Hydrogeology of Ontario
Series (Report 1)

THE HYDROGEOLOGY OF SOUTHERN ONTARIO

SECOND EDITION

By

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PREFACE TO THE SECOND EDITION

The second edition of *The Hydrogeology of Southern Ontario* provides an opportunity to make changes and additions in light of new data and studies made since 1995. The text in this edition has been extensively revised, new maps have been added, statistics related to groundwater quality have been revised, and the description of the Provincial Drinking Water Standards and Objectives has been brought up to date. A new chapter on overburden aquifers has been added. The chapter describes 164 overburden aquifers within southern Ontario in terms of location, type (confined or unconfined), composition, thickness, elevation, depths to static water levels, and well yields.

Toronto, April 2003

PREFACE TO THE FIRST EDITION

This report describes the hydrogeology of southern Ontario in terms of the hydraulic parameters of various bedrock and overburden units, and the geologic conditions under which groundwater flow systems operate. In addition, the report provides an assessment of the long-term groundwater recharge and discharge, and an evaluation of groundwater quality. The report is intended to provide basic hydrogeologic information that can be used for the wise management of the groundwater resources in southern Ontario.

Toronto, June 1995

TABLE OF CONTENTS

Page

Page

LIST OF TABLES

LIST OF ILLUSTRATIONS

Appendix II

1. EXECUTIVE SUMMARY

This report describes, on a regional scale, the occurrence, distribution, quantity and quality of groundwater in southern Ontario. The report is based on data obtained from the Water Well Information System (WWIS) of the Ontario Ministry of Environment (MOE) and it makes use of available information related to the physiography, geology, and hydrogeology of the province. The report consists of 200 pages of text and includes three appendices, 48 maps and figures, and 15 graphs. It also lists more than 190 groundwater references produced over the past 30 years.

Since its inception in 1972, the WWIS database was used by federal, provincial and municipal agencies as well as by academia and consulting firms to conduct hydrogeologic investigations related to groundwater quantity or quality. In the past, most of the analysis and interpretation of the information obtained from the WWIS database was done manually and only a limited number of well records could be considered. Recent advances the field of Geographic Information Systems (GIS) make it feasible to consider large databases, to present the data on thematic maps, and to conduct numerous analyses and interpretations within a relatively short time frame. RAISON and ArcView are such GIS systems and they have been used in the preparation of this report in conjunction with the WWIS database.

More than 215,000 well records were examined in this report. Of these, about 173,000 records that have the highest degree of accuracy in terms of well location and elevation were selected for further analysis. Given that each record contains up to 212 parameters, the database that was considered is extremely large.

Numerous hydrogeologic techniques were developed by MOE staff to enhance the RAISON and ArcView capabilities. These techniques were used to generate several unique maps of southern Ontario for the first time and to conduct numerous hydrogeologic analyses. Statistical techniques were used to determine the specific capacity and transmissivity distributions for bedrock and overburden wells, and a streamflow separation program was used to assess the long-term groundwater discharge and recharge on a monthly and annual basis.

Eighteen hydrogeologic units within the bedrock of southern Ontario were described and their hydraulic parameters were determined. The Bois Blanc, Detroit River Group, Salina, Bass Island, Dundee, and Amabel-Lockport-Guelph hydrogeologic units were identified as the highest water-yielding units within the bedrock of southern Ontario.

Groundwater occurrence within various overburden deposits has been described in terms of the hydraulic parameters of wells completed in areas where these deposits outcrop at the surface. Wells constructed in areas where deposits of glaciofluvial, glaciolacustrine or marine origins outcrop at the surface show the highest water-yielding capabilities. In addition, a total of 164 overburden aquifers in 26 areas within southern Ontario was identified. Each aquifer was described in terms of location, composition, thickness, type (confined or unconfined), depths to static water levels, and well yields. Where available, the hydraulic parameters of individual aquifers were cited. The Upland Aquifer Complex within the Oak Ridges Moraine, the Yonge Street Aquifer, the Norfolk Sand Plain Aquifer, and the Ausable Aquifer were identified as the highest water-yielding units within the overburden of southern Ontario.

The analysis of the configuration of the groundwater levels within the bedrock in southern Ontario indicates that it is a subdued reflection of the surface topography where the regional groundwater divides coincide closely with the topographic divides of major basins. Groundwater appears to flow through river valleys toward the Great Lakes and the Ottawa and St. Lawrence Rivers. The configuration of the groundwater levels within the overburden is similar to that in the bedrock, but the patterns are more pronounced.

Data from 33 gauging stations located in small watersheds in southern Ontario were selected for streamflow analysis. Care was taken to ensure that the size of each watershed is less than 200 square kilometres, the streamflows at all the stations are natural flows, and the period of record at each station is long enough to allow for the estimation of the long-term means of groundwater discharge and recharge.

The streamflow analysis indicates that the long-term means of monthly and annual groundwater discharge are highest during the months of March, April and May; they decrease steadily during the period June-October and start to recover during November and December. The long-term means of annual groundwater discharge and recharge, calculated for the 33 stations, range from 83.3 to 284.9 mm.

Chemical analyses for 1,055 water samples, collected from wells completed in various bedrock and overburden units, were used to evaluate the natural (raw) groundwater quality and the types of groundwater found in these wells. The quality parameters considered were sodium, total iron, chloride, sulphate, nitrate, hardness, and total dissolved solids.

In general, the natural groundwater quality in southern Ontario was found to be good in terms of sodium, total iron, chloride, sulphate and total dissolved solids. At times, however, groundwater quality failed to meet the Provincial Drinking Water Aesthetic Objectives for some of these parameters.

The DUROV Water Quality Analyser computer program was used to determine the types of groundwater encountered in bedrock and overburden wells. Most samples indicate that groundwater in both the bedrock and the overburden is of bicarbonate or calcium-bicarbonate type.

2. INTRODUCTION

2.1 THE SIGNIFICANCE OF ONTARIO'S GROUNDWATER RESOURCES

Groundwater is a valuable resource, which is of great significance to the public health and economic well-being of all the people of Ontario. It is a major source of water supply for agricultural, commercial, industrial, municipal, and non-municipal public uses; it is also critical for the survival of fish and aquatic life in Ontario's watercourses.

Where available in sufficient quantity, groundwater offers substantial advantages over surface water supplies, including minimum treatment requirements in most cases; avoidance of long, costly pipelines for municipal supplies; uniform temperature and water quality; and with proper protection, dependable supply.

More than 500,000 records of water wells constructed after 1945 are on file with MOE. The total number of wells constructed in the province prior to 1945 is unknown. In recent years, some 12,000 to 20,000 additional wells are reported annually. The construction of water wells has changed considerably since they were dug with pick and shovel to limited depths. Today, modern drilling equipment allows wells to reach depths of several hundred meters. Similarly, today wells and supply systems are more reliable than their predecessors.

Over one-half of all municipal water supplies in Ontario are from groundwater sources. The municipal population dependant on groundwater is approximately 1.5 million. In rural settings, an additional 1.3 million people obtain their water supplies from private groundwater sources (Singer 1990). It is estimated that the daily water requirements for domestic purposes range from 270 to 450 L/day/person (MOE 1987). Based on these figures, the total domestic groundwater use in Ontario is estimated to range from 756,000 to 1,260,000 m^3/day.

Water wells are by far the major source of water supply for farm operations. In Ontario, about 90% of farms make use of groundwater for household purposes (30,000-65,000 m^3/day) and about 80% make use of it for livestock watering (210,000-240,000 m^3/day) (OMAF 1985). Groundwater is also an important source of water supply for irrigation purposes. Approximately, 40,250 ha of cropland are being irrigated from surface and groundwater sources. Irrigation requires an enormous amount of water (150,000-170,000 m^3/day), and it is concentrated in several weeks of the year during critical periods of the growing season (OMAF 1985).

With consumer trends to eat healthier food, demand for fish in Ontario is continually rising. An aquacultural industry (fish hatcheries) is expanding in the province to meet this increasing consumer demand. While aquacultural operations are usually associated with surface water, groundwater is a major source of water supply for many of these operations.

Based on published water well records (1946-1984), about 6,000 wells provided water supplies to service stations, motels, snow making, car washes, arenas, shopping plazas, laundromats, restaurants, and cold storage sheds, to name a few. Approximately 1,700 wells provided water supplies to food processing plants, industrial cooling, steam boilers, hydrostatic testing of pipelines, mining operations, and gravel and crushed stone washing. Also, more than 6,000 wells are being used for non-municipal public water supply. Schools, hospitals, churches, public washrooms, campgrounds, picnic grounds, and conservation areas all make use of groundwater supplies.

Heat pumps and airconditioning units make use of the nearly constant groundwater temperature, and their popularity is on the increase. To date, about 25,000 ground-source heat pump systems have been installed in Ontario and many of these systems are of the open-loop type.

To date, there are no reliable estimates of the amount of groundwater use for commercial, industrial, and non-municipal public supplies or for aquacultural operations and open-loop heat pump systems.

One of the most important attributes of groundwater, which is often overlooked, is its perennial contribution to surface water throughout the year. Over most of Ontario, the mean annual contribution of groundwater to streamflow is less than 20%. However, groundwater contribution to streamflow can be up to 60% of the mean annual flow in areas where sand and gravel deposits are at the surface. During low flow periods, up to 100% of the flow in many streams consists of groundwater discharge.

Groundwater perennial contribution to streamflow is significant for the survival of fish and aquatic life and it is essential for the preservation of Ontario's coldwater fisheries. During drought periods, the waste assimilative capacities of many Ontario streams are entirely dependant on the groundwater contribution to streamflow.

2.2 IMPORTANCE OF SCALE IN HYDROGEOLOGIC STUDIES

The term “scale” is usually used in hydrogeology as an indication of the order of magnitude rather than a specific value. Complicating factors result from the attempt to map the dynamic groundwater regime such as the water table elevations using data measured at different times or the attempt to solve issues related to groundwater using mapping techniques with insufficient data. By and large, the scale of a hydrogeologic study determines the type and amount of data required, the techniques used, the degree of accuracy of the maps produced, and most importantly the cost of the study.

In Ontario, a hydrogeologic study on a site scale of 1:5,000-1:10,000 is conducted to solve problems in a small local area. Examples include provision of water supplies to new subdivisions, selection of a landfill site, decommissioning of a contaminated site or extraction of sand and gravel. The size of the area of interest is measured in a few hectares. The study is usually intensive and the data have to be highly accurate. Also, the study may involve the production of an accurate topographic map, drilling of many wells, detailed analyses of geologic logs, pumping tests, and a water quality assessment.

A hydrogeologic study on a sub-watershed scale of 1:10,000-1:25,000 usually focuses on the specific details that a watershed study does not allow for. The size of the area of interest ranges from 10-100 km^2. The study may involve spot streamflow measurements, construction of cumulative stream discharge graphs, use of piezometers and seepage meters, continuous measurements of limited runoff events, spot temperature measurements, delineation of groundwater recharge and discharge areas, measurement of water levels in wells, pumping tests, water mass balance, and groundwater modelling.

In a hydrogeologic study on a watershed scale of 1:50,000 -1:100,000, the objective is to describe the groundwater resources in the watershed. The size of the watershed usually ranges from 100 to 1500 km^2. The study may include the compilation, analysis and interpretation of existing watershed physical data; the compilation, analysis, and interpretation of geologic information; the identification of major aquifers and their water-yielding capabilities; the quantification of groundwater long-term recharge and discharge; a water budget analysis; and the evaluation of groundwater quality.

In a hydrogeologic study on a regional scale of 1:500,000-1:1,000,000, the objective is to provide a general overview of the significant elements of the groundwater regime within the area of interest which is usually more than 5,000 km^2 in size. Such a study is intended to provide basic background information that can be used in hydrogeologic studies of larger scales. It usually provides a general overview of the area's physical information, aquifers and hydrogeologic units and their water-yielding capabilities, groundwater regimes, long-term groundwater discharge and recharge, and general water quality.

2.3 PURPOSE AND SCOPE OF THE STUDY

The purpose of this report is to assess, on a regional scale, the occurrence, quantity and quality of the groundwater resources in southern Ontario. This includes the following:

- the compilation, analysis and interpretation of existing information related to topography, drainage and climate, physiography, geology, and hydrogeology;
- the identification of major overburden aquifers and bedrock hydrogeologic units;
- the determination of the hydraulic parameters of the bedrock hydrogeologic units;
- the identification of the geologic conditions under which various groundwater flow systems operate;
- the evaluation of the long-term groundwater recharge and discharge for selected watersheds; and
- the assessment of groundwater quality.

Some maps included in this report are of 1:3,300,000 scale. These maps, however, are accurate to a scale of 1:1,000,000. Other maps are of scales ranging from 1:300,000 to 1:750,000. Enlargement of the maps beyond their scales will introduce errors and is not recommended.

2.4 LOCATION

The area of interest, referred to in this report as southern Ontario, has an area of about 100,000.0 km^2, a length of about 830.0 km in a northeast-southwest direction and a width which varies between 40.0 and 360.0 km in a northwest-southeast direction.

Southern Ontario extends between the longitudes of 74° 20' and 83° 7' W and the latitudes of 41° 54' and 45° 34' N. It is bounded on the north by the counties of Muskoka, Nipissing, and Renfrew as well as by Georgian Bay and the Ottawa River; on the east by the Province of Quebec, on the south by the St. Lawrence River, Lake Ontario, and Lake Erie; and on the west by the Detroit River, Lake St. Clair, the St. Clair River and Lake Huron.

For the most part, the study area is of modest relief with elevations ranging from about 45.0 m above sea level (a.s.l.) along the Ottawa River to about 550.0 m (a.s.l.) on the Blue Mountain south of Collingwood. It is underlain by Precambrian and Paleozoic rocks and has been subjected to glaciation during the Pleistocene age which left in places a thick overburden mantle. Figure 1 shows the location of the study area relative to other parts of Ontario and Figure 2 shows the counties and regional municipalities included in the study.

2.5 RELEVANT INVESTIGATIONS

Bostock (1970) described the physiography of Canada and identified major physiographic regions in Ontario. Chapman and Putnam (1984), in their classic publication entitled: "The Physiography of Southern Ontario", provided a detailed description of the physiography of southern Ontario and an overview of its glacial geology. This publication, which has been cited frequently in this report, is as an invaluable source of physiographic information with important hydrogeologic relevance.

Over the last 100 years, numerous geologists and researchers made valuable contributions to enhance the knowledge and understanding of Ontario's geology. These contributions in the form of bulletins, scientific papers, theses, reports and maps continue to provide valuable background information to practitioners in the field of applied hydrogeology.

In 1992, the Ontario Geological Survey and the Ministry of Northern Development and Mines published a comprehensive volume entitled:"Geology of Ontario", consisting of 1,430 pages of text, and 41 sheets of maps and charts. This unique volume (Thurston et al. 1991-92) presents a synthesis of the massive information and data related to the geology of Ontario that have accumulated over the past 100 years. Chapter 19 of the volume by Easton (1992) describes the Grenville Province and the Proterozoic history of central and southern Ontario. Chapter 20 by Johnson et al. (1992) describes the Paleozoic and Mesozoic geology of the province using a sequence stratigraphy approach, and Chapter 21 by Barnett (1992) provides the first synthesis of Ontario's Quaternary geology. The information contained in this outstanding publication provided essential background information that was used extensively in this study.

Regional Analysis of low flow characteristics for the southwestern and west-central regions of southern Ontario was completed in 1990. Similar analysis for the central and southeastern regions of southern Ontario was completed in 1991 (Cumming Cockburn Limited 1990 and 1991).

2.6 PREVIOUS HYDROGEOLOGIC INVESTIGATIONS

The first preliminary groundwater survey in Ontario was conducted by Gwynne in 1945 (Watt 1952). After this survey was completed, it was realized that any future groundwater studies must have accurate drilling records as their basis. The Well Drillers' Act provided the framework for the water well legislation and the Minister of Mines was given the authority to make the necessary regulations regarding the issuance of licences to drillers and the submission of well records. Currently, the Minister of Environment has under the Ontario Water Resources Act the supervision of all the surface and groundwater resources in the province.

A great body of knowledge related to Ontario's groundwater resources has accumulated since 1945. Caley et al. (1947 and 1948) and Hainstock et al. (1952) gave general descriptions of groundwater conditions in various areas within the central parts of southern Ontario. Watt (1952) provided the first overview of groundwater in the province. The overview was based on measurements of water levels in various monitoring wells and on well records.

In 1969, the Ontario Water Resources Commission published its first drainage basin report in its Water Resources Series. This tradition was continued after the incorporation of the Commission within MOE. Twenty-five reports, which provide detailed information on the water resources of various watersheds in Ontario, have been published. The reports contain information on groundwater flow systems, bedrock topography, overburden and bedrock geology, and hydrochemistry.

Sibul (1969) described the water resources of the Big Otter Creek basin in terms of water occurrence, distribution, quantity and quality in relation to the existing water uses in the basin. The report contains a hydrologic budget analysis that accounts for changes in groundwater storage.

Yakutchik and Lammers (1970) described the water resources of the Big Creek basin. The report provides information about the bedrock and surficial geology of the basin and examines the source, occurrence, movement and recharge of groundwater.

Two reports by Barouch were published in 1971.The first report deals with hydrograph separation in the Wilmot Creek basin using recession factor analysis and chemistry of streamflow. The second report provides an evaluation of the groundwater storage capacity in the Soper Creek basin using a physical parametric approach.

Sibul and Choo-Ying (1971) described the water resources of the Upper Nottawasaga River basin. The report contains information about the occurrence, distribution, quantity and quality of water in the basin.

Sibul et al. (1974) described the water resources of the Moira River basin. The report provides information about the occurrence of groundwater in Precambrian, Paleozoic and overburden aquifers.

Singer (1974) described the hydrogeology along the north shore of Lake Ontario in the Bowmanville-Newcastle area, and provided an estimate of the quantity of groundwater flow into Lake Ontario. Also, a paper by Singer (1975) describes the simulation of the dynamic response of groundwater to natural stresses in the Wilmot Creek basin. The computer simulation was based on finite difference techniques.

Two reports by Funk were published in 1977. The first report describes the geology and groundwater resources of the Wilton Creek basin. The second report describes the geology and water resources of the Bowmanville, Soper and Wilmot Creeks basin. Also, Funk (1979) described the geology and water resources of the East and Middle Oakville Creeks basin.

Coward and Barouch (1978) described the groundwater resources in the Blue Springs Creek basin. The authors also described a groundwater model, which simulates groundwater flow in the basin.

Sibul et al. (1978) described the groundwater resources of the Duffins Creek-Rouge River drainage basins. The report contains the results of subsurface geologic investigation aimed at locating and defining the major aquifer systems in the basins.

Two reports by Ostry were published in 1979. The first report describes the hydrogeology of the Forty Mile and Oakville Creeks basins. The second report describes the results of a hydrogeologic investigation of an area within the Duffins Creek basin.

Chin et al. (1980) provided a brief description of the water resources of the South Nation River basin. The report contains maps, graphs and tables related to the quality and availability of groundwater in the basin.

Sibul et al. (1980) described the groundwater resources in the Grand River basin. The report provides information about water yields of wells completed in various bedrock and overburden aquifers.

Fligg and Rodrigues (1981) evaluated the application of geophysical well logging in groundwater investigations and described a few case histories in the Grand River basin.

Goff and Brown (1981) described the groundwater resources of the Thames River basin. The report contains 13 sheets of maps, which show the distribution, quality and availability of groundwater in the basin.

Singer (1981) provided an evaluation of the groundwater responses in the Bowmanville, Soper, and Wilmot Creeks basin. The report examines the interrelationships between groundwater and other components of the hydrologic cycle.

Ostry and Singer (1981) investigated groundwater occurrence in selected areas within the Moira River and Wilton Creek basins and the Thousand Islands area. The investigation was conducted as part of estimating the quantity of groundwater flow into Lake Ontario.

Vallery et al. (1982) provided a summary of the water resources of the Holland and Black River basins. The report contains several sheets of maps related to the availability and quality of groundwater in both basins.

Issues related to groundwater contamination in Ontario were described by Beak Consultants ltd. (1986) and Cherry (1986) as part of a Canada-wide evaluation.

The occurrence, quantity and quality of groundwater in the Grand River basin have received a great deal of attention because of the extreme importance of groundwater as a source of water supply. Several studies were conducted regarding the provision of water supplies (Andrejiw 1973 and 1976, Dixon 1974, Hudgins 1977 and 1991, Banks and Morrison 1984 and 1987, Gray et al. 1990, Karrow et al. 1993, Blackport and Johnston 1995, and Johnston and Blackport 1995). Other studies were conducted regarding the feasibility of induced infiltration (Pawley et al. 1976 and Sibul et al. 1980). Several other studies focussed on groundwater issues within the Regional Municipality of Waterloo (Golder Associates Ltd. 1992, Robinson and Greese 1993, McLaren and Sudicky 1993). Singer (1997) prepared a review of geologic and hydrogeologic studies conducted within the basin.

Kaye (1986) described the recharge characteristics of the Oak Ridges Moraine Aquifer Complex and Gerber (1994) conducted a recharge analysis of the central portion of the Oak Ridges Moraine. In 1990, the Ontario Government announced a Provincial Expression of Interest in the Oak Ridges Moraine in response to increasing development pressures on this environmentally significant landform. As a result, a hydrogeologic study of the Moraine was initiated in 1991as part of the planning process. A number of federal, provincial and municipal agencies as well as consulting firms and the University of Toronto participated in the study. As part of this effort several geologic and hydrogeologic investigations were undertaken (Barnett 1992, 1993, 1994, Barnett et al. 1998, Sharpe and Finley 1994, Sharpe et al. 1996 and 1997). Hunter and Associate Limited and Raven/Beck Environmental Limited (1996) prepared an executive summary and a comprehensive technical report regarding the study.

McRitchie et al. (1994) described the groundwater conditions in Ontario. They provided a hydrogeologic background for the province and identified groundwater quality concerns and management issues.

Singer et al. (1994) provided an evaluation of the groundwater resources in the Credit River watershed. The report contains an assessment of the long-term groundwater recharge and discharge in the watershed as well as an analysis of ground and surface water quality.

Holysh (1995) prepared a report which described the background hydrogeology of the Regional Municipality of Halton. The report was a part of the preparation of an aquifer management plan for the municipality.

In 1998, MOE established the Groundwater Management Studies Fund. It was designed to assist municipalities and public utility commissions undertake studies to ensure the long-term protection and use of groundwater resources. Thirty-four groundwater studies were initiated under this program. Many of these local studies focussed on issues related to water supply, water contamination, and the development of long-term water budgets (MOE 2000).

In 1994, MOE conducted a review of the existing groundwater monitoring programs (MOE 1994). The review affirmed the need to establish a monitoring network in Ontario. To this end, two reports were prepared. One report describes the monitoring concepts, suggested priority basins, and a design example (MOE et al. 1998), and the second report described the design of monitoring networks for ten basins in southern Ontario (MOE et al. 1999).

Three reports were prepared by Singer et al. (1999, 2000, and 2002). The first report evaluates the groundwater resources of the Severn Sound drainage area, the second report gives an assessment of the groundwater resources of the East Holland sub-watershed, and the third report gives an assessment of the groundwater resources in areas draining into Hudson Bay, James Bay, and Upper Ottawa River in northern Ontario.

Between 1973 and 1978, MOE published the Major Aquifers in Ontario Map Series, consisting of eight maps that covered most of central and eastern Ontario. The Series identified major aquifers in terms of their spatial extent and groundwater yield potential (Turner, 1976, 1977 and 1978).

The Groundwater Probability Map Series was initiated in 1969. Between 1969 and 1986, fourteen maps were published. These maps covered large areas in southwestern and central Ontario and illustrated the potential availability of groundwater in these areas.

Between 1981 and 1986, MOE has prepared susceptibility maps for 26 areas in the province. The maps show the relative susceptibility of groundwater to contamination in those areas. A high/low rating system was used to prepare the maps. The rating system was based on the presence or absence of shallow aquifers, the permeability of surface materials and groundwater use.

Numerous scientists, associated with various Ontario universities and consulting firms, have made great contributions that enriched our knowledge regarding the hydrogeology of the province. Through their research and investigations, massive amounts of information and data on groundwater conditions in various parts of Ontario have been generated.

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3. GEOGRAPHY

3.1 PHYSIOGRAPHY

The physiography of southern Ontario has been shaped by geological processes including plutonism, sedimentation, faulting, glaciation, uplifting, erosion, and weathering. One of the most important processes that profoundly reshaped the surface features of southern Ontario during the Quaternary Period has been glaciation. A variety of glacial landforms such as drumlins, eskers, kames, and moraines contribute to the diversity in relief.

According to Bostock (1970) and Thurston et al. (1991), geological and physiographic distinctions can be made between two main physiographic regions of Ontario: the uplifted broad dome of the Canadian Shield and the surrounding flatter lowlands termed the Borderlands. The land lying north of lines drawn from Waubaushene on Georgian Bay to Kingston on Lake Ontario, and from Brockville on the St. Lawrence River to Braeside on the Ottawa River, is called the Laurentian Highlands (Figure 3).

The Laurentian Highlands are underlain by Precambrian bedrock and are characterized by a rugged profile. The surface elevation of the Laurentian Highlands ranges from 485.0 to 530.0 m above sea level (a.s.l.) in the northern parts of Haliburton and Hastings Counties to about 60.0 m (a.s.l.) in the southeast along the shores of the St. Lawrence River. The Laurentian Highlands act as a topographic divide diverting surface drainage to the Ottawa River, Lake Ontario and Georgian Bay.

To the east of the Laurentian Highlands, a triangular-shaped area, which is enclosed between the Ottawa River and the St. Lawrence River, is known as the Central St. Lawrence Lowlands physiographic region. The surface elevation of this region ranges from about 60.0 to 120.0 m (a.s.l.). The area to the west of the Laurentian Highlands is known as the Western St. Lawrence Lowland physiographic region. It ranges in elevation from about 75.0 to 550.0 m (a.s.l.).

Two ridges of Precambrian rocks, known as the Frontenac and Algonquin Arches, transect both the Laurentian Highlands and the Western St. Lawrence Lowland. Although these arches no longer form major topographic features, the distribution of Phanerozoic sedimentary rocks around the arches indicates that they had been important topographic elements controlling the deposition of the Phanerozoic sedimentary rocks (Thurston et al.1991).

The Niagara Escarpment subdivides the Western St. Lawrence physiographic region into two parts: the Ontario Lowland to the east of the Escarpment and the Ontario Upland to the west of it. The Niagara Escarpment extends from Queenston, where it is a 90-metre bluff, along the south shore of Lake Ontario through Hamilton and northward to Collingwood on Georgian Bay. It owes its form to the differential erosion of Paleozoic rocks that consist of dense dolomites underlain by softer shales. Differential erosion of these dense and soft rocks has resulted in the formation of steep cliffs rising above the Ontario Lowland to the east.

