ENVIRONMENTAL ASSESSMENT OF LAKE GIBSON SEDIMENTS, WATER QUALITY, AND SOILS OF THE NIAGARA REGION.

A Thesis Submitted to the Department of Earth Sciences
in partial fulfillment of the requirements for the degree
Master of Science

by
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ABSTRACT

In light of the fact that literature on toxicity of heavy metals in non-acidified freshwater systems is sparse, this project was initiated to conduct an environmental assessment of Lake Gibson. Chemistry of soils from adjacent areas and vineyards in the region provide a comparative background database. Water quality determinations were used to identify and highlight areas of environmental concern within the Lake Gibson watershed.

A Shelby Corer was used to obtain 66 sediment cores from Lake Gibson. These were sectioned according to lithology and color to yield 298 samples. A suite of 122 soil samples was collected in the region and vicinity of Lake Gibson. All were tested for metals and some for Total Petroleum Hydrocarbons (TPH). Evaluation of the results leads to the following conclusions:

1. Metal concentrations of Al, Cd, Cu, Cr, Pb, Ni, Fe and Zn in soils from the Niagara Region are well below background limits set by the Ministry of the Environment and Energy (MOEE) for provincial soils.

2. There is a spatial and depth difference for some of the metals within the various soils. The Cr, Ni and Pb contents of soils vary throughout the region (p<0.05). In addition, Pb contents tend to be highest in surficial soil samples (p<0.05), an observation consistent with deposition by airborne particulates.

3. The Ni contents of sediments from Lake Gibson fall below the LEL (Lower Effect Level) guideline specified by the MOEE for aquatic ecosystems.

4. All other metal contents exceed the LEL, and in some instances they also exceed the SEL (Severe Effect Level) guideline. In this instance acute toxicity testing of
the sediments is required to assess impact on the aquatic biota.

5. Specifically, effluents and discharges from outfalls, roadways, railways and industrial activities are all degrading the local ecosystem.

6. Mineral oil and greases are a major environmental concern in the sediments of Lake Gibson. Of the 240 samples tested for TPH, 200 samples exceed the MOEE Open Water Disposal Guideline of 1,500 mg/kg.

7. Four areas within Lake Gibson are especially degraded with respect to TPH. One area is just downstream from the Old Welland Canal divergence point and waterfall. Other areas of concern are located just south of Beaverdams Road and just west of the Ontario Hydro control pipes; south of the Village of Beaverdams. The fourth area of environmental concern and TPH impact is located between Highway 406 and Merrittville Highway.
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And then there was one ...... Neva. It is to you that I dedicate this thesis, with all my love.
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INTRODUCTION

Lake Gibson is situated atop the Niagara Escarpment, west of the Welland Ship Canal and south west of the City of Thorold (Figure 1). Marlatt’s Pond and Lake Moodie are located in the north-eastern and western parts of Lake Gibson (Figure 1). In 1905, the flooding of low-lying land created this lake to act as a reservoir for hydroelectric power generation. Its primary water source is the Welland Ship Canal and ultimately Lake Erie. Lake Gibson, a reservoir for the Decew Power Generating Plant, is also used for recreational, municipal and industrial purposes. Residents use the lake for fishing (Figure 2) and swimming, and plans are in place for the development of Mel Swart Lake Gibson Conservation Area along the north shore of the lake. The water from the Welland Ship Canal enters the Power Canal which is further diverted into a drinking water reservoir for St. Catharines and other municipalities. Industrial and municipal effluents enter the lake via several storm sewers and outfalls along the lake. Lake Gibson is considered a non-acidified softwater lake, however much of the metal work done on freshwater environments deals with acidified lakes, streams and rivers. It has been suggested/observed that in acidified lakes metal speciation increases with decreasing pH, and hence increasing toxicity of the water and metals (Brezonik et al., 1990). It is assumed that hardwater water lakes are less toxic due to the presence of calcium and magnesium ions and their complexing capacity.
Figure 1. Lake Gibson is located atop the Niagara escarpment, west of the Welland Ship Canal and south-west of the City of Thorold.
Figure 2. Sport-fishing is a major recreational use of Lake Gibson.
Metals in the Environment

Heavy metals are defined as elements with an atomic density greater than 6g/cm³ (Phipps, 1981). According to Holdgate (1979, p. 10) “Pollution is the introduction by man into the environment of substances or energy liable to cause hazards to human health, harm to living resources and ecological systems, damage to structures or amenity, or interference with legitimate uses of the environment”.

In general, natural and pristine freshwater ecosystems have low metal levels. Background levels of metals in sediments of the Great Lakes Basin (Persaud et al., 1992) are given below.

<table>
<thead>
<tr>
<th>Metal</th>
<th>Background Level (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cadmium (Cd)</td>
<td>4.2</td>
</tr>
<tr>
<td>Chromium (Cr)</td>
<td>1.1</td>
</tr>
<tr>
<td>Copper (Cu)</td>
<td>25</td>
</tr>
<tr>
<td>Iron (Fe)</td>
<td>31,200</td>
</tr>
<tr>
<td>Lead (Pb)</td>
<td>23</td>
</tr>
<tr>
<td>Nickel (Ni)</td>
<td>31</td>
</tr>
<tr>
<td>Zinc (Zn)</td>
<td>65</td>
</tr>
</tbody>
</table>

Most trace elements, especially the heavy metals, do not exist in soluble forms for a long time in waters since soluble fractions of trace cations are rapidly incorporated either by clays or organic compounds and deposited in bottom sediments, or they are absorbed by root tissues of aquatic plants. In aquatic systems, metals form complexes with ligands and although they can remain in solution for extended periods of time, their ultimate fate is deposition in the sediments. Sediments may be regarded as the ultimate sink for heavy metals that are discharged into the aquatic environment (Pendias and Pendias, 1992, p. 27). Thus
concentrations of trace metals in bottom sediments or in plankton reflect geochemical anomalies of the bedrock as well as the different anthropogenic sources of pollution (Pendias and Pendias, 1992).

The behaviour of metals in sediments is complex and cannot be easily characterized. This difficulty lies with the number of different forms in which metals can exist. These forms, and the sediment components in which they can reside, have direct implications in their bioavailability and rate of uptake by aquatic biota.

Chemical complexities of the behaviour of metals are not sufficiently understood and the interpretation of the results is not necessarily straightforward or even, in some cases, possible (Mance, 1987). The polluting effects of metals have been recognized for a long time, and the adverse effects on aquatic environments have also been documented. For example, in Japan itai-itai (ouch-ouch) disease occurred in villages along the Jintsu River in 1947. The people developed painful skeletal deformities. It was due to waste waters from a local Zinc mine and the disease was attributed to Cadmium (Mason, 1991).

In the context of human health, Pb in drinking water has been the focus of the press, particularly as the source of Pb was not from effluents but rather from the dissolution of domestic plumbing. In the 1960's, Zn and Cu were considered among the 5 commonest toxic pollutants in rivers (Mance, 1987).

Contaminated sediment has been singled out as a major environmental problem (Persaud et al, 1992). The concern is that persistent toxic substances in sediment will accumulate in fish, epibenthos and infaunal organisms. These contaminants may be transferred to fish either because they feed on the organisms or come into contact with the
sediments. These chemicals may be transferred again to wildlife, birds and eventually people, if they eat the fish. The two processes through which this occurs are bioaccumulation and biomagnification. The first refers to the selective uptake and storage of a chemical, by an organism, from water or food. The latter is the accumulation of a chemical through the food chain (Beamish, 1996). Primary sources of contaminants in sediments are toxic chemicals in industrial and municipal waste water discharges, followed by runoff from cities, towns and agricultural areas. Other sources include building of shorelines with rubble, bricks, stones, concrete and loose earth (unless the fill is free of contaminants). Furthermore chemicals from factory emissions may attach themselves to particles of dust or droplets of water, which eventually fall back to the Earth in the form of dust, rain, sleet, hail and snow. The analysis of water for heavy metals has many problems associated with it. This includes low metal concentrations, variations in water (pH and Hardness) and chemical speciation. Since sediments and biota contain higher concentrations of metals, they provide useful information in relation to spatial and temporal trends and possible hazard levels (Mance, 1987). Sources of metals include mining activities, industrial waste waters, urban run-off and leachate from solid waste disposal sites.

Heavy metals important in fresh water and aquatic studies include Cd, Cr, Cu, Pb, Hg, Ni and Zn. Their toxicity is related to speciation and many are capable of being bioaccumulated (Hellawell, 1988). A slight increase of trace metal levels in lake waters may be ecologically hazardous, because some elements such as Cd and Cu may have negative impacts on the ecosystem, even at concentrations slightly above natural background levels (Borg and Johansson, 1989). At very low concentrations Cd accumulates in tissue
and causes developmental abnormalities in fish. Furthermore, crustacea and algae tend to
be particularly sensitive to abnormal Cd incorporation (Hellawell, 1988).

The Ontario Provincial Ministry of the Environment and Energy set out Sediment
Quality Guidelines to protect the aquatic environment by setting safe levels for metals,
nutrients and organic compounds (Persaud et al., 1992). The guidelines used for the total
metal fraction are based on two parameters, which are the LEL and the SEL. LEL is the
Lowest Effect Level and at this level of contamination the chemicals in the sediment have
no effect on the majority of sediment-dwelling organisms, although acute ecotoxic effects
become apparent. The sediment is considered to be clean to marginally polluted.
Contamination in sediments that exceeds the Lowest Effect Level may require further testing
and a management plan. In areas where contaminants in sediments are at or above the LEL,
steps should be taken to control all point and non-point contaminant sources to the area.
The SEL is the Severe Effect Level, and at this level the sediment is considered heavily
polluted and is likely to affect the health of bottom-dwelling organisms (Persaud et al.,
1992). If the level of contamination exceeds the Severe Effect Level, then testing is required
to determine whether or not the sediment is acutely toxic. At this level a management plan
may be required. It may include controlling the source of the contamination and removing
the sediment.

The No Effect Level is defined as the level at which the chemicals in the sediment
do not affect fish or the sediment dwelling organisms. There is no transfer of chemicals
through the food chain and no effect is expected on water quality. This level was designed
to protect against biomagnification through the food chain.
When metal concentrations exceed the LEL and/or SEL guidelines, the health of bottom-dwelling organisms may be affected. The effects can be magnified further up the food chain. Lake Gibson supports relatively extensive areas of macrophyte growth. These areas may be suitable spawning habitats for smallmouth and largemouth bass, northern pike, carp, bullheads and catfish. Other species of fish found in the lake include suckers, perch, crappie and goldfish (SNC/Sandwell Inc., 1990). These species of fish are capable of bioaccumulating the metals found in the sediments, which may affect their health. But more importantly, it could affect the health of local residents who catch and eat these fish.

Once the fish have bioaccumulated metals and other contaminants, other wildlife and birds who ingest the contaminated fish can be affected. Mammals in the vicinity of Lake Gibson include ducks, white-tailed deer, raccoons, meadow voles, skunks, squirrels, chipmunks and cotton-tailed rabbits (SNC/Sandwell Inc., 1990). These mammals may be affected by the water they drink. Reptiles and amphibians such as turtles, toads and frogs may be affected as well if the sediments are disturbed and the metals become resuspended in the water (Schmidtke, 1988).

The principal contaminants in urban runoff are Cu, Zn, and Pb, largely a result of automotive activity and corrosion of metallic surfaces and fittings (Schmidtke, 1988). Most contaminants in urban runoff are associated with suspended particulates. As a consequence, effects of runoff should be fairly localized and concentrated in sediment depositional zones near outfalls.
In shallow lakes, sediment re-suspension and transport occurs throughout the lake and contaminant effects may be more widely distributed. The significance of pollutants in fresh waters is modified by characteristics of running waters, of which flow is most significant. Flow can transport, disperse, and dilute pollutants from their point of origin. Pollutants associated with sediments may be re-suspended during higher flows, and resettled further downstream (Hellawell, 1988). Schmidtke (1988) discusses cross boundary transport of toxic pollutants. Pollutants (such as metals) are not necessarily deposited at source from which they come, but can travel over large distances. In the case of Lake Gibson, the pollutants can come from the Welland Canal, or even as far as Lake Erie which flows into the Welland Ship Canal. Lake Erie has its own pollution problems, some of which originate from upstream sources. Urban runoff, industrial wastes, phosphates and other pollutants from these sources can travel from Lake Erie into the Welland Canal, into Lake Gibson and Marlatt's Pond, down the Twelve Mile Creek, into Martindale Pond, and ultimately end up in Lake Ontario. The other possibility is that the pollutants may settle out during any part of the route, depending on water flow. Pollutants can enter a freshwater ecosystem via air deposition. Metal-containing particulates are washed from the atmosphere by rain and snow. They are deposited in drainage basins and ultimately end up in rivers and lakes. One metal readily deposited into water bodies from air is Ni (Fergusson, 1990).
OBJECTIVES

The primary objective of this thesis is the environmental assessment of Lake Gibson waters and sediments. The overall scope of the environmental assessment includes the following components:

1) to evaluate the water quality and water chemistry of Lake Gibson,

2) to analyse sediments for their total metal contents and compare them to the MOEE Provincial Sediment Quality Guidelines for Metals and Nutrients, and with soil background concentrations of the Region,

3) to determine and evaluate the concentration of Total Petroleum Hydrocarbons (TPH) in Lake Gibson sediments, and

4) to evaluate the distribution of metals and TPH in the sediments of Lake Gibson and identify possible point and non-point sources.

BACKGROUND

History

Marlatt’s Pond was created during the construction of the first Welland Canal in 1829. Today, it is a portion of Lake Gibson. In 1897, a power canal was dug from Allenburg through to Decew Falls (Figure 3). Its purpose was to provide water for the Power Glen Power House, and the project was referred to as the Klondyke work after the gold rush in the Yukon (Jubilee History of Thorold, 1897).

The Decew Power Plant was built in 1898 about 6 km south west from St.Catharines, atop the Niagara Escarpment (Figure 3). The plant was the first in Canada to supply power
Figure 3.- The Power House Water Supply and Diversion.
Water is diverted from the Welland Ship Canal into Lake Gibson which acts as a natural reservoir and forebay for the Decew Power Generating Plant (Articles on Decew Falls, 1958).
by long distance transmission to consumers. The electrical power was transmitted from the
Decew Power Plant to Hamilton; a distance of 56 km (Articles on Decew Falls, 1958).
Need for additional hydroelectric power lead to the purchase of 322 ha (800 acres) of land
south of the present City of Thorold, and to the damming of Beaverdam Creek, a tributary
of Twelve Mile Creek. With the permission of the government, the Hamilton Cataract Power
Company commenced flooding of the area in December of 1904, and flooding was complete
in 1905. Several artificial waterways were formed as a result of this project: Lakes Gibson,
Moodie and Patterson with a total water surface area of 13.3 ha (33 acres; Jackson and
Wilson, 1992). Lake Gibson was constructed as a forebay reservoir for the Decew Power
Generating Plant. Water from Lakes Gibson and Moodie is conveyed through penstocks
down the Niagara Escarpment to the power plant below, a fall of 80.7m (265 feet;
SNC/Sandwell, 1990). The tail-race water is discharged into Twelve Mile Creek, which
empties into Lake Ontario (Figure 3). The lake was named after John Gibson, President of
the Dominion Power and Transmission Company Limited (Jackson and Wilson, 1992).

SURFICIAL BEDROCK

The stratigraphy in the Niagara Region is represented by the Niagara Escarpment
(Figure 4). The Paleozoic bedrock in the area is Ordovician to Silurian in age (Haynes,
1995). The area around Lake Gibson is underlain by gently dipping Palaeozoic bituminous
dolomite and shale, which represents the Eramosa Member of the Guelph Formation. The
bedrock in the area is covered by various glacial deposits. These Quaternary sediments
consist primarily of lacustrine stratified sand, silt and clay (Haynes, 1995).
Figure 4. Composite north-south section of the geology and physiography of the Niagara Escarpment in the eastern Niagara Peninsula (modified from Haynes, 1995).
SOILS

Soils around Lake Gibson are classified as the Beverly, Brantford, Toledo and Alluvium soils (Kingston and Presant, 1989). The Beverly soils consist of mostly lacustrine silty clay, which is poorly drained with moderate to low hydraulic conductivity. The material of the Brantford and Toledo soils is a lacustrine silty clay, and drainage varies from moderately well to poor (Kingston and Presant, 1989). There are numerous deposits consisting of sandy loam and sandy soils throughout the Thorold area (Jubilee book, 1897).

