THE EFFECTS OF LAND USE CHANGES ON WATER QUALITY OF URBAN LAKES IN THE HALIFAX/DARTMOUTH REGION

BY

PAUL R. MANDELL

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE

AT

DALHOUSIE UNIVERSITY

HALIFAX, NOVA SCOTIA

MARCH, 1994

Extracts from

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MSc thesis, Dalhousie University 1994

Note:
I was on Paul Mandell's supervisory Committee and had many interactions with him outside of the committee. He was passionate about lakes and Halifax area lakes in particular. The volume of work he conducted was immense and it is a valuable record of the condition of 36 lakes in 1991/92, as well as a review of related information up to 1994.

Thirty-four of the lakes, including Sandy Lake in Bedford, NS, were sampled four times (the "extensive lakes") and two were sampled 30 times (the "intensive lakes").These same lakes had been sampled in 1971 by DR Alexander and J.G. Ogden enabling Mandell to make some assessment of changes over the period 1971 to 1991/2.

Paul Mandell's thesis is not available in digital form. I have had a copy sitting in my files all these years and have often consulted it. I tried to track Paul down to see if he had a digital copy and could make it available, and could not locate him. His supervisor and a close friend of mine – Bill Freedman – passed away in 2015. Finally I decided to scan the thesis and submit it DalSpace (Dalhousie University's Institutional Repository) as that is where it belongs. I am waiting on that process.

In the meantime, I extracted pages relevant to Sandy Lake, which are those in this document. Specific references to Sandy Lake are yellow-highlighted.

I think Paul would be pleased to see the work so used, and we can be grateful to Paul for his very fine work.

- David Patriquin Dec 17, 2020

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ABSTRACT

Land use changes as sources of anthropogenic stress can cause changes in urban lake water quality. In order to examine and delineate effects of land use changes, the following 3 research questions were asked: as a result of anthropogenic stress (1) what is the current water quality of Halifax/Dartmouth Lakes, (2) have there been changes in urban lake water quality over time, and (3) if there have been changes in urban lake water quality over time, can these changes be related to changes in land use?

The underlying theoretical basis of the study was the idea of urban lake water quality under anthropogenic stress. Six anthropogenic stressors and indicators for each were chosen to assess water quality of urban lakes.

Thirty four urban lakes in the Metro region were chosen for extensive study. These extensively studied lakes were sampled 4 times from November, 1991to November, 1992. Two of the extensive lakes, Bell and Settle, were chosen for intensive study. Each of the intensive lakes was sampled 30 times from May 13-Nov 29, 1992. Bell Lake had undergone sustainable development, while Settle Lake had been unsustainably developed. Examination of the indicators of anthropogenic stress demonstrated (1) Settle Lake water quality was being stressed by physical disturbance, eutrophication, bacterial contamination, road salt contamination, and oxygen deficit, while Bell Lake water quality was stressed by physical distrubance, (2) the delineated indicators of anthropogenic stress were efficacious and accurate in assessing urban lake water quality under stress. Stress assesments were then completed on the remaining 32 urban lakes. 20.6% of the urban lakes were being stressed by acidification, 47.1% were being stressed by eutrophication, 67.7% were being stressed by bacteriological contamination, 70.6% were being stressed by physical disturbance, and 88.2% were being stressed by roadsalt contamination.

In order to investigate the possibility that urban lake water quality had changed over time as a result of anthropogenic stress, 1991-92 stress assessments were compared with 1971 stress assesments. The entire suite of 6 stressors could not be used as the 1971 data was only comparable to the 1992 data on stress by acidification, eutrophication, and road salt contamination. Even using 3 stressors, the analysis indicated an increase from 1971-92 of 24.1% in the number of urban lakes' stressed by eutrophication, an increase of 17.2% in stress by acidification, and an increase in 48.3% stressed by road salt contamination. The per cent decrease in urban lakes whose water quality was unstressed by any of the 3 comparable stressors was 55.2%. Having demonstrated changes in urban lake water quality over time due to anthropogenic stress, the relationship between land use changes and changes in urban lake water were explored. Watersheds of the extensive lakes were digitized. Land use categories as per cent of the watershed were obtained for each watershed for 1967 and 1986. Land use changes, expressed as changes in per cent land use for each category were computed for each watershed for 1967 and 1986. Special attention was paid to urban land use. Initially, it was hypothesized there would be a strong correlation between the magnitude of urban land use change and resultant anthropogenic stress to urban lakes. On closer examination, it was found that the specific change in land use(road building etc.) was responsible for the resultant anthropogenic stress to urban lakes. For the majority of lakes, resultant stressors and cause due to specific change in land use were elucidated. The importance of anthropogenic stress assessment as a tool to identify stressors of urban lake water quality was demonstrated by comparing Vollenweider-Kerekes trophic categories to anthropogenic stress assessment for Governor Lake. According to Vollenweider-Kerekes, Governor Lake is oligotrophic, suggesting its water quality is unstressed. The use of anthropogenic stress assessment reveals Governor Lake water quality to be stressed by the entire suite of stressors. Anthropogenic stress assessment is a rigorous ecological tool for the determination of urban water quality. By analysing anthropogenic stressors of urban lake water quality, it may also be possible to attenuate their effects.

ACKNOWLEDGEMENTS

I would like to thank my thesis advisor, Dr.Bill Freedman, for allowing me to follow my own research ideas. Only when I temporarily lost the ball would he suggest how I might find it again. He was usually right! His knowledge of ecology is profound, in the quintessential meaning of that word. I have greatly enjoyed our scientific discussions on theoretical ecology, especially our disagreements. Spice is more enjoyable than whitebread, to my way of thinking, anyway.

I would like to thank the members of my committee, Dr. M. Willison, Dr. D. Patriquin, and Dr. N. Watson. Dr. Willison has been very helpful in clarifying my thinking on the importance of community stewardship, and how best to implement connections between communities and ecosystems, so that ecosystems can be preserved and protected.

I benefited greatly from Dr. Patriquin's module on "Closing Nutrient Cycles." This module deepened my understanding of the relationship between lake and watershed.

Dr. Nelson Watson has always been available to answer my questions on the finer points of limnology. He also encouraged me to continue this work, when any sane person would have quit.

I would like to thank Dr. Bezanson in Microbiology at the Path Lab, Victoria General Hospital, Halifax Nova Scotia, who graciously analysed my bacteriological samples gratis. Dr. Raul Subaru, Bedford Institute of Oceanography, Dartmouth Nova Scotia also allowed me to use his laboratory for analysis of chlorophyll-*a*.

Dr. Bob Rogers, statistician "extraordinaire" revealed to me the intricacies of factor analysis with great cunning and humour.

Geoff Howell of Environment Canada kindly let me use his digitizing equipment to determine land use in the watersheds of the lakes I was studying.

Tom Clair and Guy Brun of Inland Waters Directorate, Moncton New Brunswick, analysed my water samples. Their "just in time" supply of water sample bottles was greatly appreciated.

Stefen Gerriets, my "partner in slime", slogged with me, through the sun, rain, ice and snow to collect the samples. When he finally showed true sense and bailed out, Andrew Hebda walked the last miles with me through the snows of November '92 to finish the job.

I would like to express my deep appreciation to Doug Giles and the crew at Latter's Irving in Dartmouth. Anybody who is anybody in aquatic ecology, knows that the field vehicle of choice is a 1967 yellow Chevette, affectionately known as "Baby Duck." Doug kept "Baby Duck" merrily waddling through the ups and downs of mechanical breakdowns with great patience and humour. In terms of creative car mechanics, Doug is truly an artist.

I would also like to thank my wife and family for their patience while dad was running around, trying to get it all done. I do this work in the hope that my children, and all the children in this community, will inherit a more peaceful, safe and ecologically whole biosphere.

INTRODUCTION

THE IMPORTANCE OF URBAN LAKES

A recent special issue of the *Water Pollution Research Journal of Canada* was devoted entirely to research papers on urban lakes (Barica, 1992). The issue contained 13 selected contributions from the participants of the international symposium "Management of Urban Lakes", held in conjunction with the 27th Central Canadian Symposium on Water Pollution Research on February 12, 1992. In his introduction, the editor, Jan Barica remarked,

> The special session was organised to address the emerging issues of urbanisation and its potential impact on the environment, particularly the urban water resources, taking into consideration the fact that *by the year 2000 half of the earth's population will be living in urban centres* [italics added].

Urban lakes, either natural or man-made, will play an increasing important role in ensuring the quality of life in urban areas, through sustainable development and an ecosystem approach to water management." R.J. Allan, Director, Lakes Research Branch, National Water Research Institute, remarked in his introduction (*ibid.*) "Urban lakes may even be indicators of urban environmental health, or reflect the degree to which cities are developing in sustainable environmental directions."

The present study is an attempt to relate changes in urban lake water quality to changes in land use. One assumption implicit in the idea of change, is that at some point in its history, a lake was relatively anthropogenically unstressed. Rapport, (1992), using a medical analogy, argues for the concept of aquatic ecosystem health. Rapport's (1992) position, however, begs the question, what is the water quality of a healthy lake?

Lake water quality.criteria are usually defined by use. For example, the *Canadian Water Quality Guidelines* (CCREM, 1987), set out strict criteria for potable water. For uses other than drinking water, much confusion exists in attempting to define water quality. Several scales, such as the *Carlson Trophic State Index* (Carlson, 1977) and the *Vollenweider-Kerekes Trophic Categories* (Vollenweider and Kerekes, 1982) have been developed to measure lake and reservoir water quality.

An inherent problem with scales such as these, is their inability to measure more than one stressor of lake water quality. To continue the medical analogy, if only one symptom is looked at, others, if indeed they exist, may be overlooked. One could look at the *Trophic State Index* (TSI) or Vollenweider and Kerekes scale, and determine a lake was oligotrophic; its water quality was not being degraded by eutrophication. However, the pH of that lake might be 3.6, reflecting ongoing acidification by regional and/or local sources. The lake would eventually suffer loss of trout and other acid-sensitive species of fish (Harvey and Lee, 1982). Is it a healthy lake?

A more ecological way of looking at lake water quality, is to consider the idea of lake water quality under stress (Freedman, 1989). Freedman (1989) defined stress as "any environmental influence that causes a measurable ecological change." He also includes in his definition of stress, the idea of an implied "anthropogenic judgement about the quality of the ecological change, that is, whether the resulting effect is 'good' or, more usually, 'bad' from the human perspective" (*ibid.*).

