Effects of Watershed Characteristics and Disturbance History on the Water Quality of Lakes in Eastern Manitoba

A Final Report Submitted to the Sustainable Development Innovations Fund and the Manitoba Model Forest

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SDIF Project: Water Quality on the East Side of Lake Winnipeg (#24020)

TABLE OF CONTENTS:

Introduction

The eastern side of Lake Winnipeg is a vast area of largely untouched boreal landscape, part of the largest intact Boreal Forest remaining in the world. This landscape is rich in natural resources and contains a myriad of aquatic habitats including lakes, wetlands, rivers, streams and creeks. The region is an important economic, recreational and traditional land use area supporting, forestry, mining, recreational and food fishing as well as cottage development. Deteriorating water quality is becoming an increasing concern in Manitoba. This has become particularly evident in Lake Winnipeg however this is also a concern for other areas. The water quality of Lake Winnipeg is directly affected by the quality of water entering the lake from all areas of its large watershed. Unfortunately, due to the inaccessibility of much of the east side of Lake Winnipeg, baseline data is very scarce. In particular, information on water quality is largely restricted to a few of the largest rivers (Poplar, Pigeon, Berens and Bloodvein) and is almost non-existent for lakes in Ecoregion 90 (EBM Science Team Report, 2002). Monitoring programs on some of the rivers (e.g., Manigotagan, Black) have been discontinued many years ago, and water quality information on lakes has only been collected on a handful of lakes (primarily where cottage subdivisions exist) with most sampling programs carried out in the 1970s and 1980s. Lack of baseline information makes it impossible to gain insight into whether water quality has changed over time and what factors may influence water quality. Management decisions concerning land use practices are difficult in the absence of such vital information.

In addition to a lack of baseline data, our understanding of what controls water quality in boreal shield water bodies is limited. Water quality in a water body is a direct reflection of the characteristics of the watershed, both in terms of structure and processes. Watershed characteristics such as soil and forest cover type (e.g., rock outcrops vs. wetland, conifer vs. hardwood forests, deep organic soils vs. shallow luvisols), watershed size, to name a few, may have a profound effect on the water chemistry of a water body. In addition to the physical and chemical attributes of a watershed, disturbance regimes, including wildfire and logging have been shown to have an impact on water quality, although this impact is usually transitory.

Based on the above, our 2 year project had the following objectives:

- To determine baseline conditions of the water quality of lakes in the region
- To identify the factors influencing water quality in lakes in eastern Manitoba so human activities can be better managed to promote sustainable development

- To develop tools for forest management planning which provide for the maintenance of water quality
- To identify candidate lakes for long-term monitoring

Results and Discussion

Our water quality project included a survey of lake water quality that was conducted as part of a MSc. degree for Kevin Jacobs at the University of Manitoba. Mr. Jacobs has just completed his MSc degree and was supervised by Dr. Gordon Goldsborough, Department of Botany. Mr. Jacobs was supported through an NSERC-Industrial Post Graduate Fellowship, with funding from both NSERC and Tembec Industries (Pine Falls Operations). The second, related component involved a survey of river and stream water quality and hydrology. This component was conducted under the guidance of Dr. Brian Kotak (Miette Environmental Consulting Inc) with the help of the Environment Department of Black River First Nation. **This report focuses on the results of the lake surveys in 2004 and 2005, along with the results of the data analysis. A final project report that summarized the river and stream survey work from 2004, as well as a technical report (Kotak, B.G., A. Selinger and B. Johnston, 2005) has been produced - "Influence of watershed features and disturbance history on water quality in Boreal Shield streams and rivers of eastern Manitoba" (Manitoba Model Forest Report 04-2-63) and were submitted to SDIF previously. As part of the funding agreement between SDIF and the Manitoba Model Forest, a separate final report is being produced for the river and streams component covering the field surveys conducted in 2005.**

The field research part of the lake component of the project occurred over 2 years (2004 and 2005).

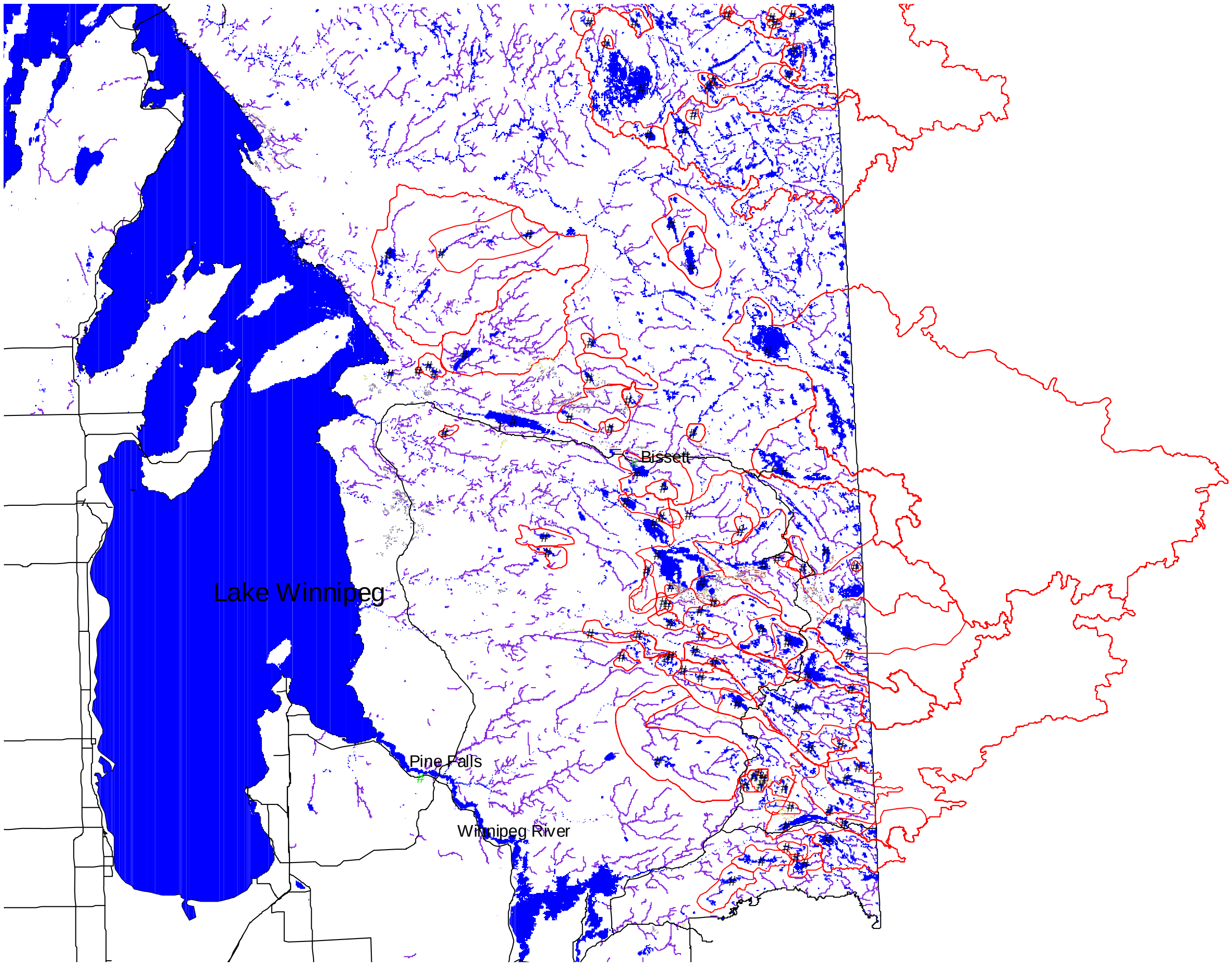
The project will result in several publications (both peer-reviewed journal publications and Manitoba Model Forest reports), as well as an MSc. thesis. The MSc thesis will be completed in 2006, with peer-reviewed journal publications to follow.

Lake Water Quality:

Background:

The water quality of approximately 100 lakes was sampled by means of a float plane in a geographic area along the east side of Lake Winnipeg from the northern portion of Whiteshell Provincial Park to, and including, Atikaki Wilderness Park. In 2005 approximately 28 of these lakes were sampled in the spring, summer and fall. For many of the lakes in the survey, it was the first time that water quality data has ever been collected, thus providing important baseline information.

Lakes were selected using aerial reconnaissance and GIS layers of disturbance history and an evaluation of existing water quality data. An aerial reconnaissance flight took place on July 8, 2004. Lakes selected targeted a broad range of watershed features, lake sizes and land use practices in this region. Of these lakes, 12 had extensively harvested watersheds as evidenced by aerial observations. Including these, 24 lakes have harvesting in their catchments as indicated by GIS data from 1983-2003. Approximately 20 lakes had burned watersheds with several recent burns in the northern portion of the study area in the proximity of Dogskin Lake and Sasaginnigak Lake. Two lakes (Rice Lake near Bissett and Bernic Lake) have mining operations located on their shores. Approximately five of the lakes sampled had extensive cottage developments. There were fishing lodges and outposts on several of the northern lakes.



Map 1: Study lakes and their associated watersheds. Black dots represent sampling locations in 2004. Note: 25 of the 99 lakes sampled in 2004 had at least portions of their watershed originating in North Western Ontario.

Methods:

Year 1: Summer 2004

Sampling was generally conducted at the deepest location or centre of each lake unless weather conditions and/or safety necessitated anchoring at a wind protected location. The anchor was lowered gently taking care not to disturb the sediment.

Sampling occurred in 99 lakes from the pontoon of a float equipped Piper Super Cub aircraft between July 26th and August 11th 2004 (see Map 1 for the locations of each lake). Water samples were collected using an integrated column sampler with a one way check valve to a depth of approximately 2m (this was reduced where warranted by shallow conditions). Both the sampler and sampled bottles were triple rinsed before sampling each lake. One sample was collected at each site with triplicate samples at approximately every 15 lakes. Water samples were collected in 500ml Nalgene bottles and were kept on ice in the dark and transported by courier for analysis. Samples were analysed in Winnipeg at the analytical labs of the Fresh Water Institute (Fisheries and Oceans, Canada) according to standard methods.

Analysis included: dissolved nitrate/ nitrite, suspended nitrogen, total dissolved nitrogen, suspended phosphorus, total dissolved phosphorus, dissolved inorganic carbon, suspended carbon, dissolved organic carbon, chlorophyll *a, c*hloride, sulphate, sodium, potassium, calcium, magnesium pH, conductivity and alkalinity.

Additional surface water samples were collected in pre-acidified containers for trace metal analysis of lake water. Triplicate samples were collected at approximately every 10 lakes. These samples were sent to the Ultra Clean Trace Elements Laboratory at the University of Manitoba and are currently pending analysis. Anticipated analysis include concentrations of Ag, Al, As, Ba, Be, Bi, Ca, Cd, Co, Cr, Cs, Cu, Fe, Ga, In, K, Li, Mg, Mn, Na, Ni, Pb, Rb, Se, Sr, Tl, U, V, Zn (by ICP-MS).

