trace levels to a relative abundance of ~10%. The planktonic diatom *Cyclotella bodanica* var. aff. *lemanica*, also indicative of productive conditions, appeared for the first time in the record in 1864 and remained a consistent component of the diatom assemblages to the top of the core, albeit in low relative abundances of less than 5%. Diatom-inferred total phosphorus concentrations increased from previous years to a mean of 20.0 μg/L.

Between 1948 and 1952, a major change occurred in the diatom assemblages. The relative abundance of *A. subarctica* declined from its previous abundance of between 20 and 30% to less than 5% and other diatoms (*Fragilaria crotonensis, Fragilaria capucina* var. *mesolepta*) indicative of more productive conditions increased in relative abundance. This change in diatom assemblages resulted in an increase in diatom-inferred total phosphorus concentration to 25.1 μg/L in 1952. Phosphorus concentrations remained elevated and relatively stable from 1952 to 2007 with a mean concentration of 32.5 μg/L.

Figure 7. Profiles of dominant diatom taxa and diatom-inferred total phosphorus concentrations for Callander Bay.



4. Discussion

The paleolimnological record from the Callander Bay sediment core spans to the time of early exploration in the North Bay and French River area by Samuel de Champlain in the early 1600s. In these early times, and for the next ~250 years, the diatom assemblages changed little and suggest relatively stable phosphorus concentrations indicative of moderately productive (mesotrophic conditions). Diatom-inferred phosphorus concentrations during this time were ~16 μg/L.

Over the past ~150 years since European settlement in the area, changes in the sedimentary diatom assemblages suggest that Callander Bay has become nutrient-enriched. A summary of changes in the Callander Bay sediment record since settlement, and major historical events that could have contributed to the eutrophication of Callander Bay are provided in Figure 8. Following settlement in the Callander Bay in the mid 1800s, there were subtle changes in the diatom assemblages indicative of slight nutrient enrichment to a mean diatom-inferred TP of 20 μg/L between ~1850 and ~1950. Human activities in the watershed including logging, agriculture and saw mill activity in the bay most likely contributed to this increased lake productivity by increasing the phosphorus load to the bay. In addition, the building of the Big and Little Chaudiere dams at the outlet of Lake Nipissing in 1916 may have altered the hydrological conditions of Callander Bay, potentially contributing to nutrient enrichment. Water level records, however, do not extend to this time and so the effect of these dams on hydrology, water quality and nutrient dynamics in Callander Bay can only be speculated. Finally, increased lake productivity is a common observation at the turn of the 20th century in many paleolimnological records from temperate areas and has been attributed to the onset of warmer climates following the so-called 'Little Ice Age'.

The greatest changes in the paleolimnological record from Callander Bay occurred ~1950 with the notable decrease in the previously dominant planktonic diatom *Aulacoseira subarctica* and rise of the eutrophic diatom indicator *Fragilaria capucina* var *mesolepta*. *F. capucina* var. *mesolepta* can form large ribbon-like colonies that can entangle on substrates (Round et al., 1990) and is commonly found growing amongst aquatic vegetation in productive aquatic systems. This change in the diatom assemblages therefore likely indicates greater aquatic plant production in Callander Bay with an increase in total phosphorus concentrations. Diatom-inferred total phosphorus concentrations increased by more than 10 μg/L to a mean of 32.5 μg/L by ~1955-1960. It should be noted that the diatom model does not perform as well (greater error) at calculating more elevated phosphorus concentrations (greater than ~20 μg/L). This occurs in part because there are relatively few lakes in the model that have phosphorus concentrations higher than 20 μg/L. Despite inaccuracies of the model, the mean inferred phosphorus concentration of 32.5 μg/L compares reasonably well with the measured mean ice free concentration in Callander Bay of 24 μg/L (based on 2002, 2008 and 2007 data). These concentrations exceed the Provincial Water Quality Objective of 20 μg/L for the protection against growth of nuisance aquatic plants including algae.

Eutrophication caused by land use such as agriculture or associated with climate variability would be expected to occur gradually over the course of decades or more. For Callander Bay, the relatively rapid change in diatom assemblages ~1950 indicative of eutrophication suggests the influence of a sudden or abrupt impact on Callander Bay that altered nutrient dynamics. It is possible that the ~1950 eutrophication of

Callander Bay resulted from hydrological changes associated with the construction of the Portage Dam at the outlet of Lake Nipissing in the same year.