If measurements are taken on several defined stressors of lake water quality, rather than using only one scale, one can have a more ecological interpretation of the state of lake water quality. In terms of the idea of aquatic ecosystem health (Rapport, 1992), more than one diagnostic indicator will be employed. Implicit in the idea of diagnosis is treatment; the removal of agents stressing lake water quality, and, remediation of damage done to lake water quality (Olem and Flock, 1990).

In order to refine the quantification of the effects of anthropogenic stress on lake water quality, biological indicators of stressors.of lake water quality will be needed. Stress implies a biological response to environmental change. Therefore, it will also be necessay to attempt to define thresholds of change, and quantify resultant biological responses.

1.0 LAKE WATER QUALITY UNDER STRESS

1.1 STRESSORS OF LAKE WATER QUALITY

Stressors of lake water quality can be characterized into two main types: natural and anthropogenic. The most important natural stressors of lake water quality are nutrient supply and climate. For example, arctic lakes are considered to be amongst the most severely affected by natural stressors. The productivity of arctic lakes is limited by a small nutrient input, shortness of growing season, and temperature inhibition of nutrient cycling (Schindler *et al.*, 1974, Hobbie, 1984).

Anthropogenic stressors also affect lake water quality, including the direct and indirect effects of forestry practices, road construction, and housing development (Harper, 1992). The general effects of these activities are briefly discussed below:

Housing. The construction of housing and paving of streets in the watershed of lakes reduces the capacity of the soil to absorb water. The resulting increase of runoff is often diverted by storm drains into the lake. Stormwater inputs often contain large concentrations of nitrogen and phosphorus, originating from fertiliser used on lawns and gardens, or animal excrement, and these can contribute to eutrophication (Harper, 1992). Nutrient inputs can also occur through drainage from septic systems and treatment plants, and these can also contribute to lake eutrophication. Runoff can also contain road salt which can increase sodium and chloride concentrations in water. Pesticides are used in substantial quantities in and around homes and these may also contaminate lakes.

Sewage-contaminated runoff contains large concentrations of faecal coliform bacteria, possibly indicating the presence of various other pathogenic micro-organisms (Gyles, 1984). Stormwater can also be similarly contaminated by bacteria, originating with non-human excrement. Bacterial contamination affects the use of a lake for swimming and other recreational activities, and for drinking water.

Road construction. The potential for surface erosion is directly related to the amount of bare compacted soil exposed to rainfall and runoff. Road surfaces, landings, skid trails, ditches and disturbed clear cut areas can contribute large quantities of fine sediments to streams and lakes (Meehan, 1991). Excessive use of road salt can increase conductivity in lakes receiving salt-contaminated runoff. This runoff can also cause ectogenic meromixis, a condition where the development of a heavy layer of salt in a freshwater lake prevents the lake from turning over, causing a permanent anoxic hypolimnion (Wetzel, 1983). Judd, 1970 demonstrated a concentration of 91 mg/l chloride and 40 mg/l sodium were sufficient concentrations of these ions to cause what he calls " temporary monomixis" in First Sister Lake, April 1967.

If the watershed contains pyrites, road construction can expose these minerals to air and moisture, resulting in a substantial generation of acidity (Hennigar and Gibb, 1987). The resulting mobilisation of aluminum can cause fish kills in lakes and streams (Spry and Wiener, 1991).

Forestry practices. The harvesting of forests in the watershed can affect nutrient cycles, causing an increase in the export of nutrients to streams and lakes (Likens, 1985).

The disturbance of forests also affects watershed hydrology, by temporarily reducing evapotranspiration (Freedman, 1989).

The result is larger yields of water, and an earlier and more intense meltwater flush in the springtime, often accompanied by increased erosion and sediment loads in streams. The deposition of eroded materials in streams and lakes can affect the spawning habitat of fish, and cause other ecological damage. Improper construction of logging roads can also cause erosion and increased sediment loading to streams and lakes (Meehan, 1991).

1.2 REGIONAL AND LOCAL SOURCES OF STRESS

The Halifax/Dartmouth area of Nova Scotia, known as the Metro Region, contains a large number of lakes. These are important because they are used for drinking water and many recreational purposes by the community. These lakes are also habitat for many aquatic and terrestrial biota such as ducks, amphibians, and fish (Dean and Lister, 1971).

The most important, regional-scale, anthropogenic stressor affecting lake water quality in Nova Scotia is the deposition of acidifying substances from the atmosphere, i.e. through wet and dry deposition of sulphur- and nitrogen-containing gases, particulates, and ions. In Nova Scotia, the average pH of precipitation is about 4.5-4.6 (Underwood *et al.*, 1989). Because of the abundance of emission sources in urban areas, the local dry deposition of acidifying gases and particulates is relatively large (Freedman, 1989, Shaw, 1979) and is often more substantial than the wet deposition. Weakly buffered surface waters are vulnerable to acidification by these depositions, and the secondary mobilisation of aluminum can be toxic to fish and other biota (Freedman, 1989).

The most important local stressors of lake water quality in Metro are related to inputs of nutrients by direct discharge of sewage, stormwater drainage, septic fields, agricultural fertiliser, and other practices. These inputs are enriched in phosphorous and nitrogen, which encourage eutrophication when their rate of availability is enhanced (Schindler and Fee, 1974; Vollenweider and Kerekes, 1982). Sewage also has a substantial oxygen-consumption capacity and can contain pathogenic micro-organisms.

Anthropogenic stressors are generally associated with many activities occurring as a result of the "development" of watersheds. These stressors affect water quality and the lake ecosystems. The potential effects of development on other resource values, such as those associated with environmental and ecological resources, are considered during an environmental impact assessment (EIA), if such is required as part of the planning process. Consideration of the environmental costs and benefits of development-related activities contributes to decisions to (1) not undertake the development, (2) modify the development plan to avoid certain degradative consequences, (3) mitigate negative consequences that may result or (4) develop as planned and eat the consequences (Freedman *et al.*, 1993).

1.3 PREVIOUS STUDIES OF HALIFAX/DARTMOUTH LAKES

Early investigations of Halifax/Dartmouth (Metro) lake water quality emphasised (1) the effects of geology on water quality and (2) fish surveys .

1.31 Effects of Geology on Water Quality

Gorham (1957) investigated twenty-three surface lake waters in Halifax County, Nova Scotia. He concluded

> ...the three main factors governing chemical composition are shown to be (1) the nature of the geological substratum, (2) the influence of topography as expressed in

the accumulation of mineral sediments and peat in and around lake basins, and (3) proximity to the sea.

No attempt was made to relate land use to potential changes in water quality.

1.32 Fish Surveys

Sherman (1958, unpublished) carried out a lake survey of Maynard Lake, Dartmouth Nova Scotia. The survey's purpose was "to determine the feasibility of poisoning and restocking with speckled trout." The survey protocol included the results of a plankton tow and Ekman dredge of bottom fauna. Water chemistry analysis includes dissolved oxygen (DO) readings, and pH measurements of surface, thermocline and bottom.

Dean and Lister (1971) compiled a "Natural Environment Survey-Description of the Intrinsic Values of the Natural Environment Around Greater Halifax-Dartmouth", an extensive analysis of significant ecosystems in the Metro area. The report emphasised the importance of preserving and protecting ecosystems at risk from growing populations *viz.*

> ...the immediate values of a tidal marsh, a heron colony, a virgin hemlock-birch forest, or a barrier beach sand dune complex are not readily apparent to the expanding societies that now compromise the majority of the population of Canada. Yet the preservation and development of diversity in and around urban centres will allow citizens to experience and enjoy a fuller and more complete existence within their immediate environs....

Dean and Lister (1971) emphasised the value of Metro lakes as a fishery resource. Forty lakes in the Halifax/Dartmouth area were described in terms of their considered suitability for game fish production. Lake data included surface area, maximum depth, access for fishing and access restrictions. A bathymetric map, conductivity and surface temperature measurements were also included for each lake assessed.

The report also contained strong statements encouraging long-range planning:

Land erosion and domestic sewage will likely be the major source of water quality impairment in lakes and small streams of the Metro area. Considerable advance planning, involving developers and resource agencies will be needed to ensure the environmental damage is minimised. Most lakes in the area are small and shallow. Any enrichment from sewage will in winter draw on what are now probably barely adequate reserves of oxygen, thus rendering the environment unsuitable for trout. Dean and Lister (1971) specified Paper Mill, Russell, Bissett, Wliiams, Bell, Settle, Oathill, First, Second, Washmill and Kearney lakes as areas of immediate concern because of the "imminence of danger of development." They also emphasised the importance of long range planning for Rocky, Powder Mill, Third, Charles, Colbart and Williams Lake.

Alexander (1971) published a comprehensive study of Halifax/Dartmouth lakes. The rationale for the survey was still freshwater sport fishing rather than an examination of water quality *per se*. Alexander (1971) concurred with Dean and Lister's (1971) assessment of the natural recreational assets of the Halifax/Dartmouth Metro area. He argued that recreational facilities (i.e. freshwater sport fishing) will not be sufficient for a growing Metro population. Alexander (1971) surveyed twenty-nine lakes in the Metro region. He was interested in their fishing enhancement potential. Extensive fishery management recommendations were made. The report contained considerable information on lake morphometry, fish populations, and lake water chemistry. No analysis of land use or land-use changes and possible effects on lake water quality were carried out.

1.33 Watershed Management Planning

The first attempt at some kind of watershed management planning was undertaken by Gordon Ogden, limnologists at Dalhousie University. It was Ogden who had analysed the lake water samples for Alexander's 1971 Halifax/Dartmouth lake survey. At the request of the Task Group on The Water Supply and Waste Disposal/MPAC (Metropolitan Area Planning Committee) Ogden expanded his analytical work into a report titled "Water Quality Survey For Selected Metropolitan Area Lakes" (Ogden, 1971). As specified by task force chairperson W.C. Lee P.Eng, the purpose of the report was

> ... primarily to provide an information base on which future decision necessary for the proper management of lakes and watersheds can be made. *It was not the intention of this study to provide specific recommendations for specific lakes rather...as a background to land and water management related to Metropolitan lakes"* (Italics added).