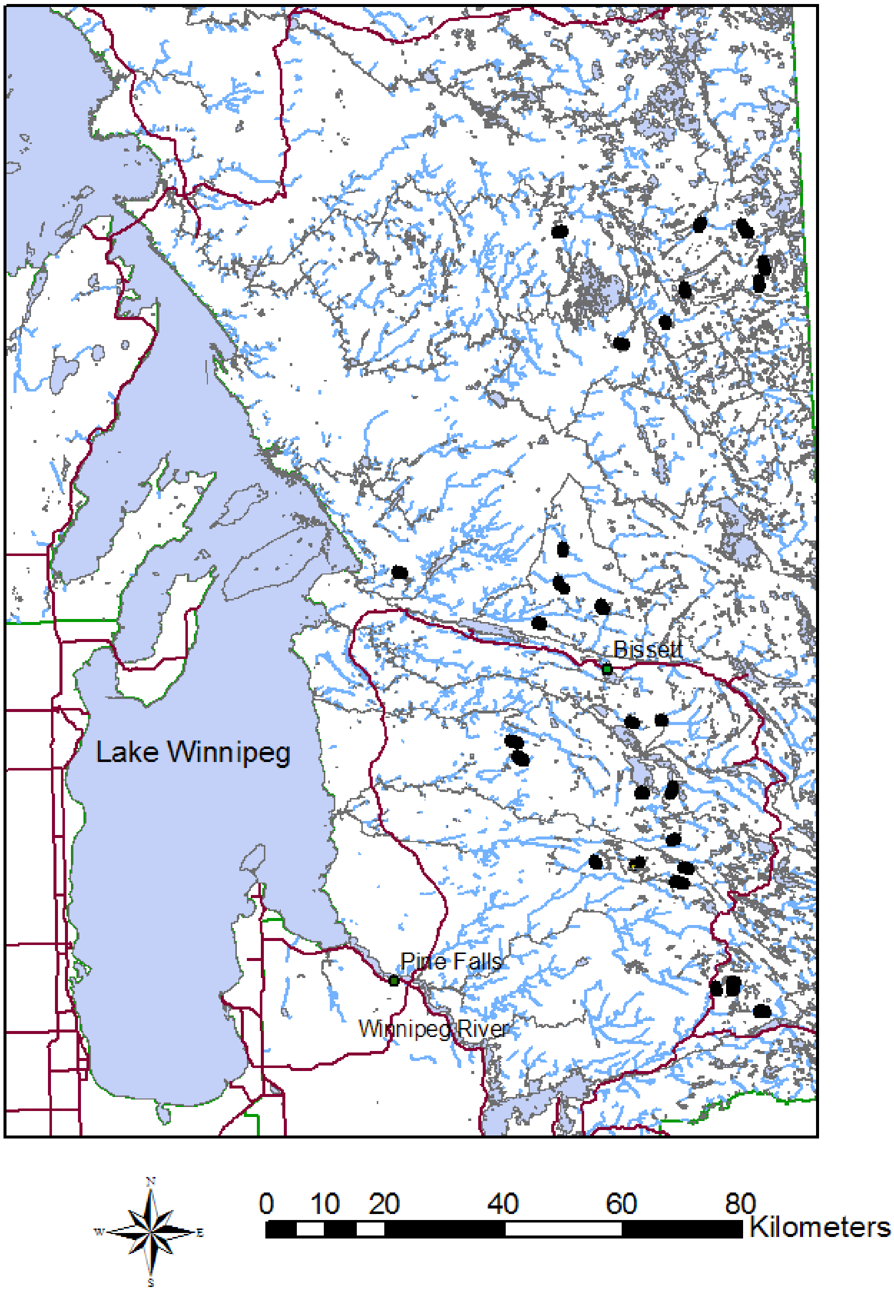
One phytoplankton sample from each lake was collected for species identification using several vertical hauls of the phytoplankton net. The net was rinsed twice before sampling each lake to prevent cross-lake contamination of samples. Phytoplankton samples were preserved to a final concentration of 2-4% formalin these were sent to Dr. Gordon Robinson at the University of Manitoba for species identification.

Secchi disk depths were collected for each lake using a 20 cm diameter Secchi Disk. Readings were taken from the pontoons of the aircraft in the shade of the aircraft wings. Light measurements were collected at 1 metre intervals using a Licor LI-193 spherical underwater sensor (Licor Biosciences, Lincoln, Nebraska U.S.A) attached to a frame that was lowered at metre intervals. Measurements were taken on the sunny side of the aircraft. The cable was held as far away from the pontoon as possible to avoid interference of the wings or pontoon with the measurement. Shading by the wing of the aircraft and the tendency of the aircraft to weathercock made taking consistent light extinction profiles difficult. In addition, dissolved oxygen, conductivity and temperature measurements were collected at 1 metre depth intervals using YSI Model 85 conductivity/ salinity/ oxygen probe with a 15 metre cable (YSI incorporated Yellow Springs, Ohio U.S.A). The tendency for the aircraft to drift even with an anchor made taking consistent profiles difficult. pH was measured in the field using a Fisher Accumet® AP61 portable pH meter.

The location and depth of each site was recorded using a Garmin (GPS Map 168) sounding GPS. Basic bathymetric data were collected for each lake by transecting along one axis of each lake and marking waypoints at approximately 100 metre intervals. Shoreline and disturbance observations were made for each lake when circling from the air.

Year 2: May-September 2005:

A subset totalling 28 of the 100 lakes sampled in 2004 were selected for study in 2005. Headwater lakes were selected to reduce possible upstream influences. Of the watersheds of these lakes, 12 were harvested, 9 were burned by forest fire and 7 were reference). Due to a change in the aircraft from a float equipped Piper Supercub to a Cessna 172 with the increased takeoff and landing area required some of the smallest lakes from the sampling regime had to be eliminated. In total 23 lakes were sampled inclusively in May, August and September.



Map 2: Samples sites in 2005. Sampling in 2005 took place in May, August and September. Black dots represent May sampling locations on each lake.

Sampling took place at three locations on each lake in May (May 20-26), and single central locations in August (August 7-13) and September (18-22). Sampling consisted of raw water for chemical analysis, conductivity, temperature and oxygen profiles, Secchi depth measurements and light extinction profiles. An equipment malfunction prevented light extinction readings in August and September. Sampling methods were as in Year 1. Water samples were delivered to Enviro-Test Laboratories in Winnipeg for analysis of total dissolved phosphorus, total phosphorus, ammonia, dissolved organic carbon, total Kjeldahl nitrogen, total suspended solids, turbidity, pH, total dissolved solids, sulphate soluble, nitrate + nitrite, calcium- extractable, potassium-extractable, magnesium-extractable, sodium-extractable, hardness (as $CaCO_3$), conductivity, chloride soluble, and alkalinity according to standard methods. Samples for metals (calcium, potassium, magnesium, and sodium) were preserved in the field with the addition of 2.5ml 20% nitric acid.

Photo 1: Kevin Jacobs sampling Farrington Lake water from float of Piper Super Cub

Additional water samples were filtered in the field (Whatman GF/C Glass microfibre catelogue No. 1822 042). Filters were frozen for chlorophyll analysis and were analysed by methanol extraction according to the method of Marker et al. (1980). The filtrate was retained for analysis of dissolved organic carbon.

Additional raw water samples were collected in 100ml HDPE bottles for analysis of microcystin L-R. MC-LR samples were analyzed by AlgalTox International, Pine Falls, MB.

One phytoplankton sample from each lake was collected for species identification using several vertical hauls of a phytoplankton net. Phytoplankton samples were preserved by formalin injection to a final concentration of 2%-4%.

Data Analysis:

Watershed boundaries for each lake were determined from 1:50,000 NTS maps and the Prairie Farm Rehabilitation Program's (PFRA) draft subwatershed boundaries for Manitoba. These were then digitised into a geographic information System (ArcView GIS version 3.2 ESRI, 1999). Watershed areas were calculated using the X-tools extension (Oregon Department of Forestry 2003). Percent disturbance for each watershed was determined by intersecting digitized watersheds with GIS layers of disturbance history maintained by the Tembec Paper Group, Pine Falls Operations. Areas of recent and historical disturbance from forest fire, forest harvesting and insect and disease were determined for each watershed. Where watersheds originated in Ontario, this disturbance information was not available. Data analysis concerning watershed features excluded these watersheds.

Lakes were grouped based on watershed disturbance history into 7 classes.

- Lakes with watershed harvesting within the last five years,
- Lakes with watershed fire within the last five years
- Lakes with watershed harvesting within last 15 years
- Lakes with watershed fire within the last 15 years
- Old harvests including watersheds with harvest disturbance older than 15 years
- Old fires including lakes with watershed fire older than 15 years (for example, the 1980 and 1987 Wallace lake fires).
- Reference watersheds having no recent harvest or fire disturbance history in the last 60 years.

Watershed features such as the type of wetlands and forest type were delineated for each watershed from the Manitoba Forest Resource Inventory (1997). For lakes in Atikaki Provincial Wilderness Park, the most recent Forest Resource Inventory dated from 1983. **Land type** and **Subtype** classifications were used to determine the percent of each landtype, e.g. (Jackpine, Black Spruce, Beaver Floods, Black Spruce Treed Muskeg, Bare Rock and Will Alder). The areas from the categories Muskeg, Black Spruce Treed Muskeg, Beaver Flood, Marsh and Will Alder were merged, producing a measurement of the total percentage of wetlands in each watershed.

Soils data were obtained from the 1:1,000,000 Enduring Features GIS database developed by the World Wildlife Fund (1997). Soils are classified into broad categories including:

- BR/D bedrock/dark grey chernozem, BR/F- bedrock/grey brown luvisol, BR/R2- bedrock/ acidic hard rock, BR/Y23- bedrock/ organic mesisol
- DB/D deep basin/ dark grey chernozem, DB/F- deep basin/ grey brown luvisol DB/R2- deep basin bedrock/ acidic hard rock, BR/Y23- bedrock/ organic mesisol
- GD/R2 glaciofluvial deposit/ acidic hard rock
- OD/D organic deposit/ dark grey chernozem, OD/F – organic deposit/grey brown luvisol, OD/R2- organic deposit/ acidic hard rock, OD/Y23 – organic deposit/organic mesisol
- T3/R2 glacial till derived from Precambrian rock/ acidic hard rock

The extent of forest harvesting and forest fire within each watershed was determined from the four databases. **Forest fire** disturbance was broken into two datasets. The location of historical fires was determined from the fire history database 1881 to 1971 maintained by Tembec. This database was created from fire history maps and provides the general locations of major fire events. More recent fire distribution has been collected digitally since 1976. This database is updated annually and was used to determine the locations of forest fires since 1976.

The extent of **forest harvesting** was determined from two databases. The historical harvesting GIS database was generated through old harvest history maps (1950's to 1985) and provides the approximate locations where forest harvesting took place. Newer harvest information like the fire history has been digitally collected since 1976 and is updated annually.