LAND USE

The land use around Lake Gibson has remained fairly static until the 1970s. Two major roads, Merrittville Highway and Beaverdams Road transect the lake, and a small residential community (Beaverdams Village, Figure 5) is located on the eastern periphery of Lake Gibson (Figure 6). Some industrial complexes, leftovers from the Second Welland Canal, are located northeast of Marlatt’s Pond of Lake Gibson. The major landuse, as seen in the 1954 air photo (Figure 6), is agricultural on three sides of the lake. The Old and current Welland Canal form the eastern boundary of the lake watershed/basin.

In the forty years since, major institutional, commercial and residential, in addition to roadway construction has taken place north of Lake Gibson (Figure 7). Brock University sits on the shore of Lake Moodie, as do the Niagara Regional Government Offices. A major subdivision, Confederation Heights, was developed, and is still expanding west along the north shore of Lake Gibson (Figure 7). Further industrial development has taken place on the north shore of Marlatt’s Pond and the “New” Welland Canal. A major roadway,
Figure 5. Cottage-type lifestyle along Lake Gibson, Village of Beaverdams.
Figure 6. 1954 Aerial photograph of Lake Gibson and the surrounding area. Ontario Air Photo Library. [Niagara air photo: 1:16000, L4304/28, Photo 114, Toronto, Ontario].
Figure 7. 1994 Aerial photograph of Lake Gibson. A represents Marlatt's Pond, B is the Welland Ship Canal. Aquarius Flight Inc. [Niagara airphoto, 1:25000, L7 003. Photo 24. Markham, Ontario]. This photo has been reduced to 1:31,242.
Highway 406, traverses the western portion of Lake Gibson (Figure 8). For the most part though, the lands south of Lake Gibson are under agricultural consideration. All of these land use changes bring additional pressures and concerns to the lake, through illegal dumping (Figure 9), discharges of effluents (Figure 10) and storm waters (Figure 11), and until recently (early 1990s), sanitary sewage from the Village of Beaverdams (City of Thorold).

METHODOLOGY

Field Methods

Soils

A soil map and aerial photographs were obtained for the area surrounding Lake Gibson. Based on the type of soil, sampling locations were chosen in areas that were relatively undisturbed, primarily at the edges of open fields, in areas where the soils had not been tilled, or in woodlots (Figures 12 and 13).

Soil samples were extracted using an AMS Auger. At each site, surficial samples were taken at depths of 10 and 30 cm, with the exception of Site 5 at which both samples were taken at 10 cm as the water table was near the surface. The soil samples were placed in labelled plastic bags, and were stored in a cooler for transport to the laboratory. A log was kept of the soil type occurring at each sampling location.

The methodology in sampling the viticultural areas of the Niagara Peninsula was as follows: When permission to sample a number of vineyards was obtained from the owners/operators, one of the conditions was that the vineyards’ names would not be mentioned in the written report; hence they will not appear in this thesis. The proposed
Figure 9. Asphalt shingles and other refuse are dumped along the shores of the lake in forested areas.
Figure 10. An industrial outfall along Beaverdams Rd., through which cream and rust-coloured liquid waste are discharged.

Figure 11. Storm sewer outfall along Decew Rd. drains a residential subdivision of approximately 500+ homes.
Figure 12. Photograph of sampling location 5, a typical Alluvium soil locality.

Figure 13. Photograph of a typical sampling area.
sampling agenda was to sample all vineyards on the same day.

Field work was carried out on May 22, 1997. This consisted of visiting each of the 9 vineyards and taking soil samples from three different locations within each vineyard, and at three different depths, for a total of 9 soil samples per vineyard. The locations were chosen as far away from buildings and roads as possible so that the samples would be representative of natural background conditions.

Sediments

52 cores were taken from Lake Gibson (Figure 14), with 42 cores taken from a boat and 10 cores (cores 60, 61, G1, C1, C2, C3, B1, Ex4, G2 and P1) taken from shore. 14 cores were taken in Marlatt’s pond, all of them from shore. The cores were collected between July 1995 and September 1997. The samples were taken from areas where deposition of fine-grained sediment would occur. In some places the sediment was so waterlogged that it drained out of the sampler and therefore a sample could not be obtained.

All cores were taken with a Shelby Tube Corer. Inside the stainless steel case was a clean 30 cm plastic sleeve. When a larger corer was used, 50 cm and 1m long plastic sleeves were utilized. Once the core was retrieved, the sleeve was capped with a red plastic cap to denote “top” and a black plastic cap denoted “bottom”. The sleeves were placed in a cooler for transport to the laboratory.
Figure 14. Sediment sampling station diagram of Lake Gibson, Thorold Ontario. Insets and general map show sediment sampling stations.
Water

On July 24, 1995, temperature, pH, salinity, turbidity, conductivity, and dissolved oxygen readings were taken at sites 1, 2, and 4-9 of Marlatt’s Pond, with a Horiba U-10 Water Quality Meter. Water quality readings were taken at 16 sites around Lake Gibson (sites 3, 10-24) throughout the summer of 1997 (Figure 15). The data are listed in Appendix 1. All readings were taken no more than four ft. from shore. Equipment used included a Horiba U10 Water Quality Meter, a Hach Conductivity/TDS Meter and a Hach pH/Eh meter. The Horiba was calibrated for pH with pH buffer solutions of pH 4, 7, and 10 prior to each use. The electrodes were rinsed with deionized water after and between each use, and were stored in water. The calibration for conductivity was done using a 1,000 ppm NaCl (sodium chloride) solution and the calibration for turbidity utilized a Formazin solution of 800 NTU. The Eh/pH electrodes were stored in a 2 molar KCL (potassium chloride) solution. The electrodes were rinsed with deionized water after each use and stored in their respective solutions.

In the field, the probe was gently lowered into the water, the Horiba was turned on, once the readings stabilized, a reading was taken and recorded in a chart or field book. The electrodes were rinsed with double deionized water and stored in tap/lake water in between stations.
Figure 15. Water quality and chemistry sampling stations, Lake Gibson, Thorold Ontario.
**Lab Methods**

**Soils**

In the laboratory, the soil samples were frozen until they were ready to be processed. The frozen soil samples were sectioned according to texture (sand, silt or clay) and color. Subsequently, the samples were freeze dried for two days.

After freeze drying, all samples, both from around Lake Gibson and in the Niagara Peninsula viticultural areas, were disaggregated. Approximately 0.6g of sample was weighed out for each. An aqua regia digestion procedure (a modification of U.S. EPA Method 3050), and a magnesium chloride extraction method (a modification of Tessier et al., 1979) were carried out.

All samples were analysed by flame atomic absorption spectroscopy (AAS). Samples, duplicates and blanks were analysed for Al, Cd, Cu, Cr, Pb, Ni, Fe and Zn. Accuracy of methodology was confirmed by evaluation of National Institute of Standards and Technology (NIST) standard reference material (SRM) 2704 (Buffalo River Sediment).

Data are listed in Appendix 2. All statistical evaluations were determined by One Way ANOVA using the Minitab Program. Statistics were used to order to verify apparent differences in metal concentrations occurring within the 9 vineyards.

**Sediments**

Once the cores were transported to the laboratory, they were placed in the freezer. The sediment was extracted from the sleeve by running a little hot water on the outside of the sleeve to loosen the sediment from the core, then the sediment was extracted with a clean
stainless-steel rod. The core was rinsed with deionized water and then sectioned according to lithology (Appendix 3), which was recorded in a log book. The sample was taken from the middle of the core to minimize smearing and thus avoid cross contamination. Each sample was measured, described, placed in a clean, labelled 100 mL glass beaker, and placed in a freeze dryer (freezer for 1 day, in vacuum for 4 days). Once the samples were freeze-dried, they were disaggregated using a clean glass test tube. Approximately 0.5g of each sample was taken for total metal analysis.

The samples taken from Marlatt’s Pond were sieved into 4 size classes, <60 \mu m, 60-120\mu m, >150 \mu m, and a coarse-grained size. Ideally the smaller size fraction is preferred as it is likely to contain the greatest amount of contaminants (Mudroch and Duncan, 1986). However, due to a lack of sufficient fine grained sediment, one size class of <150 \mu m was utilized for the Marlatt’s Pond samples. Upon consultation with a commercial laboratory that follows MOEE guidelines, it was discovered that they do not sieve their samples, they simply disaggregate them and take a sub sample. Upon freeze drying, the Lake Gibson sediment samples were handled according to commercial laboratory procedures.

**TPH Extraction**

Approximately 1 to 5 grams of sediment per sample was weighed out and placed into plastic bottles. 20 mL of hexane was added to extract the oil and grease. The jars were placed in a rotator for one hour, after which they were removed and the sediment was allowed to settle. The supernatant was pipetted into a funnel which contained a plug made up of glass wool, silica gel (approximately 1 g) and a layer of anhydrous sodium sulfate (2
g). The solution was filtered through this system into pre-weighed aluminum weighing trays. Once the hexane evaporated, the tray was weighed. This procedure was carried out again, for a total of three times. After the last rotation, the bottle was placed in a sonic bath for half an hour to further extract any remaining oil and grease from the sediments. The data are listed in Appendix 4.

**Chemical Extraction of Total Metals**

Marlatt’s Pond Samples 1-14, 37a, 38a and 39a were analysed using the following procedure: Approximately 0.25g of each sediment sample was weighed out and placed in a Teflon beaker. The sediment was digested using the following procedure:

- preheat hotplate to 92 degrees centigrade
- to each sample add a total of 30 mL of Aqua Regia, 1 mL Hydrogen Peroxide and 2 mL Hydrofluoric acid at time intervals of fifteen minutes
- cover the beaker with a watch glass and place on the preheated hotplate
- remove the solution from the hot plate once it boils down to approximately 5 mL and allow it to cool
- filter the cooled solution through filter paper and into a 10 mL volumetric, bring to mark with quadruple deionized water.
- pour the solution into a labelled test tube and store in the fridge until ready for analysis.
The remaining samples were digested by an Aqua Regia digestion procedure (a modification of U.S. EPA Method 3050) as follows:

Weigh out approximately 0.5g sub sample and put it in a labelled glass beaker.

- add 10 mL of 1:1 HNO₃ and water, cover with a watch glass and place on the hot plate.
After 15 minutes remove the sample from the hot plate and allow it to cool.

- when cool add 10 mL concentrated HNO₃, cover with watch glass and place on hot plate. After 30 minutes remove it and allow it to cool.

- when cool add 2 mL hydrogen peroxide, cover with watch glass and place on hot plate.
  After 30 minutes remove it and allowed it to cool.

- when cool add 10 mL 1:1 HCl, cover with watch glass and place on hot plate for 3 hours or until it refluxes down to 25 mL mark on beaker, remove from hot plate and allow to cool.

- filter the cooled solution into a 25 mL volumetric, top to 25 mL mark with quadruple deionized water, and store in plastic bottles in fridge at 4°C until ready for analysis.

**QA/QC Procedures**

Blanks were utilized to ensure that cross contamination did not occur, and to show the purity of water and acids used. Duplicates were used to show that the results could be reproduced. NIST (National Institute of Standards and Technology) standard reference material (SRM) 2704 (Buffalo River Sediment) was used to show the reliability of the extraction method.
All glassware, bottles, caps, etc. were cleaned with soap and water, rinsed three times, and then further cleaned with aqua regia, then rinsed 3 times with quad-deionized water. All sampling instruments were rinsed with distilled and deionized water, as well as calibrated properly before each use. Laboratory handling equipment such as spatulas, mortar and pestle etc., were rinsed before use and between individual samples. HNO₃ and HCl were purified in a quartz still. Water was distilled and quadruply deionized. Every precaution was taken to avoid sample contamination. The AAS analysis, accuracy and precision determination all follow standard Good Laboratory Practices (GLP).

The samples, duplicates and blanks from all metal extraction procedures were analysed on a Varian Spectra AA-400P Atomic Absorption Spectrometer by air acetylene flame for Cd, Cu, Ni, Zn, Fe and Pb. Nitrous Oxide combined with air acetylene was used to analyse for Al and Cr. Accuracy of methodology was confirmed by evaluation of National Institute of Standards and Technology (NIST) standard reference material (SRM) 2704 (Buffalo River Sediment). Data are listed in Appendix 4. Precision was calculated through the use of duplicate samples.

The samples, duplicates and blanks for TPH evaluations were determined by gravimetric means. Accuracy was determined through spike recovery.
SOIL EVALUATION

INTRODUCTION

Soil Formation

Soil is a natural body, having both mineral and organic components as well as physical, chemical and biological properties. The composition of soils is extremely diverse and is governed by many different factors, of which climatic conditions and parent material are the most significant. Soil is formed by the weathering of rock(s) as the result of interactive geological, hydrological and biological processes (Manahan, 1993). Soil is composed of three phases, solid, liquid and gaseous (Kabata-Pendias, and Pendias, 1992).

Lithogenic elements are those which are directly inherited from the lithosphere (parent material). Pedogenic elements are of lithogenic origin also, but their concentration and distribution in soil layers and soil particles are changed due to pedogenic processes. Anthropogenic elements are those deposited into soils as direct or indirect results of human activities (Kabata-Pendias, and Pendias, 1992).

Distribution of heavy metals in soil profiles is often uniform, although bioactivity and leaching may redistribute elements within the soil profile (Harmsen, 1977). As long as heavy metals remain tightly bound to solid soil constituents, there will generally be little effect on the environment. When soil conditions change in such a way that heavy metals go into solution, the increased content of heavy metals in the soil can impose a direct environmental hazard (Sposito, 1984). Environmental effects of heavy metals are governed by their mobility, which, in turn, is governed by their solubility. Significant increases in solubility occur by lowering soil pH, waterlogging the soils and increasing microbial decomposition.
of organic material. Precipitation and adsorption reactions also tend to increase solubility (Harmsen, 1977).

Soils function as a filter to protect groundwater from inputs of potentially harmful metals, and act as a geochemical sink for contaminants (Alloway, 1995). The persistence of contaminants in soil is much longer than in other compartments of the biosphere, and contamination of soil, especially by heavy metals, appears to be virtually permanent (Kabata-Pendias, and Pendias, 1992). The factors controlling the total and bioavailable concentrations of heavy metals are of great importance with regard to both human toxicology and agricultural productivity since the most important role of soil is in supporting the production of food (Manahan, 1993).

**Soils Located in the Study Area**

The Regional Municipality of Niagara has many geologic and physiographic features. The features associated with Lake Gibson and its surroundings are the Haldimand Clay Plain and the Iroquois Bench (Figure 16). The Haldimand Clay Plain is composed of clay soils, predominantly silty clays. In areas where the clay deposits thicken to >1m, these represent the Beverly and Toledo soils (Kingston and Presant, 1989).

The predominant soil types in the vicinity of Lake Gibson are Alluvium, Beverly, Brantford and Toledo soils. Soil types and sampling stations are illustrated in Figure 17. Alluvium soils are associated with alluvial sediments on flood plains, and their physiographic features tend to be active river and stream flood plains. The Beverly, Brantford and Toledo soils consist of glaciolacustrine silty clays. They are associated with
Figure 16. Geologic and physiologic features of the Regional Municipality of Niagara (modified from Kingston and Presant, 1989).
Figure 17. Locality map of Alluvium, Beverly, Brantford and Toledo Soils, in the Lake Gibson area and sampling stations (modified from Kingston and Presant, 1989). Scale 1:25,000
deep water lacustrine silty clay and clay. The Toledo soils are poorly drained, the Beverly soils are imperfectly drained, and the Brantford and Alluvium soils are well drained, although the Alluvium can have variable drainage. These soils have various agricultural land uses and are used for grass forage crops, small grains, corn, soybeans, winter wheat and alfalfa. Near the Niagara Escarpment, hardier fruit crops such as labrusca grapes, apples, plums and pears are grown (Kingston and Present, 1989).

Environmental Guidelines

Although the particle size compositions of the Alluvium, Beverly, Brantford and Toledo soils are known, literature pertaining to the heavy metal chemistry of these soils is unavailable. This study was initiated in order to establish the background concentrations for Al, Cd, Cr, Cu, Fe, Ni, Pb and Zn for the soils in the vicinity of Lake Gibson and to characterize the soil chemistry of vineyards in the Niagara Region (Figure 18).

Remediation action is required wherever contaminants are present at concentrations above ambient (background) levels. The Ministry of the Environment and Energy (MOEE) defines ambient or background concentrations as the level of a substance in the local area (Phyper and Ibbotson, 1994). Chemical results of the samples were compared to several guidelines in order to assess the heavy metal content in the soils. The Guideline for use at Contaminated Sites in Ontario, Soil Remediation Criteria, Table F was used to compare the obtained metal concentrations to Ontario Typical Range Soil Concentrations (background). The total metal content was compared to Table A (MOEE, 1996). This table is applicable for surface soils in agricultural, residential/parkland and industrial/commercial land use for a potable groundwater condition.
Figure 18. Map of the Niagara Peninsula viticultural area. Numbers 1-9 correspond to the sampling locations for the viticultural soil samples taken throughout the Niagara peninsula.
RESULTS

Total Metal Fraction- Soils surrounding Lake Gibson

There is no significant difference (p > 0.05) between the concentration of Al, Cu, Cr, Ni, Pb, Fe and Zn within the four different soil types, but there is a statistical difference in Cd concentrations between the four different soil types (p=0.045). The mean Cd concentration in the Beverly soil samples is 0.08 ppm, whereas the mean Cd concentration in the Alluvium, Toledo and Brantford soils are 0.19, 0.29 and 0.20 ppm, respectively (Table 1).

