Eutrophication in Northwestern Ontario? The Unique Case Study of Cloud Lake.

by

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Abstract

This thesis investigates freshwater lake classification in Northwestern Ontario, Canada. The research is based on a case study of Cloud Lake, 40km south of Thunder Bay Ontario, Canada. Complaints of decreasing water quality brought attention to the need for a detailed assessment of the current conditions on Cloud Lake. The purpose of this thesis was to determine Cloud Lake's present trophic state based on two currently implemented trophic state indexing (TSI) methods, (Carlson's TSI, and the Ontario Ministry of the Environment and Climate Changes).

This thesis provides biological, chemical, and physical evidence that Cloud Lake's water quality is a serious concern. Cloud Lake is a mesotrophic lake with confirmed occurrences of toxin producing cyanobacteria. The results underlie a misconception within current monitoring of inland lakes located within Northwestern Ontario that environmental conditions are pristine. Therefore, lakes in the geographic region should all be oligotrophic. Despite the absence of significant anthropogenic inputs (i.e. agricultural or urban development) Cloud Lake demonstrates a number of symptoms associated with eutrophication in larger, more developed lakes that relate to internal loading being a dynamic factor. The thesis provides recommendations for future monitoring and research to better understand the complex causes of eutrophication in Cloud Lake.

Acknowledgments

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Chapter 1
Introduction

1.1 The Human and Natural Aspects of Eutrophication

Although eutrophication of surface water is a natural process in the evolution of freshwater lakes, human induced eutrophication can rapidly change pristine water bodies to aesthetically unpleasing and potentially hazardous environments. Eutrophication is the enrichment of freshwater resulting in a classification shift from one trophic state to a higher trophic state (Carlson 1977, Wetzel 2001). A shift in trophic states is characterized by changes in biological, chemical, and physical characteristics of a water body. Such changes are recognized as the consequences of nutrient enrichment or increased nutrient loading (Carlson 1977; Vollenweider 1990; Wetzel 2001). These changes may be expressed as an increase in algal growth including cyanobacteria, water turbidity, anoxic conditions, and a decrease in aquatic species abundance (individually or any combination).

The management of surface water eutrophication has focused primarily on anthropogenic inputs such as sources of water treatment discharge, and agricultural runoff. Academic research has focused on understanding specific causes and effects of cultural or anthropogenic eutrophication on surface water (Allinger and Revic 2013; Bunting et al., 2011; Kling et al., 2011; Steffen et al., 2014; and Matisoff et al., 2017). Schindler (1974) concluded that nutrient loading, specifically phosphorus, was a key factor in eutrophication and recommended that removing phosphorus inputs to the system could reduce eutrophication and its associated symptoms (i.e. phytoplankton blooms). In 1972 Canada and the United States signed the Great Lakes Water Quality Agreement (GLWQA) with the overall goal of protecting the valuable aquatic resources of the Great Lakes from cultural eutrophication through the reduction of excessive phosphorus inputs from various human activities (De Pinto et al., 1986). This agreement between the Canadian and American governments provided a major boost to research and monitoring through increased funding and commitment to maintaining clean water from both countries.

1.2 Cloud Lake

A number of lakes in Canada have been the focus of extensive studies after showing signs of eutrophication, including Lake Simcoe, Lake of the Woods, Lake Winnipeg, and Lake Erie. These large bodies of water all have an abundance of anthropogenic inputs ranging from septic systems and waste water treatment plants, to agricultural runoff. Unlike the previously mentioned cases, Cloud Lake is a small inland water body, with a surface area of 402.9 (ha), relatively few residents 82, and no agricultural inputs. Despite this, over the last few decades Cloud Lake has shown signs of eutrophication. Previous studies on Cloud Lake have been conducted as part of routine monitoring by the Ontario Ministry of Environment and Climate Change (OMOECC). The OMOECC reports of 1973, 1985, and 1991 concluded that Cloud Lake was 'fine' at those times. However, in a 2003 – 2005 follow up the OMOECC found that spring phosphorus concentrations exceeded the Provincial Water Quality (PWQO) objective of 20 µg/L. In conjunction, local residents began lodging complaints regarding the overall health of Cloud Lake specifically noting an increase in phytoplankton, and decreases in the preferred fish community, Walleye. Residents were also concerned with the inconsistency of sampling of Cloud Lake and believed the infrequent research was not fully capturing what was happening on their lake.

This thesis is part of a larger study that was conducted on Cloud Lake in 2015 which took an adaptive ecosystem approach. A collaborative effort was undertaken by Lakehead University, OMOECC, OMNRF, and community partners to establish a detailed baseline for Cloud Lake as well as better insight into the current trophic state of Cloud Lake.

1.3 Study Purpose and Objectives

The purpose of this study was to provide more detailed data on the current conditions within Cloud Lake. This study was conducted over a single sampling season in the spring, summer, and fall of 2015. This is a short sampling period in comparison to larger projects looking at nutrient loading and eutrophication. This study had 4 main focuses:

1) to determine the total phosphorus within Cloud Lake,
2) to investigate and describe the seasonal variation of total phosphorus, dissolved oxygen and the thermocline,
3) to better understand the trophic state of Cloud Lake, and
4) to observe and characterize reported nuisance algal blooms within Cloud Lake.

The approach for this study was to collect water samples throughout the water column for chemical analysis, secchi depth readings, along with temperature and dissolved oxygen profiles at two previous study sites. Inflow and outflow samples were also taken when water flow was enough to collect discharge measurements. These samples were collected bi-monthly during the spring and fall, and monthly during the summer months.

1.4 Thesis Organization

Chapter 2 of this thesis will discuss relevant literature associated with the management of surface water eutrophication and the rise of eutrophication as a global issue. Case studies of surface water eutrophication within Canada, and the various research and management approaches associated with those cases, will be briefly examined. This section will end with an examination of literature on the parameters associated with Carlson's 1974 research on trophic states and how surface water eutrophication is measured.

Chapter 3 will provide an understanding of the unique characteristics of Cloud Lake and how it compares to the well-known examples of lake eutrophication from Canada. Previous studies will be explored to provide a contextual framework on previous monitoring of Cloud Lake and the current transition that is taking place. This chapter also provides information about the various aspects of the Cloud River Watershed.

Chapter 4 presents the research methodology used in the 2015 Cloud Lake project. The study objectives were accomplished through sampling of inflow, outflow, and two deep water lake sites. The parameters selected for this project are based on those used by the MOECC as developed by Robert Carlson for trophic state indicators in 1977. These include total phosphorus, chlorophyll *a*, and secchi depths. In conjunction with the previous parameters, several other water chemistry parameters were collected. These included temperature and dissolved oxygen profiles, as well as discharge at river inflows and lake outflow into Cloud River. The sampling schedule for the 2015 data collection was bi-monthly during spring and fall turnover, and monthly through the summer.

The results and discussion chapters highlight the key parameters that, when plotted in the MOECC classification and Carlson's trophic state indicator tables, provide evidence that Cloud Lake is in transition to a higher trophic state. The results of the 2015 field data show limited tributary discharge and inflow of nutrients entering Cloud Lake beyond the spring freshet. Seasonal variations in thermal and dissolved oxygen show Cloud Lake is a dimictic lake developing a significant anoxic zone and high concentrations of phosphorus in the hypolimnion during summer stratification indicative of internal loading. Cloud Lake's spring total phosphorus was 8.5µg/L and mean annual phosphorus was 21.3µg/L. Algae identification found filamentous green algae (ex. spyrogyra *spp.*) as well as several potentially toxin producing cyanobacteria (ex. dolichospermum *spp*) and confirm residents' concerns regarding algae presence on Cloud Lake. Secondary data results from a spring Smallmouth Bass nesting and submerged aquatic vegetation survey collected during 2015 further support the classification of the lake as a higher productive mesotrophic lake that is not considered characteristic of Northwestern Ontario.

Chapter 6 discusses the results in comparison to the existing literature with a particular focus on Cloud Lake's spring and mean annual phosphorus concentrations and the discovery of potential internal loading as defined by Nürnberg (2009). Similarities and differences between Cloud Lake, comparative lakes, and previous studies conducted on Cloud Lake emphasize the implications associated with the presence of internal loading and cyanobacteria and provides recommendations for further research and monitoring of cyanobacteria to gain a better understanding of the risks to the Cloud Lake ecosystem.

With the increasing concern over eutrophication, research about the complexities and drivers of eutrophication from a whole-lake ecosystem approach can help to better classify the trophic state of Northwestern Ontario lakes and better manage phosphorus loading to reduce the potential degradation of freshwater lakes. As seen in the case study of Cloud Lake, an understanding of internal loading, a previously ignored aspect of eutrophication, is critical and requires the monitoring of temperature and dissolved oxygen as key parameters of lake management programs. Currently, these parameters are considered more secondary data through provincial or TSI classifications and therefore provides too narrow a view of the potential trophic state and changes occurring to inland lakes of Northwestern Ontario.

Chapter 2
Literature Review

2.1 Introduction

The chapter provides three key sections to outline the main schools of thought supporting a transition of lake health risk management. Section 2.2 examines academic literature addressing the understanding of eutrophication. This will include a brief overview of the development of trophic classification parameters as the major components for this understanding. The focus will be on highlighting the importance of managing phosphorus inputs into aquatic systems and the impacts associated with an increase of phosphorus to the system. The section ends by drawing attention to the establishment of international committees and agreements aimed at implementing proper management practices.

Section 2.3 discusses historic and present case studies on eutrophication of surface water within Canada. There are numerous ways in which eutrophication impacts are monitored but the focus in examining these case studies will be on the management of anthropogenic eutrophication. This will provide a better understanding of real world monitoring and management of aquatic systems.

Finally, Section 2.4 begins with a brief overview of previous studies conducted on Cloud Lake, drawing attention to noteworthy results which help support the approach and focus of this study during the 2015 field season. This section will also identify major differences between previously discussed case studies and Cloud Lake.

2.2 The Study of Eutrophication

Eutrophication is "the process of organic enrichment of a body of water as a result of increased nutrient loading and the subsequent increase in autotrophic production" (Mackie, 2004: pg. 694). Initial work done by Schindler and Fee (1974) determined that an increase in phosphorus into an aquatic system directly effects the abundance of phytoplankton blooms. Since that time eutrophication of surface waters has remained one of the major problems around the world (Bennett et al., 2001; Dodds and Smith, 2016; Schindler, 2006; Smith, 2003, 2016; Parel et al., 2011; and Ritter et al., 2011). Bennett et al., (2001) estimate that globally terrestrial and aquatic phosphorus is 75% higher than preindustrial levels of storage in these systems. Ritter et al., (2002) estimates that 80% of the present phosphorus within water systems world-wide is the result of human activity. Efforts in re-oligotrophication, or reversing eutrophication, eliminates anthropogenic phosphorus loading (i.e.

diverting waste water output) have been successful in diminishing anthropogenic loading of nutrients (Jeppesen et al., 2005). However, eutrophication is still a world-wide issue associated with urban and agricultural expansion, changes in aquatic community composition, internal loading of phosphorus, as well as more frequent and significant rain events associated with climate change. This results in continuing and increased nutrient input causing increased macrophyte growth, periodic fish kills due to hypoxia, and most importantly, increased algal blooms (Bunting et al., 2011, 2016; Dodds and Smith, 2016; Jenny et al., 2016; He et al., 2014; Kling et al., 2011; Matisoff et al., 2017; McCullough et al., 2012; Schindler et al., 2012).

2.3 Lake Classification

To document the transition of a body of water when it was changing, or 'eutrophying', and compare systems to one another, a classification system was required (Schindler and Fee 1974). Initial approaches to classify lakes relied on either multidimensional indices such as in Brezonik and Shannon (1971) and Michalski and Conroy (1972), or single criterion such as Rodhe (1969), and Beeton and Edmondson (1972). These multidimensional and single criterion approaches were variable between case studies. In 1977 Robert Carlson published his numerical trophic stat index (TSI) for lakes. Carlson provided a predictive tool which could be used by researchers and the public for lake management programs. This TSI uses three independent variables that are known to be correlated; concentrations of chlorophyll *a*, concentrations of total phosphorus, and secchi depth. By establishing trophic conditions on a lake, it is possible to provide a description of the abiotic and biotic condition of waterbodies, gain insight into possible relationships between chemical and biological parameters, as well as characterize the condition of a lake in relation to human needs or values (Jarosiewicz et al. 2012). The trophic state indices proposed by Carlson (1977) are used to describe the condition of surface waters, therefore this study employs these indicators to determine the current trophic status of Cloud Lake.

> "the trophic status of a lake does not define the trophic status. In other words, chlorophyll or total phosphorus are not considered as the basis of a definition of trophic state but only as indicators of a more broadly defined concept. The best indicator of trophic status may vary from lake to lake and also seasonally, so the best index to use should be chosen on pragmatic grounds" (Carlson 1977: pg. 366).

Although some researchers have added variations to Carlson's TSI, such as Vollenweider and Kerekes (1982), the parameters identified are still widely used for the classification for lakes and surface water. The use of TSI's provide the ability for comparative research and monitoring between two systems that would otherwise be difficult to compare. However, as Carlson's quote suggests the simplifications achieved through classification systems does not always capture the complexity that exists within aquatic systems.

2.4 Algae Blooms and Phosphorus

Phytoplankton blooms on lakes are visually easy to observe and generally unappealing to those who use the water body. There is a strong correlation established between the abundance of phosphorus and the amount of chlorophyll *a* found in surface water, more phosphorus results in more phytoplankton growth resulting in lower secchi depth, and higher chlorophyll *a* quantities (Maki, 2004; Schindler and Fee, 1974; Schindler, 2006; Schindler et al., 2016; Watson et al., 2016; Wetzel, 2001).

Although the relationship between phosphorus and algae blooms is well established, more recent research has begun to examine the complex interactions of multiple variables in association with phosphorus as causal factors in harmful cyanobacteria blooms (cHABs). Environmental changes such as damming to create hydroelectric reservoirs or the introduction of invasive organisms can have huge impacts on nutrient distribution within a lake resulting in increased cHABs (Kling et al., 2011, Higgins et al., 2008). Other researchers have examined the link between hypoxia in the hypolimnion during summer with internal increases in nutrients as the source of nutrients driving cHABs (Kling et al., 2011; Scavia et al., 2014; Watson et al., 2016; Zhou et al., 2013, 2015). Molot et al., (2014) and Sorichetti et al., (2014) examined concentrations of iron as well as phosphorus, nitrogen, and sulphate within the anoxic hypolimnion of Ontario lakes as predictive of cyanobacteria bloom potential. Yet despite the increased understanding of the complexity within fresh water systems the abundance of phosphorus is still held as the fundamental driver of algae blooms and specifically cHABs (Bunting et al, 2011; Descy et al., 2016; Higgins et al., 2008; Kling et al, 2011; Matisoff et al, 2017; McCullough et al, 2012; Michalak et al., 2013; Scavia et al., 2014; Steffen et al., 2014; Zhou et al., 2013, 2015; Watson et al., 2016).

2.5 Cyanobacteria

The number and magnitude of algal blooms within Canada also reflects the increasing global trend (Hallegraeff, 1993; Pick, 2015; Winter, DeSellas et al., 2011; Winter, Young et al., 2011). Cyanobacteria blooms can be difficult to observe, they are most often seen as thick scum layers on surface water (Khan and Ansari, 2005), but because of the organism's unique ability to self-regulate buoyancy it can be located throughout the water column (Pearl et al., 2001). Cyanobacteria blooms are a major issue for the health of all animals that make use of surface water, humans included. These blooms have been linked to increased hypoxic conditions within lakes resulting in fish kills (Ibelings et al., 2016; Pandey et al., 2014; Pick, 2015; Pearl et al., 2001; Steinmen et al., 2015). However, the more important aspect is the toxin production of cyanobacteria. There are a wide variety of toxins that can be produced by cyanobacteria. The toxin that is of most concern to human health is microcystin-LR a hepatotoxin associated with animal and human deaths (Pouria et al., 1998;

Miller et al., 2010). Recent research looks at the ratio of nitrogen and phosphorus as well as iron correlating to the concentration of microcystin indicating that concentrations of microcystin increase as trophic state increases for lakes across Canada (Orihel et al., 2012). Currently Health Canada's guidelines for consumption of algal toxins from drinking water are 1.5µg/L. However, some question the lack of knowledge surrounding this set threshold given the lack of longitudinal studies (Ritter et al., 2011).

2.6 Eutrophication Management in Freshwater Lakes

The body of literature surrounding fresh water monitoring is extensive ranging from monitoring impacts of invasive species to climate change and food web alterations as factors in eutrophication management (Pick, 2015). There are numerous government and private groups that participate in studying fresh water systems within Canada and the United States of America. A majority of this research in North America started with the establishment of the GLWQA in 1972. Monitoring done by the Canadian Ministry of Environment and Climate Change, Ministry of Natural Resources and Forestry, Department and Fisheries and Oceans, the United States Environmental Protection Agency, and numerous university research projects have examined the various aspects of freshwater habitats from overall fish community monitoring and surveillance (Mahmood et al., 2013; and Rockwell et al., 2005), to contamination of biota in Areas of Concern on the Great Lakes (Elliot et al., 2001; Minns et al., 2011; Simon et al., 2016), to research on the management of water treatment (Tabe et al., 2016; Ziajahromi et al., 2016). For the purpose of this thesis however, focus will be given to the development and monitoring of nutrient loading and the subsequent impacts to the occurrence of cyanobacteria.

Schindler and Fee (1974) definitively concluded that phosphorus loading is essential to eutrophication and provided insight into the shifting phytoplankton community as a result of phosphorus loading in lake 226 in the Experimental Lake Area. This Experimental Lake Study showed cyanobacteria, *Anabaena spirodies*, as a result of the fertilization of phosphorus. In contrast, lake 227 was not fertilized with phosphorus and saw no change in phytoplankton community. It was noted upon removal of the phosphorus input lake 226 returned to the trophic state and condition observed prior to phosphorus loading. The results of this study provided the foundation of many monitoring programs and policies of concern to the International Joint Commission (IJC), the Ontario Provincial Water Quality Objectives (PWQO), and many Best Management Practices (BMPs). The study therefore led to a focus on the reduction of external phosphorus as the primary aspect of maintaining healthy freshwater systems.

2.7 Canadian Case Studies

The next section of this chapter will go over three well documented examples of eutrophication from within Canada. These case studies show how increases in total phosphorus through external loading has been directly linked to eutrophication documented as increased phytoplankton blooms, increased size and duration of oxygen depletion zones in the hypolimnion, and overall increased concerns of health as it relates to human usage of the water body. The Canadian case studies include three major fresh water systems within Canada: Lake Erie, Lake Winnipeg, and Lake Simcoe. Each case study will briefly touch on the suspected issues that have resulted in eutrophication of the system before transitioning into research surrounding the causal factors that are currently being monitored in the Cloud Lake case study.

2.7.1 Lake Erie

Eutrophication across many of the Great Lakes since the mid 1900's resulted in wide spread cyanobacteria blooms. During these early years these blooms were not fully understood and seen only as nuisance blooms (Carmichael, 2008). Over the last century, however, significant ecological regime changes within Lake Erie watershed have resulted in toxic cyanobacteria blooms or cHABs (Smith et al., 1999; Watson et al., 2016). Lake Erie is boarded by the province of Ontario, and the states of Michigan, Ohio, Pennsylvania, and New York. Lake Erie is relied upon by over eleven million people, and provides more than $50 billion in support through tourism, shipping, fisheries, and other industries. All of the people and industries within the Lake Erie watershed are threatened by the increased magnitude and extent of harmful algal blooms and hypoxia seen as a result of increased nutrients entering and found within the Lake (Higgins et al., 2008; Michalak et al., 2013; Scavia et al., 2014; Steffen et al., 2014; Zhou et al., 2013, 2015; Watson et al., 2016).

It was determined that the major symptoms of the eutrophication on Lake Erie were direct impacts of increased anthropogenic nutrient loading associated with increased population, urban development, and agricultural development within the watershed at different times over the 1900's (Watson et al., 2016). The industrial revolution is regarded as the onset of enrichment within Lake Erie. Work done by Allinger and Revic (2013), and Steffen et al. (2014) looked at plankton and sediment cores from long term data to determine that blooms are not a new phenomenon to Lake Erie. A dramatic shift has occurred in the species composition over the last 50 years to toxic cyanobacteria.

In 2012 the International Joint Commission (IJC) and the Lake Erie Ecosystem Priority (LEEP) began an evaluation of current conditions on Lake Erie with the goal of providing sustained restoration and management programs. (Watson et al., 2015). Phosphorus (P), as previously mentioned, is accepted as a key component to eutrophication, and even within Lake Erie P is recognized as the primary driver of higher phytoplankton biomass (Downing et al., 2001; Michalak et al., 2013). Reducing the inputs of P into Lake Erie is the focus of the Lake Erie Lake wide Action and Management Plan (LAMP) as part of the GLWQA and IJC (Binational.net 2014). In 2016 the IJC met again to reevaluate the state of Lake Erie and the proposed mitigation strategies of the 2012 and 2014 plans. The goal set forth is to reduce P inputs by 40% or 3316 metric tons from the United States and 212 metric tons from Canada. This reduction aims to remove the driving factor of biomass production and in turn reduce the extent of hypoxic conditions within Lake Erie. However, Watson et al., (2016), and McElmurry et al., (2013) suggest that this is a much more dynamic issue and a more comprehensive understanding of impacts such as climate change and internal phosphorus loading is necessary for the development and implication of Best Management Practices (BMPs).

2.7.2 Lake Winnipeg

Located in Manitoba, Canada, Lake Winnipeg is a non-Laurentian Great Lake, the sixth-largest freshwater lake in Canada. It differs from the other Great Lakes with a shallower average depth while having a larger catchment area, 953,000 km^2, and upwards of 6.6 million people living within the watershed (Kling et al., 2011; McCulllough et al., 2012). Similar to Lake Erie, Lake Winnipeg has development within the watershed, both urban or agricultural, which has been associated with contributing increased nutrient loading (Bunting et al., 2011; Kling et al., 2011; McCullough et al., 2012; Schindler et al., 2012). Lake Winnipeg has been determined to be historically a mildly eutrophic lake in its natural state (Schinder et al., 2012). The lake has become more eutrophic since 1994 due to increased nutrient loading specifically from the Red and Winnipeg Rivers (Matisoff et al., 2017).

As seen in Lake Erie the increase in nutrient runoff, specifically P, from urban and/or agricultural development of the watershed is associated with changes in the composition of phytoplankton throughout Lake Winnipeg (Board, 2006; Bunting et al., 2011; Kling et al., 2011; Matisoff et al., 2017; McCullough et al., 2012; Schindler et al., 2012). Lake Winnipeg has one major difference from the other Great Lakes. It has been transformed into a hydroelectric reservoir significantly impacting flushing rates in the lake (Kling et al., 2011). Matisoff et al., (2017) analyzed sediment cores from 1994 which showed a direct relationship between increased phosphorus, carbon, and chlorophyll to watershed development in the 1950's and hydro-electric damming in the 1960's. As was shown with Lake Erie, the current management approach to eutrophication in Lake Winnipeg aims to minimize the overall input of nutrients and reduce the occurrence of toxin producing cyanobacteria blooms (Lake Winnipeg Stewardship Board 2006; Bunting et al., 2011; McCullough et al., 2012; Matisoff et al., 2017; McCullough et al., 2012; and Schindler et al., 2012; Schindler et al., 2016).

2.7.3 Lake Simcoe

Lake Simcoe is a large freshwater lake (722 km^2) located in the central region of Ontario. It is considered a mesotrophic lake (Winter et al., 2007) showing signs of eutrophication due to nutrient inputs since the shore was settled in approximately 1796 (North, 2013). Since 1990 there has been extensive water quality monitoring done by the Lake Simcoe Regional Conservation Authority (LSRCA) and the OMOECC in order to determine total phosphorus (TP) through external loading (Nürnberg et al., 2013) and to understand the extent of an anoxic hypolimnion which resulted in a significant downfall in cold water fish species (Young et al., 2011). It was during the 1960's and 1970's that the cold-water fishery of Lake Simcoe collapsed. Increased algal blooms are blamed for reduced and limited dissolved oxygen causing the collapse of the cold-water fishery (Winter et al., 2007) and were linked to increased urbanization and agricultural development within the watershed (North, 2013).

North, (2013) indicates that increased nutrients were not the only stressors contributing to the issues of Lake Simcoe. Climate change and invasive species have contributed to the ongoing issues found on Lake Simcoe. Although reduction of nutrient input into Lake Simcoe has been successful (Winter et al., 2007; Crossman et al., 2012) it is still debated in the literature as to which management strategies are needed in the future. Gurtrud Nürnberg (2013) has done extensive work looking at the contribution of phosphorus from Lake Simcoe's sediment and the influence on phytoplankton blooms on the lake. Given the timing of late summer and early fall anoxic conditions phosphorus released from the sediment has been determined to be bioavailable and associated with influencing the phytoplankton blooms on Lake Simcoe (Nürnberg et al., 2009). O'Conner et al., (2012) and Scott et al., (2001, 2013) determined that Lake Simcoe has a water residence of eleven years and Nürnberg et al., (2013) speculates that, given this delayed flushing rate and the contribution of TP from sediments during anoxic conditions, the response of Lake Simcoe to reduced external loading of TP will be slow. Smith et al., (2011) studied the composition of phytoplankton in Lake Simcoe and found evidence suggesting that internal loading of P was correlated with increased cyanobacteria blooms. These studies on the importance of managing nutrient loading will be applied and further discussed as a possible approach on Cloud Lake in the discussion found in Chapter 6.

2.7.4 Cloud Lake

This section will summarize the findings of previous studies conducted to monitor Cloud Lake including data collected by the Ontario Ministry of the Environment and Climate Change (OMOECC) and the Lake Partner Database. Monitoring of Cloud Lake begins in the 1970's using the OMOECC classification and progresses through to the most recent 2000's studies conducted in response to residents' complaints. The OMOECC classifies lakes into four categories or levels as seen in table 1.

Table 1. OMOE Lake Level Classification (Pugh, 1992).

Parameter	Level 1	Level 2	Level 3	Level 4
Mean Chlorophyll *a* (µg/L)	0-2	2-5	5-10	10-25
Mean Secchi Disk Depth (m)	>5	2-5	1-2	<1
Springtime Total Phosphorous (µg/L)	0-9.9	9.9-18.5	18.5-29.9	29.9-56.3
Water Quality	excellent	good	fair	poor
Suitability for Water-based Recreation	suitable	suitable	reduced suitability	unsuitable

The OMOE table is a variation on the Trophic State Index (TSI) table developed by Carlson in 1977 and modified by Vollenweider and Kerekes (1982) as seen in table 2.

Table 2. Lake Level Classification Trophic State Index (Vollenweider and Kerekes 1982).

Trophic Category	TP (µg/L)	Mean Chlorophyll *a* (µg/L)	Max Chlorophyll *a* (µg/L)	Mean Secchi Depth (m)	Min Secchi Depth (m)
Ultra-oligotrophic	<4	<1	<2.5	>12	>6
Oligotrophic	<10	<2.5	<8	>6	>3
Mesotrophic	10-35	2.5-8	8-25	6-3	3-1.5
Eutrophic	35-100	8-25	25-75	3-1.5	1.5-0.7
Hyper-eutrophic	>100	>25	>75	<1.5	<0.7

TP – mean annual in lake total phosphorus concentration;
Mean Chlorophyll – mean annual chlorophyll ***a*** concentration in surface waters;
Max Chlorophyll – peak annual chlorophyll ***a*** concentrations in surface waters;
Mean Secchi Depth – mean annual Secchi Disk depth;
Min Secchi Depth – minimum annual Secchi Disk Depth.

There are subtle differences between these two classification tables but the most notable difference is that the OMOECC use spring total phosphorus as a representation of potential nutrients available, rather than a mean annual TP as collected in the Carlson example. Collection of spring TP is done during spring freshet and turnover when dimictic lakes are homogenous in temperature and dissolved oxygen. Spring sampling provides an estimate of total available nutrients that may be accessed throughout the 'growing season' of summer. Cloud Lake has historically been managed as a Level 2 lake, with good water quality. However, as will be shown this is no longer the case, and in response to the increasing concern of residents, a need for more detailed data is required to understand the intricacies of the Cloud Lake watershed.

2.7.4.1 1970s MOE Cloud Lake Reports

Water quality sampling was conducted by the OMOECC (then named the Ontario Ministry of the Environment) in 1979, and modelling (Dillon and Righer, 1975) data indicated that natural supplies of phosphorous were much greater than anthropogenic sources on Cloud Lake (Maki, 1980). Maki (1980) recommended that steps should be taken to control artificial sources of phosphorous but indicates that this does not necessarily require limiting new development around Cloud Lake (Maki, 1980).

2.7.4.2 1980s OMOE Cloud Lake Reports

In 1980, the OMOE conducted a Cottage Pollution Control Program on Cloud (OMOE, 1980). This consisted of an inspection of all sewage disposal systems of all residents on Cloud Lake and the determination of the bacteriological quality of the lake waters and of the drinking water supplies serving the cottages. For each cottage lot (n=57), the owner was interviewed and a sketch was made including all sewage disposal systems with the systems distance from any water sources being recorded. Some limited soil borings were conducted to determine the quantity and quality of soil. Water samples for chemical and bacteriological analyses were taken at various points along the shoreline. Of the 57 completed surveys, disposal systems were found to be satisfactory for 27 cottages. A total of 29 abatement orders were issued, one for a seriously substandard Class 2 system that deposited septic wastes on to a rocky area near the cottage. The majority of problems required the construction of leaching pits for sauna and kitchen wastes, and vermin-proofing of privies. Nine cottage-owners were not interviewed, but the sewage disposal systems were assessed and no serious problems detected. Five of the 13 water samples were adverse for bacteria, including one adverse sample from lake water (as opposed to well or spring water).

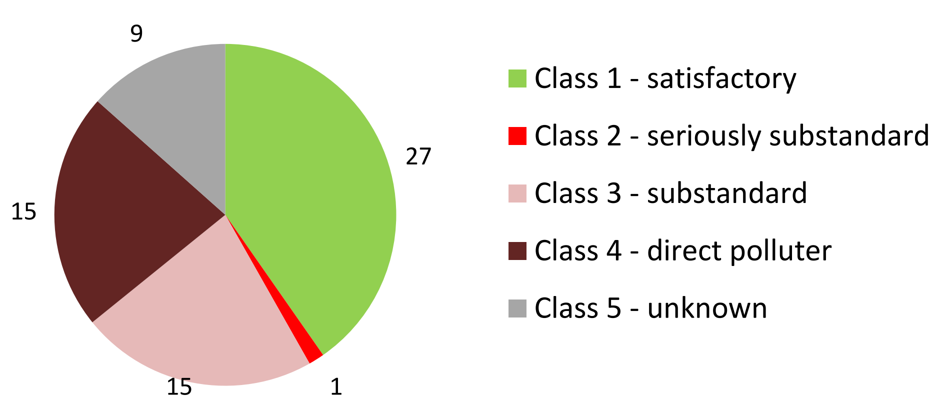


Figure 1. Pie chart of 1980 pollution survey.
OMOE (1980) Cloud Lake cottage pollution control survey results (57 full surveys and 9 partial surveys).