Portage Dam at French River

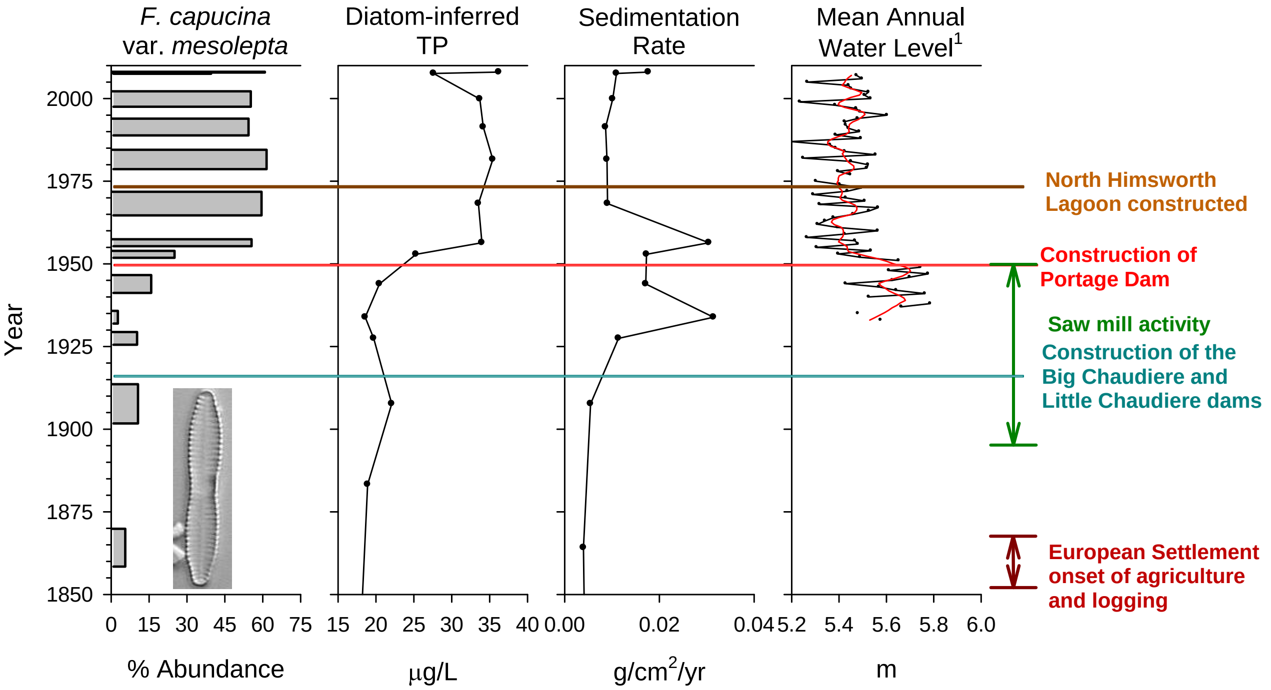
The Portage Dam is owned and operated by the Government of Canada, along with the Big Chaudière and Little Chaudière dams. This dam was constructed to more effectively control water levels in Lake Nipissing and to avoid large scale flooding of the lake like that which occurred in the spring of 1947. To construct the dam, a large channel was blasted at the outlet of Lake Nipissing to the French River, which could effectively double the discharge out of Lake Nipissing. In October of each year, after Thanksgiving weekend, waters are released from the French River dams to lower lake levels by approximately 1.3 m (~1 cm/day until March 15) in order to accommodate spring runoff (Phil Hall, MNR North Bay, Pers. comm.). The summer operating level for Lake Nipissing is 195.75 m a.s.l. however lake water levels are very sensitive to precipitation and can fluctuate up to half a meter during the open water season following precipitation events (PWGSC, 2007). Based on water level data in Lake Nipissing at North Bay, mean annual water levels since construction of the Portage Dam have been significantly lower than those prior to the dam between 1933 and 1950 (T test, $p<0.001$) by about 0.2 m.