Within the Ontario Lowland, a great ridge, known as the Oak Ridges Moraine, extends north of Lake Ontario from the Niagara Escarpment in the west to Trenton in the east. The moraine stands about 350.0 m (a.s.l.). The steep south-facing slopes of the moraine descend to Lake Ontario whereas its gentle north-facing slopes fall off to the Simcoe and Kawartha Lakes region.

The land surface of the Ontario Upland dips regionally to the west and south away from the Niagara Escarpment toward Lake Huron and Lake Erie. The greatest elevation in this area is within Dufferin and Grey Counties where heights between 520.0 and 550.0 m (a.s.l.) are reached.

In order to point up the variety and contrast of the landscape within southern Ontario, Chapman and Putnam (1984) delineated 52 minor physiographic regions. Their delineation was primarily based on the topographic characteristics of the various regions and the composition of their surface materials.

3.2 DRAINAGE

A drainage basin determines the amount and direction of movement that surface water takes and often the direction of movement that groundwater takes. The Ottawa River, The St. Lawrence River, Lake Ontario, the Niagara River, Lake Erie, The Detroit River, Lake St. Clair, the St. Clair River, Lake Huron and Georgian Bay form a continuous water boundary around southern Ontario toward which a myriad of drainage systems flow.

Southern Ontario contains parts of the following six major drainage basins (Figure 4):

- the Ottawa River basin,
- the St. Lawrence River basin,
- the Lake Ontario basin,
- the Lake Erie and Lake St. Clair basin,
- the Lake Huron basin, and
- the Georgian Bay basin.

The main tributaries to the Ottawa River are the South Nation, Rideau, and Mississippi Rivers. Only the South Nation River is entirely within the Central St. Lawrence Lowland physiographic region. The other two rivers rise and have parts of their courses in the Laurentian Highlands physiographic region.

The Cataraqui and Gananoque Rivers are the two main tributaries to the St. Lawrence River. They join the St. Lawrence River at Kingston and Gananoque, respectively. The watersheds of both rivers contain numerous narrow, long lakes.

Most of the rivers that flow into Lake Ontario have small catchments. One notable exception is the Niagara River, which joins Lake Erie to Lake Ontario across the Niagara cuesta. Also, the Trent and Moira Rivers have fairly large drainage basins.

Between Niagara-on-the-Lake and Hamilton, a number of small streams drain parts of the back slopes of the Niagara cuesta, descend through V-shaped gorges, and on reaching the base of the Niagara Escarpment they proceed directly to Lake Ontario. Among these are the Four Mile, Twelve Mile, Twenty Mile, Stoney, and Red Hill Creeks.

Between Hamilton and the Bay of Quinte, the Lake Ontario basin is bounded by the Niagara cuesta and the Oak Ridges Moraine. All the streams that flow into Lake Ontario in this part of the basin are short in length. Among them are the Sixteen Mile and Etobicoke Creeks; the Humber, Don and Rouge Rivers; the Duffins, Oshawa and Bowmanville Creeks; and the Ganaraska River.

A number of large rivers drain into the Bay of Quinte, including the Trent, Moira, and Salmon Rivers. All these rivers have their headwaters within the Canadian Shield.

Lake Erie receives no major rivers except the Detroit and Grand Rivers. The Detroit River joins Lake St. Clair to Lake Erie. The Grand River, on the other hand, has the largest basin in southwestern Ontario and drains most of the highest portions of the Niagara cuesta. Numerous small streams enter Lake Erie at various points along its 400-km shoreline. Among these are Kettle, Catfish, Big Otter, and Big Creeks.

The drainage into Lake St. Clair includes the St. Clair, Sydenham and Thames Rivers. The St. Clair River connects Lake Huron to Lake St. Clair, while the Sydenham River drains most of the clay plains of Lambton County. The Thames River is the second largest river in southwestern Ontario. Its main two branches, the North Thames and the South Thames, originate in Logan Township and west of Tavistock, respectively.

The Sauble, Saugeen, Maitland, Bayfield and Ausable Rivers are the major watercourses draining into Lake Huron. Of all these rivers, the Saugeen has the largest catchment that includes some of the highest lands in the southwestern part of southern Ontario.

A number of rivers drain into Georgian Bay, including the Severn, Nottawasaga, Beaver and Bighead Rivers. Most of the drainage area of the Severn River is located south of the Canadian Shield. The Severn River drains Lake Couchiching, which in turn drains Lake Simcoe. The Nottawasaga, Beaver and Bighead Rivers rise on the Niagara cuesta and flow to Georgian Bay.

In order to make the St. Lawrence River navigable, a series of canals was constructed. This effort was culminated in the building of the St. Lawrence International Seaway which was opened in 1959. The Welland Canal was built to facilitate navigation between Lake Erie and Lake Ontario. Also, the Trent-Severn Waterway was built to facilitate navigation between Lake Ontario and Georgian Bay.

3.3 CLIMATE

Geology and climate are two critical factors that determine the hydrologic and hydrogeologic characteristics of an area. Geology governs the suitability of certain geologic deposits to act as aquifers, whereas climate controls the availability of water to replenish these aquifers.

According to Brown et al. (1968), southern Ontario has a temperate climate with warm summers, mild winters and reliable precipitation. Climatic conditions, however, differ from one location to another and from one year to another. The local variations are created by topography, the proximity to the Great Lakes and the prevailing wind. The annual variations, on the other hand, depend on the nature and frequency of the weather systems that cross the local area.

Precipitation, mainly in the form of rain and snowfall, is fairly uniformly distributed throughout the year. The mean annual precipitation varies from less than 800.0 mm to more than 1000.0 mm (Figure 5a). It is heaviest in the lee of Lake Huron and Georgian Bay at elevations between 400.0 and 450.0 m (a.s.l.), and is lightest along the eastern shores of the Detroit and St. Clair Rivers as well as below the Niagara Escarpment from Niagara through Hamilton to Toronto.

The mean annual snowfall ranges from less than 100.0 cm to more than 300.0 cm. Snowfall is lightest along the northern shores of Lake Erie and it is heaviest along the southern shores of Georgian Bay (Figure 5b).

According to Brown et al. (1968), the mean annual frost-free period is longest, about 180 days, on Pelee Island in Lake Erie and shortest, about 90 days, in Algonquin Park. Those areas bordering the Great Lakes have significantly longer frost-free periods than farther inland.

Evapotranspiration is the combined removal of water to the atmosphere through evaporation from inland water bodies, snow and soil surfaces as well as through transpiration by plants. Water removed in this way is not available for streamflow or groundwater. According to the Ministry of Natural Resources (MNR 1984), the mean annual evapotranspiration varies from less than 500.0 mm to more than 600.0 mm (Figure 5c). Most evapotranspiration occurs along the northern shores of Lake Erie, and least evapotranspiration occurs in the northern parts of Durham and Victoria Counties.

Runoff consists of that portion of precipitation that reaches rivers and lakes from surface drainage and groundwater. Figure 5d shows the spatial distribution of the mean annual runoff in southern Ontario, expressed as depth of water averaged over the drainage area. The mean annual runoff ranges from less than 200.0 mm to greater than 450.0 mm. Highest values are observed within the Ontario Upland in Dufferin and Grey Counties. Lowest values are observed in Essex, Kent and Lambton Counties in southwestern Ontario (MNR 1984).

4. DATA AND METHODS USED IN THE STUDY

4.1 DATA USED IN THE STUDY

This study is based mainly on data obtained from the MOE Water Well Information System (WWIS). Base map information such as county boundaries and shorelines were digitized from 1:100,000 maps produced by the Ontario Ministry of Transportation. Additional information such as surface drainage and highways were obtained from digitized maps produced by the Federal Department of Energy, Mines and Resources. Geologic maps of the bedrock and Quaternary geology of southern Ontario were digitized from 1:1,000,000 maps produced by the Ministry of Northern Development and Mines.

Daily streamflow data for 33 hydrometric gauging stations, being maintained by Environment Canada, were used to determine the long-term groundwater discharge and recharge in various watersheds within southern Ontario. In addition, the results of 1,055 chemical analyses for water samples, collected from wells completed in various bedrock and overburden units, were used to determine the types of groundwater found in these units.

Appendix I provides details about methods and assumptions that were made during the preparation of maps and graphs.

4.2 THE WATER WELL INFORMATION SYSTEM

The water well regulations requiring well records to be submitted to the Ontario Department of Mines came into force early in 1946. The number of records submitted by well drillers annually increased steadily from less than 500 in 1946 to more than 4,000 in 1971. To deal with this increasing number of records, the previous Ontario Water Resources Commission decided to initiate the Water Well Information System (WWIS).

The WWIS is a computerized database that was designed in 1972 to allow for the easy input and retrieval of data describing the characteristics of water wells in Ontario (Mantha 1988). As of 2003, the WWIS database contains more than 500,000 well records. Most of the records are for wells constructed after 1946.

The well record is a document designed mainly to protect the interest of the well owner should a problem related to poor well construction arise, or should maintenance or repairs become necessary. The record is equally important to MOE staff in their efforts to regulate the well construction industry and assess the groundwater resources of the province.

The well record contains information on up to 212 parameters, including:

- surface elevation;
- location: UTM coordinates, county or district, township, borough, city, town or village, lot, concession, and watershed;
- geology: types of materials encountered during drilling;
- water: depths at which water was found, depth to static level, and the kind of water found in terms of being fresh, salty, sulphurous, or containing iron or gas;
- pumping test and well yield;
- well construction details: casings, screens, plugs, and seals;

- date of well completion; and
- names and addresses of well owner and well driller.

The WWIS database also contains a quality control feature which assigns different quality indices to the well coordinates and elevations. These indices range from1 for high quality data to 9 for poor quality data. This feature allows the user to select only those data that have the highest degree of accuracy in terms of well location and elevation.

The WWIS database has proven to be an indispensable tool for the mapping and protection of Ontario's groundwater resources. Since its inception, no hydrogeologic investigation has been conducted in Ontario without strong reliance on it. The WWIS database continues to provide valuable information on the occurrence, quantity and quality of groundwater to home owners, well contractors, hydrogeologic consultants, academia and various government agencies.

4.3 THE GIS SYSTEMS USED IN THE STUDY

In the past, the analysis and interpretation of information obtained from the WWIS database for a given area was done manually. This was a time-consuming process because of the great number of records that had to be considered.

Advances in the area of Geographic Information Systems (GIS) during the last fifteen years make it feasible to consider a large amount of data, to present these data on thematic maps, and to conduct numerous analyses and interpretations within a short time frame. The Regional Analysis by Intelligent Systems on a Microcomputer (RAISON), and ArcView are such GIS systems, and are suitable for use with the WWIS database. These two systems are data analysis tools which were designed for use on personal computers.

The RAISON system was developed as a joint research project by the National Water Research Institute and the University of Guelph, Ontario. It was used to produce the majority of the figures for the first edition of this report. ArcView, on the other hand, is a commercial computer program and it was used to produce the new figures for the second edition of this report.

The RAISON system integrates databases, spreadsheets and GIS capabilities that are particularly suitable for applications involving point data. It provides an environment for displaying the data and analytical results in the context of local geography. In addition, enhanced statistical techniques are included in RAISON and advanced modelling can be performed.

The "RAISON Database" is a subsystem within RAISON that allows the user to maintain files through the use of "Delete Record" and "Edit Record" functions. Data may be exported in dBASE or Lotus 123 formats for use in programs external to RAISON, or for exchange with other users using similar data formats. In addition, data may be imported into RAISON as ASCII files from a mainframe computer or from other software packages. Normally, data are either entered manually into RAISON or retrieved from an existing database. Using the RAISON Database subsystem, links and basic analyses may be done. Relevant results may then be transferred into a spreadsheet and further analyses can be performed.

Like RAISON, ArcView provides an environment for displaying the water well data and analytical results in the context of local geography. It provides the opportunity to visualize, explore, query, and analyse the well data geographically. For additional functionality, the Spatial Analyst Extension of ArcView is used in conjunction with the well data to create contour maps.

The results obtained from both GIS systems may be displayed graphically in the form of charts, graphs, maps or cross-sections. The results can be displayed in colours or symbols so that similar regions may be readily identified. This display capability of both GIS systems has been extremely useful in conducting the hydrogeologic analyses presented in this report.

A number of hydrogeologic, analytical techniques were developed by MOE staff specifically for the interpretation of the WWIS database in conjunction with the RAISON and ArcView GIS systems. These techniques allow the user to produce various maps and geologic cross-sections, to convert the specific capacity data to transmissivity estimates, and to perform streamflow separation.

The following types of maps and graphs, all of which are contained in this report, have been produced:

- well location,
- well type (bedrock or overburden),
- kind of groundwater in the bedrock,
- kind of water in the overburden,
- bedrock topography,
- overburden thickness,
- groundwater level elevation in the bedrock,
- groundwater level elevation in the overburden,
- specific capacity of bedrock wells,
- specific capacity of overburden wells,
- transmissivity of bedrock wells, and
- transmissivity of overburden wells.

5. HYDROGEOLOGIC DEFINITIONS

5.1 GROUNDWATER

Subsurface waters occur in two zones below the land surface: the unsaturated vadose zone and the saturated zone. The first zone extends from the land surface down to the water table and includes the capillary fringe. It contains liquid water under less than atmospheric pressure and water vapour, air, or other gases at atmospheric pressure. In parts of this zone, interstices, particularly the small ones, may be temporarily or permanently filled with water. The second zone (i.e. the saturated zone) is that zone in which all voids, large and small, are filled with water under pressure greater than atmospheric (Lohman 1972). The top boundary of the saturated zone, at which pressure is atmospheric, is called the water table.

Groundwater is that part of the subsurface water, which occurs in the zone of saturation and is subject to continuous movement. The geometry and intensity of groundwater flow are dependent on the hydrologic environment, consisting of topography, climate and geology (To'th 1972). The source of, and the recharge to groundwater comes from precipitation, directly by infiltration from the land surface or indirectly by surface water leaking from streams, ditches or ponds.

The land surface topography exerts a controlling influence upon the configuration of the water table, the distribution of flow systems and, consequently, groundwater movement. The occurrence, movement, quality and availability of groundwater also depend on geologic factors such as lithology, porosity, permeability and the spatial distribution of various deposits.

5.2 AQUIFERS

An aquifer is a geologic deposit capable of storing and transmitting a large quantity of water. Aquifers vary in thickness and areal extent. Some aquifers are small and may only be able to supply water to one or a few households. Others are large ranging in size from a few hectares to hundreds of square kilometres.

Aquifers may be found in the bedrock or in the overburden (unconsolidated materials) overlying the bedrock. The more fractures and openings there are in the bedrock the higher is the water yield of the aquifer. In the overburden, aquifers consist of sand and/or gravel. Deposits of coarse sand and gravel are good aquifers, while deposits of fine sand and silt are poor aquifers.

The best bedrock aquifer in southern Ontario, which provides high quality water, is the Amabel-Lockport-Guelph Aquifer Complex. This aquifer complex occurs in the Niagara Peninsula and in the area between Hamilton and Owen Sound. The largest overburden aquifers, on the other hand, are the Oak Ridges Moraine Aquifer Complex located north of Lake Ontario, the Norfolk Sand Plain Aquifer which extends between Lake Erie and Bradford, and the Alliston Aquifer Complex located south of Georgian Bay.

A geologic deposit that is saturated with water but has low permeability and, therefore, does not furnish an adequate supply of water is called an aquitard. Examples of aquitards are clay deposits or poorly-fractured rock formations with a few interconnected pore spaces.

An aquifer that is overlain by a confining layer that has low permeability is called an artesian or a confined aquifer. Groundwater in wells drilled in confined aquifers rises above the point where the water is found and may flow over the ground surface.

5.3 HYDRAULIC PARAMETERS

Groundwater occurs in the openings within the aquifer. These openings may be in the form of pore spaces between the grains of silt, sand or gravel, or in the form of solution cavities, fissures, joints and bedding planes. The ratio of the volume of the pore spaces to the total volume of the water-bearing material is called porosity.

In unconsolidated deposits, porosity is controlled by the shape, arrangement, degree of sorting and cementation of particles. Porosity is high in well sorted deposits and low in poorly sorted and highly cemented deposits. In consolidated rocks, porosity is dependent on the extent of cementation and the degree of development of the fissure system or the solution cavity openings. Effective porosity refers to the interconnected pore spaces or other openings available for water transmission.

Porosity is not a measure of the amount of water that an aquifer will ultimately yield. The ratio of the volume of water that the rock, after being saturated, will yield by gravity to the total volume of the rock is called the specific yield. The specific retention is the complement of the specific yield. It is the ratio of the volume of the water that the rock, after being saturated, will retain against the force of gravity to the total volume of the rock.

The storage coefficient is the volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head. In an unconfined aquifer, the storage coefficient is virtually equal to the specific yield. However, in a confined aquifer, it is less than the specific yield as the water derived from storage comes from expansion of the water and compression of the aquifer. Similarly, water added to storage is accommodated by compression of the water and expansion of the aquifer (Lohman 1972).

Groundwater flow occurs under a hydraulic gradient which is defined as the change in static head per unit of distance along the groundwater flow path. The relative ease with which a water bearing material can transmit water under a hydraulic gradient is a measure of the permeability or hydraulic conductivity of the material, and is a measure of the capacity of the material to transmit water.

Transmissivity is the rate at which water, at the prevailing kinematic viscosity, is transmitted through a unit width of the aquifer under a unit hydraulic gradient, and is equal to the product of the hydraulic conductivity of the aquifer and its thickness.

The specific capacity of a well is defined as its yield per unit of drawdown, expressed as litres per minute per metre of drawdown (L/min/m). Dividing the yield of a well by the drawdown for a specific time during a pump test, gives the value of specific capacity.

The specific capacity of a well is a function of the type of the aquifer, well diameter, pumping time, partial penetration, hydrogeologic boundaries and well construction characteristics. Because of the above-mentioned constraints, the specific capacity is not an exact criterion with which to calculate the transmissivity. It is, however, a useful index to describe the water-yielding characteristics of the well and of the formation the well taps. In general, high specific capacities are indicative of high transmissivities and, consequently, high water-yielding capabilities.

In applied hydrogeology, pumping and recovery tests of wells generally give the most reliable results for determination of the hydraulic constants of materials surrounding a well. Often, however, the only available data for the wells are the final drawdowns associated with pumping tests of short durations. These data can be used to calculate the specific capacity distribution for the wells and to describe the water-yielding characteristics of the formation the wells tap.

The hydraulic properties of an aquifer are expressed quantitatively by the hydraulic conductivity, and by the coefficients of transmissivity and storage. These properties can be estimated using pumping test data.

There are a number of methods to calculate the aquifer constants from pumping test data. The most widely used methods are based on:

- measurement of drawdown in a monitoring well during pumping,
- measurement of drawdown of the pumped well during recovery, and
- drawdown-distance method, using the drawdowns in the observation and pumped wells at the end of the pumping period.

Unfortunately, only a few data on pumping tests are available for wells in the study area and most of these data are incomplete. On the other hand, thousands of specific capacity values, based on short-duration pumping tests, are available. These data were used to supplement the data on pumping tests.

Theis et al. (1963) described a method for estimating the transmissivity of an aquifer from the specific capacity of a well. The method is based on the Jacob Equation, given in consistent units as:

$$T = (Q/12.6 * s) \ln [(2.25 T * t)/(r^2 * S)] \qquad (1)$$

where

T = transmissivity (L^2/t),
Q = discharge (L^3/t),
s = drawdown in the well (L),
t = pumping time (t),
S = storage coefficient (dimensionless), and
r = radius of the well (L).

Because T appears twice, equation (1) cannot be solved directly. Graphical solutions involving matching the specific capacity data to a family of curves were proposed. These solutions, however, have the disadvantage of requiring a different set of curves for every possible combination of a well radius, pumping period and storage coefficient. In addition, any corrections for partial penetration or well loss require additional calculations.

A computer program, which uses an iterative technique, corrects for partial penetration and well loss, and provides a rapid estimate of transmissivities at hundreds of data points, was developed by Bradbury and Rothschild (1985). The program was modified to accept the format of the WWIS data, and was linked to the RAISON GIS system to allow for the use of RAISON's contour mapping routines and statistical programs. Using the above computer program, the transmissivity values for wells completed in various hydrogeologic units were determined.

To determine the statistical distribution, mean and range of the specific capacities and transmissivity values, a statistical analysis was applied. For example, in the case of transmissivity, the values for each unit were listed in ascending order of magnitude and assigned probabilities according to the relationship:

$$F = (100 * m)/(n + 1) \qquad (2)$$

where

F = percentage of wells where transmissivities are less than the transmissivity of well of serial number m,
m = serial number of well arranged in ascending order of transmissivity, and
n = total number of wells.

The transmissivity values for various units were then plotted against the percentage of wells on logarithmic probability paper. The transmissivity values for most hydrogeologic units plot approximately as straight lines, indicating that the samples have lognormal frequency distributions. Therefore, it could be concluded that the most probable transmissivity value for a given hydrogeologic unit is equal to the geometric mean of its individual transmissivity values.

The 10 and 90 percentile values are the transmissivities not exceeded by 10% and 90% of the wells, respectively. They provide a measure of the dispersion of the transmissivity values; a large difference between the 10 and 90 percentiles indicates a large spread and a high standard deviation.

Similar analyses were conducted using the specific capacity data for various hydrogeologic units. The results of these analyses are reported as part of the description of each unit.

6. GROUNDWATER OCCURRENCE IN THE BEDROCK

The occurrence, flow and quality of groundwater are strongly influenced by geology. Therefore, it is important in any groundwater investigation to have a full consideration of the characteristics of the geologic deposits within the area under study.

The bedrock in southern Ontario is a major source of water supplies to agricultural, commercial and industrial operations as well as to municipalities and private home owners. This is specifically true in areas where the overburden is absent or where the thickness of the overburden is small.

Figure 6 shows the locations of wells that are completed in the bedrock. The figure indicates that most of these wells are located in eastern Ontario, to the north of the Oak Ridges Moraine, and above the Niagara Escarpment.

In this study, the records of 133,609 water wells, completed in various bedrock units, were examined. Information related to the quality of groundwater, encountered in various bedrock units, is available for 129,797 wells. Table 1 gives the total number of bedrock wells by county and summarizes the data related to the kind of water found in bedrock wells in terms of being fresh, salty, mineral, sulphurous or containing gas.

A total of 69,649 records, which have the highest degree of accuracy in terms of well location and elevation, were selected to determine the specific capacity and transmissivity distributions for various hydrogeologic units within the bedrock of southern Ontario.

6.1 BEDROCK TOPOGRAPHY

The bedrock in most of the central and southwestern parts of southern Ontario is obscured by a thick mantle of overburden deposits. The bedrock, however, outcrops at the surface over large areas in the central and eastern parts of southern Ontario.

Precambrian rocks of the Canadian Shield outcrop at the surface over most of the Laurentian Highlands physiographic region. Thin Quaternary deposits obscure the Precambrian rocks only at a few places.

It is possible to identify three bands where Paleozoic rocks outcrop at the surface. One band flanks the eastern rim of the Canadian Shield, extending from the Ottawa River in the north to the St. Lawrence River in the south. The second band runs along the southwestern slopes of the Canadian Shield, extending from Addington and Prince Edward Counties in the southeast to Lake Simcoe in the northwest. A third band extends along the northern shores of Lake Ontario from Mississauga to Burlington. Paleozoic rocks also outcrop at many locations along the Niagara Escarpment and in Bruce County.

Figure 7 is a map of bedrock elevation in southern Ontario. Hatched areas on the figure are those areas where the bedrock is at the surface. The figure indicates that the general topography of the bedrock, in areas where it is currently obscured by a mantle of overburden deposits, is very similar to present-day topography.

The elevation of the bedrock within the Canadian Shield decreases radially from 485.0 to 530.0 m (a.s.l.) in the north within Haliburton and Hastings Counties to 40.0 to 80.0 m (a.s.l.) in the south along the shores of Lake Ontario. Within the Oak Ridges Moraine, the elevation of the bedrock ranges from 160.0 to 200.0 m (a.s.l.). Bedrock elevations of 40.0 to 80.0 m (a.s.l.) are observed in most of the Central St. Lawrence Lowland physiographic region in the eastern part of southern Ontario (see Section on Physiography).

6.1.1 Dundalk Dome

Above the Niagara Escarpment, a dome-like bedrock structure dominates the topography of the area. The highest parts of the structure are located in Dufferin and Grey Counties where they reach more than 480.0 m (a.s.l.) in elevation. This part of the structure will be referred to in this report as the Dundalk Dome.

During preglacial time, the Dundalk Dome controlled the drainage patterns in the southwestern part of southern Ontario and diverted surface runoff radially to the east, south, west and north. A major topographic divide, which ran in a southwesterly direction, can be traced from the Dundalk Dome to Essex County. A second topographic divide, ran parallel to the Niagara Escarpment, extending from Collingwood on Nottawasaga Bay to Burlington on Lake Ontario. A third topographic divide ran from the Dundalk Dome through the Bruce Peninsula. A forth divide ran from the Niagara River through the Niagara Peninsula and continued through the Counties of Haldimand, Brant, Oxford and Perth.

6.1.2 Bedrock Valleys

A wide bedrock valley, known as the Laurentian Channel, extends to the east of the Niagara Escarpment from Georgian Bay to Lake Ontario (Eyles et al. 1983). Figure 7 shows the outline of this wide channel. Numerous small bedrock valleys drained the eastern parts of the Dundalk Dome into this channel. Also, numerous small bedrock valleys drained an area, currently occupied by the Oak Ridges Moraine, either into this channel or into the Lake Ontario basin.

A large bedrock valley, parts of which are currently occupied by the Grand River system, drained the southern slopes of the Dundalk Dome. The valley can be traced to the western tip of Lake Ontario. The first reference to this valley was made by Karrow (1973) who named it the Dundas Valley (Figure 7). Another large bedrock valley, which overlap parts of the current Saugeen River system, drained the western slopes of the Dundalk Dome (Figure 7).

A wide bedrock depression runs in an east-west direction through the Niagara Peninsula. Also, two major bedrock valleys occur within the peninsula. One valley empties into Lake Ontario between Fonthill and St. Catharines and the second empties into the Niagara River. In addition, a buried connection to Lake Erie occurs west of Port Colborne.

6.2 PRECAMBRIAN ROCKS

The oldest rocks in southern Ontario are the Precambrian rocks of the Canadian Shield. These rocks form a basement on which all younger deposits rest. As indicated earlier, Precambrian rocks occur at or close to the surface within the Laurentian Highlands physiographic region. The surrounding areas, which occur to the east and southwest of this region, are underlain by younger, sedimentary rocks of the Paleozoic era.

The Precambrian rocks in southern Ontario are considered part of the Grenville Province, which has been subdivided, from north to south, into the Grenville Front Tectonic Zone, the Central

Gneiss Belt, and the Central Metasedimentary Belt. Easton (1992) provided a comprehensive description of the Grenville Province based on the latest available information, and compiled an extensive list of references related to Precambrian geology.

According to Easton (1992), the Grenville Front Tectonic Zone extends from north to south through Georgian Bay, Lake Huron, Lake St. Clair, and Essex County. It consists of rocks that are deformed and metamorphosed.