In 1985, the OMOE's modelling indicated that "the number of permissible cottage units which Cloud Lake could support without changing from Level 2 to Level 3 water quality is in excess of 500" (Vander Wall, 1985: pg. 4). The 1985 memo also indicates that if all of the existing lots are converted to permanent dwellings, water quality would push the upper limit of Level 2. This suggested that the creation of permanent dwellings on all existing lots in Cloud Lake was permissible from a water quality stand point, the creation of new lots beyond those in existence would result in over-development and concomitant water quality degradation (Vander Wall, 1985). This was proven by future monitoring of lake water quality to be a very optimistic prediction.

2.7.4.3 1990s OMOE Cloud Lake Reports

Some of the first water quality monitoring conducted in response to cottagers' complaints of increased algal blooms was in 1990-1991 by the OMOE by Pugh (1992). According to Pugh (1992) the water quality of Cloud Lake remained good, and cottage developments did not appear to be impairing water quality.

Table 3. Summary of Cloud Lake water quality parameters by Pugh (1992).

Mean Secchi Disc Depth (m), Mean Chlorophyll *a* (μg/L) and Springtime Total Phosphorus Data (μg/L) collected at Cloud Lake in 1973 and 1990/91.		
	1973	1990/91
Mean Secchi Disc Depth (m)	2.3	4.1
Mean Chlorophyll *a* (μg/L)	3.0	6.3
Springtime Total Phosphorus (μg/L)	16.5	16.0

Table 3 shows springtime total phosphorous remained similar to previous reports, mean chlorophyll *a* concentrations were found to have doubled from 3.0 μg/L to 6.3 μg/L, mean secchi disk depth had increased as well. The increase in secchi disk depth was attributed by Pugh (1992) to a shift in phytoplankton species composition from shallow water to deep water, not an unnatural shift that happens from time to time. The changes in chlorophyll *a* levels were attributed to changes in laboratory analytical methods, specifically the way euphotic zone depth is estimated. Pugh's 1992 report noted the development of anoxic conditions during the establishment of epilimnion and hypolimnion during summer thermal stratification as seen in figure 2.

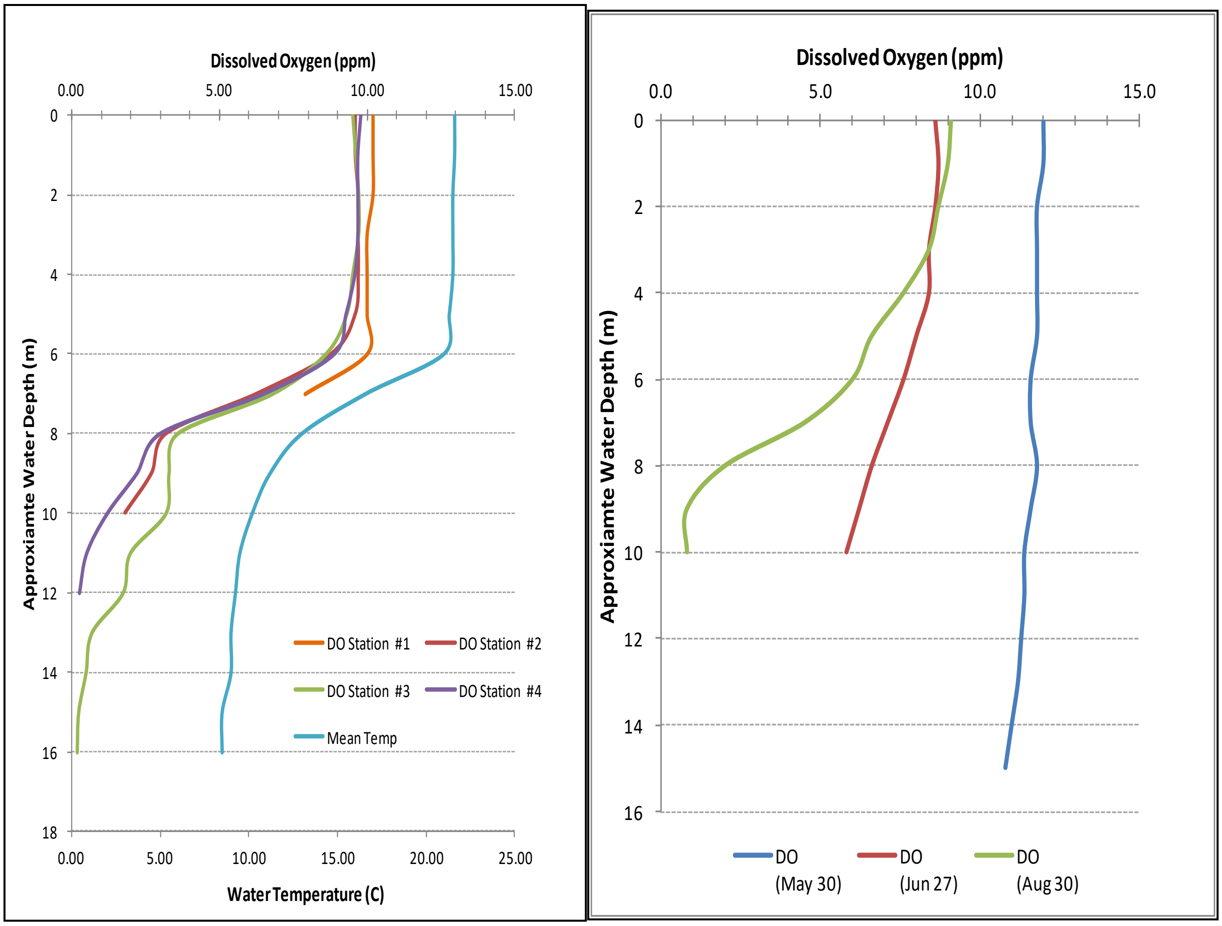


Figure 2. Cloud Lake 1972 and 1990 temperature and dissolved oxygen profiles.
Water temperature (mean lake wide for 1990-1991) and dissolved oxygen (DO) profiles from the four stations on Cloud Lake on August 2, 1990 (Left) and dissolved oxygen (DO) profiles from Station 3 on Cloud Lake on three dates in 1973 (right) (adapted from Pugh 1992). Pugh (1992) indicates that Cloud Lake's hypolimnion, deeper waters, experienced significant dissolved oxygen depletion during the mid to late summer with increased concentrations of total phosphorus, however oxygen replenishment occurs during the fall lake turnover. Despite this note no major concerns are raised regarding the management or use of Cloud Lake.

2.7.4.4 2000s to 2014 OMOECC Cloud Lake Reports

Although Cloud Lake has previously been classified as a level 2 or mesotrophic lake, phosphorous levels in the lake have increased recently (Figure 3, Table 3). Sampling done by OMOECC in 2003-2005 indicated mean levels of spring phosphorous concentration of 25.2mg/m^3 (µg/L), which pushed Cloud Lake into the level 3 category. The Provincial Water Quality Objective (PWQO) is 20µg/L. As a result, the OMOECC no longer supports any further development on Cloud Lake including the conversion of any seasonal dwellings to permanent homes (Statlander 2006).

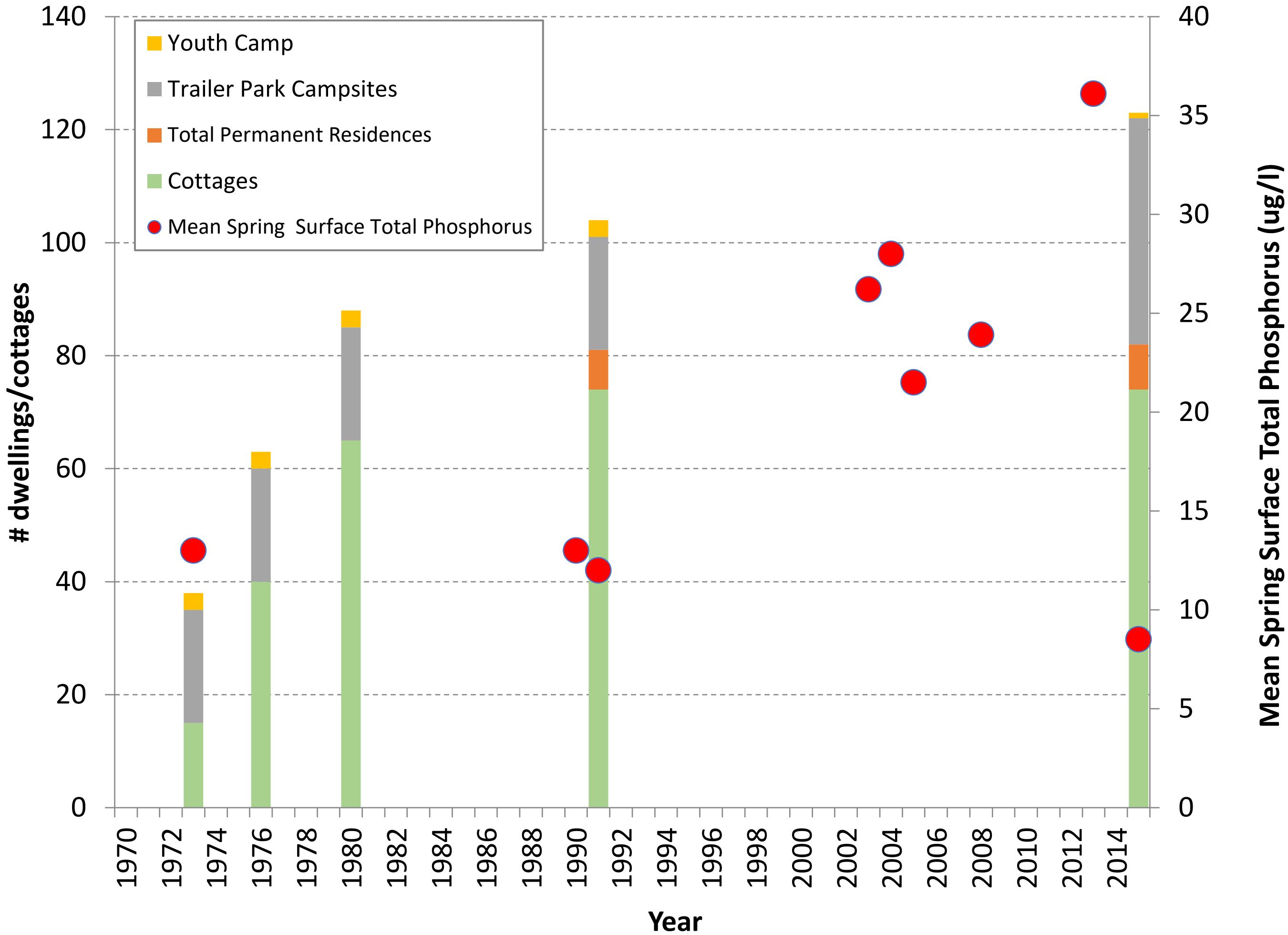


Figure 3. Cloud Lake composite graph of spring total phosphorus and residents.
Figure 3 illustrates the association between residents and springtime total phosphorus concentrations. Since 1973 the number of cottages and concentration of spring total phosphorus has consistently increased in a delayed linear fashion with spring total phosphorus concentrations increasing after the increase in cottagers. The 2015 spring total phosphorus does not maintain this trend.

Table 4. Summary of historic water quality parameters for Cloud Lake.

Source	Date	Surface TP Sample Depth (m)	TP1 (µg/L)*	TP2 (µg/L)*	Mean Surface TP (µg/L)	Mean Deep TP (µg/L)	Deep TP Sample Depth (m)	Mean Secchi Depth (m)	Composite Sample Depth (m)	Chorophyll a (µg/l)
Maki 1980	1973-05-20							2.8	5.40	2.1
Maki 1980	1973-06-27							2.5	4.80	4.1
Maki 1980	1973-07-30							2.8	5.40	3.1
Maki 1980	1973-08-20							1.8	3.60	7.4
Maki 1980	1973-06-12	0.9			13.0	20.0	12.2	2.5	4.80	0.5
Maki 1980	1973-08-15	0.9			18.0	42.0	12.2	1.8	3.60	5.3
Maki 1980	1973-07-12	0.9			20.0	30.0	14.0	2.3	4.50	2.7
Maki 1980	1973-10-25	0.9			24.0	20.0	9.8	2.5		2.1
OMNR Lake Survey	1976-06-29							3.7		
Pugh 1992	1990-07-05	1.0			10.0	13.0	6.5	3.0	7.50	8.2
Pugh 1992	1990-07-05	1.0			13.0	14.0	7.5	3.3	8.75	7.2
Pugh 1992	1990-07-05	1.0			13.0	13.0	7.5	4.3	10.60	7.5
Pugh 1992	1990-07-05	1.0			16.0	12.0	7.5	4.3	10.60	7.5
Pugh 1992	1990-08-02					13.0	8.0	2.5	6.25	3.7
Pugh 1992	1990-08-02					18.0	10.0	3.0	7.50	4.2
Pugh 1992	1990-08-02					141.0	15.0	3.0	7.50	5.1
Pugh 1992	1990-08-02					76.0	12.0	3.0	7.50	5.1

Source	Date	Surface TP Sample Depth (m)	TP1 (µg/L)*	TP2 (µg/L)*	Mean Surface TP (µg/L)	Mean Deep TP (µg/L)	Deep TP Sample Depth (m)	Mean Secchi Depth (m)	Composite Sample Depth (m)	Chorophyll a (µg/l)
Pugh 1992	1991-05-30	1.0			11.0	22.0	7.0	4.5	7.00	5.9
Pugh 1992	1991-05-30	1.0			11.0	16.0	7.0	3.0	7.00	6.1
Pugh 1992	1991-05-30	1.0			11.0	21.0	10.0	5.2	12.50	6.3
Pugh 1992	1991-05-30	1.0			15.0	16.0	10.0	5.0	10.00	5.5
Lake Partner Database	2003-05-14	1.0	24.0	27.8	25.9					
Lake Partner Database	2003-05-14	1.0	26.7	26.3	26.5					
Lake Partner Database	2004-05-19	1.0	28.3	25.2	26.7					
Lake Partner Database	2004-05-19	1.0	26.5	31.8	29.2					
Lake Partner Database	2005-05-05	1.0	21.2	21.8	21.5					
Lake Partner Database	2005-05-05	1.0	21.3	21.9	21.6					
Lake Partner Database	2008-06-20	1.0	15.1	32.7	23.9			1.3		
Lake Partner Database	2013-05-13	1.0	32.0	32.4	32.2					
Lake Partner Database	2013-05-31	1.0	40.4	39.4	39.9					

All sample site locations can be found in figure 7. *TP1 and TP2 are the total phosphorus values for spring total phosphorus.

2.8 Conclusion

This literature review covered the development and understanding of eutrophication in relation to nutrient loading and increased harmful algae blooms, specifically cyanobacteria blooms. Three Canadian case studies were examined showing similarity in causal factors of eutrophication. Most research continues to focus on classifying a lake's trophic state relative to the abundance of total phosphorus. However, focus is being placed on understanding the role of other aspects such as hypoxia and internal loading which have been previously overlooked. The next chapter will focus on providing relative information on the case study, Cloud Lake, to further situate the reader before going into the methods for the research conducted in this project. The methods chosen use the past research as a guideline so comparisons can be made later.

Chapter 3
Case Study

3.1 Cloud River Watershed

This chapter provides information on the Cloud Lake watershed to better understand the uniqueness of this case study and why the project was undertaken. This chapter begins with general geographic characteristics of the whole Cloud River Watershed will be explained with a particular focus on Cloud Lake. Maps depicting the variation in elevation within the watershed along with bathymetric data show the limited surrounding inflow as well as the overall morphology of the lake basin. This will be relevant in understanding how potentially limited flushing may prevent movement of nutrients out of the lake. Next, information on past and present human activities such as development, forest harvesting and fish introduction will address the human impacts on the lake. This chapter will conclude with discussion about previous and continued residents' concerns of the health of Cloud Lake.

3.2 Cloud River Watershed Physical Characteristics

Cloud Lake is located in Northwestern Ontario approximately 45 km. southwest of Thunder Bay, just off highway 61 heading towards the USA border (see figure 4). The watershed drains into Lake Superior's Cloud Bay 21.7km southeast of Cloud Lake. Overall the Cloud River watershed is approximately 80km^2. The watershed is located in the transition region where the more Southern Great Lake-St. Lawrence meets the northern boreal forest region. The tree story within the watershed reflects this with a mixture of common boreal forest species, such as jack pine, black spruce, white spruce, white birch, and trembling aspen, with pockets of sugar maple, red pine, and white pine (Rowe, 1972).

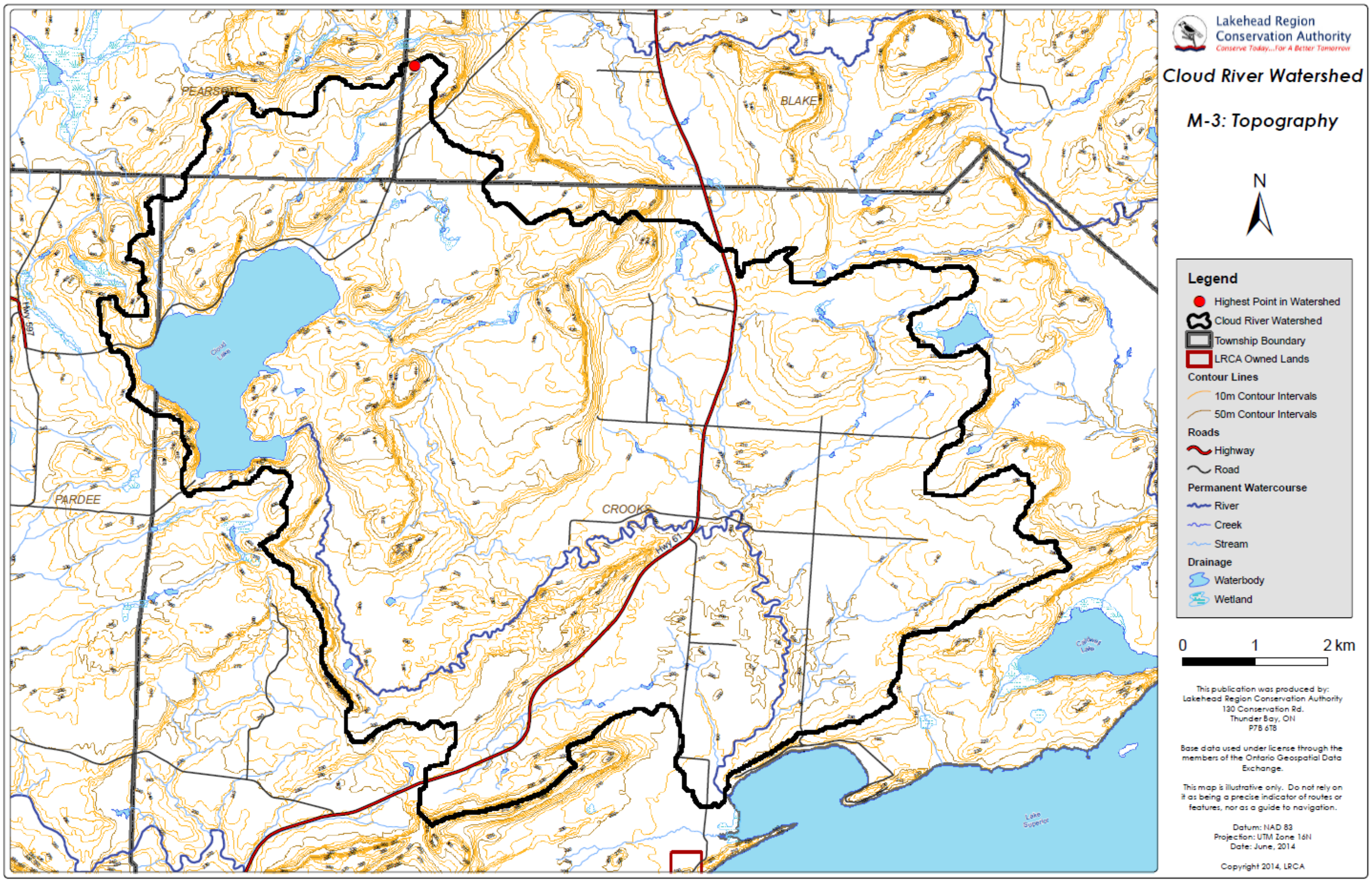


Figure 4. Cloud Lake watershed in relation to Cloud River and Cloud Bay, Lake Superior

Note in figure 4 the location of Cloud Lake is in elevated headwaters of the Cloud River watershed with limited collection from the land north of the lake to provide input into Cloud Lake. The elevation contours indicate sharp relief along the western border of the watershed as well as to the east as Cloud River exits Cloud Lake.

Figure 5. Cloud Lake and adjacent watershed (OMNRF imagery).
Note in figure 5 the distribution of cottages focused along the northern shore. Most cottages are concentrated along this shore with only a few located along the western shore and the church camp on the southern shore being the only development in that area.

The surficial geology of the region was summarized by Suttie (2014) as mainly glaciolacustrian plans from the Rove Formation and includes bedrock, organic accumulation, esker, kame, outwash plains, and moraines. Clay loam is the most abundant soil type comprising 21.5km^2 followed by moderately coarse sandy loam at 3.9km^2, and rock, silty clay, and silt loam making up the last 50.5km^2 of the watersheds. In the upper portions of the river, the first 1.6km from the Cloud Lake outflow, the slope gradient is steep. This quickly changes towards the flatter lower reaches as the Cloud River widens before reaching Cloud Bay. Cloud Lake is a moderate size at 420ha, with a shoreline length of 12km, a mean depth of 9m, and a max depth of 17m. (Table 5).

Table 5. Cloud Lake Physical Characteristics

Parameter	Value
Area (ha)	420.9
A6- Area deeper than 2 m (ha)	310.5
Shoreline Length (km)	12
% Littoral Zone[1]	26
Mean Depth (m)	9.0
Maximum Depth (m)	16.5
Volume ($10^4 m^3$)	3806.4
Secchi (m)	3.7
Morphoedaphic Index (MEI)	5.6
Total Dissolved Solids (mg/L)	50.4
Growing Degree Days (GDD)	1500

[1] based on 2 m depth

Table 5 was produced from the OMNR Aquatic Habitat Inventory database 1976

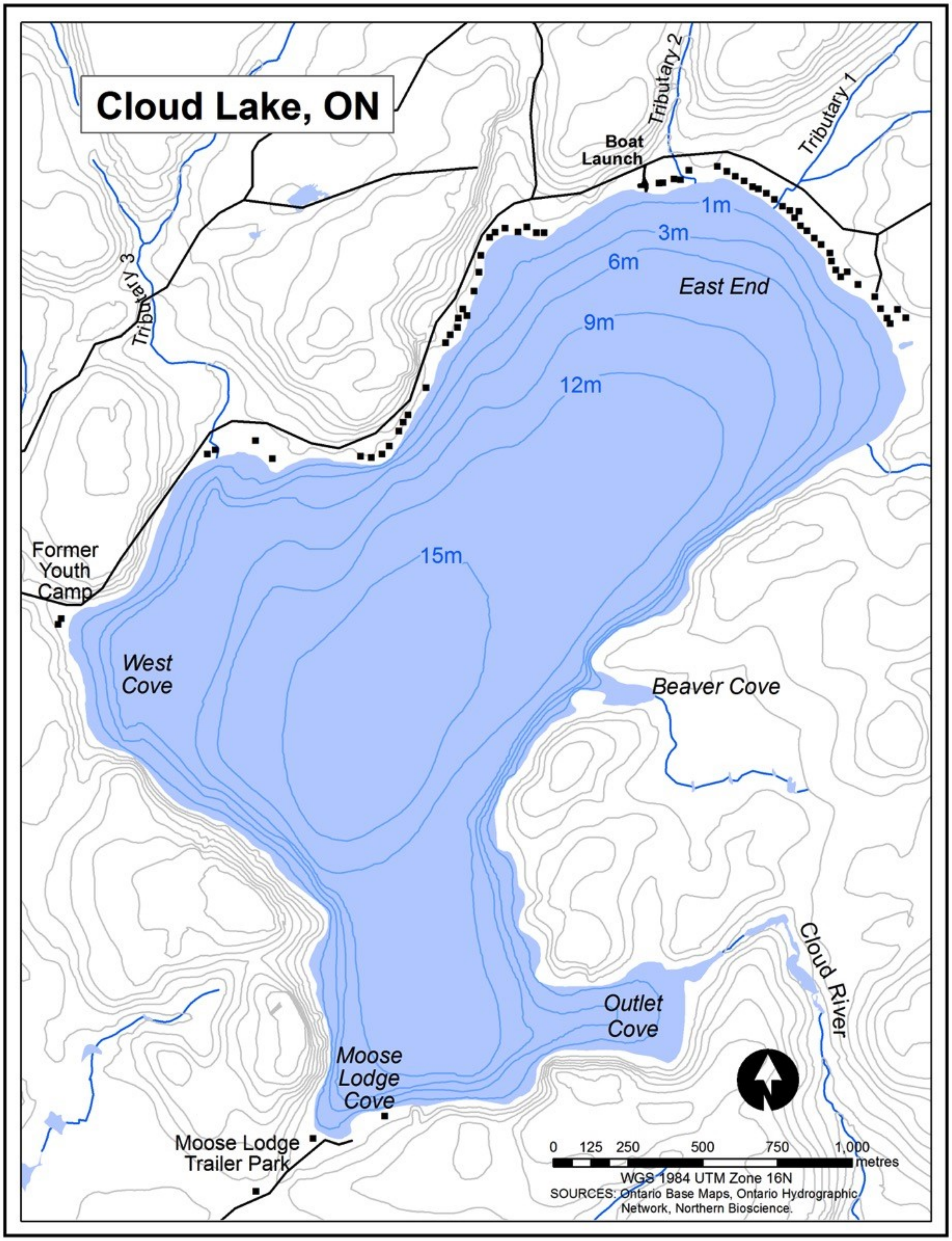


Figure 6. Bathymetry of Cloud Lake.

A majority of the shoreline is rocky and steep. Sandy shallow areas are found in the northeastern, northwestern, and the outlet bay. As can be seen in the bathymetry map (figure 6) Cloud Lake resembles a bowl or sink in general shape.

3.3 Human Occupation and use

3.3.1 Development

The Cloud River watershed has experienced a number of human activities from early logging to more recent recreational development. The first human impact within the watershed was logging in the early 1900's. In the 1940's logging throughout the Cloud River watershed was at its peak. Logs harvested in the region were transported down the river to Cloud Bay where a mill was located and has since been dismantled. The area was logged out during this time and according to local reports the area was burned after improper maintenance of slash piles (pers. comm. to R.J. Winkworth 1980, OMNR files). In the 1980's commercial logging of trembling aspen began and persisted periodically into the 2000's (Foster, 2016). Although logging in the area slowed, recreational use of the lake has been consistent.

The first planned cottages came after the construction of an allowed road access to Cloud Lake during the late 1950's (Foster, 2016). In 1973 Cloud Lake, had approximately 15 cottages, 20 campsites at the Loyal Order of the Moose Lodge (ROML), and a small youth camp. As of 2015 Cloud Lake had approximately 75 cottages, 40 camp sites part of the ROML, 10 permanent residents, and a small youth camp located around Cloud Lake (Foster, 2016). In 2005 Cloud Lake's spring TP was first noted to be over the PWQO guideline of 20ug/L and the Ministry of the Environment declared that no further development including conversion of seasonal dwellings to permanent homes could be undertaken (Statlander, 2006). In response to this the Municipality of Neebing implemented the Official Plan (OP), which was approved by the Ministry of Municipal Affairs and Housing (MMAH) in January 2008 (Lynde, Paul Associates Inc. 2008). The implementation of this plan requires approval of any development by the municipality to ensure sources of nutrients (septic systems) are more than 300 meters back, and that no water quality impact will be incurred. Any development within 300 meters of the lake edge is only allowed after proof that the proposed development will not result in net phosphorus loading to Cloud Lake. The entire shore line around Cloud Lake is listed as privately owned on the Ontario Ministry of Natural Resources and Forestry's online Crown Land Use and Policy Atlas (http://www.giscoeapp.lrc.gov.on.ca/CLUPA/Index.html?site=CLUPA&viewer=CLUPA&locale=en-US).

3.3.2 Fish Community

It is reported that within Cloud Lake thirteen species of fish have been documented. Table 6 Shows these species indicating which are native or introduced. There are four introduced species. Rock Bass, and Smallmouth Bass were introduced to Cloud Lake in 1964 by the OMNR. Walleye are a popular game fish for many anglers in Northwestern Ontario. At the request of the Cloud Lake Campers Association the OMNR introduced Walleye into Cloud Lake in September 1964 (OMNR 1976 and unpublished records). Anecdotal reports during the 1970's along with OMNR monitoring in the spring of 1979 suggest that both Smallmouth Bass and Walleye populations in Cloud Lake were in excellent condition.

Issues began to appear in the 1980's. OMNR reports summarized by Foster in 2016 suggest that the population saw decline in the abundance of "trophy Walleye". Their efforts resulted in an estimation that the original strain of Walleye was a river spawning rather than a shoal-spawning strain. In 1989 and 1991 the OMNR stocked Walleye from Lac des Milles Lacs. In 1999 OMNR Fall Walleye Index Netting (FWIN) suggested that Cloud Lake had a significant large, heavy, and older Walleye population than other Northern Ontario Lakes. Unfortunately, the FWIN data showed the best recruitment year was immediately after the 1991 introduction, then declined steadily. Stocking in Cloud Lake continued with the help of resident private efforts. Despite this effort the Walleye population on Cloud Lake has continued to be a cause for concern to locals and was one of the main reasons the 2015 project went forward.

Table 6. Fish species documented in Cloud Lake.

Family	Common Name	Scientific Name	MNR Code	Status in Cloud Lake	Source
Salmonidae	Cisco (Lake Herring)	*Coregonus artedii*	093	native	AHI 1976
Osmeridae	Rainbow Smelt	*Osmerus mordax*	121	introduced	AHI 1976
Esocidae	Northern Pike	*Esox lucius*	131	native	AHI 1977
Umbridae	Central Mudminnow	*Umbra limi*	141	native	AHI 1978
Catostomidae	White Sucker	*Catostomus commersoni*	163	native	AHI 1979
Cyprinidadae	Finescale Dace	*Chrosomus neogaeus*	183	native	OMNR 1976
Cyprinidadae	Blacknose Shiner	*Notropus heterolepus*	200	native	OMNR 1976
Centrarchidae	Rock Bass	*Ambloplites rupestris*	311	introduced	AHI 1975
Centrarchidae	Smallmouth Bass	*Micropterus dolomieu*	316	introduced	AHI 1976
Percidae	Yellow Perch	*Perca flavescens*	331	native	AHI 1976
Percidae	Walleye	*Sander vitreus vitreus*	334	introduced	AHI 1976

Percidae	Iowa Darter	*Etheostoma exile*	338	native	OMNR 1976
Cottidae	Sculpin	*Cottus* sp.	382	native	FWIN 1998

Based on table 6 Cloud Lake had 9 native fish species and 4 introduced species. The introduced species have been the focus of follow up studies due to the favoritism of anglers to target these species.

Cloud lake is an interesting case study because the elevation in the watershed means Cloud Lake is perched above a majority of the watershed. There is limited area immediately around the lake that can provide surface runoff and non-point source nutrient inputs into the lake. The next interesting feature of Cloud Lake described above is the bathymetric data seen in figure 6. The general shape of the lake shows a relatively steep shore line into a deep single basin. This shape would suggest that any nutrients coming into Cloud Lake are being held within this 'bowl' or basin. As the number of residents around the shore increased, so did the spring TP. Cloud Lake does not have any major agricultural inputs and forestry within the watershed has been periodic since the 1980's and is expected to provide minimal nutrient loading.