Table 1. Mean Cd concentrations and P-values for metal concentrations as compared for the Alluvium, Beverly, Brantford and Toledo soils, as obtained by a One Way ANOVA.

<table>
<thead>
<tr>
<th>mean (ppm)</th>
<th>Al</th>
<th>Cd</th>
<th>Cu</th>
<th>Cr</th>
<th>Pb</th>
<th>Ni</th>
<th>Fe</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alluvium</td>
<td>35,418</td>
<td><strong>0.19</strong></td>
<td>16</td>
<td>43</td>
<td>10</td>
<td>25</td>
<td>23,317</td>
<td>649</td>
</tr>
<tr>
<td>Beverly</td>
<td>41,776</td>
<td><strong>0.08</strong></td>
<td>20</td>
<td>51</td>
<td>8</td>
<td>31</td>
<td>25,701</td>
<td>688</td>
</tr>
<tr>
<td>Brantford</td>
<td>39,322</td>
<td><strong>0.20</strong></td>
<td>20</td>
<td>49</td>
<td>6</td>
<td>28</td>
<td>26,940</td>
<td>695</td>
</tr>
<tr>
<td>Toledo</td>
<td>53,001</td>
<td><strong>0.29</strong></td>
<td>19</td>
<td>55</td>
<td>7</td>
<td>28</td>
<td>26,771</td>
<td>714</td>
</tr>
<tr>
<td>p-value</td>
<td>0.213</td>
<td><strong>0.045</strong></td>
<td>0.628</td>
<td>0.230</td>
<td>0.593</td>
<td>0.542</td>
<td>0.696</td>
<td>0.886</td>
</tr>
</tbody>
</table>

Although there is a statistically significant difference in Cd concentrations between the four different soil types, all samples are below the MOEE (1996) background value of 1 ppm. Furthermore, all samples are below the 3 ppm Soil Clean-Up Criteria (MOEE, 1996) in Table A (Appendix 2).
The background concentration for Cu and Pb is 56 ppm. All soil samples contained less than 35 ppm of Cu and Pb. Furthermore, all samples are below the Soil Clean Up Criteria (Table A) of 150 and 200 ppm, respectively.

Chromium concentrations for 6 samples are above the background value of 67 ppm. Background exceedances occur in Brantford (3-2), Beverly (10-3, 14-2, 15-2) and Toledo (12-1, 12-2) soil samples. The spatial distribution of these samples is random. None of the samples exceed the Soil Clean Up Criteria (Table A) for Cr of 750 ppm.

Two Beverly soil samples, 14-2 and 15-2, are above the background concentration of 43 ppm for Ni. The average Ni concentration for each of the different soil types is less than 30 ppm, and below the Soil Clean Up Criteria (Table A) of 150 ppm.

Soil background concentrations of Zn should be less than 150 ppm (MOEE, 1996). All the soil samples were below the background and Soil Clean Up Criteria (Table A) for Zn.

Background concentrations for Al and Fe are not given in Table F. Based on the data gathered, it is proposed that the background concentration should be 66,518 ppm for Al and 35,085 ppm for Fe. These numbers are based on the 90 percentile of all samples collected and analysed for Al and Fe, following the procedure outlined by the MOEE Aquatic Sediment Quality Guidelines (1992).

The metal concentrations of all samples, regardless of soil type, were pooled into one of two categories: surficial samples or samples taken at depth. Surficial samples were those taken at a depth of 10 cm, samples at depth were those taken at 30 cm.

The mean Al surficial concentration is 37,965 ppm and at depth it is 48,001 ppm. Although Al concentration appears to increase with depth, statistically there is no significant
difference \( p = 0.062 \) between Al concentrations in surface samples and samples taken at depth (Table 2).

Table 2. P-values and various mean metal concentrations occurring in soil samples collected at depths of 10 and 30 cm, as calculated by the statistical package Minitab, are given below. Statistically significant values (i.e. \( p < 0.05 \)) are indicated in bold.

<table>
<thead>
<tr>
<th></th>
<th>Al</th>
<th>Cd</th>
<th>Cu</th>
<th>Cr</th>
<th>Ni</th>
<th>Pb</th>
<th>Fe</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>p-value</td>
<td>0.062</td>
<td>0.174</td>
<td>0.001</td>
<td>0.024</td>
<td>0.009</td>
<td>0.000</td>
<td>0.015</td>
<td>0.185</td>
</tr>
<tr>
<td>mean concentration 10 cm depth (ppm)</td>
<td>37,965</td>
<td>0.20</td>
<td>16</td>
<td>46.5</td>
<td>25.5</td>
<td>10.8</td>
<td>23,679</td>
<td>718</td>
</tr>
<tr>
<td>mean concentration 30 cm depth (ppm)</td>
<td>48,001</td>
<td>0.12</td>
<td>22</td>
<td>54.4</td>
<td>32.5</td>
<td>4.1</td>
<td>28,292</td>
<td>655</td>
</tr>
</tbody>
</table>

The mean Cd surficial concentration is 0.19 ppm and at depth it is 0.16 ppm. The mean Zn surficial concentration is 72 ppm, whereas at depth it is 66 ppm. Although it appears that the concentrations of Cd and Zn are decreasing with depth, these concentrations do not vary significantly with depth \( p = 0.174 \) and \( 0.185 \), respectively.

Cu, Cr, Pb, Ni and Fe all show statistically significant differences in metal concentration with depth \( p = 0.001, 0.024, 0.000, 0.009 \) and \( 0.015 \), respectively. Cu concentrations are higher at 30 cm depths in 11 of the 18 sampling locations. At 7 locations Cu concentrations are higher at the 10 cm depth. For the majority of the samples, there is a large difference in the Cu concentration between the two depths at each site. Cr, Ni (Figure 19) and Fe show the same general pattern. At sites 4, 8, 9, 13, 18 and 19 higher concentrations of Cu, Cr, Ni and Fe occur at the 10 cm depth whereas all other sites show
Figure 19. Ni concentrations at 10 cm and 30 cm depths in soils adjacent to Lake Gibson. Although there is a statistical difference between metal concentration and depth, no apparent trend is noted.

Figure 20. Lead concentrations are higher in soils at the 10 cm depth than at 30 cm.
higher concentrations at the 30 cm depth. Although the difference is statistically significant, the spatial variation between these 6 sites is random.

Pb also shows a wide range in concentration between the 10 cm and 30 cm depths at each sampling location (Figure 20). Unlike the other metals there is a significant difference (p<0.05), with higher Pb concentrations occurring at 10 cm depth.

**Total Metal Fraction- Soils from Viticultural Areas, Niagara Peninsula**

There are three soil samples that were above the Guideline for use at Contaminated Sites in Ontario, Table F (Ontario Typical Range soil concentrations (background) for Cu. Those samples are 1-1b, 1-2b and 6-1c. These samples have copper concentrations of 74, 75 and 60 ppm, respectively.

In all other soil samples, metal concentrations are below the Guideline for use at Contaminated Sites in Ontario Table A (Surface soil and Groundwater criteria for agricultural, residential/parkland, industrial/commercial land-use for a potable groundwater condition (Appendix 2). Thus there is no soil contamination problem with respect to Al, Cd, Cr, Ni, Pb, Fe and Zn.

All samples, irrespective of vineyard, were pooled into three depth categories of 10 cm, 30 cm and 60 cm. There is no statistical significance for metal concentration varying with depth for Al, Cd and Cu (Table 3). There is a statistical difference between Cr (p=0.001), Ni (p=0.000), Pb (p=0.004), Fe (p=0.032) and Zn (p=0.034) concentrations and depth. It appears that Cr, Ni (Figure 21) and Fe concentrations are lower at the surface (i.e. 10 cm) and concentrations increase with depth. This could indicate that Cr, Ni and Fe are
Figure 21. Nickel concentrations are lowest in the surficial soil samples and increase with depth. Chromium samples display a similar trend.

Figure 22. Lead concentrations occurring in the soil samples are highest in surficial samples (10 cm) and decrease with depth.
leached down through the soil profile. Pb shows the reverse trend, having higher concentrations at the surface and decreasing concentrations with depth (Figure 22). This may be attributed to the deposition of lead-carrying airborne particulates. Zn concentrations are similar to Pb concentrations in that they are higher at the surface and decrease with depth.

Table 3. Statistical analysis of soils from vineyards of the Niagara Peninsula (p-values and mean concentrations; in ppm).

<table>
<thead>
<tr>
<th></th>
<th>Al</th>
<th>Cd</th>
<th>Cu</th>
<th>Cr</th>
<th>Pb</th>
<th>Ni</th>
<th>Fe</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>p-value</td>
<td>0.188</td>
<td>0.435</td>
<td>0.961</td>
<td><strong>0.001</strong></td>
<td><strong>0.004</strong></td>
<td><strong>0.000</strong></td>
<td><strong>0.032</strong></td>
<td><strong>0.034</strong></td>
</tr>
<tr>
<td>10 cm</td>
<td>24,817</td>
<td>0.22</td>
<td>24</td>
<td>33</td>
<td>10</td>
<td>14</td>
<td>23,577</td>
<td>59</td>
</tr>
<tr>
<td>30 cm</td>
<td>33,830</td>
<td>0.23</td>
<td>23</td>
<td>40</td>
<td>5</td>
<td>17</td>
<td>25,713</td>
<td>51</td>
</tr>
<tr>
<td>60 cm</td>
<td>30,581</td>
<td>0.17</td>
<td>24</td>
<td>42</td>
<td>4</td>
<td>22</td>
<td>28,128</td>
<td>48</td>
</tr>
</tbody>
</table>

The mean metal concentrations and p-values from all 9 vineyards are listed in Table 4. There is a statistical difference in Cu, Cr, Pb, Ni and Fe concentrations occurring within these vineyards. Copper concentrations were highest in Vineyards 1 and 6, and lowest in Vineyards 4 and 7 (Figure 23). Zinc concentrations were higher in Vineyards 2 and 5, and lower in Vineyards 8 and 9 (Figure 24).

Chromium concentrations were higher in Vineyards 2, 3, 4, 5 and 6, and lower in Vineyards 1, 7, 8 and 9 (Figure 25). Iron concentrations exhibit the same trend as chromium, being higher in Vineyards 2, 3, 4, 5 and 6, and lower in Vineyards 1, 7, 8 and 9 (Figure 26). Pb concentrations were highest in Vineyards 1 and 8.
Figure 23. There is a statistical difference in soil copper concentrations occurring in the 9 vineyards. Vineyards 1 and 6 have the highest copper concentrations while vineyard 7 has the lowest concentration.

Figure 24. There is a statistical difference in soil zinc concentrations occurring in the 9 vineyards. Vineyards 2 and 5 have the highest zinc concentrations. Soil samples taken from Niagara on the Lake (vineyards 8 and 9) have lower values.
Figure 25. There is a statistical difference in chromium concentrations occurring in the 9 vineyards. Vineyards 2, 3, 5 and 6 have the highest copper concentrations, while vineyards 1, 7, 8 and 9 have lower concentrations.

Figure 26. There is a statistical difference in iron concentrations occurring in the 9 vineyards. Vineyards 2, 3, 4 and 5 have higher iron concentrations, while vineyards 1, 7, 8 and 9 have lower concentrations.
Table 4. p-values and mean metal concentrations for the 9 vineyard soil samples. All concentrations are in ppm and statistically significant differences are in bold.

<table>
<thead>
<tr>
<th></th>
<th>Al</th>
<th>Cd</th>
<th>Cu</th>
<th>Cr</th>
<th>Pb</th>
<th>Ni</th>
<th>Fe</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>p-value</td>
<td>0.108</td>
<td>0.395</td>
<td>0.001</td>
<td>0.000</td>
<td>0.016</td>
<td>0.083</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Vineyard 1</td>
<td>23,188</td>
<td>0.32</td>
<td>35</td>
<td>31</td>
<td>14</td>
<td>13</td>
<td>22,614</td>
<td>55</td>
</tr>
<tr>
<td>Vineyard 2</td>
<td>36,242</td>
<td>0.17</td>
<td>26</td>
<td>44</td>
<td>4</td>
<td>21</td>
<td>28,706</td>
<td>68</td>
</tr>
<tr>
<td>Vineyard 3</td>
<td>35,264</td>
<td>0.22</td>
<td>26</td>
<td>44</td>
<td>6</td>
<td>20</td>
<td>28,842</td>
<td>60</td>
</tr>
<tr>
<td>Vineyard 4</td>
<td>32,301</td>
<td>0.22</td>
<td>17</td>
<td>40</td>
<td>5</td>
<td>17</td>
<td>28,375</td>
<td>44</td>
</tr>
<tr>
<td>Vineyard 5</td>
<td>38,074</td>
<td>0.20</td>
<td>22</td>
<td>47</td>
<td>6</td>
<td>20</td>
<td>31,494</td>
<td>63</td>
</tr>
<tr>
<td>Vineyard 6</td>
<td>33,665</td>
<td>0.17</td>
<td>34</td>
<td>44</td>
<td>4</td>
<td>22</td>
<td>30,159</td>
<td>56</td>
</tr>
<tr>
<td>Vineyard 7</td>
<td>20,517</td>
<td>0.27</td>
<td>14</td>
<td>33</td>
<td>4</td>
<td>15</td>
<td>21,369</td>
<td>48</td>
</tr>
<tr>
<td>Vineyard 8</td>
<td>32,152</td>
<td>0.13</td>
<td>23</td>
<td>31</td>
<td>9</td>
<td>15</td>
<td>21,223</td>
<td>38</td>
</tr>
<tr>
<td>Vineyard 9</td>
<td>16,281</td>
<td>0.13</td>
<td>19</td>
<td>29</td>
<td>5</td>
<td>16</td>
<td>19,471</td>
<td>40</td>
</tr>
</tbody>
</table>

Originally it was thought that the differences in metal concentrations may be due to the geographic locations of the vineyards. The most obvious breakdown, based on geography, was to place the samples into one of two groups, those being above the escarpment and below the escarpment. Based on this categorization scheme, there was no significant difference for the Cd, Cu, or Pb concentrations. Al, Cr, Ni, Fe and Zn concentrations were higher in the samples taken above the escarpment (Table 5).
Table 5. p-values and mean metal concentrations for vineyard soil samples classified as taken above or below the escarpment. All concentrations are in ppm and statistically significant differences are in bold.

<table>
<thead>
<tr>
<th></th>
<th>Al</th>
<th>Cd</th>
<th>Cu</th>
<th>Cr</th>
<th>Pb</th>
<th>Ni</th>
<th>Fe</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>p-value</td>
<td>0.011</td>
<td>0.986</td>
<td>0.351</td>
<td>0.000</td>
<td>0.259</td>
<td>0.043</td>
<td>0.000</td>
<td>0.002</td>
</tr>
<tr>
<td>above</td>
<td>35,470</td>
<td>0.20</td>
<td>22</td>
<td>44</td>
<td>5</td>
<td>20</td>
<td>29,354</td>
<td>59</td>
</tr>
<tr>
<td>below</td>
<td>25,161</td>
<td>0.20</td>
<td>25</td>
<td>34</td>
<td>7</td>
<td>16</td>
<td>22,967</td>
<td>48</td>
</tr>
</tbody>
</table>

The statistics indicated that a third area existed, so the samples were re-organized to include Niagara-on-the-Lake, and the samples were statistically re-evaluated. With this classification scheme, there were no statistical differences in Cd, Ni and Pb concentrations. There were differences in Al, Cu, Cr, Fe, and Zn concentrations. Soil samples from Niagara-on-the-Lake have lower Cu, Cr, Fe and Zn concentrations than samples from other geographic locations (Table 6).

Table 6. p-values and mean metal concentrations for the vineyard soil samples classified as Niagara-on-the-Lake, above and below the escarpment. All concentrations are in ppm and statistically significant differences are in bold.