The Central Gneiss Belt extends from the Ottawa River in the northeast to Lake Erie in the southwest. The belt consists mainly of amphibolite and granulite facies as well as gneisses (Easton 1992).

The Central Metasedimentary Belt is found throughout the remaining parts of southern Ontario and outcrops at or close to the surface within the Laurentian Highlands physiographic region. The belt comprises plutonic and metasedimentary rocks resulting from the extreme metamorphism of older rocks of igneous origin. Plutonic rock types found within this belt include granite, gneiss, granodiorite, diorite, syenite, pegmatite, and gabbro. The metasedimentary rock types include marble, conglomerate, breccia, arkose, and metamorphosed limestone and siltstone (Easton 1992).

6.2.1 Precambrian Hydrogeologic Unit

From a hydrogeologic point of view, those Precambrian rocks that are at or close to the surface are significant as a source of groundwater supplies. The remaining Precambrian rocks are buried under thick sequences of younger rocks and are not tapped for groundwater.

Two groundwater flow systems have been identified within the Precambrian rocks of the Canadian Shield. One shallow system, explored to a depth of about 150.0 m by the drilling of water wells, contains fresh water. A second deep system of brine water extends hundreds of meters in depth (Thorne and Gascoyne 1993). From a hydrogeologic point of view, the shallow groundwater system is significant as a source of water supplies especially in areas where the overburden is absent or thin.

Research to identify areas suitable for nuclear waste repositories has identified the occurrence of high salinity Ca -Na - Cl brines in the crystalline rocks of the Canadian Shield and in similar rocks outside Canada. Nuclear agencies became interested in learning more about these saline fluids, and how they may affect corrosion and transport of radioactive waste that may be buried in such deep crystalline environments. The research showed that these fluids are present at depths below the active groundwater flow systems in most crystalline rock environments, and that they are enriched in deuterium. The origin of these fluids and their age are still under investigation.

The shallow groundwater system is characterized by many small, localized aquifers. In some parts of the Canadian shield, groundwater in the overburden and in the bedrock may be hydraulically connected. Multiple layered aquifer/aquitard settings appear to be rare. Data are insufficient to define the shape of the water table within the Precambrian rocks but it is likely a subdued replica of the surface topography.

Significant movement of groundwater in the shallow bedrock is entirely dependent on the secondary permeability created by the fractures in the rock. Lineament analysis of space images, conducted at the Goddard Space Flight Centre, has been particularly valuable in determining regional and subcontinental fracture patterns within the Canadian Shield (Short 2002). The images show that, where soil and glacial cover are small, the Shield contains a very high density of fractures. It is possible that these fractures have developed at the time of emplacement of the individual terrains that collided and assembled to form the Shield.

The fracture systems within the Superior and Grenville Provinces were investigated (Short 2002). Many fractures in each province stand out as linear glacially-scoured gouges that are now filled with water. When the orientations of the lineaments are plotted in rose diagrams for each province, two characteristics emerge. The first characteristic is that both provinces have a dominant east-northeast fracture trend. The second is that the Superior Province has an extra north-northeast dominant trend, and the Grenville Province has an extra north-northwest trend.

The intensity and distribution of the fracture systems play a major role in determining the total porosity of the rocks of the Canadian Shield, their hydraulic conductivity, water yield, and groundwater recharge. The determination of total porosity is highly site-specific, however, and cannot be done without field observations.

The hydraulic conductivity of a fracture zone depends on the degree of crushing, the presence of fracture filling, and the characteristics of the individual fractures. According to Ericsson and Ronge (1986), tension fractures, called joints, are generally more conductive than faults. Since these joints become narrower and smaller with depth, the bulk hydraulic conductivity of the rock should decrease with depth. Further, due to the fact that the well yield is dependent only on the hydraulic properties of the area close to the well, the relationship between a well yield and the distance to fractures and faults is expected to be weak.

Many studies have been conducted in Ontario for areas containing parts of the Canadian Shield. Sibul et al. (1974), assessed the groundwater resources of the Moira River basin. The authors showed that approximately 85% of 400 wells, drilled in Precambrian rocks within the basin, obtained suitable water supplies within 15.0 m of the ground surface. Five percent of the wells failed to supply sufficient water for domestic use, and 40% yielded less than 10.0 L/min. Well yields of more than 2,000.0 L/min, however, have been reported for some municipal wells at Deloro, Madoc, and Tweed. According to Sibul et al. (1974), the groundwater yield from the Precambrian rocks depends on the number and size of fractures and joints encountered by the well. Because these openings can begin and end abruptly and because they possess strong directional orientations, well yields in the Precambrian rocks are highly variable.

Wang and Chin (1978) assessed the groundwater resources of five northern Ontario basins draining into the Hudson Bay and James Bay. As part of their study, 16 test holes were constructed in the Albany River basin. The degree and extent of fractures in the Precambrian rocks were inferred from rock cores collected from the16 test holes. Core recoveries ranged from 97% to 99% which shows that the rocks have generally few fractures. Injection tests in the same holes showed that the permeability of the rocks varies greatly. In some intervals, the water losses were very small showing a few fractures and low permeability, in others, the water losses were very large showing a highly fractured rock and high permeability. The rate of water loss was used to compute an average permeability of less than 0.1 m/day for the Precambrian rocks in the Albany River basin.

According to Wang and Chin (1978), additional 33 test holes were also constructed at seven sites in the Precambrian rocks of the Attawapiskat, Winisk, and Severn River basins. Average core recovery from the test holes ranged from 80% to100%, and the degree and extent of fractures in the Precambrian rocks was inferred from the collected cores. According to the authors, the cores showed that the Precambrian rocks in the three basins contained a few fractures. Most of these fractures occurred at less than 12.0 m below the bedrock surface although some were found up to 48.0 m below the bedrock surface. Injection tests in the same holes showed that the mean permeability values for the Precambrian rocks in the three basins were generally of the same magnitude as those for the Albany River basin.

In addition, Wang and Chin (1978) examined data related to short-term pumping tests for 74 wells in the Albany River basin, 932 wells in the Moose River basin, and four test holes in the Severn River basin. The data were used to determine the mean specific capacity and transmissivity values for the wells that taped water in the rocks of the Canadian Shield. The results showed that the wells constructed in the Albany River basin had a mean specific capacity of 1.8 L/min/m and a mean transmissivity of 2.9 m^2/day. Wells constructed in the Moose River basin, on the other hand, had a mean specific capacity of 2.1 L/min/m and a mean transmissivity of 3.1 m^2/day. The transmissivities for the four test holes in the Severn River basin were 1.5, 6.0, 7.1, and 28.2 m^2/day. According to Wang and Chin (1978), the high transmissivity value of 28.2 m^2/day for one of the test holes reflects, most likely, the combined transmissivity of the Precambrian rocks and the sand till which may be providing some water to the well.

Ostry and Singer (1981) reported on the hydraulic conductivity of 179 wells completed in the Precambrian rocks within the Thousand Islands area. The hydraulic conductivity values for the wells ranged from 10^{-5} m/day to 1.3 m/day with a mean of 0.1 m/day.

Singer and Cheng (2002) assessed the records of 10,022 wells constructed within the Canadian Shield in northern Ontario. Of these, a total of 717 wells has been reported as dry. In all the productive wells, water was found at depths of 280.4 m or less. Approximately 90% of the wells, however, obtain water at depths of 67.1 m or less. Also, more than 50% of the wells obtain water at depths of 28.4 m or less. Of the 10,022 wells, 8,366 have data related to short-term pumping tests. An examination of the specific capacity values, calculated from the pumping test data, showed the following:

Specific Capacity Range (L/min/m)	Number of Wells	% of Wells
0 - 1	2,539	30.3
1 - 5	3,104	37.1
5 - 10	835	10.0
10 - 50	874	10.5
> 50	1,014	12.1

In this report, a total of 12,381 wells was identified in areas where the Precambrian hydrogeologic unit outcrops at the surface. Of this total, a sample of 7,875 wells was selected to determine their specific capacity and transmissivity distributions. Figure 8 shows the locations of the wells and the ranges of their specific capacities.

An examination of the specific capacity data indicates that 5,158 wells in the sample have specific capacity values less than 5.0 L/min/m. A fair number of wells (2,274), however, show good specific capacity values ranging from 5.0 to 50.0 L/min/m; while a minority of wells (50) have specific capacity values higher than 50.0 L/min/m.

The transmissivity distribution for the wells in the sample was derived from the specific capacity data. Figure A1 (Appendix II) shows a transmissivity-probability graph for wells constructed in the Precambrian hydrogeologic unit. The transmissivity values plot approximately as a straight line, indicating that the sample has lognormal distribution. The 10 and 90 percentile values are 0.4 and 42.5 m^2/day, and the geometric mean of the distribution is 4.2 m^2/day.

Given the large number of wells in the sample, it is possible to assume its transmissivity distribution is representative of the water-yielding capability of the Precambrian hydrogeologic unit. The low value of the distribution's geometric mean suggests that the unit has a poor water-yielding capability.

6.3 PALEOZOIC ROCKS

The Paleozoic rocks in southern Ontario are principally shales, limestones, dolomites and sandstones. In the central and southwestern parts of southern Ontario, these rocks appear to be flat lying but dip gently to the south or west. In the eastern parts of southern Ontario, however, the relations among the rock formations have been made complex through considerable faulting. Johnson et al. (1992) provided a comprehensive description of the Paleozoic geology of Ontario using a sequence stratigraphy approach and compiled an extensive list of references related to Paleozoic geology.

A large number of Paleozoic groups, formations, and members of Cambrian, Ordovician, Silurian, and Devonian age have been identified in southern Ontario. From a hydrogeologic point of view, many Paleozoic units are of limited significance as a source of groundwater either because of their finite spatial extent or because they are buried under thick sequences of younger rocks.

In the following sections, an attempt has been made to describe the Paleozoic units within southern Ontario and to highlight the hydrogeologic characteristics of selected units. The geologic descriptions of the various units are based on Johnson et al. (1992), and will be given according to geographic location and in order of oldest to youngest units.

6.3.1 Early Cambrian Strata

The Covey Hill Formation has been identified in the eastern part of southern Ontario as of Early Cambrian age. The unit has a limited extent and consists of conglomerates and sandstones with a maximum thickness of 13.0 m. Due to its limited extent, the formation is of little hydrogeologic significance.

6.3.2 Upper Cambrian and Lower Ordovician Strata

The Nepean Formation of the Potsdam Group has been identified in the eastern part of southern Ontario as of Upper Cambrian age. It consists of sandstones with conglomerate interbeds, and has a thickness of up to 300.0 m.

Three formations that appear to correlate with the Nepean Formation have been identified in the subsurface of the southwestern part of southern Ontario east of Longitude 81^0W. These units include the Potsdam Formation (conglomerates and sandstones up to 46.0 m thick), the Theresa Formation (sandstones and sandy dolostones up to 107.0 m thick), and the Little Falls Formation (dolostones up to 31.0 m thick).

West of Longitude 81^0W, three additional units that also appear to correlate with the Nepean Formation were identified in the subsurface. These units are the Mount Simon Formation (sandstones up to 50.0 m thick), the Eau Claire Formation (dolomitic sandstones up to 80.0 m thick), and the Trempealeau Formation (dolostones up to 75.0 m thick).

The March and Oxford Formations of the Beekmantown Group have been identified in the eastern part of southern Ontario as of Lower Ordovician age. The March Formation consists of sandstones, dolomitic sandstones, sandy dolostones and dolostones. It ranges in thickness from 6.0 to 64.0 m. The Oxford Formation consists of dolostones with a maximum thickness of 200.0 m.

6.3.2.1 The Nepean-March-Oxford Hydrogeologic Unit

No data are available to describe the occurrence of groundwater in the Potsdam, Theresa, Little Falls, Mount Simon, Eau Claire or the Trempealeau Formations. Given that these units are overlain by thick sequences of younger rocks, it may be possible to conclude that they are of limited hydrogeologic significance.

Due to their similar lithological composition, the Nepean, March and Oxford Formations were treated in this report as one hydrogeologic unit. A total of 17,642 wells has been identified within the unit. Of this total, a sample of 7,418 wells was selected to determine their specific capacity and transmissivity distributions. Figure 10 shows the locations of the wells tapping the unit and the ranges of their specific capacity values.

An examination of the specific capacity data indicates that 339 wells in the sample have values less than 1.0 L/min/m, 1,884 wells have values between 1.0 and 5.0 L/min/m, 1,466 wells have values between 5.0 and 10.0 L/min/m, 3,025 wells have values between 10.0 and 50.0 L/min/m, and 697 wells have values greater than 50.0 L/min/m.

The transmissivity values for the wells in the sample were derived from the specific capacity data. Figure A2 (Appendix II) is a transmissivity-probability graph for these wells, which plots as approximately a straight line. The 10 and 90 percentile values are 0.4 and 120.5 m^2/day, respectively, and the geometric mean is 20.0 m^2/day.

Given the large number of wells in the sample, it is possible to assume that its transmissivity distribution is representative of the water-yielding capability of the Nepean-March-Oxford hydrogeologic unit. The relatively high value of the distribution's geometric mean suggests that the unit has a good water-yielding capability.

6.3.3 Middle to Late Ordovician Strata

The Middle to Late Ordovician deposits occur over a large area in the south-central and southeastern parts of southern Ontario and extend from the Ottawa River to Georgian Bay. The major types of rocks are limestones, dolostones, sandstones and shales.

The Rockcliffe Formation (Middle Ordovician) has been identified in a number of small areas in the eastern part of southern Ontario. It consists mainly of sandstones and shales and has a thickness up to 125.0 m.

The Shadow Lake Formation is present in the eastern, south-central, and southwestern parts of southern Ontario. The thickness of the formation is generally 2.0 to 3.0 m and the maximum thickness is 15.0 m. In the eastern part of southern Ontario, the formation consists of dolostones with interbeds of calcareous sandstones. In the south-central and southwestern parts of southern Ontario, the formation consists of dolomitic or calcareous sandstones and mudstones.

Overlying the Shadow Lake Formation is a series of limestones and shales, which comprise the Gull River, Bobcaygeon, Verulam and Lindsay Formations. These units form the Simcoe Group in the south-central part of southern Ontario, and along with the Shadow Lake Formation they comprise the Ottawa Group in the eastern part. In the southwestern part of southern Ontario, the Middle Ordovician rocks consist of the Black River and Trenton Groups.

The Gull River Formation, with a thickness range of 7.5 to 136.0 m, is divided into a lower member and an upper member. The lower member consists of limestones and silty dolostones, whereas the upper member consists of limestones. The Bobcaygeon Formation consists of 7.0 to 87.0 m of limestones with some shales. The Verulam Formation consists of limestones with interbeds of shales. The unit has a thickness range of 32.0 to 65.0 m.

The youngest unit in the sequence is the Lindsay Formation. It has a thickness of up to 67.0 m and comprises two members. The lower member (unnamed) consists of limestones. The upper member is represented by the Eastview Member in the eastern part of southern Ontario and the Collingwood Member in the south-central and southwestern parts. The unit consists of up to 10.0 m of limestones and calcareous shales.

6.3.3.1 Rockcliffe Hydrogeologic Unit

A total of 2,117 wells has been identified within the Rockcliffe hydrogeologic unit. Of this total, a sample of 1,771 wells was selected to determine their specific capacity and transmissivity distributions. The minimum and maximum specific capacity values for the sample are 0.1 and 1,069.0 L/min/m, respectively. The 10 and 90 percentile values are 1.3 and 49.7 L/min/m, respectively, and the geometric mean is 7.9 L/min/m.

The minimum and maximum transmissivity values, derived from the sample's specific capacity data, are 0.1 and 2,906.0 m^2/day, respectively. Figure A3 (Appendix II) is a transmissivity-probability graph for the wells in the sample. The 10 and 90 percentile values are 2.1 and 103.9 m^2/day, respectively, and the geometric mean is 15.5 m^2/day.

Given the large number of wells in the sample, it is possible to assume that its transmissivity distribution is representative of the water-yielding capability of the Rockcliffe hydrogeologic unit. The relatively high value of the distribution's geometric mean suggests that the unit has a good water-yielding capability.

6.3.3.2 Ottawa Group Hydrogeologic Unit

A total of 10,357 wells has been identified within the Ottawa Group hydrogeologic unit. Of this total, a sample of 7,251 wells was selected to determine their specific capacity and transmissivity distributions.

The minimum and maximum specific capacity values for the sample are 0.1 and 2,610.0 L/min/m, respectively. The 10 and 90 percentile values are 0.8 and 33.9 L/min/m, respectively, and the geometric mean is 5.9 L/min/m.

The minimum and maximum transmissivity values, derived from the sample's specific capacity data, are 0.1 and 8,082.0 m^2/day, respectively. Figure A4 (Appendix II) is a transmissivity-probability graph for the wells in the sample. The 10 and 90 percentile values are 1.3 and 70.9 m^2/day, respectively, and the geometric mean is 11.7 m^2/day.

Given the large number of wells in the sample, it is possible to assume that its transmissivity distribution is representative of the water-yielding capability of the Ottawa Group hydrogeologic unit. The relatively high value of the distribution's geometric mean suggests that the unit has a good water-yielding capability.

6.3.3.3 Simcoe Group Hydrogeologic Unit

An evaluation of the groundwater resources of the Wilton Creek basin was carried out by Funk (1977). The Wilton Creek basin is located in the southeastern part of southern Ontario about 20 km west of the City of Kingston. The bedrock in the basin consists of deposits of the Shadow Lake, Gull River, Bobcaygeon, and Verulam Formations. Funk (1977) reported on the results of pumping tests for a number of wells finished in the bedrock. The transmissivity values for these wells range from 1.3 to 58.1 m^2/day.

In this report, a total of 28,172 wells has been identified within the Simcoe Group hydrogeologic unit. Of this total, a sample of 6,414 wells was selected to determine their specific capacity and transmissivity distributions for the wells within the unit. Figure 11 shows the locations of the wells and the ranges of their specific capacities.

The minimum and maximum specific capacity values are 0.1 and 1,044.0 L/min/m. The 10 and 90 percentile values are 0.5 and 29.8 L/min/m, respectively, and the geometric mean of the sample's specific capacity distribution is 3.0 L/min/m.

The minimum and maximum transmissivity values, derived from the sample's specific capacity data, are 0.1 and 3,062.0 m^2/day, respectively. Figure A5 (Appendix II) is a transmissivity-probability graph showing the transmissivity distribution for the wells in the sample. The 10 and 90 percentile values are 0.7 and 63.8 m^2/day, respectively, and the geometric mean is 5.7 m^2/day.

Given the large number of wells in the sample, it is possible to assume that its transmissivity distribution is representative of the water-yielding capability of the Simcoe Group hydrogeologic unit. The relatively low value of the distribution's geometric mean suggests that the water-yielding capability of the unit is fair.

6.3.4 Upper Ordovician Strata

The Upper Ordovician strata are represented in the eastern part of southern Ontario by the Billings, Carlsbad and Queenston Formations, and in central part by the Blue Mountain, Georgian Bay and Queenston Formations. These units consist mainly of shales.

The Billings Formation consists of shales with thin interbeddings of limestones. It has a thickness of up to 62.0 m. The Carlsbad Formation, with a maximum thickness of 186.0 m, comprises interbedded shales, siltstones and limestones. The Blue Mountain Formation consists of shales and has a maximum thickness of 60.0 m. The Georgian Bay Formation, with an average thickness of 100.0 m and a maximum thickness of 200.0 m, comprises shales with minor interbeds of siltstones and limestones.

The youngest unit in the Upper Ordovician sequence is the Queenston Formation with a thickness ranging from 45.0 to 335.0 m. The unit consists of shales with interbeds of limestones and calcareous siltstones.

6.3.4.1 Billings-Carlsbad-Queenston Hydrogeologic Unit

A total of 1,106 wells has been identified within the Billings-Carlsbad-Queenston hydrogeologic unit. Of this total, a sample of 969 wells was selected to determine their specific capacity and transmissivity distributions.

The minimum and maximum specific capacity values for the sample are 0.1 and 745.0 L/min/m, respectively. The 10 and 90 percentile values are 0.6 and 24.8 L/min/m, respectively, and the geometric mean is 4.5 L/min/m.

The minimum and maximum transmissivity values, derived from the sample's specific capacity data, are 0.1 and 1,803.0 m^2/day. Figure A6 (Appendix II) is a transmissivity-probability graph for the wells in the sample. The 10 and 90 percentile values are 0.9 and 52.2 m^2/day, respectively, and the geometric mean is 5.8 m^2/day.

Given the large number of wells in the sample, it is possible to assume that its transmissivity distribution is representative of the water-yielding capability of the Billings-Carlsbad-Queenston hydrogeologic unit. The relatively low value of the distribution's geometric mean suggests that the unit has a fair water-yielding capability.

6.3.4.2 Blue Mountain-Georgian Bay hydrogeologic unit

Ostry (1979) evaluated the hydrogeology of an area within the Duffins Creek and the Rouge River basins and provided estimates of the hydraulic conductivities for 42 wells within it. The wells were completed in the Blue Mountain Formation and the estimates of their hydraulic conductivities ranged from less than 0.1 to 1.7 m/day with a mean value of 0.3 m/day.

In their study of the groundwater resources of the Credit River watershed, Singer el al. (1994) indicated that groundwater occurs in the upper 3.0 to 5.0 m of the Georgian Bay Formation. Further, they noted that only a few wells tap groundwater in the formation, which they described as a poor aquifer. According to Singer et al. (1994), the specific capacity values for wells constructed in the Georgian Bay Formation ranged from 0.5 to 10.0 L/min/m, while the geometric mean of the formation's transmissivity distribution is 2.2 m^2/day.

In this report, the Blue Mountain and Georgian Bay Formations were treated as one hydrogeologic unit. A total of 2,130 wells has been identified within the unit. Of this total, a sample of 1,293 wells was selected to determine their specific capacity and transmissivity distributions. Figure 12 shows the locations of water wells within the Blue Mountain-Georgian Bay and Queenston hydrogeologic units and the ranges of their specific capacities.

The minimum and maximum specific capacity values for the sample are 0.1 and 447.0 L/min/m, respectively. The 10 and 90 percentile values are 0.3 and 16.7 L/min/m, respectively, and the geometric mean is 1.7 L/min/m.

The minimum and maximum transmissivity values, derived from the sample's specific capacity data, are 0.1 and 1,194.0 m^2/day, respectively. Figure A7 (Appendix II) is a transmissivity-probability graph for the wells in the sample. The 10 and 90 percentile values are 0.5 and 36.5 m^2/day, respectively, and the geometric mean is 2.9 m^2/day.

Given the large number of wells in the sample, it is possible to assume that its transmissivity distribution is representative of the water-yielding capability of the Blue Mountain-Georgian Bay hydrogeologic unit. The low value of the distribution's geometric mean suggests that the unit has a poor water-yielding capability.

6.3.4.3 Queenston Hydrogeologic Unit

According to Singer et al. (1994), the pore spaces in the compact, dense shales of the Queenston Formation within the Credit River watershed have relatively poor interconnections. The unit does not readily fracture or dissolve thus limiting its effective porosity. Only the top three to five metres are weathered and may provide sufficient water supplies to meet domestic needs. Singer et al. (1994) also indicated that the specific capacity values for wells constructed in the Queenston Formation within the Credit River watershed range from less than 0.5 to 20.0 L/min/m, while the geometric mean of the transmissivity distribution for wells constructed in the formation equals 5.0 m^2/day.

Dames and Moore, Canada (1992) indicated that on the west side of the Credit River, from Terra Cotta to Inglewood, a number of domestic wells obtain their water from the Queenston Formation. These wells generally produce about 10.0 L/min using the maximum available drawdown, often to the bottom of the well.

In this report, a total of 3,580 wells was identified within the Queenston hydrogeologic unit in the central part of southern Ontario. Of this total, a sample of 2,505 wells was selected to determine their specific capacity and transmissivity distributions (Figure 12).

The minimum and maximum specific capacity values for the sample are 0.6 and 1,491.0 L/min/m, respectively. The 10 and 90 percentile values are 0.3 and 14.9 L/min/m, respectively, and the geometric mean is 1.5 L/min/m.

The minimum and maximum transmissivity values, derived from the sample's specific capacity data, are 0.1 and 4,357.0 m^2/day, respectively. Figure A8 (Appendix II) is a transmissivity-probability graph for the wells in the sample. The 10 and 90 percentile values are 0.5 and 27.9 m^2/day, respectively, and the geometric mean is 2.7 m^2/day.

Given the large number of wells in the sample, it is possible to assume that its transmissivity distribution is representative of the water-yielding capability of the Queenston hydrogeologic unit. The low value of the distribution's geometric mean suggests that the unit has a poor water-yielding capability.

6.3.5 Lower Silurian Strata

Overlying the Ordovician rocks are formations comprised mainly of dolostones, shales, limestones and sandstones of Lower Silurian age. In the southwestern part of Ontario, the Lower Silurian is represented by the Cataract Group, which includes the Whirlpool, Manitoulin, Cabot Head and Grimsby Formations.

The Whirlpool Formation outcrops along the Niagara Escarpment and comprises up to 9.0 m of sandstones. The Manitoulin Formation outcrops along the Niagara Escarpment and occurs extensively in the subsurface of the southwestern part of southern Ontario. It consists of dolostones with a maximum thickness of 25.0 m.

The Cabot Head Formation occurs throughout the southwestern part of southern Ontario and the Niagara Peninsula. It consists of 10.0 to 39.0 m of non-calcareous shales with minor calcareous sandstones, dolostones and limestones. The sandstones and shales of the Grimsby Formation overlie the Cabot Head Formation in the Niagara Peninsula and have a maximum thickness of 15.8 m. The formation thins northward and has not been identified north of Hamilton.

6.3.5.1 Cataract Group Hydrogeologic Unit

In their evaluation of the groundwater resources of the Credit River watershed, Singer et al. (1994) noted that the specific capacity values of wells constructed in the Manitoulin Formation of the Cataract Group ranged from 1.5 to 20.0 L/min/m, and they also noted that the geometric mean of the transmissivity distribution for the wells equalled 4.0 m^2/day. Singer et al. (1994) concluded that the Manitoulin Formation does not constitute an important aquifer within the Credit River watershed.

Within the Niagara Peninsula, all the formations of the Cataract Group are buried under thick sequences of younger rocks. From a hydrogeologic point of view, the Cataract Group hydrogeologic unit is of limited significance as a source of groundwater.

6.3.6 Middle Silurian Strata

The Middle Silurian sequence is represented by the Dyer Bay, Wingfield and St. Edmund Formations; the Clinton Group (Thorold, Neahga, Reynales, Irondequoit, Rochester and Decew Formations); and the Fossil Hill, Amabel, Lockport and Guelph Formations. The major types of rocks are dolostones, shales, and sandstones.

The Dyer Bay Formation, which consists of dolostones, has an average thickness of 2.0 to 4.0 m and a maximum thickness of 7.6 m. The unit outcrops in the Bruce Peninsula and has been reported in the subsurface in Essex and Kent Counties.