Chapter 4
Research Methodology

4.1 Introduction

The goal of this thesis is to classify the current trophic state of Cloud Lake. Freshwater eutrophication research focuses on the impact of increased nutrients resulting in cyanobacteria blooms, specifically where or these driving nutrients (phosphorus, nitrogen, iron) are within the system (Dillion and Molot 1996, Matisoff et al., 2017; Molot et al., 2014, Nürnberg 1984, Sorichetti et al., 2014, Steinman et al., 2015; Watson et al., 2016). It is important to note that their research is part of extensive previous work providing supplemental baseline data for comparison. My research will investigate the mean spatial and temporal patterns of phosphorus, dissolved oxygen, and temperature within Cloud Lake. This information will be used to create a complete baseline of conditions in a lake that has limited data, and to characterize Cloud Lake's current trophic state.

4.2 Field Sample Sites

Selection of sampling sites for the 2015 project were based on limited studies conducted on Cloud Lake, as well as CCME guidelines, recommendations of the Ontario Ministry of Environment and Climate Change (MOECC), Ministry of Natural Resources and Forestry (MNRF), and the input of local experts who participated in a working group held at Lakehead University prior to the 2015 sampling season. The participants represented a range of stakeholders including Ontario Ministry of Environment and Climate Change (OMOECC), Ministry of Natural Resources and Forestry (MNRF), Lakehead Regional Conservation Authority (LRCA), North Shore Steelhead Association (NSSA), Lakehead University, Thunder Bay Stewardship Council, Neebing township council members, and various public members.

A total of nine sites were selected; one site on each of the three inflow tributaries, two lake sites, and four outflow sites (see figure 7). These sites provide comparative data for the lake representing the inputs, outputs, and different depths in the lake.

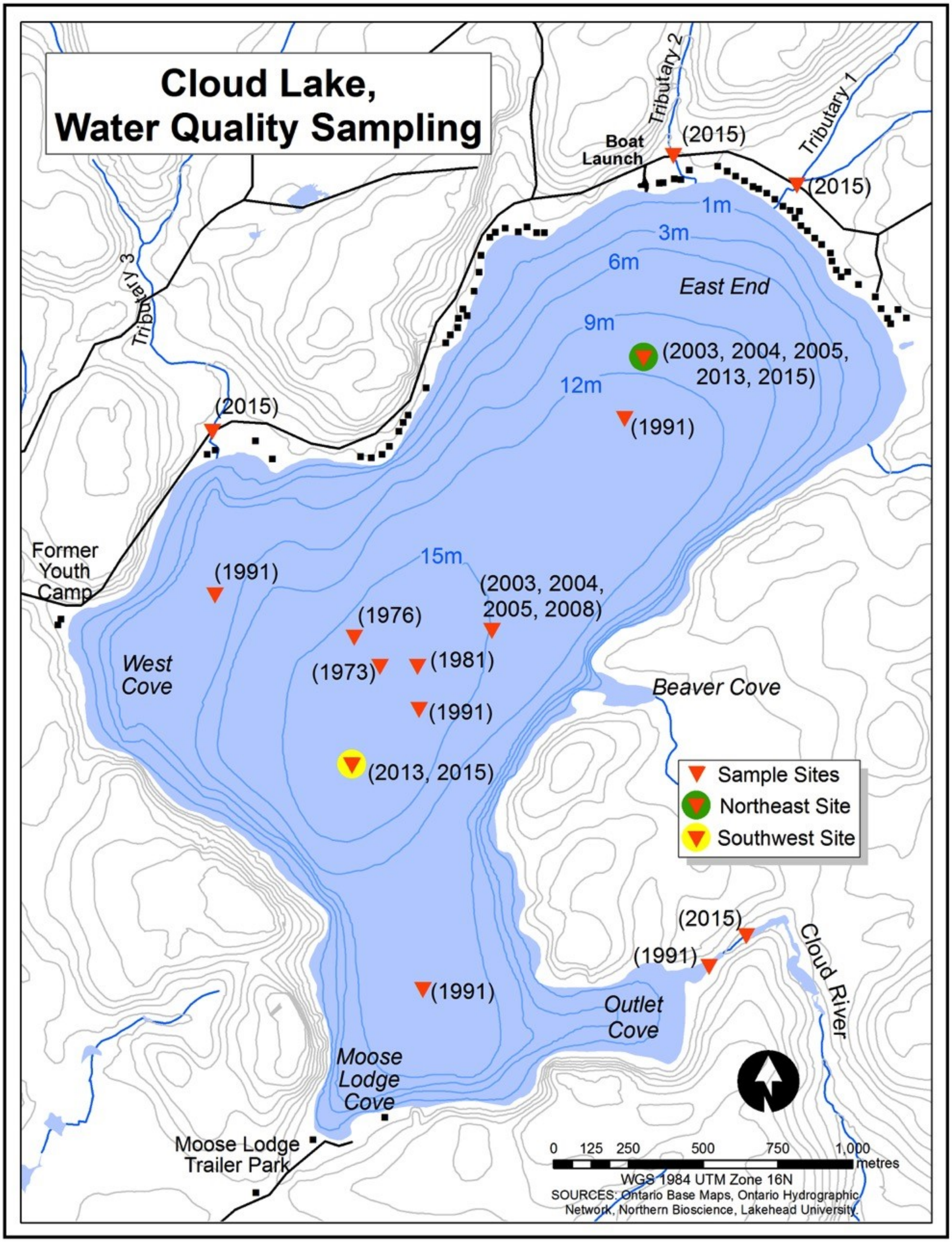


Figure 7. Cloud Lake Sampling sites past and present.

Cloud Lake water quality sampling sites since the first study in 1973 – 2015.

4.3 Profiles Introduction

Comparative data used for the study includes profile data for temperature, dissolved oxygen, discharge of inflow tributaries and outflow collected on Cloud Lake. Temperature profiles provide information on thermal stratification as well as mixing periods allowing for a determination of monomictic, dimictic, or polymictic conditions (Wetzel, 2001). Monitoring temperatures throughout the water column help to understand the development and movements of the thermocline separating the epilimnion and hypolimnion. Dissolved oxygen (DO) profiles are used to examine the distribution of oxygen concentrations within the water column (Mackie, 2004). DO profiles are used to monitor for development of anaerobic conditions in the hypolimnion which have known implications on nutrient concentrations (Boehrer and Schultze, 2008; Lampert and Sommer, 2007; Wetzel, 2001). Discharge measurements provide information about general characteristics of the water system (Cuadrado, 2008). Morphological features of the watershed influence the amount of water entering and exiting a lake. Discharge profiles, therefore, provide an indication of how much water is entering and exiting Cloud Lake through the inflow and outflow tributaries. All of these profiles contribute information on the unique interactions that add understanding of nutrient distribution, concentration and location on Cloud Lake.

4.3.1 Sampling Schedule

Previous Cloud Lake reports conducted by the OMOECC suggest that Cloud Lake is dimictic (turns over twice a year) (Pugh, 1992). Spring turnover is noted as an important time for collecting water samples as it is during this time that lake water is fully mixed and homogenous. As summer progresses, dimictic lakes stratify before fall turnover (Wetzel, 2001). The 2015 parameters and schedule can be found in appendix (a), which shows bi-weekly sampling for spring and fall to catch these turn-overs and monthly sampling during summer stratification.

4.3.2 Temperature and Dissolved Oxygen Profiles

Lake temperature and dissolved oxygen profiles for Cloud Lake were collected using a handheld Hanna HI 9828 multi probe. The first sample was collected on April 13th 2015 when Cloud Lake was still frozen. This sample was collected by walking to the Southwest lake site and drilling a hole to access the water below. Subsequent profiles were collected at (Northeast and Southwest) sites beginning on May 8th 2015 when open water allowed for sampling. Profile data was collected at one meter intervals from the surface down the water column to the water sediment interface. Open water measurements were collected in situ while anchored at the sample site and recorded in a water proof field notebook.

4.3.3 Stream Profiles

Discharge profiles were collected when conditions in the tributaries allowed. The three main inflow tributaries were sampled just below the road crossing before the tributary entered the lake (see figure 7). Profiles were done on May 8th, May 25th and June 9th 2015 after which measurements were not possible due to lack of flow. A single rain event was collected at the end of August in an attempt to capture inputs as a result of rain runoff. The outflow was monitored May 8th, May 25th June 9th, and July 10th 2015 at which point it was noted that beavers dammed the outflow cutting off water leaving Cloud Lake. The dam remained in place until winter freeze up occurred in mid-December 2015. Discharge profiles were collected using a flow meter at 50cm intervals across the tributary and used to calculate Q or discharge as a function of flow and volume. During this time, wetted depth and width of the tributaries were collected. In situ measurements were recorded on a chart printed on water proof paper (see appendix b).

4.4 Water Chemistry Samples

A full list of analyzed water quality parameters can be found in Appendix (E). For this thesis, the focus will be on total phosphorus (TP) and chlorophyll ***a***. Lake water chemistry samples were collected at the same time as the DO and temperature profiles mentioned in the previous section while anchored on a boat. TP and chlorophyll *a* samples were collected on 12 occasions over the 2015 season (see Table 10 and 11). Lake water samples were collected with the use of a Kemmerer. Samples were taken at depths of one meter below surface, halfway down the water column, between five and six meters for the Northeast site and eight and nine meters for the Southwest site. The last sample was taken one meter above lake sediment at both sites (Northeast and Southwest). Two samples were collected at each site, one 1000mL (PET) bottle for chlorophyll *a* and one 500mL (PET) bottle for all other general chemistry parameters including TP. The sample one meter below surface was taken first followed by the mid column and lastly the one meter above the sediment water interface.

Sample bottles were labeled in order and stored in a cooler to restrict the sample from heating up in direct sunlight while being transported back to Lakehead University lab. Water samples were taken directly to Lakehead Universities Environmental Lab (LUEL), an ISO 17025 accredited lab, using photometric analysis techniques to determine water chemistry parameters. If overnight storage was needed, samples were frozen to maintain water chemistry until it was possible to deposit samples at LUEL. Tributary TP and chlorophyll *a* samples did not require the use of a Kemmerer as depth was not an issue. Sample collection at the tributary sites was taken first thing when arriving on site to avoid contamination. Care was taken to acquire the sample upstream from discharge site to avoid any contamination introduced through possible disturbances. Two bottles, one 1000mL (PET) and one 500mL (PET), were collected for each tributary when flow was sufficient. LUEL's total phosphorus, chlorophyll *a*, and other water chemistry procedures can be found at http://lucas.lakeheadu.ca/luel/.

4.5 Secchi Depth

Secchi disc measurements provide insight into aspects such as turbidity of the euphotic zone. Inhibited light penetration, usually due to increased algae abundance, is a sign of a higher eutrophic state (Wetzel, 2001). Secchi depth is the distance below the water surface where an observer can visually distinguish the black and white pattern on a 20cm diameter disc. Secchi depth is an easy parameter to measure and is still monitored as part of the OMOECC trophic state index of lakes. Background information on the water conditions of a given lake is critical when collecting this data. Some known complications can be the result of high tannin as well as ferric acid and may cause complications when using a secchi disc (Wetzel, 2001). Fortunately, Cloud Lake does not experience these conditions, allowing for secchi depth to be collected at both lake sites in addition to profiles and water samples. This measurement was taken on the leeward side of the boat while wearing polarized sunglasses. These criteria were met each time to remove possible observational differences between sampling days.

4.5.1 Algae Identification/Cyanobacteria Identification

Part of the original concerns about the lake's health stem from complaints made by residents of increased algae blooms. Although monitoring the water chemistry provides insight into the abundance of nutrients available on the lake, it does not provide information about what algae blooms exist on the lake. During the collection of data for this project, several blooms were witnessed on the lake. This section will discuss the processes taken to capture and identify dominant algae within these blooms.

Grab samples were collected in 500 mL PET bottles and stored in a cooler for transport back to Lakehead University. Samples where filtered over 5µm Nano filter paper. The sample was removed from the filter paper and placed on a slide. Samples were placed on glass slide and a 20x40 Fisher Brand glass cover slip was placed on top of the sample. Some samples were permanently fixed. These samples were set aside to dry for approximately 10 minutes to remove excess moisture. Permanent mounts were glued with entellan and left under a fume hood for thirty minutes to allow for drying and dissipation of fumes. All slides, both wet and permanent mounts, were then examined under an Olympus BX51 microscope with and Olympus DP72 camera at magnifications from 10X to 50X. Algae keys and field guides were used to ensure a proper identification, such as the Canadian Agriculture and Agri-Food Canada Agri-Environment Services Branch Algae

Identification Field Guide, and the Landcare Research Freshwater Identification Guide. Examination and comparison of features of the algae allowed for the determination of the dominant species observed on the slide. Pictures of the samples were then taken while the samples were under the microscope, and many were sent for verification of identification to experts within the MOECC as well as other academic institutions.

4.5.2 Bass Nest Survey

Smallmouth Bass nest surveying is necessary to identify spawning and nursery habitat. As part of the larger project on Cloud Lake a survey of Smallmouth Bass nests was conducted to address concerns of algae impact speculated to be a potential cause of decrease in fish habitat and population. These surveys focus on identifying current areas of spawning and nursery habitat. The methods for this survey were adapted from Foster and Harris (2010). Fish nesting surveys are also necessary to identify fish spawning and nursery habitat to better understand recruitment of Smallmouth Bass on Cloud Lake. Recruitment data along with population data collected by the MNRF's nearshore index and broad scale netting were used to assess the concerns about the impact of algae on current Smallmouth Bass populations on Cloud Lake. This section will focus specifically on the conduction of Smallmouth Bass nest surveying.

The bass nest survey is a visual inspection of the near shore littoral zone in order to identify the presence of bass beds. According to the Ontario Ministry of Natural Resources and Forestry Smallmouth Bass begin spawning when lake surface water temperatures exceed 15°C for at least 5 consecutive days. Typically this would be early June, however surface temperatures on Cloud Lake did not meet this threshold until the third week in June. June 17th 2015 was the first day of surveying and incorporated training by Dr. Robert Foster of the divers who would be completing the survey on Cloud Lake. Teams of one diver and one recorder surveyed from June 22 – 26. 10kms of the total 12kms of shoreline were surveyed on Cloud Lake. We used wet and dry suits along with scuba mask, fins, snorkel, marker buoy, and 1 meter quadrates divided into 5 cm intervals. When nests were discovered the diver would relay information on a number of parameters from presence or absence of male bass, fry or eggs, and condition of observed eggs to depth of water and composition of substrate the nest was located on (see appendix D for spring Smallmouth Bass nesting form) to the recorder who logged the GPS coordinates of the nest along with the number of any pictures taken on the Smallmouth Bass nesting data form. This data was then entered into ArcGIS ver. 10.4 for spatial analysis.

4.5.3 Macrophage Survey

Video was collected using a boat and a SeaViewer "Sea Drop 950" color video camera (with LED lighting), "Sea Trak" GPS video overlay unit, and a video capture unit (DVR-SD) for storing the video to SD cards (Figure 8). This system allows for GPS coordinates and time/date to be overlain on the video as it is recorded, which allowed for precise georeferencing of all images. A 3-person crew from Lakehead University (1 boat driver, 1 camera operator, and a note-taker) were used for the 2015 surveys. The camera unit was suspended by hand over the side of the boat using the kevlar-reinforced video cable and a 5lb downrigger ball, which helped maintain camera depth as the watercraft cruises along. A handheld Garmin GPS was used to maintain position along the transects and record locations of particular features (e.g. vegetation beds, grab samples).

Figure 8. SeaViewer unit.
Figure 8 shows entire set up with camera and downrigger ball (in hand, at left)

Survey effort e.g., spacing of transects can be adapted to available time and personnel resources. The transects should focus on the littoral zone where light penetration is sufficient to allow submergent growth. The survey approach was conducted using several transects on the lake at set distances from shore (e.g., 5, 10, 15 m) within the littoral zone. A handheld GPS records the tracks to be inputted into GIS for further analysis.

Videos can be downloaded and viewed on-screen using custom software provided by SeaView as well as Windows MediaPlayer. Georeferenced sample points should be extracted approximately every 5-10m along the survey tracks and attribute data entered into a spreadsheet, which can then be brought into ArcGIS for mapping and analysis. The entire video footage was viewed during the analysis, and representative still images (jpeg) were extracted as desired from the video.

At each sample point the following was recorded/interpreted:

- Submergent abundance in the following cover classes: 0%, 1-5%, 5-25%, 25-50%, 50-75%, 75-100%;
- Submergent species composition. Grabs can be taken at select locations in the field using a rake, grappling hook or snorkeler to confirm species identifications that can later be used to "ground-truth" the videos;
- Other habitat features (e.g., coarse woody debris);
- Substrate type (e.g., fine sediments, medium to coarse sand, gravel, cobble, bark, mixed).
- Benthic algae abundance in the following cover classes: <5%, 5-25%, 26-50%, 50-75%, >75% ;
- Photo number (for selected points).

Water depth can be interpolated from existing bathymetric data in conjunction with the GPS coordinates. Video analysis of substrate types has some inherent limitations that must be recognized. Different classes of fine sediments are impossible to discriminate, therefore clays (<.002 mm), silts (0.002 - 0.05 mm), and fine to very fine sands (0.002 - 0.25mm) silts should be pooled as "fine sediments".

Figure 9. Submerged aquatic vegetation image.
Example image from SeaView camera with curly-leaved pondweed (*Potamogeton amplexifolius*).

Chapter 5
Results

5.1 Introduction

This chapter presents the results of the data collected during the 2015 field season on Cloud Lake in order to classify the trophic state of the lake based on both the Ontario Ministry of the Environment and Climate Change (OMOECC) classification scales and classifications derived from Carlson's (1974) Trophic State Index (TSI). In Section 5.1, inflow and outflow tributaries provide an indication of water discharge and nutrient levels entering Cloud Lake during spring freshet followed by the results of the two lake sites that represent the Total Phosphorous measurements and the trophic state indicators (secchi depths, chlorophyll *a* concentrations, temperature and dissolved oxygen profiles).

Section 5.2 provides the results of the baseline data collected to better understand the ecological characteristics of Cloud Lake. The vegetation survey results provide the distribution of aquatic submergent vegetation around Cloud Lake and the presence algae. The spring Smallmouth Bass survey presents the overall number and distribution of nests that were observed during June 2015 and the results of algae identified on Cloud Lake provide the variety and frequency of algae observed throughout the 2015 field season.

5.2 Inflow and outflow

Table 7 shows inflow and outflow tributary discharge in ($m^3s\text{-}^1$) during the spring freshet and rain event during the 2015 season. The three inflow tributaries show a consistent trend of diminishing flow through the spring freshet. The highest discharge was captured on May 8th with discharge lessening to 0 on July 10th. The mean discharge for tributary 1 was 0.14$m^3s\text{-}^1$ with a minimum flow of 0.03$m^3s\text{-}^1$ and maximum flow of 0.29 $m^3s\text{-}^1$. For tributary 2 the mean was 0.09$m^3s\text{-}^1$ with a minimum flow of 0.04$m^3s\text{-}^1$ and maximum flow of 0.12 $m^3s\text{-}^1$. For tributary 3 the mean was 0.13$m^3s\text{-}^1$ with a minimum of 0.08$m^3s\text{-}^1$ and maximum flow of 0.32 $m^3s\text{-}^1$. The sample collected on August 29th represents a summer rainfall event used to capture potential surface input during the summer.

Table 7. Tributary and outflow discharge in (m^3s^{-1}) for the 2015 field season

Date	May 8	May 15	June 9	July 10	Aug. 29
Trib 1	0.29	0.10	0.03	N/A	0.01
Trib 2	0.12	0.09	0.04	N/A	0.03
Trib 3	0.32	0.08	0.00	N/A	0.01
Outflow	0.87	0.81	0.57	0.62	N/A

Table 8 shows the TP concentrations in (µg/L) for the three inflow tributaries and the outflow tributary for the spring freshet and rain event during 2015. The mean for the outflow was 0.67m^3s^{-1} with a minimum flow of 0.57m^3s^{-1} and maximum flow of 0.81 m^3s^{-1}. The mean total phosphorus for tributary 1 was 36µg/L, tributary 2 was 32µg/L, and tributary 3 was 36µg/L. The combined tributary mean was 35µg/L. The outflow shows less total phosphorus during this time ranging from 8 to 12µg/L with a mean of 10µg/L. The sample collected on August 29th represents a summer rainfall event used to capture potential surface input during the summer.

Table 8. Tributary and outflow total phosphorus in (µg/L) for the 2015 field season

Date	April 13	May 8	May 15	June 9	July 10	Aug. 29
Trib 1	77	31	15	20	N/A	36
Trib 2	64	22	18	24	N/A	31
Trib 3	72	35	16	21	N/A	43
Outflow	N/A	12	8	12	14	N/A

Figures 10 and 11 show two representations of combined total phosphorus and discharge data for the inflow and outflow. These figures show visually the trends that developed over the 2015 season. During the spring freshet (April 13 – May 25) total phosphorus concentrations in the three inflow tributaries ranged from 77 to 64µg/L. These concentrations rapidly diminished to 15 to 18µg/L on May 25th. After June 9th all three inflow tributaries show N/A or not measurable due to lack of flow halting discharge and water quality monitoring on the inflow tributaries.

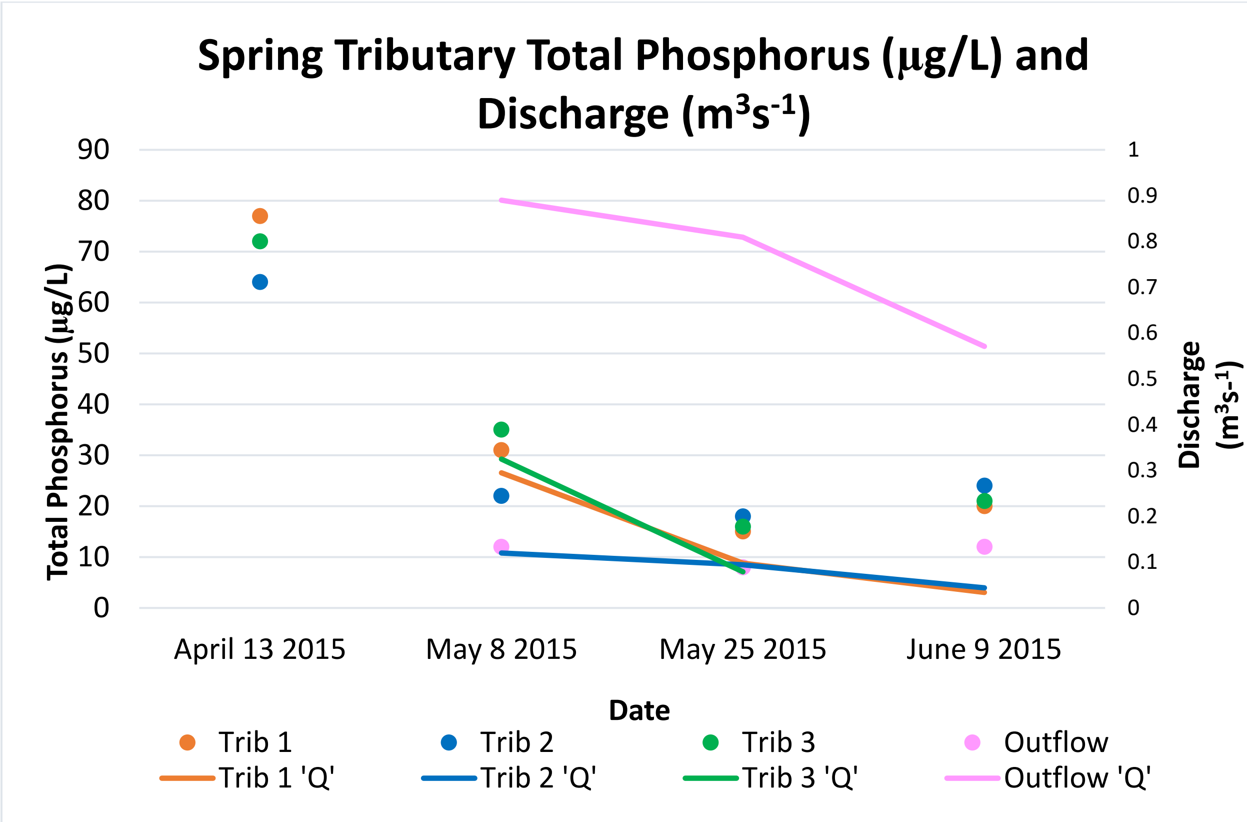


Figure 10. Cloud Lake 2015 tributary spring phosphorus and discharge.
This graph shows the tributaries and outflow comparing discharge in (m^3s^{-1}) on the left x-axis with total phosphorus in (µg/L) on the right x-axis for 2015 field season. This figure shows the comparison and trends between discharge and total phosphorus. Both parameters are higher during the early season diminishing as the season progresses.

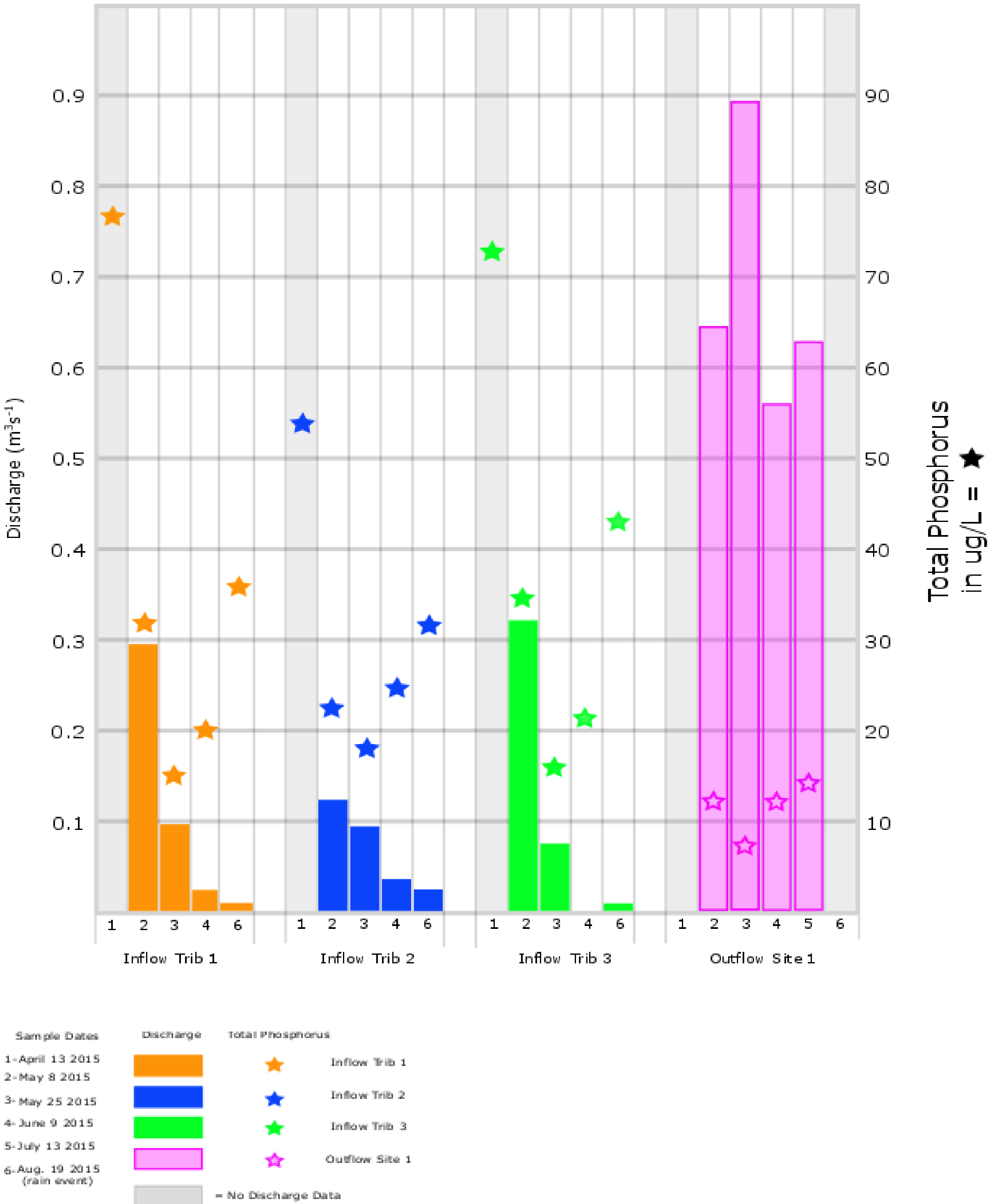


Figure 11. Cloud Lake 2015 tributary discharge and total phosphorus.

This graph shows tributaries and outflow comparing discharge in (m^3s^{-1}) on the left x-axis with total phosphorus in (μg/L) on the right x-axis for 2015 field season. The coloured bars represent discharge with the stars indicating total phosphorus in (μg/L).

Figure 11 shows an alternative representation of the discharge and total phosphorus for the inflow and outflow. In this figure discharge is represented by the bars and total phosphorus by coloured stars. Unlike the previous figure 10 the August 29th rain event has been included to show the diminished flow with higher concentrations of total phosphorus than what was captured at the end of the spring freshet samples collected on June 9th. An important difference is the representation of the outflow data in figure 11. There is a discrepancy between discharge and total phosphorus of the outflow when compared to the inflow discharge and total phosphorus. The outflow discharge remains rather high throughout the spring freshet and into early summer. The total phosphorus is relatively consistent with little change throughout the same time.

Table 7 and figures 10 and 11 show that the majority of discharge for the three tributaries occurred early in the season and then discharge from the tributaries into Cloud Lake were dramatically reduced for the remainder of the season. July 10th had no discharge for the inflow tributaries and represents the rapid decline in tributary flow outside of the spring freshet. Tributary three did show higher discharge during the initial freshet but was not significantly different from the other two tributaries and corresponding phosphorous measurements. Phosphorous measurements for the tributaries show the same pattern to the discharge measurements, and indicates that the three tributaries are relatively similar and provide a good indication of total discharge/phosphorous loading into Cloud Lake. The outflow phosphorus measurements show little difference throughout the spring freshet. The discharge appears to increase later into the spring freshet in comparison to the inflows, as seen in figure 11.

5.3 Secchi Depth

The results of the secchi depth for the 2015 field season show a range of secchi depths from 1.1m to 4.75m with a mean secchi depth of 1.6m for both Cloud Lake sites. There were minor differences between the sites showing rather uniform results across the lake with the biggest difference occurring on May 21st with a difference of 1.3m between the Northeast and Southwest sites.

Table 9. Secchi depths for both Cloud Lake sites for 2015 field season.