Ogden (1971) analysed several anthropogenic stressors of lakes: (1) inputs of nutrients, (2) physical disturbance and (3) road salt. He commented

> ...these consequences are virtually inevitable with the introduction of human activities into a watershed. The rate of change...is a function of the care and protection provided to the lake watershed during the course of development and utilisation.

Ogden's 1971 survey of forty Metro lakes was relatively complete. It included bathymetry, hydrology, water chemistry and in some cases dissolved oxygen (DO) profiles. Important comments on land use were also included. However, the type of land use development carried out and subsequent (if any) effects on water quality were not delineated.

Ogden (1971) concluded by categorising the forty surveyed lakes into three categories:

(1) **Highly oligotrophic:** Lemont, Long Lake, Otter, Spruce Hill, Third, Topsail and Webber lakes.

(2) **Oligotrophic lakes** showing increase in turbidity after a heavy rain and some influence due to road salting: Loon, Banook, Micmac, Albro, Power Pond, Charles, Sandy, Second, Kidston.

(3) **Substantial cultural influence** ranked from most to least affected: northern half of Russell, Henry, Cranberry, Lovett, Governor, Long Pond (inlet), Bissett, Chocolate, Penhorn, Maynard, Morris, Oathill, Three Mile, and Colbart lakes.

Ogden (1971) also recommended "future developments in adjacent watersheds should be monitored in the Halifax/Dartmouth area." Unfortunately, little monitoring has been done in the Halifax area.

1.34 Water Quality Monitoring Studies

Ogden's 1971 water quality monitoring recommendation was adopted by the City of Dartmouth. The Dartmouth Lakes Advisory Board (DLAB) was created in 1971 to monitor Dartmouth lake water quality. Its other functions were (1) to advise the city on the potential effects of proposed developments on Dartmouth lakes, (2) provide an outlet for citizens' concerns about Dartmouth lakes, and (3) public education on conservation and protection of lakes (Gordon, *pers. comm.*). It should be noted that the DLAB has only an advisory, not a decision-making function.

The first intensive study of a Dartmouth lake was carried out in 1974 by Farmer *et al.*, after consultation with the Dartmouth Lakes Advisory Board. Farmer *et al.* (1974), studied the water quality of Wildwood (Cranberry) Lake.

Wildwood Lake water quality was being stressed by the addition of nutrients from the surrounding watershed (Ogden, 1971). Primary-treated sewage effluent from Greenough Subdivision (76-thousand L/day) was also a source of anthropogenic stress. Farmer *et al.* (1974) collected water samples from four sampling station on August 2, 1974. The results of their analysis indicated Wildwood Lake water quality was not being stressed by faecal coliform bacteria. All coliform counts were <100/100 ml per sample.

Farmer *et al.* concluded Wildwood lake was being stressed by physical disturbance. Suspended solid values were 122 mg/l in the sewage system, 100 mg/l at the south end of the lake, <10 mg/l in the middle of the lake, and 48 mg/l at the north end of the lake. Comparable values for lakes Banook and Micmac during summer 1973 were 1.7 and 3.2 mg/l respectively.

Conductivity values in the sewage stream were 190 μsiemens/cm, and at the three lake stations, about 176 μSie /cm. Farmer *et al.* (1974) noted conductivity values indicated stress from input of road salt. Apparent eutrophication of Wildwood lake was attributed to significant concentrations of nitrates and phosphate in the sewage effluent stream stressing the lake's water quality.

Farmer *et al.* (1974) made several recommendations to reduce the various stressors of Wildwood Lake water quality: (1) immediate action to divert sewage effluent into the city sewer system, (2) instructions for the proper use of fertilisers be given to homeowners living in the watershed, (3) a lake protection zone of 62 m setback from the lake should be established. Farmer *et al.* (1974) were concerned development on the eastern shore of the lake would cause further stress. They also recommended reviewing the necessity of salting Wildwood boulevard, and the use of crushed stone berms to control discharge of silt from the storm sewer entering Wildwood lake.

Gordon (1976), a member of the Dartmouth Lakes Advisory Board, conducted a Secchi disk study of Dartmouth Lakes. He was assisted by fourteen citizen volunteers. The subtitle of his study is "Citizen Involvement In Water Quality Measurements." Thirteen lakes were studied. Gordon (1976) constructed a classification system based on Secchi depth in feet. From lowest to highest Secchi depth, the lakes grade out as follows: Bissett, Cranberry, Little Albro, Russell, Settle, Oathill, Morris, Banook, Penhorn, Micmac, Big Albro, Bell and Charles.

Gordon (1976) recommended "proper land management practices which minimise the further accumulation of sediment and nutrients can help to prevent further deterioration." Gordon repeated his Secchi Disk study in 1977. He concluded there was no change in lake ranking as compared to the 1976 study.

Smith (1981) compared water quality in Bell and Penhorn lakes. She characterized Bell Lake as pristine and Penhorn as urbanised. She concluded Penhorn Lake had been markedly affected by urbanisation while Bell Lake reflects "natural influences only." The urbanisation effects on Penhorn Lake included (1) excessive decreases in dissolved oxygen during winter months, (2) increased pH, (3) increased concentrations of chloride, sulphate and nitrate and (4) the formation of a chemocline during the winter months.

The Dartmouth Lakes Advisory Board carried out a synoptic water quality study of fifty lakes in the Halifax/Dartmouth area (Gordon *et al.*, 1980). The report was dedicated to the Dartmouth City Council. Gordon *et al.* state (1980) "the future of our lakes rests upon enlightened government decisions such as this." Surface water samples were collected from fifty Metro lakes on April 14, 1980. It was assumed turnover and mixing of lakes had occurred. Four laboratories measured eighteen water quality parameters. Data were factor analysed. Three factors accounting for more than 80% of the total variance in the data were: (1) total ions, (2) nutrients and (3) acidity. Frequency plots of each variable measured were also included. The study was repeated in April 1991 (Keizer *et al.*, 1991). There is some question of the veracity of the water analysis for both the 1980 and 1991 studies. Kaiser et. al remarked " there is some question about the accuracy of the 1991 total phosphorus data and nitrate was measured by different laboratories in 1980 and 1991.". They also state

> Surprisingly, there was a poor correlation between total phosphorus and chlorophyll which suggests that the analytical method used for total phosphorus may have missed some of the organic phosphorus present in the algal cells (*ibid.*, p.31)

None of these studies attempted to relate possible changes in lake water quality to land use changes.

Further work on Dartmouth lakes was proposed by the DLAB in 1985. The Board wrote a feasibility study for restoration of Little Albro and Cranberry lakes (DLAB, 1985). The suggested restoration method was sediment removal by dredging. Cost (in 1985 dollars) was estimated to be $160,000. Some work was carried out on Little Albro lake. Anecdotal reports at the time indicated subjective improvement in water quality. No rigorous analysis of change in water quality was undertaken.

From May to August 1990 an extensive survey of the Shubenacadie lakes system was carried out by the Centre for Water Resources Studies (CWRS) at the Technical University of Nova Scotia (Scott, 1990). Lakes studied included Charles, William, Thomas, Fletcher and Grand. The report consisted of a large data set. No analysis of the data was given, save the comment "there were no areas of concern with respect to water quality results compiled in this data set." No evidence for this conclusion was presented.

The Centre for Water Resources Study (Hart and Waller, 1990) also examined the sources of bacterial and chemical contamination of First Lake, Halifax County Nova Scotia. The study concluded " bacterial levels and chemical quality of First Lake are typical of other urban lakes. The most likely source of bacteria is dog faeces, although other sources such as water fowl, lake bottom sediments and illicit household connections may also be contributing." Recommendations of the study included source controls, storage and treatment of stormwater and minimising amounts of fertilising and de-icing chemicals used in the watershed

The Soil and Water Conservation Society of Metro Halifax conducted a limnological study of twenty-seven Halifax lakes in March 1991 (SWCS, 1991). Samples were collected from over the deepest part of each lake at a depth of 0-1 metres from the surface Sampling was done in spring, summer and fall. Data analysis consisted of plots of 1971 values of water quality parameters versus 1990 values for the same parameter. The variables plotted included conductance, sodium, chloride, sulphate, calcium, and pH, Trophic State Indices (TSI) based on the total phosphorus (TP), total chlorophyll-*a* (TCHA), and Secchi disc (SD) are calculated for the lakes. Some attempt was made to classify lakes, but the TSI scale gives different classifications for each index for each lake. Significant conclusions using TSI are difficult to achieve (Ogden, *pers.comm)*

1.4 DEFICIENCIES OF PREVIOUS STUDIES

Major deficiencies exist in previous studies of surface water quality in Halifax/Dartmouth lakes. No study has attempted to quantify the combined effects of major anthropogenic stressors on water quality of these lakes. For example, Gorham (1955) investigated acidic deposition only. Hart and Waller (1990) examined only the effects of bacterial contamination on First Lake and so on. While some studies (Ogden 1971, Soil and Water Conservation Society, 1991) comment on land use changes, the relationship of these land use changes to possible changes in lake water quality has not been delineated. No study has specifically addressed the questions of watershed management planning, and restoration of lakes whose water quality has been anthropogenically stressed.

1.5 THE PRESENT STUDY

The present study is an attempt to remedy the deficiencies of previous studies by posing three research questions:

- As a result of regional and local anthropogenic stressors, what is the current water quality of Halifax/Dartmouth lakes
- What changes in water quality have occurred in Metro Lakes as a result of changes in land use?
- What planning and remediation measures are needed to be put in place to insure (a) water quality is maintained according to preferred use and (b) restoration is carried out on lakes whose water quality is being unacceptably degraded?

1.6 INDICATORS OF ANTHROPOGENIC STRESS

To better understand the nature of changes in water quality caused by anthropogenic stressors, it is useful to consider a variety of potential indicators of water quality, including chemical and physical variables. The indicators most relevant to the research questions posed in this thesis are the following:

1.61 Indicators of acidification

Acidification can be caused by various agencies. Wet and/or dry deposition are well known acidifying processes that are regionally important in Nova Scotia (Freedman, 1989). Also well recognised in Halifax County and elsewhere is extreme acidification, caused by the oxidation of pyritic minerals, which produces a highly acidic leachate (Hennigar and Gibb, 1987). In addition, natural drainage from bogs can be very acidic as well as darkly stained by dissolved organic substances (Kortelainen and Mannio, 1990). pH is the most frequently used indicator of acidity of a waterbody. Sulphate can be an indicator of pyrite oxidation. Organic acids or DOC can be indicators of bog-related acidification. Dissolved aluminum can indicate acid-related toxicity.