Mechanical site preparation data since 1994 was used to determine the extent and type of mechanical site preparation in each harvested watershed.

The scale of intensity of **insect disturbance** by Forest Tent Caterpillar (*Malacosoma disstria)* and Spruce Budworm (*Choristoneura fumiferana)* was determined for each watershed. Since 1995 information on the extent and severity of insect disturbance has been collected digitally and updated annually.

Results:

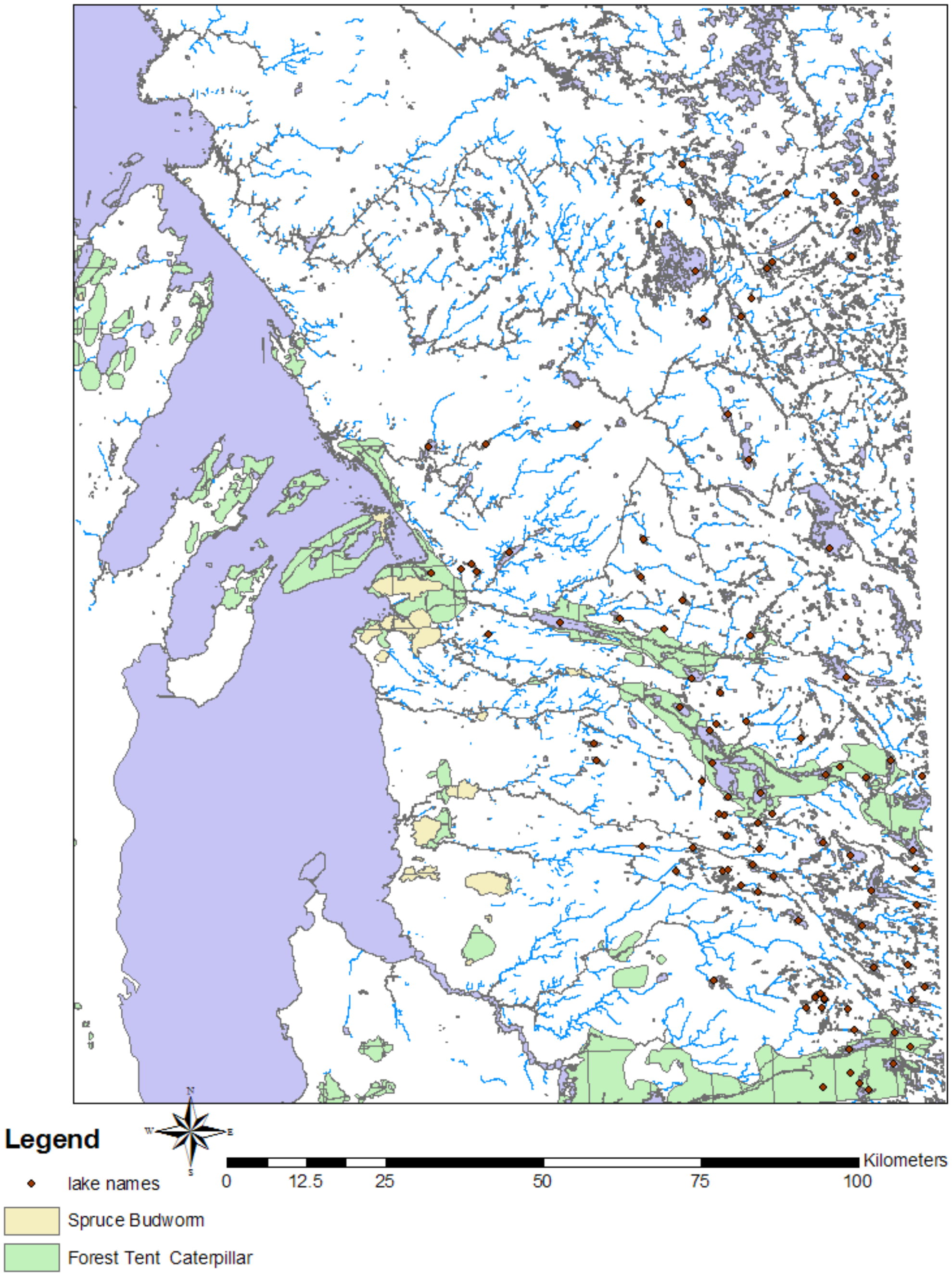
Watershed Features:

Fire:

Fire disturbance typically affects a large proportion of a watershed. Within the period 1998-2003 one watershed was completely burned while another watershed had 84% of its area burned. In the last 35 years, eleven watersheds have been completely burnt by forest fire. Of these, it appears seven have been affected by more than one fire (for example 100% of watershed 54 was burned by fire in 1989 and 40% of the area was re-burned in 1999). Fire is a significant natural ecological process in this region. Historical fire data indicates only 11 out of 99 watersheds have had less than five percent of their area burned since records began in 1885. As of 2005, recent fires taking place since 2000 of are restricted to the northern section of the study area.

Insect and Disease:

Insect infestations and disease outbreaks can result in significant losses or merchantable timber, decreased property values and, in some cases, result in the decimation of a tree species. No evaluation on whether insect and disease outbreaks in a watershed have an impact on water quality has been conducted. The two most common insect pests in the study area are deciduas specific Forest tent caterpillars (*Malacosoma disstria*) and the coniferous specific Spruce budworm (*Choristoneura fumiferana*). Forest tent caterpillar infestations have occurred in 28 of out 99 watersheds which affected on average 35% of each watershed in the period 1998 to 2003 (range 0.1% to 159%). Insect outbreaks often reoccur in a watershed. The Badou Lake catchment had forest tent caterpillar outbreaks in 1998, 1999 and 2000, which, accumulated to over 100% of the watershed area. Outbreaks of forest tent caterpillar are primarily observed along the major river systems (Bird, Manigotogan and Wanipigow). Map 3, demonstrates that insect infestations appear to parallel watercourses and developed areas. There are no observations north of the Wanipigow Lake watershed. This could be due to the remote nature of many of the watersheds where either insect outbreaks have not occurred or more likely monitoring has not taken place. Many of the effected watersheds appear to have been subject to repeat disturbance.



Map 3: The distribution of spruce budworm and forest tent caterpillar infestation. Forest tent caterpillar infestations appear along major river systems and developed areas.

With respect to spruce budworm, 26 watersheds have evidence of spruce budworm occurrence affecting twelve percent of the watershed area (range <1%-92%). Of the watersheds containing spruce budworm infestation 23 out of 26 also harbor forest tent caterpillar populations. The average basal extent of insect damage from either spruce budworm, forest tent caterpillar or both, is 44% of the watershed area (<1% to 191%). Given the mean is highly affected by repeat insect infestations, the median area of insect damage may be more appropriate and is 24%

Forest Harvesting:

Though extensive watershed harvesting began in the 1950's, recent harvests (2002-2003) are concentrated north of Bird Lake, west of Happy Lake, north of Wanipigow Lake, in the Rainy Lake area, and Maskwa Lake. Most active forest harvesting is concentrated outside of Nopiming Provincial Park while no historical or active harvesting has occurred in Atikaki Wilderness Park.

Extensive river systems connect many lakes. Although these lakes may have active watershed harvesting in close proximity to the lakeshore, the relative proportion of the watershed disturbed in many cases is small.

Generally, forest harvesting in the last five years has removed a low percentage of each watershed. Recent forest harvesting has generally been below 10% of the watershed area with the exception of harvesting north of Bird Lake in the Eastland Lake watershed (22%) and the Kinsley Lake watershed (13%).

In contrast, in the last 35 years as much as 70% of the watershed area was logged for two watersheds (Blue Lake and Rush Lake) while seven watersheds experienced logging of approximately 50% of the catchment area.

Mechanical Site Preparation:

Mechanical site preparation is often an important process needed for forest renewal in silviculture applications. However, site preparation has been observed to cause water quality changes in Finnish lakes (Rask et al. 1998). Mechanical site preparation utilized on the forest management lease includes drag chains, barrels, disk trenching, and shear blading. Disk trenching and shear blading cause the greatest disturbance to soil and are typically used to regenerate a black spruce dominated forest. Drag chains have been found effective as a means of seed disbursal in what was formerly Jack Pine dominated stands. Of the study watersheds, 18 have been subject to mechanical site preparation in support of silviculture operations. This has been accomplished predominantly through drag chains, disk trenching and shear blading. On average, mechanical site preparation in the last ten years has effected approximately three percent of the area of prepared watersheds. In the Saxton Lake watershed however, site preparation (disk trenching) between 1994 and 1999 occurred on approximately twelve percent of the watershed area.

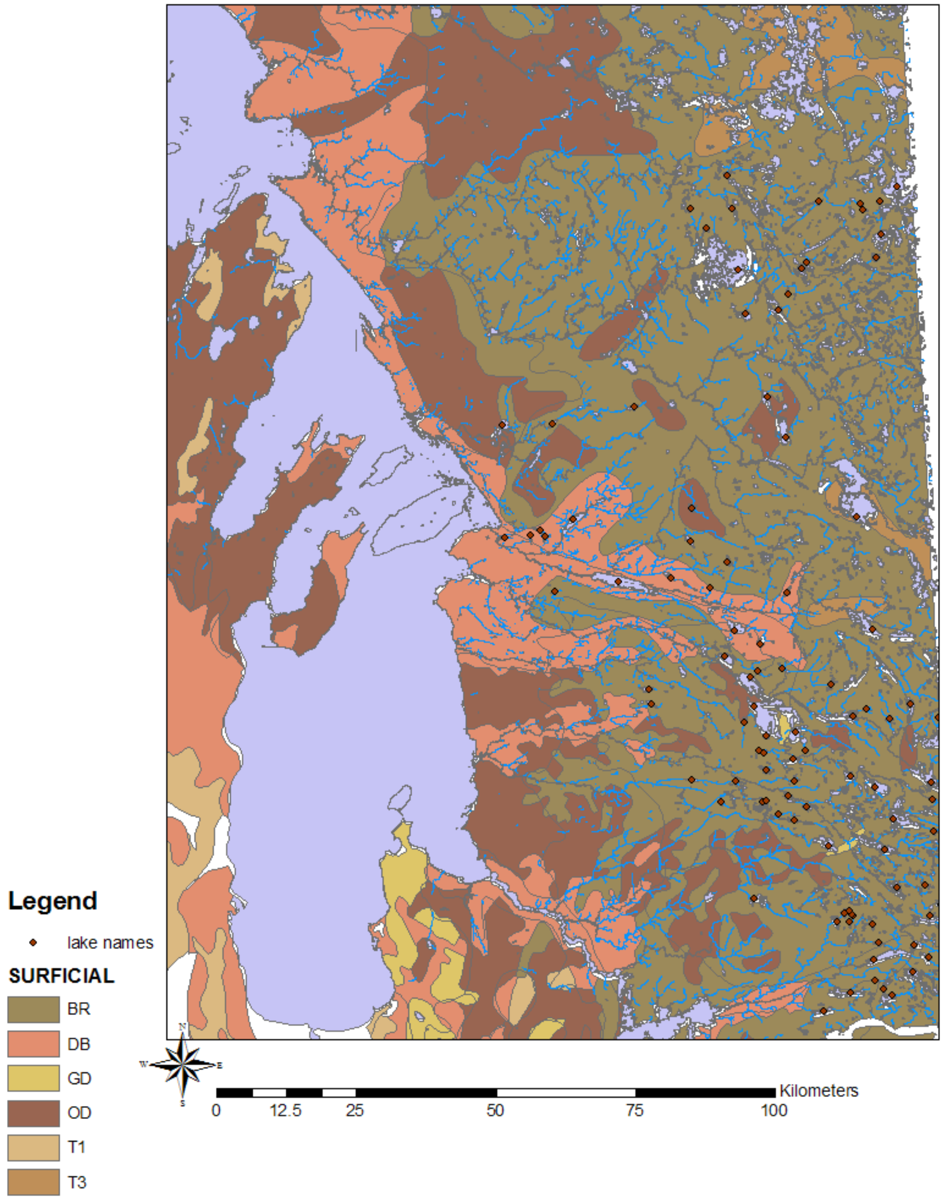
Soils:

Soils of this region are typical of the Canadian Shield ecozone and are dominated by granitic bedrock. The majority of watersheds were dominated by acidic bedrock (BR/R2). Due to missing data for Ontario the watersheds from Ontario had to be excluded from the soils analysis. In fact, only 5 of 74 watersheds not originating in Ontario were not dominated by bedrock soil. These included Okimaw Lake, Lake 96, Gold Lake and the Dawson and Boulette watersheds.

The watershed soil composition of Dawson, Boulette, Gold Lake and Lake 96 were dominated by deep basin acidic bedrock (DB/R2). The Okimaw Lake watershed was dominated by organic deposit acidic rock (OD/R2).

Soil conditions observed in the study area also included gaciofluvial deposit acid hard rock (GD/R2) and glacial till, resulting from Precambrian rock/ acidic hard rock (T3) though these categories never exceeded four percent of any watershed.

The north and east of the study area are dominated by acidic bedrock. Further west towards the shores of Lake Winnipeg and south west of the study area an increased prevalence of deep basin and organic soils becomes evident. In the Wanipigow lake region a band of deep basin soil extends from south of Wanipigow lake to Lake Winnipeg (Map 4).



Map 4: Distribution of soils in the study area. BR= bedrock dominated soils, DB= Deep Basin Soils, GD=glaciofluvial deposit/ acidic hard rock, OD= Organic Deposits, T3=glacial till derived from Precambrian rock

Forest Resource Inventory:

The majority of the watersheds are dominated by coniferous species (Jackpine, Black Spruce). On average, Jackpine occupies 46 percent of the study watersheds. However, this was 88% for L38. Black Spruce ranges from an average of 9% to a high of 46% of a watershed area. The non productive categories Muskeg, Black Spruce Treed Muskeg, Beaver Flood, Marsh and Will Alder were merged, producing a measurement of the total percentage of wetlands in each watershed. On average, wetlands of this type occupied 19% of the watershed area. However, the Okimaw lake watershed had a wetland percentage of 43%.

Physical Characteristics of the Lakes:

Watershed Size:

Watersheds in 2004 ranged in size from 64 hectares to over 200,000 hectares. In 2005 watershed size ranged from 19 hectares to 6,700 hectares (Table 1). Sampling in 2005 focused on smaller headwater lakes which typically had smaller watersheds.

Lake Size:

Lakes sampled in 2004 represented a large range of lake sizes, depths and characteristics (headwater lakes versus lakes on major river systems). Lakes ranged from shallow wetlands to deep meteor impact lakes. The goal of 2004 was to gain an understanding of baseline conditions in a wide cross section of lake types. Time constraints and the size of some lakes made detailed sounding beyond the scope of this work. Lake size in 2004 ranged from 10.5 hectares to 4395 hectares. In 2005 lake size ranged from 10.5 hectares to 504 hectares. Average lake size was 106 hectares in 2005 and 349 hectares in 2004 (this is result of the focus on smaller headwater lakes in 2005)

Watershed to Lake Area Ratio:

The watershed to lake area ratio or drainage ratio is typically a measure of the flushing/ renewal time of a water body. It is expected that lakes with high drainage ratios will be more sensitive to disturbance in the watershed. Watershed to lake area ratios are represented in Table 1.

Lake Depth:

There is wide range of approximate lake depths in this region from less than 1 metre to approximately 25 metres (Table 1). Lakes sampled in 2005 represented a wide range of average depths from 1.8 meters to 14.9 meters. Maximum depths at each lake recorded ranged from 2.2 meters to 20.5 meters.

Water Clarity:

Photic Depth:

The photic depth as calculated by the depth below the surface at which incident solar photic available radiation (PAR) reaches one percent ranged from 0.9 to 11.9 meters.

In many of the shallow lakes sampled in 2004, the photic depth was greater than the actual depth at the sampling site indicating a capability for photosynthetic growth throughout the entire water column.

Photo 1: Pilot Chad Bayes measuring light extinction

Light extinction profiles in 2004 indicated that the photic depth exceeded the depth of the sample site in 17 out of 99 lakes. Many of these shallow lakes support extensive submergent macrophyte communities. Wildrice is an abundant and economically important resource in many of these shallow lakes.

Concerning watershed disturbance, lakes sampled in 2004 with recent and historical watershed fire had the lowest photic depths i.e. the light extinction coefficient was highest in these lakes. Lakes with watershed harvesting showed the next lowest photic depths, followed by "reference" lakes without recently disturbed watersheds. These results were not supported by Secchi depth readings.

Secchi Depth:

Secchi depth in 2004 ranged from 0.75m to 4.84m. Mean secchi depth was highest in lakes with watershed fire and lowest in lakes with watershed harvesting (Figure 1). However, these differences were not significant. Lakes with recent watershed fire, having the highest secchi depth, are located in the north of the study area and the observed differences may be due to geographic location and different soil and geologic conditions in the northern watersheds.

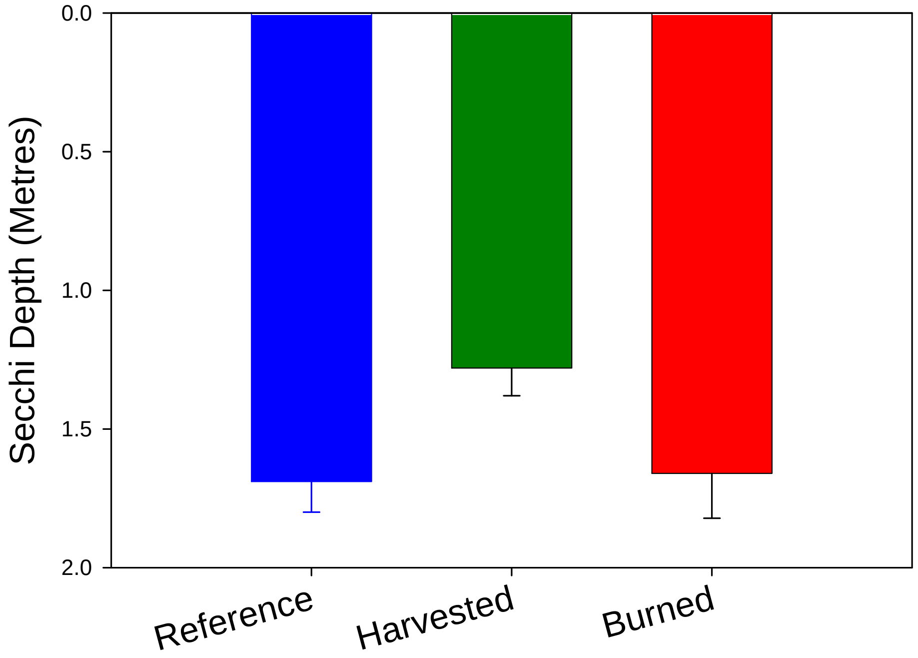


Figure 2: Mean 2004 Secchi Depth +/- Standard Error

Secchi depth in 2005 ranged from 0.28 to 2.58 metres. The lowest Secchi depth was measured in shallow Lake 43 on an extremely windy day. It is likely the wind and wave action causing re-suspension of sediment, was responsible for this low Secchi disk reading.

Water Chemistry Results:

Total Phosphorus:

Phosphorus load is typically the primary determinant of productivity in Boreal Shield lakes where the nitrogen to phosphorus ratio can influence the composition of algal populations (Schindler 1977).

Total phosphorus concentrations for the 99 lakes in 2004 ranged from 5 µg/L to 76 µg/L, with a mean of 18 µg/L. Total phosphorus values were highest in Saxton Lake, Farrington Lake and Badou lake at 76, 42 and 39 µg/L respectively. It is interesting to note that watershed harvesting of these three lakes occurred in the early to mid 1980's. A number of lakes shared low concentrations of total phosphorus in 2004 (less than 10 µg/L). These included Birse Lake, Terminal Lake, Lost Claim Lake, Gordon Lake, Lake 79, Aikins Lake, Lake 89, Lake 90, Peacock Lake, Lake 6, Lake 38, and Bird Lake. The majority of these lakes are reference lakes having less than 30% total disturbance within the last 60 years.

Average concentrations observed in 2005 ranged from 12 to 36 µg/L, As in 2004, the highest concentrations were observed in Saxton Lake.

Total Nitrogen:

Total nitrogen varied throughout the region and generally paralleled trends in total phosphorus. Total nitrogen ranged from 392 µg/L to 1478 µg/L. The mean total nitrogen concentration was 721 µg/L. High concentrations of total phosphorus did not always correspond with high nitrogen concentrations (r=0.77). For example, Farrington Lake had the second highest concentration of total phosphorus but had the ninth highest nitrogen concentration. Total nitrogen was highest in Saxton Lake, Badou Lake and Lake 43.

Dissolved Organic Carbon:

Dissolved organic carbon is one of the key determinants of the ecology of Boreal Shield lakes (Schindler et al. 1992, 1997). Dissolved organic carbon is responsible for giving lake water a brown-tea like appearance. Most dissolved organic carbon derived from the drainage basin of a lake where a primary source is often wetlands, (peatlands, bogs and fens). DOC is also extremely important as an energy source in stream systems to the microbial community and regulates many of the thermal and optical properties of lake water (Fee et al. 1996). Higher DOC in harvested systems increases light extinction coefficients (Lamontagne et al 2000). DOC export from a watershed may also transport contaminants such as mercury into lakes (Garcia and Carignan 1999). Dissolved organic carbon in 2004 ranged from 630 μg/L to 3300 μg/L with a average concentration of 1500 μg/L.

Chlorophyll *a:*

Chlorophyll *a,* an indicator of algal biomass, ranged from 2 μg/L to 47 μg/L. The highest concentrations were observed in Saxton Lake followed by Badou Lake at 28 μg/L. In many of the lakes algal blooms were observed to occur (Photo 1) and blooms were observed in many cases in remote lakes with no indication of human or natural watershed disturbance.