The Wingfield Formation was identified in the Bruce Peninsula and consists of shales and dolostones ranging in thickness from 2.0 to 15.0 m. The St. Edmund Formation has also been identified in the Bruce Peninsula. It has a thickness of about 3.0 m and consists of dolostones.

The Thorold Formation, which has an average thickness of 3.0 m and a maximum thickness of 6.5 m, has been identified in the Niagara peninsula and in the area of east-central Lake Erie. The unit consists of sandstones.

The Neahga Formation has been identified in the Niagara Peninsula. The unit consists of shales with minor limestone interbeds and has a maximum thickness of 2.0 m.

The Reynales Formation has been identified in the Niagara Peninsula and in the subsurface of the southwestern part of southern Ontario. It consists of dolostones and dolomitic limestones with silty and/or shaly interbeds. The maximum thickness of the unit is 5.0 m.

The Irondequoit Formation has been identified in the Niagara Peninsula and in the subsurface of the southwestern part of southern Ontario. The unit consists of limestones that are locally dolomitic and has a maximum thickness of 3.0 m.

The Rochester Formation has been identified in the Niagara Peninsula and in the subsurface of the southwestern part of southern Ontario. The unit consists of shales and siltstones with carbonate interbeds. It has a maximum thickness of 24.0 m.

The Decew Formation, which has a thickness of up to 4.0 m, has been identified in the Niagara Peninsula. The unit is composed of dolostones with an increasing shale content toward the base of the formation.

The Fossil Hill Formation has been identified in the Bruce Peninsula and in the subsurface of the southwestern part of southern Ontario. It consists of dolostones with a maximum thickness of 24.0 m.

The Amabel Formation has been identified in an area which extends from the Bruce Peninsula in the north to Burlington in the south. It has also been identified in the subsurface of the southwestern part of southern Ontario. It consists of dolostones up to 38.0 m thick.

The Lockport Formation has been identified in the Niagara Peninsula and in the subsurface of the southwestern part of southern Ontario. The unit consists of three members: the Gasport Member (up to 10.0 m in thickness), the Goat Island Member (a maximum thickness of 16.0 m), and the Eramosa Member (a maximum thickness of 20.0 m). The Gasport Member is made up of dolomites and limestones, while the Goat Island and Eramosa Members are dolostones.

The youngest unit in the Middle Silurian sequence is the Guelph Formation which has been identified in the Niagara and Bruce Peninsulas. The unit is composed of dolostones and has a highly variable thickness ranging from 4.0 to 100.0 m.

6.3.6.1 Dyer-Wingfield-St. Edmund Hydrogeologic Unit

Although no data related to this hydrogeologic unit are available, it is possible to assume, based on the types of rocks found in the unit, that it may act as an aquifer in the Bruce Peninsula area.

6.3.6.2 Clinton Group Hydrogeologic Unit

The dolostones of the Decew Formation, which occur at the base of the Lockport Formation in the Niagara Peninsula, are likely a part of the Lockport aquifer. The shales of the Rochester Formation, which occur under the Decew Formation in the same area, have much lower permeability and are likely to act as a barrier, diverting groundwater flow within the overlying, younger rocks into a horizontal direction. The remaining formations within the Clinton Group are buried under thick sequences of younger rocks in the Niagara Peninsula as well as in the subsurface in the southwestern part of southern Ontario. Therefore, it is possible to conclude that the Clinton Group hydrogeologic unit is of little significance as a source of groundwater in southern Ontario.

6.3.6.3 Amabel-Lockport-Guelph Hydrogeologic Unit

Four maps, which describe groundwater flow within this hydrogeologic unit, were published by Turner in 1976 and 1978. The maps cover an area that extends from the Niagara River to Owen Sound. According to Turner (1976), the Amabel, Lockport and Guelph Formations constitute a high-capacity aquifer in the Niagara Peninsula and in the area between Hamilton and Owen Sound.

The permeability of the Amabel, Lockport and Guelph aquifer is highly variable, and is due primarily to a fracturing and chemical dissolution of the upper few meters of dolomites. Most domestic wells obtain adequate water supplies with penetrations of less than 3.0 m, and the potential for developing high-capacity wells in the aquifer is good (Turner 1976).

In his assessment of the groundwater resources of the East and Middle Oakville Creeks basin, Funk (1979) described the Amabel Formation as one of the most important and productive bedrock aquifers in Ontario, and noted that the water yield of the formation is dependent on the degree of fracturing and available drawdown. The transmissivities of five municipal wells, constructed in the Amabel formation, were reported by Funk (1979) to range from 150.0 to 1,400.0 m^2/day. The coefficients of storage for the same wells range from 10^{-8} to 10^{-2}. Of the five wells, two are located in Acton, two in Rockwood, and one in Campbellville.

Sibul et al. (1980) indicated that domestic supplies can be obtained readily throughout the Amabel-Lockport-Guelph Aquifer. They also noted that several high-capacity municipal wells tapping the aquifer provide water supplies for the cities of Cambridge, Guelph and many other smaller towns. Areas containing highest well yields, outside of the major urbanized areas, are located in the vicinity of the towns of Fergus-Elora, Arthur and Dundalk, and in Puslinch, Erin, Amaranth and East Luther Townships.

According to Sibul et al. (1980), the depths of wells in the Amabel-Lockport-Guelph Aquifer are variable and depend on the overburden thickness. Generally, most of the domestic wells obtain water from the upper 15.0 m of the aquifer, while municipal and some industrial wells penetrate the bedrock to depths of 30.0 to 188.0 m.

Singer et al. (1994) described the results of four pumping tests conducted in municipal wells that are constructed in the Amabel Formation. One well is located in Mono Township, two wells in Erin, and one well in Orangeville. The values of the coefficients of transmissivity for the four wells range from 40.0 to 380.0 m^2/day. The values of the coefficients of storage, on the other hand, range from $3*10^{-4}$ to 10^{-1}.

Singer et al. (1994) noted that because the Amabel Formation is fairly thick, its porosity and water-yielding capability are highly variable. These factors render the effective thickness of the aquifer to become considerably smaller than the measured thickness. This is to be expected in fractured bedrock.

In this report, a total of 23,559 wells has been identified within the Amabel-Lockport-Guelph hydrogeologic unit. Figure 13 shows the locations of these wells and the ranges of their specific capacities. Groundwater occurrence within each of the three formations will be described separately.

A sample that contains 6,516 wells was selected to determine the specific capacity and transmissivity distributions for wells constructed in the Amabel Formation. The minimum and maximum specific capacity values for the sample are 0.1 and 2,908.0 L/min/m, respectively. The 10 and 90 percentile values are 0.9 and 59.7 L/min/m, respectively, and the geometric mean is 7.8 L/min/m.

The minimum and maximum transmissivity values, derived from the specific capacity data for the sample, are 0.1 and 7,548.0 m^2/day, respectively. Figure A9 (Appendix II) shows a transmissivity-probability graph for the wells in the sample. The 10 and 90 percentile values are 1.5 and 134.8 m^2/day, respectively, and the geometric mean is 15.5 m^2/day.

A second sample of 1,662 wells was selected to determine the specific capacity and transmissivity distributions for wells constructed in the Lockport Formation. The minimum and maximum specific capacity values for the second sample are 0.1 and 671.0 L/min/m, respectively. The 10 and 90 percentile values are 1.1 and 63.9 L/min/m, respectively, and the geometric mean of the second sample's specific capacity distribution is 10.6 L/min/m.

The minimum and maximum transmissivity values, derived from the second sample's specific capacity data, are 0.1 and 1,879.0 m^2/day, respectively. Figure A9 shows a transmissivity-probability graph for the wells in second sample. The 10 and 90 percentile values are 1.7 and 141.0 m^2/day, respectively, and the geometric mean of the second sample's transmissivity distribution is 20.6 m^2/day.

A third sample of 6,072 wells was selected to determine the specific capacity and transmissivity distributions for wells constructed in the Guelph Formation. The minimum and maximum specific capacity values for the third sample are 0.1 and 2,076.0 L/min/m, respectively. The 10 and 90 percentile values are 0.8 and 49.7 L/min/m, respectively, and the geometric mean of the third sample's specific capacity distribution is 6.2 L/min/m.

The minimum and maximum transmissivity values, derived from the specific capacity data for the third sample, are 0.1 and 5,719.0 m^2/day, respectively. Figure A9 shows a transmissivity-probability graph for the wells in the third sample. The 10 and 90 percentile values are 1.4 and 104.9 m^2/day, respectively, and the geometric mean of the third sample's transmissivity distribution is 12.1 m^2/day.

The above results indicate that the specific capacity and transmissivity values of the Amabel, Lockport and Guelph Formations are highly variable, which is most likely a reflection of the variable distribution of the fissure systems within these formations. Nevertheless, the 10 and 90 percentile values for both the specific capacity and transmissivity distributions for the three samples are within similar range. The same is also true for the geometric means of the three distributions.

Given the large number of wells in each of the above three samples, it is possible to assume that their transmissivity distributions are representative of the water-yielding capabilities of the Amabel, Lockport and Guelph Formations. The relatively high values of the geometric means of the three distributions suggest that the water-yielding capabilities of the three formations are good.

The Amabel, Lockport and Guelph Formations are made up mainly of dolostones and limestones. Due to the similarities between their specific capacity and transmissivity distributions, it is possible to treat the three formations as one hydrogeologic unit.

6.3.7 Upper Silurian Strata

The Upper Silurian sequence consists of the Salina Formation (southwestern part of southern Ontario), the Bertie Formation (Niagara Peninsula) and the Bass Island Formation (Bruce Peninsula and the subsurface of the southwestern part of southern Ontario). The Bertie and Bass Island Formations appear to be of the same age.

The Salina Formation has been subdivided into eight units, named A-1, A-2, and B through G. In general, these units consist of dolostones, evaporites, evaporitic carbonates and shales. The total maximum thickness of the Salina Formation is 330.0 m.

The Bertie Formation consists of up to 14.0 m of dolostones with numerous bituminous partings. The upper surface of the formation contains joints and fractures in-filled with sandstones of the Oriskany Formation of Lower Devonian age.

The youngest Silurian strata in southern Ontario are represented by the Bass Island Formation, which consists of dolostones. Its thickness ranges from 22.0 to 28.0 meters.

6.3.7.1 Salina Hydrogeologic Unit

In their study of the groundwater resources in the Grand River basin, Sibul et al. (1980) described the Salina Formation as a high-capacity, water-supply source north of Kitchener-Waterloo. The authors also reported on substantial fracturing within the formation that was encountered in two test holes located south of Kitchener. Mud circulation could not be maintained in both test holes after approximately one metre of penetrating the bedrock. According to Sibul et al. (1980), the fracturing at both test holes is indicative of the high permeability of the Salina Formation.

In this report, a total of 3,756 wells has been identified within the Salina Formation. The depths of these wells vary considerably due to large variations in overburden thickness. Once through the overburden, however, the wells penetrate generally less than 15.0 m into the Salina Formation. Figure 13 shows the locations of these wells and the ranges of their specific capacities.

A sample of 2,994 wells was selected to determine the specific capacity and transmissivity distributions for the wells constructed in the Salina Formation. The minimum and maximum specific capacity values for the sample are 0.1 and 3,729.0 L/min/m, respectively. The 10 and 90 percentile values are 1.7 and 82.9 L/min/m, respectively, and the geometric mean is 13.2 L/min/m.

The minimum and maximum transmissivity values, derived from the samples' specific capacity data, are 0.1 and 10,197.0 m^2/day, respectively. Figure A10 (Appendix II) shows a transmissivity-probability graph for the wells in the sample. The 10 and 90 percentile values are 3.2 and 189.0 m^2/day, respectively, and the geometric mean is 28.2 m^2/day.

Given the large number of wells in the sample, it is possible to assume that its transmissivity distribution is representative of the water-yielding capability of the Salina hydrogeologic unit. The relatively high value of the distribution's geometric mean suggests that the unit has a very good water-yielding capability.

6.3.7.2 Bass Island Hydrogeologic Unit

Only 16 wells have been identified within the Bertie Formation. This is insufficient to determine the hydrogeologic significance of this unit. Given that the Bertie Formation is similar in composition to the Bass Island Formation, it is possible to assume that the water-yielding capabilities of both formations are similar.

A total of 807 wells, has been identified within the Bass Island Formation. Of this total, a sample of 739 wells was selected to determine their specific capacity and transmissivity distributions. Figure 13 shows the locations of the wells and the ranges of their specific capacities.

The minimum and maximum specific capacity values for the sample are 0.3 and 5,599.0 L/min/m, respectively. The 10 and 90 percentile values are 2.9 and 47.6 L/min/m, respectively, and the geometric mean is 14.9 L/min/m.

The minimum and maximum transmissivity values, derived from the sample's specific capacity data, are 0.4 and 14,219.0 m^2/day, respectively. Figure A10 (Appendix II) shows a transmissivity-probability graph for the wells in the sample. The 10 and 90 percentile values are 5.4 and 179.0 m^2/day, respectively, and the geometric mean is 30.9 m^2/day.

Given the large number of wells in the sample, it is possible to assume that its transmissivity distribution is representative of the water-yielding capability of the Bass Island hydrogeologic unit. The relatively high value of the distribution's geometric mean suggests that the unit has a very good water-yielding capability.

6.3.8 Lower Devonian Strata

The Lower Devonian sequence in southern Ontario consists of the Oriskany Formation which occurs in the Niagara Peninsula area, and the Bois Blanc Formation which extends as a narrow band from the Niagara Peninsula to Lake Huron.

The Oriskany Formation consists of calcareous sandstones with a maximum thickness of 6.0 m. The Bois Blanc Formation, which ranges in thickness from 3.0 to 50.0 meters, consists of cherty limestones that grade into dolostones toward the west.

No hydrogeologic data are available for the Oriskany Formation. Given its composition and small thickness, it is possible to assume that the formation is a minor aquifer.

6.3.8.1 Bois Blanc Hydrogeologic Unit

A total of 1,261 wells has been identified to penetrate the Bois Blanc hydrogeologic unit. Of this total, a sample of 1,069 wells was selected to determine their specific capacity and transmissivity distributions. Figure 14 shows the locations of these wells and the ranges of their specific capacities.

The minimum and maximum specific capacity values for the sample are 0.3 and 5,719.0 L/min/m, respectively. The 10 and 90 percentile values are 3.3 and 112.0 L/min/m, respectively, and the geometric mean is 18.6 L/min/m.

The minimum and maximum transmissivity values, derived from the sample's specific capacity data, are 0.4 and 3,905.0 m^2/day, respectively. Figure A11 (Appendix II) is a transmissivity-probability graph for the wells in the sample. The 10 and 90 percentile values are 6.3 and 274.5 m^2/day, respectively, and the geometric mean is 40.4 m^2/day.

Given the large number of wells in the sample, it is possible to assume that its transmissivity distribution is representative of the water-yielding capability of the Bois Blanc hydrogeologic unit. The relatively high value of the distribution's geometric mean suggests the unit has an excellent water-yielding capability.

6.3.9 Middle Devonian Strata

The Middle Devonian sequence includes the Onondaga Formation in the Niagara Peninsula and the corresponding Detroit River Group in the southwestern part of southern Ontario. The sequence also includes the Dundee and Marcellus Formations and the Hamilton Group in the southwestern part of southern Ontario. The major types of rocks are limestones, dolostones, sandstones and shales.

The Onondaga Formation consists of three members: the Edgecliffe Member (limestones up to 21.0 m thick), the Clarence Member (cherty limestones, 5.0 to 8.0 m thick), and the Moorehouse Member (limestones, 4.5 m thick). No hydrogeologic data are available for the Onondaga

Formation. Therefore, it is not possible to make any assumptions concerning its hydrogeologic significance.

The Detroit River Group consists of three formations: Sylvania, Amherstburg, and Lucas. The Sylvania Formation consists of up to 25.0 m of sandstones; the Amherstburg Formation consists of 40.0 to 60.0 m of limestones becoming dolostones towards the southwest; and the Lucas Formation consists of 40.0 to 75.0 m of limestones and dolostones.

Overlying the Lucas and Onondaga Formations, are the Dundee and Marcellus Formations. The Dundee Formation consists of limestones and has an average thickness of 35.0 to 45.0 m. The Marcellus Formation occurs between Port Stanley and Long Point on Lake Erie, and extends inland as far as Aylmer and St. Thomas. The unit consists mainly of shales and has a maximum thickness of 12.0 m.

The Hamilton Group contains six units: the Bell, Rockport Quarry, Arkona, Hungry Hollow, Widder, and Ipperwash Formations. The lowest unit in the Hamilton Group is the Bell Formation. With an average thickness of 14.5 m, the formation consists mainly of shales with thin, organic shale interbeds.

The Rockport Quarry Formation consists of limestones with shale interbeds. It has an average thickness of 5.7 m. The Arkona Formation consists of shales with occasional limestone interbeds. It has an average thickness of 32.0 m. The Hungry Hollow Formation consists of limestones and is about 2.0 m in thickness. The Widder Formation consists of shales with limestone interbeds. The unit has a maximum thickness of 21.0 m.

The uppermost member of the Hamilton Group is the Ipperwash Formation, which consists of limestones with minor cherts. The unit's thickness ranges from 2.0 to 13.0 m.

6.3.9.1 Detroit River Group Hydrogeologic Unit

A total of 7,818 wells has been identified to penetrate the rocks of the Detroit River Group. Of this total, a sample of 6,762 was selected to determine their specific capacity and transmissivity distributions. Figure 14 shows the locations of these wells and the ranges of their specific capacities.

The minimum and maximum specific capacity values are 0.1 and 2,237.0 L/min/m, respectively. The 10 and 90 percentile values are 2.1 and 89.5 L/min/m, respectively, and the geometric mean is 14.9 L/min/m.

The minimum and maximum transmissivity values, derived from the sample's specific capacity data, are 0.1 and 6,472.0 m^2/day, respectively. Figure A12 (Appendix II) shows a transmissivity-probability graph for the wells in the sample. The 10 and 90 percentile values are 4.0 and 214.0 m^2/day, respectively, and the geometric mean is 30.9 m^2/day.

Given the large number of wells in the sample, it is possible to assume that its transmissivity distribution is representative of the water-yielding capability of the Detroit River Group hydrogeologic unit. The relatively high value of the distribution's geometric mean suggests that the unit has a very good water-yielding capability.

6.3.9.2 Dundee Hydrogeologic Unit

Due to the high thickness of the overburden deposits along the northern shores of Lake Erie between Port Stanley and Long Point, only a few wells have been identified in the Dundee or Marcellus Formations in that area. On the other hand, a total of 5,030 wells has been identified to penetrate the rocks of the Dundee Formation elsewhere. Of this total, a sample of 4,199 wells was selected to determine their specific capacity and transmissivity distributions. Figure 14 shows the locations of these wells and the ranges of their specific capacities.

The minimum and maximum specific capacity values for the sample are 0.1 and 3,281.0 L/min/m, respectively. The 10 and 90 percentile values are 1.6 and 74.6 L/min/m, respectively, and the geometric mean of the sample's specific capacity distribution is 13.1 L/min/m.

The minimum and maximum transmissivity values, derived from the sample's specific capacity data, are 0.1 and 9,380.0 m^2/day, respectively. Figure A12 (Appendix II) shows a transmissivity-probability graph for the sample. The 10 and 90 percentile values are 3.1 and 169.1 m^2/day, respectively, and the geometric mean of the sample's transmissivity distribution is 27.1 m^2/day.

Given the large number of wells in the sample, it is possible to assume its transmissivity distribution is representative of the water-yielding capability of the Dundee hydrogeologic unit. The relatively high value of the distribution's geometric mean suggests that the unit has a very good water-yielding capability.

6.3.9.3 Hamilton Group Hydrogeologic Unit

A total of 2,208 wells has been identified to penetrate the rocks of the Hamilton Group. Of this total, a sample of 1,044 wells was selected to determine their specific capacity and transmissivity distributions. Figure 14 shows the locations of these wells and the ranges of their specific capacities.

The minimum and maximum specific capacity values for the sample are 0.1 and 1,007.0 L/min/m, respectively. The 10 and 90 percentile values are 0.3 and 27.7 L/min/m, respectively, and the geometric mean is 2.7 L/min/m.

The minimum and maximum transmissivity values, derived from the sample's specific capacity data, are 0.1 and 2,638.0 m^2/day, respectively. Figure A12 (Appendix II) shows a transmissivity-probability graph for the sample. The 10 and 90 percentile values are 0.6 and 63.5 m^2/day, respectively, and the geometric mean of the sample's transmissivity distribution is 5.3 m^2/day.

Given the large number of wells in the sample, it is possible to assume that its transmissivity distribution is representative of the water-yielding capability of the Hamilton Group hydrogeologic unit. The relatively low value of the distribution's geometric mean suggests the unit has a fair water-yielding capability.

6.3.10 Upper Devonian and Mississippian Strata

The Kettle Point Formation represents the youngest strata in the Devonian sequence in southern Ontario. The unit, which extends from the vicinity of Chatham area to the vicinity of Sarnia, has a thickness ranging from 30.0 to 75.0 m and consists mainly of shales and siltstones.

The Port Lambton Group has been identified in the subsurface in a small area in Lambton County. Its age is either Upper Devonian or Early Mississippian. Three formations have been identified within the Port Lambton Group: Bedford, Berea, and Sunbury.

The Bedford Formation consists of 30.0 m of shales with silty and sandy interbeds in the upper part of the unit. The Berea Formation (60.0 m) consists of sandstones which are interbedded with shales and siltstones. The Sunbury Formation consists of shales and has a maximum thickness of 20.0 m.

6.3.10.1 Kettle Point Hydrogeologic Unit

No hydrogeologic information is available for the Port Lambton Group. Given its small areal extent, the group is of minor significance as a source of groundwater.

A total of 6,145 wells has been identified within the Kettle Point hydrogeologic unit. Of this total, a sample of 3,096 wells was selected to determine their specific capacity and transmissivity distributions. Figure 14 shows the locations of the wells and the ranges of their specific capacities.

The minimum and maximum specific capacity values for the sample are 0.1 and 745.7 L/min/m, respectively. The 10 and 90 percentile values are 0.5 and 37.3 L/min/m, respectively, and the geometric mean is 4.2 L/min/m.

The minimum and maximum transmissivity values, derived from the sample's specific capacity data, are 0.1 and 1,675.0 m^2/day, respectively. Figure A13 (Appendix II) is a transmissivity-probability graph for the sample. The 10 and 90 percentile values are 0.9 and 82.8 m^2/day, respectively, and the geometric mean is 8.6 m^2/day.

Given the large number of wells in the sample, it is possible to assume that its transmissivity distribution is representative of the water-yielding capability of the Kettle Point hydrogeologic unit. The relatively low value of the distribution's geometric mean suggests that the unit has a fair water-yielding capability.

6.4 A COMPARISON OF THE WATER-YIELDING CAPABILITIES AMONG VARIOUS BEDROCK HYDROGEOLOGIC UNITS

Table 2 and Figure 15 provide a summary and a graphical display of the water-yielding capabilities of various bedrock hydrogeologic units in southern Ontario. To assess the water-yielding capabilities of the various units, a qualitative scale was used. The scale, which is based on the ranges of the geometric means of the transmissivity distributions for the units, is as follows:

Geometric mean m^2/day	Water-yielding capability
less than 5.0	poor
5.0 - 10.0	fair
10.0 - 20.0	good
20.0 - 30.0	very good
30.0 - 40.0	excellent

Based on the above scale, the Bois Blanc, Detroit River, Salina, Bass Island, Dundee, and Amabel-Lockport-Guelph hydrogeologic units have been identified as the best water-yielding units within the bedrock of southern Ontario.

7. GROUNDWATER OCCURRENCE IN THE OVERBURDEN

Most of the bedrock in southern Ontario is obscured by a mantle of unconsolidated sediments known as the overburden. The overburden was deposited during the Quaternary Period which has been subdivided into the Pleistocene (Great Ice Age) and the Holocene (Recent) epochs. The Pleistocene Epoch is the period when great ice sheets covered parts of Ontario several times. The Holocene Epoch includes postglacial times up to and including the present.

The ice advances and recessions during the Quaternary Period have played a major role in shaping the landscape of southern Ontario and have left behind a variety of unconsolidated deposits consisting of tills, gravels, sands, silts, and clays. These deposits are associated with the two main glacial stages of the Pleistocene Epoch, the Illinoian and Wisconsinan as well as with the interglacial Sangamonian Stage and the Holocene Epoch. Sediments deposited prior to the Late Wisconsinan substage in southern Ontario are rarely found at the surface and are observed mainly in man-made excavations. Exposures of sediments of the Late Wisconsinan, however, are widespread and have been extensively investigated. Figure 16 is a correlation chart of Wisconsinan deposits in southwestern Ontario (Thurston et al. 1992). The chart was modified from Karrow (1989).

Barnett (1992) provided a comprehensive description of the Quaternary geology of southern Ontario. Among other things, his description provided a review of the genesis and character of glacial landforms in Ontario, identified the major stratigraphic units, and compiled an extensive list of references related to this topic.

In this report, the geologic descriptions of various overburden units in southern Ontario are based on Barnett (1992), and will be given according to geographic location and in order of the oldest to the youngest unit. In addition, Map 2556, scale 1:1,000,000 (Barnett et al. 1991), published by the Ontario Geological Survey (OGS), was used in this report to delineate the geologic boundaries of the overburden units at the surface.

Two approaches have been adopted in this report to describe the occurrence of groundwater within the overburden. In this chapter, the various overburden units that occur at the surface will be identified, and the specific capacity values for wells constructed within each unit will be provided. In the following chapter, an attempt will be made to identify and describe individual overburden aquifers.

When dealing with groundwater occurrence within the overburden, it is important to keep the following two critical facts in mind:

1. The overburden is highly variable in terms of composition and thickness both vertically and horizontally.

2. An overburden well could penetrate a number of tills, silts, sands or gravels, and it is not always clear which one of these materials contributes most of the water to the well.

Figure 17 shows the locations of wells constructed in the overburden. The figure indicates that most of these wells are located in the central and southwestern parts of southern Ontario where the thickness of the overburden can be substantial.

In this report, the records of 82,232 wells constructed in the overburden were examined. Of these, 43,321 wells that have the highest degree of accuracy in terms of well location and elevation, were selected to determine the ranges of their specific capacity values. Table 3 gives the number of overburden wells by county and the kind of water encountered in these wells in terms of being fresh, salty, sulphurous, mineral or containing gas.

7.1 OVERBURDEN THICKNESS

Figure 18 shows the spatial distribution of overburden thickness in southern Ontario. The figure indicates that the thickness of the overburden is quite variable. It is very thin over the Canadian Shield, along the Niagara Escarpment, and over most of the eastern parts of southern Ontario.

In the central parts of southern Ontario, within the Oak Ridges Moraine and in the area between Lake Simcoe and Georgian Bay, the overburden is more than 110.0 m in thickness. Above the Niagara Escarpment, the overburden thickness ranges from less than 10.0 m where the bedrock is close to surface to more than 110.0 m within the Waterloo Moraine.