1.62 Indicators of physical disturbance

Perhaps the most important effect of physical disturbance is erosion, which in surface waters is best indicated by the concentration of suspended inorganic matter, such as clay, silt or sand (Rand *et al.*, 1974). This is usually measured as turbidity, and sometimes by the process of siltation itself.

1.63 Indicators of eutrophication

Phosphorus (as phosphate) is the most-frequently limiting nutrient causing eutrophication. of freshwaters (Schindler and Fee, 1974; Vollenweider and Kerekes, 1982). The concentration of springtime phosphorus can therefore be an excellent indicator of eutrophication, as can the concentration of growing season chlorophyll-*a* which indicates the standing crop of planktonic primary producers. A strong correlation exists between log (spring concentration of phosphorus) and log (summer chlorophyll-*a*) (Vollenweider and Kerekes, 1981). In some cases, the concentration of fixed nitrogen in water may also be a useful indicator of eutrophication, especially in fresh water in which phosphorus supply is abundant (Vollenweider and Kerekes, 1981).

1.64 Indicators of bacteriological contamination by sewage pathogens

Faecal coliform bacteria are found in the faeces of warm-blooded animals. The presence of faecal coliforms in water is the most common indicator of contamination of a waterbody by sewage (Gyles, 1984).

1.65 Indicators of contamination by road salt.

Inputs of road salt to lakes increase the conductivity value. This increase is caused by the addition of large amounts of the cation sodium (also calcium in some cases), and the anion chloride. Conductivity is measured in µsiemens/cm. Sodium and chloride concentrations are measured in mg/l

1.66 Indicators of oxygen demand

The areal hypolimnetic oxygen deficit (AHOD) is the most common indicator of oxygen demand used in the study of lakes. It is the difference between the total amount of oxygen per unit-area of hypolimnion at some sampling date, and the amount of oxygen present at the vernal overturn (Cole, 1979). AHOD is an indicator of eutrophication and organic loadings (Cole, 1979).

1.7 INDICATOR THRESHOLDS

In order to determine whether urban lake water quality is being unacceptably stressed by the indicators chosen, some baseline water quality values must be established. In this study, reference values were determined for three lake-types most relevant to the Metro Lakes being assessed. The reference lakes used were headwater lakes whose water quality was not being locally anthropogenically stressed. The reference lakes were Beaverskin, Bluehill Pond, and Pebblelogitch

Beaverskin Lake is located at 44° 18' N, 65° 20' W. Soil of the terrestrial watershed of Beaverskin is largely mapped in the Gibraltar Series. This soil is developed from a moderately coarse granitic till and has a sandy loam texture. Gibraltar soil is notably defficient in calcium. Water quality was sampled in Beaverskin Lake between November 1981 and May 1983 (Kerekes and Freedman, 1989). Bluehill Pond Lake is located in Terra Nova National Park, Newfoundland. Its exact location is 48° 36'N, 53 56'.W. The underlying geology is the Connecting Point Group. This group is Precambrian rock composed of green to black greywacke, cherty quartzite, slate, and some sandstone and conglomerate. Bluehill Pond was sampled for 17 months, starting in April 1969 and concluding in August, 1970. Pebblelogitch Lake is located at 44°.8' N, 65° 21' W. Soil of the terrestrial watershed of Pebblelogitch is largely mapped in the Gibraltar series.However, about 1/3 of the Pebblelogitch Watershed is *Sphagnum* bog on undrained and poorly-drained sites. Water quality in Pebblelogitch Lake was sampled between November 1981 and May 1983. In summary then, the reference lake-types and lake names are as follows: Type1(Beaverskin Lake)-marginally acid with thin granitic till in the watershed; Type 2 (Bluehill Pond)-marginally acid with thicker till present in the watershed, Type 3 (Pebblelogitch)- dystrophic. The reference lake water quality parameters (Table 1) were taken as threshold values for the delineated indicators of anthropogenic stress. Reference lake values are after Kerekes 1974, and Kerekes,*et al*, 1989, with the addition of a calculated reference value for faecal coliform bacteria.

All stress assessments in this study are based on comparisons of current water quality parameters of the Metro lakes studied, to the water quality parameters of the reference lakes. The appropriate reference lake used for the assessment of each lake being studied is indicated in the text.

A threshold level for faecal coliform counts in "natural" lakes was calculated from data obtained from the Nova Scotia Department of Health, Sydney,(Jerome Ardrelli, (*pers. comm.*.). The department regularly samples "natural" lakes which serve as water supply for various Cape Breton communities. Faecal coliform counts were obtained from sixteen lakes, each sampled at least four times a month, for August and September, 1993. The range of faecal coliform counts was 0-204/100 ml sample. An average background faecal coliform value, used as a criteria for this study, was 18/100 ml sample.

2.1 STUDY LAKES

2.11 Extensive lakes

Thirty four lakes were chosen for extensive sampling in this study. The selection criteria included (1) a need to achieve a suite of lakes representing a gradient of anthropogenic stress, (2) public concern for a specific lake, and (3) limnological uniqueness of a specific lake. The lakes, their limnological (Ogden, 1971), geological (Stea *et al.*, 1992) and soil characterisations (MacDougall and Cann, 1963) are shown in Table 1. Z is the maximum depth in meters of each lake (ref). Mean Z is the mean depth of each lake. Mean Z is calculated by dividing the volume of a lake by its surface area.

2.12 Intensive lakes

From the suite of extensive lakes, two lakes, Settle and Bell, were chosen for intensive study. Bell lake was chosen as an example of sustainable lake development. By sustainable lake development is meant the best possible preservation of extant water quality in the lake, while housing is built around the lake or in the watershed. It also means the best possible preservation of extant flora and fauna, as measured by quantifiable biological indicators of environmental change. In terms of development as defined earlier (Freedman *et al.*, 1993) any possible stress-inducing consequences of development on water quality are mitigated, not eaten. Settle lake however, is a eutrophied lake. Eutrophication occurred as a result of unsustainable lake development. By unsustainable lake development is meant the degradation of lake water quality due to housing construction around the lake or in its watershed.

2.2 SAMPLE COLLECTION, EXTENSIVE AND INTENSIVE LAKES

The extensive lakes were initially sampled from October 27 to November 12, 1991. Three additional surveys were carried out in 1992. The surveys were done during significant periods in the yearly cycles of the extensive lakes: (1) spring overturn, (2) summer stratification, and (3) fall overturn (Wetzel, 1983). Spring overturn sampling took place from May 17-29, 1992. Summer stratification sampling occurred from August 27-September 16, 1992. Fall overturn was sampled from November 18 to December 7, 1992.

The intensive lakes, Bell and Settle were sampled weekly from May 13, 1992 to freeze up on November 29, 1992. Including initial sampling in October and November 1991, Settle and Bell Lake were each sampled thirty times.

2.21 SAMPLING PROCEDURES AND PRELIMINARY ANALYSES

Water samples were taken from surface locations over the deep hole of each lake. Location of the deep hole was obtained from a bathymetric map of the lake to be sampled. The deep hole was reached by canoe. At each sampling event, five (5) sample bottles were collected, for the following purposes:

Bottle 1: Major Ion sample A clean 1 litre Nalgene bottle and its cap were rinsed three times. with lakewater. The bottle was then filled and capped.

Bottle 2: Metal sample A clean acid-washed 250 ml Nalgene bottle and its cap were rinsed three times. The bottle was then filled and capped.

Bottle 3: Bacteriological sample A 200 ml Nalgene bottle with preservative *in situ* was filled and capped.

Bottle 4: Chlorophyll-*a* sample A 500 ml clean Nalgene bottle and its cap were rinsed three times. The bottle was then filled and capped.

Bottle 5: Phosphorus sample A 50 ml phosphorus-free bottle and its cap were rinsed three times. The bottle was then filled and capped.

Dissolved oxygen profiles Dissolved oxygen (DO) profiles were taken at the intensive lakes, Bell and Settle, and two of the extensive lakes, Maynard and Oathill. Initial profiles were measured in these lakes after spring turnover on June 1, 1992. DO profiles were also taken at two subsequent monthly intervals: July 2, 1992 and August 5, 1992. Dissolved oxygen and temperature profiles were taken from each deep hole of each of the four lakes sampled at 1 m intervals. The location of the deep holes of each lake were obtained from bathymetric maps. Sampling sites were reached by canoe. The depth of each deep hole was verified by using a weighted rope marked off in meters. The rope was anchored to stabilise the canoe while profiles were taken. Areal hypolimnetic oxygen deficits (AHODS) were calculated for each sampling event for each lake studied (Cole, 1979).

2.22 PRELIMINARY ANALYSIS AND SAMPLE STORAGE

Bottle 1: Major Ion sample. As soon as possible after return from the field, pH and conductivity were determined from this sample bottle. Bottle 1 was then refrigerated till shipment to the Inland Waters Directorate Laboratory in Moncton, New Brunswick for appropriate analyses.

Bottle 2: Metal sample. After return to shore from sampling, the metal sample bottle was immediately acidified with 2 ml of 50% analytical grade nitric acid. The bottle was shaken to homogeneously distribute the nitric acid in the sample. Bottle 2 was then refrigerated till shipment to the Inland Waters Directorate Laboratory in Moncton, for appropriate analysis.

Bottle 3: Bacteriological sample. Upon return to shore, Bottle 3 was placed in crushed ice. Bottle 3 was then either delivered in ice directly to the bacteriological laboratory for analysis, or refrigerated overnight and taken for analysis the next morning to the Bacteriology Department, Victoria General Hospital, Halifax.

Bottle 4: Chlorophyll-*a* sample. Upon return to shore, Bottle 4 was placed in crushed ice. It was then transferred to a black garbage bag and refrigerated overnightin the dark. The next morning, the sample was taken in ice for analysis at the lab of Dr. Subaru at the Bedford Institute of Oceanography, Bedford, Nova Scotia.