Photo 1: Bloom of phytoplankton in Walton Lake observed from the air in September 2004. Note: Walton Lake was not one of the study lakes. Photo credit Brian Kotak.

Total chlorophyll combined with total phosphorus is used as an indicator of the trophic or nutrient status of a lake. Water quality results from 2004 indicate that overall the water quality of the region is quite good. The majority of the lakes can be categorised as oligotrophic to mesotrophic (Figure 3). A number of the lakes can be classified as eutrophic. It is interesting to note that of the eutrophic lakes, 39% of their watersheds have experienced forest fire between 1980 and 2002 and 56% of the eutrophic lakes have experienced watershed harvesting between 1968 and 2004. Only two of these lakes have had watersheds harvested within the last five years. The influence of watershed disturbance on the water quality of the region will be discussed further below.

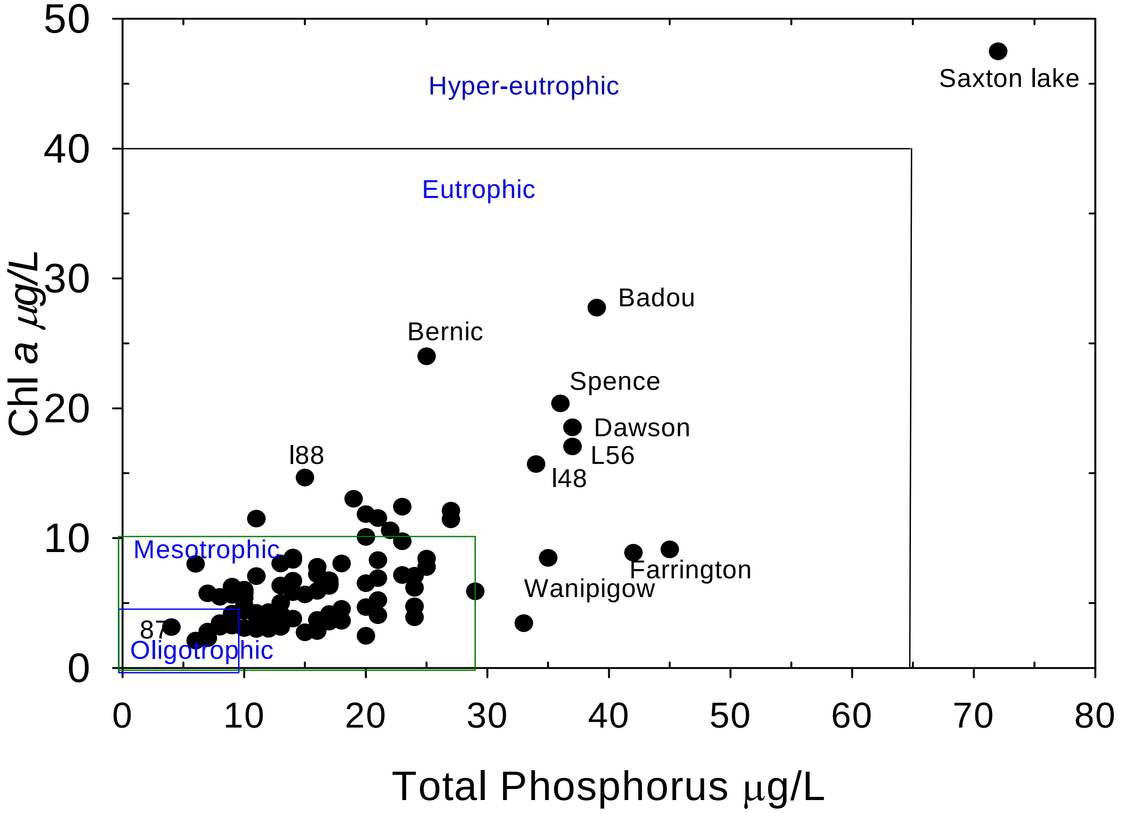


Figure 3: Trophic status of study lakes in 2004. Of the eutrophic lakes, the majority of watersheds were historically subjected to either watershed fire or watershed harvesting. Note: criteria from Carlson (1977)

Microcystin-LR

Water samples for microcystin were collected from three sites on each lake in May, 2005 and at a single, central site in August and September, 2005. Water samples were analyzed at the analytical laboratory of AlgalTox International (Pine Falls, MB) using a colorimetric protein phosphatase inhibition assay. Water sample were prepared for analysis by disrupting the cells using an ultrasonicator, followed by filtration though Millipore 0.45 um nitrocellulose filters. The microcystin results reported here present the total toxin concentration of dissolved (aqueous) and cell-bound toxin. The detection limit for this method was 0.100 ug/L (100 ng/L), and results are reported as total microcystin-LR equivalents.

Microcystin-LR was detected in lake water samples, although the proportion of samples containing detectable concentrations of the toxin was low (23 of 123 samples, 19%). In addition, concentrations were also low (seasonal mean of all lakes of 0.24 ug/L). Maximum concentrations were 0.85 ug/L in May, 0.48 ug/L in August and 0.70 ug/L in September. These concentrations are significantly below the Health Canada drinking water guideline level of 1.5 ug/L and significantly below any concentrations which would indicate a risk to recreational contact use, ad determined by the World Health Organization recreational contact guidelines. Higher microcystin concentrations have been reported in more productive, prairie water bodies, including lakes, dugouts and rivers, in Manitoba (Jones et al., 1998a,b; Jones, 1999) and in Alberta (Kotak et al., 1996, 2000). The low concentration detected in our study lakes in 2005 may reflect the fact that many of the lakes do not have very high concentrations of TP, usually support only low levels of algal biomass and have a fairly high N:P ration (35 – 70). Previous work in Alberta has shown that both the frequency of occurrence of microcystin-containing algal blooms and the concentration of microcystin-LR increases with increasing TP concentration, and decreasing N:P ratio (Kotak et al., 2000)

Spatial Variation within Each Lake:

May 2005 samples, which were taken at three locations within each lake, indicate that the central sampling site of 2004 was representative of the overall water quality. Only site C on Lake 92 had total phosphorus and nitrogen concentrations that were significantly different from sites A or B. Site C was considerably more shallow at 1.3m versus >2m for A or B. The higher observed nutrient concentrations may be indicative of the shallow nature of this site and potential for re-suspended sediment entering the water samples.

Seasonal Comparison 2005:

Concerning seasonal variation within each lake, several trends can be observed. On average, total phosphorus and total dissolved phosphorus increased in concentration through the open water season. Total nitrogen concentration was highest in August and May samples and decreased substantially on average in September samples. Total dissolved solids and sulphate increased substantially on average through the open water season whereas only slight increases in hardness and calcium occurred. Alkalinity decreased in August from May levels and rebounded in September. Changes observed in TP from May to September were significant at ($p<.01$). Total nitrogen increased significantly from May to August however, the overall total nitrogen in September was not significantly different from May.

Note: At the time of writing, final results for 2005 chlorophyll concentrations and dissolved organic carbon are forth coming. All the results will be addressed in detail in the thesis to be completed in the spring of 2006.

Comparison Between 2004 and 2005:

A change in analytical labs used and different techniques of analysis make direct comparison of 2004 and 2005 data difficult. With that said, total dissolved phosphorus and total phosphorus were almost consistently higher in lakes sampled in 2005 versus the same lakes sampled in 2004. Total nitrogen concentrations showed the same trend. Concentrations of metals, (sodium, potassium, calcium, magnesium) and conductivity did not differ appreciably from 2004 to 2005.

Relationships Between Watershed Features and Water Quality:

Watershed Size:

Watershed size did not appear to correlate with any key water quality variable. Watershed size was positively correlated with many key water quality variables though none of these correlations were statistically significant.

Table 2: Pearson product moment correlation coefficients and *P* values between watershed size and various water quality parameters measured in 2004.

Water Quality Parameter	**r**	**P value**
Secchi Depth	-0.17	NS
NO_3	0.25	NS
TDN	0.25	NS
TN	0.17	NS
TDP	0.28	NS
TP	0.16	NS
DOC	0.17	NS
Chlorophyll *a*	-0.03	NS
SO_4	-0.04	NS
PH	0.18	NS
Alkalinity	0.17	NS
Ca	0.15	NS
Conductivity	0.15	NS

P values: NS= not statistically significant (P>.10),
*=P<.10, ** P<0.05, *** P<.01

Soil Type:

Soils in the study area are mapped at a very course scale (1:100,000). Surficial geology of most of the study watersheds is comprised of bedrock soils. Lakes were classified based on the predominance of either bedrock or deep organic and/or deep basin (BD) soils into three categories. Catchments with greater than 50% deep basin and/ or organic soils, catchments with approximately 50% deep basin or organic soils, and catchments with over 90% bedrock. However, only five out the 74 watersheds not originating in Ontario[1] were not dominated by bedrock soil. These included Okimaw Lake, Lake 96, Gold Lake and the Dawson and Boulette watersheds[2]. A number of the study watersheds had approximately 50% bedrock. These lakes included Saxton, 82 and 83, English, Little Beaver, Shallow, Wanipigow and Happy. It is expected that soil characteristics of the watershed play an important role of governing water quality in lakes and rivers. Watersheds dominated with deep basin and/ or organic soils had the highest average concentration of DOC in lake water. On average total nitrogen and total phosphorus

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[1] Due to missing GIS data for watersheds originating in Ontario these watersheds were dropped from the watershed analysis.
[2] Dawson and Boulette Lake were considered to be from one watershed.

concentrations were also higher in lakes with deep basin /organic soils than lakes with watersheds dominated by bedrock soils. Lakes with watersheds having 50% or more deep basin/ organic soils had the highest concentrations of nutrients on average. The mean was highly affected by Saxton Lake, which had high concentrations of nitrogen and phosphorus. Lakes with bedrock-dominated watersheds typically had the lowest concentrations of DOC, total nitrogen and total phosphorus. There were some exceptions to this rule. For example, Badou Lake, Owl Lake and Farrington Lakes all had elevated concentrations of DOC, TP and TN relative to the mean despite having a low proportion of deep basin or organic soils. However, the watersheds of these lakes were subject to harvesting disturbance of 11% to 37% of their watershed areas. In fact of the lakes having 50% or more organic or deep basin soils 10 out of 12 watersheds have been subject to either forest fire or forest harvesting disturbance.

The relationship between lake water quality and soil type was also evaluated through correlation. The categories bedrock (BR), deep basin (DB), organic deposits, glacial fluvial deposits (GD) and glacial till (T3) were used to plot soil type against key water quality parameters. One watershed had glacial till soil and only three watersheds had soil composed of fluvial deposits. In all instances, the proportion of these soil types were small. Given that statistical analysis on such few data points is questionable; these soil types were removed from the analysis.