Date	Southwest Site	Northeast Site
May 8th 2015	1.1m	1.1m
May 21st 2015	2.2m	1.5m
June 5th 2015	2.0m	2.2m
July 10th 2015	4.75m	4.75m
Aug 5th 2015	2m	2.2m
Aug 29th 2015	1.6m	1.9m
Sept 10th 2015	2.5m	2.7m
Sept 25th 2015	1.9m	1.9m
Oct. 14th 2015	1.7m	1.6
Oct. 22nd 2015	2.6m	2.4m
Nov. 2nd 2015	4.5m	4m

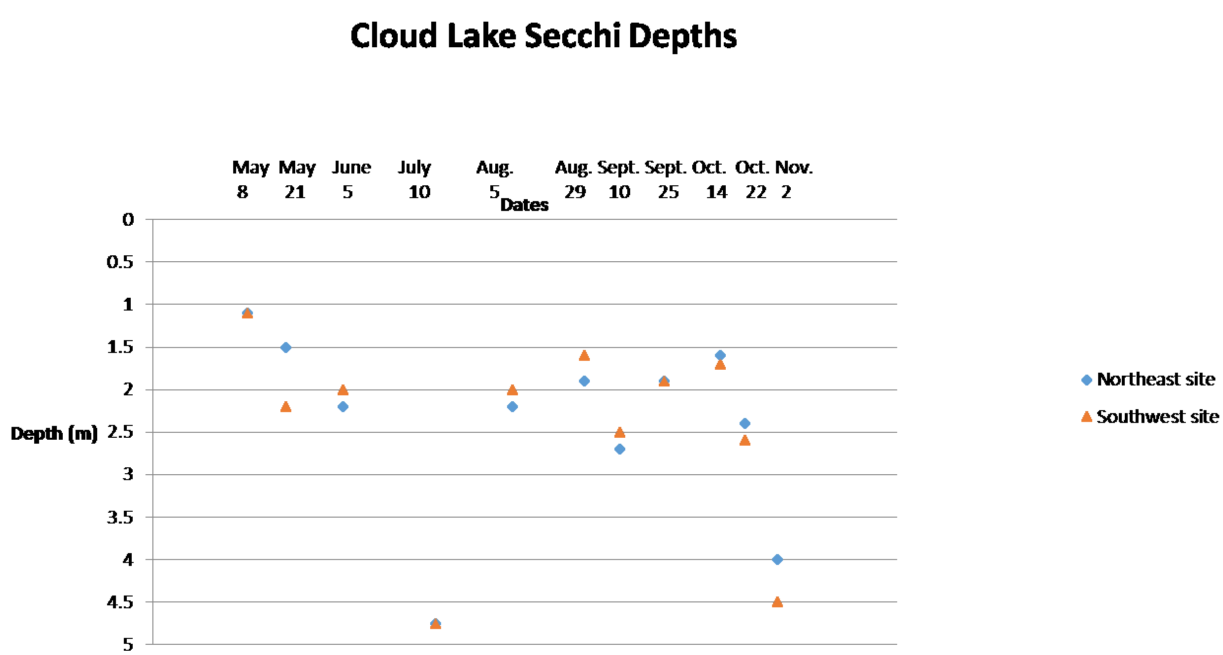


Figure 12. Cloud Lake secchi depths.
Graph showing the secchi depth measurements for both Northeast and Southwest Sites during the 2015 field season.

Figure 12 shows a graphical representation of the secchi depths in 0.5 meter intervals along the left y-axis with sample dates for both the Northeast and Southwest sites from May 8th 2015 to November 2nd 2015 on the bottom x-axis. Note the observation of increased clarity on measurements taken on July 10th and October 22nd. The July 10th increase in water clarity coincides with the diminishing input from the inflow tributaries at the end of the spring freshet (Figure 10) when sediment loading would no longer be taking place and the summer stratification would be beginning. The October 22nd increase in clarity coincides with fall turnover. The biggest difference in secchi depth reading occurs on May 21st, toward the end of the spring freshet, with a difference of 0.7m between the Northeast site 1.5m reading and the Southwest site 2.2m reading. Despite the two increases in clarity on July 10th and Oct 22nd there is consistency between secchi depths across the two lake sites and a relatively uniform light penetration of the littoral zone for Cloud Lake. Observations in the field clearly showed that water clarity was limited from the inhibited light penetration of the littoral zone throughout Cloud Lake.

5.4 Chlorophyll *a* concentration and distribution

The results of the chlorophyll *a* sampling (Table 10 and 11) showed a mean concentration of 3.33mg/L with a minimum concentration of 0.7mg/L on May 8th and maximum concentration of 10.5mg/L on September 25th. Chlorophyll *a* samples were collected at both the Northeast and Southwest sites. The concentration mean at the Northeast site was 3.35mg/L with a minimum of 0.6mg/L on May 8th and a maximum of 10.3mg/L on September 25th. The Southeast site had a mean concentration of 3.32mg/L with a minimum of 0.7mg/L on May 8th and maximum of 10.5mg/L on September 25th. When examined over the duration of the 2015 field season it can be seen that chlorophyll *a* concentrations steadily rose from early spring freshet through the summer before declining during fall turnover.

Table 10. Chlorophyll *a* concentrations for Northwest site Cloud Lake 2015

Northeast Chlorophyll *a* (μg/L)										
Date	May 8	May 25	June 9	July 10	Aug. 5	Aug. 29	Sept. 10	Sept. 25	Oct. 20	Nov. 2
1m	0.7	0.8	2.7	2.4	3.8	4.8	5.2	10.3	3	3.3
6m	0.9	0.8	5.3	2.2	4.6	4.3	4.4	10.1	3.2	3.1
11m	0.6	1	3.3	3.6	3.5	3.6	2	1.3	2.7	3.1

Southwest Chlorophyll *a* (μg/L)										
Date	May 8	May 25	June 9	July 10	Aug. 5	Aug. 29	Sept. 10	Sept. 25	Oct. 20	Nov. 2
1m	0.7	1	2.6	2.1	3.5	4.3	4.7	10.5	2.8	3.2
9m	0.8	0.9	4.5	4.2	2.7	2.9	4.2	8.8	3	3.7

17m	0.7	1	3	2.8	4	4.3	3.4	2.8	2.7	3.7

Table 11. Chlorophyll *a* concentrations for Southeast site Cloud Lake 2015

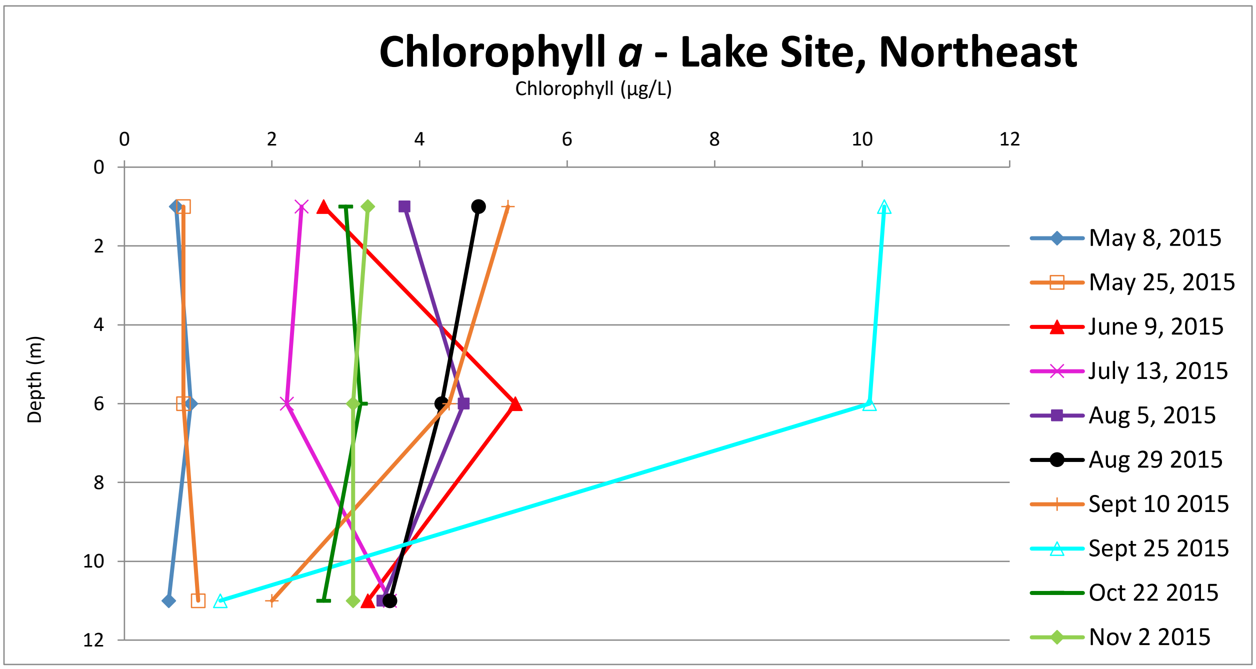


Figure 13. Northeast site chlorophyll *a* profile.
Line graph showing the chlorophyll *a* concentrations for the Northeast Site for the 2015 field season. This graph shows chlorophyll *a* in µg/L on the top x-axis with depth in two meter intervals on the left y-axis.

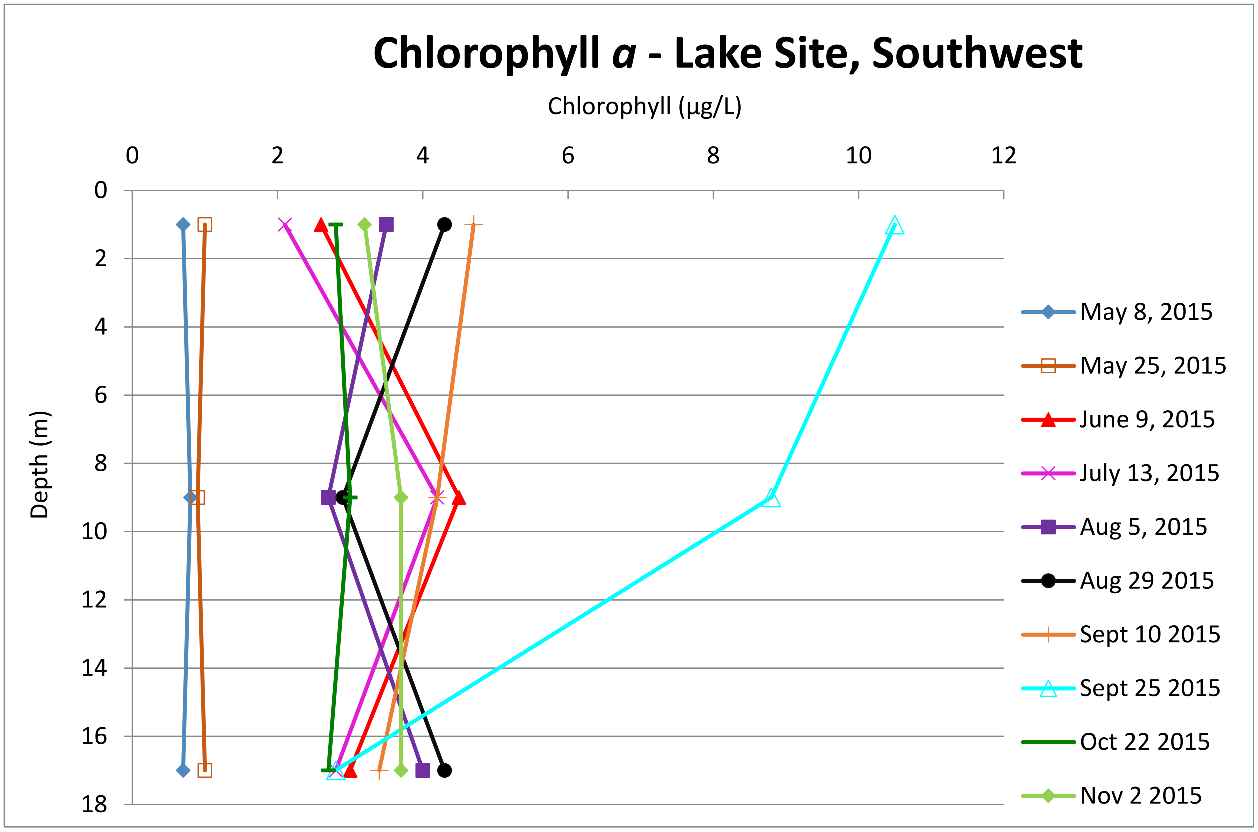


Figure 14. Southwest chlorophyll *a* profile.
Graph showing the chlorophyll *a* concentrations for the Southwest or (LW) Site for the 2015 field season. This graph shows chlorophyll *a* in µg/L on the top x-axis with depth in two meter intervals on the left y-axis.

Figures 13 and 14 show graphical representations of the trends seen in Tables 10 and 11 with the added feature of comparing them with depth, or within the hypolimnion and epilimnion. Consistently low concentrations were found in the early May during the spring freshet rising to peak at both sites on September 25th in the epilimnion. After this peak chlorophyll *a* concentrations diminish to similar levels as seen in early summer. Also of note is the June 9th sample for the Northeast site and the June 9th and July 10th sample for the Southwest site. These samples show concentrations being lower in the epilimnion peaking toward the middle of the water column, 6m and 9m respectively, and then back to the lower concentration at depth. Although there is some variation between the sites in general the distribution of chlorophyll *a* is similar between the sites and suggests consistency in the trends throughout Cloud Lake.

5.5 Lake temperature profiles

A total of twelve temperature profiles were collected at two sites on Cloud Lake during the 2015 field season. The first profile was collected at the Southwest site, the deepest point on Cloud Lake on April 13th when the lake was still covered in ice. The remaining eleven profiles were collected during the open water season from early spring to late fall. The range of temperatures for the Northeast site shows the lowest temperature of 5.06ºC on May 8th and the highest temperature of 21ºC on August 5th. The mean temperature for the whole of the Northeast site was 12.75ºC. The Southwest site range in temperature shows the lowest temperature of 2.42ºC on April 13th and the highest temperature of 20.5ºC on August 29th. The mean temperature for the Southwest site was 10.77ºC. The mean temperature from both sites was 11.76ºC.

Table 12. Temperature profiles for Northeast site Cloud Lake 2015.

Northeast site Temp. (ºC)											
Date	May 8	May 25	June 9	July 10	Aug. 5	Aug. 29	Sept. 10	Sept. 25	Oct. 14	Oct. 22	Nov. 2
1m	7.78	8.80	13.67	20.70	21.00	19.90	19.45	16.68	12.70	10.40	8.83
2m	7.68	8.75	13.59	20.60	20.80	19.90	19.45	16.69	12.70	10.35	8.58
3m	7.38	8.68	13.3	20.40	20.70	19.90	19.45	16.69	12.70	10.25	8.50
4m	7.03	8.64	13.01	20.35	20.40	19.90	19.45	16.69	12.70	10.25	8.48
5m	6.6	8.59	12.6	20.25	20.40	19.80	18.15	16.68	12.70	10.25	8.47
6m	6.54	8.57	12.15	17.80	20.40	17.90	17.80	16.68	12.70	10.25	8.45
7m	6.32	8.45	10.75	15.40	20.00	14.30	17.50	16.68	12.70	10.25	8.45
8m	5.75	8.21	9.02	13.30	18.50	11.10	16.80	15.68	12.70	10.25	8.44
9m	5.55	7.91	8.45	11.40	11.60	10.10	16.10	14.18	12.70	10.2	8.44
10m	5.26	6.80	8.03	10.20	11.00	9.10	15.10	14.10	12.50	10.15	8.44
11m	5.06	6.80	7.98	9.90	9.60	9.10	15.00	13.30	12.40	10.15	8.44

Table 13. Temperature profiles for Southwest site Cloud Lake 2015.

Southwest site Temp. (ºC)												
Date	Apr. 13	May 8	May 25	June 9	July 10	Aug. 5	Aug. 29	Sept. 10	Sept. 25	Oct. 14	Oct. 22	Nov. 2
1m	2.43	6.60	8.75	14.20	20.50	21.40	20.10	19.60	16.68	12.72	10.40	8.82
2m	2.42	6.60	8.70	14.04	20.4	21.00	20.10	19.60	16.68	12.72	10.40	8.77
3m	2.41	6.60	8.70	13.97	20.25	20.7	20.10	19.60	16.68	12.71	10.30	8.69
4m	2.41	6.59	8.60	13.87	20.2	20.5	20.10	19.60	16.68	12.70	10.30	8.55
5m	2.42	6.59	8.55	13.63	20.1	20.3	20.10	19.60	16.68	12.70	10.30	8.53
6m	2.41	6.53	8.40	12.3	19.1	20.3	20.10	19.60	16.68	12.70	10.25	8.52
7m	2.42	6.49	8.35	11.62	15.7	20.3	20.10	19.00	16.67	12.70	10.25	8.51
8m	2.43	6.47	8.02	10.83	11.8	15.1	15.20	15.80	16.68	12.70	10.25	8.51
9m	2.44	6.42	7.80	10.12	10.1	12.00	11.40	14.30	16.67	12.60	10.25	8.51
10m	2.59	6.28	7.65	9.57	9.6	10.5	10.00	12.30	16.67	12.60	10.25	8.51
11m	2.79	6.24	7.45	9.15	9.15	9.64	9.20	10.10	16.59	12.60	10.25	8.51
12m	2.99	6.23	7.40	8.87	8.72	9.00	8.70	9.70	12.43	11.00	10.25	8.50
13m	3.32	6.18	7.38	8.63	8.42	8.72	8.60	9.10	10.80	9.50	10.25	8.50
14m	3.68	6.10	7.30	8.47	8.22	8.52	8.20	8.50	9.87	8.50	10.25	8.50
15m	N/A	6.07	7.25	8.19	8.12	8.32	8.00	8.30	9.15	8.30	10.25	8.50
16m	N/A	5.91	7.10	7.85	7.92	8.22	7.90	8.20	8.78	8.20	10.15	8.50
17m	N/A	5.50	7.03	7.70	7.92	8.00	7.90	8.15	N/A	8.15	10.10	8.49

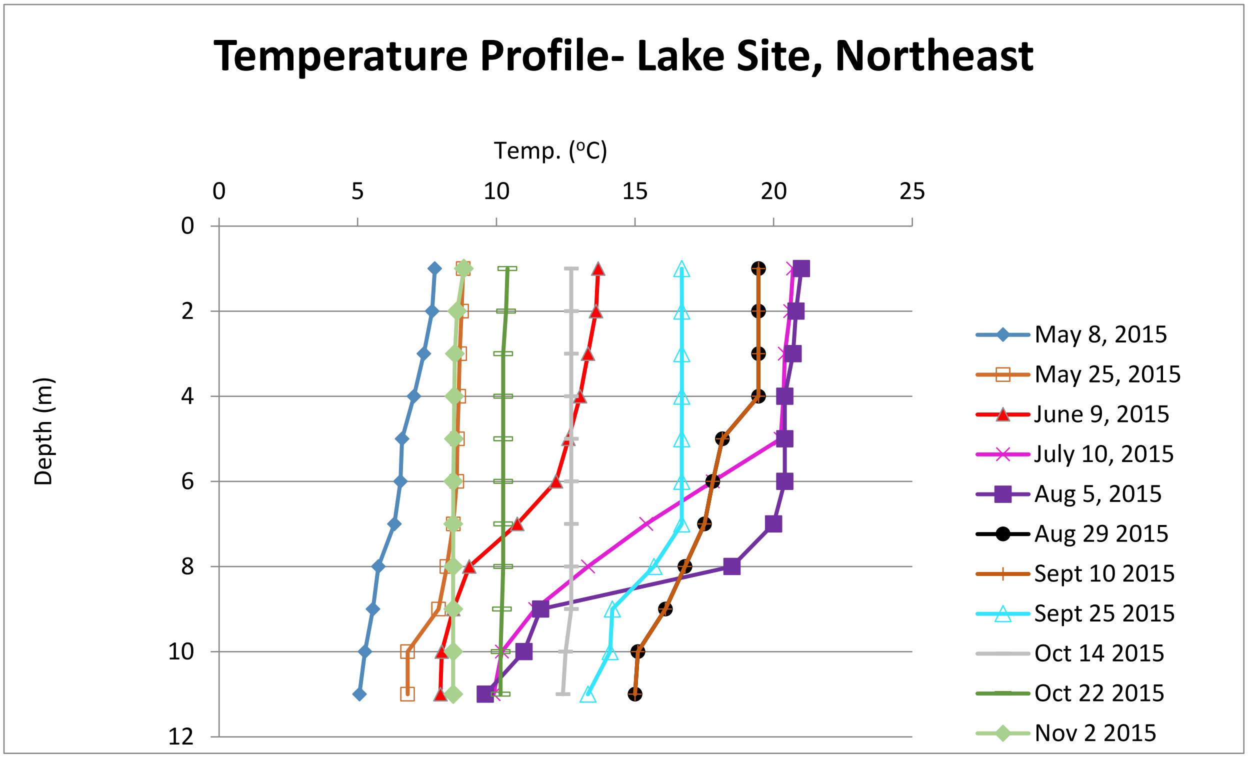


Figure 15. Northeast site temperature profile.
Line graph showing temperature in (°C) on the top x-axis with depth in two meter intervals on the left y-axis for the Northeast site for the 2015 field season.

Figure 15 shows the temperature in degrees Celsius on the top x-axis and the depth at two meter intervals on the y-axis. Note the beginning stratification of the lake as represented by a weak thermocline beginning on June 9th 2015 and becoming much more pronounced on July 10th 2015. The line shifts to the left and represents denser, cooler water. This profile shows Cloud Lake mixing during the spring and fall with summer stratification.

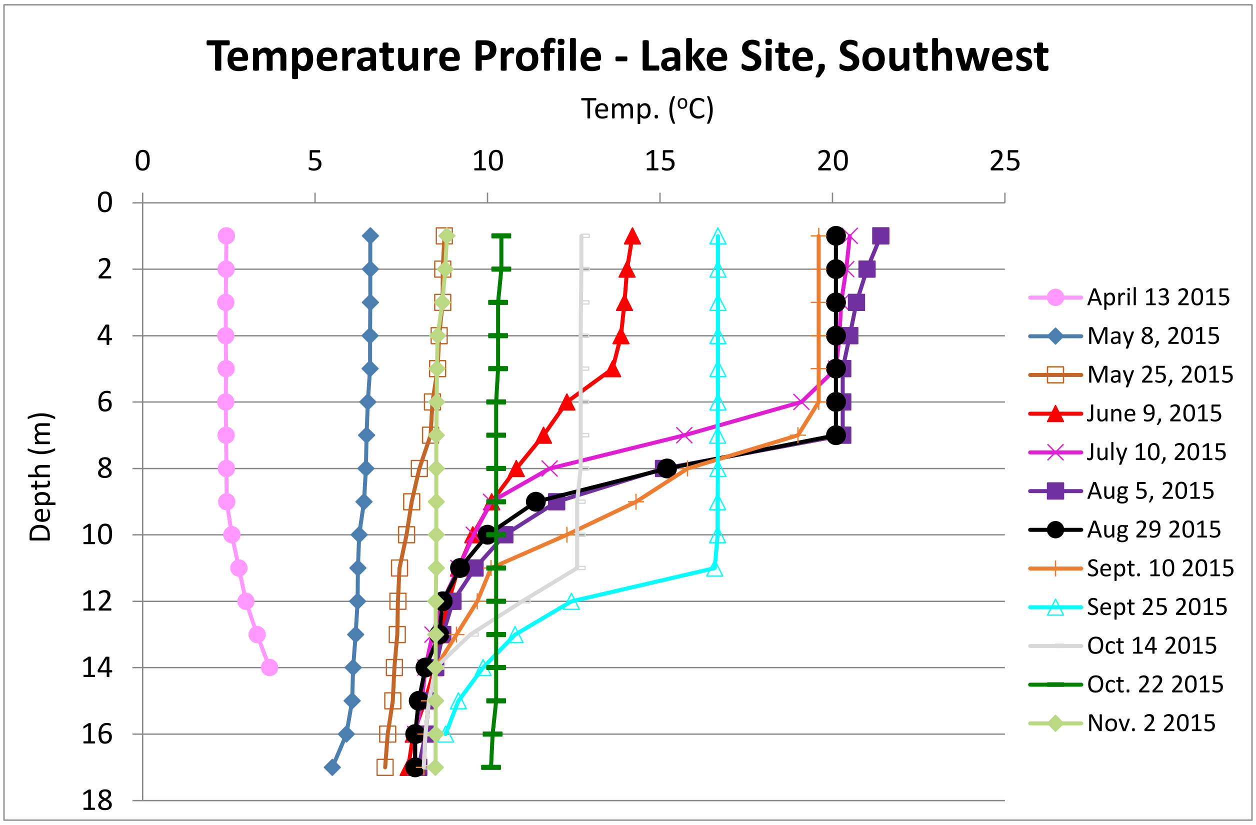


Figure 16. Southwest site temperature profile.
Line graph showing temperature in (°C) on the top x-axis with depth in two meter intervals on the left y-axis for the Southwest site for the 2015 field season.

Figure 16 shows temperature in degrees Celsius on the top x-axis and depth at two meter intervals on the y-axis for the Northeast and Southwest Cloud Lake sites. The first sample collected at the Southwest site on April 13th shows consistent water temperature around 2.5°C increasing only at a significant depth and is not the inverse stratification that was expected. The early spring sample collected at both sites in May reflected the anticipated thermal mixing expected during a spring turnover event. As spring progresses stratification can be seen beginning on June 9th at both sites.

The distinction between the epilimnion, warmer less dense water separated by the metalimnion from the denser and cooler water forming the hypolimnion, can be fully seen on July 10th. This is indicated by the line shifting to the left. As summer continues to warm the epilimnion, it pushes the thermocline deeper. For the Northeast site this produces an interesting occurrence for September 25 as the water column appears uniformly distributed. However, upon confirmation with the Southwest site, it can be seen that the thermocline at this point is below the 11m depth of the Northeast site. October 22nd and November 2nd show thermal continuity indicating fall turnover throughout Cloud Lake. These results indicate Cloud Lake is a dimictic lake fully mixing at least twice a year in the spring and fall.

5.6 Lake dissolved oxygen profiles

Dissolved oxygen (DO) profiles were collected alongside temperature profiles at both the Northeast and Southwest lake sites. There were eleven profiles collected for the Northeast site with a minimum DO of 0ppm on July 10th, Aug. 29th, and Oct. 22nd. The DO maximum of 15.6ppm was on May 8th, with a mean of 9.94ppm for the 2015 field season. The Southwest site had twelve DO profiles with a minimum DO of 0ppm on Aug. 5th, Aug.29th, and Sept. 10th. The DO maximum of 15.9ppm was on May 25th, and a mean of 9.02ppm for the 2015 field season. The combined mean for the whole of Cloud Lake was 9.48ppm.

Table 14. Dissolved oxygen profiles for the Northeast site Cloud Lake 2015.

Northeast site DO (ppm)											
Date	May 8	May 25	June 9	July 10	Aug. 5	Aug. 29	Sept. 10	Sept. 25	Oct. 14	Oct. 22	Nov. 2
1m	15.6	15.6	13.1	7.9	9.9	10.05	10.75	6.19	9.85	11.9	12.52
2m	15.5	15.3	11.9	8.1	10	9.8	10.55	8.02	9.65	11.6	12.66
3m	15.3	15.1	12.4	8.3	10	9.9	10.65	9.3	9.8	11.7	12.3
4m	15.5	15.7	12.8	8.9	9.9	10.2	10.6	9.44	9.75	11.5	12.4
5m	15.7	16	12.7	8.4	9.9	10	8.6	9.42	9.6	11.8	11.8
6m	15.2	16	13	8.1	9.8	6.9	8.3	9.32	9.4	11.7	12.4
7m	15.4	15.6	13.8	8.7	9.6	4.25	7.7	8.79	9.4	11.6	12.1
8m	15.2	15.4	12.3	8.3	7.3	1.9	6.75	7.04	9.4	11.5	11.8
9m	14.8	15.8	10.9	7.5	5	0.9	5.7	5.73	9.4	11.5	12.3
10m	14.7	15.1	10.6	5.5	3.8	0	3.9	8.07	8.9	11.1	11.32
11m	3.6	3.1	4.6	0	1.1	0	3.8	6.8	8.8	0	12.5

Table 15. Dissolved oxygen profiles for the Southwest site Cloud Lake 2015.

Southwest site DO (ppm)											
Date	April 13	May 8	May 25	June 9	July 10	Aug. 5	Aug. 29	Sept. 10	Sept. 25	Oct. 22	Nov. 2
1m	9.63	15.45	15.9	13.9	6.9	9.38	9.9	11.1	10.62	11.7	12.31
2m	9.5	15.25	15.8	13.7	7	9.4	10	11.1	9.93	11.8	12.4
3m	9.51	15.3	15.7	13.5	7.4	9.5	10.1	10.8	9.45	11.3	12.6
4m	9.4	15.01	15.8	13.1	7.25	9.5	10.3	11.2	9.2	11.5	12.4
5m	9.4	15.02	15.7	13.2	7	9.6	10.3	11.1	8.44	11.5	12

6m	8.49	15.08	15.5	12.5	6.6	9.6	10.2	11.1	9	11.3	11.75
7m	8.41	15.15	15.6	13	6.4	9.6	9.8	10.6	9.13	11.4	12.12
8m	8.53	15.22	15.4	13.5	6.2	5.45	3.5	5.4	9.05	11.4	12
9m	8.02	15.2	15.3	13.4	5.8	4.6	2.75	3.3	8.73	11.3	12.38
10m	4.19	15.28	15	13	7.7	3.8	2.4	0.8	8.53	11.5	11.8
11m	3.46	15.25	14.95	12.8	7.2	3.6	1.3	0.2	8.59	11.3	12.28
12m	1.68	14.92	14.75	12.6	6.7	1.3	0	0	4.36	11.2	11.91
13m	0.82	15	15.1	12.3	6.8	0.6	0	0	3.8	11.4	12.35
14m	0.59	14.95	14.8	12.2	6.2	0	0	0	3.6	11.2	11.99
15m	N/A	15	14.5	11.5	4	0	0	0	3.72	11.2	12.2
16m	N/A	15.1	14.4	10.7	2	0	0	0	3.05	11.2	12.02
17m	N/A	2.1	2.5	2.2	0.5	0	0	0	N/A	0.9	9.05

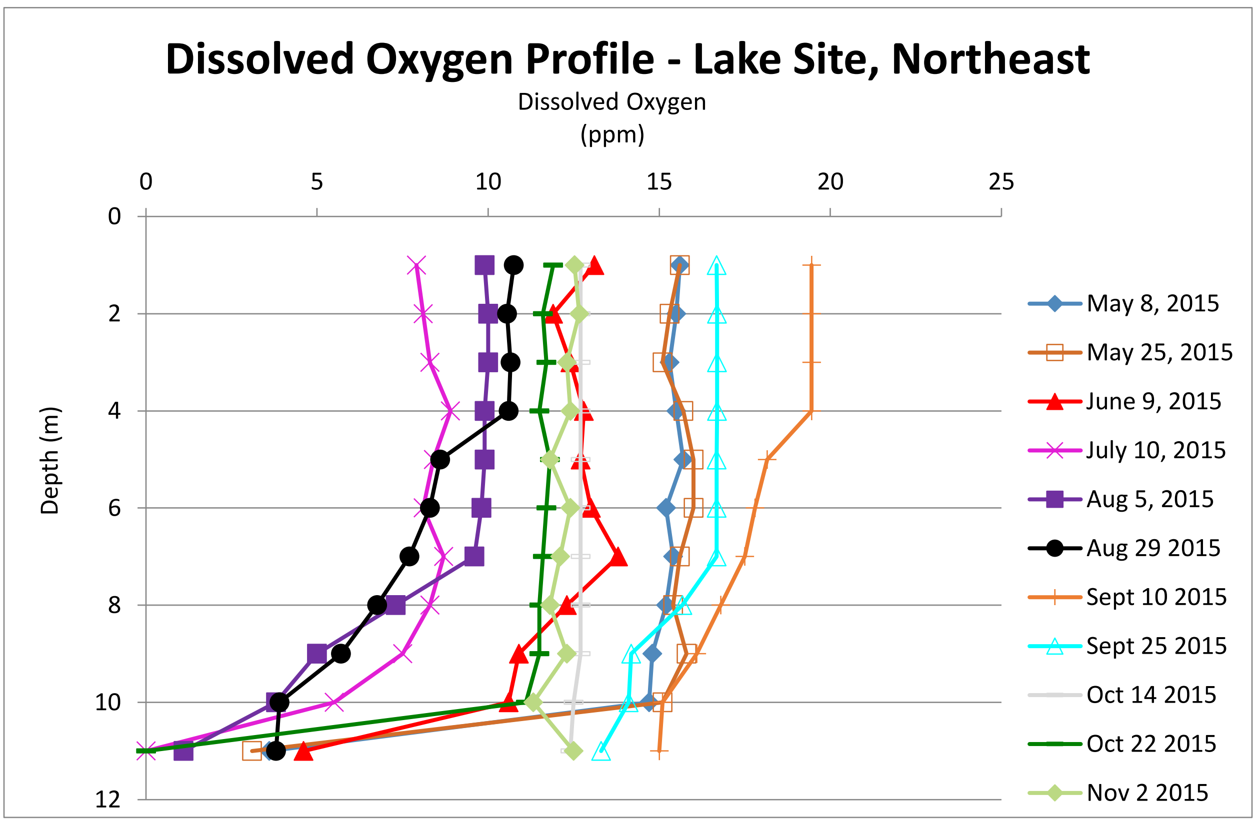


Figure 17. Northeast site dissolved oxygen profiles.
Line graph showing the dissolved oxygen in (ppm) on the top x-axis with depth in two meter intervals on the left y-axis for the Northeast site for the 2015 field season.