Thick overburden deposits (30.0-90.0 m) are found within an area extending along the northern shores of Lake Erie from Long Point Bay to Blenheim. The overburden is also thick within the numerous moraines and kames that are scattered throughout the southwestern part of southern Ontario. The overburden thickness within most of these landforms ranges on the average from 30.0 to 90.0 m.

In this report, the thickness of various overburden units is given when available from literature.

7.2 ILLINOIAN GLACIAL DEPOSITS

The York Till (clayey sand till) found in Toronto and Woodbridge and the Bradtville Drift encountered in boreholes along the northern shores of Lake Erie, are probably the oldest Quaternary deposits in southern Ontario. It is believed that they were deposited during or possibly before the Illinoian Glaciation. According to Karrow (1984), the thickness of the York Till in the Toronto area ranges from zero to six metres.

In regional terms, the Illinoian glacial deposits may be of limited hydrogeologic significance due to their limited spacial extent.

7.3 SANGAMONIAN INTERGLACIAL DEPOSITS

The Sangamonian Interglacial deposits are represented by the Don Formation. The formation has been identified in the Scarborough Bluffs east of Toronto, in the Don Brickyard in Toronto, and in Woodbridge. It ranges in thickness from 0.0 to 18.0 m and is believed to have been deposited under warm climatic conditions similar to those of today. The unit, which consists of gravels, sands, silts and clays, is probably of deltaic origin (Karrow 1984).

In regional terms, the Sangamonian Interglacial deposits may be of limited hydrogeologic significance due to their limited spatial extent.

7.4 EARLY WISCONSINAN DEPOSITS

The best documented deposits of Early Wisconsinan age are found in the Scarborough Bluffs, in the Don Brickyard in Toronto and in Woodbridge. These deposits belong to three stratigraphic units: the Scarborough Formation, the Pottery Road Formation, and the Sunnybrook drift. The Canning Till, found in the Hamilton area, is also believed to be of Early Wisconsinan age.

The Scarborough Formation (3.0-30.0 m thick) consists of clay and silt rhythmites at the base, and of cross-bedded sands at the top. It is believed that the unit is of deltaic origin (Karrow 1984).

The Pottery Road Formation, which ranges in thickness from 0.0 to 7.0 m, consists of gravel and gravely sand. The unit occurs within channels that cut the Scarborough and Don Formations, and it is probably of alluvial origin (Karrow 1984).

The Sunnybrook drift (3.0-24.0 m thick) consists of a lower member termed the Sunnybrook Till and an upper member termed the Bloor Member. According to Karrow (1984), the Scarborough Till is a silt to silty-clay till, 6.0 to 10.0 m in thickness. The Bloor Member, on the other hand, consists of varved clays.

The Scarborough and Pottery Road Formations constitute local aquifers. Data, however, are not adequate to describe the exact spatial extent of these aquifers.

7.5 MIDDLE WISCONSINAN DEPOSITS

The deposits of Middle Wisconsinan age are represented by the Thorncliffe Formation in the Scarborough Bluffs, and by the Tyconnell and Wallacetown Formations in the Lake Erie basin.

The Thorncliffe Formation is approximately 47.0 m in thickness (Karrow 1984) and is composed of stratified sediments of glaciofluvial and glaciolacustrine origins. Two tills have been identified in the Scarborough Bluffs: the silty Seminary Till and the clayey Meadocliffe Till. These two tills separate the Thorncliffe Formation into a Lower, Middle, and Upper Members. The tills, however, appear to pinch out farther inland and the Thorncliffe Formation becomes a continuous unit.

The deposits of Middle Wisconsinan age in the Lake Erie basin consist of a buried soil and two main organic-bearing units. Each unit is separated by glaciolacustrine sediments.

The sands of glaciofluvial and glaciolacustrine origins within the Thorncliffe Formation constitute aquifers of local significance. Groundwater issuing at the base of these sands in the form of small springs is one important factor which is continuously undermining the stability of the Scarborough Bluffs.

7.6 LATE WISCONSINAN DEPOSITS

According to Barnett (1992), the record of the Late Wisconsinan is by far the most extensive, continuous, and best understood. Almost all parts of Ontario bear evidence of this ice advance that covered the entire province.

Barnett (1992) indicated that three significant periods of ice advance directly affected the Lower Great Lakes region during the Late Wisconsinan. These periods were termed the Nissouri, the Port Bruce, and the Port Huron stades. Two warm periods: the Erie and the Mackinaw interstades, characterized by ice-margin recession, separated the three stades.

The Port Huron Stade was followed by a warm period known as the Two Creeks Interstade. This, in turn, was followed by a minor and final ice advance known as the Greatlakean Stade.

7.6.1 Nissouri Stadial Deposits

The deposits of the Nissouri Stadial s are represented by the Catfish Creek and the Dunwich Tills. The Catfish Creek Till is widespread in the subsurface throughout southwestern Ontario. This sandy silt to silt till outcrops along Catfish Creek near Sparta, in the Lake Erie Bluffs near Port Talbot, and in the vicinity of Woodstock and Dundalk. The Dunwich Till, on the other hand, is believed to be a Huron lobe facies of the Catfish Creek Till.

A total of 206 wells was identified in areas where the Catfish Creek Till outcrops at the surface. No dry wells have been reported. General information related to quality of groundwater is available for 201 wells. All these wells have been reported to yield fresh water.

A sample of 167 wells was selected to determine the statistical parameters for their specific capacity distribution. The results are as follows:

Parameter	Specific capacity L/min/m
minimum	0.4
10 percentile	1.4
mean	8.7
90 percentile	44.7
maximum	223.7

7.6.2 Erie Interstadial Deposits

Warm climatic conditions prevailed during the Erie Interstade resulting in an ice-marginal recession in the Lakes Michigan, Huron, and Erie basins, and in the formation of a series of ice-contact proglacial lakes. Most of the records of these lakes, however, were destroyed by subsequent events.

A thick sequence of glaciolacustrine rhythmites in the central part of the Lake Erie basin termed the "Malihide Formation" and deposits of silt termed the "Wildwood Silts" near St. Marys have been assigned to the Erie Interstade (Barnett 1992). No information is available to evaluate the hydrogeologic significance of the Erie Interstadial deposits.

7.6.3 Port Bruce Stadial Deposits

During the Port Bruce Stade, ice sheets advanced radially across southern Ontario from Georgian Bay and Lakes Huron, Erie, Ontario and Simcoe. The ice lobes advanced, laid down numerous tills, and formed moraines. The Ingersoll, Waterloo and Orangeville Moraines mark the northern extent of the Erie-Ontario lobe, while the Blenheim, Ingersoll, Waterloo and Orangeville Moraines mark the eastern and southern advance of the Huron-Georgian Bay lobe.

7.6.3.1 Deposits Associated with the Combined Erie-Ontario Lobe

The fluctuations of the Erie-Ontario lobe are represented by the Maryhill Till and the Port Stanley Drift. The Maryhill Till has been identified beneath Port Stanley Drift in an area between Woodstock and Kitchener. It is a calcareous, silty clay to clay till.

Along the north-central shores of Lake Erie, the Port Stanley Drift includes up to five layers of clayey silt to silty clay till, termed the Port Stanley Till. The till layers are separated by glaciolacustrine sediments. Farther inland, the five layers merge into one layer of silt to sandy silt type till, while the glaciolacustrine deposits become glaciofluvial.

A total of 375 wells was identified in small areas located to the southwest of Kitchener where the Maryhill Till outcrops at the surface. Seven wells have been reported as dry.

A sample of 241 wells was selected to determine their specific capacity distribution. The results are as follows:

Parameter	Specific Capacity L/min/m
minimum	0.4
10 percentile	2.7
mean	5.1
90 percentile	79.3
maximum	809.0

The relatively high specific capacity values of some wells are likely the result of tapping groundwater in the sand and gravel deposits associated with the Waterloo Moraine.

A total of 5,191 wells has been identified in areas where the Port Stanley Till outcrops at the surface. Of this total, 107 wells have been reported to be dry.

General information related to the quality of groundwater is available for 4,702 wells. Approximately, 99% of these wells yield fresh water, and the remaining 1% yield mainly sulphurous water.

A sample of 3,651 wells was selected to determine their specific capacity distribution. The results are as follows:

Parameter	Specific capacity L/min/m
minimum	0.1
10 percentile	1.2
mean	7.2
90 percentile	44.7
maximum	1551.0

7.6.3.2 Deposits Associated with the Combined Huron-Georgian Bay Lobe

Five tills were laid down by the combined Huron-Georgian Bay lobe. They are the Stirton, Tavistock, Mornington, Stratford and Wartburg Tills.

The Stirton Till occurs in the subsurface within the Conestogo River Valley. This calcareous, silty clay to clayey silty till, has a thickness of 1.0 to 3.0 m. No water wells associated with the Stirton Till have been identified.

South of Lake Huron and Lake St. Clair, the Tavistock Till is a calcareous, silty clay to clay silt till, 2.0 to 15.0 m thick. The till changes into calcareous, silty sand till in the London and Woodstock area, and into a calcareous, silty clay to silt till in an area to the north of Waterloo.

The Mornington Till is calcareous, silty clay till. It occurs at the surface to the northwest of Waterloo as a sheet of a ground moraine, 1.0 to 3.0 m thick.

The Stratford Till is calcareous, sandy silt to silt till. It is a sheet of a ground moraine, 1.0 to 3.0 m thick, and occurs at the surface to the north and southeast of Stratford.

The Wartburg Till is calcareous, silty clay till, two to 15.0 m thick. It forms the core of the Milverton Moraine, which is located to the west of Waterloo. No wells that are associated with the Wartburg Till have been identified.

A total of 2,525 wells was identified in areas where the Tavistock Till outcrops at the surface. Sixty-three of the wells have been reported to be dry. General information related to the quality of groundwater is available for 2,315 wells. Approximately, 98.0% of these wells yield fresh water, and the remaining 2.0% yield either sulphurous or salty water.

A sample of 1,678 wells was selected to determine their specific capacity distribution. The results are as follows:

Parameter	Specific capacity L/min/m
Minimum	0.1
10 percentile	1.6
mean	10.4
90 percentile	62.1
maximum	2237.0

A total of 395 wells has been identified in areas where the Mornington Till outcrops at the surface. Of this total, six wells have been reported to be dry. General information related to the quality of groundwater is available for 368 wells. Approximately, 97.0% of these wells yield fresh water, and the remaining 3.0% yield either salty or mineral water.

A sample of 281 wells was selected to determine their specific capacity distribution. The results are as follows:

Parameter	Specific capacity L/min/m
minimum	0.8
10 percentile	2.4
mean	4.9
90 percentile	62.1
maximum	358.0

A total of 131 wells has been identified in areas where the Stratford Till outcrops at the surface. Two of these wells have been reported as dry. General information related to the quality of groundwater is available for 125 wells. All the wells have been reported to yield fresh water.

A sample of 86 wells was selected to determine their specific capacity distribution. The results are as follows:

Parameter	Specific capacity L/min/m
minimum	0.8
10 percentile	2.7
mean	5.9
90 percentile	55.9
maximum	746.0

7.6.3.3 Deposits Associated with the Georgian Bay Lobe

Two tills were laid down by the Georgian Bay lobe: the Elma Till and the Dunkeld Till. The Elma Till is calcareous, silt, sandy silt and clayey silt till. It ranges in thickness between 2.0 and 15.0 m and covers a wide area extending from Owen Sound to Stratford. The till occurs as a ground moraine and in the drumlins of the Teeswater Drumlin Field, and is also associated with the Singhampton Moraine. The Dunkeld Till is found as a ground moraine within a small area within the Saugeen River Valley. The unit is calcareous silt till.

A total of 557 wells was identified in areas where the Elma Till outcrops at the surface. Of this total, 21 wells have been reported to be dry. General information related to groundwater quality is available for 494 wells. Approximately, 99.0% of these wells yield fresh water, and the remaining 1.0% yield either salty or sulphurous water.

A sample of 392 wells was selected to determine their specific capacity distribution. The results are as follows:

Parameter	Specific capacity L/min/m
minimum	0.1
10 percentile	1.3
mean	6.1
90 percentile	59.6
maximum	671.0

A total of 16 wells has been identified in areas where the Dunkeld Till outcrops at the surface. All the wells yield fresh water. It was not possible to select a suitable sample for statistical analysis.

7.6.3.4 Deposits Associated with the Huron Lobe

The Rannoch Till was laid down by the Huron lobe. It outcrops over a large area extending from the St. Clair River to the headwaters of the Maitland River. The till occurs as a ground moraine and in a number of end moraines including the Centralia, Dublin, Lucan, Mitchell, and Seaforth Moraines. It is calcareous, silt to silty clay till with an average thickness of 2.0 to 6.0 m and a maximum thickness of 75.0 m.

A total of 2,638 wells has been identified in areas where the Rannoch Till outcrops at the surface. Of this total, 112 wells have been reported to be dry. General information related to the quality of groundwater is available for 2,291 wells. Approximately, 99.0% of these wells yield fresh water, and the remaining 1.0% yield either sulphurous or salty water.

A sample of 1,530 wells was selected to determine their specific capacity distribution. The results are as follows:

Parameter	Specific capacity L/min/m
minimum	0.2
10 percentile	1.4
mean	9.3
90 percentile	67.8
maximum	895.0

7.6.3.5 Deposits Associated with the Simcoe Lobe

The Newmarket Till was deposited by the Simcoe lobe. It is calcareous, silt to sandy silt till, which is less than 12.0 m in thickness. The till outcrops in the Holland and Nottawasaga River basins as a ground moraine, and above the Niagara Escarpment as hummocky end moraines. It is often covered by glaciofluvial and glaciolacustrine sands and silts.

A total of 3,762 wells has been identified in areas where the Newmarket Till outcrops at the surface. Of this total, 83 wells have been reported to be dry. General information related to the quality of groundwater is available for 3,153 wells. More than 99.8% of these wells yield fresh water and the remaining 0.2% yield either salty or sulphurous water.

A sample of 1,791 wells was selected to determine their specific capacity distribution. The results are as follows:

Parameter	Specific capacity L/min/m
minimum	0.1
10 percentile	0.9
mean	4.5
90 percentile	24.9
maximum	915.0

7.6.3.6 Glaciofluvial and Glaciolacustrine Deposits Associated with the Port Bruce Stade

During the Port Bruce Stade, ice-margin recessions caused the ponding of meltwaters several times in the western end of the Lake Erie basin and in the southern end of the Lake Huron basin. This resulted in the formation of glacial lakes termed: Maumee I, Maumee II, Maumee III and Maumee IV. These glacial lakes and the rivers that flowed into them left large amounts of glaciofluvial and glaciolacustrine deposits. The occurrence of groundwater in these deposits is discussed as part of the descriptions of various glaciofluvial and glaciolacustrine deposits.

7.6.4 Mackinaw Interstadial Deposits

During this warming period, the retreat of the ice continued and a glacial Lake Arkona formed in the combined basins of Lakes Huron and Erie. The Wentworth Till is believed to have been deposited during this period as a result of a readjustment of the Erie-Ontario lobe margin.

The Wentworth Till is found as a ground moraine, drumlins and moraines. The Paris, Galt and Moffat Moraines consist of this till. In the north where the Wentworth Till is associated with outwash gravels and sands, it is calcareous, sandy silt till. It becomes a clay to silty clay till, however, in the south along the Lake Erie shoreline.

During the later parts of the Mackinaw Interstade, the Lake Ontario lobe started to separate from the Simcoe lobe and the Oak Ridges Moraine began to form. In addition, glaciofluvial outwash sediments were deposited in front of the Paris and Galt Moraines as well as to the south of the Singhampton and Gibraltar Moraines. The groundwater occurrence in these deposits is discussed as part of the description of glaciofluvial deposits.

A total of 873 wells has been identified in areas where the Wentworth Till outcrops at the surface. Of this total, eight wells have been reported to be dry. General information related to the quality of groundwater is available for 838 wells. Approximately, 99.5% of the wells yield fresh water, and the remaining 0.5% yield either sulphurous or salty water.

A sample of 662 wells was selected to determine their specific capacity distribution. The results are as follows:

Parameter	Specific capacity L/min/m
minimum	0.2
10 percentile	2.8
mean	6.6
90 percentile	74.6
maximum	298.0

7.6.5 Port Huron Stadial Deposits

The readvance of the ice margin during Port Huron Stade into the eastern end of Lake Erie and the southern end of Lake Huron resulted in the deposition of a number of tills. The Halton Till was deposited by the Erie-Ontario lobe, the Kettleby Till by the Simcoe lobe, and the St. Joseph Till by the Huron and Georgian Bay lobes.

The Halton Till occurs as a ground moraine over a large area to the north of Lake Ontario extending from Hamilton through Georgetown and Aurora to east of Orono. The till also occurs in a series of low-relief end and recessional moraines in the Niagara Peninsula area. To the north of Lake Ontario, the Halton Till is primarily a sandy silt to silt till. However, it is a clayey silt to silty clay till in the Niagara Peninsula.

The Kettleby Till was deposited by the Simcoe lobe and occurs as a discontinuous sheet of a ground moraine to the north of the Oak Ridges Moraine and above the Niagara Escarpment. It is a calcareous, silty clay to clay till less than 2.0 m thick.

The St. Joseph Till is calcareous, silt to silty clay till. The till covers an area, which extends mostly along the shores of Lake Huron from the Saugeen River in the north to the St. Clair River in the south. The till occurs as a ground moraine and is found within the Wyoming, Banks and Williscroft Moraines.

During the Port Huron Stade a number of proglacial lakes formed in the Lake Erie-Huron basin including: Lake Whittlesey, Lake Warren, Lake Lundy, Lake Peel and Lake Schomberg. A variety of sediments, which are associated with these proglacial lakes, were deposited, including:

- shoreline deposits that are associated with Lake Whittlesey to the north of Lake Erie,
- deltaic deposits that are associated with Lake Whittlesey at Bradford and west of London,
- shoreline deposits that are associated with Lake Warren at Leamington, Ridgetown and along the Wyoming Moraine,
- glaciolacustrine sediments including the sand plains of Norfolk, Caradoc and Bothwell, and the clay plains of St. Clair and Haldimand, and
- thick clay and silt rhythmites that are associated with Lake Schomberg.

Groundwater occurrence in the Port Huron Stadial deposits is discussed as part of the description of the glaciofluvial and glaciolacustrine deposits.

The Halton Till in the East and Middle Oakville Creeks basin was described by Funk (1979) as an aquitard which is a water-bearing geologic unit that does not yield or transmit water readily. Also, Singer et al. (1994) described the Halton Till in the Credit River watershed as a poor aquifer. The specific capacities for 216 wells, constructed in the Halton Till, were found to range from 0.3 to 60.0 L/min/m.

In this report, a total of 9,598 wells has been identified in areas where the Halton Till outcrops at the surface. Of this total, 274 wells have been reported to be dry. General information related to the quality of groundwater is available for 8,214 wells. The majority of these wells yield fresh water, 15 wells yield salty water, and 14 wells yield either sulphurous or mineral water.

A sample of 5,576 wells was selected to determine their specific capacity distribution. The results are as follows:

Parameter	Specific capacity L/min/m
minimum	0.3
10 percentile	0.9
mean	4.3
90 percentile	29.8
maximum	299.3

A total of 1,312 wells has been identified in areas where the Kettleby Till outcrops at the surface. Of this total, 40 wells have been reported to be dry. General information related to the quality of groundwater is available for 865 wells. One well yields sulphurous water, one well yields mineral water, and the remaining 863 wells yield fresh water.

A sample of 569 well was selected to determine their specific capacity distribution. The results are as follows:

Parameter	Specific capacity L/min/m
minimum	0.1
10 percentile	0.9
mean	3.7
90 percentile	18.6
maximum	373.0

A total of 651 wells has been identified in areas where the St. Joseph Till outcrops at the surface. Of this total, 43 wells have been reported to be dry. General information related to the quality of groundwater is available for 526 wells. Approximately, 99.0% of these wells yield fresh water, and the remaining 1.0% yields either sulphurous or salty water.

A sample of 314 wells was selected to determine their specific capacity distribution. The results are as follows:

Parameter	Specific capacity L/min/m
mean	0.2
10 percentile	0.9
mean	5.9
90 percentile	44.7
maximum	447.0

7.6.6 Two Creeks Interstadial Deposits

The Two Creeks Interstade is a period of continued northward ice-marginal recession when most of the southwestern and central parts of southern Ontario became free of ice. Lake Iroquois occupied the Lake Ontario basin, Early Lake Erie occupied the Lake Erie basin, and Lake Algonquin occupied the southern parts of Lake Huron and Georgian Bay and extended eastward through the Lake Simcoe basin as far as Lake Scugog.

Shoreline deposits and glaciolacustrine sediments were left by Lake Iroquois to the north of Lake Ontario and by Lake Algonquin in the area between Lake Simcoe and Georgian Bay.

Four undifferentiated tills were deposited during this period due to minor oscillations of the ice margin (Map 2556, Barnett, 1991):

- a sandy till, low in matrix carbonate content, which outcrops in small areas across the southern slopes of the Canadian Shield (Map Unit 18),
- a sandy silt to silt till which outcrops in many areas along the northern shores of Lake Ontario from Toronto to Belleville as well as in the Counties of Simcoe, Victoria, Leeds, Lanark, Dundas, and Stormont (Map Unit 19),
- a sandy till which outcrops in an area extending from Victoria to Lennox-Addington Counties (Map Unit 20), and
- a silty clay to silt till which outcrops in a small area in Simcoe County (Map Unit 21).

A total of 17 wells has been identified in areas where Map Unit 18 outcrops at the surface. The available information is insufficient to draw any meaningful conclusions about the characteristics of the wells within the unit. A total of 10,660 wells has been identified in areas where Map Unit 19 outcrops at the surface. Of this total, 115 wells have been reported to be dry. General information related to the quality of groundwater is available for 9,887 wells. Approximately, 99.5% of these wells yield fresh water, and the remaining 0.5% yield sulphurous, salty or mineral water.

A sample of 8,140 wells was selected to determine their specific capacity distribution. The results are as follows:

Parameter	Specific capacity L/min/m
minimum	0.1
10 percentile	1.3
mean	5.9
90 percentile	29.8
maximum	869.0

A total of 190 wells has been identified in areas where Map Unit 20 outcrops at the surface. Of this total, four wells have been reported to be dry. General information related to groundwater quality is available for 177 wells. One well yield sulphurous water and the remaining wells yield fresh water.

A sample of 153 wells was selected to determine their specific capacity distribution. The results are as follows:

Parameter	Specific capacity L/min/m
minimum	0.4
10 percentile	1.4
mean	7.5
90 percentile	44.7
maximum	597.0

A total of 142 wells has been identified in areas where Unit 21 outcrops at the surface. Of this total, three wells have been reported to be dry. General information related to the quality of groundwater is available for 135 wells. Approximately, 98.0% of these wells yield fresh water, and the remaining 2.0% yield either salty or mineral water.

A sample of 113 wells was selected to determine their specific capacity distribution. The results are as follows:

Parameter	Specific capacity L/min/m
minimum	0.1
10 percentile	1.1
mean	5.3
90 percentile	25.9
maximum	89.5

7.6.7 Greatlakean Stade Deposits

Climatic conditions became cold again during the Greatlakean Stade which is characterized by a minor glacial advance. Evidence of such an advance exists in Wisconsin, but has not been documented in southern Ontario.

With the continued northward retreat of the ice margin, sea water invaded the valleys of the Ottawa and St. Lawrence Rivers to form the Champlain Sea. According to Barnett (1992), the general sequence of sediments, deposited within the Champlain Sea, includes:

- an ice-marginal delta and subaqueous fan of sands and gravels,
- laminated silts and clays,
- clayey silts to clays containing marine fossils,
- laminated to varved silts and clays deposited at bottoms of the large deltas, which formed during regression of the Champlain sea, and
- nearshore and beach of sands and gravels.

Sands and gravels of glaciomarine origin occur in the Edwardsburg Sand Plain, which extends from Brockville and Cardinal in the south to Gloucester in the north. Similar deposits cover a large area, extending from Ottawa to Hawkesbury, and also form the Russell and Prescott Sand Plains.

During the Greatlakean Stade, glacial Lake Algonquin ended as the valleys of the Mattawa and Ottawa Rivers became ice-free about 10,400 to 10,000 years ago (Barnett, 1992).

7.6.8 Glaciofluvial, Glaciolacustrine, Glaciomarine and Marine Deposits

Throughout the Quaternary Period, sands and gravels of glaciofluvial, glaciolacustrine, glaciomarine or marine origins were deposited in various parts of southern Ontario. These deposits occur at different depths and locations. They can be small in size and capable of yielding enough water to satisfy the needs of a single home, or they can be large enough to satisfy the water needs of a village or a town. Table 4 gives a brief summary of these deposits in terms of age, stratigraphic unit, and origin.

Exposures of the sand and gravel deposits can be found at the surface over large areas in the eastern and southwestern parts of southern Ontario. In addition, the geologic logs of many water wells and test holes indicate that substantial amounts of sand and gravel occur at various depths in many parts of the province.

Singer (1981) described data collected from deep monitoring wells drilled in the Oak Ridges Moraine. The data indicate that the moraine has a capping of sand and gravel with minor amounts of silt and till up to 100.0 m in thickness.

In a preliminary report on the stratigraphic drilling of Quaternary sediments in the Barrie area, Simcoe County, Barnett (1991) described the types of sediments occurring at depth in eight boreholes. The logs of most of these boreholes show the presence of thick silt, sand and gravel deposits. For example, the log of borehole No. 90-7 reveals the following deposits:

Depth (m)	Soil/Rock Description
0.0 - 0.3	Fill
0.3 - 3.0	Sand
3.0 - 11.2	Silt
11.2 - 39.3	Sand
39.3 - 39.6	Gravel
39.6 - 69.2	Sand
69.2 - 71.3	Gravel
71.3 - 72.2	Silt and sand
72.2 - 81.4	Sand
81.4 - 84.9	Silt
84.9 - 86.8	Sand
86.8 - 92.1	Till
92.1 - 95.4	Bedrock

The origin of the glaciofluvial deposits in southern Ontario can be traced to the large volumes of meltwater that have been discharged by glaciers. Meltwater flowing from glaciers can carry a large amount of debris of various grain sizes, and deposit them either in close proximity to the glaciers or farther away in stream channels, river deltas, glacier-fed lakes or the sea.

The glaciofluvial deposits are two types: ice-contact stratified drift and outwash. The ice-contact stratified drift occurs within or immediately adjacent to glaciers. The outwash, on the other hand, is deposited in rivers and streams beyond the glacier margin.

The make-up of the ice-contact deposits is highly variable both laterally and vertically. They consist mainly of discontinuous layers of sand and gravel with some silt, clay and till. Eskers, kames, kame terraces, and ice-marginal deltas occur mainly within the central and western parts of southern Ontario. These landforms consist of ice-contact deposits.

The outwash deposits are found mainly in the southwestern parts of southern Ontario. They consist of sands and gravels. The gravels are usually deposited in close proximity to the ice margin, whereas the sands are found farther downstream. Deltas formed by meltwater streams at their entrances into glacier-fed lakes are also considered outwash deposits.