There are several possible mechanisms by which operation of the Portage Dam may have altered nutrient dynamics in Callander Bay resulting in eutrophication of the bay. For example, lowering of water levels and thus a reduction in lake volume could have increased phosphorus concentrations given the same phosphorus loads to the bay. Operation of the dam may have also resulted in a combination of physical changes to Callander Bay including an altered mixing regime, changes in rate and timing of flushing and mixing with waters in the main basin of Lake Nipissing, exposure of productive low lying areas, and increased the size of the shallow littoral zone, all of which could contribute to increased phosphorus concentrations. While the exact mechanism of change cannot be determined without further study, it is clear that phosphorous concentrations in Callander Bay were sensitive to this major hydrological change.

Since ~1955, diatom assemblages in Callander Bay have changed little and total phosphorus concentrations are inferred to have remained relatively constant with a mean of 32.5 μg/L. There is no evidence from the diatom record to suggest further eutrophication of Callander Bay since ~1955 despite known land use changes (e.g., shoreline development) that can increase phosphorus loads to the bay and point source nutrient loads from the township’s wastewater lagoon. Additional studies, such as the development of a detailed nutrient budget, would be required to determine the relative influence of these sources on phosphorus concentrations in Callander Bay.

Unfortunately, the present study is not able to reconstruct bluegreen algal productivity in Callander Bay. This type of reconstruction is possible by analyzing algal pigments contained in the sediment using high performance liquid chromatography (HPLC).

Figure 8. Paleoenvironmental summary of Callander Bay, Lake Nipissing (1850-2008).



[1]*Mean annual water levels in Lake Nipissing at North Bay, Station 02DD006, Canadian Hydrological Data, Environment Canada*

5. Conclusions and Recommendations

Analysis of sedimentary diatom assemblages indicates that Callander Bay was moderately productive (mesotrophic) for at least 250 years prior to European settlement (~1850) in the watershed. Human activities in the watershed prior to 1950 resulted in a slight increase in phosphorus concentrations, but still the bay maintained mesotrophic conditions. In ~1950, a large change in the diatom assemblages occurred that is indicative of higher total phosphorus concentrations and increased aquatic plant production in Callander Bay. The timing of this shift is coincident with the construction of the Portage Dam to control water levels in Lake Nipissing. It is hypothesized that hydrological changes resulting from the operation of the dam altered nutrient dynamics in Callander Bay thereby causing eutrophication. Eutrophic conditions have continued in Callander Bay to the present time and there is no evidence from the diatom assemblages to suggest further eutrophication in recent years.

While the paleolimnological results from this study provide very useful information about historical nutrient conditions in Callander Bay, we suggest that additional studies are required for the development of sound lake management strategies to control or reduce nutrient concentrations and the risk of cyanobacterial blooms. Recommended studies to inform lake management plans for Callander Bay include:

1. Assessment of factors controlling historical cyanobacteria blooms in Callander Bay.

There is anecdotal evidence to suggest that cyanobacteria production has increased in Callander Bay over the past several years. Unfortunately, only limited monitoring data exist to quantify algal biomass, which is insufficient to determine whether there is a pattern of increasing algal production or to assess the factors controlling bloom activity. While phosphorus concentrations often control algal production, other factors can also play a role in promoting cyanobacterial blooms (e.g., physical habitat conditions, competition, nitrogen limitation, weather patterns, climate change). A thorough understanding of previous bloom formation and factors controlling those blooms is essential for the development of effective management strategies to reduce the risk of bloom formation. To this end, we recommend that archived sediments from the Callander Bay sediment core be analyzed for fossil algal pigments to determine past algal productivity in Callander Bay and then relate any changes in algal productivity to potential controlling factors.

2. Development of a nutrient budget and model for Callander Bay

Any lake management strategy aimed at reducing nutrient concentrations requires knowledge of the sources of nutrients to the system and the response of the system to changes in nutrient loads. The present paleolimnological study has demonstrated that total phosphorus concentrations have remained relatively stable over the past several decades, however, the relative contribution of phosphorus from different sources (i.e., human and natural) to the bay are still unknown. We therefore recommend the calculation of a detailed nutrient budget that includes all phosphorus sources to the bay and then the development of a nutrient model to predict the response of Callander Bay to reduced nutrient inputs. Together, this information would provide a means to focus nutrient reduction efforts most efficiently and to set realistic remedial targets for Callander Bay.

6. References

Appleby, P.G. and F. Oldfield, 1978:
The calculation of 210Pb dates assuming a constant rate of supply of unsupported 210Pb to the sediment. Catena 5:1-8.