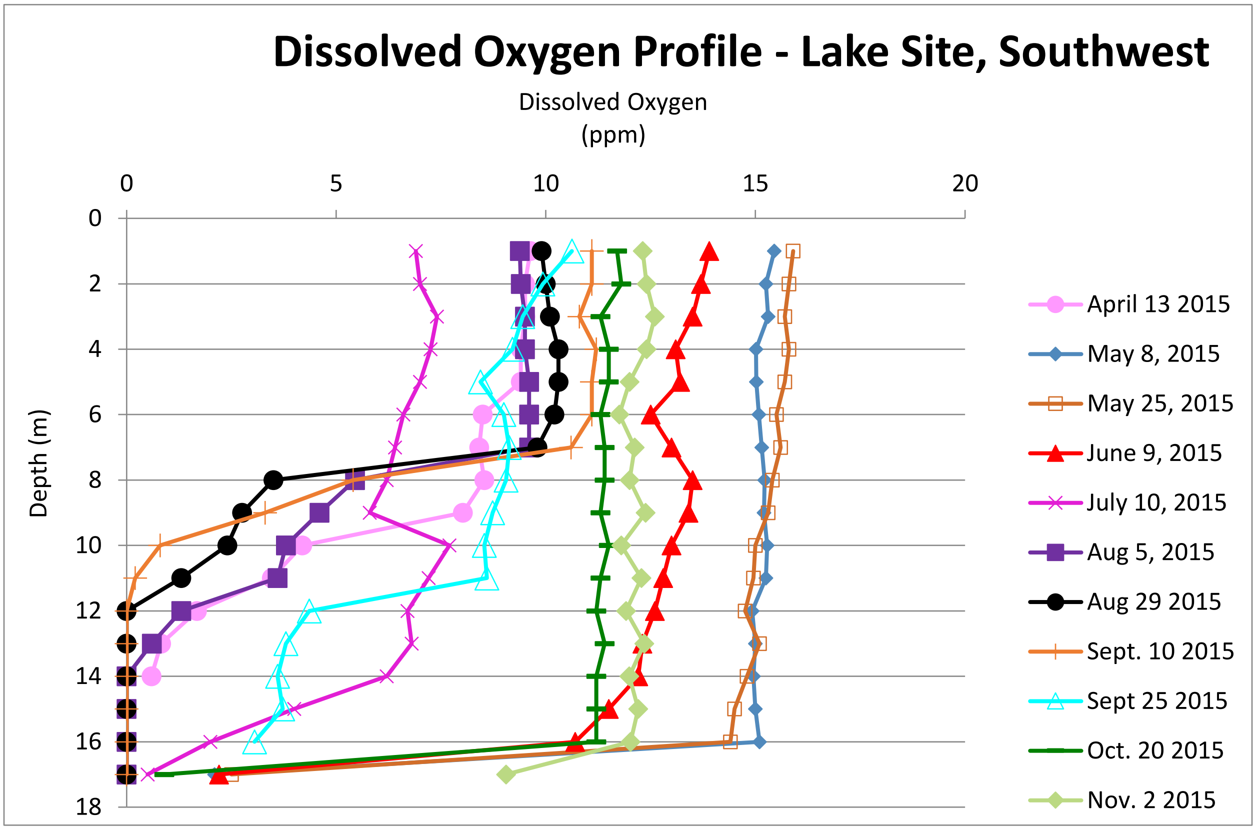


Figure 18. Southwest site dissolved oxygen profiles.
Line graph showing the dissolved oxygen in (ppm) on the top x-axis with depth in two meter intervals for the Southwest site for the 2015 field season.

Figures 17 and 18 show line graphs of dissolved oxygen in parts per million (ppm) on the top x-axis, with depth in two meter intervals on the left Y-axis, for all profiles collected at both Cloud Lake sites for the 2015 field season. Similar to the temperature profiles after August, the epilimnion extends below the Northeast sites 11m depth and disrupts the appearance of trends seen in the Southwest site. However, before this period during spring turnover and after during fall turnover, both sites demonstrate a consistency in DO distribution across Cloud Lake. Both sites show the development of oxygen depletion beginning on July 10th 2015 with the Southwest site showing a significant region of anoxic conditions, which is indicated by a shift to the left, established on August 5th 2015. This anoxic zone at its peak includes the bottom 8m of this sample location. The anoxic conditions persisted from August 5th to late September at which time fall turnover began and the DO is distributed evenly throughout the water column of both sites. The other difference to note between the two sites is the April 13th profile, which showed anoxic conditions that had developed 9m below the ice. Unfortunately, a profile was not collected at the Northeast site during ice conditions for comparison.

5.7 Combined temperature and dissolved oxygen

This section provides two figures showing the distribution of DO and temperature profiles across Cloud Lake. These figures show the same data from the previous sections 5.1.4 and 5.1.5 arranged with the temperature and dissolved oxygen profiles on colour gradients to show the distribution throughout the 2015 fields season. The temperature profiles are blue with darker blue representing cooler water and lighter blue indicating warmer water. Pink bars have been placed on the temperature profiles to show the secchi disc depth for that site and day. Green bars represent the metalimnion distinguishing between the warmer epilimnion and cooler hypolimnion. The DO profile uses darker orange to indicate higher concentrations of oxygen in the water and lighter orange to indicate less oxygen and white for anoxic conditions. Purple bars have been placed to indicate the upper limit of anoxic water within the water column. Figure 20 shows the profiles for the Northeast site from May 8th to November 2nd. Figure 21 shows the profiles for the Southeast site from April 13th to November 2nd. These figures provide a different perspective to compare the depth of the thermocline as well as the extent of the anoxic region.

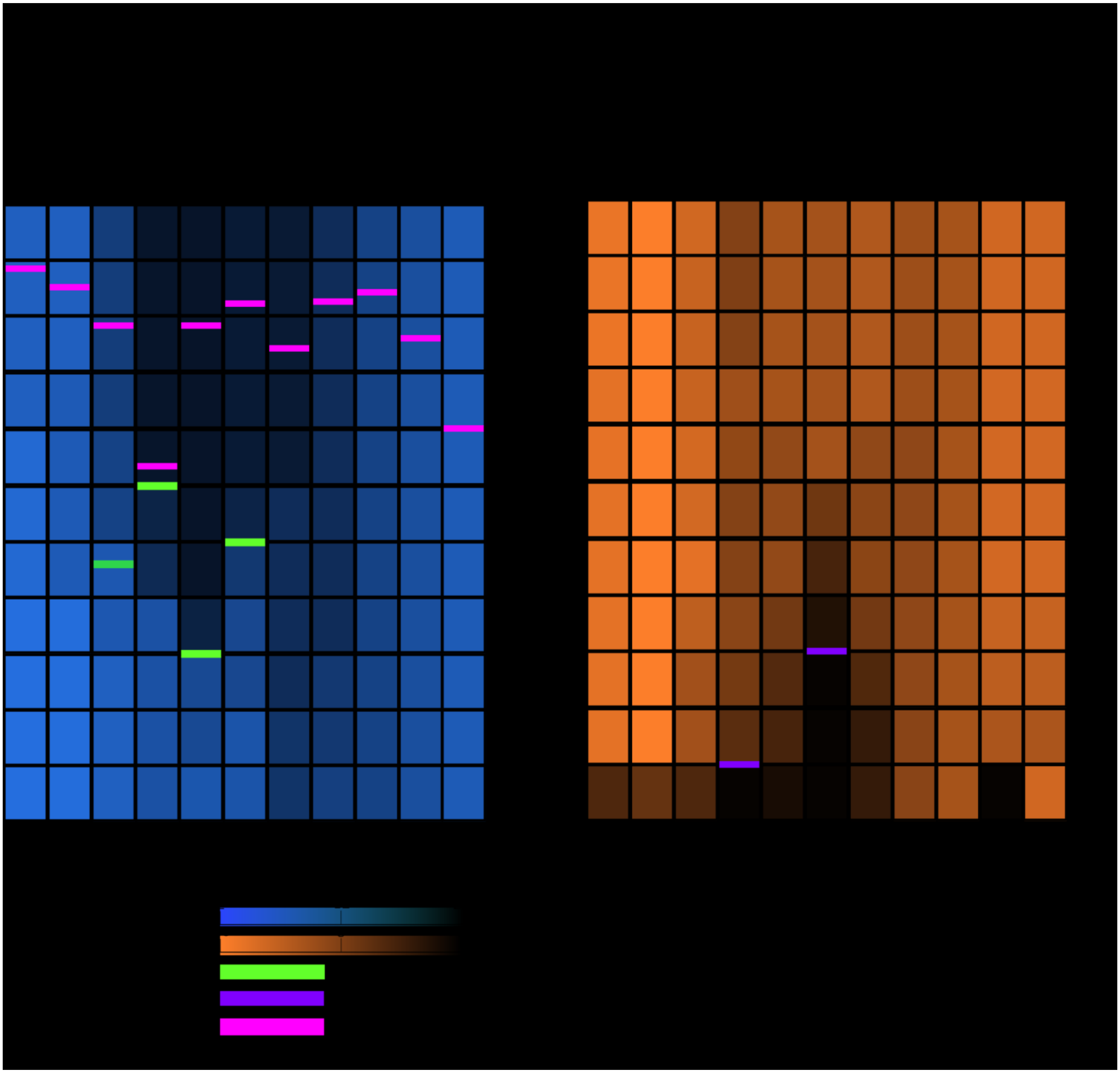


Figure 20. Northeast site combined temperature and dissolved oxygen profiles.
Graphic showing compiled data for the Northwest site. Temperature in (ºC) on the left with thermocline and secchi disc depth measured throughout the 2015 field season. On the right is D.O. in (ppm) for the 2015 field season.

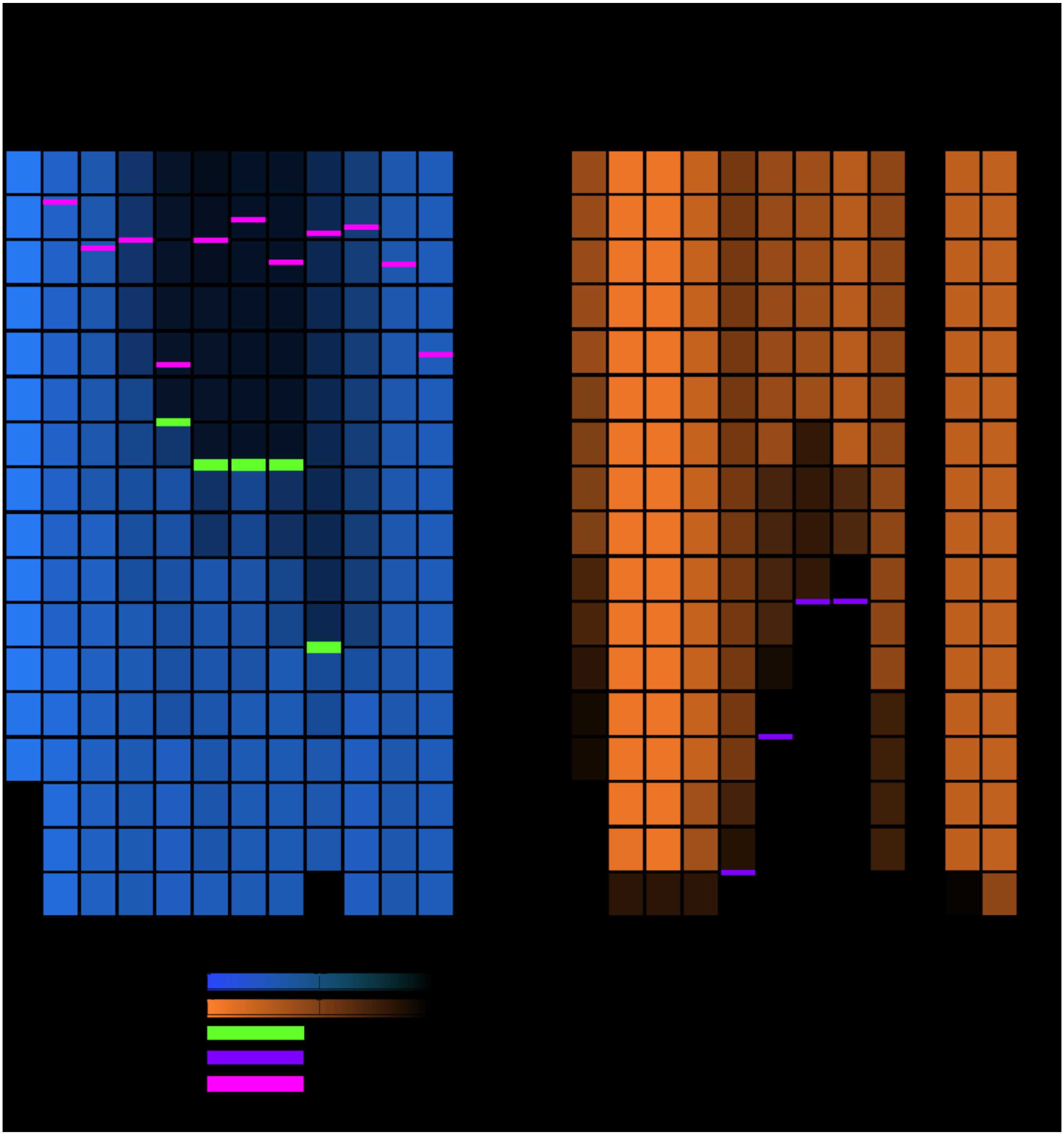


Figure 21. Southwest site combined temperature and dissolved oxygen profiles.
Graphic showing compiled data for the Southwest Lake site temperature and dissolved oxygen profiles over the 2015 field season.

Both Figures 20 and 21 show the fully mixed water column during spring turnover from May 8th and May 21st. Both temperature and DO show no change in colour gradient throughout the water column. The first change in colour indicates the beginning of stratification on June 5th. On July 10th,thermal separation of the epilimnion and hypolimnion by the metalimnion can be seen in the shifting of light blue to darker blue around the 6m depth for both the Northeast site and Southwest site. Thermal stratification for both sites persists until September 25th. However, for the Northeast site profiles of September 10th and 25th the water column appears to be mixed because the epilimnion has extended to the full depth of the site. During summer stratification the development of anoxic water can be seen as indicated by the shifting orange to white colours. The October 25th profiles for both sites show profiles that represent the fall turnover with consistent thermal and DO from surface to the sediment water interface.

5.8 Lake total phosphorus distribution

Total phosphorus samples were collected at both the Northeast and Southwest sites at three places in the water column; 1m below the surface, approximately half way down the water column (6m for the Northeast site and 9m for the Southwest site) and 1m above the sediment water interface. These samples were collected a total of ten times for the Northeast site and eleven times for the Southwest site. For the Northeast site the range of phosphorus at 1m below the surface is 10µg/L to 30µg/L with the seasonal mean being 16.9µg/L. The range of phosphorus for half way down the water column is 9µg/L to 18µg/L with the seasonal mean being 13.6µg/L. The range for the 1m above the sediment water interface is 10µg/L to 26 µg/L with the seasonal mean being 15.9µg/L. The 2015 field mean annual total phosphorus for Northeast site is 15.47µg/L. For the Southwest site the range of phosphorus at 1m below the surface is 6µg/L to 26µg/L with a seasonal mean of 17.38µg/L. Half way down the water column the range is 7µg/L to 30µg/L with a seasonal mean of 16µg/L. At 1m above the sediment water interface the range is 7µg/L to 184µg/L with a seasonal mean of 48.27µg/L. The 2015 mean annual total phosphorus for this site is 27.2µg/L.

Table 16. Total phosphorus concentrations for the Northeast site Cloud Lake 2015.

Northeast TP (µg/L)										
Date	May 8	May 25	June 9	July 10	Aug. 5	Aug. 29	Sept. 10	Sept. 25	Oct. 20	Nov. 2
1m	15	11	10	15	11	30	13	22	17	25
6m	13	10	12	9	10	17	16	18	15	16
11m	10	10	12	17	16	13	25	26	15	15

Table 17. Total phosphorus concentrations for the Southwest site Cloud Lake 2015.

Southwest TP (µg/L)											
Date	April 13	May 8	May 25	June 9	July 10	Aug. 5	Aug. 29	Sept. 10	Sept. 25	Oct. 20	Nov. 2
1m	26	13	6	9	25	15	23	16	26	14	18
9m	11	12	7	12	15	30	13	23	22	11	20
17m	16	11	7	13	58	49	62	184	93	20	18

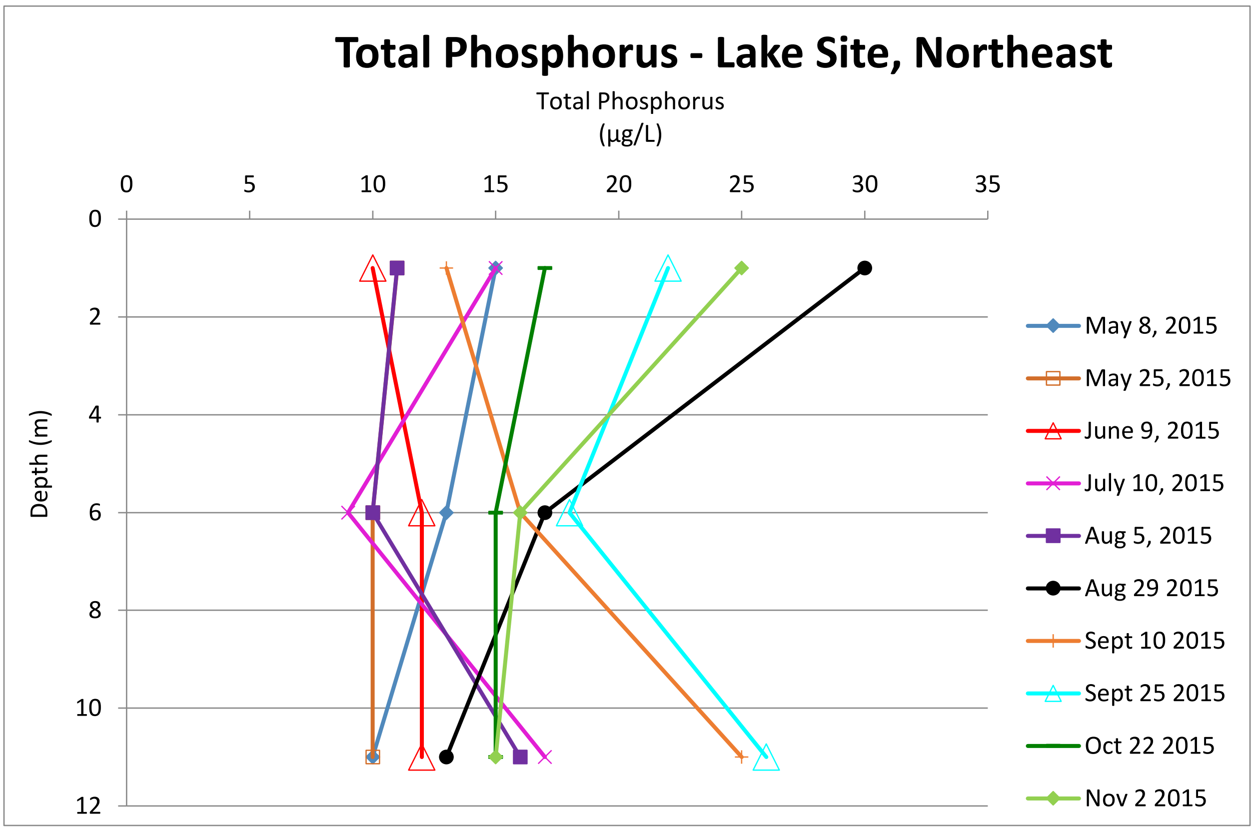


Figure 22. Northeast site total phosphorus profiles.

Line graph showing total phosphorus concentrations for the Northeast site in µg/L on the top x-axis with depth in two meter intervals on the left y-axis.

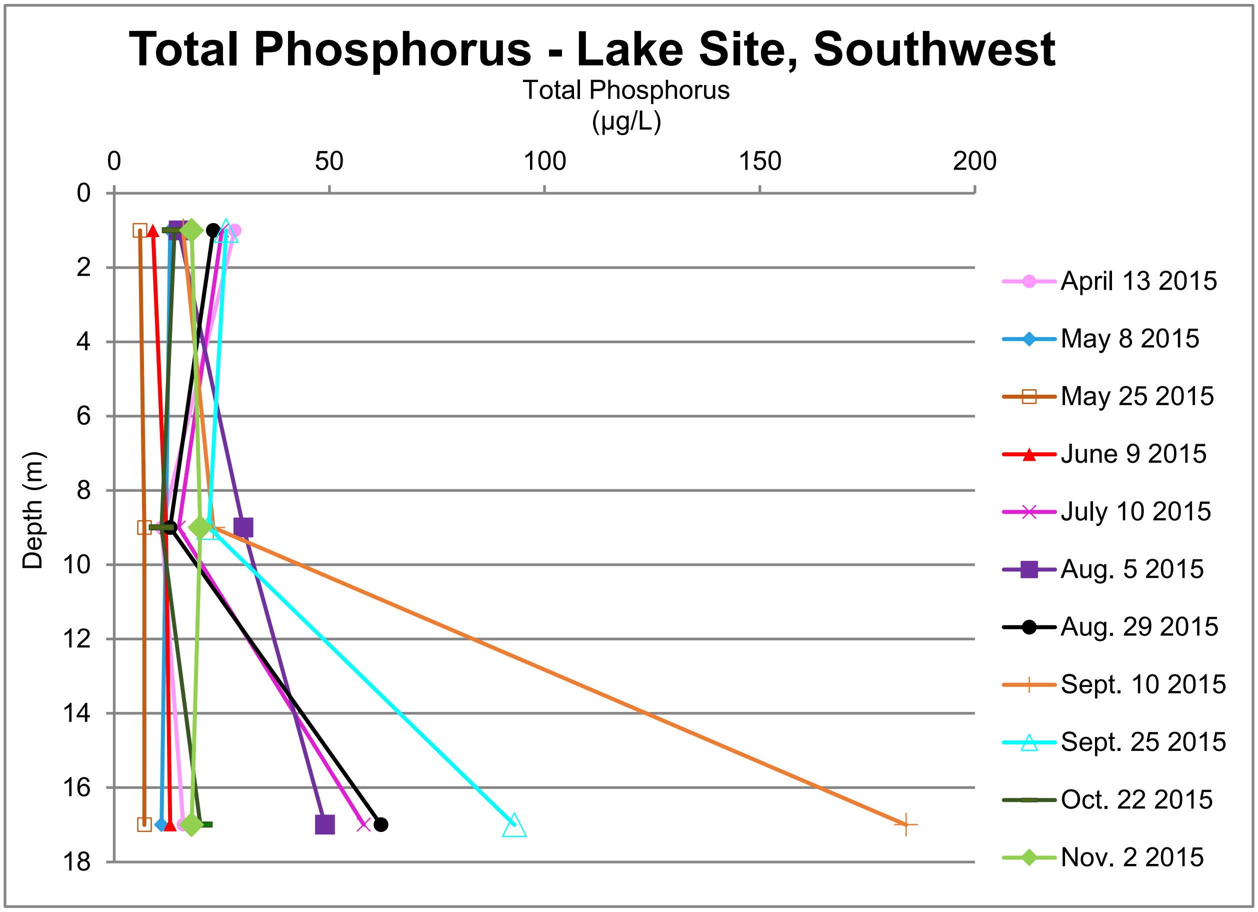


Figure 23. Southwest site total phosphorus profiles.
Line graph showing total phosphorus concentrations on the top x-axis in µg/L with depth on the left y-axis in two meter intervals throughout 2015 field season at the Southwest lake site.

Figures 22 and 23 show the total phosphorus concentrations distributed throughout the water column for the sampling of 2015. The distribution of phosphorus at both sites is similar during spring and fall turnover with phosphorus concentrations being evenly distributed. The Southwest site sample on April 13th showed higher epilimnion total phosphorus than the rest of the water column. Beginning July 10th, concentrations of total phosphorus start to rise at both sites, however, the Southwest site shows much higher concentrations in the sample 1m above the sediment water interface. The total phosphorus for the Northeast site peaks at 30µg/L on August 29th in the epilimnion. Alternatively, the peak for the Southwest site is on September 10th in the hypolimnion at 184µg/L, much higher than any other sample result collected up to and including the 2015 results. Both the Northeast and Southwest sites during early spring and fall showed concentrations, were higher within the top portion of the water column. Within the hypolimnion the late spring and summer concentrations were higher than samples taken from the epilimnion. The distribution of phosphorus across Cloud Lake showed a trend for the Southwest site having higher concentrations throughout the year.

5.9 Cloud Lake water quality summary

This section compiles the results of the mean chlorophyll *a*, maximum chlorophyll *a*, mean total phosphorus, mean secchi disc, and the mean springtime phosphorus concentration (May 25th measurement) into Table 18. The table shows measurements from each site as well as the mean of the two sites combined for Cloud Lake using both the modified Carlson TSI as well as the OMOECC's lake classification.

Table 18. Cloud Lake Trophic Classifications Parameters Summary

Site	Mean Chlorophyll *a* (µg/L)	Max Chlorophyll *a* (µg/L)	Mean TP (µg/L)	Mean Secchi Depth (m)	Spring TP (µg/L)
South	3.12	10.5	15.47	2.44	6.67
North	3.53	10.3	27.21	2.38	10.33
Lake Total	3.33	10.4	21.34	2.41	8.5
Classification	Mesotrophic and level 2	Mesotrophic	Mesotrophic	Eutrophic and level 2	Level 1

Using the Carlson parameters of max chlorophyll *a*, and mean annual total phosphorus Cloud Lake's 2015 measurements fall into the mesotrophic classification. The mean chlorophyll *a* measurements for each site and the lake total alone, however, fall into the eutrophic classification. The OMOECC parameters of mean chlorophyll *a*, and mean secchi depth for each site and the lake total are level 2, while the spring TP for both sites and the lake total are in the lowest category of level 1.

5.10 Secondary Data Results

5.10.1 Submerged Aquatic Vegetation Survey

The results of the submerged aquatic vegetation survey show areas with higher density of submergents in shallow water areas with a wider littoral zone, due to more gradual slope, such as the Outlet Cove, Moose Lodge Cove, East End (Northeast Bay), and Beaver Cove (Figure 24).

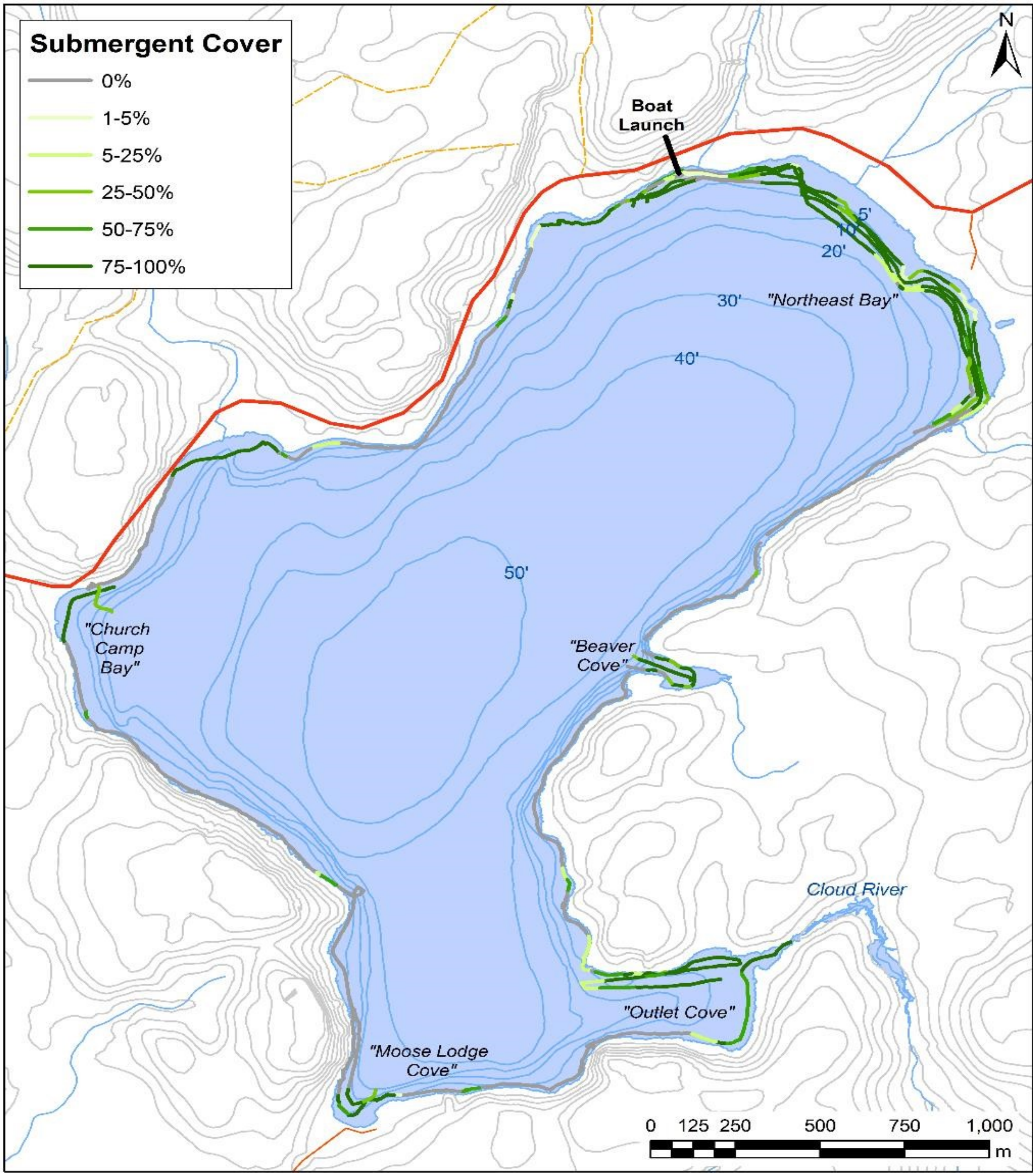


Figure 24. Submerged aquatic vegetation distribution Cloud Lake 2015.
Relative abundance of submergent (aquatic macrophytes) plant density divisions of GPS tracks collected during survey of Cloud Lake 2015.