Bottle 5: Phosphorus sample. Upon return to shore, Bottle 5 was placed in crushed ice. It was then refrigerated till shipment for analysis to the laboratory of the Inland Waters Directorate, Moncton.

2.3 ANALYTICAL METHODS

Methods used to describe lake water quality in this study are summarised below (after APHA *et al.*, 1976): NAQUADAT, 1984

pH is the negative logarithm (to the base 10) of the hydrogen ion concentration. pH measures the most important component of acidity in surface water, where acidity might be defined as the ability of a solution to donate protons. pH was measured using a pH meter calibrated with standard buffer solutions. Glass and calomel (Hg_2Cl_2) electrodes were used in this study (NAQUADAT 1031; American Public Health Association *et al.*, 1974).

Conductivity is a quantitative indicator of total-ion concentration. in waters. Specific conductance was measured in units of µsiemens/cm with a battery-operated Hydrolab TC-2 conductivity-temperature meter (NAQUADAT 10110).

Gran Alkalinity (measured in mg/l $CaCO_3$) is an indicator of acid-neutralising capacity. Alkalinity can be positive or negative; a negative value reflects a neutralising capacity deficit. Gran alkalinity is computed from a curve generated by the titration of 100 ml of a water sample with 0.001N HCl (NAQUADAT 10110).

Apparent Colour is a measure of the concentration of strongly coloured fulvic acids derived from wetlands, especially bogs, and is an indicator of lake dystrophism. To some extent, apparent colour also reflects algal standing crop. An aliquot of the sample contained in a Nessler tube was compared with a platinum standard colour in a Helige Aqua Tester. (NAQUADAT 02011).

Turbidity is an indicator of suspended particles in water. Turbidity was measured by photometry using a Hach Turbidimeter, in Jackson Turbidity Units (JTUs). NAQUADAT 02073).

Total nitrogen is an indicator of the concentration of fixed-nitrogen in all chemical forms. This can be an indicator of the input of a nutrient important in eutrophication. Measurement was by ultraviolet digestion. followed by colorimetry on an autoanalyser. Units are mg/l (NAQUADAT 07601).

Total Phosphorus is an indicator of the most frequently limiting nutrient of eutrophication. Total phosphorus was measured in mg/l by colorimetry, using an autoanalyser (NAQUADAT 15413).

Calcium is an important plant nutrient often correlated with buffering capacity of non-acidified waters. Calcium is measured in mg/l by flame atomic absorption (NAQUADAT 20110).

Magnesium is an important plant nutrient often correlated with ANC capacity of non-acidified waters. Magnesium was measured in mg/l by automated atomic absorption (NAQUADAT 12107).

Potassium is an important plant nutrient. Potassium was measured in mg/l by flame photometry using an autoanalyser (NAQUADAT 19103).

Sodium indicates the influence of road salt and proximity to the ocean, through sea salt deposition. Sodium was measured in mg/l by flame photometry with an internal standard on an autoanalyser (NAQUADAT 11103).

Chloride indicates the influence of road salt and proximity to the ocean, through sea salt deposition. Chloride was measured in mg/l by ion chromatography (NAQUADAT 17209).

Sulphate is an indicator of acidification by atmospheric deposition, and by the oxidation of pyrites. Sulphate was measured in mg/l by ion chromatography (NAQUADAT 16309).

Dissolved organic carbon (DOC) is an energy source for heterotrophic bacteria. DOC is also an indicator of the concentration of humic substances present. The measurement of DOC in mg/l uses colourmetric analysis (NAQUADAT 06107).

Silica is an essential component of frustules in diatoms. Silica was measured in mg/l by automated colourmetric analysis. (NAQUADAT 14105)

Arsenic is a toxic element indicating the presence of mine tailings or leachate from acidified Meguma rock. Arsenic was measured in mg/l by flameless atomic absorption spectrophotometry. (NAQUADAT 33007).

Aluminum is a potentially toxic metal naturally present in soil and rock. The most toxic from of aluminum is the ionic species Al^{3+}. Aluminum is mobilised into solution by acidic waters. Aluminum is measured in mg/l by atomic absorption with solvent extraction (NAQUADAT 13305).

Lead is a potentially toxic metal associated with human activities such as mining and emissions from leaded gasoline. Lead is mobilised into solution by acidic waters. Lead was measured in mg/l by atomic absorption. (NAQUADAT 82302).

Trace metals Manganese, zinc and iron are potentially toxic metals naturally present in soil and rock, but can also be pollutants associated with human activities. Manganese, iron and zinc are mobilised into solution by acidic waters. Manganese, iron and zinc were measured in mg/l by atomic absorption (NAQUADAT 25304, 26304, 30304).

Chlorophyll-*a* indicates the standing crop of planktonic primary producers. Chlorophyll-*a* was measured in micrograms by fluorometry after extraction in 90% acetone. (NAQUADAT 06715).

Bacteria Total coliform bacteria is an indicator of the presence of intestinal bacteria and contamination by human and/ or animal sewage. Especially important are total faecal coliforms, which are specific indicators of sewage. Total faecal coliforms are measured as number/100ml of sample. Total coliform count is determined by filtering sample, placing on broth, incubating broth, and counting total number of coliform. Faecal coliform is determined by plating of sample on Amendo faecal broth, incubating broth then counting number of faecal coliform bacteria (Bezanson, *pers .comm*).

Dissolved oxygen is a measure of primary productivity or lack of it. Dissolved oxygen is measured in mg/l using a YSI 51B oxygen meter equipped with membrane electrodes (NAQUADAT 08104, 08105.

2.4 LAND USE

Watershed maps of the extensive and intensive lakes were obtained from the Nova Scotia Department of the Environment. The watershed of each lake was digitized by the author using Tydac (SPANS) Geographic Information Software (GIS) to obtain land use categories for 1967 and 1986. The land use data base was the Nova Scotia Strategic Land Use Data Base (G. Howell). Unfortunately, the same land use categories were not used in the 1967 and 1986 land use evaluations. Categories used in 1967 were the following: urban, pasture, woods^{+}, woods^{-}, and wetland. Woods^{+} means mature forest. Woods^{-} means regenerating forest. The 1986 land use categories were the following: urban, mines, woods^{+}, woods^{-}, wetland, rock^{-}, dumps, institutions, new grass. Rock^{-} means gravel extraction. In order to attempt to make comparisons between 1967 and 1986 land use data, several of the 1986 land use categories were combined. The 1986 category "urban land use" combined the land use categories of urban, dumps and institutions. Also, the 1986 land use category "new grass" was considered equivalent to the 1967 land use category "pasture."

18. Sandy Lake (Reference lake type 1)

The average pH of Sandy Lake is 5.35 (range 5.10-5.9). The average alkalinity is 0.44 mg/l $CaCO_3$. The average pH and alkalinity are values to be expected in a lake in Halifax geology with some Aspotogan soil type (Farmer *et al.*, 1982). The average conductivity value is 111 µsiemens/cm which indicates contamination by road salt. High average sodium (15.3 mg/l) and chloride (26.9 mg/l) values support this conclusion. Average faecal count is 24/100ml sample, (range 0-92) which is high. The low average chlorophyll-*a* value of 0.99 mg/m3 (range 0.71-1.25 mg/m3) in spite of a high total phosphorus concentration of 0.009 mg/l and a low average total nitrogen concentration of 0.17 (range 0.07-.29 mg/l) indicate no input of excess nutrients. The colour is elevated at a value of 26. The average turbidity value of 1.8 JTUs is also high. The assessment of Sandy Lake water quality in terms of indicators of anthropogenic stress would therefore be:

Indicators of Acidification A moderately high average pH of 5.35, combined with an average alkalinity of 0.44 even in the presence of a high average sulphate concentration of 12.36 mg/l, indicate Sandy Lake water quality is not being stressed by acidification.

Indicators of Physical Disturbance An average turbidity of 1.8 JTUs indicates Sandy Lake is being stressed by physical disturbance.

Indicators of Eutrophication A low average chlorophyll-*a* value of 0.99 mg/m3 combined with high average total phosphorus concentration of 0.009 mg/l, and low average nitrogen concentration of 0.17 mg/l, indicate Sandy Lake water quality is not being stressed by eutrophication.

Indicators of Contamination by Sewage Pathogens A high average faecal coliform count of 24/100 ml sample indicates Sandy Lake is being stressed by sewage pathogens.

Indicators of Road Salt Contamination A high conductivity value, coupled with high sodium and chloride values, indicate the water quality of Sandy Lake is being stressed by road salt contamination.

Conclusion Sandy Lake is being stressed by physical disturbance, contamination by sewage pathogens and road salt.

19. Oathill Lake (Reference lake type 2)

Oathill Lake is underlain by the Halifax Formation. The presence of a drumlin on the eastern side suggests upwellings of groundwater (Stea *et al.*, 1992.). The average pH of 7.38

highly eutrophied waterbody, due to inputs of excess nutrients originating from massive amounts of fertiliser used on the trees and plants in the Pond in the Public Gardens. It is also highly contaminated by road salt due to road runoff which is channeled into the pond. It is also highly contaminated by sewage pathogens originating from a large population of resident and seasonal ducks.

Conclusion The pond in the Public Gardens is being stressed by eutrophication, faecal contamination, road salt and physical disturbance, due to excessive amounts of chemical fertilisers entering the pond.

17. SANDY LAKE 1967 GIS evaluation of land use in the Sandy Lake watershed indicates 0% urban and 100% woods. Ogden (1971) does not report a pH for Sandy Lake in his water quality assessment of 30th August, 1971. A federal department of Fisheries and Oceans lake survey in July, 1971 reported a pH value of 6.00. Ogden (1971) reports an alkalinity of 10 mg/l $CaCO_3$. This alkalinity is consistent with DFO's pH of 6.00, and also consistent with Halifax Geology, and Halifax/Aspotogan soil types. The sulphate value is 8.0 mg/l which is low. Both federal department of Fisheries and Oceans (1971) and Ogden (1971) report conductivities of 37 µsiemens/cm. This value is low, indicating no contamination by road salt, Ogden (1971) reports low sodium (2.3 mg/l) and low chloride (7.5 mg/l), confirming the non-contamination conclusion. Although COD at surface is high, soluble phosphate reading is 0.013 which is low, indicating no excess input of nutrients. Sandy Lake water quality was unstressed in 1967.