<table>
<thead>
<tr>
<th></th>
<th>Al</th>
<th>Cd</th>
<th>Cu</th>
<th>Cr</th>
<th>Pb</th>
<th>Ni</th>
<th>Fe</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>p-value</td>
<td>0.038</td>
<td>0.462</td>
<td>0.000</td>
<td>0.000</td>
<td>0.246</td>
<td>0.116</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>above</td>
<td>35,539</td>
<td>0.20</td>
<td>21</td>
<td>44</td>
<td>5</td>
<td>19</td>
<td>29,525</td>
<td>59</td>
</tr>
<tr>
<td>NOTL</td>
<td>22,983</td>
<td>0.18</td>
<td>19</td>
<td>31</td>
<td>6</td>
<td>15</td>
<td>20,688</td>
<td>42</td>
</tr>
<tr>
<td>below</td>
<td>30,706</td>
<td>0.24</td>
<td>31</td>
<td>40</td>
<td>8</td>
<td>19</td>
<td>27,205</td>
<td>57</td>
</tr>
</tbody>
</table>
Some of the samples showed varied chemistries that the three chosen areas did not exhibit. Based on the location of these samples, it became apparent that other geographic areas should be considered. The samples were once again reorganized to represent different areas of the Niagara Peninsula Viticultural Area, those being above the escarpment, plateau, Niagara-on-the-Lake, Winona and "other". Under this breakdown there is no statistical difference between Al or Cd concentrations in the vineyard soils. There are, however, statistically significant differences for Cu, Cr, Pb, Ni, Fe and Zn. Although there are differences, the trends are not as obvious as in the previous categorization schemes. The statistics indicate that Cu, Fe and Zn concentrations are lowest in Niagara-on-the-Lake, and are higher in the other locations. The statistics show that Cu concentrations are higher in Winona and "other", while being lower in Niagara-on-the-Lake, above the escarpment and the plateau locations. Cr and Fe concentrations are similar, being lower in Winona and Niagara-on-the-Lake, and higher in the three remaining areas. Pb concentrations are highest in Winona and lower in the remaining areas (Table 7).
Table 7. p-values and mean metal concentrations for soil samples in the Niagara Region.
All concentrations are in ppm and significant differences are in bold.

<table>
<thead>
<tr>
<th></th>
<th>Al</th>
<th>Cd</th>
<th>Cu</th>
<th>Cr</th>
<th>Pb</th>
<th>Ni</th>
<th>Fe</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>p-value</td>
<td>0.063</td>
<td>0.334</td>
<td>0.000</td>
<td>0.000</td>
<td>0.006</td>
<td>0.014</td>
<td>0.000</td>
<td>0.002</td>
</tr>
<tr>
<td>Winona</td>
<td>23,188</td>
<td>0.32</td>
<td>35</td>
<td>31</td>
<td>14</td>
<td>13</td>
<td>22,614</td>
<td>55</td>
</tr>
<tr>
<td>escarpment</td>
<td>35,539</td>
<td>0.20</td>
<td>21</td>
<td>44</td>
<td>5</td>
<td>19</td>
<td>29,525</td>
<td>59</td>
</tr>
<tr>
<td>NOTL</td>
<td>22,983</td>
<td>0.18</td>
<td>19</td>
<td>31</td>
<td>6</td>
<td>15</td>
<td>20,688</td>
<td>42</td>
</tr>
<tr>
<td>plateau</td>
<td>35,264</td>
<td>0.22</td>
<td>26</td>
<td>44</td>
<td>6</td>
<td>21</td>
<td>28,842</td>
<td>60</td>
</tr>
<tr>
<td>other</td>
<td>33,665</td>
<td>0.17</td>
<td>34</td>
<td>44</td>
<td>4</td>
<td>22</td>
<td>30,159</td>
<td>56</td>
</tr>
</tbody>
</table>

**Conclusions and Recommendations**

The environmental assessment of the Alluvium, Beverly, Brantford and Toledo soils in the vicinity of Lake Gibson, suggest the following conclusions:

1) With the exception of Cd, there is no statistical difference in metal concentration between the four different soil groups.

2) all soil samples are below the Provincial Background Guideline (MOEE, 1996) level for Cd, Cu, and Pb.

3) Based on the 90th percentile, the background concentration is calculated to be 66,518 ppm for Al and 35,085 ppm for Fe.

4) There is a significant difference (p<0.05) in metal concentration with depth for Cu, Cr, Pb, Ni and Fe. In addition, Pb concentrations are higher in the surficial samples than at depth in 16 out of 18 sampling locations.
The assessment of heavy metal in the soils in Niagara Peninsula Viticultural areas suggest the following conclusions about the ambient environmental conditions:

1. All 81 soil samples are below the Guideline for use at Contaminated Sites in Ontario Table A (Surface soil and Groundwater criteria for agricultural, residential/parkland, industrial/commercial land use for a potable groundwater condition) (Appendix 2) for all 8 metals. Thus there are no heavy metal contamination problems in these areas.

2. With the exception of three samples, the samples are below the Guideline for use at Contaminated Sites in Ontario Table F (Ontario Typical Range soil concentrations (background) for all 8 metals. The exceptions are in Cu, but they were only a few ppm higher than the guideline. It appears that metal concentrations in the vineyards fall below the background guideline.

3. There are statistical differences in Cr, Ni, Pb, Fe and Zn concentrations throughout the region. It appears that Cr, Ni and Fe concentrations are lower in surface samples and increase with depth. Pb and Zn show the opposite trend with Pb concentration being higher in surficial samples and decreasing with depth.

4. Cr, Fe and Zn concentrations are higher in vineyards that are above the escarpment and lower in vineyards classified as below the escarpment and “other”.

5. Vineyards located in areas designated as Niagara-on-the-Lake, Winona, the plateau, above the escarpment and “other” exhibit significant differences in metal chemistries.
RESULTS

WATER QUALITY

Water quality data were recorded at a number of sites throughout the year (Appendix 1). The pH of Lake Gibson ranged from 6.05 to 9.57. Overall the pH tends to be neutral to slightly basic. Lower pH readings occurred at sites 3 and at site 15 (Figure 27). Site 15 has been named “the leak” as liquid seeps out of a crack just below Beavardams Road (Figure 28). In the summer of 1997 the lowest recorded pH was 5.98 (leak) and the highest recorded pH was 9.57 (Table 8).

Table 8. Recorded pH readings below 6.5 or above 8.5 in Lake Gibson.

<table>
<thead>
<tr>
<th>Location</th>
<th>Date (1997)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(See Figure 15)</td>
<td>May 6</td>
</tr>
<tr>
<td>3</td>
<td>6.45</td>
</tr>
<tr>
<td>10</td>
<td>8.63</td>
</tr>
<tr>
<td>11</td>
<td>8.79</td>
</tr>
<tr>
<td>12</td>
<td>8.60</td>
</tr>
<tr>
<td>13</td>
<td>8.54</td>
</tr>
<tr>
<td>14</td>
<td>8.58</td>
</tr>
<tr>
<td>15</td>
<td>6.05</td>
</tr>
<tr>
<td>16</td>
<td>8.87</td>
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<tr>
<td>17</td>
<td>8.58</td>
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<tr>
<td>18</td>
<td>8.76</td>
</tr>
<tr>
<td>19</td>
<td>8.79</td>
</tr>
<tr>
<td>20</td>
<td>9.00</td>
</tr>
<tr>
<td>21</td>
<td>8.81</td>
</tr>
<tr>
<td>22</td>
<td>8.82</td>
</tr>
<tr>
<td>24</td>
<td>5.98</td>
</tr>
</tbody>
</table>
Figure 27. pH readings for sites 1, 2, 4 - 9 were taken on July 24, 1995. The readings for sites 3 and 10-24 were taken on May 27, 1997. Note the low pH at site 15.

Figure 29. Temperature readings for sites 1, 2, 4 - 9 were taken on July 24, 1995. The readings for sites 3 and 10-24 were taken on May 27, 1997. Fluctuations can be attributed to seasonal variations and other factors.
Figure 28. A mysterious "leak" was found in a ditch along Beaverdams Rd. Chemical analysis suggests that it is not "water".
Temperature measurements ranged between 8.4 and 26.1°C (Figure 29). In addition to having low pH, sites 3 (outfall) and 15 (leak) exhibit elevated electrical conductivity readings (Figure 30), as do sites 2 (outfall) and 6 (Frog Pond). Sites 6, 8 and 15 have low dissolved oxygen readings (Figure 31), and site 15 has a negative Eh (Figure 32). Turbidity readings are highest at sites 2, 4, 6, 9, 14, 20, 21 (Figure 33). The effects of nutrient loading in Lake Gibson are illustrated in Figures 34 and 35.

TPH

TPH QA/QC

A total of 11 duplicate samples were run on the Lake Gibson sediments analysed for TPH content. The average precision was 14%. The TPH extraction was carried out on samples containing waste oil and engine oil. The average recovery for these samples was 87%. The TPH blanks were high in TPH content, averaging 1500 ppm.

Sediment Chemistry - TPH

Sediment core 39a contains almost 50,000 ppm of TPH, which greatly exceeds the guideline of 1500 ppm. Cores 9, 11, 12, 17, 19, 20, 21, 25, 28, 32, 47, 52 and P1 contain over 10,000 ppm of TPH (Figure 36).

The sediment samples used for the TPH extraction were divided into two categories, surficial samples and samples taken at depth. There was no statistical difference (p=0.909) between these two categories, the average concentration of the surficial samples was 5,016 ppm and the average for deeper samples was 4,910 ppm.
Figure 30. Conductivity readings for sites 1,2, 4 - 9 were taken on July 24, 1995. The readings for sites 3 and 10-24 were taken on May 27, 1997. Note the increases at sites 2 and 3 (outfalls), 6 (Frog Pond) and 15 (the "LEAK").
Figure 31. Dissolved oxygen readings for sites 1, 2, 4 - 9 were taken on July 24, 1995. Readings for sites 3 and 10-24 were taken on May 27, 1997. Note the low readings for site 15 (LEAK) and site 6 (Frog Pond).

Figure 32. Eh readings for sites 10-24 were taken on May 27, 1997. The negative reading at site 15 (LEAK), indicates that this is not "normal water".
Figure 33. Turbidity readings for sites 1, 2, 4 - 9 were taken on July 24, 1995. The readings for sites 3 and 10-24 were taken on May 27, 1997. The Aesthetic Objective (AO) is 5 NTUs and the Aquatic Life (AL) criteria is 40 NTUs.
Figure 35. Early stage of lake eutrophication (excess growth of organic matter [algae] on the rocks) due to excess nutrient loading and increased clarity caused by zebra mussel filtration.
Figure 36. TPH concentrations throughout Lake Gibson exceed the Open Water Disposal guideline of 1500 ppm. Location 39a is of particular concern as concentrations exceed the guideline by several orders of magnitude.
There is a significant difference (p=0.000) in TPH concentrations throughout the lake. The highest concentrations are in areas R, S, T and Y, which correspond to cores taken near the Beavardams Community Centre and by the Welland Canal outfall (9,659-10,984 ppm), near the equalization channel (7,194 ppm), between Highway 406 and the Merrittville Highway (3,859 ppm), and a small area located in the southern portion of the lake (2,993 ppm). These locations represent areas of concern with respect to TPH as they exceed the oil and grease guideline of 1,500 ppm.

Average TPH concentrations below the 1,500 ppm guideline occur in areas I, K, P and V. These correspond to cores G1, 53-56, E4 and 60. Out of 87 samples, 67 samples exceed the Open Water Disposal Guideline of 1,500 ppm set by the MOEE.

Metals

QA/QC Results

A total of 27 duplicates and 17 NBS samples from Lake Gibson were evaluated by U.S. EPA method 3050. Metal concentrations occurring in the majority of the blank samples were below 1ppm. The overall precision and accuracy are summarized in Table 9.
Table 9. Mean concentrations of blanks, duplicates, NBS and expected recoveries for U.S. EPA Method 3050.

<table>
<thead>
<tr>
<th></th>
<th>Al</th>
<th>Cd</th>
<th>Cu</th>
<th>Cr</th>
<th>Ni</th>
<th>Pb</th>
<th>Fe</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blanks (ppm)</td>
<td>0.87</td>
<td>0.006</td>
<td>0.04</td>
<td>0.04</td>
<td>0.07</td>
<td>0.006</td>
<td>1.1</td>
<td>0.02</td>
</tr>
<tr>
<td>Duplicates (%)</td>
<td>9</td>
<td>14</td>
<td>10</td>
<td>10</td>
<td>9</td>
<td>17</td>
<td>12</td>
<td>21</td>
</tr>
<tr>
<td>NBS (%) Recovery</td>
<td>36</td>
<td>71</td>
<td>78</td>
<td>69</td>
<td>80</td>
<td>72</td>
<td>87</td>
<td>94</td>
</tr>
<tr>
<td>% 2704 US EPA 3050 Publication</td>
<td>n/a</td>
<td>90</td>
<td>82</td>
<td>61</td>
<td>85</td>
<td>90</td>
<td>n/a</td>
<td>90</td>
</tr>
</tbody>
</table>

**Metals**

Total metal concentrations are useful in determining areas of high elemental loading and thus may be used to extrapolate to point sources. Although metal speciation and complexation information is important from a toxicological aspect, it could not be determined from the total metal concentrations. The total metal content in the sediments will be presented with respect to provincial guidelines to evaluate their environmental status.

The guidelines used for the total metal fraction are based on two parameters, which are the LEL and the SEL. LEL is the Lowest Effect Level and at this level of contamination the chemicals in the sediment have no effect on the majority of sediment-dwelling organisms, at this level acute ecotoxic effects become apparent. The sediment is considered to be clean to marginally polluted. The SEL is the Severe Effect Level and at this level the sediment is considered heavily polluted and is likely to effect the health of bottom-dwelling
organisms (Persaud et al., 1992).

**Metals - Marlatt’s Pond**

In Marlatt’s Pond, there is no significant difference between metal concentration and depth for Al, Fe, Cd, Pb, Ni, Cu and Zn (Table 10), however there is a significant difference for Cr. Surficial samples having an average Cr concentration of 97 ppm and samples at depth having an average concentration of 72 ppm. Al concentrations in surficial samples average 29,800 ppm and those at depth average 38,860 ppm.

<table>
<thead>
<tr>
<th></th>
<th>Al</th>
<th>Cd</th>
<th>Cu</th>
<th>Cr</th>
<th>Ni</th>
<th>Pb</th>
<th>Fe</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>depth</td>
<td>0.071</td>
<td>0.806</td>
<td>0.227</td>
<td>0.026</td>
<td>0.176</td>
<td>0.279</td>
<td>0.821</td>
<td>0.228</td>
</tr>
<tr>
<td>location</td>
<td>0.001</td>
<td>0.496</td>
<td>0.109</td>
<td>0.257</td>
<td>0.031</td>
<td>0.670</td>
<td>0.034</td>
<td>0.013</td>
</tr>
</tbody>
</table>

There is no significant difference between metal concentration and location for Cd, Pb, Cr and Cu (Table 10). There are, however, significant differences between metal concentration and location for Al (p=0.001), Fe (p=0.034), Ni (p=0.031) and Zn (p=0.013). The highest Al concentrations are 108,590 ppm in core 4, 80,000 ppm in core 8 and 72,300 ppm in core 37a (Figure 37).

The highest Fe and Ni concentrations occur at the Beaverdams Road and Welland Canal Outfall locations, whereas the highest Zn concentrations only occur at the Beaverdams
Figure 37. Al concentrations in Mariatt's Pond sediments. Core 4 has the highest Al concentration approaching 110 000 ppm. Other hotspots are core 8 (by Beaverdams Community Center) and core 37a (by an outfall).

Figure 38. Fe concentrations in Mariatt's Pond sediments. Of the 17 cores, 11 exceed the SEL guideline of 40000 ppm. Fe is an environmental concern in these areas.
Road location. Samples exceeding the SEL guideline for Fe are 1-9, 37a and 39a (Figure 38). Cd concentrations exceed the LEL guideline at sites 1, 11, 12, 13 and 14 (Figure 39) while cores 6 and 7 show prominent peaks exceeding the SEL for Pb (Figure 40). Cr concentrations in the samples ranged from 27 to 250 ppm (Figure 41). The highest Ni concentrations occur in core 1 which was taken by Beaverdams Road and core 39a which was taken by the Welland Canal Outfall (Figure 42). The highest Cu concentrations occur in the following samples: core 1 (located by Beaverdams Road), core 9 (downstream from the Community Centre), core 10 (located near the corner of Kaye Ave and Beaverdams Road), and cores 11, 12, 14 and 39a (all in the vicinity of the Beaverdams Community Centre; Figure 43). Zn concentrations exceeding the SEL occur in cores 9 and 39a, both are located downstream from the Welland Ship Canal Outfall (Figure 44).

**Metals - Lake Gibson**

Overall 298 samples were studied, each of which was analysed for 8 metals and TPH, for a total of 2,384 analyses (Appendix 4). Samples from Marlatt’s Pond were analysed with a different chemical extraction method than the Lake Gibson samples, they are not included in the following discussion.