Submergents were lacking from approximately 40% of the total transect length (Figure25, Figure24), primarily due to the steep drop-off, higher wave energy, and coarse substrates.

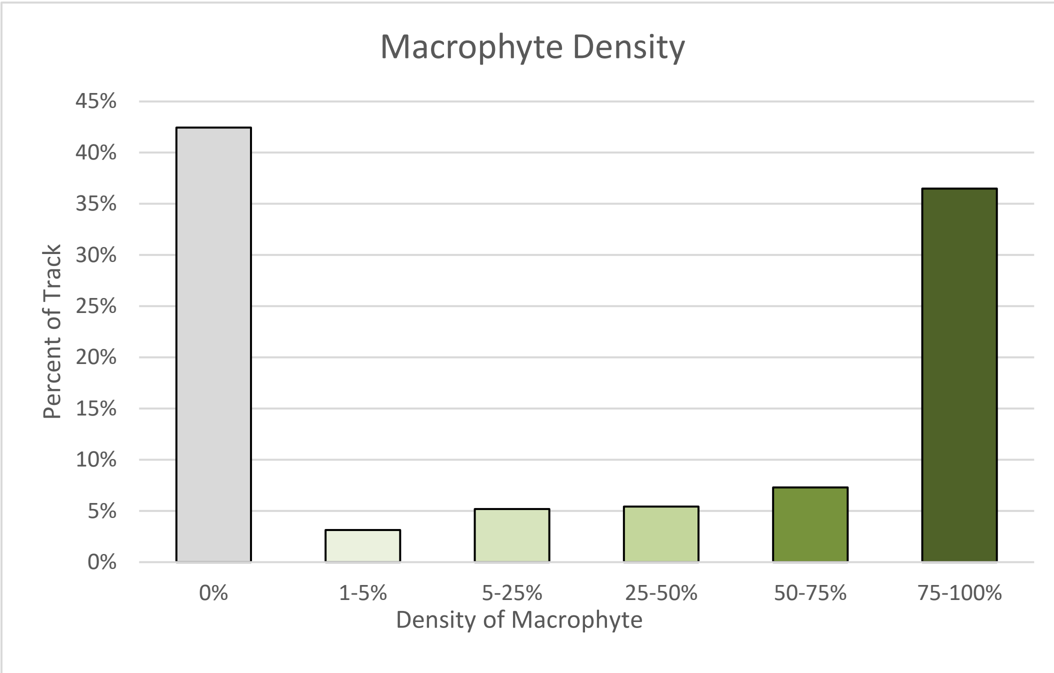


Figure 25. Submerged aquatic vegetation density graph.
Proportion of surveyed underwater video track by submerged vegetation density class. See Figure 24 for location of underwater video tracks.

Submergents were most abundant on sandy substrates, less common on cobble substrates, and rare on boulder and silt (silt is uncommon on Cloud Lake) (Figure26).

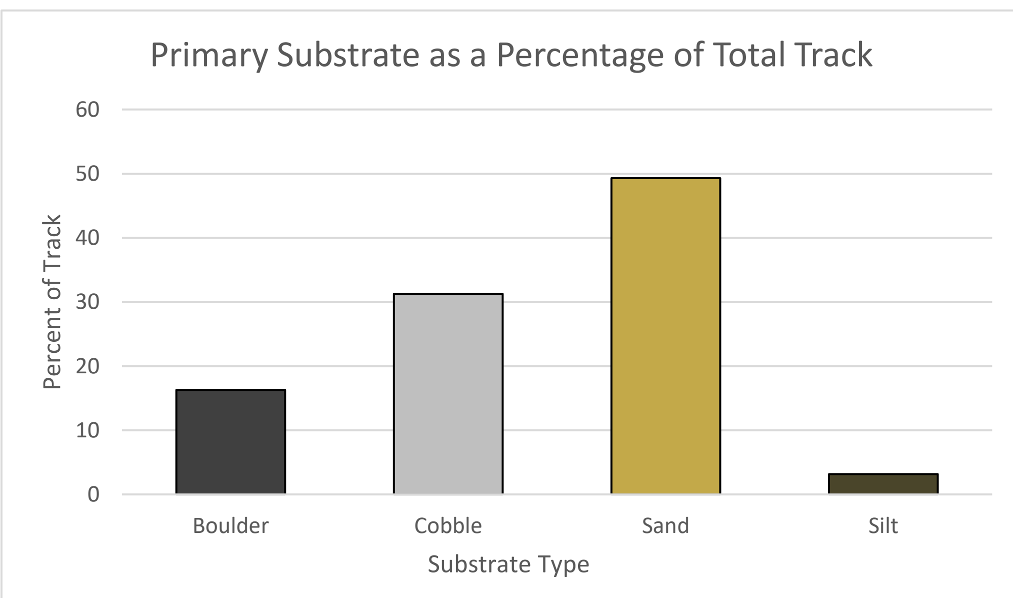


Figure 26. Substrate percentage for Cloud Lake 2015.
Proportion of surveyed underwater video track by substrate type. See Figure 24 for location of underwater video tracks.

Beds of quillwort (*Isoetes lacustris*) accounted for 3/4 of the aquatic macrophytes observed along video transects. Pondweeds accounted for most of the rest, with the main species including Richardson's pondweed (*Potamogeton richardsonii*), flat-stemmed pondweed (*P. zosteriformis*), curly-leaved pondweed (*P. amplexifolius*), and narrow-leaved pondweeds. Water milfoil (*Myriophyllum* sp.) was rare, accounting for less than 2% of submergents observed on transects.

In addition to determining the distribution and composition of submerged aquatic vegetation around Cloud Lake, the survey noted algae attached to the submerged aquatic vegetation (see figure 27).

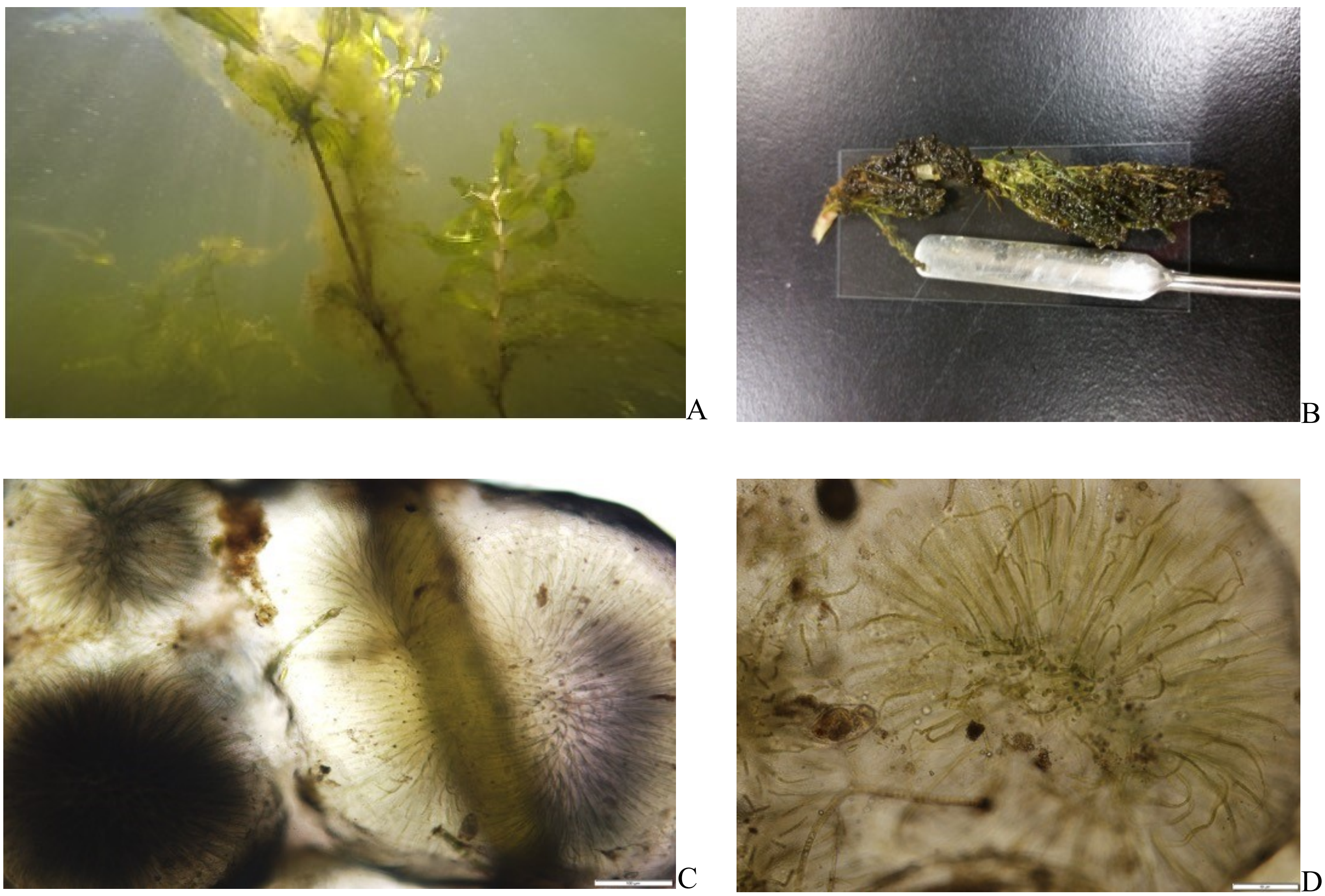


Figure 27 (A-D). Images of algae on submerged aquatic vegetation.
Image A, green filamentous algae on submerged aquatic vegetation. B, unidentified balls of algae noted to be attached to the submerged aquatic vegetation. C, and D are microscopic images of the unidentified balls.

The green filamentous algae were identified using microscopy. The top left photo shows the filamentous algae clinging to the submerged aquatic vegetation, bottom left shows the unidentified balls attached to a sample of submerged aquatic vegetation. The right, top and bottom, photos are images under the microscope of the attached balls.

5.10.2 Smallmouth Bass Survey

Smallmouth Bass nests were most abundant on the north, west, and south shorelines of Cloud Lake in 2015 (figure 28).

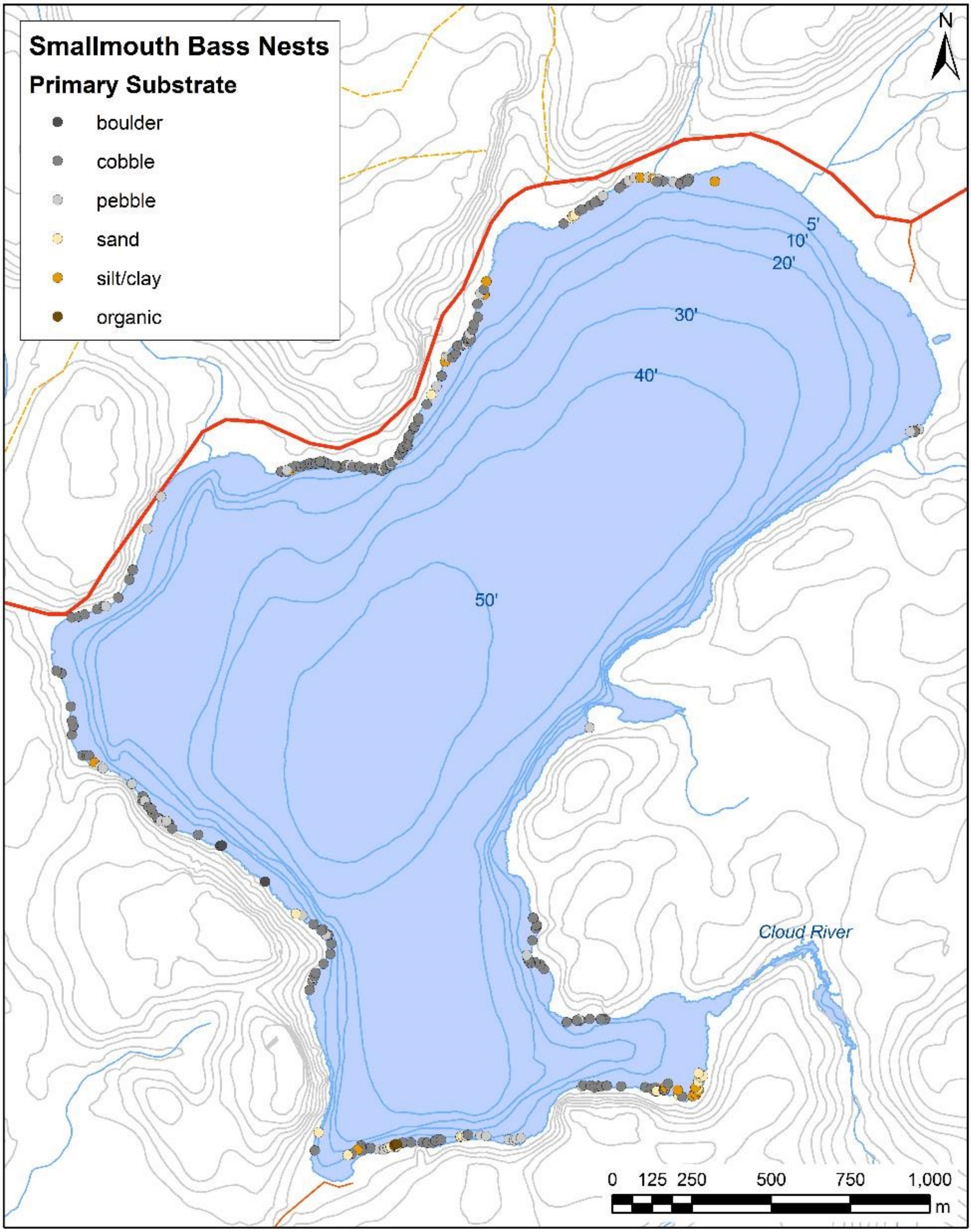


Figure 28. Spring Smallmouth Bass nesting survey.
2015 distribution of Smallmouth Bass nests and primary substrate at nest site.

Few bass nests were observed along the east shore of Cloud Lake, which is characterized by a rapid drop and very coarse substrate. The northeast bay of Cloud Lake also had few nests, likely due to dense submergents and predominantly sandy substrates. On Cloud Lake, there was on average one Smallmouth Bass nest every 45m (22.2 nests/km), although the distribution of nests was quite variable around the Cloud Lake shoreline. Smallmouth Bass nests in Cloud Lake were found in 35cm to 300cm of water, with a mean depth of 130cm. Nests were typically 3-4m from shore, although some were up to 20m from shore in shallow-sloping bays.

Smallmouth Bass nests were typically 20 to 40cm in diameter and up to 10cm deep. A total of 266 nests were observed during the 2015 survey, with only 15 lacking eggs, fry, or an attentive adult (presumably trying to attract a mate to his nest, but as yet unsuccessful). Of these 266 nests, 70% (n=186) had fry, indicating successful fertilization and incubation for at least some of the eggs in the nests. Another 58 nests (22% of total) had at least some clear, presumably viable eggs but no fry as yet (fry were hatching from nests during the survey period). This suggests that slightly over 90% of nests may have at least some successful reproduction in 2015. At least 90 nests had some dead eggs, and fungus was found on at least some of the eggs in 35 nests. Nests earlier in the survey contained only eggs, some healthy, some showing signs of fungus developing around the egg, and some with so much fungus that the egg was no longer viable (Figure29).

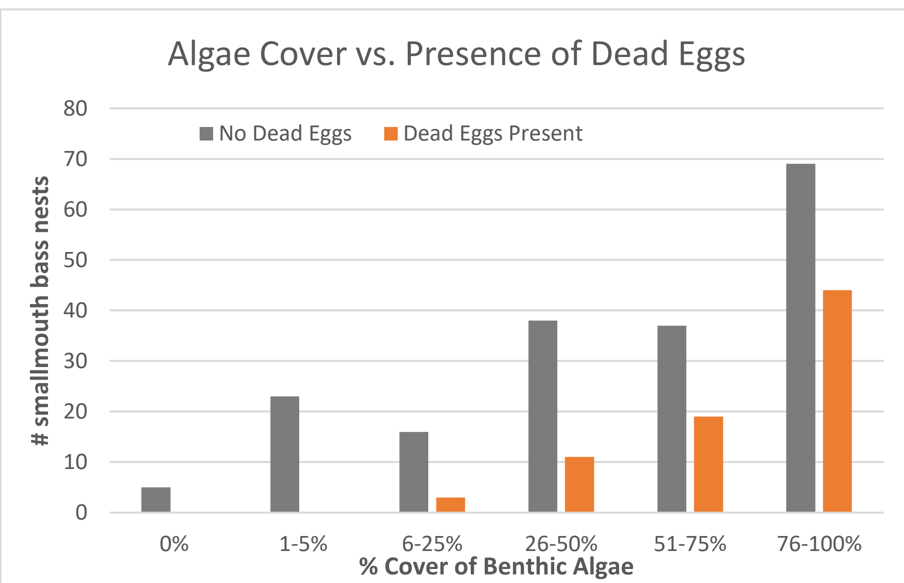


Figure 29. Abundance of algae and dead Smallmouth Bass eggs.
Relationship between cover of benthic algae at Cloud Lake Smallmouth Bass nests in 2015 and presence of at least dead eggs in the nest.

As the survey continued the eggs began to hatch and Smallmouth Bass fry started to be observed with eggs that were either unfertilized or clearly dead (opaque) due to the fungus.

Algae was observed in and around bass nests, significant amounts at times, these nests were identified by the fry which was still lingering in the filamentous algae with some unfertilized eggs seen within the algae on the sediment (Figure30).

A

B

Figure 30 (A and B). Reference images of Smallmouth Bass nests.
Smallmouth Bass nest with abundant algae and a few fry (A) and nest with dead eggs enveloped by fungus (B).

5.10.3 Phytoplankton

Throughout the 2015 field season a number of phytoplankton species were noted on Cloud Lake. Samples were collected as part of the overall project to understand the composition of species that may be on Cloud Lake. These samples were identified through microscopy with some samples being sent to have expert verification when necessary. Samples that were collected and identified to be toxin producing were tested by the OMOECC Dorset laboratory for concentrations of Microcystin-LR, none of which came back as above the maximum acceptable concentration of 1.5µg/L.

Table 19: Identified phytoplankton in Cloud Lake during 2015 field season.

Date Collected	Cyanobacteria/Filamentous	Phytoplankton Identified	Potentially toxic
June 23rd 2015	Cyanobacteria	Nostoc *spp.*	Yes
	Cyanobacteria	Gloeotrichia *spp.*	Yes
	Filamentous	Spyrogyra	No
July 10th 2015*	Cyanobacteria	Dolichospermum *spp.*	Yes
	Cyanobacteria	Gloeotrichia *spp.*	Yes
July 21st 2015*	Filamentous	Spyrogyra	No
	Filamentous	Mougeotia	No
September 11th 2015	Cyanobacteria	Gloeotrichia *spp.*	Yes
October 8th/11th 2015*	Cyanobacteria	Dolichospermum *circnale*	Yes
	Cyanobacteria	Dolichospermum *planctonicum*	Yes
	Cyanobacteria	Aphanizomenon *flos-aquae*	Yes
November 2nd 2015*	Cyanobacteria	Aphanizomenon *flos-aquae*	Yes

*** Indicates samples that were sent to the OMOECC Dorset Laboratory for identification confirmation and toxicology screening. These results will be further discussed later.**

The description given by residents of algae on Cloud Lake was described as a ‘mat like’ bloom that covered the benthic portion of the lake and docks in a thick slime. Although observations from residents suggested that there was an abundance of algae on Cloud Lake the species was not known. The first observations I noted of algae were made during water sampling and the Smallmouth Bass spring spawning survey in June 2015. Within the outflow bay clusters of dark green balls identified as Nostoc *spp.* were found. They were noted due to how they seemed to collect on sandy substrate where holes had developed in the submerged vegetation mat (see figure 31).

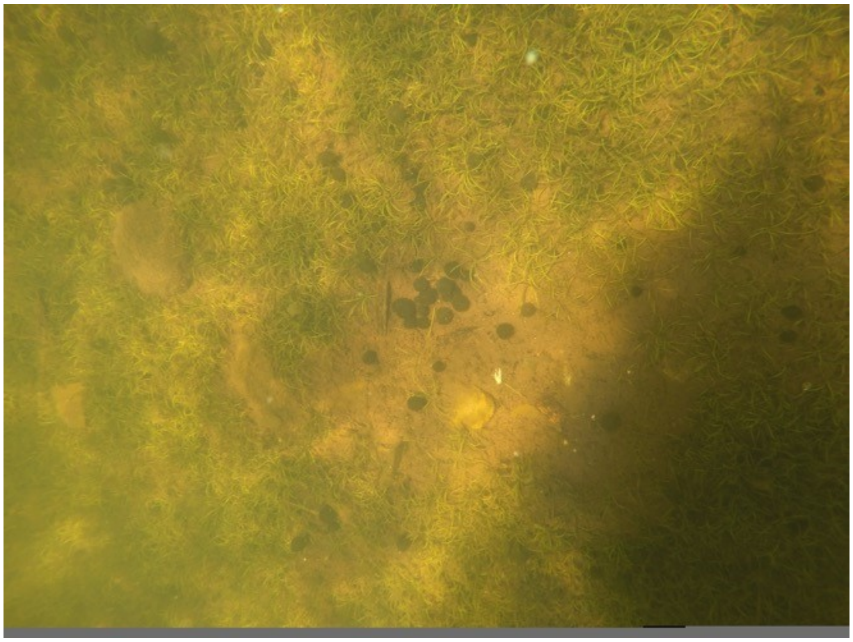
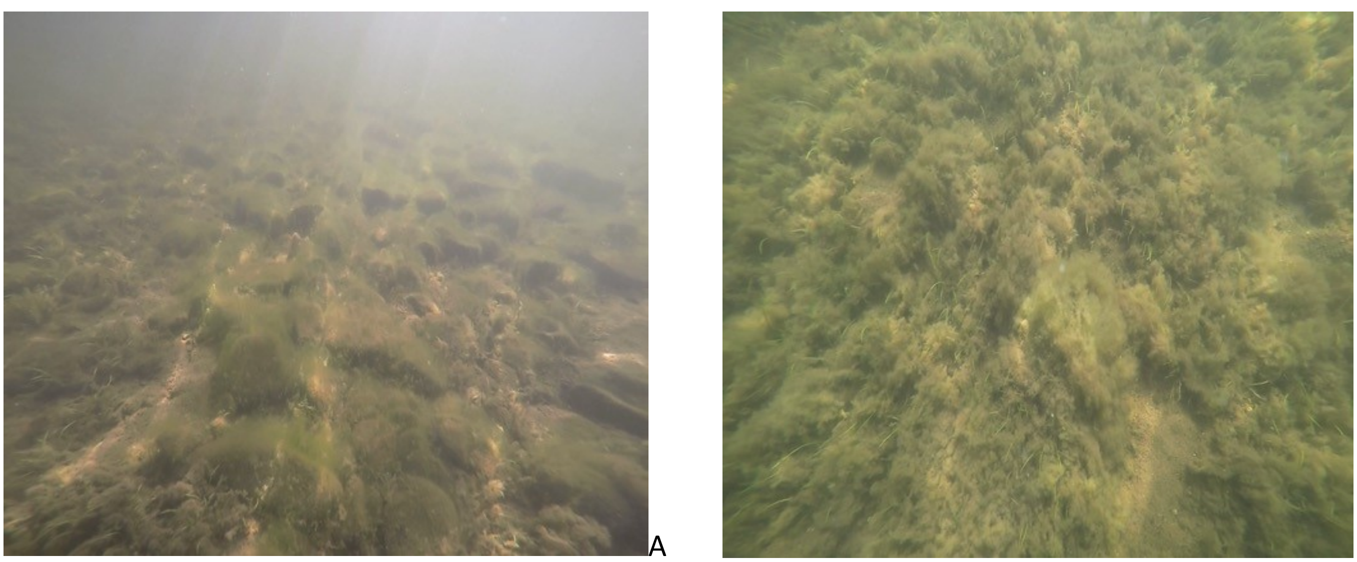


Figure 31. Nostoc on substrate.
Clusters of Nostoc noticed on the substrate during spring water quality sampling in the outflow bay.

Nostoc *spp.* was noted throughout the field season in abundance, but only in the outflow bay. Nostoc is not a concern for human or animal health issues at this time.



A B

Figure 32(A and B). Filamentous green algae on substrate.
Green filamentous algae noted late in the spring Smallmouth Bass nesting survey along the western shore of Cloud Lake.

Figure 32 show images captured while conducting the Smallmouth Bass spawning survey. A mat of thick filamentous algae appeared to have developed on the substrate in large portions of the western shoreline. Samples collected during this time were identified to consist of at least three species; figure 34 shows the syrogyra which appeared to be most abundant in the samples; figure 35 shows mougeotia the second most abundant; and figure 36 shows zygnema.

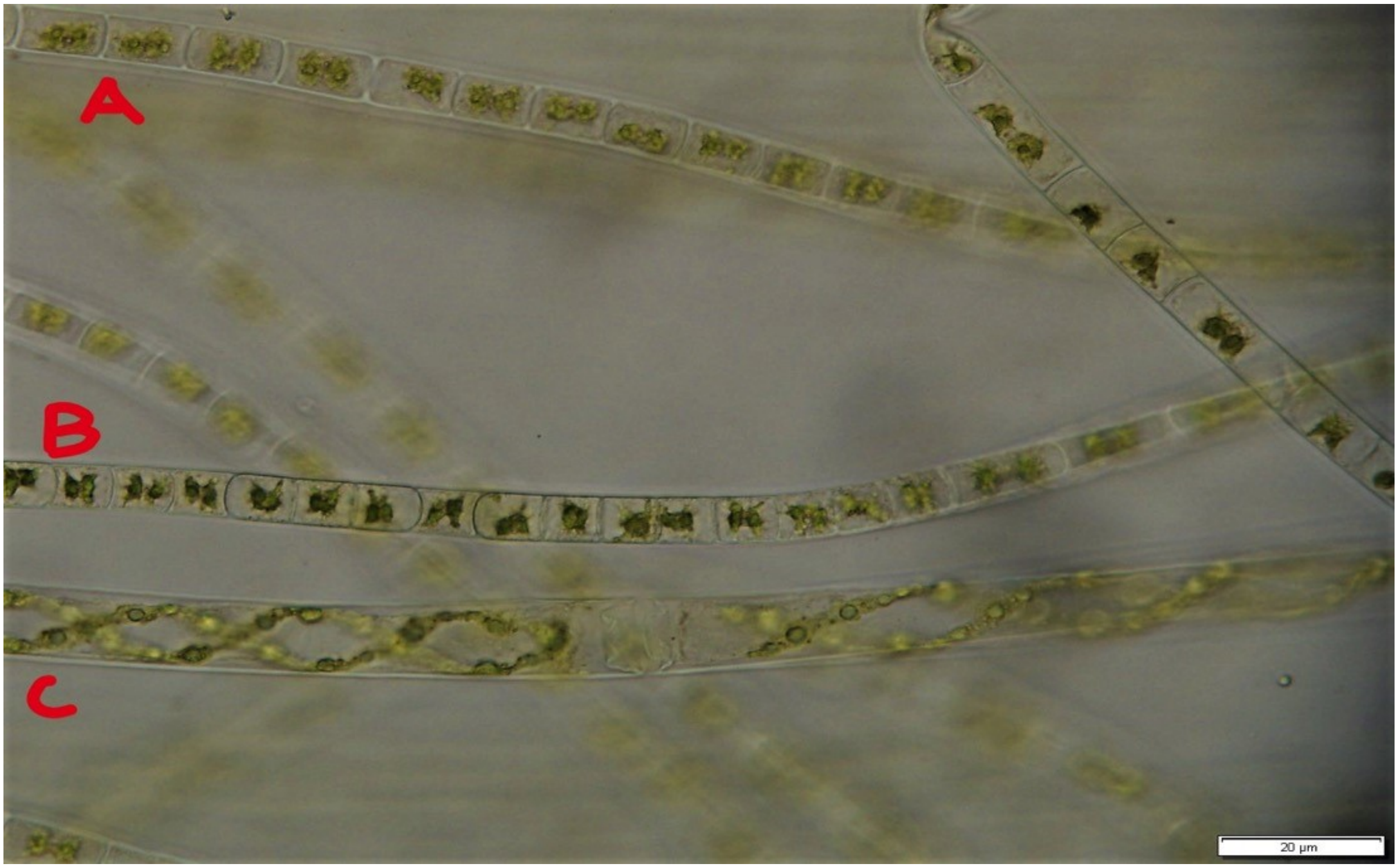


Figure 33. Image of filamentous algae under microscope.
Image of algae taken from the substrate seen in figure 32, under microscope. Top filament alga marked with the red A is mougeotia, middle filament marked with the red B is zygnema, and bottom filament marked with the red C is spyrogyra.

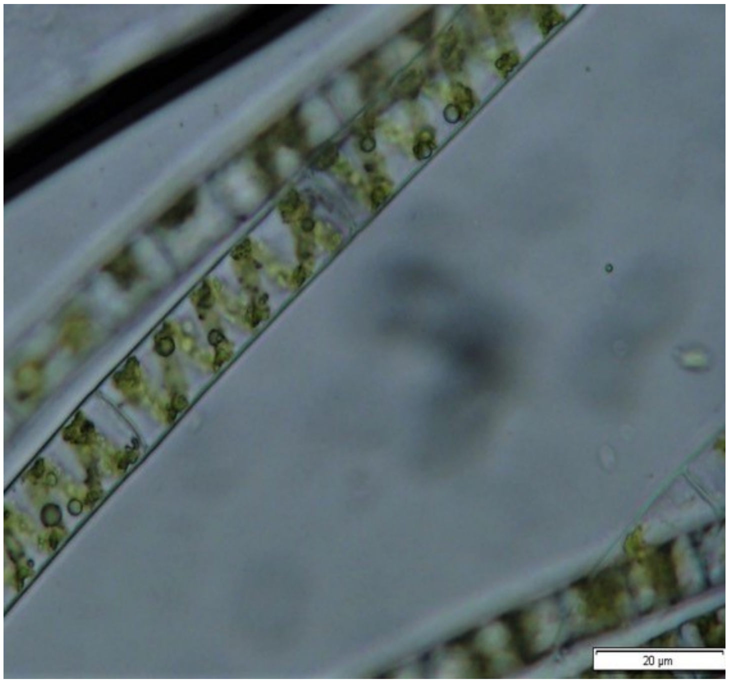


Figure 34. Microscopic image of spyrogyra.