The glaciolacustrine deposits are sediments that have been carried by glacier meltwater and subsequently deposited in glacier-fed lakes. Rhythmites are the most common types of glaciolacustrine sediments. Along the shores and in the nearshore areas of lakes, sand and gravel beaches, spits and bars, and lake plains are formed.

The glaciomarine deposits are sediments that have been carried by glacier meltwater and subsequently deposited into a sea. The most common types of glaciomarine sediments are silty clays and clays. Due to their capacity to store and transmit large amounts of water, the sands and gravels of glaciofluvial, glaciolacustrine, glaciomarine or marine origins constitute good aquifers (Figure 19).

7.6.8.1 Ice-Contact Deposits

A total of 7,908 wells has been identified in areas where the ice-contact deposits outcrop at the surface. Of this total, 145 wells have been reported to be dry. General information related to the quality of groundwater is available for 6,663 wells. Almost all these wells are reported to yield fresh water.

A sample of 5,628 wells was selected to determine their specific capacity distribution. Figure A14 (Appendix II) shows a specific capacity-probability graph for the wells in the sample. The values plot approximately as a straight line, indicating that the sample has a lognormal frequency distribution. The minimum and maximum specific capacity values are 0.1 and 5,384.0 L/min/m, respectively. The 10 and 90 percentile values are 1.3 and 37.3 L/min/m, respectively, and the sample's geometric mean is 6.0 L/min/m.

7.6.8.2 Outwash Deposits

A total of 5,227 wells has been identified in areas where the outwash deposits occur at the surface. Of this total, 62 wells have been reported to be dry. General information related to the quality of groundwater is available for 4,689 wells. Approximately, 99.0% of these wells are reported to yield fresh water, and the remaining 1.0% yields either sulphurous or salty water.

A sample of 3,341 wells was selected to determine their specific capacity distribution. Figure A14 (Appendix II) shows a specific capacity-probability graph for the wells in the sample. The minimum and maximum specific capacity values are 0.1 and 4,823.0 L/min/m, respectively. The 10 and 90 percentile values are 1.9 and 74.6 L/min/m, respectively, and the sample's geometric mean is 10.6 L/min/m.

7.6.8.3 Sands and Gravels of Glaciolacustrine Origin

A total of 17,986 wells has been identified in areas where sands and gravels of glaciolacustrine origin occur at the surface. Of this total, 395 wells have been reported to be dry. General information about the quality of groundwater is available for 16,053 wells. More than 99.0% of the wells yield fresh water, and the remaining wells yield sulphurous, salty or mineral water.

A sample of 8,025 wells was selected to determine their specific capacity distribution. Figure A15 (Appendix II) shows a specific capacity-probability graph for the wells in the sample. The minimum and maximum specific capacity values are 0.1 and 2,237.0 L/min/m, respectively. The 10 and 90 percentile values are 1.2 and 49.7 L/min/m, respectively, and the sample's geometric mean is 7.2 L/min/m.

7.6.8.4 Sands and Gravels of Glaciomarine and Marine Origins

A total of 489 wells has been identified in areas where sands and gravels of glaciomarine and marine origins outcrop at the surface. Of this total, six wells have been reported to be dry. General information related to the quality of groundwater is available for 478 wells. Approximately, 94.0% yield fresh water and the remaining 6.0% yield either sulphurous or salty water.

A sample of 409 wells was selected to determine their specific capacity distribution. Figure A15 (Appendix II) shows a specific capacity-probability graph for the wells in the sample. The minimum and maximum specific capacity values are 0.1 and 426.0 L/min/m, respectively. The 10 and 90 percentile values are 2.7 and 49.7 L/min/m, respectively, and the sample's geometric mean is 9.9 L/min/m.

7.6.8.5 Silts and Clays of Glaciolacustrine Origin

A total of 8,682 wells has been identified in areas where silt and clay deposits of glaciolacustrine origin occur at the surface. Of this total 225 wells have been reported to be dry. General information related to groundwater quality is available for 7,550 wells. Approximately, 98.0% of the wells yield fresh water and the remaining 2.0% yield sulphurous, salty or mineral water.

A sample of 4,376 wells was selected to determine their specific capacity distribution. The results are as follows:

Parameter	Specific capacity L/min/m
minimum	0.1
10 percentile	1.1
mean	7.5
90 percentile	49.7
maximum	2386.0

It is very likely that the high-capacity wells in areas these silts and clays outcrop at the surface are tapping sand or gravel aquifers at some depth.

7.6.8.6 Silts and Clays of Glaciomarine and Marine Origins

A total of 1,210 wells has been identified in areas where slit and clay deposits of glaciomarine and marine origins occur at the surface. Of this total, 14 wells have been reported to be dry. General information related to groundwater quality is available for 1,159 wells. Approximately, 89.0% of these wells yield fresh water, 5.0% yield salty water, 4.0% yield sulphurous water, and 2.0% yield mineral water.

A sample of 983 wells was selected to determine their specific capacity distribution. The results are as follows:

Parameter	Specific capacity L/min/m
minimum	0.1
10 percentile	2.2
mean	10.7
90 percentile	45.9
maximum	1305.0

Again, it is very likely that the high-capacity wells in areas these silts and clays outcrop at the surface are tapping sand or gravel aquifers at some depth.

7.7 HOLOCENE (RECENT) DEPOSITS

According to Barnett (1992), the division between the Late Wisconsinan and the Holocene is somewhat arbitrary in Ontario as almost most of the northern parts of the province remained covered by ice 10,000 years ago. Southern Ontario, however, was free of ice and low level lakes existed in Georgian Bay, Lake Huron, Lake Erie and Lake Ontario.

During the Early Holocene, the Champlain Sea receded to the east of Ottawa. Later, between 9,000 and 8,400 years ago, the flow of water from Early Lake Ontario through the St. Lawrence River became established.

As the land surface became free of ice, it began to rise isostatically. This affected the water levels in the Great Lakes basin which began also to rise. Approximately, 5,000 years ago the Nipissing Great Lakes system came into existence in the basins of Lakes Superior, Huron, Michigan and Georgian Bay. The Nipissing Great Lakes system left shoreline features that are about four metres above the present Lake Huron shoreline. Eventually, the Nipissing Great Lakes system developed into the present-day Great Lakes system.

During the Holocene Epoch, deposits started to accumulate in various bogs and swamps, in the flood plains of rivers, and along the shorelines of lakes. Generally, these deposits are of limited importance as sources of groundwater supplies.

8. OVERBURDEN AQUIFERS

As indicated earlier, a large portion of the bedrock in southern Ontario is obscured by an overburden mantle of unconsolidated sediments that was deposited during the Quaternary Period. From a hydrogeologic point of view, knowledge of the type and spatial distribution of the various overburden deposits within an area is extremely important. Clay deposits and compact tills with high clay content are usually characterized by low hydraulic conductivity. When such deposits occur at the surface they would impede the vertical infiltration of water resulting in a reduced groundwater recharge. When they occur at various depths, they act as hydraulic barriers forcing groundwater to move laterally within the overlying permeable deposits.

By contrast, sand and gravel deposits are highly permeable. Also, sandy tills can be highly permeable. When such deposits occur at the surface, have sufficient thickness, and are underlain by low permeable materials, they form a water table (unconfined) aquifer. When they are overlain by low permeable materials, they form confined aquifers.

By and large, the overburden aquifers in southern Ontario occur within the sand and/or gravel deposits of glaciofluvial, glaciolacustrine, glaciomarine or marine origins. These aquifers, which occur at various depths and locations, can be small in size and capable of yielding enough water to satisfy the needs of a single home, or they can be large enough to satisfy the needs of a village or a town.

In the following sections, an attempt will be made to identify the important overburden aquifers in various parts of southern Ontario. Each aquifer will be described in terms of location, approximate areal extent, depth, composition, thickness, type (confined or unconfined), and, where feasible, hydraulic characteristics.

8.1 AQUIFERS IN THE EASTERN PART OF SOUTHERN ONTARIO

Compared to the bedrock, the overburden in the eastern part of southern Ontario is less important as a source of water supply. This is due to the fact that the overburden in this part of Ontario is of limited thickness and areal extent. Over most of the area, the overburden is absent or has a thickness of less than 10.0 m. Only in a few places, the overburden thickness exceeds 70.0 m. It should be noted that large areas within the South Nation River basin are covered with surficial sands, but these sands are shallow and, from a hydrogeologic point of view, they constitute a poor aquifer.

8.1. 1 The Raisin Region Conservation Authority

Location: The Raisin Region Conservation Authority (the Authority) is in the eastern part of southern Ontario extending from the Quebec Border in the east to the topographic divide of the South Nation River basin in the west and from the St. Lawrence River in the south to beyond the Town of Alexandria in the north. The Authority, which is about 1,480.0 km^2 in size, includes the City of Cornwall, and the Townships of South Stormont, North Stormont, South Glengarry and North Glengarry (Figure 20).

Drainage: The Raisin River is the main stream within the Authority. Its main tributaries are the South Raisin and the North Raisin Rivers. The Raisin River rises within an upland stony area to the northeast of Monkland and descends into an almost flat clay and silty plains before it empties into the St. Lawrence River at Lancaster. Other important streams within the Authority are the Beaudette, Delisle, and Garry Rivers and the Hooples Creek.

Physiography: Chapman and Putnam (1984) identified parts of two physiographic regions within the Authority, namely, the Glengarry Till Plain and the Lancaster Flats. The Glengarry Till Plain, which extends over the northern parts of the Authority, is of low relief with long morainic ridges and a few drumlins together with intervening clay flats and swamps. The Lancaster Flats, on the other hand, occupy the southern part of the Authority along the St. Lawrence River. A large part of the till within this lowland has been buried under fluvial deposits leaving a few exposed drumlins and ridges. The fluvial deposits range from clay to very fine sand.

Bedrock Topography and Geology: The Authority is underlain by Paleozoic rocks which are covered with a thin mantle of overburden deposits. The bedrock elevation ranges from about 40.0 m (a.s.l.) along the St. Lawrence River to more than 80.0 m (a.s.l.) within a bedrock ridge that extends through the central part of the Authority.

The Paleozoic rocks, which are of Middle Ordovician age, are represented by the limestones, dolostones, shales, and sandstones of the Rockcliffe Formation and the Ottawa Group. The Rockcliffe Formation has been identified along the St. Lawrence River and within a small pocket along the Quebec Boundary in Lancaster Township. The Ottawa Group, which consists of the Shadow Lake, Gull River, Bobcaygeon, Verulam, and Lindsay Formations, underlies the rest of the Authority.

Overburden Thickness and Geology: The overburden within the Authority consists of glacial, glaciofluvial, and glaciomarine sediments of Pleistocene age and fluvial and organic deposits of Recent age. The overburden, which is missing over a small area within the central part of the Authority, is generally less than 10.0 m in thickness. Along the St. Lawrence River, however, the thickness of the overburden increases to more than 35.0 m.

Barnett et al. (1991) mapped the glacial deposits, which cover most of the Authority, as part of the undifferentiated till of Map Unit 19 (Map 2556, Quaternary Geology of Ontario). The glaciofluvial deposits, which are found in Kenyon and Osnabruck Townships, consist of a few kame ridges of ice-contact origin.The glaciomarine deposits, on the other hand, are found mainly in the southern and northeastern parts of the Authority and form large silt and clay plains. A small body of glaciomarine sands is found in association with the ice-contact deposits in Kenyon Township. In addition, a large plain of fluvial deposits of clay to fine sand is part of the Lancaster Flats along the St. Lawrence River, and organic deposits are found in river valleys and swamps.

Overburden Aquifers: There are 5,620 records on file with MOE for water wells constructed in the Authority. Of these, 4,930 (87.7%) are bedrock wells and 690 (12.3%) are overburden wells. Compared to the bedrock, therefore, the overburden is not a significant source of water supply within the Authority.

Specific capacity data are available for 602 overburden wells. Of these wells, 39 (6.5%) have specific capacities of less than 1.0 L/min/m, 155 (25.7%) have specific capacities between 1.0-5.0 L/min/m, 140 (23.3%) have specific capacities between 5.0-10.0 L/min/m, 164 (27.2%) have specific capacities between 10.0-50.0 L/min/m, and 104 (17.3%) have specific capacities above 50.0 L/min/m. Most of the wells with low specific capacities are found in the northern half of the Authority.

As indicated above, a large plain of fluvial deposits of clay to fine sand is part of the Lancaster Flats along the St. Lawrence River. From a hydrogeologic point of view, these deposits do not constitute an aquifer. However an aquifer, which was named the Lancaster-Cornwall Aquifer, has been identified under these deposits.

The Lancaster- Cornwall Aquifer: This aquifer occurs within a band about 10.0 km wide along the north shore of the St. Lawrence River extending from the Quebec Boundary in the east to Cornwall in the west. The aquifer, which consists mainly of gravel and some sand, is buried under till, and fluvial and organic deposits. Its thickness ranges from about one metre to a maximum of 14.0 m.

The wellhead elevations of 50 wells in the aquifer range between 47.0 and 81.0 m. The elevation of the top of the aquifer ranges between 26.0 and 47.0 m in the eastern part of the aquifer and from 43.0 to 62.0 m in the vicinity of Cornwall. Except for a small area near Cornwall, where the sand deposits outcrops at the surface, the aquifer is confined. The depths to the static water levels range between zero and 11.0 m and the well yields range from 15.0 to 180.0 L/min. A large number of wells tapping the aquifer have specific capacities between 10.0 and more than 50.0 L/min/m.

8.1.2 The South Nation Conservation Authority

Location: The South Nation Conservation Authority (the Authority), which is located in the eastern part of southern Ontario, comprises the South Nation River basin, which covers an area of about 3,700.0 km^2, and a small area about 215.0 km^2 in size drained by small tributaries to the Ottawa River. The Authority is almost triangular in shape with its southern tip located a few kilometres to the north of the St. Lawrence River. It is bounded by the Rideau Valley Conservation Authority on the west and northwest and by a number of small watersheds draining into the St. Lawrence River and the Raisin River Region Conservation Authority on the east and southeast. The Authority is almost a flat plain with a surface elevation ranging between 45.0 m (a.s.l.) in the north and 122.0 m (a.s.l.) in the south. Approximately 60% of the land base within the Authority is devoted to agriculture. The main urban centers are Casselman, Chesterville, Plantagenet, and Winchester (Figure 21).

Drainage: The South Nation River, which is the main watercourse within the Authority, is a major tributary to the Ottawa Rive. The river rises a few kilometres north of Brockville and travels in a northeasterly direction about 177.0 km to its confluence with the Ottawa River at Wendover to the northwest of Plantagenet. Major sub-basins are the Castor River (733.0 km^2), the Bear Brook (487.0 km^2), and the Scotch River (272.0 km^2). Large sections of the South Nation River are characterized by small channel capacities and low gradients which are responsible for flooding. Numerous swamps and bogs occur in topographically low areas, the largest ones being Alfred, Mer Bleue, Winchester, and Moose Creek bogs.

Physiography: Parts of five physiographic regions have been identified within the Authority by Chapman and Putnam (1984), including the Edwardsburg Sand Plain, the Glengarry Till Plain, the Winchester Clay Plain, the Russell and Prescott Sand Plains, and the Ottawa Valley Clay Plains.

The Edwardsburg Sand Plain lies almost completely within the southwestern parts of the Authority. The topography of the plain is mostly level or gently undulating, although hummocks and ridges appear in places.The Glengarry Till Plain is located in the southeastern portion of the Authority and it is a part of a larger region of low relief forming the drainage divide between the St. Lawrence and the Ottawa Rivers basins. The surface of the plain is undulating to rolling, consisting of long morainic ridges and a few well-formed drumlins together with intervening clay flats and swamps. The Winchester Clay Plain is an area of low relief, lying almost entirely within the Authority. In many places within this clay plain, the underlying till pokes out into the surface and there are a few low drumlins. The Russell and Prescott Sand Plains consist of a belt of large sand plains separated by clays of the lower Ottawa Valley. Most of the plains are within the Authority, but smaller parts drain to the Rideau and Ottawa Rivers. The Ottawa Valley Clay Plains extend between Pembroke and Hawkesbury and occur within the Authority in Plantagenet, Clarence, and Cumberland Townships. The plains are interrupted by ridges of rock or sand.

Bedrock Topography and Geology: The bedrock elevation ranges from 40.0 and 120.0 m(a.s.l.), but it is between 40.0 and 80.0 m (a.s.l.) over most of the Authority. Areas with higher bedrock elevations are located along the Authority's eastern, southern, and western boundaries. The largest bedrock valley extends northeastward from the Russell-Embrun area and coincides roughly with the present valley of the South Nation River. The channel of the valley is about 10.0 km wide and 15.0 m deep. This bedrock valley is joined by smaller valleys that coincide with present valleys of Castor, Bear Brook and Scotch Rivers. Faulting is extensive throughout the bedrock and in many cases the faults serve as geologic boundaries.

A very small area near the northwestern boundaries of the Authority in Gloucester Township has been identified as part of the Nepean Formation of Upper Cambrian age. Also, a large area within the southwestern part of the Authority is underlain by rocks of the March and Oxford Formations of Lower Ordovician age. Rocks of the Gull River, Bobcaygeon, Verulam and Lindsay Formations occur over large areas in the eastern and northern parts of the Authority. Along with the Shadow Lake Formation, these units comprise the Ottawa Group in eastern Ontario. The Upper Ordovician strata within the upper part of the Authority is represented by the Billings, Carlsbad and Queenston Formations (Johnson et al. 1992).

Overburden Thickness and Geology: The bedrock outcrops at the surface at several locations along the Authority's western topographic divide near South Gloucester and Metcalfe, and also within the northwestern parts. Elsewhere, the overburden thickness ranges from less than10.0 m to more than 50.0 m. Within most of the Prescott and Russell Sand Plains, the thickness of the overburden is generally greater than 30.0 m, however, the thickness of the top sand deposits are usually less than 6.0 m.

The overburden comprises glacial, glaciomarine, marine, and fluvial deposits of Pleistocene age with minor amounts of alluvial and swamp deposits of Recent age. The glacial deposits occur as undrumlinized and drumlinized till plains. The undrumlinized plains occur mostly along the Authority's eastern boundaries, whereas the drumlinized plains occur mainly within the Edwardsburg Sand Plain and the Winchester Clay Plain where the till protrudes as low drumlins. The Champlain Sea, which inundated the area following the last glaciation, has removed or modified the till within the Winchester Clay Plain through erosion.

Barnett et al.(1991) mapped the undifferentiated till within the Authority as Map Unit 19. Fine-grained marine sediments of silt and clay cover most of the Winchester Clay Plain and the Ottawa Valley Clay Plains. These sediments were deposited in deep water. Coarse-grained marine and deltaic sediments form the Edwardsburg Sand Plain and Russell and Prescott Sand Plains. By and large, these sediments were deposited under shallow water conditions. In addition, small esker-like, ice-contact deposits extend to the north and south of the Sarsfield marine beach, and bar deposits are found to the south of Maxwell along the Authority's eastern boundaries and to the south of Greely along its eastern boundaries. Extensive swamp deposits of peat and muck are found in topographically low areas mainly within Alfred, Mer Bleue, Winchester, and Moose Creek bogs.

Overburden Aquifers: There are 10,562 records on file with MOE for water wells constructed within the Authority. Of these, 8,811 (83.4%) are bedrock wells, 1,138 (10.8%) are overburden wells, and the remaining 613 (5.8%) are of unknown type. Compared to the bedrock, therefore, the overburden is not a significant source of water supply.

Data related to short-term pumping tests are available for 1,102 overburden wells. The data indicate that 213 wells (49.0%) have specific capacities ranging from 1.0 to 5.0 L/min/m, 557 wells (39.5%) have specific capacities between 5.0 and 25.0 L/min/m, 131 wells (5.9%) have specific capacities between 25.0 and 50.0 L/min/m, and the remaining 201 wells (5.6%) have specific capacities larger than 50.0 L/min/m.

Aquifers of sand and/or gravel are important sources of water within the Authority. As indicated above, permeable sands occur as surficial deposits over large areas in the northern parts of the Authority and along its northwestern boundaries.Within the southern parts of the Authority, however, the overburden deposits are generally thin (less than 15.0 m) and are predominantly clays, silts, and tills. Deposits of sand and gravel occur here as thin lenticular and discontinuous layers in buried deposits and are generally less than 3.0 m thick.

<u>The Champlain Aquifer</u>: Chin et al.(1980) identified eleven overburden aquifers within the Authority. A map outlining the boundaries of these aquifers has been prepared by Chin et al. (1980) as Sheet 4. The largest of these aquifers by area, the Champlain Aquifer, is composed of surficial sands. The boundaries of this aquifer as outlined by Chin et al.(1980) correspond to the boundaries of the Prescott and Russell Sand Plains which consist of a group of large sand plains separated by clay plains. One of these plains extends from Ottawa to Hawkesbury, and three fairly large plains are within Alfred, North Plantagenet and Clarence Townships. Taken together, these sand plains comprise an area of about 570.0 km^2. Most of this area is within the Authority and a small area is within the Rideau River basin. The thickness of the sand is about 3.0 m, but it can reach 6.0 to 10.0 m in places.

A very few wells have been constructed in the Champlain Aquifer and still a few of these wells obtain water from the aquifer itself. Considering the small thickness of the aquifer, it is of little importance as a source of water and individual wells have little potential to yield adequate supplies other than for domestic uses.

<u>The Rideau Front Aquifer</u>: This aquifer, which is composed of surficial sand and gravel of glaciofluvial origin, is the most important overburden aquifer within the Authority. Compared to the Champlain Aquifer, it has a smaller area (105.0 km^2). The aquifer extends along the Authority's western boundaries from the Village of Kempark in the north to the headwaters of the Wylie Creek in the south for a distance of about 40.0 km and it varies in width from 1.5 to 5.0 km. The aquifer also extends into the Rideau River basin.

The wells tapping the aquifer show the presence of sand and gravel deposits extending from the surface to the bedrock for depths that range from less than 10.0 m to more than 50.0 m. The water is found at depths ranging from 10.0 m to more than 20.0 m. Most of these wells have specific capacity values of more than 50.0 L/min/m. The aquifer is mostly unconfined and has the potential to yield adequate supplies for domestic and municipal uses.

<u>Small Buried Aquifers</u>: Nine buried overburden aquifers have been identified by Chin et al. (1980), including Rockland, Clarence Creek, Sarsfield, Notre Dame, Berwick, Bourget, Maple Ridge, Plantagenet, and St. Rose de Prescott. These aquifers are small in size and occupy a total area of about 60.0 km^2.

<u>The Rockland Aquifer</u>: This is a small aquifer located at Rockland. It extends about 12.0 km along the Ottawa River and has a width ranging from 100.0 to 500.0 m. More than 50 wells tap the aquifer and the majority of them have specific capacity values in excess of 10.0 L/min/m. The

geologic logs of the wells indicate that the aquifer is located on top of the bedrock beneath thick clay deposits. It consists of sands that range in thickness from a few metres to about 50.0 m. The surface elevation of these sands ranges from about 25.0 m (a.s.l.) to below sea level. The aquifer is confined and the static water levels are at or above the ground surface.

<u>The Plantagenet Aquifer</u>: This is a very small aquifer located within the flood plain of the South Nation River between Plantagenet and Wendover. The few wells tapping this aquifer have specific capacity values in excess of 10.0 L/min/m.

<u>The Clarence Creek Aquifer</u>: This is a small confined aquifer located within the Clarence Creek flood plain. It extends for a distance of about 17.0 km and has a width ranging between 1.0 and 1.5 km. The aquifer consists of sands that range in thickness from a few metres to less than 10.0 m. They are overlain by clay deposits and underlain by the bedrock. The aquifer is tapped by about 60 wells. Most of these wells have specific capacity values in excess of 10.0 L/min/m and some in excess of 50.0 L/min/m.

<u>The Sarsfield Aquifer</u>: This is a small confined aquifer that extends along the Authority's northwestern boundaries from the Cardinal Creek watershed to the Mer Blue Marsh. The aquifer also extends into the Rideau River basin. About 40 wells tap the aquifer and almost half of them have specific capacity values of more than 10.0 L/min/m. The aquifer consists of a few metres of sands that are overlain by clay deposits and underlain by the bedrock. The surface elevation of the sands ranges from 25.0 to 40.0 m (a.s.l.).

<u>The Notre Dame Aquifer</u>: This is a small confined aquifer extending to the south and west of Sarsfield. It is about 10.0 km long and 1.5 to 5.0 km wide. The aquifer consists of a few metres of sands that are overlain by clay or till deposits and underlain by the bedrock. About 50 wells tap the aquifer and most of these wells have specific capacity values in excess of 10.0 L/min/m. The well logs indicate that the surface elevation of the sand deposits ranges from 70.0 to 80.0 m (a.s.l.).

<u>The Bourget Aquifer</u>: This is a very small confined aquifer that has been identified to the north and west of Bourget. Some 20 wells tap the aquifer and eight of these wells have specific capacity values of more than 10.0 L/min/m. The well logs indicate that the aquifer consists of sands which are a few metres in thickness. The surface elevation of the sands ranges from 35.0 to 50.0 m.

<u>The Central South Nation Aquifer Complex</u>: This name is suggested for an aquifer that extends as a belt to the south of the Champlain Aquifer from St. Isidore de Prescott in the east to the western boundaries of the Authority, and it includes parts of the flood plains of the Castor and Payne Rivers. The aquifer incorporates the St. Rose de Prescott and the Rideau Front Aquifers which were identified by Chin et al.(1980). The majority of the wells tapping the aquifer have specific capacity values of more than 10.0 L/min/m and some have values more than 50.0 L/min/m.

The aquifer is discontinuous in areas where bedrock is close to or at the surface. It consists of sands which are a few metres to more than 20.0 m in thickness. The surface elevation of the sands ranges from 40.0 to 60.0 m (a.s.l.). The aquifer rests on the bedrock and thick deposits of clay and till rest on top of it. The confining clay and till deposits are missing in the western part of the aquifer where water table conditions prevail.

Although groundwater within the Authority is available in adequate quantities for private domestic supplies and the municipal needs of small communities, it is not readily available to meet the needs of large municipalities or industries. Of the aquifers identified above, only the Rideau Front

Aquifer along the Authority's western boundaries appears to have the potential for large-capacity municipal and industrial wells.

8.1. 3 The Rideau Valley Conservation Authority

Location: The Rideau Valley Conservation Authority (the Authority) is in the eastern part of southern Ontario. It is bounded on the north by the Ottawa River, on the east by the South Nation Conservation Authority, on the southeast by the Cataraqui River basin, and on the west and northwest by the Mississippi Valley Conservation Authority. The Authority includes parts of the Frontenac, Lanark, Leeds, and Ottawa-Carlton Counties. The main urban centres within the Authority are Ottawa, Manotick, Osgoode, Kemptville, and Smith Falls (Figure 22).