GIS land use evaluation for 1986 indicates an increase of +21.09% urban use, and concomitant -21.09% decrease in woods. Conductivity has increased from the 1971 value of 37 to an average 1991-92 value of 111µsiemens/cm, indicating contamination by road salt. Sodium values have increased from 2.3-15.9 mg/l and chloride values have increased from 7.5 to 26.9 mg/l, confirming the contamination conclusion. The pH of Sandy Lake has decreased from 1971 value of 6.00 to an average 1991-92 value of 5.35. Sulphate value has increased from a 1971 value of 8 mg/l to an average 1991-92 value of 12.36 mg/l. 1991-92 stress assessment on stressors comparable to Ogden's 1971 data indicates Sandy water quality is being stressed by road salt contamination.

Conclusion Sandy Lake water quality has changed from unstressed in 1971 to being stressed by road salt contamination due to an increase of 21.09% urbanisation of its watershed.

18. OATHILL LAKE1967 GIS land use evaluation of the Oathill Lake watershed indicates 100% urban land use. Ogden (1971) estimated " 33% of the watershed of this small lake is

Indicators of stress Eutrophication and road salt contamination.

land use changes Conversion of woods to intensive floriculture, construction of asphalted paths.

18. SANDY LAKE GIS indicates an increase in urban land use of 21.09% in the Sandy Lake watershed.

Indicators of stress Road salt contamination.

land use changes Highway construction.

19. OATHILL LAKE GIS evaluation indicates 0% change is urban land use from 1967 to 1986. This is because the Oathill Lake watershed was 100% urbanised in 1967. Urbanisation included extensive storm drains to remove excess water created by deforestation of the watershed. When asked if the storm drains were necessary, an engineering technician commented to the author that "80% of the drainage was for aesthetic purposes. People don't like puddles on their streets."

Indicators of stress Eutrophication, contamination by road salt.

land use changes Road and housing construction, input of stormwater drainage system.

20. SULLIVANS POND GIS indicates a decrease of -17.86 urban land use. This is probably incorrect. There are storm drains entering Sullivans Pond.

Indicators of stress Eutrophication and road salt contamination.

land use changes Housing and road construction, culverts draining roads,

21. LOON LAKE GIS indicates a 6.41% increase in urban land use of the Loon Lake watershed. Even though there are a lot of houses on the eastern side of Loon Lake, care was taken to place the septic tanks as far away from the lake as possible, given the lot size. Loon Lake receives inputs from Cranberry Lake, which is eutrophied. However the quantity of water entering does not seem to contribute excess amounts of nutrients.

Indicators of stress Road salt contamination.

land use changes Stormwater drains, minimal housing and road construction.

22. PENHORN LAKE GIS indicates 0% change in urban land use of the Penhorn Lake watershed. Urban land use in 1967 was 100%. Penhorn lake receives stormwater drainage from a major highway and shopping mall.

Table 2 Lake morphometry, geology and soil type

lake	*location*	*watershed area (ha)*	*surface area (ha)*	*maximum depth (m)*	*mean depth (m)*	*geology*	*soil type*
Powdermill	Halifax County	377.7	23.5	9.2	1.70	Goldenville	Halifax
Rocky	Halifax County	461.1	186.6	11 .0	2.20	Goldenville, Wolfville	Halifax, Wolfville
Spruce Hill	Halifax County	344.1	89.1	11.6	3.40	Plutonic monzo-granite	Rockland, Gibraltar
Third	Halifax County	256.3	91.9	24.4	8.60	Goldenville	Halifax, Wolfville
Lake William	Halifax County	6,333.1	338.9	28.4	11.60	Goldenville	Halifax
Frog Pond	Halifax City	N/A	4.55	5.5	1.39	Plutonic granodiorite	Gibraltar
Drain	Halifax County	N/A	13.9	3 .0	1.09	Goldenville	Halifax
Hatchet	Halifax County	N/A	68.3	22 .0	7.39	Plutonic monzo-granite	Bayswater, Wolfville
L.Springfield	Halifax County	N/A	8.0	7 .0	3.25	Goldenville	Halifax, Bridgewater
First	Halifax County	279.0	81.0	22.9	5.80	Goldenville	Wolfville
Williams	Halifax County	330.0	46.6	20.1	2.50	Halifax	Halifax, Wolfville
Second	Halifax County	536.0	103.6	22.9	3.72	Goldenville	Wolfville
Chocolate	Halifax City	88.0	8.9	13.4	3.90	Halifax	Bridgewater
Long	Spryfield Town	1,151.4	204.9	30.2	7.40	Plutonic monzo-granite	Gibraltar,Hfx,Wolfville,Bayswater
Governor	Halifax County	348.6	41.7	14.3	4.70	Halifax	Rockland,Gibraltar
Kearney	Halifax County	2,897.6	64 .0	26.2	9.20	Goldenville	Halifax,Rockland
PublicGardens	Halifax City	N/A	1.0	4.5	N/A	Halifax	John Edmunds
Sandy	Halifax County	1,610.1	66.8	19.2	7.60	Halifax	Halifax,Aspotogan
Oathill	Dartmouth City	32.8	4.2	8.5	3.60	Halifax	Wolfville,Mahone
Sullivans Pond	Dartmouth City	N/A	1.7	4.0	N/A	Goldenville	Wolfville,Bridgewater
Loon	Dartmouth City	222.7	68.8	6.1	3.20	Goldenville	Halifax,Wolfville,Hantsport
Penhorn	Dartmouth City	15.4	4.5	7.9	2.90	Halifax	Wolfville
Russell	Dartmouth City	283.8	33.6	7.9	3.10	Halifax	Wolfville,Hebert
Maynard	Dartmouth City	18.4	7.1	13.1	4.80	Halifax	Wolfville
Bell	Dartmouth City	19.8	9.7	8.5	3.10	Goldenville	Wolfville,Hebert
Charles	Halifax County	1,132.4	77.7	28.4	9.10	Goldenville	Halifax
Albro	Dartmouth City	57.1	23.5	6.1	1.80	Goldenville	Halifax
Micmac	Dartmouth City	966.8	139.7	6.1	3.20	Goldenville	Halifax,Wolfville,Bridgewater
Banook	Dartmouth City	225.9	47 .0	11.3	2.60	Goldenville	Bridgewater
Settle	Dartmouth City	29.1	5.0	7.0	2.10	Goldenville	Wolfville

Table 3 Lake stress assessment 1991-92

0 = stressor absent 1= stressor present

lake	acidification	eutrophication	sewage contamination	physical disturbance	roadsalt contamination	total stressor score
Powdermill	0	1	0	1	1	3
Rocky	0	0	1	0	1	2
Sprucehill	1	0	0	0	0	1
Third	0	0	1	0	0	1
William	0	1	1	0	1	3
Frog Pond	0	1	1	0	1	3
Drain	1	1	1	0	1	4
Hatchet	0	0	0	1	1	2
Little Springfield	1	0	0	1	1	2
First	0	1	1	0	1	4
Williams	0	0	0	1	1	1
Second	0	0	1	1	1	3
Chocolate	1	0	0	0	1	2
Long	1	0	0	0	1	2
Governor	1	1	1	1	1	5
Kearney	0	0	0	1	1	2
Public Gardens	0	1	1	1	1	4
Sandy	0	0	1	1	1	3
Oathill	0	1	0	1	1	3
Sullivans	0	0	1	1	1	3
Loon	0	0	1	1	1	3
Penhorn	0	0	1	1	1	3
Russell	0	1	1	1	1	4
Maynards	0	1	1	1	1	4
Charles	0	1	1	1	1	4
Albro	0	1	1	1	1	4
Micmac	0	0	1	1	1	3
Banook	0	0	1	1	1	3
Cranberry	0	1	1	1	1	4

Table 5 Percent land use changes 1967-86

	%1967	%1986	%change	%1967	%1986	%change	%1967	%1986	%change
	POWDERMILL LAKE			**ROCKY LAKE**			**SPRUCEHILL LAKE**		
urban	0.00	17.34	17.34	0.00	23.31	23.31	16.42	21.87	5.25
pasture	0.00	0.00	0.00	N/A	N/A	N/A	0.00	0.00	0.00
woods	100.00	74.49	-25.51	100.00	74.53	-25.47	83.38	78.13	-5.25
wetland	0.00	8.17	8.17	0.00	2.16	2.16	N/A	N/A	N/A
	THIRD LAKE			**LAKE WILLIAM**			**FROG POND**		
urban	38.40	33.60	-4.80	1.76	6.09	4.33	100.00	39.56	-60.44
pasture	0.00	0.00	0.00	N/A	N/A	N/A	0.00	0.00	0.00
woods	61.60	66.40	4.80	95.18	91.14	-4.04	0.00	51.65	51.65
wetland	0.00	0.00	0.00	3.06	2.76	-0.30	N/A	N/A	N/A
	LITTLE SPRINGFIELD			**DRAIN LAKE**			**HATCHET LAKE**		
urban	0.00	67.54	67.54	0.00	15.15	15.15	55.88	50.00	-5.88
pasture	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
woods	100.00	12.98	-87.00	100.00	84.85	-15.15	44.12	32.26	-11.86
wetland	0.00	0.00	0.00	0.00	0.00	0.00			
	CHOCOLATE LAKE			**SECOND LAKE**			**FIRST LAKE**		
urban	91.18	100.00	8.82	2.54	28.74	26.20	4.66	46.24	41.58
pasture	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
woods	8.82	0.00	-8.82	97.46	65.46	-32.00	95.34	49.87	-45.47
wetland	N/A	N/A	N/A	0.00	5.80	5.80	0.00	0.00	0.00
	WILLIAMS LAKE			**SANDY LAKE**			**KEARNEY LAKE**		
urban	16.40	40.35	23.95	0.00	21.09	21.09	0.00	2.28	2.28
pasture	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
woods	71.60	52.20	-19.40	100.00	78.91	-21.09	100.00	97.72	-2.28
wetland				N/A	N/A	N/A	N/A	N/A	N/A
	LONG LAKE			**GOVERNOR LAKE**			**LOON LAKE**		
urban	4.51	10.92	6.41	33.92	40.90	6.98	0.00	14.02	14.02
pasture	0.00	0.00	0.00	0.00	0.00	0.00	N/A	N/A	N/A
woods	95.50	86.06	-9.44	66.08	60.00	-6.08	100.00	84.74	-15.26
wetland	N/A	N/A	N/A				N/A	N/A	N/A