Table 3: Pearson product moment correlation coefficients and P values between soil type and various water quality parameters

Water Quality Parameter	Soil Type					
	BR		OD		DB	
Secchi Depth	0.07	NS	-0.18	NS	-0.10	NS
TDN	-0.27	***	0.31	***	0.22	*
TN	-0.29	***	0.16	NS	0.34	***
TDP	-0.14	**	0.27	**	0.03	NS
TP	-0.18	***	0.05	NS	0.25	**
DOC	-0.17	**	0.31	***	0.08	NS
Chlorophyll a	-0.10	NS	-0.09	NS	0.23	*
SO4	0.15	NS	-0.18	NS	-0.19	NS
PH	-0.03	NS	0.04	NS	0.00	NS
Alkalinity	-0.19	**	-0.02	NS	0.23	*
Ca	-0.15	NS	-0.00	NS	0.17	NS
Conductivity	-0.17	**	-0.02	NS	0.20	*

P values: NS= not statistically significant (P>.10),
*=P<.10, ** P<0.05, *** P<.01

Though the correlation coefficients were not particularly strong between any one soil type and water quality parameter, several trends can be observed. Dissolved, total nitrogen, and dissolved phosphorus were negatively correlated with bedrock soils and positively correlated with deep basin and/or organic soils. This is not surprising given that bedrock soils are generally thin and nutrient poor whereas deep basin soils are more developed and comparatively nutrient rich. Organic soils were correlated with higher concentrations of dissolved organic carbon and, conversely, decreasing Secchi depth; however, only the trend with DOC was significant. Chlorophyll *a* and alkalinity were positively correlated with deep basin soils where alkalinity was negatively associated with bedrock soils. This is not surprising given that bedrock soils of the region have little organic and mineral content and do not contribute as much nitrogen, phosphorus, calcium, alkalinity and conductivity to the watershed as do deep basin soils.

Forest Type:

Using the 1983 and 1997 forest resource inventories (FRI), we evaluated how forest type shapes lake water quality in the region. The most recent 1997 FRI excludes Atakaki Wilderness Park so the older 1983 forest resource inventory was used for these watersheds. The FRI category **Stand Type** categorises forest polygons by the dominant feature of the landscape. This may be prevalent species in a stand of tress (e.g. jack pine, black spruce, balsam fir, trembling aspen) or generic landscape features such as other hardwoods, bare rock, meadow, treed muskeg, or marsh. The areas of the categories black spruce treed muskeg, muskeg, will alder, beaver flood and marsh were combined producing a "wetlands category" to evaluate the role that wetlands in a watershed have in influencing lake water quality. The categories trembling aspen and all other hardwoods were merged, producing a hardwoods category. When examining the relationship between FRI characteristics and key water quality parameters several trends are evident (Table 4):

- Total dissolved nitrogen, dissolved phosphorus and dissolved organic carbon is strongly correlated with the proportion of wetlands in a watershed,
- Secchi depth was negatively correlated with proportion of wetlands in a watershed, That is as wetland proportion increased the water clarity decreased.
- The proportion of jack pine in a watershed was negatively correlated with nitrogen and phosphorus, DOC, conductivity, and calcium.
- The proportion of black spruce was weakly associated with most water quality parameters.
- Hard wood tree species were positively correlated with suspended nitrogen, suspended phosphorus and alkalinity.

Table 4: Pearson product moment correlation coefficients and P values between Stand Type from the Forest Resource Inventory and various water quality parameters

Water Quality Parameter	Forest Resource Inventory Stand Type Group				
	Jack Pine	**Black Spruce**	**Hardwoods**		**Wetlands**
Secchi Depth	-0.03 NS	NS		NS	***
TDN	-0.29 **	0.09 NS	-0.06	NS	0.56 ***
Suspended N	-0.16 NS	0.23 **	0.29	**	-0.08 NS
TN	-0.30 ***	0.18 NS	0.09	NS	0.39 ***
TDP	-0.22 *	-0.10 NS	0.21	*	0.44 ***
Suspended P	-0.19 NS	0.13 NS	0.29	**	0.08 NS
TP	-0.24 **	0.06 NS	0.31	***	0.24 ***
DOC	-0.19 NS	-0.06 NS	-0.23	**	0.66 ***
Chlorophyll a	-0.25 **	0.14 NS	0.15	NS	0.02 NS
SO4	0.07 NS	0.06 NS	-0.06	NS	-0.35 ***
PH	0.01 NS	-0.04 NS	0.12	NS	-0.16 NS
Alkalinity	-0.30 ***	0.17 NS	0.23	**	-0.17 NS
Ca	-0.28 **	0.16 NS	0.18	NS	-0.12 NS
Conductivity	-0.29 **	0.16 NS	0.19	NS	-0.16 NS

P values: NS= not statistically significant (P>.10),
*=P<.10, ** P<0.05, *** P<.01

Table 4 confirms the soils data, that is watersheds dominated by rocky outcrops and bedrock soils, which are also conducive to jack pine forests, have lower concentrations of most water quality constituents. Hardwood stands and wetlands, in particular appear to be associated with higher nutrient concentrations in lake water. Again, hardwood tree species are more conducive to grow on better-developed deep basin or organic soils that are more nutrient-rich and contribute more nitrogen, phosphorus, calcium, and alkalinity through the watershed to lake water. The proportion of wetlands in a watershed was strongly correlated with concentrations of dissolved organic carbon, total dissolved nitrogen and total dissolved phosphorus. Wetlands are typically sources of dissolved organic carbon and may provide habitat for nitrogen fixing algae and bacteria contributing to the observed relationship with dissolved nitrogen (Figures 4 and 5). However, wetland area also negatively correlated with sulphate concentration. This result is surprising. It appears that wetland area and forest type (hardwoods versus softwoods, itself representative of soil conditions) in a watershed is an important factor in determining the overall water quality of a lake regardless of watershed disturbance.

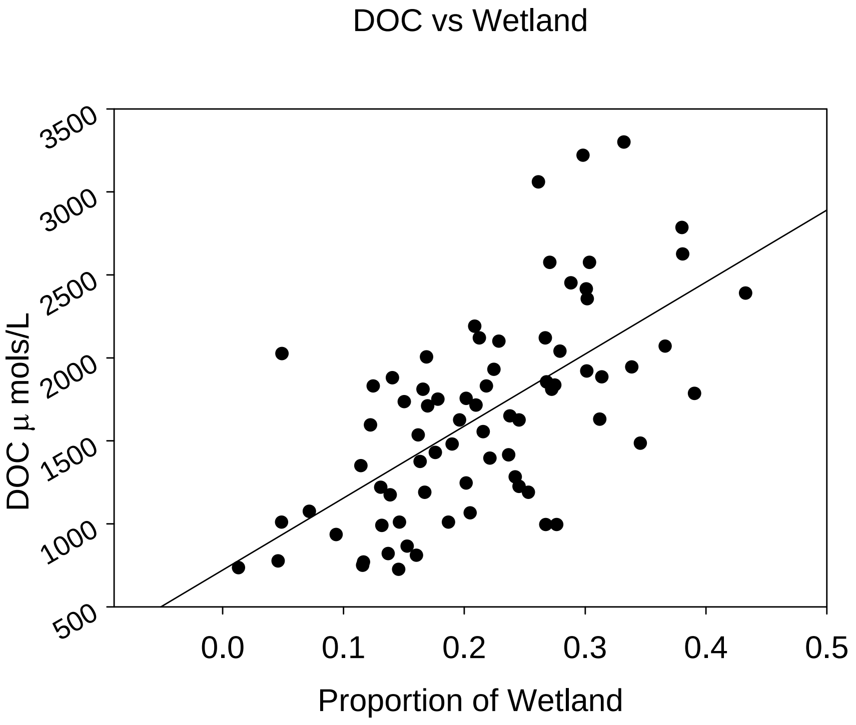

Figure 4: The relationship between wetland proportion in a watershed and total dissolved nitrogen observed from 74 lakes of the Eastern Manitoba Boreal Shield.

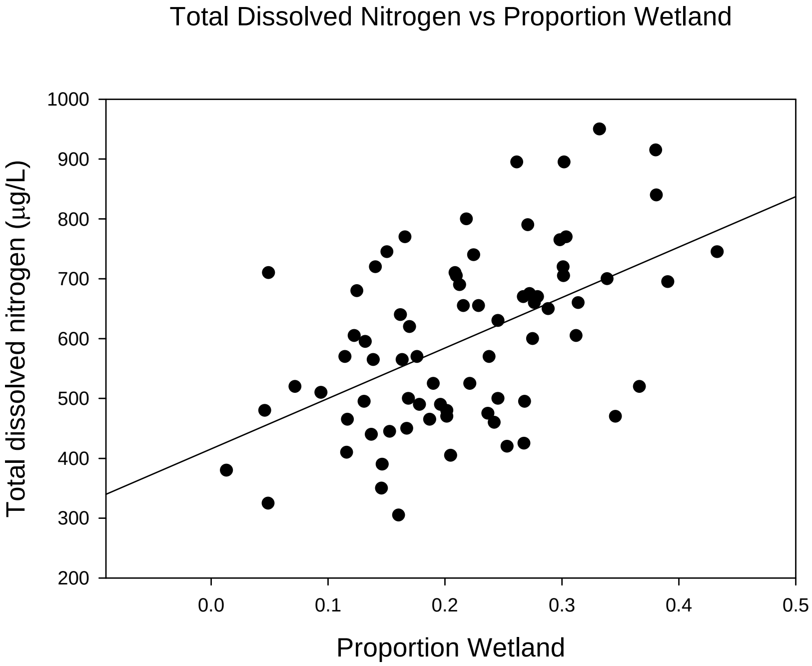

Figure 5: The relationship between wetland proportion in a watershed and concentration of dissolved organic carbon observed from 74 lakes of the Eastern Manitoba Boreal Shield.

Disturbance:

Disturbance types in the boreal forest include wind, fire, insect, disease and forest harvesting. Using GIS layers of disturbance history (insect outbreaks, forest fires, forest harvesting, and mechanical soil preparation), we examined the water quality in lakes compared to their disturbance history. Water quality results indicate that landscape disturbance appears to have a marked influence on lake water quality. This was particularly true when evaluating lakes with recent forest fires and old harvests.

Insect Outbreaks:

Insect outbreaks documented in the GIS data are restricted to the Wanipigow Lake watershed and further south. Most watersheds did not have any documented evidence of outbreaks of spruce budworm or forest tent caterpillars. In fact, only 18 of the 74 non-Ontario originating watersheds had outbreaks of spruce budworm and/or forest tent caterpillars. In many cases, these watersheds were subject to repeat insect disturbance totalling greater than 100% of the watershed area. With respect to water quality, these lakes had higher than average concentrations of all water quality parameters when compared to the overall set of lakes. However, this was more likely a function of other watershed disturbance and soil conditions in these watersheds. For example, in the past thirty-five years, these watersheds were also subject to forest harvesting on average 24% of their watershed areas. Water quality trends observed in the lakes subject to watershed insect disturbance were consistent with lakes with watershed harvesting.