There is no significant difference between metal concentration and depth for Al, Cd, Cu, Cr, Ni, Pb and Zn. There is a significant difference between metal concentration and depth for Fe (Table 11), with surficial samples averaging 25,480 ppm and samples at depth averaging 28,150 ppm. Cd concentrations in surficial samples averaged 0.65 ppm and samples at depth averaged 0.50 ppm.
Figure 39. Cd concentrations in Marlatt's Pond sediments. Core 13 contains the highest Cd concentration, the next highest concentration occurs in core 1. Of the 17 cores only 5 are above the LEL guideline of 0.6 ppm.

Figure 40. Pb concentrations in Marlatt's Pond sediments. Of the 17 cores, 4 are above the SEL guideline of 250 ppm. Cores 11 and 6 are a concern as Pb concentrations are particularly high.
Figure 41. Cr concentrations in Marlatt's Pond sediments. Of the 17 cores, 5 are above the SEL guideline of 110 ppm, 12 are above the LEL.

Figure 42. Ni concentrations in Marlatt's Pond sediments. Of the 17 cores, none are above the SEL guideline. Cores 1 and 39a are above the LEL guideline of 110 ppm.
Figure 43. Cu concentrations in Marlatt's Pond sediments. Of the 17 cores, 7 exceed the SEL guideline of 110 ppm, 10 are above the LEL guideline.

Figure 44. Zn concentrations in Marlatt's Pond sediments. Cores 9 and 39a exceed the SEL guideline of 820 ppm. Of the 17 cores, 12 exceed the LEL guideline of 120 ppm.
Table 11. Statistical analysis of metal concentrations in Lake Gibson sediments with respect to depth and location (p-values). Statistically significant differences are in bold.

<table>
<thead>
<tr>
<th></th>
<th>Al</th>
<th>Cd</th>
<th>Cu</th>
<th>Cr</th>
<th>Ni</th>
<th>Pb</th>
<th>Fe</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>depth</td>
<td>0.827</td>
<td>0.088</td>
<td>0.469</td>
<td>0.136</td>
<td>0.122</td>
<td>0.537</td>
<td>0.044</td>
<td>0.658</td>
</tr>
<tr>
<td>location</td>
<td>0.000</td>
<td>0.008</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.006</td>
<td>0.000</td>
<td>0.000</td>
</tr>
</tbody>
</table>

There is a significant difference between metal concentration and location for all metals (Table 11). The highest Al concentrations occurred in samples taken from the cream-colored stream, averaging 59,580 ppm. Other samples containing elevated Al concentrations occurred near the Old Abandoned Road/Welland Canal Outfall (46,080 ppm) (Figures 45 and 46) and the Beaverdams Community Center (40,720 ppm). The majority of the samples contained less than 50,000 ppm of Al. The exceptions to this are the G2 samples which contained over 140,000 ppm of Al (Figure 47).

There is a significant difference between Fe concentration and depth (p=0.044), with surficial samples averaging 25,477 ppm whereas those at depth average 28,152 ppm. There are also significant differences with respect to Fe concentration and location (p=0.000). Fe concentrations averaged 35,700 ppm near Beaverdams Community Center, 32,580 ppm in the cream colored stream, 31,500 ppm near the Old Abandoned Road, and 30,000 ppm in the section of lake between Highway 406 and the Merrittville Highway. Cores 17, 18, 21, 23, 24, 29, 32, 45, 46, 53, 54, 56, C3 and P1 have Fe concentrations which exceed the SEL (Figure 48). Only cores 36, 43, 60 and G2 had concentrations below the LEL. Out of 219
Figure 46. Water level of Lake Gibson is controlled, in part, by channels and pipes under the jurisdiction of Ontario Hydro.
Figure 47. Al concentrations in Lake Gibson sediments. Although there are no guidelines for Al, concentrations at G2 may be a concern.

Figure 48. Fe concentrations in Lake Gibson sediments. Of the 49 cores, 13 exceed the SEL guideline of 40000 ppm, 32 are between the LEL and the SEL.
samples, 18 exceed the SEL and 169 exceed the LEL guideline for Fe.

There is a significant difference between Cd concentration and location (p=0.008). The highest average Cd concentrations (0.9050 ppm) occurred in samples taken near the Beaverdams Community Center. The highest Cd concentrations occur in cores 16, 24, 30, 31, 42, 47, 52, 60, C3 and P1 (Figure 49).

There is a significant difference between Pb concentration and location (Table 8). The highest recorded Pb concentrations were 108 ppm near the Beaverdams Community Center, 63 ppm just downstream from falls in southern arm of Lake Gibson, and 59 ppm near the Old Abandoned Road. Sample 30 exceeds the SEL guideline and samples 17 through to 31, 39b, 42, 44, 47, 52, 60, B1, C3 and P1 exceed the LEL guideline (Figure 50).

There is a statistical difference between Cu concentration and location (p=0.000). Samples taken near the Beaverdams Community Center, cream colored stream and just below the intake waterfalls contained 107 ppm, 74 ppm, and 12 ppm of Cu, respectively. Cores 19, 30, 31, 42, 47, 52, C1, C3, E4 and G2 all contain Cu concentrations which exceed the SEL guideline (Figure 51).

There is a statistical difference between Zn concentration and location (p=0.000). Samples contained, on average, 492 ppm of Zn in the cream colored stream, 397 ppm near the Beaverdams Community Center, 280 ppm near the Old Abandoned Road, 240 ppm in the vicinity of the equalization channel and at the western end of Lake Gibson. Zinc concentrations in cores 19, 31, 47, C3 and P1 exceed the SEL guideline (Figure 52).

There is a statistical difference between Cr concentration and location (p=0.000). The highest Cr concentrations occurred in samples taken from the cream colored stream,
Figure 49. Cd concentrations in Lake Gibson sediments. Of these samples, 23 exceed the LEL guideline of 0.6 ppm. The highest concentrations occur at sites 16, 24 and 31.

Figure 50. Pb concentrations in Lake Gibson sediments. Concentrations in core 30 exceed the SEL guideline of 250 ppm. Of the 49 samples, 23 are above the LEL guideline of 31 ppm.
Figure 51. Cu concentrations in Lake Gibson sediments. Of the 49 samples, 9 exceed the SEL guideline of 110 ppm and 35 exceed the LEL guideline of 16 ppm.

Figure 52. Zn concentrations in Lake Gibson sediments. Of the 49 cores, 5 exceed the SEL guideline of 820 ppm and 31 exceed the LEL guideline of 120 ppm.
averaging 146 ppm. Samples taken near the Beaverdams Community Center and Old Abandoned Road contained 60 ppm and 51 ppm, respectively. Cores 1, 30 and G2 contain Cr concentrations that exceed the SEL guideline of 110 ppm (Figure 53). Out of 219 samples 5 were above the SEL and 198 were above the LEL.

The Ni concentrations averaging 61-69 ppm were located in samples taken across from the equalization channel, near the Beaverdams Community Center, in the section of Lake Gibson bounded by Beaverdams Road and Decew Road, where a siphon/pipe goes under Beaverdams Road, and in the area opposite the Beaverdams Road bridge. Cores containing Ni concentrations exceeding the LEL guideline are 26, 37b, 38b, 50, 52, 54 and 55 (Figure 54).

DISCUSSION

Increasing awareness of environmental concerns calls for industrial development and sustainability within sound ecological and environmental strategies. To fulfill this mandate a database must be established that identifies areas of environmental concern. These concerns may address present-day events, events in the past, and events that have longer temporal aspects (Persaud et al., 1992). The Lake Gibson aquatic environment is one that deserves study as it serves many purposes, these being recreational, municipal and industrial. Furthermore, the drinking water source for St. Catharines and the surrounding area is the same as the source of water for Lake Gibson. Thus discharges to the lake, either past or present, may have direct or indirect effects on human health and on the lake’s ecosystem. In order to assess the environmental status of Lake Gibson, several parameters
Figure 53. Cr concentrations in Lake Gibson sediments. Samples 30 and G2 exceed the SEL guideline of 110 ppm. Of the 49 samples, 44 exceed the LEL guideline of 26 ppm.

Figure 54. Ni concentrations in Lake Gibson sediments. Of the 49 cores, 7 exceed the LEL guideline of 120 ppm.
were utilized, including water quality, metal content and TPH.

Water Quality

Temperature, pH, dissolved oxygen and other water quality parameters were taken at different sampling locations throughout the study period in order to assess the water quality of Lake Gibson. Although a one day reading is not an accurate indication of what occurs on a yearly basis, some measurements can be useful as they are a snapshot of the events that occurred at a particular time.

The normal pH range for aquatic systems is 6.5-8.5. Most living organisms, plant or animal, function most effectively at neutral or near neutral pH values (Berkes, 1979). The MOEE station at the bridge along Beaverdams Road records the pH of Lake Gibson at that particular location and the readings are fairly constant. The pH readings taken during this study varied from location to location and thus can be a good indicator of localized problems. The pH readings taken at Lake Gibson ranged from 5.98 to 9.57, overall the pH is neutral to slightly basic. There were, however, a few areas of concern. The lowest pH recorded was 6.05 at station 15. A pH reading of 6.72 was taken at site 16 (Figure 55), and both of these sites are near the “leak”. The pH of the leak was 5.98 and the lower pH readings at sites 15 and 16 may be the result of the leak mixing with the waters of Lake Gibson. Another low pH reading was recorded at site 3 (pH 6.3) which is next to an outfall. Sites corresponding to pH values greater than 8.5 were taken by Highway 406, Marlatt’s Road, the Welland Canal Outfall, near sewer outfalls, by Kaye Avenue, along Beaverdams Road, and by the Merrittville Highway. The MOEE data taken at Beaverdams Road does
Figure 55. The "leak" flows through a pipe into a creek, which empties into Lake Gibson.
not show fluctuations within the lake, thus large scale sampling is better at distinguishing problem areas. There are areas of concern within Lake Gibson that have pH readings above 8.5 or below 6.5, which can be attributed to sources of anthropogenic impact.

Temperature measurements are an important aspect of water quality as temperature significantly affects the solubility of gases (e.g. dissolved oxygen) and directly affects biological and chemical reaction rates (Berkes et al., 1979). High temperatures can have deleterious effects on receiving waters and aquatic life. This may be a factor as Lake Gibson receives discharges of cooling water from local industries (Acres International Limited, 1996). Temperature readings at sites 1, 2 and 4 through 9 were taken on July 24, 1995, between 1pm and 3 pm. Temperature readings for sites 3 and 10 through 24 were taken on May 27, 1997, between 10 am and noon. Sites 1, 2 and 4 through 9 had warmer water temperatures because the readings were taken later in the day. On July 24, 1995, the sun was shining all morning long and thus the shallow water had ample time to warm up. The readings taken in May were taken early in the morning. Temperatures in May were cooler, and as it was early in the morning the sun had not as yet heated the water. The differences in lake temperature can be attributed to seasonal and diurnal variations.

Electrical Conductivity is defined as the ability of a solution to conduct electricity (Manahan, 1993). Ionized chemical compounds present in surface waters, either naturally occurring or as a result of man’s activities, contribute to electrical conductance. Thus conductivity serves as a control parameter and is an excellent indicator of water quality because it is highly sensitive to variations in dissolved solids (Berkes, 1979). Sites 2, 3, 6 and 15 all show elevated electrical conductivity readings. Sites 2 and 3 are by storm water
outfalls which tend to contain ions. Site 6 is a small pond which contains pieces of rusting metal and other refuse which may influence the ion content of the water in that area. Site 15 is the “leak”, a small pool of water which flows through a pipe, under Beaverdams Road and into Lake Gibson. Iron-colored debris is visible at the bottom of the pool. The ions in storm water and in the leak may be influencing the electrical conductivity of the water in those area.

Ample dissolved oxygen (DO) is necessary to maintain satisfactory conditions for fish and other biological life in aquatic systems (Mason, 1991). Ideally, dissolved oxygen levels should be between 5 mg/L and 9.5 mg/L. Sites 6, 8 and 15 have DO readings below this criterion. There are many factors which affect DO levels. For example, DO decreases as temperature increases. In summer the sun heats shallow waters, thereby decreasing DO. In areas where leaf litter accumulates, DO decreases as a result of decomposition and the presence of microorganisms. In stagnant waters there is a lack of aeration and hence low DO. DO will decrease in areas where there is bio-oxidation of nitrogenous materials and where there is sewage and bacteria. All of these are plausible explanations for the low DO levels occurring in the frog pond. At site 15 the water is flowing, so a lack of aeration cannot be the reason for low DO levels. It is possible that the “leak” is leachate leaking from a nearby closed waste disposal site. A unique characteristic of leachate is that regardless of the ambient temperature, it has a temperature of about 11°C (U. Brand, personal communication). At site 15 the temperature was constantly around that mark. The other possibility is that the “leak” is coming from the nearby sewage pumping station as the bacteria in the sewage would decrease DO levels.
Eh is the EMF (electromotive force) generated between an electrode in any state and the H₂ electrode in the standard state (Manahan, 1993). Another way of saying this is that Eh defines the redox potential. A positive Eh implies that the environment is a weaker reducing agent than the standard H₂ electrode, and therefore is an oxidizing environment, having the ability to accept electrons from electron donors. Environments having a negative Eh are stronger reducing agents than the standard H₂ electrode. Therefore they function as electron donors and the environment is a reducing one (Faure, 1991). Water should have a positive Eh. The Eh at all but one site in Lake Gibson is positive, as it should be. Site 15 has a negative Eh, implying a reducing environment. The negative Eh at this site indicates that the fluid at this site is not "normal water". The low DO at this site also confirms this observation. For many sites around Lake Gibson the Eh is greater than 150 mV. At six sites the Eh is slightly lower than that, ranging from 90 to 120 mV. Site 16 is across the road from the leak where the leak mixes with water from Lake Gibson. The Eh at this site may be lower due to the impact of the leak. Site 17 is by an outfall and hence the discharge from the outfall may be affecting the Eh.

Turbidity is caused by the scattering of incident light by colloidal or suspended materials such as algae, bacteria, detritus, clay and other mineral substances. These materials decrease light penetration and thus inhibits photosynthetic organisms. Turbidity readings are highest at outfall sites, at the leak, downstream from the Beaverdams Community Centre and by the Welland Canal outfall. The Aesthetic Objective Guideline for Turbidity is 5 NTU. All water quality sampling locations within Lake Gibson exceed this objective. The Aquatic Life Guideline for fish is 40 NTU and several locations within Lake Gibson
exceed this guideline. Water quality data from other sources indicate that Lake Gibson waters are “somewhat turbid” (SNC/Sandwell, 1990).

Total Dissolved Solids (TDS) is a measure of dissolved materials in water. Common sources of TDS are sewage treatment plant effluents, municipal storm drainage, industrial discharges and erosion of soil (Berkes et al., 1979). The area between the Old Welland Canal and Lake Gibson has been used as a disposal site for excavated soil material (SNC/Sandwell, 1990). Dissolved solids such as wood sugars, lignin, cellulose and organic material from pulp and paper mills also decrease DO levels (Steele et al., 1979). Historically, such effluents have been discharged into the Old Welland Canal and Lake Gibson (Steele et al., 1979). Elevated TDS measurements were recorded at sites associated with the leak, with the Ontario Hydro Outfall and with municipal outfalls.

Eutrophication is the enrichment of waters by nutrients such as nitrogen and phosphorous. Sources include sewage treatment works, untreated sewage from farming activities, fertilizers, industrial wastes and storm drainage (Mason, 1991). Figures 34 and 35 illustrate the effects of nutrient loading in Lake Gibson. Lake Gibson is a eutrophic lake as classified by the result of a phosphorous loading plot. It contains moderate amounts of nutrients as compared to Southern Ontario river systems (SNC/Sandwell, 1990). The eutrophic nature of the lake is confirmed by the dominance of oligochaete and chironomid species. Furthermore, the Village of Beavertams was not serviced by the municipal Pollution Control Plant until the early 1990's and drainage from septic systems entered the lake (Acres International Limited, 1996).

Industrial areas can have negative impacts on the environment. A good example of
this is the industrial area along Beaverdams Road. One can see vegetative stress and the loss of aesthetic appeal (Figure 56).

There are several factors which affect toxicity, some of those factors are water hardness, temperature, pH and salinity. The temperature fluctuations within Lake Gibson can be attributed to seasonal and diurnal fluctuations, with the exception of the leak. Large scale testing for pH and other water quality parameters has highlighted the areas of Lake Gibson which are impacted by roadsalt, sewer outfalls, as well as municipal and industrial uses of the lake.

TPH QA/QC Discussion

A total of 11 duplicate samples were run on the Lake Gibson sediments analysed for TPH content, and the average precision was 14%. The TPH extraction was carried out on sediment samples which were spiked with known quantities of waste oil and engine oil. The average recovery for these samples was 87%. The TPH blanks were high in TPH content, averaging 1,500 ppm. This value was subtracted from the original TPH concentrations to account for any impurities.