Birks, H. J. B. 1995 :
Quantitative paleoenvironmental reconstructions. Pages 161-254 in D. Maddy and J. S. Brew, editors. Statistical Modelling of Quaternary Science Data. Quaternary Research Association, Cambridge.

Hall, R. I., and J. P. Smol 1996:
Paleolimnological assessment of long-term water-quality changes in south-central Ontario lakes

affected by cottage development and acidification. Canadian Journal of Fisheries and Aquatic Sciences 53:1-17.

Krammer and Lange-Bertalot, 1986-1991:
Süβwasserflora von Mitteleuropa. Bacillariophyceae. Band 1-4. Spektrum Akademischer Verlag, Berlin.

Last, W.M. and J.P. Smol, 2001:
Tracking Environmental Change Using Lake Sediments. Volume 1: Basin Analysis, Coring, and Chronological Techniques. Kluwer Academic Publishers, Dordrecht.

Round, F.E., R.M. Crawford and D.G. Mann, 1990:
The Diatoms: Biology and Morphology of the Genera. Cambridge.

Smol, J.P., 2008:
Pollution of Lakes and Rivers: A Paleoenvironmental Perspective, 2nd edition. Blackwell Publishing Ltd.,Malden. 383 pp.

Smol, J.P., H.J.B. Birks and W.M. Last, 2001:
Tracking Environmental Change Using Lake Sediments. Volume 3: Terrestrial, Algal and Siliceous Indicators. Kluwer Academic Publishers, Dordrecht. 371 pp.

Reavie, E. D., and J. P. Smol 2001:
Diatom-environmental relationships in 64 alkaline southeastern Ontario (Canada) lakes: a diatom-based model for water quality reconstructions. Journal of Paleolimnology 25:25-42.

Werner, P., and J. P. Smol 2005:
Diatom-environmental relationships and nutrient transfer functions from contrasting shallow and deep limestone lakes in Ontario, Canada. Hydrobiologia 533:145-173.

Appendix A

Radioisotope and Physical Sediment Data

Callander Bay

Dating File

Core Information:

Dating Prep:

	Calendar	Numeric	Decimal
Coring Date:	25-Mar-08	**39532**	2008.00

Sample Name	Depth Interval (cm)		mid-depth (cm)	Section thickness (cm)	Dry density, ρ (g/cm3)	Dry mass (g/cm2)	Cumulative dry mass (g/cm2)
CAL 0-1	0	1	0.5	1.0	0.00689089	0.006890888	0.0069
CAL 1-2	1	2	1.5	1.0	0.07557748	0.075577481	0.0825
CAL 2-3	2	3	2.5	1.0	0.07615801	0.076158005	0.1586
CAL 4-5	4	5	4.5	1.0	0.07350432	0.073504321	0.3076
CAL 6-7	6	7	6.5	1.0	0.09848174	0.098481737	0.496988314
CAL 8-9	8	9	8.5	1.0	0.09075252	0.090752524	0.684665018
CAL 10-11	10	11	10.5	1.0	0.10079359	0.100793587	0.919297393
CAL 14-15	14	15	14.5	1.0	0.1360536	0.136053599	1.453654314
CAL 18-19	18	19	18.5	1.0	0.14847368	0.148473681	2.022138735
CAL 22-23	22	23	22.5	1.0	0.17871353	0.178713525	2.623804137
CAL 26-27	26	27	26.5	1.0	0.16799462	0.167994621	3.261959954
CAL 30-31	30	31	30.5	1.0	0.1760529	0.176052905	3.894678744
CAL 34-35	34	35	34.5	1.0	0.15196631	0.151966313	4.507426758
CAL 42-42	42	43	42.5	1.0	0.19940909	0.199409086	6.018216996
CAL 50-51	50	51	50.5	1.0	0.23088781	0.230887808	7.746644499
CAL 64-65	64	65	64.5	1.0	0.23044451	0.230444511	10.81255392
CAL 72-73	72	73	72.5	1.0	0.24813907	0.248139066	12.72068849
CAL 80-81	80	81	80.5	1.0	0.24955601	0.249556008	14.71034598

DSPEC Data:

BACKGROUND Pb-210 = 1.370
Minimum positive background value = 0.800
Minimum 210Pb value = 2.060