Drainage: The Rideau River and its main tributary, the Tay River, rise in the Canadian Shield. The headwaters of the Rideau River contain several lakes, which are located along the boundary between the Precambrian and Paleozoic rocks, including the Upper Rideau, Big Rideau, and Lower Rideau Lakes. The Rideau River flows in a northeasterly direction and enters the Ottawa River at Ottawa. Throughout almost its entire length, the Rideau River serves as a canal between Ottawa and Kingston. The canal was built in the years 1827 to 1832 and was used as a commercial artery until the 1850s.

The headwaters of the Tay River also contain a series of lakes, including the Bobs, Crow, Farret, and Christie Lakes. These later lakes, however, are within the Canadian Shield. The Tay River enters the Lower Rideau Lake a few kilometres above Smith Falls. In addition, a number of tributaries enter the Rideau from the southern and eastern sides, including the Arlen, Hutton, Irish, and Kemptville Creeks. Tributaries that enter the Rideau from the northern and western sides include the Black, Cranberry, Mud, Rosedale, and Steven Creeks.

Physiography: The physiography of the Authority reflects its two major geologic environments; one environment is characterized by the Precambrian bedrock topography of the Canadian Shield and the other by the topography of a thin overburden mantle over Paleozoic limestones. Most of the southwestern part of the Authority is covered by Precambrian bedrock where the overburden is thin or absent and, for the most part, the land terrain has rock-and-knob topography. The overburden landforms in this part of the Authority include some glacial till, a few kame mounds, and sporadic sand plains. Swamp and bog organic deposits fill numerous bedrock lows.

The middle part of the Authority has been identified by Chapman and Putnam (1984) as part of the Smiths Falls Limestone Plain. Large portions of this plain are exposed rock strata which are almost level or have a slight slope toward the northeast. In addition, small parts of four physiographic regions have been identified by Chapman and Putnam (1984) along the Authority's northern and northeastern boundaries, including the Edwardsburg Sand Plain, North Gower Drumlin Field, Ottawa Valley Clay Plains, and Russell and Prescott Sand Plains.

Bedrock Topography and Geology: The Authority is underlain by Precambrian rocks. In turn, these rocks are overlain in the central and eastern parts of the Authority by Paleozoic rocks. Thin and discontinuous overburden deposits cover the Precambrian rocks. These deposits become thicker and more continuous along the eastern part of the Authority.

The bedrock elevation ranges from about 53.0 m (a.s.l.) at the mouth of the Rideau River to between 120.0 and 130.0 m (a.s.l.) in its headwater areas. The bedrock surface of the Precambrian rocks exhibits a rock-and-knob terrain that is characterized by low relief. The Paleozoic rocks, on the hand, exhibit a gently sloping relief and they control the configuration of the present land surface topography within the Authority's central and eastern parts.

The Precambrian rocks are mainly plutonic, metasedimentary, or metavolcanic. The Paleozoic rocks are of Lower, Middle and Upper Ordovician age. The Lower Ordovician strata, which cover about two-thirds of the Authority, are represented by the dolostones and sandstones of the March and Oxford Formations of the Beekmantown Group. The Middle and Upper Ordovician strata are found as small patches in the northwestern part of the Authority. These strata are represented by the Rockcliffe Formation of Middle Ordovician age and the Ottawa Group of Middle and Upper Ordovician age. The Ottawa Group consists of the Shadow Lake, Gull River, Bobcaygeon, Verulam and Lindsay Formations (Johnson et al. 1992).

Overburden Thickness and Geology: The overburden is missing over most of the Authority's southern and western parts and where it is present, its thickness is less than10.0 m. By contrast, the eastern and northern parts of the Authority are covered by an overburden mantle which ranges in thickness from 10.0 to 50.0 m. The overburden consists of glacial, glaciofluvial, and glaciomarine deposits of Pleistocene age and alluvial and swamp deposits of Recent age.

According to Barnett (1992), the glacial deposits are part of the undifferentiated till of Map Unit 19. The glaciofluvial deposits consist of a few kame ridges of ice-contact origin and a handful of thin outwash plains that are scattered throughout the Authority. The glaciomarine deposits, on the other hand, are found mainly along the Authority's eastern and northern parts and form large silt and clay plains as well as large sand plains. Fluvial and organic deposits of Recent age are found in river valleys and swamps.

Overburden Aquifers: A total of 26,303 bedrock wells has been identified within the Authority as compared to 1,156 overburden wells which indicates that the bedrock is the more significant source of water supply. This is specifically true in the western and southern parts of the Authority where the overburden is absent or very thin. Of the overburden wells, 222 (19.2%) have no specific capacity data, 27 (2.3%) have specific capacities of less than 1 L/min/m, 136 (11.8%) have specific capacities between 1.0-5.0 L/min/m, 161 (13.9%) have specific capacities between 5.0-10.0 L/min/m, 382 (33.1%) have specific capacities between 10.0-50.0 L/min/m, and 228 (19.7%) have specific capacities that exceed 50.0 L/min/m.

The Upper and Lower Gloucester Aquifers: These names are suggested for two local aquifers that occur within Gloucester Township east of Ottawa. The upper aquifer, which consists of gravels, has a thickness of less than two metres. The aquifer is confined by up to 22.0 m of clay deposits. The records of 17 wells tapping the aquifer indicate that the wellhead elevations are between 62.0 and 92.0 m (a.s.l.), and the elevation of the top of the aquifer is between 45.0 and 78.0 m (a.s.l.). The depths to the static water levels are between one and five metres and the reported well yiels are between 20.0 and 90.0 L/min.

The lower aquifer consists of sands and gravels that are buried under up to 34.0 m of clay. The records of 12 wells tapping this aquifer indicate that the wellhead elevations are between 57.0 and 69.0 m (a.s.l.), and the elevation of the top of the aquifer is between 20.0 and 27.0 m (a.s.l.). The depths to the static water levels are between 5.0 and 27.0 m, and the reported well yiels are between 20.0 and 130.0 L/min.

The Upper and Lower Nepean-Kemptville Aquifers: These names are suggested for two aquifers that occur within a large area extending from Nepean in the northwestern tip of the Authority through Osgoode to South Gower along its southeastern boundaries

The upper aquifer consists of sequences of sands and gravels that are displayed at the surface. The records of 121 wells indicate that many wells penetrate only a few metres of the aquifer. Other wells, however, penetrate up to 38.0 m of continuous layers of sands and gravels. The wellhead elevations are between 99.0 and 114.0 m (a.s.l.), and the elevation of the top of the aquifer is between 82.0 and 114.0 m (a.s.l.). The aquifer is unconfined, the depths to the static water levels are between 2.0 and 11.0 m, and the well yields are between 20.0 and 225.0 L/min. Several wells, however, have yields ranging between 360.0 and 1,800.0 L/min.

The lower aquifer consists of sands and gravels that are buried under clay and a till-like deposit. The records of 190 wells indicate that the thickness of this lower aquifer is between 2.0 and 22.0 m, the wellhead elevations are between 76.0 and 101.0 m (a.s.l.), and the elevation of the top of the aquifer is between 58.0 and 85.0 m (a.s.l.). The aquifer is confined, the depths to the static water levels range from less than 1.0 to 18.0 m, and the well yields are between 2.0 and 50.0 L/min. Several wells, however, have yields ranging between 350.0 and 450.0 L/min.

8.1.4 The Mississippi Valley Conservation Authority

Location: The Mississippi Valley Conservation Authority (the Authority) is located in the eastern part of southern Ontario. It is bounded on the northwest by the Madawaska River basin, on the west by the Moira and Salmon River basins, and the southeast by the Rideau River basin. The main urban centres within the Authority are Almonte, Appleton, Blakeney, Carlton Place, Galetta, Lanark, and Pakenham (Figure 23).

Drainage: The Mississippi River, which is the main river within the Authority, rises on the Canadian Shield at Mazinaw Lake and travels about 193.0 km to its confluence with the Ottawa River near Galetta. Like the Rideau River, the headwater area of the Mississippi River has numerous lakes, including Shabomeka, Mississagagon, Big Gull, Pine, and Dalhousie Lakes. The two main tributaries to the Mississippi River are the Clyde and Fall Rivers.

Physiography: Most of the southwestern parts of the Authority are characterized by the rock-and-knob topography of the Precambrian rocks, and a large portion of the northeastern parts are underlain by Paleozoic rocks which have almost level topography. The overburden on the Precambrian bedrock is thin or absent and its associated landforms are limited to occasional till deposits, kame mounds, esker ridges, and organic deposits formed by sediment accumulation in bedrock depressions.

Chapman and Putnam (1984) identified parts of two physiographic regions within the Authority, the Ottawa Valley Clay Flats and the Smiths Falls Limestone Plain. The Ottawa Clay Flats are found within the lower parts of the Authority as clay plains interrupted by till deposits and Paleozoic rocks. The Smith Falls Limestone Plain is found mainly within the central parts of the Authority. A large portion of this region consists of exposed Paleozoic rocks.

Bedrock Topography and Geology: The Precambrian rocks underlie the whole of the Authority and are, in turn, overlain by Paleozoic rocks. The bedrock elevation ranges from about 265.0 m (a.s.l.) in the southwestern parts of the Authority to about 75.0 m (a.s.l.) in its northeastern parts at the confluence of the Mississippi River with of the Ottawa River near Galetta.

The Paleozoic rocks are of Lower and Middle Ordovician age. The Lower Ordovician rocks are represented by the dolostones and sandstones of the Beekmantown Group. The Middle Ordovician rocks, on the other hand, are represented by the limestones, dolostones, shales, and sandstones of the Ottawa Group.

Overburden Thickness and Geology: The overburden is missing over most of the Authority and where it is present, its thickness ranges form 10.0 to 30.0 m. Within a few places in the northeastern parts of the Authority, however, the overburden thickness may reach 50.0 m.

The overburden consists of glacial, glaciofluvial, and glaciomarine deposits of Pleistocene age and fluvial and organic deposits of Recent age. According to Barnett (1992), the glacial deposits are part of the undifferentiated tills of Map Units 18 and 19. Both tills are found mainly within the central parts of the Authority. The glaciofluvial deposits consist of a few kame ridges of ice-contact origin and a handful of thin outwash plains that are scattered within the central parts of the Authority. The glaciomarine deposits, on the other hand, are found within the northeastern parts of the Authority and form large silt and clay plains as well as a few small sand plains. Fluvial and organic deposits of Recent age are found in river valleys and swamps.

Overburden Aquifers: A total of 14, 758 bedrock wells have been identified within the Authority as compared to 641 overburden wells indicating that the bedrock is the more significant source of water supply. Of the 641 overburden wells, 118 (18.4%) have no specific capacity data, 41 (6.4%) have specific capacities of less than 1.0 L/min/m, 115 (17.9%) have specific capacities between 1.0-5.0 L/min/m, 89 (13.9%) have specific capacities between 5.0-10.0 L/min/m, 166 (25.9%) have specific capacities between 10.0-50.0 L/min/m, and 112 (17.5%) have specific capacities above 50.0 L/min/m.

The West Carlton Aquifer: This name is suggested for a local aquifer that is located in the northeastern tip of the Authority within the Municipality of West Carlton (Concessions 3, 4, and 5). The records of 111 wells tapping the aquifer indicate that their wellhead elevations range from 53.0 to 76.0 m (a.s.l.).

The aquifer consists of sands that range in thickness between one and eight metres. Its top elevation is between 49 and 67 m (a.s.l.). The aquifer is mostly unconfined except where it is buried under clay deposits. The depths to the static water levels range from 2.0 to 11.0 m and the reported well yields range from 15.0-50.0 L/min. Most of the wells have specific capacities between 5.0 and 50.0 L/min/m, but a few wells have specific capacities that exceed 50.0 L/min/m.

The Upper and Lower West Nepean Aquifers: These names are suggested for two local aquifers that are located in the southeastern part of the Authority within the Municipality of Carlton West to the west of Nepean.

The upper aquifer consists of gravel and coarse sand deposits that range in the thickness between 4.0 and 12.0 m. One well, however, penetrates 30.0 m of continuous sand and gravel deposits and a second well penetrates 32.0 m of similar deposits. The wellhead elevations of 19 wells tapping the aquifer range between 107.0 and 124.0 m (a.s.l.) and the elevation of the top of the aquifer ranges from 104.0 and 117.0 m (a.s.l.). The aquifer is mostly unconfined. The depths to the static water levels range from 1.0 to 5.0 m and the reported well yields range from 20.0-280.0 L/min. Most of the wells have specific capacities between 10.0 and 50.0 L/min/m, but some wells have specific capacities that exceed 50.0 L/min/m.

The lower aquifer also consists of sand and gravel deposits that are overlain by clay. The top elevation of the aquifer ranges from 59.0 to 87.0 m (a.s.l.) and its thickness ranges from 1.0 to 20.0 m. The aquifer is confined, the depths to the static water levels range from 2.0 to 7.0 m, and the reported well yields are between 20.0 and 90.0 L/min. Most of the wells have specific capacities between 10.0 and 50.0 L/min/m.

8.1.5 The Moira River Conservation Authority

Location: The Moira River Conservation Authority (the Authority) is located in the eastern part of southern Ontario. It is bounded on the west by the Trent River basin, on the north by the

Madawaska River basin, on the east and southeast by the Mississippi and Salmon River basins, and on the south by the Bay of Quinte (Figure 24).

The major urban centres within the Authority are the City of Belleville, which is located at the mouth of the Moira River, and the Villages of Tweed, Madoc and Deloro. Industry and agriculture form the economic base in the southern parts of the Authority, while tourism, recreation, and logging are the major activities in the northern parts where 80% of the area is woodland.

Drainage: The Moira River rises about 88.0 km north from Lake Ontario in the rocky highlands of the Counties of Hastings, and Lennox and Addington. The river and its major tributaries, the Skootamatta, Black, and Clare Rivers and the Parks Creek, drain about 2,745.0 km^2. The Skootamatta and Black Rivers drain about 40.0% of the Moira River basin; the Clare River and the Parks Creek drain another 20.0%, and the remaining 40.0% is drained by the Moira River and its smaller tributaries. Many lakes occur within the headwaters of the river, the largest being Skootamatta, Lingham, Moira and Stoco Lakes.

Physiography: The northern parts of the Authority, where the overburden is thin or absent, are characterized by the rock-and-knob topography of the Precambrian rocks. The southern parts, on the other hand, are characterized by a thin overburden mantle on Paleozoic rocks. The overburden landforms are limited to occasional kame mounds, esker ridges, and sand plains formed by sediment accumulation in bedrock depressions. Swamp and bog deposits fill numerous bedrock lows and surround many lakes (Sibul et al.1974).

Chapman and Putnam (1984) identified three physiographic regions within the southern parts of the Authority, namely, the Napanee Plain, the Peterborough Drumlin Field, and the Dummer Moraines. The Napanee Plain is a flat to undulating plain of limestone with little or no overburden. The Peterborough Drumlin Field contains numerous drumlins which are composed of calcareous till. They have a general orientation from northeast to southwest. A few eskers are also found in this region.

The Dummer Moraines extend as a belt between the Peterborough Drumlin Field in the south and the Canadian Shield to the north. The underlying bedrock consists of limestones. A discontinuous limestone cuesta, usually less than10.0 m high, defines the contact between the Precambrian plutonic rocks and the Paleozoic limestones in areas east, south and west of Stoco Lake. According to Chapman and Putnam (1984), the moraines within this region are characterized by angular fragments and blocks of limestone with many Precambrian rocks also present. The surface is extremely rough even though most of the morainic ridges are quite low. Several tributaries to the Moira River cross this morainic belt. Most of them follow preglacial valleys which are entrenched in the bedrock. A number of these valleys are blocked by glacial drift, thus creating long narrow lakes or swamps. The Moira and Stoco Lakes are prominent examples of this type.

Bedrock Topography and Geology: Precambrian rocks underlie the whole of the Authority and are, in turn, overlain in the south by approximately 105.0 m of Paleozoic limestone. Thin and discontinuous overburden deposits cover the southern edge of the Precambrian rocks and become thicker and more continuous over the Paleozoic rocks in the south.

The bedrock elevation ranges from about 75.0 m (a.s.l.) at the mouth of the Moira River to between 300.0 and 400.0 m (a.s.l.) within its headwater areas. The bedrock surface of the Precambrian rocks is characterized by a low relief. The Paleozoic rocks, on the hand, exhibit a gently sloping relief with elevation ranging between 75.0 m and 180.0 m (a.s.l.). By and large, the present land surface topography of the lower part of the Authority is determined by these rocks.

A bedrock valley extends across the Clare River flood plain through Stoco Lake to the lower reaches of the Moira River. Another bedrock valley can be traced along the valley of the Parks Creek (Sibul et al. 1974).

According to Johnson et al. (1992), the Paleozoic rocks are of Middle Ordovician age. These rocks belong to the Shadow Lake Formation of the Basal Group and the Gull River, Bobcaygeon, Verulam and Lindsay Formations of the Simcoe Group. The Shadow Lake Formation separates the Paleozoic rocks from the older Precambrian rocks.

Overburden Thickness and Geology: As indicated above, the overburden is missing over most of the northern parts of the Authority. In most of the other areas, the thickness of the overburden is less than10.0 m. Only in the kame moraine along the Authority's southwestern boundary does the thickness of the overburden increase to reach more than 70.0 m. This kame moraine is approximately 25.0 km long and attains a relief of 60.0 to 90.0 m above the surrounding land surface.

The overburden consists of glacial, glaciofluvial, and glaciolacustrine deposits of Pleistocene age and fluvial and organic deposits of Recent age. According to Barnett (1992), the glacial deposits consist of two undifferentiated tills, the till of Map Unit 19 and the till of Map Unit 20. The till of Map Unit 19 occurs as a drumlinized plain extending from Belleville in the south to Roslin in the north.The till of Map Unit 20, on the other hand, extends as a belt between the till of Map Unit 19 and the Canadian Shield. The till outcrops within the Dummer Moraine physiographic region and forms broad, gently undulating plains. In most areas, the thickness of the till is small and its surface is littered with large limestone and Precambrian boulders.

The glaciofluvial deposits are of ice-contact origin. They occur as two esker ridges and a kame moraine. One esker ridge consisting of sand and gravel deposits trends southwest from Marlbank in the north to the southeast of Myrehall in the south. The other ridge, which is locally known as the Tweed Esker, is a narrow body of sand and gravel prominently displayed on the till plain between Tweed and Zion Hill. The kame moraine extends along the southwestern boundary of the Authority. It consists mainly of sand and gravel deposits, although till occurs at the surface in some of its elevated parts.

The glaciolacustrine deposits of sand form low plains that are drained by the Chrysal and Palliser Creeks. Also, a large plain of glaciolacustrine clay occurs between Belleville and Thresher Corners. Alluvial, peat and muck deposits of Recent age are found in river valleys and swamps.

Overburden Aquifers: The total number of wells within the Authority is 3,549. Of these, 430 (12.1 %) are overburden wells, 2,921 (82.3 %) are bedrock wells, and the rest are of unknown type. All the overburden wells are located within the lower parts of the Authority and their small number reflects the limited thickness and extent of the overburden deposits.

Data related to short-term pumping tests are available for 383 overburden wells. Of these wells, 143 (37.3%) have specific capacities ranging from 1.0 to 5.0 L/min/m, 133 (34.7%) have specific capacities between 5.0 and 25.0 L/min/m, 42 wells (11.0%) have specific capacities between 25.0 and 50.0 L/min/m, and 65 (17.0%) have specific capacities exceeding 50.0 L/min/m.

Two small overburden aquifers were identified by Sibul et al.(1974) within the Authority. The first aquifer is located in the kame moraine along the Authority's southwestern edge. Rain and snowmelt infiltrate easily into much of the moraine where it is covered by sand and gravel deposits. Where a till is present on the surface, however, small lakes and swamps occur. The depths to the static water level in most wells tapping the aquifer is about 15.0 m. Although the water yields from of these wells are more than 45.0 L/min, the specific capacities of most wells are less than 5.0 L/min/m indicating that the sand and gravel deposits are not extensive and/or poorly sorted.

The second aquifer consists of sand deposits that occur at the eastern side of the kame moraine and extend along the valleys of the Chrysal and Palliser Creeks and as far as the valley of Moira River and the Parks Creek. In places the aquifer is reported to directly overlie the Paleozoic limestones. The aquifer is buried partially by till, clay or swamp deposits. Its thickness is mostly less than six metres, but thicknesses of more than 18.0 m have been reported in some wells. The water yields of most wells are about 45.0 L/min.

8.2 AQUIFERS IN THE CENTRAL PART OF SOUTHERN ONTARIO

Overburden deposits that range in thickness from about 10.0 m to more than 110.0 m are widespread within the central part of southern Ontario. These deposits include extensive sands and gravels that form surficial or buried aquifers. The Oak Ridges Moraine, which is one of the most significant physiographic features in this part of southern Ontario, is also the largest overburden aquifer complex.

8.2.1 The Oak Ridges Moraine

Location: The Oak Ridges Moraine (the Moraine) is one of the largest moraines in Ontario. It stretches about 160.0 km from the Niagara Escarpment east through the heart of the Greater Toronto Area and to Rice Lake. The upland plateau of the Moraine has an elevation of about 350.0 m (a.s.l.). A high point at 390.0 m (a.s.l.) is located north of Caledon East at Glen Major and another point at 400.0 m (a.s.l.) is located east of Pigeon River. The Moraine has a distinctive hummocky topography that consists of “knobs” and intervening depressions or “kettles” (Figure 25).

White (1975) defined the western boundaries of the Moraine on the basis of geology to include only the high level sands in King Township. Duckworth (1979) defined the Moraine using the 900.0 ft (274.4 m) contour elevation. The Moraine was defined in the Oak Ridges Moraine Planning Study by the approximate 275.0 m (a.s.l.) contour elevation (Hunter et al. 1996) which concurs with the definition by Duckworth (1979). This definition of the Moraine, which was dictated by planning considerations, recognises that the Moraine and deeper aquifers may extend considerable distances further downslope.

Forests, which are noteworthy for their plants and animals, cover about 28.0% of the Moraine and public lands, which provide recreation opportunities for five million people, cover about 9.0% of the Moraine. About 64.0% of the Moraine is in the Peel, York and Durham Regions, 20.0% in Northumberland County, 10.0% in the City of Kawartha Lakes and Peterborough County, and 6.0% in Simcoe and Dufferin Counties.

Drainage: One of the main characteristics of the Moraine is the virtual lack of surface drainage. Notwithstanding this fact, the Moraine plays an essential role in maintaining the quality and quantity of water resources in this part of Ontario. Its headwater wetlands and springs are the sources for 60 watersheds. On the north side of the Moraine, the streams flow into Georgian Bay, Lake Simcoe, Lake Scugog, Sturgeon Lake, Pigeon Lake, the Otonabee River, Rice Lake and the Trent River system. On the south side, all the streams flow into Lake Ontario. The most important watercourses are the Humber, Don, Rouge, Duffins, Oshawa, Lynde, Bowmanville, Ganaraska, and Cobourg flowing south, and the Black, Holland, Pefferlaw, Beaver, Nonquon, East Cross, Cavan, Pigeon, Baxter, Percy and Salt flowing north.

Wetlands cover about 2.0% of the Moraine's surface and they occur as a band of depressions, or kettles, along the western half of the Moraine. They are also found along the Moraine's margins where groundwater discharges to the surface.

Results of Test Drilling: Useful information related to the composition of subsurface deposits within Moraine can be obtained from the MOE water well records. These records are specially useful in the identification of sand and gravel materials at various depths which allows, in turn, for the identification of the thickness and areal extent of overburden aquifers. A great deal of uncertainty, however, is associated with the identification of encountered till-like materials which makes it difficult to use the information for stratigraphic analysis.

To identify properly the stratigraphy of buried deposits, data should be obtained from test holes that were logged by on-site project geologists during drilling. The classification of materials in such test holes should be made on the basis of visual inspection of split spoon samples and geophysical logs. In addition, geophysical seismic techniques can be extremely useful in mapping the subsurface structure and stratigraphy.

There are only a few deep domestic water wells within the Moraine because most wells are usually terminated when adequate water is encountered. The records of a few deep test holes, however, are available. The following are brief descriptions of the historical test drilling programs in the Moraine area which are relevant to the understanding of its subsurface geology.

The Ontario Water Resources Commission and later the Ministry of the Environment drilled a number of deep test holes in the Moraine that reached the bedrock. The information obtained from these holes were used to describe the subsurface geology of the Moraine in a series of water resource reports (Funk 1977, Sibul et al. 1977, Singer 1981). Three deep test holes (W-2, W-8, and W-10) were drilled in the headwater area of the Wilmot Creek watershed as part of the evaluation of the water resources of the Bowmanville, Soper and Wilmot Creeks drainage basin (Funk 1977 and Singer 1981).

The ground elevation of test hole W-2 is 313.0 m (a.s.l.). Its geologic log from top to bottom is as follows:

- 2.7 m sandy till
- 11.5 m sand, silt, and silty sand
- 83.2 m alternating sandy, silty, or clay tills
- 6.1 m silty sand
- 38.1 m clay, varved clay, and silty clay
- 11.3 m sandy silt to fine sand
- 1.5 m limestone.

The ground elevation of test hole W-8 is 366.0 m (a.s.l.). Its geologic log from top to bottom is as follows:

- 20.1 m coarse gravel with minor silt
- 12.2 m silty sandy till
- 27.5 m gravel
- 6.7 m silty sandy till
- 6.7 m gravel
- 42.1 m silty sandy till
- 7.30 m sand and gravel
- 71.4 m clay till
- 2.4 m sand

- 7.9 m sandy silt till
- 7.0 m clay silty till
- 8.2 m limestone.

The ground elevation of test hole W-10 is 360.0 m (a.s.l.). Its geologic log from top to bottom is as follows:

- 100.0 m mainly gravel with some sand and silt
- 15.2 m sandy till
- 5.5 m clay silty till
- 6.1 m clay
- 28.1 m clay till
- 4.6 m gravel
- 0.9 m silty clay till
- 9.1 m gravel with some silt
- 20.3 m clay till
- 4.1 m silty sand
- 7.3 m silty sandy till
- 4.9 m clay silty till
- 1.2 m sand
- 6.1 m limestone.

A deep test hole (Test hole No. 4885) was drilled in headwater area of the Duffins Creek and another (Test hole No.10548) was drilled in the headwater area of the Rouge River as part of the evaluation of the water resources of the Duffins Creek-Rouge River drainage basin (Sibul et al. 1977).

The ground elevation of test hole No. 4885 is 328.0 m (a.s.l.). Its geologic log from top to bottom is as follows:

- 5.8 m sand till with layers of clay and sand
- 75.9 m sand and gravel
- 6.4 m fine silty sand
- 15.5 m clayey silt till to sand silt till
- 5.2 m fine sand, silt, and clay
- 1.9 m clayey silt till to sand till
- 37.5 m fine sand
- 0.9 m sand till
- 2.4 m fine to medium sand
- 5.2 m sand till
- 41.5 m shale.