TPH Discussion

The Guidelines for the Protection and Management of Aquatic Sediment Quality of Ontario (Persaud et al., 1992) set a guideline for oil and grease content at 0.15%. This includes vegetable, animal and mineral oils. Instead of the oil and grease test, TPH (Total Petroleum Hydrocarbons) is a more definitive test of organic pollution as it determines only
Figure 56. Industrial areas along Beaverdams Rd. depict two obvious impacts: vegetation kill and the loss of aesthetic appeal.
the non-volatile and non-polar hydrocarbon content (i.e. mineral oils and greases) in sediments. Since the oil and grease guideline includes TPH and no guidelines have been set for TPH, it is reasonable to assume that one could apply the 0.15% oil and grease guideline to the TPH determinations in order to reveal impacted areas.

In order to bring the sediment sample database down to a more manageable level, the lake was subdivided into different locations (Figure 57). Table 12 contains the breakdown of areas as for statistical purposes.

Table 12. Sediment core classification scheme by location within Lake Gibson.

<table>
<thead>
<tr>
<th>Area Groups</th>
<th>Core Numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>G1</td>
</tr>
<tr>
<td>J</td>
<td>46, 47, 48, 49</td>
</tr>
<tr>
<td>K</td>
<td>53, 54, 55, 56</td>
</tr>
<tr>
<td>L</td>
<td>44, 45, 61, 51, 50</td>
</tr>
<tr>
<td>M</td>
<td>10</td>
</tr>
<tr>
<td>N</td>
<td>B1</td>
</tr>
<tr>
<td>O</td>
<td>C1, C2, C3, G2</td>
</tr>
<tr>
<td>P</td>
<td>E4</td>
</tr>
<tr>
<td>Q</td>
<td>37, 38, 1, 2, 3, 5, 6</td>
</tr>
<tr>
<td>R</td>
<td>18, 19</td>
</tr>
<tr>
<td>S</td>
<td>7, 8, 9,11, 12, 13, 14, 16, 17, 20, 29, P1</td>
</tr>
<tr>
<td>T</td>
<td>21, 22, 23, 24, 25, 26, 27, 28</td>
</tr>
<tr>
<td>U</td>
<td>40</td>
</tr>
<tr>
<td>V</td>
<td>60</td>
</tr>
<tr>
<td>W</td>
<td>42, 43</td>
</tr>
<tr>
<td>X</td>
<td>33, 34, 36</td>
</tr>
<tr>
<td>Y</td>
<td>30, 31, 32, 37b, 38b, 39b, P2</td>
</tr>
<tr>
<td>Z</td>
<td>4</td>
</tr>
</tbody>
</table>
Figure 57. Sediment core classification scheme by location within Lake Gibson (Table 9). Area groups are represented as follows: I(•), J(○), K(●), L(□), M(▲), N(△), O(+), P(×), Q(●), R(○), S(▼), T(▽), U(+), V(×), W(α), X(★), Y(σ), Z(ε).
There is a significant difference (p=0.000) in TPH concentrations throughout the lake. The highest concentrations are in areas R, S, T and Y, which correspond to cores taken near the Beaverdams Community Centre and by the Welland Canal outfall, near the equalization channel, between Highway 406 and the Merrittville Highway, and a small area located in the southern portion of the lake (Figure 58). These represent areas of concern with respect to TPH as they exceed the oil and grease guideline of 1,500 ppm. Campbell, (1996) also reports TPH concentrations exceeding the MOEE guideline in the vicinity of the Welland Canal Outfall and Beaverdams Village. Water flowing from the Welland Ship Canal and into the area near the Beaverdams Community Center may contain ballast water from ships which traverse the Welland Canal. Ballast water may contain oil and grease which ultimately ends up in Lake Gibson (personal communication, local residents). There have also been train derailments in the vicinity of Lake Gibson, one in particular was said to have dumped railway cars full of crude oil into the lake (personal communication, local residents). Some of the TPH found in Lake Gibson sediments may be attributed to such historical events. The section of lake bound by the two highways may be impacted by oil and gasoline leaking from automobiles which enters the lake via runoff from rain or melting snow. In fact, the Spills Action Center of the MOEE reports that oil leaking from a car was directly discharged into Lake Gibson, (Acres Environmental Limited, 1992). The samples used for TPH were also analysed for Pb and Cd content. Cd concentrations were highest in areas R, S, T and Y, having 0.57, 0.84, 1.00 and 0.72 ppm, respectively. This is similar to the TPH concentrations, although there was overlap in the standard deviations. Pb concentrations were highest in the same four areas, having 33, 64, 37 and 36 ppm
Figure 58. Four areas within Lake Gibson raise environmental concerns. TPH (Total Petroleum Hydrocarbon) values significantly exceed the OWG of 1500 ppm (for oil & grease).
respectively. This indicates that the Pb and Cd are associated with the oil and grease in these four areas. As Pb and Cd are components associated with gasoline and automobile exhausts, it is reasonable to assume that some of the TPH impacts in the lake are due to the impact of roads/transportation.

TPH average concentrations below the 1,500 ppm guideline occur in areas I, K, P and V. These correspond to cores G1, 53-56, E4 and 60. Core 60 was taken in the Old Welland Canal system, just before the falls. This indicates that sediments in the area prior to Lake Gibson have low oil and grease content. This could either imply that the sediments from the Welland Canal have a low TPH content, or that water at this point is flowing so quickly that the sediments (and ultimately the oil and grease) do not settle out. The core labelled E4 was taken from a creek right across the road from an industrial complex. It is interesting to note that the average TPH of this core was 1,453 ppm, while the cores taken further upstream (less than 20 m away) averaged 2,712 ppm. This raises the question “why does the TPH content drop off so rapidly when the creek barely flows?” The answer may be that although water flow in the creek was low at the time of sampling, there might have been higher water flow/discharge in the past. Cores 53-56 were taken in the western end of the lake, between Beaverdams Road and the 406. Water flow is quite rapid through this section and as a result the sediments (and TPH) do not have time to settle out in this area. And lastly, core G1 was taken at the very end of the lake, prior to Lake Moodie. It is the only core taken in this section as it was impossible to get a core from shore due to large rocks and the engineered shoreline. Furthermore, obtaining a core from the inflatable boat was impossible due to very dangerous water flow conditions. At site G1, the water flow was less turbulent than in other
sections of the lake. The core has an average TPH content of 1,373 ppm, which is below the 1,500 ppm guideline. Once again the implications are that at this point the sediments (oil and grease) have settled out by this point and hence would not flow into Lake Moodie nor Twelve Mile Creek. Another explanation is that the currents just prior to this area are strong and hence the sediments (oil and grease) are carried out into Lake Moodie and they do not settle in the G1 area.

The sediment samples used for the TPH extraction were divided into two categories, surficial samples and samples taken at depth. Although there was no statistical difference (p=0.909) between these two categories, the average concentration of the surficial samples was 5,016 ppm and the average for deeper samples was 4,910 ppm. This implies that TPH contamination of the sediments is not a historical problem, but one that continues to the present day. The TPH loading of the lake has not decreased over the years.

In summary, 67 out of 87 samples exceed the Open Water Disposal Guideline of 1500 ppm set by the MOEE. The historical and present day use of Lake Gibson have negative impacts on the sediments, as shown by elevated TPH concentrations which exceed provincial guidelines. The only two exceptions are samples taken from the Welland Canal and G1. The low TPH content in these samples may be attributed to water flow and sediment dynamics.

Contaminants can be transported and as a result they are not necessarily deposited near their source of origin (Yappa et al., 1994). Once in a river or lake, they can travel over large distances. The oil and grease levels observed in Lake Gibson sediments may be attributed to oil spills that occurred in the “Old” Welland Canal, or to industrial dumping,
or other mishaps/accidents such as train derailments and point sources such as roadways.

**Metals QA/QC Discussion**

A total of 27 duplicates and 17 NBS samples from Lake Gibson were evaluated by U.S. EPA method 3050. Metal concentrations occurring in the majority of the blank samples were below 1 ppm, indicating the purity of water and acids used as well as good laboratory procedures (i.e. no cross contamination). The average of the blanks per metal was subtracted from each sample in order to account for any impurities.

With regard to Cd there is an average of 14% difference between the duplicates. The lower precision may be explained by the facts that Cd is easily volatilized and that the concentrations in the samples were low. An explanation for the lower precision in the Pb and Zn duplicate samples may be that the sediments were not homogeneous and as a result the extraction of those particular metals was affected. With regards to recovery, Al is trivalent and hence getting more than 35% recovery is unusual. Al recovery from NBS samples tends to vary depending on the digestion procedure used and depending on the laboratory used, thus having slightly more than 35% recovery would not be unusual (Johnson, B., personal communication).

**Metals**

**Marlatt’s Pond**

In Marlatt’s Pond there is a significant difference between metal concentration and depth for Cr. Surficial samples having an average Cr concentration of 97 ppm and samples
at depth having an average concentration of 72 ppm, implicating that Cr deposition is relatively recent. The concentrations of Al, Ni, Fe and Zn vary significantly between sampling locations. The intersection of Beaverdams Road and Kaye Avenue has high concentrations of Al, Fe, Ni, Zn and Cu. Similarly, samples taken from the Old Abandoned Road contain high concentrations of Al, Fe, Ni and Cu. Samples taken near outfalls contain high amounts of Al.

**Lake Gibson**

Overall 298 samples were collected from Lake Gibson, each of which was analysed for 8 metals and TPH (Appendix 4). Samples from Marlatt’s Pond were analysed with a different chemical extraction method than the Lake Gibson samples, they are not included in the following discussion.

There are no Ministry guidelines set for Al. Despite that, it is well known that aluminum toxicity increases with decreases in pH, thus Al concentrations are a more of a concern in lakes with low pH (Sulzberger et al., 1990). Furthermore, aluminum in freshwater systems can bioaccumulate and have toxic effects on fish, as well as other biota (Kramer, 1993). This is especially important in stagnant waters where aluminum and other elements are not readily flushed out. For example, the Frog Pond is an enclosed water body. DO readings taken on July 24, 1995, confirm the stagnant nature of this pond. The sample with the highest recorded Al concentration comes from the intersection of Kaye Avenue and Beaverdams Road, containing 108,590 ppm. Other hotspots include the area just down stream from the Beaverdams Community Centre, the outfall along Beaverdams Road and
the cream colored stream. The cream colored stream contains a fair amount of leaf debris. When the debris is disturbed, black water and oil sheens become visible, as does the escape of gas (Figure 59). The surrounding waters in this area have been described as “grey with floating bottom matter and a great deal of H₂S and CH₄” (Ministry of Natural Resources, 1974). Possible sources of Al may be accidental, from the Welland Ship Canal, discharge from pulp and paper mills, or industrial complexes. In February of 1992 there was a reported spill of chrome-aluminum alloy which directly entered Lake Gibson (Acres Environmental Limited, 1996).

The lowest Al concentrations occur samples taken from the Welland Ship Canal. Reasons for the low concentration may be due to water and sediment dynamics. Water flow is high in this area and as a result the metals may not have enough of time to settle out. Another feasible explanation is that the incoming sediments may not be contaminated. Lastly, the amount and type of clay in the area may be influencing adsorption rates. Another area of low Al concentrations corresponds to the southern arm of the lake. This could be because there is another outfall on that side, which means faster flowing waters which would not allow for the metals to settle out in that area. There is a big drop in water level of 1m or more at the bridge at Beaverdams Road. In this area the water flow is fast, whirl pools are forming and there may be little or no time for sediments (metals) to settle out. There is a statistical difference between Fe concentration and depth (p=0.044). Surficial concentrations average 25,477 ppm whereas those at depth average 28,152 ppm, indicating that Fe loading in sediments has decreased over time. Furthermore, Fe concentrations vary with location. The highest concentrations occur near the Old Abandoned Road. Perhaps
Figure 59. This stream is cream-colored and covered with leaf debris. Disturbance of this top layer reveals black bottom sediments, and allowed the escape of gas and the pooling of an oil sheen.
the road acts as a barrier and sediments settle out on the opposite side of the barrier, thus being protected from fast flowing waters from intake pipe. Other areas of concern include the vicinity of the Beaverdams Community Center, the cream colored stream and the section of lake located between Highway 406 and Merrittville Highway. The lowest Fe concentrations occur in the Welland Ship Canal, prior to entry into Lake Gibson. The reason for the low Fe concentration may be that water flows are high at this point and the metal does not have time to settle out, or that what is incoming to the lake may not be contaminated at this point.

The crustal abundance of Cd is around 0.2 ppm. Levels found in sandstones and limestones range from < 0.001 - 1.6 ppm (Fergusson, 1990). There is some association of Cd with organic matter, higher Cd levels are found in peat (0.37-190 ppm) and crude oil (0.01-16 ppm) (Fergusson, 1990). Cd is used in electroplating, anticorrosive coatings, pigments, as a stabilizer in PVC, in Ni/Cd batteries, in alloys, and in control rods for nuclear reactors. Cd has a residence time of 360-720 days in lakes (Fergusson, 1990.) Cd is a relatively mobile element in the environment, and the cation Cd$^{2+}$ persists over a wide range of pH values. Cd is a cause for concern, as its toxicity may be either acute or chronic. A general increase of trace metal levels in lake waters may be ecologically hazardous as elements such as Cd and Cu might cause negative effects even at concentrations slightly above natural background levels (Borg and Johansson, 1989) Even at very low concentrations Cd can accumulate in tissues and cause developmental abnormalities in fish. Furthermore, crustacea and algae tend to be particularly sensitive to Cd (Hellawell, 1988). Urban runoff may contribute Cd as it might contain metals released from the corrosion of
The highest Cd concentrations in Lake Gibson sediments occur downstream from the Welland Canal, near the equalization channel, in the cream colored stream and near the Beaverdams Community Centre. The sources may include the past and present uses of the Welland Canal, as well as industrial effluents.

Pb is used in batteries, as a petroleum additive, in rolled and extruded products, pigments, alloys, cable sheathing and ammunition (Hellawell, 1988). It may be introduced into water from various wastes including industrial effluents and automobile exhausts (Berkes, 1979). Pb has a residence time of 25 days in lakes, and 400-3000 years in soil (Fergusson, 1990). Gasoline and pigments found in painting and staining products are often the sources of Pb found in urban runoff (Schmidtke, 1988). One would expect that Pb in a mineral phase would leach down into the deeper sediments (Borg and Johansson, 1989). Pb concentrations vary throughout Lake Gibson. The highest concentrations occur near the Beaverdams Community Center, the Old Abandoned Road and the western end of Lake Gibson just before it enters Lake Moodie. The latter site experiences lower flow rates and thus it could be that the sediments (metals) are settling out at this point. It is possible that lead is a heavier element and thus can settle out more readily than the other metals.

The source of Cu in urban runoff may be from the corrosion of Cu plumbing and from electroplating wastes. Cu is commonly used as an algicide and Cu compounds are highly toxic to aquatic life (Berkes, 1979). The toxicity of Cu is affected by temperature, dissolved oxygen concentration and pH (Hellawell, 1988). The highest Cu average concentrations occur in samples near the Beaverdams Community Center, cream colored
stream and by the intake pipe just below the waterfalls. Cu is an environmental concern for Lake Gibson.

Zn occurs only in trace amounts in surface waters as the Zn ion is believed to adsorb strongly and permanently on particulate matter which settles out of suspension (Berkes, 1979). Zn is commonly found in urban runoff as it is a component of automobile tires and a common ingredient in road salt. It is also a component of pigment in painting and staining products (Schmidtke, 1988). Zn concentrations also vary with location with the highest concentrations occurring in the cream colored stream across from an industrial complex. Other areas of concern are the Beaverdams Community Center, the Old Abandoned Road, areas near the equalization channel, and at the end of Lake Gibson prior to Lake Moodie. Ironically this last area was thought to contain “cleaner” sediments as flow rates are low and other metal concentrations were relatively low in this area.

Urban runoff may contain Cr as this metal is released from the corrosion of alloys and plated surfaces and from electroplating wastes. Cr is also used in pigments found in painting and staining products (Schmidtke, 1988). It is used as a tanning agent in the leather industry and in the manufacture of dyes, explosives and paper. As mentioned previously, there is a reported spill of chrome-aluminum alloy which directly entered Lake Gibson. The highest Cr concentrations occur in the cream colored stream, and exceed the SEL guideline. Other areas of concern include the Beaverdams Community Center area the Old Abandoned Road. Out of 219 samples 5 were above the SEL and 198 were above the LEL, thus Cr is an environmental concern for Lake Gibson.