Table 6 **Percent change in urban land use and indicators of stress**

Rs Roadsalt **E** Eutrophication **Ap** Acidification: pyrites **Ard** Acidification: regional deposition

lake	*%urban change*	*1971 stressors*	*1991 stressors*
Powdermill	17.34		E, Rs
Rocky	23.31		Rs
Sprucehill	5.25		Ard
Third	-4.80		Rs
Lake William	6.09		Rs, E
Frog Pond	-60.44	?	Rs, E
Drain	15.15	?	Rs, Ap, E
Hatchet	-5.88		Rs
Little Springfield	67.54	?	Rs, Ap
First	41.58	Rs	Rs, E
Williams	23.95	Rs	Rs
Second	26.2		Rs
Chocolate	8.82	Rs	Rs, Ard
Long	6.41		Rs, Ard
Governor	6.98	E	E, Rs, Ard
Kearney	2.28		Rs
Public Gardens	?	?	E, Rs
Sandy	21.09		Ard
Oathill	0.00	E, Rs	E, Rs
Sullivan's Pond	-17.86	?	E, Rs
Loon	14.02		Rs
Penhorn	0.00	Rs	Rs

Table 8 **Land use changes causing stress, based upon stressors comparable to Ogden 1971 data**

Xni Excess nutrient input **H** Highway construction **Ard** Acidification: regional deposition

Hpe Acidification: pyrites exposed by highway construction

lake	*1971 stressors*	*1991 stressors*
Powdermill	0	Xni, H
Rocky	0	H
Sprucehill	0	Ard
Third	0	H
Lake William	0	H, Xni
Frog Pond	?	H, Xni
Drain	?	H, Xni, Hpe
Hatchet	0	H
Little Springfield	?	H, Hpe
First	H	H, Xni
Williams	H	H
Second	0	H
Chocolate	H	H, Ard
Long	0	H, Ard
Governor	Xni	H, Xni, Ard
Kearney	0	H
Public Gardens	?	Xni, H
Sandy	0	Ard
Oathill	Xni, H	Xni, H
Sullivan's Pond	?	Xni, H
Loon	0	H

Table 10 Kerekes Vollenweider trophic categories:
1991-92 Mean annual total P and Chorophyll-*a* values

lake	*mean annual total P*	*mean annual chloraphyll-a*
Powdermill	oligotrophic	mesotrophic
Rocky	oligotrophic	ultraoligotrophic
Sprucehill	oligotrophic	ultraoligotrophic
Third	oligotrophic	oligotrophic
William	oligotrophic	oligotrophic
Frog Pond	mesotrophic	eutrophic
Drain	mesotrophic	eutrophic
Hatchet	oligotrophic	oligotrophic
L.Springfield	oligotrophic	oligotrophic
First	oligotrophic	oligotrophic
Williams	ultraoligotrophic	oligotrophic
Second	oligotrophic	oligotrophic
Chocolate	ultraoligotrophic	ultraoligotrophic
Long	ultraoligotrophic	ultraoligotrophic
Governor	oligotrophic	mesotrophic
Kearney	ultraoligotrophic	ultraoligotrophic
Public Gardens	hypertrophic	hypertrophic
Sandy	oligotrophic	ultraoligotrophic
Oathill	mesotrophic	mesotrophic
Sullivans	mesotrophic	oligotrophic
Loon	oligotrophic	ultaoligotrophic
Penhorn	oligotrophic	ultraoligotrophic
Russell	mesotrophic	mesotrophic

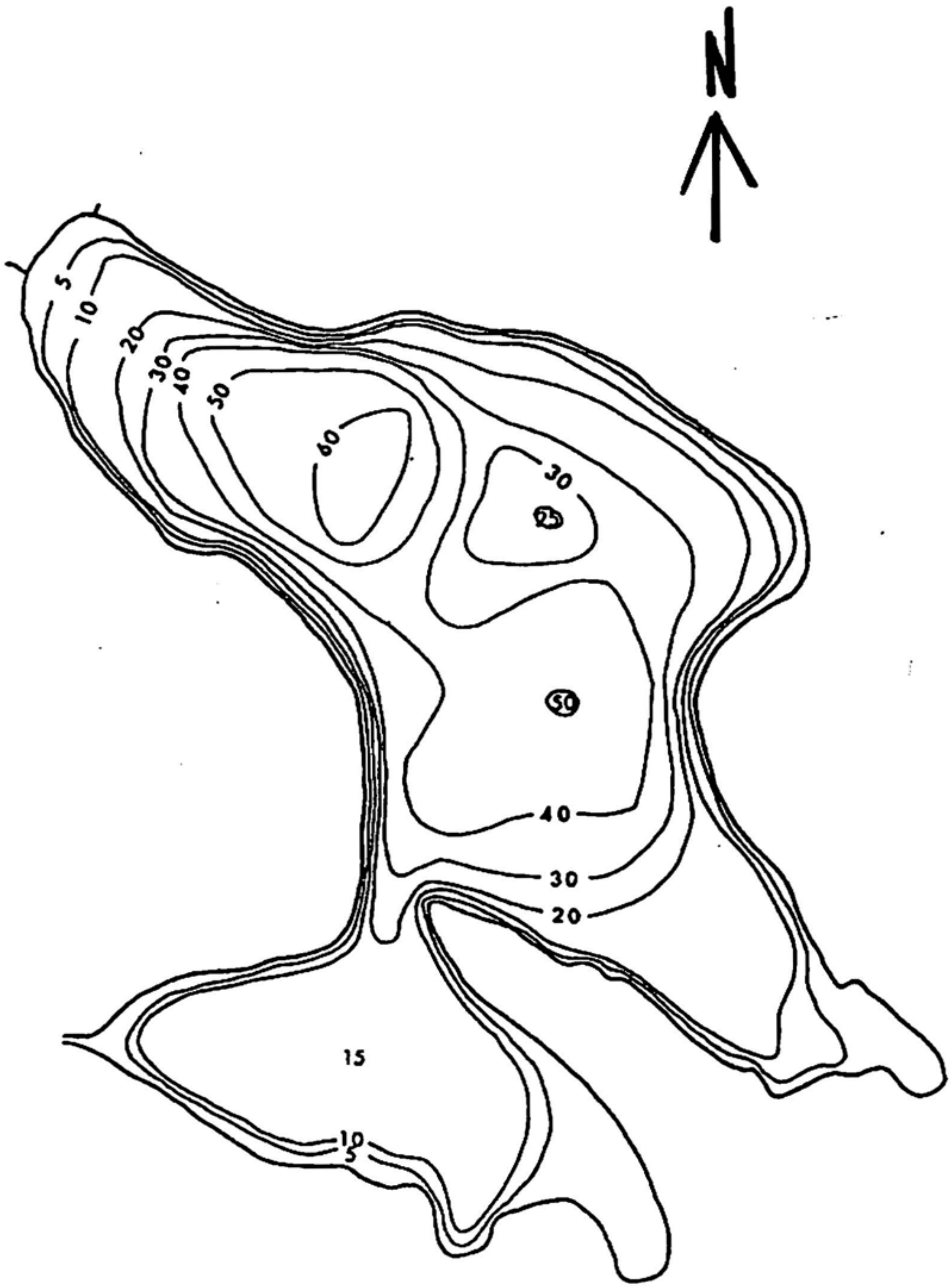
Table 11 continued (1)