Pb-210 (dpm/g)	**Bi-214** (dpm/g)	**Cs-137** (dpm/g)	**Interpolated Pb-210** (dpm/g)	**Interpolated Bi-214** (dpm/g)
13.9	5.8	3.6	13.922	5.803
21.4	1.5	3.4	21.370	1.541
18.3	1.9	3.7	18.329	1.870
16.6	1.6	3.8	16.629	1.611
12.2	1.9	4.3	12.204	1.936
8.4	0.8	3.4	8.412	0.786
2.8	1.6	1.7	2.812	1.550
3.6	1.5	0.3	3.648	1.544
3.1	1.3		3.103	1.350
2.1	1.2	-0.1	2.060	1.232
2.9	1.2	0.0	2.939	1.219
3.1	1.7	0.1	3.131	1.660
0.7	1.4	0.0	0.672	1.450
1.9	1.4	0.1	1.854	1.423
1.0	1.3	-0.1	1.027	1.339
2.4	1.2	-0.1	2.352	1.179
1.0	1.2	-0.1	0.982	1.171
1.2	1.1	-0.1	1.160	1.064

Unsupported Pb-210 (CRS Model):

Unsupported **Pb-210** Measured - background (dpm/g)	Unsupported **Pb-210** per interval (dpm/cm2)	Unsupported **Pb-210** cumulative mass (dpm/cm2)	$t = \frac{1}{\lambda}\ln\left(\frac{A(0)}{A}\right)$ CRS Date (Year AD)
12.552	0.09	7.13	2008.0
20.000	1.51	7.04	2007.6
16.959	1.29	5.53	1999.8
15.259	1.12	4.24	1991.3
10.834	1.07	3.12	1981.4
7.042	0.64	2.05	1968.0
1.442	0.15	1.41	1956.0
2.278	0.31	1.26	1952.5
1.733	0.26	0.95	1943.4
0.690	0.12	0.70	1933.3
1.569	0.26	0.57	1927.1
1.761	0.31	0.31	1907.3
0.000	0.00	0.00	#DIV/0!
0.484	0.10	#REF!	#REF!
-0.343	-0.08	#REF!	#REF!
0.982	0.23	#REF!	#REF!
-0.388	-0.10	#REF!	#REF!
-0.210	-0.05	#REF!	#REF!

Extrapolating Entire Core

all samples bottom 3 sample bottom 4 samples - bottom

CRS Date (Year AD)

Interval Midpoint	1. Cum Mass Reg Line	2. Cum Mass Reg Line	3. Cum Mass Reg Line
	-0.0395	-0.0448	-0.0743
	78.953	89.378	146.379
0.5	2008.0	2008.0	**2008.0**
1.50	2007.6	2007.6	**2007.6**
2.50	1999.8	1999.8	**1999.8**
4.50	1991.3	1991.3	**1991.3**
6.50	1981.4	1981.4	**1981.4**
8.50	1968.0	1968.0	**1968.0**
10.50	1956.0	1956.0	**1956.0**
14.50	1952.5	1952.5	**1952.5**
18.50	1943.4	1943.4	**1943.4**
22.50	1933.3	1933.3	**1933.3**
26.50	1927.1	1927.1	**1927.1**
30.50	1907.3	1907.3	***1917.7***
38.50	*1883.3*	*1894.7*	***1909.4***
50.50	*1845.0*	*1861.0*	***1889.1***
58.50	*1801.3*	*1822.4*	***1865.8***
64.50	*1723.8*	*1754.0*	***1824.6***
72.50	*1675.5*	*1711.4*	***1798.9***
80.50	*1625.2*	*1667.0*	***1772.1***

Cesium-137 Peak:

extrapolated using mean of c

Cs-137 depth	**Cs-137 (1964** (Year AD)	**Cs-137** ± error
6.5	1964	1.5

Appendix B

Diatom Data

Callander Bay

1-cm intervals

Midpoint (cm)	**0.5**	**1.50**	**2.50**	**4.50**	**6.50**	**8.50**	**10.50**	**14.50**	**18.50**	**22.50**	**26.50**	**30.50**	**38.50**	**50.50**	**58.50**	**64.50**	**72.50**	**80.50**
Taxon	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
Achanthes flexella	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.68	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Achnanthes bioretti	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Achnanthes calcar	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.00	0.00	0.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Achnanthes carissima	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.80	0.00	0.00	0.00	0.00	0.00
Achnanthes delicatula	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.27	0.00	0.00	0.00	0.00	0.00	0.00
Achnanthes didyma	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.80	0.00	0.00	0.00	0.00	0.00
Achnanthes exigua	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.66	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Achnanthes impexa	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.68	0.00	0.00	0.00	0.00	0.00	0.00	0.65	0.00	0.00
Achnanthes lacus-vulcani	0.00	0.00	0.00	0.00	0.00	0.60	0.00	0.71	0.00	0.00	0.00	0.00	0.80	0.00	0.00	0.00	0.00	0.00
Achnanthes lanceolata var. frequentissima	0.36	0.00	0.00	0.00	0.00	0.89	0.00	0.00	1.01	0.66	0.66	1.33	1.20	0.33	1.12	0.00	0.61	1.22
Achnanthes lanceolata var. rostrata	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.34	0.00	0.66	0.00	0.00	0.00	0.74	1.31	0.00	1.22
Achnanthes laterostrata	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.66	0.00	0.00	0.00	0.00
Achnanthes minutissima	0.71	0.64	0.00	0.61	0.58	0.00	1.21	0.71	1.69	0.00	1.33	0.53	2.40	1.33	1.49	0.00	1.82	3.34
Achnanthes nitidiformis	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.61	0.00
Achnanthes peragalli	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.61
Achnanthes rosenstockii	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.66	0.00	0.00	0.00	0.00
Achnanthes sp.	0.00	0.32	0.00	0.00	0.00	0.00	0.00	0.71	0.00	0.33	0.00	0.27	0.00	0.00	0.74	0.33	0.00	0.00
Achnanthes subatomoides	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.66	0.00	0.00	0.00	0.74	0.00	0.00	0.00
Achnanthes suchlandtii	0.00	0.00	0.00	0.61	0.00	0.00	0.00	0.00	1.35	0.00	0.66	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Achnanthes ventralis	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.66	0.00	0.00	0.61	0.00
Amphipleura pellucida	0.00	0.00	0.00	0.00	0.00	0.30	0.00	0.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Amphora inariensis	0.00	0.00	0.32	0.00	0.00	0.00	0.00	0.00	0.34	0.00	0.00	0.27	0.00	0.00	0.00	0.65	0.61	0.00
Asterionella formosa	3.20	4.50	3.54	1.82	4.37	5.36	2.72	3.89	10.47	6.27	6.64	5.05	4.40	9.97	11.52	13.40	18.79	17.33
Aulacoseira ambigua	11.39	14.79	15.43	13.07	7.29	6.25	3.02	15.19	7.43	13.20	10.96	10.37	9.60	10.96	14.50	17.32	6.36	2.13
Aulacoseira crenulata	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.66	0.00	0.00	0.00	1.86	0.00	0.00	0.00
Aulacoseira distans	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.35	0.68	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00
Aulacoseira granulata	4.98	4.50	6.11	7.90	3.21	1.49	3.63	6.71	1.35	8.25	7.64	13.30	7.60	6.31	10.78	4.90	2.73	0.30
Aulacoseira granulata var. angutissima	0.00	0.00	0.00	0.00	0.00	0.30	0.30	0.35	0.34	0.66	0.66	1.33	0.80	1.33	0.74	0.33	1.82	0.00
Aulacoseira islandica	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.06	0.00	1.32	1.33	0.53	5.60	3.99	0.00	2.29	0.00	2.13
Aulacoseira italica	1.07	0.00	0.00	0.00	0.00	0.00	0.00	1.06	0.00	0.00	0.33	0.00	1.60	0.00	0.74	0.00	0.00	0.00
Aulacoseira sp	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.35	0.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aulacoseira subarctica	1.42	2.57	1.93	2.13	2.92	1.79	5.44	9.54	20.95	32.34	22.59	23.67	21.20	26.58	20.45	20.26	17.27	17.33
Caloneis cf. lauta		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.61	0.00
Cocconeis placentula var. euglypta	0.00	0.00	0.00	0.00	0.00	0.60	0.00	0.00	0.00	0.00	0.00	0.27	0.00	0.00	0.00	0.00	0.00	0.00
Cocconeis placentula var. lineata	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.74	0.33	0.00	0.00
Cyclostephanos dubius	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.35	1.69	2.31	0.00	0.00	0.80	0.00	0.00	0.00	0.30	0.00
Cyclotella bodanica var. aff. lemanica	1.07	3.54	2.57	1.22	1.46	2.38	1.51	1.77	2.70	1.32	2.99	2.39	3.60	0.66	1.12	0.65	0.91	0.00
Cyclotella distinguenda	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cyclotella menenghiniana	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.66	0.00	0.65	1.21	0.00
Cyclotella michighaniana	0.36	0.00	0.00	0.00	0.00	0.00	0.00	0.71	0.00	0.66	0.66	0.00	2.40	0.00	0.74	0.98	0.61	0.00
Cyclotella pseudostelligera	2.14	2.89	1.93	1.22	0.58	3.87	1.81	2.47	4.05	2.97	2.66	1.33	3.60	2.66	5.58	3.59	3.64	7.29
Cyclotella stelligera	0.00	0.64	0.00	0.00	0.58	0.30	0.30	0.35	0.34	0.00	0.66	0.00	0.00	0.00	0.74	0.98	1.52	0.00
Cymatopleura elliptica	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cymatopleura solea	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30
Cymbella cf. caespitosa	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00
Cymbella minuta	0.00	0.32	0.00	0.00	0.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.80	0.00	0.74	0.00	0.00	0.00
Cymbella proxima	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.65	0.00	0.00
Cymbella silesiaca	0.71	0.32	0.00	0.00	0.00	0.00	0.00	1.41	1.01	0.00	0.00	0.00	0.00	0.00	0.00	0.65	1.21	0.61
Diploneis elliptica	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.68	0.00	0.00	0.27	0.00	0.00	0.00	0.33	1.82	0.91