Ni concentrations do vary with location, the highest being in the Welland Canal prior
to entry into Lake Gibson, near the equalization channel, near the Beaverdams Community Center and the section of lake where the submerged culvert passes underneath Beaverdams Road. The majority of samples are below the LEL guideline for Ni and therefore Ni are not an environmental concern. This may partially be due to companies complying with government guidelines and regulations. In instances where metal concentrations exceed the SEL, acute toxicity testing is suggested (Table 13).

Table 13. Summary of areas within Lake Gibson whose sediments should be tested for acute toxicity.

<table>
<thead>
<tr>
<th>Metal</th>
<th>Core Number</th>
<th>Areas of Lake Gibson</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cr</td>
<td>- 1, 2, 5, 8, 9, 10, 30, 39a, C3, G2</td>
<td>- intersection of Beaverdams Road and Kaye Ave - near Beaverdams Community Center - cream colored stream</td>
</tr>
<tr>
<td>Cu</td>
<td>- 1, 9, 10, 11, 12, 14, 30, 31, 39a, 19, 42, 47, 52</td>
<td>- intersection of Beaverdams Road and Kaye Ave - near Beaverdams Community Center - near Old Abandoned Road - between Highway 406 and Merrittville Highway - near submerged culvert</td>
</tr>
<tr>
<td>Pb</td>
<td>- 6, 11, 12, 30, 39a</td>
<td>- intersection of Beaverdams Road and Kaye Ave - near Beaverdams Community Center</td>
</tr>
<tr>
<td>Fe</td>
<td>- 1 - 8, 37a, 9, 17, 18, 21, 23, 24, 29, 32, 39a, P1, 45, 53, 54, 49, C3</td>
<td>- intersection of Beaverdams Road and Kaye Ave - entire area heading west from old abandoned road towards Beaverdams Road - area bound by Beaverdams, Decew and Hwy 406 - between Highway 406 and Merrittville Highway - cream colored stream</td>
</tr>
<tr>
<td>Zn</td>
<td>- 9, 19, 31, 39a, P1, 47, C3</td>
<td>- intersection of Beaverdams Road and Kaye Ave - near Old Abandoned Road - near Beaverdams Community Center - between Highway 406 and Merrittville Highway - cream colored stream</td>
</tr>
</tbody>
</table>
All samples taken from Lake Gibson were classified according to depth for statistical evaluation. In all cases, there was no significant difference between metal concentration and depth. It does appear that Cd, Cu, Cr and Zn concentrations are slightly higher in surficial samples and lower at depth. Conversely, Al, Ni, Pb and Fe concentrations appear to increase with depth.

The accumulation of metals and TPH in certain locations may be a function of past and present point sources and non-point sources of contaminants such as industrial effluents, storm water drainage, train derailments, sewage and other sources of contaminants. There are several areas of environmental concern throughout Lake Gibson, most notably the cream colored stream, the leak, and the areas near the Old Abandoned Road and the Beaverdams Community Center.

CONCLUSIONS

A Shelby Corer was used to obtain 66 cores of sediment from Lake Gibson, which were classified according to lithology and other parameters into 298 samples. A suite of 122 soil samples was collected in the region and vicinity of Lake Gibson. All were tested for a set of metals and some for Total Petroleum Hydrocarbons (TPH). Evaluation of the results leads to the following conclusions:

1. Metal concentrations of Al, Cd, Cu, Cr, Pb, Ni, Fe and Zn in soils from the Niagara Region are well below background limits set by the Ministry of the Environment and Energy (MOEE) for provincial soils.
2. There is a spatial and depth difference for some of the metals within the various soils. The Cr, Ni and Pb contents of soils vary throughout the region (p<0.05). In addition, Pb contents tend to be highest in surficial soil samples (p<0.05), an observation consistent with deposition by airborne particulates.

3. The Ni contents of sediments from Lake Gibson fall below the LEL (Lower Effect Level) guideline specified by the MOEE for aquatic ecosystems.

4. All other metal contents exceed the LEL, and in some instances they also exceed the SEL (Severe Effect Level) guideline. In this instance acute toxicity testing of the sediments is required to assess impact on the aquatic biota.

5. Specifically, areas associated with outfalls, roadways, railways and industrial activities are all degrading the local ecosystem.

6. Mineral oil and greases are a major environmental concern in the sediments of Lake Gibson. Of the 240 samples tested for TPH, 200 samples exceed the MOEE Open Water Disposal Guideline of 1500 mg/kg.

7. Four areas within Lake Gibson are especially degraded with respect to TPH. One area is just downstream from the Old Welland Canal divergence point and waterfall. Other areas of concern are located just south of Beaverdams Road and just west of the Ontario Hydro control pipes; south of the Village of Beaverdams. The fourth area of environmental concern and TPH impact is located between Highway 406 and Merrittville Highway.
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APPENDIX 1

1. Water Quality Data
# Appendix #1 - Water Quality Data

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APPENDIX 2

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2. Soil Data from Viticultural Areas
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APPENDIX 3

1. Stratigraphic, Sedimentologic and Instrumentation Log
STRATIGRAPHIC, SEDIMENTOLOGIC AND INSTRUMENTATION LOG

Date: December 27, 1996. Field Supervisor: UB. Core Method: Shelby Tube Corer.

Location: Lake Gibson, Thorold, Ontario (Cores 16, 17, 18 and 19).

Core #16

<table>
<thead>
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<td>16-1</td>
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<tr>
<td>Dark brown to black silty clay</td>
<td>16-2</td>
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<td>Dark brown silty clay</td>
<td>16-3</td>
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<tr>
<td>Light brown clay</td>
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<td>Light brown clay</td>
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Core #17

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<tr>
<td>Green algae</td>
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<tr>
<td>Light brown to dark brown silty clay</td>
<td>17-2</td>
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<tr>
<td>Black silty clay</td>
<td>17-3</td>
</tr>
<tr>
<td>Slight hydrocarbon odour</td>
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</tr>
<tr>
<td>Light brown to grey clay</td>
<td>17-4</td>
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Core #18

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<td>Organic material (wood pieces)</td>
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<tr>
<td>Black silty clay</td>
<td>18-3</td>
</tr>
<tr>
<td>Strong hydrocarbon odour</td>
<td></td>
</tr>
<tr>
<td>Brown to black clay</td>
<td>18-3</td>
</tr>
<tr>
<td>Ferrous colored flakes</td>
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Core #19

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<td>19-2</td>
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<tr>
<td>Strong hydrocarbon odour</td>
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<tr>
<td>Black to grey clay</td>
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</tr>
<tr>
<td>Hydrocarbon odour</td>
<td></td>
</tr>
<tr>
<td>Black to dark grey clay</td>
<td>19-4</td>
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<tr>
<td>Organic material (roots)</td>
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<tr>
<td>Dark grey clay</td>
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<tr>
<td>Organic material (roots)</td>
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<tr>
<td>Light black/grey clay</td>
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<td>Lots of organic matter (roots)</td>
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STRATIGRAPHIC, SEDIMENTOLOGIC AND INSTRUMENTATION LOG

Date: December 27, 1996  Field Supervisor: UB  Core Method: Shelby Tube Corer

Location: Lake Gibson, Thorold, Ontario (Cores 20, 21, 22 and 23)

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<td>Green algae</td>
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<td></td>
<td>Organic material (roots)</td>
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<tr>
<td>20-2</td>
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</tr>
<tr>
<td></td>
<td>Hydrocarbon odour</td>
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<td>Organic material (roots)</td>
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<td>Dark brown to black silty clay</td>
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<td>21-3</td>
<td>Light brown to grey silty clay</td>
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<td>21-4</td>
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<td>Silty clay</td>
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<td>Golden oily shine</td>
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<td>Hydrocarbon odour</td>
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<td>Strong Hydrocarbon odour</td>
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Core #20

Core #21

Core #22

Core #23
STRATIGRAPHIC, SEDIMENTOLOGIC AND INSTRUMENTATION LOG

Date: January 7, 1997. Field Supervisor: UB Core Method: Shelby Tube Corer

Location: Lake Gibson, Thorold, Ontario (Cores 24, 25a, 25b and 26)

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<tr>
<td>Light brown to black clay</td>
<td>25-3a</td>
</tr>
<tr>
<td>Pebbles</td>
<td></td>
</tr>
<tr>
<td>Hydrocarbon odour</td>
<td></td>
</tr>
<tr>
<td>Light brown to black clay</td>
<td>25-4a</td>
</tr>
<tr>
<td>end of core</td>
<td></td>
</tr>
</tbody>
</table>

Core #26

<table>
<thead>
<tr>
<th>Description</th>
<th>Sample #</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light brown sandy clay</td>
<td>26-1</td>
</tr>
<tr>
<td>Hydrocarbon odour</td>
<td></td>
</tr>
<tr>
<td>Light to dark brown clay</td>
<td>26-2</td>
</tr>
<tr>
<td>Black streaks</td>
<td></td>
</tr>
<tr>
<td>Black clay</td>
<td>26-3</td>
</tr>
<tr>
<td>Strong hydrocarbon odour</td>
<td></td>
</tr>
<tr>
<td>end of core</td>
<td></td>
</tr>
</tbody>
</table>

Core #25b

<table>
<thead>
<tr>
<th>Description</th>
<th>Sample #</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dark brown clay</td>
<td>25-1b</td>
</tr>
<tr>
<td>Strong hydrocarbon odour</td>
<td></td>
</tr>
<tr>
<td>Light brown clay</td>
<td>25-2b</td>
</tr>
<tr>
<td>Strong Hydrocarbon odour</td>
<td></td>
</tr>
<tr>
<td>Pink tint</td>
<td></td>
</tr>
<tr>
<td>Light brown clay</td>
<td>25-3b</td>
</tr>
<tr>
<td>Strong hydrocarbon odour</td>
<td></td>
</tr>
<tr>
<td>Dark brown clay</td>
<td>25-4b</td>
</tr>
<tr>
<td>Hydrocarbon odour</td>
<td></td>
</tr>
<tr>
<td>Organic matter</td>
<td></td>
</tr>
<tr>
<td>Golden glitter</td>
<td></td>
</tr>
<tr>
<td>end of core</td>
<td></td>
</tr>
</tbody>
</table>
**STRATIGRAPHIC, SEDIMENTOLOGIC AND INSTRUMENTATION LOG**

**Location:** Lake Gibson, Thorold, Ontario (Cores 27, 28, 29 and 32)

<table>
<thead>
<tr>
<th>Description</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Dark brown silty clay</td>
<td>27-1</td>
</tr>
<tr>
<td>Hydrocarbon odour</td>
<td></td>
</tr>
<tr>
<td>Lighter brown silty clay</td>
<td>27-2</td>
</tr>
<tr>
<td>Strong hydrocarbon odour</td>
<td></td>
</tr>
<tr>
<td>Golden shiny</td>
<td></td>
</tr>
<tr>
<td>Dark brown silty clay</td>
<td>27-3</td>
</tr>
<tr>
<td>Strong hydrocarbon odour</td>
<td></td>
</tr>
<tr>
<td>Black silty clay</td>
<td>27-4</td>
</tr>
<tr>
<td>Strong hydrocarbon odour</td>
<td></td>
</tr>
<tr>
<td>Golden shine</td>
<td></td>
</tr>
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</tbody>
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Core #27

<table>
<thead>
<tr>
<th>Description</th>
<th>Sample #</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light to dark brown clay</td>
<td>29-1</td>
</tr>
<tr>
<td>Strong hydrocarbon odour</td>
<td></td>
</tr>
<tr>
<td>Light brown silty clay</td>
<td>29-2</td>
</tr>
<tr>
<td>Strong hydrocarbon odour</td>
<td></td>
</tr>
<tr>
<td>Organic matter</td>
<td></td>
</tr>
<tr>
<td>Brown to grey clay</td>
<td>29-3</td>
</tr>
<tr>
<td>Strong hydrocarbon odour</td>
<td></td>
</tr>
<tr>
<td>Organic matter (roots)</td>
<td></td>
</tr>
<tr>
<td>end of core</td>
<td></td>
</tr>
</tbody>
</table>

Core #29

<table>
<thead>
<tr>
<th>Description</th>
<th>Sample #</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light to dark brown clay</td>
<td>32-1</td>
</tr>
<tr>
<td>Strong hydrocarbon odour</td>
<td></td>
</tr>
<tr>
<td>Dark brown to black clay</td>
<td>32-2</td>
</tr>
<tr>
<td>Strong Hydrocarbon odour</td>
<td></td>
</tr>
<tr>
<td>Black to dark brown clay</td>
<td>32-3</td>
</tr>
<tr>
<td>Hydrocarbon odour</td>
<td></td>
</tr>
<tr>
<td>Black in dark brown clay</td>
<td>32-4</td>
</tr>
<tr>
<td>Hydrocarbon odour</td>
<td></td>
</tr>
<tr>
<td>Light brown to black clay</td>
<td>32-5</td>
</tr>
<tr>
<td>Organic matter</td>
<td></td>
</tr>
<tr>
<td>end of core</td>
<td></td>
</tr>
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Core #32
### STRATIGRAPHIC, SEDIMENTOLOGIC AND INSTRUMENTATION LOG

**Date:** December 27, 1996  
**Field Supervisor:** UB  
**Core Method:** Shelby Tube Corer

**Location:** Lake Gibson, Thorold, Ontario (Cores 33, 34, 36 and 39b)

<table>
<thead>
<tr>
<th>Core #33</th>
<th>Core #34</th>
<th>Core #36</th>
<th>Core #39b</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Description</strong></td>
<td><strong>Sample #</strong></td>
<td><strong>Description</strong></td>
<td><strong>Sample #</strong></td>
</tr>
<tr>
<td>Light black silty clay</td>
<td>33-1</td>
<td>Light brown to grey silty clay</td>
<td>34-1</td>
</tr>
<tr>
<td>Manure odour</td>
<td></td>
<td>Pebbles</td>
<td></td>
</tr>
<tr>
<td>Organic matter (wood pieces)</td>
<td></td>
<td>Ferrous streak</td>
<td></td>
</tr>
<tr>
<td>Light brown to black silty clay</td>
<td>33-2</td>
<td>Light black clay</td>
<td>34-2</td>
</tr>
<tr>
<td>Black flakes</td>
<td></td>
<td>Golden shine</td>
<td></td>
</tr>
<tr>
<td>Organic matter (wood pieces)</td>
<td></td>
<td>Organic matter (wood pieces)</td>
<td></td>
</tr>
<tr>
<td>Light brown silty clay</td>
<td>33-3</td>
<td>Light brown silty clay</td>
<td>34-3</td>
</tr>
<tr>
<td>Organic matter (roots)</td>
<td></td>
<td>Organic matter (wood pieces)</td>
<td></td>
</tr>
<tr>
<td>Light brown to grey clay</td>
<td>33-4</td>
<td>Light brown silty clay</td>
<td>34-4</td>
</tr>
<tr>
<td>Organic matter (wood pieces)</td>
<td></td>
<td>Raw sewage-like odour</td>
<td></td>
</tr>
<tr>
<td>end of core</td>
<td></td>
<td>Pebbles</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Organic matter (roots)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Core #36</th>
<th>Core #39b</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Description</strong></td>
<td><strong>Sample #</strong></td>
</tr>
<tr>
<td>Ferrous to black silty clay</td>
<td>36-1</td>
</tr>
<tr>
<td>Organic matter (wood pieces)</td>
<td></td>
</tr>
<tr>
<td>Light black clay</td>
<td>36-2</td>
</tr>
<tr>
<td>Organic matter</td>
<td></td>
</tr>
<tr>
<td>end of core</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Dark brown to black sandy clay</td>
<td>39-1b</td>
</tr>
<tr>
<td>Organic matter (leaves)</td>
<td></td>
</tr>
<tr>
<td>Light brown to black sandy clay</td>
<td>39-2b</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Dark brown sandy clay</td>
<td>39-3b</td>
</tr>
<tr>
<td>Organic matter (wood pieces)</td>
<td></td>
</tr>
<tr>
<td>end of core</td>
<td></td>
</tr>
</tbody>
</table>
STRATIGRAPHIC, SEDIMENTOLOGIC AND INSTRUMENTATION LOG

Date: April 29, 1996.
Field Supervisor: UB
Core Method: Shelby Tube Corer
Location: Lake Gibson, Thorold, Ontario (Cores 40, 42a, 43 and 44)

**Core #44**

<table>
<thead>
<tr>
<th>Sample #</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>44-1</td>
<td>Light to dark brown clay, Yellow oil like shine, Organic matter (wood pieces)</td>
</tr>
<tr>
<td>44-2</td>
<td>Brown to black silty clay, Organic matter (wood pieces)</td>
</tr>
<tr>
<td>44-3</td>
<td>Dark brown silty clay, Yellow oil like shine, Organic matter (wood pieces)</td>
</tr>
<tr>
<td>44-4</td>
<td>Brown to yellow clay, Ferrous patches, Organic matter (wood pieces and roots), Hydrocarbon odour, Oil like shine, end of core</td>
</tr>
</tbody>
</table>