The Effects of Forest Fire and Forest Harvesting on Water Quality:

Recent fires (within the last five years) are restricted to the north of the study area where there is no forest harvesting. These recent fires burned on average 45% of the watershed. Forest harvests within the last 15 years have been limited to an average of 15% of the affected watersheds whereas harvests within the last five years were limited to an average of 5% of the watershed area. Water quality in lakes with older watershed harvests (older than 20 years) showed the greatest differences with respect to reference systems. Lakes with a the majority of watershed harvesting 20 years old or older contained, on average, the highest concentrations of total nitrogen, total phosphorus, dissolved organic carbon, chlorophyll *a,* and calcium (Figures 6-11). Conductivity was also highest in these historically harvested systems. However, the large error bars indicate that considerable variation exists in the water quality of lakes with watershed harvesting and watershed fire. When considering watershed fire, total nitrogen, total phosphorus, dissolved organic carbon, chlorophyll *a,* calcium and conductivity were all elevated in these lakes over reference systems.

Mean total nitrogen, phosphorus, calcium, conductivity and chlorophyll *a* were higher in lakes affected by watershed harvesting than lakes affected by watershed fire, though these results were highly variable.

Secchi depth was significantly different among the treatments (P=0.03). For total nitrogen, lakes with harvesting and fire were significantly different from each other at α = .05. Total phosphorus was significantly different from reference systems in lakes with harvested and burned watersheds; however, lakes with watershed fire and harvesting were not significantly different from each other. Dissolved organic carbon concentration was significantly different among all disturbance types. Chlorophyll *a* and calcium concentrations showed the same result.

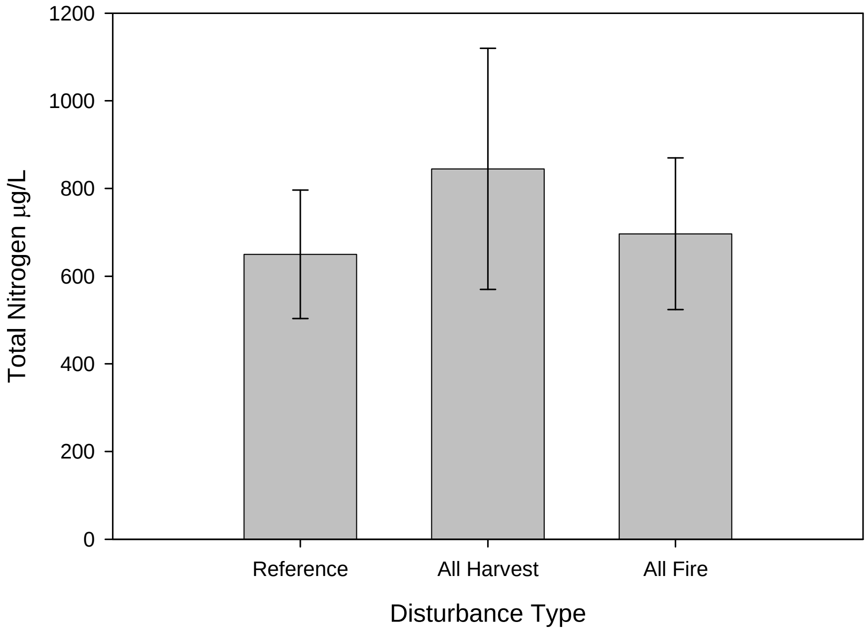

Figure 6: Effects of watershed disturbance type on 2004 total nitrogen concentration in the study lakes: Vertical bars are one standard deviation +/- from the mean.

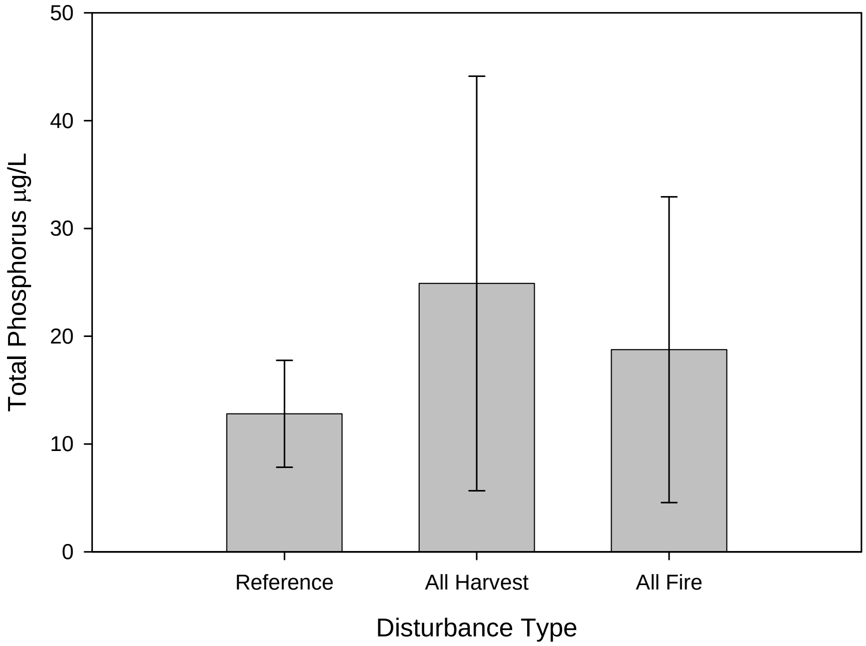

Figure 7: Effects of watershed disturbance type on 2004 total phosphorus concentration in the study lakes: Vertical bars are one standard deviation +/- from the mean.

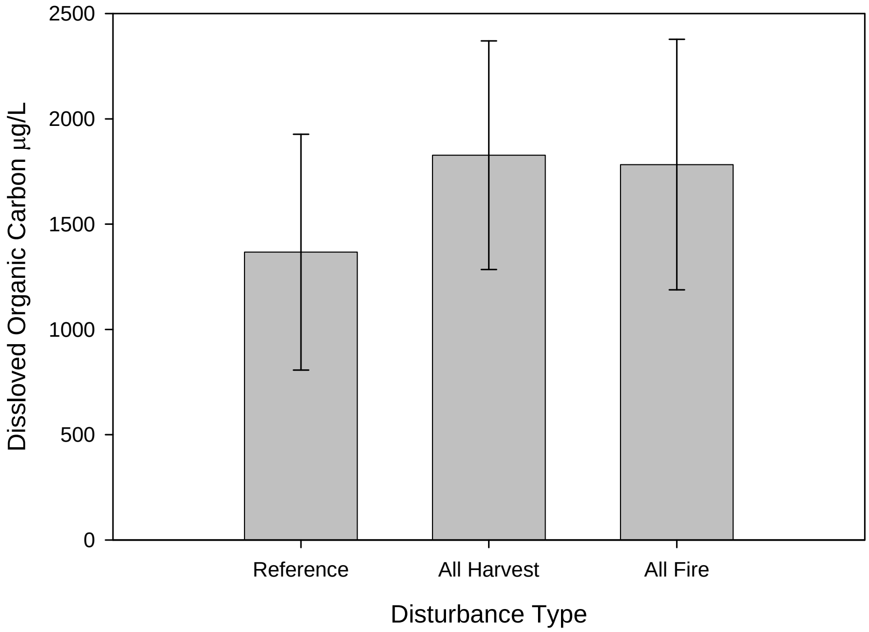

Figure 8: Effects of watershed disturbance type on 2004 dissolved organic carbon concentration in the study lakes: Vertical bars are one standard deviation +/- from the mean.

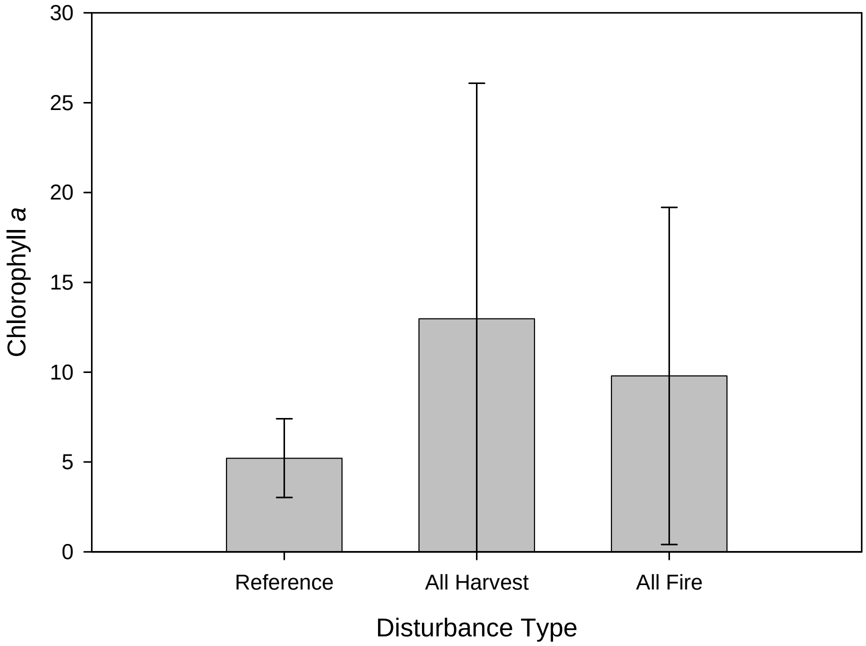

Figure 9: Effects of watershed disturbance type on 2004 chlorophyll *a* concentration in the study lakes: Vertical bars are one standard deviation +/- from the mean.

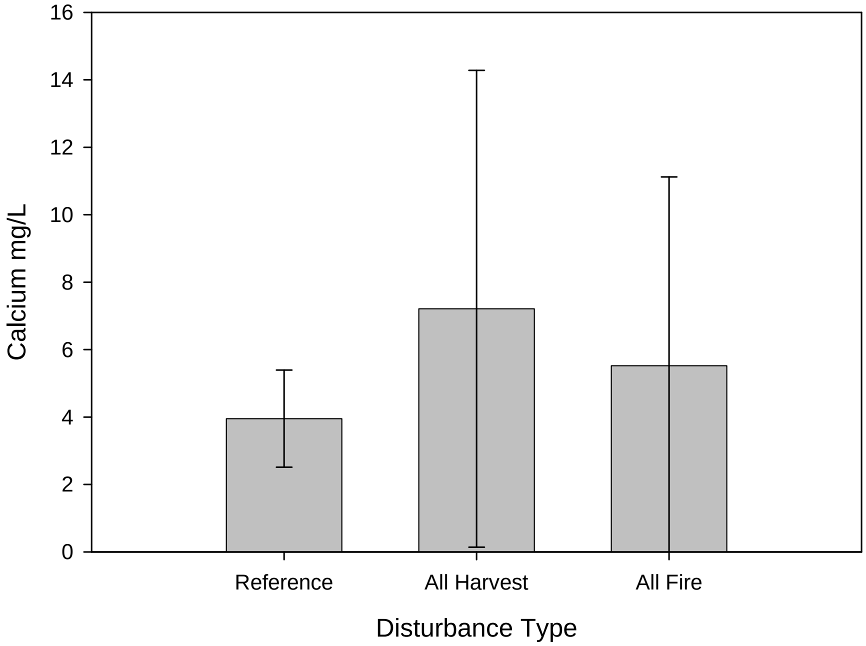

Figure 10: Effects of watershed disturbance type on 2004 calcium concentration in the study lakes: Vertical bars are one standard deviation +/- from the mean.