Diploneis marginestriata	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.66	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Diploneis petersenii	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Entomoneis ornata	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.74	0.00	0.00	0.00
Entomoneis paludosa	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00
Epithemia adnata	0.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00
Epithemia turgida	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.53	0.00	0.00	0.00	0.00	0.00	0.00
Eunotia glacialis	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.80	0.00	0.00	0.00	0.00	0.00
Eunotia incisa	0.00	0.00	0.00	0.00	0.58	0.00	0.00	0.35	0.00	0.00	0.00	0.00	0.00	0.66	0.00	0.00	0.00	0.00
Fragilaria brevistriata	0.00	2.89	0.00	0.00	0.00	0.00	1.51	0.00	0.68	0.66	0.00	0.00	0.00	1.33	0.00	0.65	1.82	0.00
Fragilaria capucina	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.68	0.00	0.66	2.13	1.60	1.99	0.00	0.00	0.00	0.00
Fragilaria capucina var. mesolepta	60.85	39.55	55.31	54.41	61.52	59.52	55.59	25.09	15.88	2.64	10.30	10.64	5.60	0.00	0.00	0.00	0.00	1.52
Fragilaria capucina var. vaucheriae	0.00	0.64	0.00	0.00	0.00	0.00	0.00	0.00	2.03	0.00	0.66	0.00	0.00	0.66	0.00	0.65	0.00	0.00
Fragilaria construens	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00
Fragilaria construens var. venter	0.00	0.00	0.00	0.00	1.17	0.60	0.00	0.00	0.00	0.00	1.33	0.00	0.00	1.99	0.00	0.00	0.00	0.00
Fragilaria crotonensis	2.49	7.40	2.57	7.90	5.83	4.17	5.44	3.18	2.70	0.66	1.00	2.13	1.60	2.66	2.23	3.92	3.64	0.61
Fragilaria nanana	0.71	0.00	0.00	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.80	0.00	0.00	0.65	0.00	0.00
Fragilaria parasitica	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.82
Fragilaria pinnata	0.00	4.82	1.93	1.82	0.58	3.27	3.63	2.12	2.03	3.30	5.65	5.85	1.60	2.99	1.49	4.58	7.58	8.81
Fragilaria tenera	2.14	1.29	0.00	0.00	0.00	0.00	1.21	0.35	2.70	0.99	0.00	0.00	0.80	0.00	1.12	0.65	0.00	0.91
Frustulia rhomboides	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gomphonema sp.	0.00	0.00	0.00	0.61	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.66	0.00	0.00	0.00	0.00
Gyrosigma acuminatum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.30	0.00
Navicula cocconeiformis	0.00	0.00	0.00	0.00	0.00	0.60	0.00	0.00	1.69	1.32	0.00	1.86	0.80	1.99	0.00	0.98	0.61	3.04
Navicula cryptocephala	0.00	0.00	0.00	0.00	1.46	0.00	0.30	0.00	0.00	0.99	0.66	1.33	0.00	0.00	0.00	1.31	0.61	0.00
Navicula cryptotenella	0.00	0.00	0.00	0.00	0.58	0.00	0.60	0.00	0.68	0.00	0.00	0.00	0.80	0.66	1.49	0.65	0.00	0.00
Navicula disjuncta	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.66	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Navicula helensis	0.00	0.00	0.00	0.00	0.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Navicula minima	0.00	0.00	1.29	0.61	0.58	1.19	1.21	3.53	1.35	2.64	1.33	0.53	2.40	3.32	1.49	0.00	0.61	3.65
Navicula pseudoscutiformis	0.00	0.00	0.00	0.00	0.00	0.00	0.60	0.71	1.01	1.32	0.00	0.00	0.00	0.00	0.00	0.65	0.30	0.00
Navicula pupula	0.00	0.00	0.64	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.66	0.80	0.80	1.00	0.74	0.00	1.82	0.00