**Core #42a**

<table>
<thead>
<tr>
<th>Sample #</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>42-1a</td>
<td>Light brown silt, Ferrous streak, Pebbles, Organic matter (roots)</td>
</tr>
<tr>
<td>42-2a</td>
<td>Light brown clay, Ferrous mottles, Pebbles, Organic matter (roots)</td>
</tr>
<tr>
<td>42-3a</td>
<td>Light brown to grey clay, Ferrous mottles, Black streaks in center of core, end of core</td>
</tr>
</tbody>
</table>

**Core #40**

<table>
<thead>
<tr>
<th>Sample #</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>40-1</td>
<td>Yellow grey clay, Pink tint</td>
</tr>
<tr>
<td>40-2</td>
<td>Light brown to grey clay, end of core</td>
</tr>
</tbody>
</table>

**Core #43**

<table>
<thead>
<tr>
<th>Sample #</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>43-1</td>
<td>Light to darker brown silty clay, Organic matter (rooot)</td>
</tr>
<tr>
<td>43-2</td>
<td>Black to light brown silty clay</td>
</tr>
<tr>
<td>43-3</td>
<td>Light brown clay, end of core</td>
</tr>
<tr>
<td>Sample #</td>
<td>Description</td>
</tr>
<tr>
<td>----------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>45-1</td>
<td>Light brown to yellow silty clay</td>
</tr>
<tr>
<td></td>
<td>Organic matter (wood pieces)</td>
</tr>
<tr>
<td>45-2</td>
<td>Darker brown to yellow silty clay</td>
</tr>
<tr>
<td></td>
<td>Center of core black</td>
</tr>
<tr>
<td></td>
<td>Organic matter (wood pieces)</td>
</tr>
<tr>
<td>45-3</td>
<td>Dark brown silty clay</td>
</tr>
<tr>
<td></td>
<td>Organic matter (wood pieces and roots)</td>
</tr>
<tr>
<td></td>
<td>end of core</td>
</tr>
<tr>
<td>46-1</td>
<td>Light brown to yellow silty clay</td>
</tr>
<tr>
<td></td>
<td>Organic matter (roots)</td>
</tr>
<tr>
<td>46-2</td>
<td>Yellow-brown to dark brown clay</td>
</tr>
<tr>
<td></td>
<td>Pebbles</td>
</tr>
<tr>
<td></td>
<td>Pink tint</td>
</tr>
<tr>
<td>46-3</td>
<td>Dark yellow-brown clay</td>
</tr>
<tr>
<td></td>
<td>end of core</td>
</tr>
<tr>
<td>47-1a</td>
<td>Dark brown silty clay</td>
</tr>
<tr>
<td></td>
<td>end of core</td>
</tr>
<tr>
<td>47-2a</td>
<td>Dark brown to black silty clay</td>
</tr>
<tr>
<td></td>
<td>Organic matter (roots)</td>
</tr>
<tr>
<td></td>
<td>Hydrocarbon odour</td>
</tr>
<tr>
<td>47-3a</td>
<td>Black to dark brown silty clay</td>
</tr>
<tr>
<td></td>
<td>end of core</td>
</tr>
<tr>
<td>48-1</td>
<td>Light to darker brown silty clay</td>
</tr>
<tr>
<td></td>
<td>Organic matter (roots)</td>
</tr>
<tr>
<td>48-2</td>
<td>Black to light brown silty clay</td>
</tr>
<tr>
<td>48-3</td>
<td>Light brown clay</td>
</tr>
<tr>
<td></td>
<td>end of core</td>
</tr>
</tbody>
</table>
STRATIGRAPHIC, SEDIMENTOLOGIC AND INSTRUMENTATION LOG

Date: June 9, 1996. Field Supervisor: UB Core Method: Shelby Tube Corer

Location: Lake Gibson, Thorold, Ontario (Cores 49, 50, 51 and 53)

Core #49

Sample #

0

Dark brown to yellow silty clay 49-1
Zebra Mussel Shells

Yellow brown sandy clay 49-2
Organic material (roots)

Grey-yellow sandy clay 49-3

Yellow brown clay 49-4

Yellow grey clay 49-5
end of core

Core #50

Sample #

0

Black grey sandy clay 50-1

Grey brown clay 50-2
Pebbles
Hydrocarbon odour

Black grey clay 50-3
Hydrocarbon odour
Golden shine

Grey clay 50-4
Golden shine

Grey black clay 50-5

end of core

Core #51

Sample #

0

Black silt 51-1
Organic material (leaves)
Golden shine
Hydrocarbon odour

Black grey silty clay 51-2
Hydrocarbon odour
Organic material (leaves)
Golden shine

Grey black silty clay 51-3
Golden shine
Hydrocarbon odour

Grey clay 51-4
Golden shine
Hydrocarbon odour
Organic material (leaves)
end of core

Core #53

Sample #

0

Black to light brown sandy clay 53-1
Pebbles
Organic material (roots)
Pink tint to sediment

Light brown to yellow sandy clay 53-2
Golden shine

Yellow to brown clay 53-3
Golden shine

Yellow black sandy clay 53-4
end of core
STRATIGRAPHIC, SEDIMENTOLOGIC AND INSTRUMENTATION LOG

Date: October 7, 1997. Field Supervisor: UB Core Method: Shelby Tube Corer

Location: Lake Gibson, Thorold, Ontario (Cores cream1, cream3, park and 39a)

Core #cream1

<table>
<thead>
<tr>
<th>Depth of core (cm)</th>
<th>Description</th>
<th>Sample #</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Brown cream sand, Organic matter (leaves, stems)</td>
<td>cream1-1</td>
</tr>
<tr>
<td>2</td>
<td>Light yellow brown clay, Organic matter (roots)</td>
<td>cream1-2</td>
</tr>
<tr>
<td>6</td>
<td>Yellow brown clay, Organic matter (roots)</td>
<td>cream1-3</td>
</tr>
<tr>
<td>10</td>
<td>Grey sandy clay, Golden shine</td>
<td>cream1-4</td>
</tr>
<tr>
<td>14</td>
<td>Yellow brown sandy clay</td>
<td>cream1-5</td>
</tr>
<tr>
<td>18</td>
<td></td>
<td></td>
</tr>
<tr>
<td>22</td>
<td></td>
<td></td>
</tr>
<tr>
<td>26</td>
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<td></td>
</tr>
<tr>
<td>30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>32</td>
<td></td>
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Core #cream3

<table>
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<th>Description</th>
<th>Sample #</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Dark brown sandy clay, Organic matter (leaves)</td>
<td>cream3-1</td>
</tr>
<tr>
<td>2</td>
<td>Pebbles</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Dark brown to black sandy clay, Organic matter, pebbles</td>
<td>cream3-2</td>
</tr>
<tr>
<td>6</td>
<td>Grey black sand</td>
<td>cream3-3</td>
</tr>
<tr>
<td>8</td>
<td>Black to light brown sand, Organic matter</td>
<td>cream3-4</td>
</tr>
<tr>
<td>10</td>
<td>Yellow brown clay</td>
<td>cream3-5</td>
</tr>
<tr>
<td>12</td>
<td>Yellow clay</td>
<td>cream3-6</td>
</tr>
<tr>
<td>18</td>
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<td>22</td>
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<td></td>
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</tr>
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<td>32</td>
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</table>

Core #park

<table>
<thead>
<tr>
<th>Depth of core (cm)</th>
<th>Description</th>
<th>Sample #</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Brown black sandy silt, Pebbles, Strong hydrocarbon odour</td>
<td>park-1</td>
</tr>
<tr>
<td>2</td>
<td>Black sandy silt, Pebbles, Strong hydrocarbon odour</td>
<td>park-2</td>
</tr>
<tr>
<td>4</td>
<td>Black to yellow-brown sandy clay, Strong hydrocarbon odour</td>
<td>park-3</td>
</tr>
<tr>
<td>6</td>
<td>Dark brown to black silty clay, Strong hydrocarbon odour</td>
<td>park-4</td>
</tr>
<tr>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td></td>
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</tr>
<tr>
<td>14</td>
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<tr>
<td>16</td>
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</tr>
<tr>
<td>20</td>
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<td>22</td>
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<td>32</td>
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Core #39a

<table>
<thead>
<tr>
<th>Depth of core (cm)</th>
<th>Description</th>
<th>Sample #</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Dark brown clay, Very high in peat</td>
<td>39-1a</td>
</tr>
<tr>
<td>2</td>
<td>Pebbles</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Dark brown to black sandy clay</td>
<td>39-2a</td>
</tr>
<tr>
<td>6</td>
<td>Light grey clay</td>
<td>39-3a</td>
</tr>
<tr>
<td>8</td>
<td>Light brown clay</td>
<td>39-4a</td>
</tr>
<tr>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
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</tr>
<tr>
<td>18</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
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<tr>
<td>22</td>
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<tr>
<td>24</td>
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<td></td>
</tr>
<tr>
<td>26</td>
<td></td>
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<tr>
<td>30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>32</td>
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</tr>
</tbody>
</table>
Date: October 7, 1997. Field Supervisor: UB  Core Method: Shelby Tube Corer

Location: Lake Gibson, Thorold, Ontario (Cores cream1, cream3, park and 39A)

Core # 54

Description | Sample #
---|---
Golden grey silty clay | 54-1
Waterlogged
Grey black clay | 54-2
Golden shine
Hydrocarbon odour
Brown in grey clay | 54-3
Golden shine
Black silt | 54-4
Golden shine
Hydrocarbon odour
Organic matter (roots and leaves)
Darker black silty clay | 54-5
Golden shine
end of core

Core # 55

Description | Sample #
---|---
Dark brown sandy clay | 55-1
Organic matter (roots)
Dark to light brown silty clay | 55-2
Light brown to yellow clay | 55-3
Light to dark brown clay | 55-4
Black silt | 55-5
Golden shine
Organic matter (wood chips)
end of core

Core # 56

Description | Sample #
---|---
Light yellow-brown clay | 56-1
Grey-brown clay | 56-2
Yellow-brown clay | 56-3
Grey-yellow clay | 56-4
Yellow to light brown clay | 56-5
end of core

Core # 60

Description | Sample #
---|---
Brown silty clay | 60-1
Organic matter
Grey black silty clay | 60-2
Orange flakes throughout
Hydrocarbon odour
Black to grey silty clay | 60-3
Hydrocarbon odour, roots
Black silty clay, roots | 60-4
Orange flakes, pebbles
Brown black silty clay | 60-5
Brown black silty clay, pebbles | 60-6
Brown black silty clay, organic matter | 60-7
Brown black silty clay | 60-8
end of core
### STRATIGRAPHIC, SEDIMENTOLOGIC AND INSTRUMENTATION LOG

**Date:** July 24, 1995  
**Field Supervisor:** UB  
**Core Method:** Shelby Tube Corer

**Location:** Lake Gibson, Thorold, Ontario (Cores 1, 2, 3 and 4)

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<td>silty sand + black with cream and orange pebbles</td>
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<td>silty sand + dark brown to black</td>
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<tr>
<td>clay + brown/black</td>
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<td>clay + light brown + grey</td>
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<tr>
<td>clay + light brown</td>
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**Description** | **Sample #** |
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<td>sandy clay + brown to yellow</td>
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<tr>
<td>clay + dark brown with ferrous colored streaks</td>
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<tr>
<td>clay + yellow to light brown</td>
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Date: January 16, 1996. Field Supervisor: UB  Core Method: Shelby Tube Corer

Location: Lake Gibson, Thorold, Ontario (Cores 13, 14, 37a and 38a)

Core #13

Description: Sample #
- black/brown silt 13-1
- organic material
- olfactory evidence of hydrocarbons
- brown to grey clay 13-2
- organic material
- olfactory evidence of hydrocarbons
- grey clay 13-3
- organic material
- olfactory evidence of hydrocarbons
- grey to brown clay 13-4
- organic matter
- olfactory evidence of hydrocarbons
- grey in brown clay 13-5
- organic material
- olfactory evidence of hydrocarbons
- brown/grey clay 13-6
- organic material
- end of core

Core #14

Description: Sample #
- brown silty clay 14-1
- organic material
- olfactory evidence of hydrocarbons
- light brown silty clay 14-2
- organic material
- olfactory evidence of hydrocarbons
- light brown clay 14-3
- organic material
- olfactory evidence of hydrocarbons
- light brown silty clay 14-4
- organic matter
- olfactory evidence of hydrocarbons
- black/brown silty clay 14-5
- organic material
- olfactory evidence of hydrocarbons
- black/brown silty clay 14-6
- organic material
- end of core

Core #37

Description: Sample #
- sandy clay 37-1
- dark black
- clay 37-2
- light brown clay
- interlaced with thin lenses of dark black sandy clay
- high in peat
- sandy clay 37-3
- brown
- minor pebble content
- end of core

Core #38

Description: Sample #
- sandy clay 38-1
- black
- clay 38-2
- black
- sandy clay 38-3
- light brown
- end of core
Location: Lake Gibson, Thorold, Ontario (Cores 5, 6, 7 and 8)
Date: July 24, 1995
Field Supervisor: UB
Core Method: Shelby Tube Corer

Location: Lake Gibson, Thorold, Ontario (Cores 9, 10, 11 and 12)

Core #9

Description Sample #
- brown sand 9.1
- sand 9.2
- black to grey
- olfactory evidence of hydrocarbons 9.3
- silt 9.4
- brown/yellow
- olfactory evidence of hydrocarbons
- black
- olfactory evidence of hydrocarbons
- end of core

Core #10

Description Sample #
- black to dark brown silty sand and organic material 10-1
- black to dark brown silty sand and organic material 10-2
- black to dark brown silty sand and organic material 10-3
- clay 10-4
- brown to light grey
- clay 10-5
- brown to light grey
- end of core

Core #11

Description Sample #
- brown silty clay 11-1
- ferrous streak
- olfactory evidence of hydrocarbons
- darker brown silty sand and organic material 11-2
- organic material
- olfactory evidence of hydrocarbons
- clay 11-3
- black to grey
- olfactory evidence of hydrocarbons
- clay 11-4
- black to grey
- olfactory evidence of hydrocarbons
- clay 11-5
- yellow/grey
- organic material
- olfactory evidence of hydrocarbons
- end of core

Core #12

Description Sample #
- brown silty clay 12-1
- ferrous streak
- organic material
- olfactory evidence of hydrocarbons
- brown silty clay 12-2
- ferrous streak
- organic material
- olfactory evidence of hydrocarbons
- brown silty clay 12-3
- organic material
- olfactory evidence of hydrocarbons
- dark brown silty clay 12-4
- organic matter
- olfactory evidence of hydrocarbons
- silty clay 12-5
- dark to light brown
- organic material
- olfactory evidence of hydrocarbons
- brown/silty clay 12-6
- organic material
- brown/grey clay
- end of core
STRATIGRAPHIC, SEDIMENTOLOGIC AND INSTRUMENTATION LOG

Date: October 7, 1997. Field Supervisor: UB Core Method: Shelby Tube Corer

Location: Lake Gibson, Thorold, Ontario (Cores 61, bxo, grab, gib and cream2)

### Core #61

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<tr>
<td>12</td>
<td>Grey brown silty clay Black and orange streak</td>
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<tr>
<td>14</td>
<td>Grey brown silty clay Black and cream streaks</td>
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<td>Grey brown silty clay Black flakes throughout</td>
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<td>Brown silty clay Black flakes throughout</td>
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### Core #BXO

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<td>Dark brown sand Organic matter (leaves) Pebbles</td>
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<tr>
<td>12</td>
<td>Dark brown sandy clay Organic matter (leaves)</td>
<td>bxo-2</td>
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<tr>
<td>14</td>
<td>Light brown in grey clay</td>
<td>bxo-3</td>
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<td>16</td>
<td>Black to brown clay</td>
<td>bxo-4</td>
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### Core #GRAB

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<td>0</td>
<td>Black sand Yellow sawdust-like material</td>
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<td>Black sand Strange odour</td>
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### Core #CREAM2

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<td>Cream to light brown silty clay Organic matter (leaves)</td>
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### Core #GIB

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<td>17</td>
<td>Yellow brown sandy clay Organic matter (roots)</td>
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<td>19</td>
<td>Yellow brown clay Black streak throughout</td>
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<td>21</td>
<td>Yellow brown clay</td>
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APPENDIX 4

1. Marlatt's Pond Sediment Data
2. Lake Gibson Sediment Data
3. TPH Data
## Appendix 4 - Marlatt's Pond Sediment Data

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