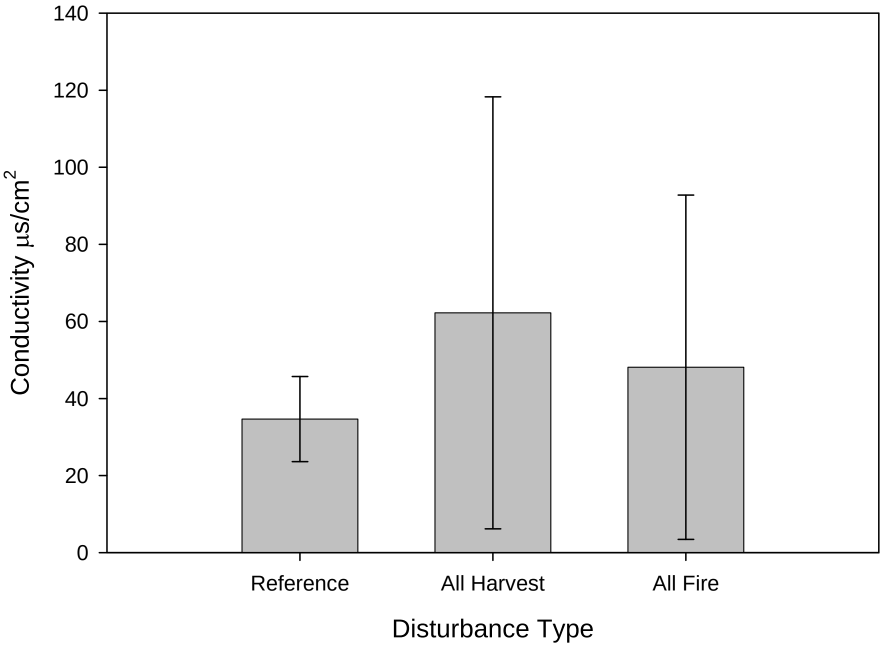

Figure 11: Effects of watershed disturbance type on 2004 conductivity in the study lakes: Vertical bars are one standard deviation +/- from the mean.

Correlation analysis indicates that the association amongst cumulative proportion of a watershed disturbed by forest fire within the last 35 years and key water quality parameters is markedly different from that observed with forest harvesting during the same period (Table 5). While forest fire proportion within the last 15 years was positively correlated with total dissolved and total phosphorus, this did not hold true for older fires. In fact, with respect to forest fire other than phosphorus, there were no significant correlations between the proportion of a watershed burned and key water quality variables. The cumulative proportion of forest harvested during the last five years was not significantly correlated with any water quality variables. On the other hand, correlations between several water quality variables and the cumulative proportion of forest harvested within the last 15, 35 and 50 years were significant (Table 5).

Table 5: Pearson product-moment correlation coefficients and *P* values between various water quality parameters and the cumulative proportion of a watershed disturbed by logging or fire within the last 5, 15, 35 and 50 years

Parameter	Forest Fire								Harvesting							
	Last 5		Last 15		Last 35		Last 50		Last 5		Last 15		Last 35		Last 50	
Secchi Depth	0.07	NS	-0.03	NS	0.16	NS	0.16	NS	-0.17	NS	-0.12	NS	-0.17	NS	-0.18	NS
TDN	-0.02	NS	0.06	NS	-0.17	NS	-0.17	NS	-0.02	NS	0.20	*	0.26	**	0.27	**
TN	-0.16	NS	0.13	NS	-0.15	NS	-0.15	NS	-0.06	NS	0.27	**	0.33	***	0.33	***
TDP	-0.03	NS	0.28	**	-0.10	NS	-0.10	NS	-0.08	NS	0.01	NS	0.16	NS	0.17	NS
TP	0.00	NS	0.24	**	-0.11	NS	-0.11	NS	-0.09	NS	0.26	**	0.31	***	0.31	***
DOC	-0.24	**	0.00	NS	-0.17	NS	-0.17	NS	0.15	NS	0.16	NS	0.18	NS	0.19	*
SO4	-0.01	NS	-0.14	NS	-0.02	NS	-0.02	NS	-0.07	NS	-0.16	NS	0.20	*	0.18	NS
pH	-0.06	NS	0.04	NS	0.07	NS	0.07	NS	-0.14	NS	0.11	NS	0.20	*	0.19	*
Ca	-0.17	NS	-0.06	NS	0.01	NS	0.01	NS	-0.11	NS	0.43	***	0.41	***	0.41	***
Alkalinity	-0.16	NS	-0.03	NS	0.03	NS	0.03	NS	-0.13	NS	0.50	***	0.47	***	0.46	***
Conductivity	-0.16	NS	-0.04	NS	0.02	NS	0.02	NS	-0.11	NS	0.46	***	0.49	***	0.49	***
Chlorophyll a	-0.04	NS	0.16	NS	-0.08	NS	-0.08	NS	-0.02	NS	0.31	***	0.30	***	0.29	**

P values: NS= not statistically significant (P>.10), *=P<.10, ** P<0.05, *** P<.01

From this data, it appears that, at least with respect to older harvest and forest fires, the effects of each on water quality are quite different. Part of the discrepancy could be due to inclusion of fire-affected watersheds within Atikaki Park where no watershed harvesting has occurred and nutrient concentrations generally are lower than in lakes that are more southern in location.

Mechanical Site Preparation

Mechanical site preparation in support of silviculture operations is a common practice in many areas. Soil scarification in watersheds has the potential to affect water quality. In Finland, soil scarification between 15-30% of a watershed was identified as a major influence changing water quality in three lakes (Rask et al. 1998). Nutrient concentrations, pH and alkalinity increased after soil scarification.

In the study area, only eleven watersheds were subject to soil preparation with an average of three percent of the area of each prepared watershed. The small number of watersheds with site preparation makes statistical analysis difficult. Furthermore, it is impossible to separate possible harvesting effects from site preparation; thus, an analysis of the effects of mechanical site preparation in watersheds on the water quality of the region was not possible.

Project Promotion and Communications:

The project, its objectives, preliminary results and project partners have been promoted in several different ways, to a variety of audiences. Below is a summary of the project promotion and communications in 2005/06.

- In January 2005, Kevin Jacobs gave a poster presentation at the joint meeting of the Society of Canadian Limnologists and the Canadian Council for Fisheries Research in Windsor Ontario.
- In February 2005, for the Lakes project an oral presentation was given at the Prairie University Biology Symposium in Saskatoon Saskatchewan.

- In May 2005. Kevin Jacobs gave an oral presentation to the Board of the Manitoba Model Forest
- In November 2005, Dr. Brian Kotak, Kevin Jacobs and Dr. Gordon Goldsborough attended the 25th International Symposium of the North American Lake Management Society in Madison Wisconsin. Oral presentations were made on the lake and rivers/stream components of the project.
- In January 2006, Kevin Jacobs gave an oral presentation at the joint meeting of the Society of Canadian Limnologists and the Canadian Council for Fisheries
- Research in Calgary Alberta.
- In February 2006, Kevin Jacobs gave an oral presentation at the Prairie University Biology Symposium at the University of Calgary.

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Appendix 1. Summary of Microcystin-LR data from the study lakes in 2005.

Table: 2005 microcystin results. Note sampling occurred at three locations in each lake in May and a central location in August and September. Dashed line indicates lake could not be sampled because it was too small for the aircraft used, ND= no data available, Latitude and Longitude in decimal degrees

				May			August	September
				Result (ųg/L MCLR-equivalent)				
Lake ID	Lake name	Latitude	Longitude	Site A	Site B	Site C	Central Site	
7	Metcalfe	50.542300	95.410140	<0.10	<0.10	<0.10	-	-
8	Kinsley	50.546120	95.431950	<0.10	0.10	<0.10	<0.10	<0.10
16	Eastland	50.497230	95.348960	<0.10	0.11	0.13	0.14	<0.10
18	Glen	50.721120	95.513190	<0.10	<0.10	0.39	<0.10	<0.10
19	Terminal	50.699010	95.547140	<0.10	0.17	ND	<0.10	<0.10
43	un-named	50.836930	95.607150	<0.10	<0.10	<0.10	<0.10	0.10
44	Happy	50.841100	95.533600	<0.10	<0.10	<0.10	<0.10	0.12
9	Springer	50.532350	95.451700	0.23	0.15	<0.10	<0.10	<0.10
45	Spence	50.941830	95.623270	<0.10	<0.10	0.14	<0.10	<0.10
52	Boulette	51.183590	96.162180	0.10	<0.10	<0.10	<0.10	<0.10
57	Owl	50.920560	95.902120	<0.10	<0.10	<0.10	<0.10	<0.10
58	Farrington	50.896370	95.896330	0.18	0.11	0.17	<0.10	<0.10
59	un-named	51.596740	95.267300	<0.10	<0.10	<0.10	0.48	<0.10
60	un-named	51.633330	95.249900	<0.10	<0.10	<0.10	<0.10	0.70
63	un-named	51.684700	95.300630	<0.10	<0.10	0.13	<0.10	ND
64	un-named	51.675370	95.293500	<0.10	<0.10	<0.10	<0.10	<0.10
65	Manning	51.691840	95.407970	<0.10	<0.10	<0.10	-	-
67	un-named	51.594640	95.448530	<0.10	<0.10	<0.10	<0.10	-
68	un-named	51.544690	95.499380	<0.10	<0.10	ND	-	-
76	Round	51.517540	95.611080	0.10	<0.10	<0.10	<0.10	<0.10
80	un-named	51.690710	95.740860	<0.10	<0.10	<0.10	<0.10	<0.10
87	Brooks	50.761660	95.541360	0.85	0.17	0.11	<0.10	-

92	West Rat	50.735110	95.730520	0.13	0.14	ND	-	-
94	Faraway	50.915660	95.435320	0.11	0.14	-	-	-
97	un-named	51.120160	95.687890	<0.10	<0.10	<0.10	<0.10	<0.10
98	Kakaki	51.208430	95.771730	<0.10	0.24	0.24	<0.10	<0.10
99	Okimaw	51.154890	95.780050	0.10	<0.10	<0.10	<0.10	<0.10
100	Saxton	51.097420	95.831360	<0.10	<0.10	<0.10	<0.10	<0.10
	min			<0.10	<0.10	<0.10	<0.10	<0.10
	median			0.12	<10	<10	<10	<10
	mean*			0.23	0.15	0.19	0.31	0.31
	max			0.85	0.24	0.39	0.48	0.70

* mean concentration detected when above the limit of detection