date	lake	pH	µsiemens conduc.	$CaCO_3$ mg/l alka.	faecal coliform bacteria	mg/m3 chlor-a	JTUs turbid.	Hazen units colour	mg/l Ca	mg/l Mg	mg/l K	mg/l Na	mg/l Cl	mg/l SO4	µg/l totP	mg/l doc	µg/l totN	mg/l Si	mg/l Fe
Oct 27 91	First	7.30	281	25.76	6	2.76	0.60	1	15.00	2.00	1.80	45.00	83.00	16.00	7	2.40	160	1.10	0.03
May 17 92	First	7.88	320	30.55	0	2.75	0.60	5	2.60	2.00	1.80	48.00	84.50	18.50	8	1.80	180	0.60	0.03
Aug 30 92	First	8.20	319	27.01	60	1.38	0.60	5	16.00	2.10	1.90	51.00	120.00	17.90	5	2.00	120	0.46	0.02
Nov 22 92	First	7.40	333	27.39	52	2.75	0.60	40	16.00	2.30	2.00	53.00	82.00	17.60	9	1.50	150	0.94	0.07
Oct 27 91	Williams	6.40	145	3.53	0	0.93	0.40	10	4.80	0.95	0.92	25.00	27.00	12.20	3	3.20	180	2.00	0.08
May 13 92	Williams	6.33	205	2.22	0	1.15	0.40	20	0.95	1.00	0.85	36.00	54.50	12.90	5	2.20	200	2.10	0.08
Aug 27 92	Williams	6.70	223	4.04	4	1.16	0.40	5	6.20	1.20	1.00	37.00	66.00	13.80	3	1.60	100	0.56	0.04
Nov 18 92	Williams	6.50	225	2.99	0	0.89	0.40	5	6.40	1.30	1.10	39.00	64.00	13.70	2	1.60	100	1.10	0.05
Oct 27 91	Second	6.63	68	4.54	0	2.12	0.60	5	3.60	0.78	0.74	8.90	17.00	7.00	4	3.10	130	1.70	0.05
May 17 92	Second	6.85	82	5.05	0	1.45	0.60	10	4.00	0.80	0.63	11.20	20.00	7.00	4	2.30	110	1.10	0.04
Aug 30 92	Second	7.00	84	3.79	400	1.15	0.60	5	4.10	0.91	0.70	11.90	21.20	6.70	4	2.10	100	0.51	0.01
Nov 22 92	Second	6.80	81	3.64	0	0.44	0.60	10	3.90	0.88	0.67	11.10	18.20	6.70	2	1.80	120	0.88	0.05
Oct 27 91	Chocolate	4.93	382	-1.00	0	0.23	0.30	1	11.00	2.40	1.50	60.00	120.00	50.00	1	0.40	280	3.20	0.05
May 13 92	Chocolate	5.10	525	-0.80	0	0.07	0.30	5	12.00	2.30	1.40	93.00	157.20	34.70	2	0.40	240	3.20	0.03
Aug 27 92	Chocolate	5.79	585	0.15	0	0.11	0.30	5	15.00	2.50	1.50	106.00	175.00	35.80	4	0.50	110	3.50	0.03
Nov 18 92	Chocolate	5.85	509	0.60	0	0.16	0.30	5	13.00	2.30	1.50	94.00	140.00	34.00	1	0.50	190	3.00	0.02
Oct 27 91	Long	4.69	142	-1.10	0	0.46	0.30	25	4.00	1.30	0.70	22.00	40.00	16.00	2	4.70	180	4.20	0.3
May 13 92	Long	4.64	218	-1.20	0	0.80	0.30	50	1.50	1.30	0.72	37.00	57.50	16.10	4	3.00	160	3.50	0.29
Aug 27 92	Long	4.75	223	-0.50	0	0.13	0.30	5	5.80	1.50	0.76	36.00	55.00	16.60	2	1.10	100	3.40	0.16
Nov 18 92	Long	4.80	223	-0.70	0	0.21	0.30	20	5.50	1.50	0.76	36.00	58.00	16.10	5	1.00	130	4.00	0.26
Oct 27 91	Governor	4.63	181	-0.10	2	8.43	3.00	45	6.90	2.00	1.10	22.00	26.00	32.00	10	3.10	250	4.80	0.35
May 13 92	Governor	4.78	268	-0.60	0	1.56	3.00	85	6.90	1.90	1.20	43.00	69.60	25.20	7	1.80	250	4.10	0.29
Aug 27 92	Governor	4.90	274	-0.80	2	0.76	3.00	5	8.50	2.00	1.20	43.00	71.00	24.30	5	0.50	100	4.00	0.29
Nov 18 92	Governor	5.40	228	-0.50	14	1.60	3.00	20	8.40	2.10	1.30	40.00	66.00	23.10	10	1.60	330	4.50	0.27
Oct 27 91	Kearney	6.23	60	2.53	0	0.93	0.50	10	2.70	0.71	0.63	8.90	14.40	6.80	4	3.00	220	3.10	0.05
May 13 92	Kearney	5.90	83	0.60	0	0.98	0.50	25	2.80	0.68	0.50	11.80	20.80	6.40	2	2.30	180	2.60	0.08
Aug 27 92	Kearney	6.40	91	1.62	0	0.57	0.50	6	3.30	0.83	0.61	13.60	22.90	6.70	3	1.10	100	2.20	0.05
Nov 18 92	Kearney	6.35	92	2.34	0	0.47	0.50	15	3.50	0.81	0.65	13.80	23.30	7.00	1	1.80	180	2.60	0.06
Oct 27 91	Public Gdns	7.20	513	45.96	2000	116.48	4.00	10	34.00	2.20	2.30	76.00	125.00	40.00	2550	4.30	1600	8.10	1.5
May 13 92	Public Gdns	7.40	1248	50.50	130	95.00	4.00	10	44.00	3.00	3.60	222.00	462.00	36.70	250	1.60	700	2.10	1.3
Aug 27 92	Public Gdns	6.90	244	55.55	3000	200.91	4.00	70	20.00	1.30	1.70	31.00	47.00	8.20	440	1.90	1700	6.70	2.7
Nov 18 92	Public Gdns	7.10	441	37.85	1000	397.10	4.00	160	32.00	2.20	2.70	62.00	110.00	42.20	270	1.50	2200	5.20	1.4
Oct 27 91	Sandy	5.01	96	0.10	0	1.11	1.80	10	3.80	1.00	0.79	11.90	23.00	14.50	8	3.40	140	3.50	0.33
May 13 92	Sandy	5.33	107	0.02	0	1.25	1.80	35	3.60	0.90	0.75	14.50	24.90	11.24	10	2.40	160	3.20	0.3
Aug 27 92	Sandy	5.70	118	0.05	4	0.88	1.80	5	4.10	1.10	0.71	17.50	28.90	12.20	5	1.30	70	2.50	0.13
Nov 18 92	Sandy	5.90	123	1.59	92	0.71	1.80	55	5.60	1.20	0.96	17.30	31.00	11.50	14	5.00	290	3.90	0.33

Table 13 Mean water chemistry values for study lakes, 1991-92

lake	pH	µsiemens conduc.	CaCO3 mg/l alka.	mg/m3 chlor-a	JTUs turbid.	Hazen units colour	mg/l Ca	mg/l Mg	mg/l K	mg/l Na	mg/l Cl	mg/l SO4	µg/l totP	mg/l DOC	µg/l totN	mg/l Si	mg/l Fe	faecal coliform bacteria
Albro	7.03	368.00	8	2.09	1	7.50	11.00	2	1.10	67.00	96.00	16.05	280.00	1.50	210	1.70	0.12	356
Banook	7.35	348.00	14	1.97	1	11.00	13.00	2	1.30	59.00	92.00	18.10	9.00	1.70	170	1.70	0.07	44
Bell	5.67	49.00	0	1.41	1	2.00	2.60	1	0.73	4.90	9.00	9.60	5.00	0.30	60	0.56	0.04	14
Bissett	7.72	475.00	32	3.97	3	9.00	19.00	3	2.20	83.00	136.00	17.30	15.00	3.05	300	1.25	0.12	50
Charles	7.09	187.00	9	2.09	1	6.00	7.70	1	1.10	29.00	49.00	12.90	18.00	1.80	760	2.10	0.05	451
Chocolate	5.21	500.00	0	0.14	0	4.00	13.00	2	4.50	88.00	148.00	39.00	2.00	0.45	200	3.20	0.1	0
Cranberry	7.37	473.00	24	5.84	1	9.00	17.00	2	1.70	84.00	145.00	17.60	15.00	2.30	270	1.01	0.09	35
Drain	5.14	190.00	1	14.32	1	27.00	4.90	1	0.96	32.00	50.00	17.40	33.00	1.45	480	0.95	0.42	108
First	7.57	313.00	28	2.41	1	13.00	12.40	2	1.88	49.00	92.00	17.50	7.00	1.90	150	0.78	0.04	30
Frog	7.2	626.00	19	9.01	1	18.00	21.00	3	2.20	113.00	184.00	29.00	10.00	3.60	240	1.37	0.14	44
Governor	4.85	238.00	-1	3.09	3	39.00	7.70	2	1.20	37.00	43.00	26.00	8.00	1.80	230	4.40	0.3	5
Hatchet	6.72	111.00	3	1.95	1	13.00	3.58	1	1.21	16.30	28.20	8.80	5.00	3.50	180	1.03	0.08	2
Kearney	6.17	82.00	2	0.74	1	14.00	3.08	1	0.60	12.00	20.40	6.70	3.00	2.05	170	2.60	0.06	0
L.Springfield	3.76	296.00	-10	1.58	0	6.00	5.90	3	0.78	34.00	49.00	33.00	5.00	0.50	80	2.90	0.43	0
Long	4.72	202.00	-1	0.40	0	25.00	7.70	1	0.74	33.00	53.00	16.20	3.00	2.50	100	3.78	0.26	0
Loon	7.17	284.00	9	1.18	1	5.00	9.20	1	1.20	48.00	76.00	14.40	6.00	1.60	140	2.00	0.08	23
Maynards	7.29	367.00	16	2.62	1	8.00	11.00	2	1.40	62.00	87.00	14.20	7.00	1.75	210	1.50	0.17	119
Micmac	7.18	314.00	13	1.22	1	15.00	12.30	2	1.23	54.00	83.70	17.00	6.00	1.70	170	1.50	0.06	83
Morris	7.21	323.00	16	3.20	1	10.00	12.00	2	1.50	55.00	78.00	17.50	17.00	2.20	400	1.90	0.13	30
Oathill	7.38	601.00	37	2.50	1	14.00	25.00	4	2.60	110.00	172.00	24.50	12.00	2.50	500	3.20	0.1	15
Penhorn	7.52	549.00	25	1.72	1	6.60	19.00	2	1.20	100.00	168.00	15.90	8.00	2.20	140	1.50	0.05	28
Pockwock	5.32	33.00	0	0.53	1	5.00	1.40	1	0.39	3.80	6.20	6.00	4.00	1.80	90	1.50	0.06	0
Powder Mill	7.29	139.00	13	3.89	1	7.00	8.50	1	1.30	18.80	29.10	9.68	7.00	2.15	160	1.40	0.08	14
PublicGdns	7.11	612.00	47	202.40	4	63.00	32.50	2	2.60	98.00	186.00	31.80	880.00	2.30	1600	5.50	1.7	1553
Rocky	7.47	186.00	23	0.85	0	14.00	13.00	1	2.00	24.30	36.80	11.50	5.00	2.40	260	1.26	0.07	33
Russel	7.15	521.00	16	6.34	1	11.00	16.00	2	1.45	97.00	144.00	19.50	20.00	2.60	140	2.19	0.07	752
Sandy	5.35	111.00	0	0.99	2	26.00	4.30	1	0.80	15.30	26.90	12.36	9.00	3.00	170	3.30	0.27	24
Second	6.84	79.00	4	1.29	1	8.00	3.90	1	0.69	10.80	19.10	6.90	4.00	2.30	120	1.05	0.04	100
Settle	7.45	504.00	27	7.43	1	13.00	17.10	3	2.10	90.00	148.00	17.70	18.00	2.80	270	0.91	0.13	29
Spruce	4.78	29.00	-1	0.94	1	27.00	0.52	0	0.27	2.80	10.60	8.80	5.00	2.50	130	1.19	0.15	0
Sullivans	7.33	357.00	14	1.50	1	7.00	14.00	2	1.40	62.00	107.00	18.00	14.00	1.60	200	1.60	0.11	507
Third	6.88	81.00	5	2.20	0	13.00	4.50	1	0.72	10.90	17.90	7.10	4.00	2.28	110	1.28	0.05	152
L.William	7	137.00	8	2.47	0	9.00	6.20	1	0.98	20.50	34.90	10.10	6.00	2.40	160	1.95	0.08	203
Williams	6.46	200.00	3	1.03	0	10.00	4.60	1	0.97	34.00	53.00	13.20	3.00	2.15	150	1.44	0.06	1

MAP 25 SANDY LAKE



1"=675'(app.)

44°44'00"N 63°42'10"W

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