Navicula pygmaea	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.66	0.53	0.00	0.00	0.00	0.00	0.00	0.00
Navicula radiosa	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.35	0.00	0.66	0.00	0.00	0.80	0.00	0.00	0.00	0.00	1.52
Navicula rhyncocephala	0.00	0.00	0.64	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.74	0.00	0.00	0.00
Navicula shoenfeldtii	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.66	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Navicula sp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.68	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.42	0.00
Navicula submuralis	0.71	0.32	0.00	0.00	0.00	0.30	0.00	0.71	0.00	3.96	3.32	3.19	2.40	0.00	0.00	0.33	3.03	3.34
Navicula trivialis	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.80	0.00	0.00	0.65	0.61	0.00
Neidium ampliatum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.66	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nitzchia acicularis	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.61	0.00
Nitzchia amphibia	0.00	0.64	0.00	0.00	0.00	0.00	0.00	0.00	0.34	0.00	0.00	0.27	0.00	0.00	0.00	0.33	0.00	0.30
Nitzchia gracilis	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.35	0.00	0.00	0.00	0.00	1.00	0.74	0.00	0.61	0.00
Nitzchia palea	0.00	0.64	0.00	0.00	0.00	0.00	0.91	0.00	0.00	0.00	0.66	0.53	1.20	1.99	0.00	0.00	0.61	2.13
Nitzchia perminuta	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.65	0.61	0.00
Nitzchia recta	0.00	0.32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.61	0.00
Nitzchia subacicularis	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.22
Pinnularia pulchra	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.27	0.00	0.00	0.00	0.00	0.00	0.00
Pinnularia viridis	0.00	0.00	0.00	0.00	0.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rhizoselenia longiseta	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.27	0.00	0.33	0.00	0.00	0.00	0.30
Stauroneis phoenicenteron	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.27	0.00	0.00	0.00	0.00	0.00	0.00
Stephanodiscus hantzchii	0.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.34	0.00	0.66	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Stephanodiscus minutulus	0.00	1.29	0.00	0.00	0.58	0.00	0.60	1.06	0.34	0.66	1.99	1.33	3.20	0.33	0.74	0.00	1.82	1.82
Stephanodiscus niagarae	2.14	0.32	0.96	0.61	0.58	0.89	0.00	0.71	0.68	1.65	0.00	1.60	2.40	1.33	1.86	4.90	1.52	1.52
Stephanodiscus parvus	0.00	0.00	0.64	0.00	0.00	0.00	0.00	0.00	0.00	0.66	0.00	0.27	0.00	0.00	0.00	0.00	0.00	0.30
Surirella angusta	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.74	0.00	0.00	0.00
Surirella cf. linearis	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Surirella ovalis	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30
Surirella sp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00
Synedra ulna	1.42	0.00	0.00	0.00	0.00	0.30	0.00	0.00	1.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.26
Tabellaria flocculosa	1.42	4.82	4.18	4.26	4.08	5.06	7.85	12.37	5.07	5.28	5.65	4.52	3.60	6.98	10.78	6.86	7.27	7.90
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00