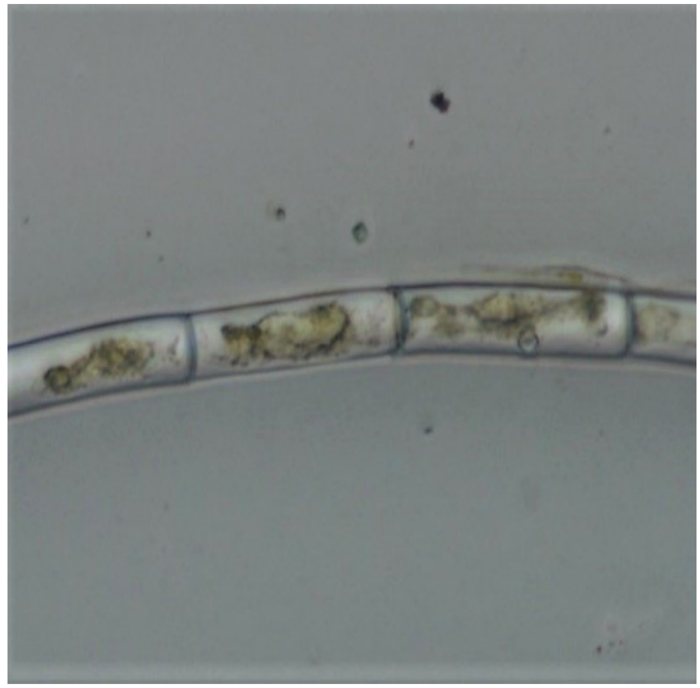


Figure 35. Microscopic image of mougeotia.

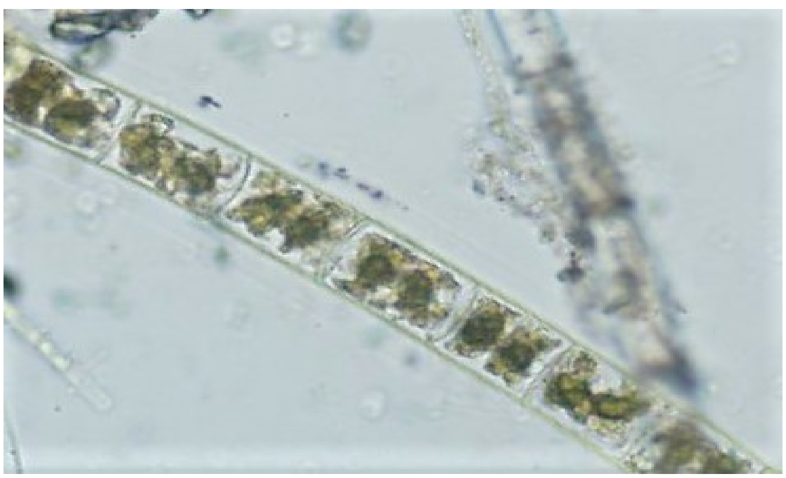


Figure 36. Microscopic image of zygnema.

These algae did not persist, and were not seen, in such quantities resembling a bloom again during the 2015 sampling season.

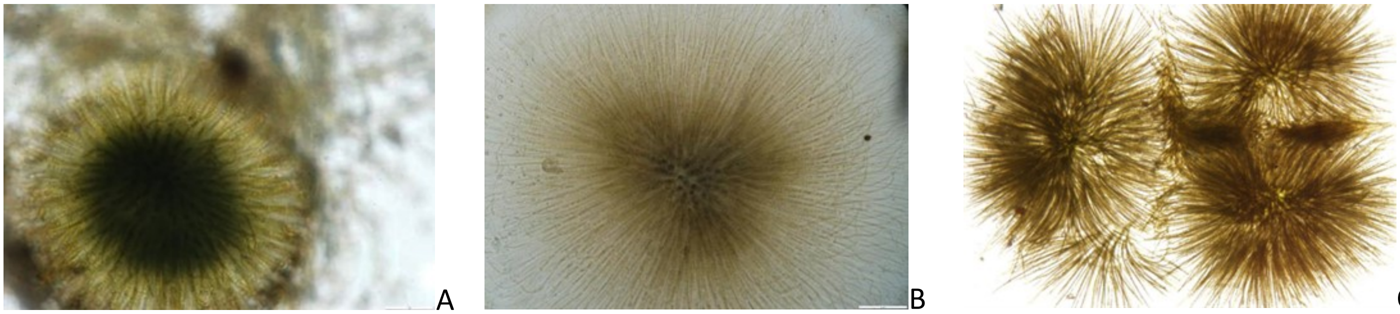
During the July 10th water quality sampling an abundance of floating algae was seen on the surface of Cloud Lake beginning 70m from shore (see figure 37 and 38).

Figure 37. Surface bloom on July 10th 2015.

Figure 38. Disturbance of surface bloom on July 10th 2015.

Figure 39. Subsurface image of July 10th 2015 algal bloom.

Figure 39 shows an image captured below the water surface of this same 'bloom' and shows the density of 'ball-like' structures suspended under the water's surface. Samples were taken and figure 40 shows the gloeotrichia spp. cyanobacteria, the predominant algae within the sample.

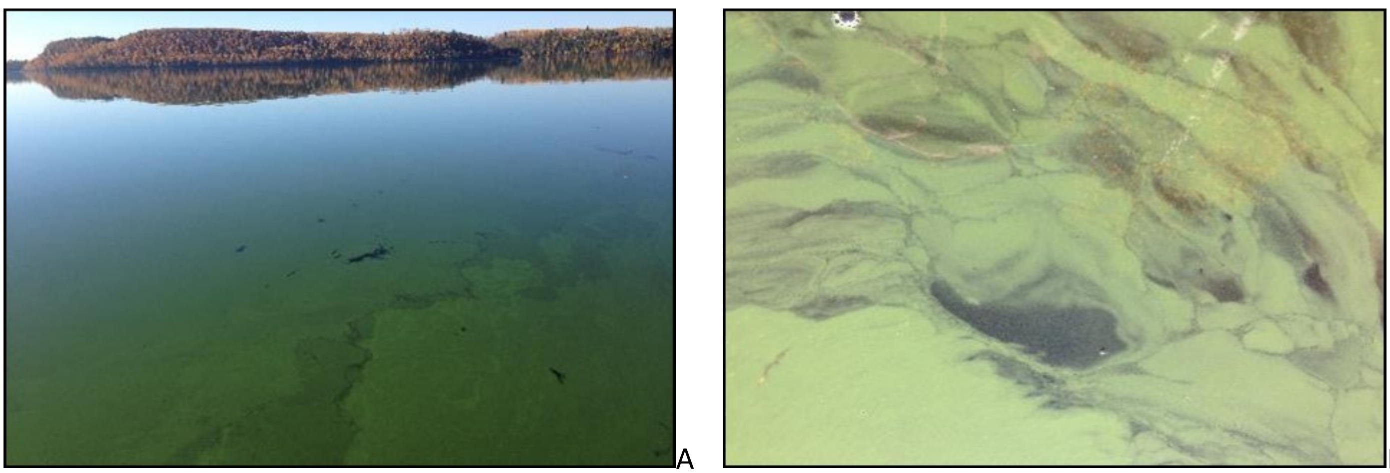


A B C

Figure 40 (A, B, and C) Gloeotrichia *spp.* left sample from July 10th, b center image from sample collected on Sept. 11th 2015 right image from sample collected on Oct. 11th 2015

The dispersion was difficult to determine due to increase turbulence of surface water making it difficult to discern after the morning. Gloeotrichia spp. was also noted to be present in samples collected at other times in the season including September 11th and October 11th (see figures 40 a-c). The quantities of gloeotrichia spp. appeared to be present more than any other cyanobacteria.

Figure 41 show clear indications of a cyanobacteria bloom captured on October 8th 2015. This bloom was the only one in 2015 witnessed at this magnitude.



A B

Figure 41 (A and B). Algal Bloom on Cloud Lake, October 8th 2015.
Images curtesy of Rob Foster Cloud Lake cottager. Images of surface dolichospermum *spp.* cyanobacteria bloom.

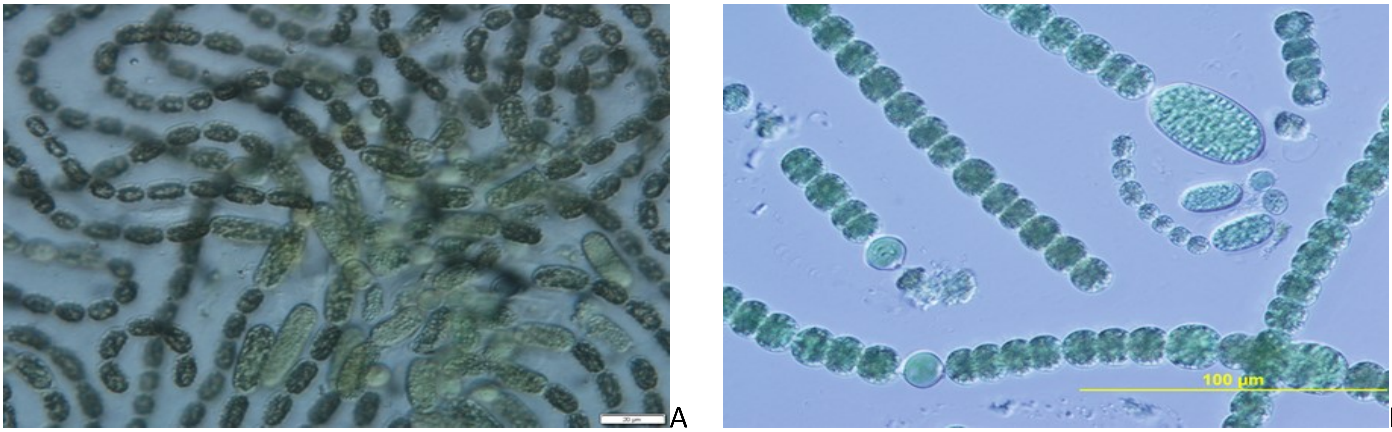


Figure 42 (A and B). Microscopic images of dolichospermum *spp.*

Figure 42 shows microscopic images of this bloom in which Dolichospermum cicnale and Dolichospermum planctonicum were identified as the predominant species with Aphanizomenon flos-aquae present but not as abundant. The distribution of this bloom was reported to include a large section of the western shoreline from the entrance of tributary 3 north to approximately ¾ of the way to the boat launch extending across roughly 2km of shoreline. It extended into the lake approximately 200 yards from shore. This bloom also lasted for 24 hours before beginning to disperse much longer than any other bloom (see figures 41 and 42).

Chapter 6
Conclusion

6.1 Introduction

This chapter addresses the success of the 2015 results in fulfilling the four objectives of the project. The objectives of the project were stated as:

1. To investigate and describe seasonal variation of dissolved oxygen, the thermocline, and total phosphorus
2. To determine the spring and mean annual phosphorus within Cloud Lake,
3. To determine the trophic state of Cloud Lake,
4. To identify algal blooms within Cloud Lake.

Each objective will be addressed and examined while drawing comparisons to other lakes and studies to better understand the current conditions of Cloud Lake.

6.2 Seasonal variations of thermal regime and dissolved oxygen

As described in section 3.1 Cloud Lake is situated in the upper portion of the headwaters of the Cloud River watershed located 45 minutes southwest of Thunder Bay in Northwestern Ontario. The results from section 5.1.1 show discharge of the inflow tributaries peaked in early spring and diminished to zero input with sporadic and minimal contributions during rain events (see figure 10 and 11). The outflow discharge shows more consistent discharge until the establishment of a beaver dam at the outflow of Cloud Lake occurs. There is minimal drainage into Cloud Lake from the surrounding area. This limited input and output, in association with geographic information, supports the description of Cloud Lake morphologically as being a reservoir.

During the 2015 monitoring period Cloud Lake was observed to fully mix, or turn over, on two separate occasions, once during the spring freshet and once during the fall. Thermal and dissolved oxygen profiles collected during May and October show temperature and dissolved oxygen distribution as consistent throughout the water column for both the Northeast and Southwest sites. Cloud Lake stratified during the summer as indicated by the separation of warmer less dense water of the epilimnion from the cooler denser hypolimnion by the metalimnion. The morphological characteristic of Cloud Lake acting as a reservoir, combined with the finding that the lake fully stratifies and mixes twice a year, is indicative of a dimictic lake (Wetzel, 2001).

The thermal and dissolved oxygen profiles show clear indication of significant stratification during the summer. Cloud Lake has a epilimnion which pushes down to approximately 12m encompassing the whole of the Northeast site. At the same time, anoxic conditions developed at the Southwest site in the hypolimnion extending upwards of 8m from the sediment water interface leaving little room in the water column for cool water fish species such as Walleye. The relationship seen on Cloud Lake between the thermal and dissolved oxygen profiles is conducive to the clinograde. As pointed out in Wetzel (2001) clinograde is associated with mesotrophic and eutrophic lakes, not oligotrophic. Correll (1998) North (2013), Nürnberg (1987), and Watson et al., (2016) indicate significant impacts associated with the development of anoxic conditions within lakes ranging from the disappearance of cold water fish species due to a lack of habitat to the continued eutrophication caused by internal loading even after removal of external inputs of phosphorus.

Total phosphorus measurements at both sites show higher concentrations in the epilimnion during early spring freshet inputs into Cloud Lake. As spring progresses concentrations throughout the water column diminish into summer. During summer total phosphorus concentrations progressively increase. The Northeast site does not show any trend in terms of higher concentrations being found in a consistent portion of the water column. It is important to reiterate that seasonal variations in temperature and dissolved oxygen indicate that eventually the epilimnion fully encompassed the entire Northeast site's water column. During the summer the Southwest site samples collected in the hypolimnion had the highest total phosphorus concentrations. The high hypolimnion concentrations coincide with the development of thermal stratification and anoxic conditions. All three of these parameters indicate that Cloud Lake has potentially significant internal loading of phosphorus as discussed in Nürnberg (2009).

During late summer water sampling of the hypolimnion observations were noted regarding a distinct smell of rotten egg associated with the presence of hydrogen sulfide or methane gas. These observations provide further evidence to support that internal loading is occurring in Cloud Lake, as described by Nürnberg (2009). Internal loading of phosphorus is often an overlooked aspect of lake and reservoir management as it is difficult to discern the source of the phosphorus which is responsible for the internal loading (Nürnberg, 2009). Despite this Matisoff et al., (2017), Nürnberg (2009; 2013) and Schindler (2006) have indicated that internal loading of phosphorus has significant impacts comparable to that of external loading delaying eutrophication management efforts as well as continued cyanobacteria blooms. Kling et al., (2011) determined in Lake Winnipeg that increased sediment phosphorus accumulation is directly linked to the reservoir characteristics developed in Lake Winnipeg after damming resulting in phytoplankton shift to potentially toxic species of cyanobacteria. Internal loading in Cloud Lake is a major concern that requires further research. These findings support the need for further research to address residence time of water along with sediment sampling of Cloud Lake to determine the potential impact of internal loading from sediment during anoxic conditions at the Southwest site.

6.3 Spring and Mean Annual Phosphorus on Cloud Lake

Studies such as McCullough et al., (2012), Matisoff et al., (2017), Sharply (2015), and Winter et al., (2007) have examined phosphorus inputs entering systems such as Lake Winnipeg, Lake Erie, and Lake Simcoe. They determined that the abundance of phosphorus entering these lakes is coming from continuous sources of anthropogenic inputs such as agricultural runoff. Cloud Lake does not share these characteristics. As discussed above Cloud Lake is seasonally limited with limited inputs contributing an insignificant amount of phosphorus during the spring. Previous reports (Foster and Wilson, 2016) have discussed the industrial background of the area. This along with modern review of satellite imagery confirms that despite logging of the upper portion of the input watershed there is no development or agricultural development that would provide significant input.

Cullen and Forsberg (1988), and Edmondson (1970) documented the importance of domestic sewage inputs in eutrophication. Cloud Lake has a concentrated number of residents along the north shoreline. The current condition of septic systems was not addressed in this study as the advising committee aimed to foster good public relationship toward follow up studies, and examination of septic systems tends to be invasive and potentially alienating for residents. Addressing the current condition of septic systems as the major external inputs would be a logical next step for Cloud Lake. Fastner et al., (2015) has linked untreated wastewater as point source phosphorus inputs with harmful cyanobacteria on eight lakes in Europe. Dillion and Molot (1996) have looked at nutrient contribution and retention from septic systems to lake's. Although no numerical value was placed on the contribution of septic systems it is clear that some retention of phosphorus within sediments and soils takes place.

Total phosphorus results from section 5.1.7 show the concentration distribution of phosphorus at both the Northeast and Southwest sites for Cloud Lake. The Ontario Ministry of Environment and Climate Change's (OMOECC) previous monitoring of spring total phosphorus on Cloud Lake has established an increasing trend of spring total phosphorus quantities peaking in 2013 at 39µg/L (Foster and Wilson, 2016). The OMOECC lake monitoring protocol is based on the work of Dillion and Rigler (1974) which established a correlation between spring total phosphorus and summer chlorophyll *a* concentrations. Spring total phosphorus is a much less intensive and costly measure as it is a single sampling event during spring turn over when the water column is fully mixed. The Cloud Lake spring total phosphorus samples were collected on May 25th. The spring total phosphorus results for 2015 showed a significant decline to 8.5µg/L. This trend was supported by the OMOECC 2015 spring total phosphorus sampling.

The total phosphorus concentrations collected at 1m below the surface half way down the water column and 1m above the sediment water interface provide Cloud Lake's mean annual phosphorus concentration of 15.47µg/L for the Northeast site and 27.21µg/L for the Southwest site. Cloud Lake was 21.34µg/L for the 2015 field season. Although not as high as what was expected prior to the undertaking of this project this is still above the Provincial Water Quality Objective (PWQO) of 20µg/L.

6.4 Understanding Cloud Lake's Current State

The results from the 2015 data collection help to understand Cloud Lake in relation to the OMOECC and Carlson's TSI (see table 18 section 5.9). These results indicate that during 2015 Cloud Lake was designated a level 2 or mesotrophic lake with overall suitable water quality. For the OMOECC lake management classification two of three parameters (mean secchi disc depth, and mean chlorophyll *a*) fell under level 2 or 'good' while spring total phosphorus was level 1 or 'excellent'. On the TSI classification three of four parameters (mean chlorophyll *a*, mean total phosphorus, maximum chlorophyll *a*) were mesotrophic while mean secchi disc depth was eutrophic. The 2015 Cloud Lake results more closely resemble those seen in the 1972 (Maki) report than those of the 1992 (Pugh) report. This is further supported by the spring total phosphorus concentration of 8.9µg/L for 2015 significantly lower than the previously reported 39µg/L of 2013 (Foster and Wilson, 2016). The contrast between the current OMOECC classification system and the Carlson based trophic indicators provide somewhat contradictory findings. The OMOECC classifications for 2015 indicate Cloud Lake should not be a priority for further monitoring. However, there are significant findings from the 2015 data collection such as internal loading and the presence of known toxin producing cyanobacteria that support further monitoring of Cloud Lake. Nürnberg (1984), Nürnberg et al., (1986) have indicated as trophic state increases, so does the rate of phosphorus released from sediment within anoxic conditions of a lake's hypolimnion. This anoxic and internal loading also have significant impact on the lake's recovery. Lakes with anoxic condtions and internal loading were noted to take longer to recover than those without (Nürnberg 1984). These results in conjunction with the current TSI support the need for further research and perhaps the reassessment or addition of parameters to the current systematic implementation of management strategies.

6.4.1 Nuisance Algal Blooms

Prior to 2015, reports from residents indicated that a notable increase in slimy 'rock snot' algae was covering nearshore rocks and dock supports. It is well established that high nutrients, specifically phosphorus as seen in Cloud Lake, are directly linked to increased abundance of algae occurrences and blooms (Wetzel, 2001). One of the objectives for the Cloud Lake study was observing and identifying nuisance algae blooms during the 2015 data collection. Observations and sampling were undertaken during collection of 1) water quality samples,

2) spring Smallmouth Bass nesting survey, and 3) surveying for aquatic vegetation when researchers were on Cloud Lake. Several algae species were observed throughout the 2015 data collection including filamentous green algae such as Spyrogyra, but more importantly, potentially toxin producing cyanobacteria such as Dolichospermum *sp.* and Aphanizomenon *flos-aquae* were also found. The observation of these potentially toxin producing cyanobacteria adds significant concerns about the current state of Cloud Lake. However, water quality parameters based on OMOECC guidelines would indicate that Cloud Lake does not require further monitoring.

The previous resident observations suggested that the observed green algae were abundant and persistent for most of the ice-free season. Two observations were made in 2015 of high densities of filamentous green algae. The first was in June during the Smallmouth Bass nesting survey. These densities did not persist, and over time, the algae became difficult to find as summer progressed. The second was during the aquatic vegetation survey when filamentous green algae were noted to be caught on the leaves of submerged vegetation. The density during the aquatic vegetation survey was not as high as seen during the Smallmouth Bass nesting survey. It was acknowledged by residents that 2015 was inconsistent with previous years and that the 'rock snot' was not as abundant.

Several limitations arose regarding the 2015 algae observation and identification. Observations were limited to times when researchers were on Cloud Lake for alternative work. The duration of algae blooms observed may be another limitation. As noted during the July 10th Gloeotrichia *spp.* bloom it was quickly dispersed from the surface under increased turbulence caused by wave action and rising winds. However, underwater video footage clearly showed a significant abundance suspended below the surface. The limited sample time may restrict the accuracy of sample collection. Additionally, there is concern over the delay of sample analysis incurred by travel from the office to the lake as well as the transportation of samples from Thunder Bay to Toronto. Identification of algae presented another limitation. Samples of algae collected by both Lakehead University researchers and OMOECC surface water technicians were brought to Lakehead University for morphological identification through microscopy as well as being sent to the OMOECC's Dorset laboratory for verification of morphological identification and liquid chromatography mass spectrometry (LCMS) screening for microcystin-LR toxicity quantification. Several samples sent to the Dorset lab were returned as being too degraded to be identified. Samples processed at Lakehead University did not suffer the same issues and provided imagery that was used for successful morphological identification. None of the samples screened through LCMS by the OMOECC indicated microcystin-LR concentrations above the Provincial Water Quality Standard concentration of 1.5μg/L. Further monitoring in an attempt to fully capture the extent of algal blooms, specifically cyanobacteria blooms on Cloud Lake, is a major priority. The 2015 observations were fortunate in capturing the five that were observed. There is a high potential that blooms were missed and the issue of cyanobacteria is a major concern for residents on Cloud Lake.

6.4.2 Macrophage

The submerged vegetation survey results show the distribution and abundance around the shore of Cloud Lake. Previous data on the distribution and abundance of submerged vegetation was limited to resident observations, and therefore, the 2015 results provide an excellent base line for comparative future research looking for potential changes. The results from 2015 indicate that there is no significant issue present with the current distribution and abundance of submerged vegetation on Cloud Lake. The abundance of submerged aquatic vegetation with relation to water quality shows an insightful interaction. Liu (2013), and Zhang (2016) have examined the trends in abundance with water quality parameters such as high concentrations of nutrients, phytoplankton blooms, turbidity and overall poor water quality. A unique interaction is provided in these studies showing lakes with high biomass of submerged aquatic vegetation being associated with lower concentrations of nutrients, phytoplankton, and turbidity. As conditions worsen and higher nutrients are found, water clarity decreases and inhibits the ability for submerged aquatic vegetation to access sunlight. This is the first-time Cloud Lake submerged aquatic vegetation has been examined and quantified to this extent. Future studies of submerged aquatic vegetation on Cloud Lake would build upon this base line. Cloud Lake is likely to see maintained abundance of submerged aquatic vegetation similar to that documented in this survey. If eutrophication of Cloud Lake continues the abundance of submerged aquatic vegetation would see significant drop off in follow up surveys. Signs of potential issues were observed during this survey with several observations of algae clinging to the leaves and stems of plants during grab samples. Specifically noted were two species of algae, one filamentous green algae spyrogira, and an unidentified ball-like alga that was affixed to the leaves and stems for plants. The quantities of the filamentous alga appeared to be significant enough that it was assumed the aquatic plants would not persist. Fortunately, this was not the case and although the filamentous alga was observed throughout the duration of the study it did not at this time seem to effect the submerged aquatic vegetation. Follow up surveys would provide better assessment of the possible impact of these algae on the health of submerged aquatic vegetation on Cloud Lake.

6.4.3 Spring Smallmouth Bass Nest Survey

The Spring Smallmouth Bass nest survey (smbns) of 2015 was the first conducted on Cloud Lake and provides a baseline set of conditions on the health of the bass nests and the presence and impacts of algae under the surface of the water. The results of the bass nest survey are comparable to studies done on Lerome and Plateau lakes also located in northwestern Ontario. The survey yielded typical results with Smallmouth Bass nests being located on rock and cobble shoreline with patchy distribution reflecting availability of preferred substrate (Foster and Harris, 2010; Rejwan et al., 1997; Scott, 1996). Cloud Lake had a higher density of nests, 1 every 45m, compared to Lerome and Plateau, 1 every 60m (Foster and Harris, 2010). Mean depth of water for Smallmouth Bass nests was similar to Lerome Lake near Atikokan 130 cm, with a very comparable water clarity (secchi depth of 3.6m compared to 3.7m for Cloud Lake). In comparison, mean bass nest depth was only 60cm in the darker-stained waters of Plateau Lake, which has a secchi depth of 2.3m (Foster and Harris, 2010). The Smallmouth Bass survey provides a baseline useable for future research comparisons.

The higher density of Smallmouth Bass nests on Cloud Lake is supported by the results of near shore community index netting (NSCIN) conducted by the MNRF which indicated Cloud Lake has higher quantities of Smallmouth Bass with older average age class of 7.5 year compared to 5.4 years and higher catch per unit effort also indicating lager heavier bass on Cloud Lake than surrounding studied lakes (Foster and Wilson, 2016). During the spring Smallmouth Bass survey an abundance of nests were observed with large male bass guarding the nests indicating a strong population of Smallmouth Bass within Cloud Lake. Specific locations on Cloud Lake (i.e. the Western shore) were observed to experience significant bloom of filamentous algae toward the end of the survey. The dominant species of this bloom was identified as spyrogyra. As these observations were made toward the end of June and the spring spawning period several of the nests where identified based on the presence of Smallmouth Bass fry. The algae were observed in higher densities within the cleared substrate of the Smallmouth Bass nests. The observed hatched fry were seen resting and hiding within the algae, some unhatched dead eggs were observed tangled within the substrate and algae. It is unclear what impact the algal bloom had on the Smallmouth Bass spawn Foster and Wilson (2016) indicate that the MNRF NSCIN was not able to fully address the potential issues caused by the filamentous algae seen during the spring Smallmouth Bass nesting survey as Year 1 and 2 classes were lacking. Further monitoring and research is suggested to better understand the potential impact that dense filamentous algae may have on Smallmouth Bass recruitment.

The results of the MNRF BDSM and NSCIN for Cloud Lake supports the results from the water quality portion of this project indicating Cloud Lake is transitioning. These results demonstrate that the current composition of fish within Cloud Lake is more like that of a warm water mesotrophic lake then a cool water oligotrophic lake. The limited habitat for species such as Walleye does not seem to impact shallow, warmer water species such as Yellow Perch, Northern Pike, and Smallmouth Bass populations. Future BDSM and NSCIN along with the spring Smallmouth Bass nesting survey would continue to document any changes within the aquatic community. This further research could provide a more accurate assessment of the interaction of shifting water conditions as well as the impact of algal blooms on recruitment on Cloud Lake.

Chapter 7
Conclusion

7.1 Introduction

Understanding the multiple interactions within a lake ecosystem provides far clearer indications of what future studies need to address and which areas should be focused on for monitoring and managing eutrophication. The idea of interaction between various environmental parameters is not unique to Cloud Lake. Monitoring and management of eutrophication in lakes such as Erie, Winnipeg, and Simcoe initially focused on understanding and removal of external phosphorus into the system. After years of working on mitigating external sources, eutrophication has persisted in these systems. Managing external sources alone proved to be ineffective and research now focuses on better understanding the complex interactions within the whole lake ecosystem. Recent research has clearly indicated that internal loading can potentially cause expedited and prolonged eutrophication and cyanobacteria blooms even after external sources of nutrients have been removed. On Cloud Lake, thermal and dissolved oxygen profiles revealed that internal loading of phosphorus is occurring from the anoxic hypolimnion during summer stratification. The presence of toxic cyanobacteria further provides evidence that the lake is symptomatic of issues that are of great concern to lake managers.

The results of this study have successfully characterized the trophic state of Cloud Lake by using both the OMOECC and Carlson's 1977 TSI classification. The results of the 2015 sampling season indicate that Cloud Lake is a level 2 lake with level 1 spring total phosphorus using the OMOECC criteria. Level 2 indicates less than 20µg/L spring total phosphorus with decent water clarity associated with 'good' water quality. Level 1 indicates pristine or 'excellent' water quality with little to no potential risk for issues. However, the Carlson based TSI indicates that Cloud Lake is a mesotrophic lake with eutrophic mean secchi depth suggesting that the Lake is transitioning to a higher trophic state with worsening water quality. Furthermore, additional data collected during 2015, such as thermal and dissolved oxygen profiles, spring Smallmouth Bass nesting and submerged aquatic vegetation surveys, observations of surface and subsurface algae characteristics and types, and the identification of potentially toxic cyanobacteria blooms, provides further evidence that Cloud Lake's problematic water quality is of higher concern for eutrophication management than relying on the OMOECC index alone. Specifically, this data supported the two major assumptions that internal loading of phosphorus and cyanobacteria blooms of known toxin producing species are occurring on Cloud Lake.

7.2 Recommendations for Future Research and Monitoring

7.2.1 Enhanced classification

The TSI classification provides accounting for seasonal variations in phosphorus by using mean annual total phosphorus. The OMOECC classification relies on spring total phosphorus collected during spring turn over only, essentially ignoring variations during summer stratification associated with internal loading. Internal sources of phosphorus were previously thought to be isolated and not biologically available, however, it is now known that this phosphorus is biologically available. Studies conducted on Lake Winnipeg (Matisoff et al., 2017) and Simcoe (Nürnberg, 2013) have determined that internal loading of phosphorus has sustained eutrophication symptoms within these systems even after the management of external phosphorus inputs.

To better manage the eutrophication of Cloud Lake further research is required. A more accurate understanding of current conditions of Cloud Lake requires more intensive sampling throughout the year. This would include winter sampling, something no study has currently done on Cloud Lake. Sampling of trophic state indicators such as phosphorus, chlorophyll *a*, and secchi disc depth are useful in gaining a basic understanding of general conditions within the system. However, as seen in this study, secondary parameters such as thermal and dissolved oxygen profiles and discharge allow for important interpretations of the complex interactions of the whole lake ecosystem. Managing an aquatic system based on Carlson (1977) trophic state indicators or the OMOECC parameters can only provide broad indication of transitions in water quality.

7.2.2 Longitudinal Studies for the Management of Eutrophication

To fully comprehend the complex interactions within the Cloud Lake ecosystem future studies are required. These studies should aim to address the remaining gaps in knowledge regarding Cloud Lake's current state and possible future. For example, reexamination of the status of septic system integrity, and continued residential and land-use development on Cloud Lake, would help understand the anthropogenic impacts from potential sources of phosphorus. Research into water residence time and internal loading of phosphorus will provide an indication of how long current phosphorous inputs persist and influence the water quality of Cloud Lake. Increased public outreach should raise public awareness about the anthropogenic impacts to Cloud Lake, and allow for more detailed documentation and sampling of algae (cyanobacteria or other) blooms. These actions, in conjunction with the increased water quality sampling, would provide essential information to sufficiently understand the conditions of Cloud Lake.

The 2015 Cloud Lake project was unable to address other potential sources of phosphorus: the anthropogenic inputs coming from improperly maintained septic systems; phosphorous from the surrounding geology and surface cover; atmospheric deposition through rain fall; and, phosphorous from the lake sediment. A future study examining the contribution of septic input around Cloud Lake would be a priority in understanding other possible sources of phosphorus entering the lake. Unfortunately, there is no guarantee that these other sources of phosphorous are 'the' driving factors in the potential eutrophication of Cloud Lake. An assessment of internal loading of phosphorus from the sediment in the anoxic regions of Cloud Lake, coupled with a determination of water residence time, would also provide a needed indication of the current compounding effect to the potential of eutrophication.

Discharge results from this study indicate that it is likely that Cloud Lake has a high residence time, further supporting the notion of Cloud Lake resembling a reservoir. As seen in Lake Winnipeg this would mean that the internal loading of phosphorus would cause a delay in observed results after management of external nutrients. Knowing this would allow managers to properly inform the public of the expected lapse. There is currently no established standardized methodology for internal loading. Research methodologies can use laboratory analysis of pore water total phosphorus, porosity of sediments, and coefficients for the biochemical processes to estimate the phosphorus release from sediment under anoxic conditions (Dittrich, 2013). Other statistical methods (Nürnberg, 2013) use statistical analysis of in situ estimations of variation in hypoxia and phosphorus to estimate the extent of internal loading. Further literature review beyond the scope of this thesis would be required to select the appropriate method for Cloud Lake.

A paleolimnology study on Cloud Lake would be useful in providing a more accurate assessment of the rate of eutrophication on Cloud Lake. Sediment cores can be used to characterize lake history providing insight into conditions of both the aquatic and terrestrial environments. This is accomplished using radioisotope dating and sedimentation rates (Smol, 1994). Paleolimnology studies of sediment cores can provide data to correlate human settlement and activity with associated peaks of phosphorus and composition shifts in microscopic organisms, such as diatoms trapped within sediment layers (Karst, 1998).

7.3 Monitoring of Cyanobacteria and other Algal Blooms

The continued monitoring of algal blooms on Cloud Lake is essential. The identification of several known toxin producing cyanobacteria species is a potentially major human health risk. Cyanobacteria can regulate their buoyancy allowing them to access the potentially biologically available phosphorus within the hypolimnion. The presence of several known toxin producing cyanobacteria on Cloud Lake is a significant concern for human and wildlife health. Time is a major concern for cyanobacteria blooms in Northwestern Ontario. Unlike larger lake systems bloom durations on Cloud Lake were generally short. Blooms were obvious early in the morning but quickly disturbed by surface turbulence. Although none of the samples collected during the 2015 blooms returned results above the provincial water quality threshold for microcystin, uncertainties arose regarding the timeframe of sampling to public notification. Additional questions such as the impact of time delay from collection to analysis on sample degradation and the accuracy of results in such circumstances need to be studied. Are samples experiencing degradation during transportation from Thunder Bay to Toronto? Would collection of a sample during the early stages of a bloom provide different results than samples collected toward the end of the bloom?

7.4 Conclusion

This thesis provides biological, chemical, and physical evidence that Cloud Lake is a mesotrophic lake and confirms the occurrence of toxin producing cyanobacteria. Cloud Lake's water quality is therefore a serious concern, particularly in a region where cold climates and freshwater ecosystems result in the general perception that most lakes are oligotrophic. The findings therefore suggest the possibility that Cloud Lake is a lake in transition and has a significant potential for continued eutrophication into the future.

Eutrophication is a natural process within aquatic ecosystems taking place over centuries. Anthropogenic impacts are no doubt increasing the rate of eutrophication, however, the literature covering many of the larger aquatic systems (Lakes Erie, Winnipeg, and Simcoe) receive most of the attention due to the obvious degradations to these systems from agriculture and urban density. Cloud Lake, however, is located in a region associated with limited anthropogenic inputs. This suggests that processes in lake ecosystems (i.e. internal loading) and surrounding environment and climate are also key factors in understanding the current changes in trophic states and therefore understanding the future health of this lake.

As a result of the perceptions that this geographic region is not at risk to lake eutrophication, the previous and existing management and monitoring strategies are insufficient in determining the cause and solution to lake eutrophication in Northwestern Ontario. Even if management efforts begin to better account for and reduce the anthropogenic influences on the eutrophication processes, eutrophication may still occur due to natural environmental factors that are not being monitored or understood. New research into internal loading provides a first step towards addressing a whole ecosystem and adaptive approach to better understand eutrophication in aquatic systems of Northwestern Ontario. This requires multi-scale monitoring and management, agency or regulatory approaches, academic research and education, stewardship efforts with residents, the public and local governments.

References

Allinger, L. E., & Reavie, E. D. (2013). The ecological history of Lake Erie as recorded by the phytoplankton community. *Journal of Great Lakes Research*, *39*(3), 365-382.

Brezonik, P. L., & Shannon, E. E. (1971). Trophic state of lakes in north central Florida.

Board, L. W. S. (2006). *Reducing Nutrient Loading to Lake Winnipeg and Its Watershed: Our Collective Responsibility and Commitment to Action: Report to the Minister of Water Stewardship*. Lake Winnipeg Stewardship Board.

Bunting, L., Leavitt, P. R., Wissel, B., Laird, K. R., Cumming, B. F., St Amand, A., & Engstrom, D. R. (2011). Sudden ecosystem state change in Lake Winnipeg, Canada, caused by eutrophication arising from crop and livestock production during the 20th century. *Final report to Manitoba Water Stewardship, Winnipeg, Manitoba, Canada*, *785*.

Carlson, R. E. (1977). A trophic state index for lakes. *Limnology and oceanography*, *22*(2), 361-369.

Carmichael, W. (2008). A world overview—One-hundred-twenty-seven years of research on toxic cyanobacteria—Where do we go from here?. In *Cyanobacterial harmful algal blooms: State of the science and research needs* (pp. 105-125). Springer New York.

Churchill, R. T., Schummer, M. L., Petrie, S. A., & Henry, H. A. (2016). Long-term changes in distribution and abundance of submerged aquatic vegetation and dreissenid mussels in Long Point Bay, Lake Erie. *Journal of Great Lakes Research*, *42*(5), 1060-1069

Cuadrado, D. G. (2008). Geomorphology: A Canadian Perspective.

Bennett, E. M., Carpenter, S. R., & Caraco, N. F. (2001). Human impact on erodable phosphorus and eutrophication: a global perspective increasing accumulation of phosphorus in soil threatens rivers, lakes, and coastal oceans with eutrophication. *BioScience*, *51*(3), 227-234.

Descy, J. P., Leprieur, F., Pirlot, S., Leporcq, B., Van Wichelen, J., Peretyatko, A., ... & Wilmotte, A. (2016). Identifying the factors determining blooms of cyanobacteria in a set of shallow lakes. *Ecological Informatics*, *34*, 129-138.

De Pinto, J. V., Young, T. C., & McIlroy, L. M. (1986). Great Lakes water quality improvement. *Environmental science & technology*, *20*(8), 752-759.

Dillon, P. J., Reid, R. A., & Evans, H. E. (1993). The relative magnitude of phosphorus sources for small, oligotrophic lakes in Ontario, Canada. TRAV. ASSOC. INT. LIMNOL. THEOR. APPL.]., 25(1).

Dillon, P. J., & Molot, L. A. (1996). Long-term phosphorus budgets and an examination of a steady-state mass balance model for central Ontario lakes. *Water Research*, *30*(10), 2273-2280.

Dittrich, M., Chesnyuk, A., Gudimov, A., McCulloch, J., Quazi, S., Young, J., ... & Arhonditsis, G. (2013). Phosphorus retention in a mesotrophic lake under transient loading conditions: Insights from a sediment phosphorus binding form study. *water research*, *47*(3), 1433-1447.

Dodds, W., & Smith, V. H. (2016). Nitrogen, phosphorus, and eutrophication in streams. *Inland Waters*, *6*(2), 155-164.

Downing, J. A., Watson, S. B., & McCauley, E. (2001). Predicting cyanobacteria dominance in lakes. *Canadian journal of fisheries and aquatic sciences*, *58*(10), 1905-1908.

Elliott, S. J., Eyles, J., & DeLuca, P. (2001). Mapping health in the Great Lakes areas of concern: a user-friendly tool for policy and decision makers. *Environmental health perspectives*, *109*(Suppl 6), 817.

Fastner, J., Abella, S., Litt, A., Morabito, G., Vörös, L., Pálffy, K., ... & Chorus, I. (2016). Combating cyanobacterial proliferation by avoiding or treating inflows with high P load—experiences from eight case studies. *Aquatic Ecology*, *50*(3), 367-383.

Foster, R., & Wilson, N. (2016). Cloudy Conditions? The State of the Cloud Lake and the Cloud River Watershed. Report commissioned by the Thunder Bay Stewardship Council. Unpublished.

Francis, G. (1878). Poisonous Australia lake. *Nature*, *18*, 11-12.

Hallegraeff, G.M. 1993. A review of harmful algal blooms and their apparent global increase. Phycologia, 32: 79–99. doi:10.2216/i0031-8884-32-2-79.1.

Higgins, S. N., Malkin, S. Y., Todd Howell, E., Guildford, S. J., Campbell, L., Hiriart-Baer, V., & Hecky, R. E. (2008). An ecological review of Cladophora glomerata (Chlorophyta) in the Laurentian Great Lakes. *Journal of Phycology*, *44*(4), 839-854.

He, Z., Hiscock, J. G., Merlin, A., Hornung, L., Liu, Y., & Zhang, J. (2014). Phosphorus budget and land use relationships for the Lake Okeechobee Watershed, Florida. *Ecological Engineering*,*64*325-336. doi:10.1016/j.ecoleng.2013.12.043.

Ibelings, B. W., Fastner, J., Bormans, M., & Visser, P. M. (2016). Cyanobacterial blooms. Ecology, prevention, mitigation and control: Editorial to a CYANOCOST Special Issue. *Aquatic Ecology*, *50*(3), 327-331.

Jarosiewicz, A., Ficek, D. & Zapadka, T. (2012). Eutrophication parameters and Carlson-type trophic state indices in selected Pomeranian lakes. *Limnological Review*, 11(1), pp. 15-23. Retrieved 16 Oct. 2016, from doi:10.2478/v10194-011-0023-3

Jenny, J. P., Normandeau, A., Francus, P., Taranu, Z. E., Gregory-Eaves, I., Lapointe, F., ... & Zolitschka, B. (2016). Urban point sources of nutrients were the leading cause for the historical spread of hypoxia across European lakes. *Proceedings of the National Academy of Sciences*, 201605480..

Jeppesen, E., Søndergaard, M., Meerhoff, M., Lauridsen, T. L., & Jensen, J. P. (2007). Shallow lake restoration by nutrient loading reduction—some recent findings and challenges ahead. *Hydrobiologia*, *584*(1), 239-252.

Karst, T. L., & Smol, J. P. (1998). Tracking the cultural eutrophication history of Collins Lake (southeastern Ontario, Canada) using paleolimnological techniques. *Lake and Reservoir Management*, *14*(4), 456-465.

Kling, H. J., Watson, S. B., McCullough, G. K., & Stainton, M. P. (2011). Bloom development and phytoplankton succession in Lake Winnipeg: a comparison of historical records with recent data. *Aquatic Ecosystem Health & Management*, *14*(2), 219-224.

Kolada, A. (2014). The effect of lake morphology on aquatic vegetation development and changes under the influence of eutrophication. *Ecological Indicators*, *38*, 282-293.

Lynde, P. Associates Incorporated. 2008. Official Plan for the Municipality of Neebing. 49 p. Available at http://www.neebing.org/planning.html [accessed Mar 2015].

Mackie, G. (2004). *Applied aquatic ecosystem concepts*. Kendall Hunt.

Maki, L.W. 1979. The water quality of Cloud Lake, Crooks Township, District of Thunder Bay. Ontario Ministry of Environment, Thunder Bay. Draft report, December 1979. 11 p. + attachments.

Maki, L.W. 1980. The water quality of Cloud Lake, Crooks Township, District of Thunder Bay. Ontario Ministry of Environment, Thunder Bay. Final report, January 1980. 11 p.

Mahmood, M., Bhavsar, S. P., & Arhonditsis, G. B. (2013). Fish contamination in Lake Erie: An examination of temporal trends of organochlorine contaminants and a Bayesian approach to consumption advisories. *Ecological informatics*, *18*, 131-148.

Matisoff, G., Watson, S. B., Guo, J., Duewiger, A., & Steely, R. (2017). Sediment and nutrient distribution and resuspension in Lake Winnipeg. *Science of The Total Environment*, *575*, 173-186.

McCullough, G. K., Page, S. J., Hesslein, R. H., Stainton, M. P., Kling, H. J., Salki, A. G., & Barber, D. G. (2012). Hydrological forcing of a recent trophic surge in Lake Winnipeg. *Journal of Great Lakes Research*, *38*, 95-105.

McElmurry, S. P., Confesor Jr, R., & Richards, R. P. (2013). Reducing Phosphorus Loads to Lake Erie: Best Management Practices. *A draft literature review prepared for the International Joint Commission's Lake Erie Ecosystem PriorityIJC Great Lakes Regional Office, Windsor, ON*.

Michalak, A. M., Anderson, E. J., Beletsky, D., Boland, S., Bosch, N. S., Bridgeman, T. B., ... & DePinto, J. V. (2013). Record-setting algal bloom in Lake Erie caused by agricultural and meteorological trends consistent with expected future conditions. *Proceedings of the National Academy of Sciences*, *110*(16), 6448-6452.

Michalski, M. F. P., & Conroy, N. (1973). THE'OLIGOTROPHICATION' OF LITTLE OTTER LAKE, PARRY SOUND DISTRICT.

Minns, C. K., Cairns, V. W., Randall, R. G., & Moore, J. E. (1994). An index of biotic integrity (IBI) for fish assemblages in the littoral zone of Great Lakes' areas of concern. *Canadian Journal of Fisheries and Aquatic Sciences*, *51*(8), 1804-1822.

Molot, L. A., Watson, S. B., Creed, I. F., Trick, C. G., McCabe, S. K., Verschoor, M. J., ... & Schiff, S. L. (2014). A novel model for cyanobacteria bloom formation: the critical role of anoxia and ferrous iron. *Freshwater Biology*, *59*(6), 1323-1340.

North, R. L. (2013). The state of Lake Simcoe (Ontario, Canada): the effects of multiple stressors on phosphorus and oxygen dynamics. *Inland Waters*, *3*(1), 51-74.

Nürnberg, G. K. (1984). The prediction of internal phosphorus load in lakes with anoxic hypolimnia. Limnology and oceanography, 29(1), 111-124.

Nürnberg, G. K., Shaw, M., Dillon, P. J., & McQueen, D. J. (1986). Internal phosphorus load in an oligotrophic Precambrian Shield lake with an anoxic hypolimnion. Canadian Journal of Fisheries and Aquatic Sciences, 43(3), 574-580

Nürnberg, G. K. (1987). A comparison of internal phosphorus loads in lakes with anoxic hypolimnia: laboratory incubation versus in situ hypolimnetic phosphorus accumulation. *Limnology and Oceanography*, *32*(5), 1160-1164.

Nürnberg, G. K. (1988). Prediction of phosphorus release rates from total and reductant-soluble phosphorus in anoxic lake sediments. *Canadian Journal of Fisheries and Aquatic Sciences*, *45*(3), 453-462.

Nürnberg, G. K. (2009). Assessing internal phosphorus load–problems to be solved. *Lake and Reservoir Management*, *25*(4), 419-432.

Nürnberg, G. K., LaZerte, B. D., Loh, P. S., & Molot, L. A. (2013). Quantification of internal phosphorus load in large, partially polymictic and mesotrophic Lake Simcoe, Ontario. *Journal of Great Lakes Research*, *39*(2), 271-279.

Scavia, D., Allan, J. D., Arend, K. K., Bartell, S., Beletsky, D., Bosch, N. S., ... & Dolan, D. M. (2014). Assessing and addressing the re-eutrophication of Lake Erie: Central basin hypoxia. *Journal of Great Lakes Research*, *40*(2), 226-246.

Schindler, D. W., & Fee, E. J. (1974). Experimental lakes area: whole-lake experiments in eutrophication. *Journal of the Fisheries Board of Canada*, *31*(5), 937-953.

Schindler, D. W. "Recent advances in the understanding and management of eutrophication." *Limnology and Oceanography* 51.1 (2006): 356-363.

Schindler, D. W., and John R. Vallentyne. *algal bowl*. University of Alberta Press, 2008.

Schindler, D. W., Hecky, R. E., & McCullough, G. K. (2012). The rapid eutrophication of Lake Winnipeg: Greening under global change. *Journal of Great Lakes Research*, *38*, 6-13.

Schindler, D. W., Carpenter, S. R., Chapra, S. C., Hecky, R. E., & Orihel, D. M. (2016). Reducingphosphorus to curb lake eutrophication is a success.

Scott, W. B., & Crossman, E. J. (1973). Freshwater fishes of Canada. *Fisheries Research Board of Canada Bulletin*, *184*.

Simon, K. L. (2016). *BALD EAGLES (HALIAEETUS LEUCOCEPHALUS) AS INDICATORS OF GREAT LAKES ECOSYSTEM HEALTH* (Doctoral dissertation).

Steffen, M. M., Belisle, B. S., Watson, S. B., Boyer, G. L., & Wilhelm, S. W. (2014). Status, causes and controls of cyanobacterial blooms in Lake Erie. *J. Great Lakes Res*, *40*(2), 215-225.

Smith, V. H., Tilman, G. D., & Nekola, J. C. (1999). Eutrophication: impacts of excess nutrient inputs on freshwater, marine, and terrestrial ecosystems. *Environmental pollution*, *100*(1), 179-196.

Smith, V. H. (2003). Eutrophication of freshwater and coastal marine ecosystems a global problem. *Environmental Science and Pollution Research*, *10*(2), 126-139.

Smol, J. P., Cumming, B. F., Douglas, M. S., & Pienitz, R. (1994). Inferring Past Climatic Changes in Canada Using Paleolimnological Techniques. *Geoscience Canada*, *21*(3).

Sorichetti, R. J., Creed, I. F., & Trick, C. G. (2014). Evidence for iron-regulated cyanobacterial predominance in oligotrophic lakes. Freshwater biology, 59(4), 679-691

Szlag, D. C., Sinclair, J. L., Southwell, B., & Westrick, J. A. (2015). Cyanobacteria and Cyanotoxins Occurrence and Removal from Five High-Risk Conventional Treatment Drinking Water Plants. *Toxins*, *7*(6), 2198-2220.

Paerl, H. W., Fulton, R. S., Moisander, P. H., & Dyble, J. (2001). Harmful freshwater algal blooms, with an emphasis on cyanobacteria. *The Scientific World Journal*, *1*, 76-113.

Paerl, H. W., Xu, H., McCarthy, M. J., Zhu, G., Qin, B., Li, Y., & Gardner, W. S. (2011). Controlling harmful cyanobacterial blooms in a hyper-eutrophic lake (Lake Taihu, China): the need for a dual nutrient (N & P) management strategy. *Water Research*, *45*(5), 1973-1983.

Pick, F. R. (2016). Blooming algae: a Canadian perspective on the rise of toxic cyanobacteria. *Canadian Journal of Fisheries and Aquatic Sciences*, *73*(7), 1149-1158.

Ritter, Keith Solomon, Paul Sibley, Ken Hall, Patricia Keen, Gevan Mattu, Beth Linton, L. (2002). Sources, pathways, and relative risks of contaminants in surface water and groundwater: a perspective prepared for the Walkerton inquiry. *Journal of Toxicology and Environmental Health Part A*, *65*(1), 1-142.

Rockwell, D. C., Warren, G. J., Bertram, P. E., Salisbury, D. K., & Burns, N. M. (2005). The US EPA Lake Erie indicators monitoring program 1983–2002: trends in phosphorus, silica, and chlorophyll a in the central basin. *Journal of Great Lakes Research*, *31*, 23-34

Tabe, S., Parrott, J., Nowierski, M., Pileggi, V., Kleywegt, S., & Yang, P. (2016). Occurrence, environmental impacts and removal of legacy and emerging contaminants from two wastewater and one water treatment plant in Southern Ontario. Part II: environmental impacts. *Water Practice and Technology*, *11*(2), 315-328.

Vollenweider, R. A., & Kerekes, J. (1982). Eutrophication of waters. Monitoring, assessment and control. *Organization for Economic Co-Operation and Development (OECD), Paris*, *156*.

Vander Wal, J. 1985. Cloud Lake Water Quality. Memorandum to M. Sutterfield. Ontario Ministry of the Environment, Thunder Bay. 5 p.

Watson, S. B., Miller, C., Arhonditsis, G., Boyer, G. L., Carmichael, W., Charlton, M. N., ... & Matisoff, G. (2016). The re-eutrophication of Lake Erie: Harmful algal blooms and hypoxia. *Harmful Algae*, *56*, 44-66.

Wetzel, R. G. (2001). *Limnology: lake and river ecosystems*. Gulf Professional Publishing.

Winter, J. G., Dillon, P. J., Futter, M. N., Nicholls, K. H., Scheider, W. A., & Scott, L. D. (2002). Total phosphorus budgets and nitrogen loads: Lake Simcoe, Ontario (1990 to 1998). *Journal of Great Lakes Research*, *28*(3), 301-314

Winter, J. G., Eimers, M. C., Dillon, P. J., Scott, L. D., Scheider, W. A., & Willox, C. C. (2007). Phosphorus inputs to Lake Simcoe from 1990 to 2003: declines in tributary loads and observations on lake water quality. *Journal of great lakes research*, *33*(2), 381-396.

Winter, J. G., Young, J. D., Landre, A., Stainsby, E., & Jarjanazi, H. (2011). Changes in phytoplankton community composition of Lake Simcoe from 1980 to 2007 and relationships with multiple stressors. *Journal of Great Lakes Research*, *37*, 63-71.

Winter, J.G., DeSellas, A.M., Fletcher, R., Heintsch, L., Morley, A., Nakamoto, L., and Utsumi, K. (2011). Algal blooms in Ontario, Canada: increases in reports since 1994. Lake Reserv. Manage. 27: 107–114. doi:10.1080/07438141.2011. 557765.

Ziajahromi, S., Neale, P. A., & Leusch, F. D. (2016). Wastewater treatment plant effluent as a source of microplastics: review of the fate, chemical interactions and potential risks to aquatic organisms. *Water Science and Technology*, *74*(10), 2253-2269.

Zhang, Y., Liu, X., Qin, B., Shi, K., Deng, J., & Zhou, Y. (2016). Aquatic vegetation in response to increased eutrophication and degraded light climate in Eastern Lake Taihu: Implications for lake ecological restoration. *Scientific Reports*, *6*, 23867. http://doi.org/10.1038/srep23867.

Zhou, Y., Michalak, A. M., Beletsky, D., Rao, Y. R., & Richards, R. P. (2015). Record-breaking Lake Erie hypoxia during 2012 drought. *Environmental science & technology*, *49*(2), 800-807.

Zhou, Y., Obenour, D. R., Scavia, D., Johengen, T. H., & Michalak, A. M. (2013). Spatial and temporal trends in Lake Erie hypoxia, 1987–2007. *Environmental science & technology*, *47*(2), 899-905.

Appendices

Appendix A- Cloud Lake 2015 sampling schedule

Parameter Measured	Tributary Discharge	Temperature Profile	Dissolved oxygen Profile	Water Chemistry	Secchi
Date					
April 13th 2015	N/A	SW	SW	SW	N/A
May 8th 2015	Trib 1-3	Trib 1-3, NE, SW, OF	Trib 1-3, NE, SW, OF	Trib 1-3, NE, SW, OF	NE, SW
May 21st 2015	Trib 1-3, OF	Trib 1-3, NE, SW, OF	Trib 1-3, NE, SW, OF	Trib 1-3, NE, SW, OF	NE, SW
June 5th 2015	Trib 1-3, OF	Trib 1-3, NE, SW, OF	Trib 1-3, NE, SW, OF	Trib 1-3, NE, SW, OF	NE, SW
July 10th 2015	N/A	NE, SW, OF	NE, SW, OF	NE, SW, OF	NE, SW
Aug 5th 2015	N/A	SW, NE	SW, NE	SW, NE	NE, SW
Aug 29th 2015	Trib 1-3, OF	Trib 1-3, NE, SW, OF	Trib 1-3, NE, SW, OF	Trib 1-3, NE, SW, OF	NE, SW
Sept 10th 2015	N/A	NE, SW	NE, SW	NE, SW	NE, SW
Sept 25th 2015	N/A	NE, SW	NE, SW	NE, SW	NE, SW
Oct. 14th 2015	N/A	NE, SW	NE, SW	NE, SW	NE, SW
Oct. 22nd 2015	N/A	NE, SW	NE, SW	NE, SW	NE, SW
Nov. 2nd 2015	N/A	NE, SW	NE, SW	NE, SW	NE, SW

Legend

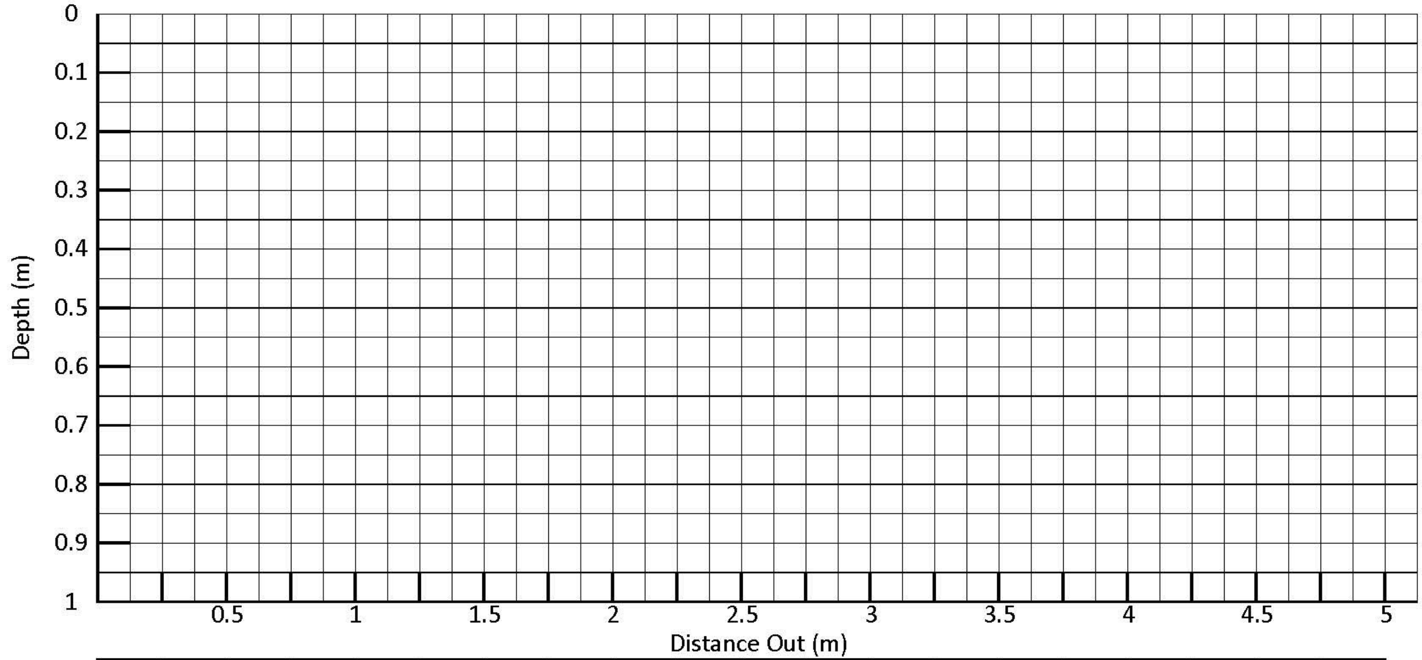
Trib – Tributary, NE – Northeast lake site, SW – Southwest lake site, OF – Outflow tributary, N/A – Parameter not sampled

Appendix B - Tributary discharge and profile form.

Cross-Sectional Profile and Discharge Calculation for the Cloud River Watershed Date:__________________

Specific Location: ______________________________ GPS, Easting: ______________, Northing: ______________

Cloud River Watershed Assessment - 2015



# of squares:																				
Area (m^2):																				
Impeller Count:																				
Flow velocity ($m\ s^{-1}$):																				
Discharge ($m^3\ s^{-1}$):																				

Total Discharge (Q) = _______________ $m^3 s^{-1}$

Temperaure = _______°C Diss. O_2 = _________ppm Diss. O_2 = _________%

Cond. = ____________uS cm^{-1} Cond. = _____________uS cm^{-1} A pH = ______________

Notes:

Flow velocity (v) = 0.000854(c) + 0.05 where c represents the impeller count for 60 seconds.

Area of one square = 0.125mX0.05m = 0.00625m^2

Total Discharge (Q) = ∑ of all discharge calculations

Appendix C - Submerged aquatic vegetation survey form.

Date	Waypoint ID	Location	Density	Primary	Secondary	Other	Health	Algae Coverage	Substrate	Notes:
			H / M/ L							
			H / M/ L							
			H / M/ L							
			H / M/ L							
			H / M/ L							

Appendix D - Spring Smallmouth Bass nesting survey form.

Date:____________ Diver:________________________ Recorder:________________________

Nest ID	Easting:	Northing:	Bass Present	Bass Size[1]	Eggs Present	Fry Present	Water Depth (m)	Main Substrate[2]	Secondary Substrate[2]	Surrounding Substrate	% Algae[3]
B	E	N	Y / N		Y / N	Y / N					
Notes:											
B	E	N	Y / N		Y / N	Y / N					
Notes:											
B	E	N	Y / N		Y / N	Y / N					
Notes:											
B	E	N	Y / N		Y / N	Y / N					
Notes:											
B	E	N	Y / N		Y / N	Y / N					
Notes:											
B	E	N	Y / N		Y / N	Y / N					
Notes:											
B	E	N	Y / N		Y / N	Y / N					
Notes:											
B	E	N	Y / N		Y / N	Y / N					
Notes:											
B	E	N	Y / N		Y / N	Y / N					
Notes:											
B	E	N	Y / N		Y / N	Y / N					
Notes:											
B	E	N	Y / N		Y / N	Y / N					
Notes:											
B	E	N	Y / N		Y / N	Y / N					
Notes:											
B	E	N	Y / N		Y / N	Y / N					
Notes:											

1 Bass Size Codes: U - Unknown; S - Small <35cm (13.5"); M - Medium 35-45cm (13.5" - 18"); L - Large >45cm (18")

2 Substrate Codes: SC - silty clay; S - Sand; G - Gravel; P - Pebble; C - Cobble; B - Boulder; BR - Bedrock; O - Organic; FWD/CWD - Fine/Coarse Woody Debris

3 Algae Cover Classes: 0 (not present); 1-5% (Trace); 6-25%; 26-50%; 51-75%; 76-100%

Appendix E - Water chemistry parameters sampled during 2015.

Chlorophyll "a"
Phosphates (as P)
Total Dissolved Solids
Total Phosphorous
Total Suspended Solids
Total Nitrogen
Calcium
Potassium
Magnesium
Sodium
True Colour
Dissolved Organic
Carbon
Hardness (by calculation)
Chloride (IC)
N-NH4+NH3
Nitrite NO2-N (IC)
Nitrate NO3-N [IC]
Sulphate (SO4) [IC]
Total Solids
pH
Total Alkalinity as CaCO3
Conductivity