The ground elevation of test hole No.10548 is 312.0 m (a.s.l.). Its geologic log from top to bottom is as follows:

- 12.2 m silty sand till
- 1.8 m silt clay
- 2.4 m clay silt till
- 3.4 m sand
- 4.6 m clay
- 44.5 m sand and gravel with some silt
- 16.8 m silty sand till
- 23.5 m sand, clay, and silt

- 10.1 m clayey silt till
- 26.8 m silt, clay and sand with some gravel
- 4.3 m silty sand till
- 3.1 m shale.

In 1993, the Ontario Geological Survey drilled six test holes within the Moraine to depths of about 90.0 m. None of these test holes reached the bedrock. One test hole (OSG-16) is located within the East Holland River watershed west of Ballantrae. It did not encounter any till and its log consists mainly of stratified sand and silt with minor clay. The remaining five test holes intersected a dense sandy diamicton which is believed to be the Newmarket Till at elevations varying from 220.0 to 290.0 m (a.s.l.).

Three test holes were drilled by the Geological Survey of Canada in 1994. One test hole (GSC -2MC) is adjacent to test hole OGS-16 and it penetrated 106.0 m of stratified sand with minor amounts of gravel and glaciolacustrine sediments underlain by diamicton (Newmarket Till). A second test hole (GSC MC -1) is located at Davis Drive and McCowan Road within the East Holland watershed. The test hole has a ground elevation of 282.0 m (a.s.l.). It penetrated 100.0 m of stratified sandy sediments and diamicton before reaching the bedrock. A third test hole (GSC-1VD) is located at Vandorf Road within the East Holland watershed. The test hole has a ground elevation of 304.0 m (a.s.l.). It penetrated stratified sands, a thick glaciolacustrine rhythmite with some sandy interbeds, a thin diamicton, a thin basal gravel, and another diamicton (Newmarket Till?).

An examination of the results of the various test drilling programs within the Moraine indicates that the thickness and composition of the overburden are highly variable. The test holes show that the Moraine has a cap of heterogeneous sand and gravel with minor amounts of silt and clay. The cap is covered in places by a few meters of the Halton Till and is underlain by a silty sandy till which is assumed to be the Newmarket Till. This till, in turn, rests on the bedrock in some test holes, and it is underlain by sequences of gravels, sands, silts, clays, and diamictons in others.

The diamictons together with the sequences of sand, gravel, silt, and clay found under the cap were interpreted in the past by various authors (Singer 1974 and 1981, Funk 1977, Sibul et al. 1977, and Ostry 1979). These authors suggested that these can be correlated with the Illinoian, and Early and Middle Wisconsinan deposits which were described by Karrow (1967) in the Scarborough area.

<u>Bedrock Topography and Geology</u>: The bedrock surface elevation under the Moraine is not well defined due to the lack of data. A number of test holes that have been drilled to the bedrock within the Moraine show that its top surface is about 152.0 m (a.s.l.) within the Bowmanville, Soper and Wilmot Creek drainage area (Funk 1977 and Singer 1974), 201.0 m (a.s.l.) in the Rouge River basin (Sibul et al. 1977), 293.0 m (a.s.l.) in the Bolton area (White 1975), and about 420.0 m (a.s.l.) on the crest of the Niagara Escarpment. The Moraine is underlain by southwesterly dipping shales and limestones of Ordovician age. These strata overlie Precambrian rocks.

<u>Overburden Thickness and Geology</u>: Scientific views regarding the definition and origin of the Moraine differed substantially over time. Barnett et al. (1998) provided a concise historical summary of how these views have changed. Taylor (1913), Chapman and Putnam (1943), and Gravenor (1957) suggested that the Moraine is interlobate in origin. On the other hand, Duckworth (1979) suggested that the Moraine is not interlobate. Also, Gwyn and Cowan (1978) suggested that the Moraine is a young feature and not of an interlobate origin. According to Barnett et al. (1998), the Moraine forms a sequence up to 150.0 m thick of

stratified sediments deposited rapidly on a high-relief, regional erosional surface. This surface is defined by a network of tunnel channels and the intervening drumlinized uplands. The upper stratigraphic portion of the Moraine consists mainly of subaqueous fan and rhythmite channel sediments with an abundance of sand materials.

Six plateaus, namely, Albion Hills, Kettleby, Uxbridge, Pontypool, Rice Lake, and Mt. Wolfe have been identified in the upper stratigraphic portion of the Moraine. The plateaus, which have an elevation range between 350.0 and 375.0 m (a.s.l.), rest on a drumlinized surface of the Newmarket Till and are capped locally by the Halton Till on the south and by the Kettleby Till on the north. The Newmarket Till overlies older glacial and glaciolacustrine deposits. A basal till on bedrock at a number of locations in the Oak Ridges Moraine has been interpreted as York Till of Illinoian age (Sibul et al. 1977).

A model for the origin of the moraine was proposed by Barnett et al. (1998). The model is based on morphologic features, surface mapping, sediment characteristics, seismic profiles, and test hole data, and it recognizes the following factors:

- The Peterborough Drumlin Field, which is composed of the Newmarket Till, occurs both north and south of the Moraine.
- Drill cores obtained from test holes within the area indicate that the Newmarket Till is intercepted between elevations of 200.0-280.0 m (a.s.l.).
- Seismic profiles from a survey run across the Moraine show the presence of ridges similar to drumlins found north of the Moraine which confirms the assumption that a regional till sheet and a drumlin field continue beneath the Moraine.
- There is little change in drumlin long-axis orientation on either side of the Moraine suggesting that these structures extend beneath the Moraine and were formed by a common process.
- The drumlin field north of the Moraine is cut by a network of deep, wide, flat-floored valleys (tunnel channels) which may have been formed by sub-glacial meltwater flow.
- Deep drilling and reflection seismic profiles indicate that, in places, the tunnel channels continue beneath the Moraine.

Burnett et al. (1998) also suggested that the development of the Moraine has occurred in four stages. These stages are:

(a) sub-glacial sedimentation,
(b) subaqueous fan sedimentation,
(c) fan to delta sedimentation, and
(d) ice-marginal sedimentation.

According to Barnett et al. (1998), as time passed from the first stage to the fourth, a general transition from sub-glaciofluvial to glaciolacustrine and from subaqueous to sub-aerial environments of deposition occurred. During the first stage about 18,000 years before present, erosional processes, caused by catastrophic floods that resulted from the ablation of the Laurentide ice sheet produced an extensive network of sub-glacial channels and cavities. Within the core of the Moraine and beyond, this network was filled by sediment-laden meltwater which deposited coarse sediment sequences that have been observed in seismic profiles and logs of test holes.

During the second stage, the network of sub-glacial channels and cavities expanded and a subaqueous fan sedimentation process occurred. The process was dominated first by deposition of gravel and then by deposition of sand. Early fan sedimentation within the Moraine could have taken place in water depths of more than 100.0 m. The third stage includes the transition to deltaic sedimentation, where ice-confined sedimentation occurred. Fan sedimentation occurred in a large ice-controlled lake and extensive sediments (fine sand, silt and clay rhythmites) were deposited during this stage. The fourth stage includes the deposition of glaciolacustrine stratified sediments and massive to bedded diamictons (Halton Till and debris flows) along the southern flank of the Moraine and in the deeper basinal areas. As proglacial lake levels continued to decline, the Moraine emerged as an extended continuous system.

8.2.1.1 Characteristics of the Oak Ridges Moraine Hydrogeologic System

From a hydrogeologic point of view, the Moraine is a system of highly permeable sand and gravel deposits that act as aquifers separated by low permeable deposits of till, silt, and clay that act as aquitards. In 1991, the Ontario Ministry of Natural Resources conducted a Planing Study as part of the development of a long-term strategy for the environmental protection and management of the Moraine. A team from various provincial, federal, and municipal agencies as well as consulting firms, academia, environmental groups and the public participated in the study. One of the most important objectives of this study was to identify, characterize and delineate key hydrogeologic features of the Moraine.

Hunter et al. (1996) prepared a technical report which included an overview of the aquifer systems within the Moraine. For the most part, these aquifer systems are found within stratigraphic units that occur over discrete elevation ranges, and they were named the Upland Aquifer Complex, the Lowland Aquifer Complex, the Bounded Channel Aquifers, and the Basal Aquifers. These names will be adopted in this report. Each aquifer system consists of sands and/or gravels that are related with respect to time and place of deposition. The aquifers are partially separated by extensive less permeable, fine-grained aquitards, but regionally they are hydraulically connected.

The Newmarket Till is a regional aquitard that separates the Upland Aquifer Complex from the Lowland Aquifer Complex below. In turn, the Lowland Aquifer Complex is separated from the lower aquifers by aquitards of silt, clay and pre-Newmarket tills. Where the aquitards are missing, hydraulic connections between the aquifers have developed.

A large portion of the knob-and-kettle surface of the Moraine is covered with sequences of sand and gravel deposits up to 100.0 m in thickness. These deposits are covered mainly with a sandy soil. Rain and snowmelt infiltrate readily through the soil and either return back to the atmosphere via evapotranspiration or percolate down to recharge the groundwater regime whenever the soil moisture is above field capacity. This leaves little or no water for overland flow.

The surficial sand and gravel deposits within the Moraine constitute one of the main groundwater recharge zones in southern Ontario. The groundwater recharge within the Moraine differs from place to place and from year to year. It is controlled by the permeability and thickness of the soil and subsoil deposits, level of soil moisture, vegetal cover, land use, depth to water table, and form of precipitation as rain or snow.

Singer (1981) calculated the long-term annual baseflow from a small catchment which is 10.8 km^2 in size. The catchment is located in the upper part of the Wilmot Creek watershed and is entirely within the Moraine. The average baseflow in the catchment was estimated at 315.0 mm. Further, the author estimated the recharge within the Oak Ridges Moraine physiographic region at 275.0 to 375.0 mm/yr. Hunter et al. (1996) placed the recharge in the Moraine areas within Peel, York and Durham Regions at 363,000.0, 365800.0, and 885,500.0 m^3/day, respectively. The unit recharge for the Moraine was placed at 270.0 mm/yr.

Groundwater flow within the Moraine is a three-dimensional process which is dependant on topography, climate, and geology. The geologic setting of the Moraine with a thick mantle of sand and gravel deposits resting on a till of low permeability forces the bulk of groundwater to move laterally toward its northern and southern flanks where a regional groundwater discharge zone occurs. This discharge zone occurs mainly at elevations between 280.0 and 290.0 m (a.s.l.). It consists of seepage faces and springs within the headwaters of 60 streams where the channels of these streams intersect the aquifer. Locally, groundwater may discharge into wetlands and some kettle lakes at higher elevations.

Vertical groundwater flow into deeper aquifers is controlled by the thickness and permeability of the aquitards separating the aquifers. This resistivity to recharge, which is expressed as the thickness of the aquitard divided by its permeability and is measured in days, varies vertically and laterally throughout the Moraine.Where the aquitards are missing, hydraulic connections between the aquifers have developed.

8.2.1.2 The Upland Aquifer Complex

According to Hunter et al. (1996), the Upland Aquifer Complex is an important regional storage unit that contributes to stream baseflow and recharge to deeper aquifer systems. The aquifer complex includes coarse sandy deposits derived from glacial meltwater above an elevation of 260.0 m (a.s.l.) and may be further vertically subdivided into discrete lateral units (aquifers) which occur at about 260.0, 280.0 and above 300.0 m (a.s.l.). These discrete units are separated by fine textured rhythmite sequences.

Based on the description of the Upland Aquifer Complex given by Hunter et al. (1996), it would appear that the aquifer complex is the same as the Oak Ridges Aquifer Complex described by Turner (1977), Sibul et al. (1977), Funk (1977), Singer (1981), and Vallery et al. (1982).

As part of the "Major Aquifers in Ontario" series, published by the Ministry of the Environment, Turner (1977) was the first to map the Oak Ridges Aquifer Complex in southern Ontario. The hydrogeologic interpretations regarding this aquifer complex were made on the basis of data derived from well records on file with MOE as of August 1977. Further, the identification of the extent and continuity of the aquifer complex were based on elevation data. Similar approaches have been used to map parts of this aquifer complex in the Duffins Creek-Rouge River basins (Sibul et al.1977), the Bowmanville, Soper and Wilmot Creeks basin (Funk 1977, Singer 1981), and the Black and Holland River basins (Vallery et al.1982).

According to Turner (1977), the aquifer complex extends from Highway 400 in King Township to the southern tip of Rice Lake in Hope Township with a gap located to the south of Lake Scugog. The author noted that although there are wells in the aquifer complex that have reported continuous, permeable deposits of more than 60.0 m in thickness, it is unlikely that these deposits are capable to yield water throughout their total thicknesses. The average thickness of the aquifer complex is approximately 30.0 m with individual lenses of highly permeable sands and/or gravels being substantially thinner. A thick layer of a till underlies the permeable materials and represents the bottom of the aquifer complex.

The aquifer complex is overlain in some areas by till, while in most other areas permeable sands and/or gravels are exposed at the surface. Groundwater is unconfined in the central portions of the aquifer complex and becomes confined toward the northern and southern boundaries. The groundwater divide within the aquifer complex represents a regional divide which results in flow toward Lake Ontario in the south and toward Lake Simcoe and Lake Scugog in the north. Turner (1977) described the yields from existing wells in the aquifer complex as ranging from good to excellent. In most areas, the yields are sufficient to supply at least domestic needs of 10.0 to 45.0 L/min. On the other hand, the water yields of the high-capacity wells that were developed for municipal, industrial, commercial and irrigation uses range from about 450.0 to 2,700.0 L/min.

Singer et al. (2000) evaluated the yields of wells tapping the aquifer complex within the East Holland River watershed. According to the authors, 54.0 % of the wells have specific capacities ranging from 1.0 to 5.0 L/min/m, 37.0% have specific capacities between 5.0 and 25.0 L/min/m, 4.0% have specific capacities between 25.0 and 50.0 L/min/m, and the remaining 5.0% have specific capacities larger than 50.0 L/min/m. The depths of the wells tapping the aquifer complex are variable ranging from about 30.0 m to more than 180.0 m. The reported depths of where groundwater was found are also variable ranging from about 10.0 m to more than 120.0 m. Further, the reported depths to static water levels range from less than 5.0 m to more than 20.0 m.

Information related to the transmissivity of the aquifer complex has been reported in a number of studies. Sibul et al. (1977) estimated the average transmissivity of the aquifer complex within the Duffins Creek-Rouge River basins to be in the range of 55.0 m^2/day. Singer (1981) applied a mathematical model to simulate the groundwater flow within the Wilmot Creek watershed which includes part of the aquifer complex. Good agreement between observed and simulated groundwater levels were obtained by using a transmissivity range of 18.0 to 313.0 m^2/day for the aquifer complex.

Hunter et al. (1996) noted that high producing wells have been developed in this aquifer complex. The short-term transmissivity for production and test wells, screened within the 260.0 to 280.0 m (a.s.l.) zones, ranges from 225.0 to 400.0 m^2/day. At Stouffville, a production well (PW-5), which is screened within a highly permeable zone, has a long-term transmissivity of 672.0 m^2/day and a specific yield of 0.02.

8.2.1.3 The Lowland Aquifer Complex

An aquifer complex that occurs in the general elevation range from 200.0 to about 240.0 m (a.s.l.) was identified by Hunter et al. (1996) in the Moraine and was named the Lowland Aquifer Complex. Vallery et al. (1982) identified a similar aquifer complex between 207.0 and 247.0 m (a.s.l.) within the Holland River basin, which they named the Holt Aquifer Complex. The aquifer, which consists of buried sands and gravels up to 3.0 m in thickness, extends from Aurora and Vandorf to Pleasantville and Sharon. Also, International Water Consultants Ltd. (1991) described an aquifer zone of sand and gravel within the Holland River basin which occurs at an elevation range of 180.0 to 260.0 m (a.s.l.) This aquifer zone, which was called the Intermediate Aquifers, overlaps the range of the Holt Aquifer Complex identified by Vallery et al. (1982) and the Lowland Aquifer Complex identified by Hunter et al. (1996).

According to Hunter et al. (1996), the Lowland Aquifer Complex includes sandy meltwater channel deposits that extend into the tunnel channels which cut into and through the Newmarket Till. It also extends under the Moraine as deep channel deposits fanning out into the regional lowlands as discrete aquifer units. These aquifer units merge with the Upland Aquifer Complex at higher elevations providing a regional aquifer hydraulic connection. Many rural settlements on the lower slopes adjacent to the Moraine depend on this aquifer complex for potable water supply. In addition, a number of golf course irrigation wells and a number of municipal production well fields are located in this aquifer complex.

According to International Water Consultants Ltd. (1991), a number of municipal wells have been developed in the Intermediate Aquifers, including the Doane, Simcoe, Bingham, Newmarket Wells 9 and 14, and the Oak Ridges wells. The reported transmissivities for these wells are generally moderate and in the order of 100.0 to 400.0 m^2/day with storativity of 1.0 x 10^{-2} to 1.0 x10^{-4}.

In addition, Hunter et al. (1996) indicated that some municipal production well fields that tap the Lowland Aquifer Complex show intermediate and high transmissivities. The following are some long-term transmissivity values that were reported:

Well Number	Location	Transmissivity in m^2/day
PW-3	East Caledon	335.0
PW-2	Centreville	500.0
PW-2	Palgrave	597.0
PW-3	Palgrave	1,771.0
	Oxbridge	780.0
	Port Perry	740.0

The storage coefficient values reported for the above wells are typical of confined aquifers and close to the high end (i.e. 0.001).

8.2.1.4 The Bounded Channel Aquifers

A number of aquifers have been reported at elevations between 110.0 and 180.0 m (a.s.l.) within and outside the Moraine. The most famous of these is the Yonge Street Aquifer. Vallery et al. (1982) identified an aquifer complex within the Lake Simcoe basin which they correlated with the Alliston Aquifer Complex described by Turner (1977). International Water Consultants Ltd. (1991) described an aquifer along the Yonge Street core which ranges in elevation from 150.0 to 200.0 m (a.s.l.) and another aquifer in the Bradford and Holland Marsh area which appears to range in elevation from 110.0 to 180.0 m (a.s.l.).

Hunter et al. (1996) indicate that highly transmissive, bounded, channel aquifers occur at elevations below 180.0 m (a.s.l.) at many locations within the Moraine and up to150.0 m (a.s.l.) or deeper south of the Moraine. According to the authors, a number of these channel aquifers are pre-Newmarket Till in age and are loosely associated with bedrock valleys and tunnel channels extending into the Moraine upland. These aquifers, which they named the “Bounded Channel Aquifers” include the deep well fields at Aurora, Newmarket, Oak Ridges, former production wells at Markham and Unionville, Richmond Hill Well No. 6, the Ministry of Natural Resources well field at Maple, the King City and Nobleton wells, and a number of golf course irrigation wells.

8.2.1.5 The Basal Aquifers

Sand deposits of a few metres in thickness have been reported above the bedrock in association with a lower drift unit in monitoring wells W-2, W-8, W-10 in the Moraine (Funk 1977 and Singer 1981). Similar deposits were also reported by Sibul et al. (1977) in test hole 4885 in the Duffins Creek-Rouge River basin at elevations between 165.0 and 175.0 m (a.s.l.). Hunter et al. (1996) also reported regionally extensive basal granular aquifers 1.0-3.0 m thick which occur on the bedrock and resistant till surfaces in tunnel channel and valley lowland areas between about 260.0 and 150.0 m (a.s.l.). According to Hunter et al. (1996), these aquifers may occur in association with the bounded channel aquifers and have high transmissivity values and storage coefficient ranges of confined aquifers.

8.2.2 The Trent River Drainage Basin

<u>Location</u>: The Trent River basin is one of the largest inland basins in the central part of southern Ontario. Its drainage area, which comprises part of the Canadian Shield in its headwaters and Paleozoic rocks in its lower parts, is about 12,400.0 km^2. The basin is bounded on the south by the Oak Ridges Moraine and Lake Ontario, on the west by the Lake Simcoe basin, on the north by river systems that flow into the Ottawa River, and on the east by the Moira River basin (Figure 26).

Four conservation authorities are within the basin, namely, the Kawartha, Otonabee, Crowe Valley, and Lower Trent. The basin includes parts of the Counties of Durham, Haliburton, Hastings, Northumberland, Peterborough, and Victoria. The major urban centres in the basin are Peterborough, Hastings, Lindsay, and Campbellford. The basin contains a number of beautiful lakes which are considered one of Ontario's most accessible and best recreational areas.

<u>Drainage</u>: The headwaters of the Trent consist of a number of rivers that rise on the Canadian Shield and flow in a southwesterly direction toward the Kawartha Lakes. They include the Gull, the Burnt, and the Irondale Rivers, and the Eels and the Nogies Creeks. Other streams that drain the northern flank of the Oak Ridges Moraine enter the Kawartha Lakes from the south, including the Scugog and the Pigeon Rivers. Both rivers run through swampy valleys of low gradient.

The Kawartha Lakes, which serve as natural water reservoirs, include Lakes Balsam, Cameron, Sturgeon, Pigeon, Buckhorn, Chemong, katchewanooka, and Stony. The lakes lie along the juncture of the Paleozoic rocks and the Canadian Shield and occupy portions of a preglacial valley that drained toward the southwest and acted as an outlet for glacial Lake Algonquin (Chapman and Putnam 1984). The Kawartha Lakes drain to Rice Lake by way of the Otonabee and Indian Rivers. From Rice Lake, the Trent flows northeastward for a few kilometres then eastward for a few more kilometres before it is joined by the Crowe River at the Crowe Bridge Conservation Area. The Trent then flows southward to Percy Reach before it turns eastward and flows to a point at the southwest of Sterling. From that point the river flows in a southerly direction to enter Lake Ontario at Trenton.

The Crowe River is one of the main tributaries to the Trent. Its headwaters are within the Canadian Shield in the vicinity of Cardiff and Paudash. The Crowe River watershed contains numerous lakes, including Lakes Chandos, Tangamong, Whetstone, Mud Turtle, and Belmont. The main tributaries to the Crow River are the Beaver Creek and the North and the Deer Rivers.

<u>Physiography</u>: The northern headwaters of the basin are characterized by the rock-and-knob topography of the Precambrian rocks. The rest of the basin is overlain by Paleozoic limestones which exhibit a gently sloping relief.

Thin and discontinuous overburden deposits cover the Precambrian rocks in the north and become thicker and more continuous over the Paleozoic rocks in the south. Landforms within the overburden include numerous drumlins, occasional kame mounds, esker ridges, and sand plains formed by sediment accumulation in bedrock depressions. Swamp and bog deposits fill the numerous bedrock lows and surround many lakes.

Chapman and Putnam (1984) identified parts of eight physiographic regions within the basin, including the Georgian Bay Fringe, the Dummer Moraines, the Carden Plain, the Peterborough Drumlin Field, the Schomberg Clay Plains, the Oak Ridges Moraine, the South Slope, and the Iroquois Plan.

The Georgian Bay Fringe, which extends as a broad belt to Georgian Bay, is found within the northern part of the basin. This physiographic region is characterized by bare rock nobs, ridges, scanty drift coverings, and shallow soil.

Within the basin, the Dummer Moraines extend from the Kawartha Lakes to the Crowe River. This morainic belt, which borders the Canadian Shield, is crossed by several tributaries to the Trent River. It is underlain by Paleozoic rocks which form escarpments in several places.

The Carden Plain extends between the Kawartha Lakes and Lake Couchiching and consists of a limestone plain with a very little overburden. The plain, which was under glacial Lake Algonquin, contains some sand deposits.

The Peterborough Drumlin Field covers the central parts of the basin. The field is notable for its eskers as well as its drumlins. The general orientation of the drumlins is from northeast to southwest.

Part of the Schomberg Clay Plains physiographic region is found to the north of Lake Scugog. Within the basin, this region consists of stratified clay and silt deposits and a few drumlins on top of a flat till plain.

The South Slope within the basin constitutes the eastern extremity of this physiographic region in Ontario. It extends between the abandoned Lake Iroquois shoreline and the southern edge of the Oak Ridges Moraine, has an average width of 9.0 to 11.0 km, and is covered by big drumlins pointing to the southwest.

Most of the southern part of the basin is occupied by the Oak Ridges Moraine. The surface of this physiographic region, which is covered mainly with glaciofluvial sands and gravels, is hilly with a knob-and-basin relief.

The Iroquois Plain extends as a narrow band about five kilometers in width along the lowland bordering Lake Ontario, and then expands inland to include a large area of the Trent River Valley. By and large, the Iroquois Plain is covered by glaciolacustrine sand, silt and clay deposits, and it contains numerous drumlins which have a northeast-southwest alignment. The term “Trent Embayment” describes a large area embodying much of the Lower Trent River which used to be a great bay of Lake Iroquois and contained many islands (Chapman and Putnam 1984).

Bedrock Topography and Geology: As indicated above, the Precambrian rocks underlie the whole of the basin and they are, in turn, overlain by Paleozoic limestones. The bedrock elevation ranges from about 300.0 and 360.0 m (a.s.l.) in the headwater areas to about 40.0 and 80.0 m (a.s.l.) in the lower part of the basin.

The Precambrian rocks consist of plutonic, metasedimentary, and metavolcanic rocks. The Paleozoic rocks, on the other hand, are of Middle Ordovician age. They consist of the Shadow Lake Formation of the Basal Group and the Gull River, Bobcaygeon, Verulam and Lindsay Formations of the Simcoe Group.

Overburden Thickness and Geology: As indicated above, the overburden is missing over most of the northern part of the basin. Where it is present, however, its thickness is less than10.0 m. Within the Oak Ridges Moraine in the southern part of the basin, on the other hand, the thickness of the overburden is more than 200.0 m.

The overburden within the basin consists of glacial, glaciofluvial, and glaciolacustrine sediments of Pleistocene age with alluvial and swamp deposits of Recent age. According to Barnett (1992), the glacial deposits consist of two undifferentiated tills, namely, the till of Map Unit 19 and the till of Map Unit 20. The till of Map 19 covers the central parts of the basin and forms the countless drumlins of the Peterborough Drumlin Field. The till of Map Unit 20, on the other hand, is a broad, gently undulating plain that is littered with large limestone and Precambrian boulders.

Thick ice-contact deposits are found within the Oak Ridges Moraine. They are also found within the western parts of the Otonabee River watershed and in the lower parts of the Crowe River watershed. Outwash plains are found mainly within the central parts of the Otonabee watershed, in the northwestern parts of the Crowe River watershed, and at a few locations elsewhere. The glaciolacustrine deposits form sand and clay plains within the Kawartha region, the central parts of the Otonabee watershed, and over most of the Lower Trent watershed. Alluvial, peat and muck deposits of Recent age are found in river valleys and swamps.

Overburden Aquifers: The sand and gravel deposits of glaciofluvial and glaciolacustrine origins are the main aquifers within the basin. A total of 17,982 overburden wells has been identified in the basin as compared to 26,541 bedrock wells indicating that both the bedrock and the overburden are important as sources of water supply.

Of the 17,982 overburden wells, 2,340 (13.0%) have no specific capacity data, 1,065 (5.9%) have specific capacities of less than 1.0 L/min/m, 5,724 (31.8%) have specific capacities between 1.0-5.0 L/min/m, 3,033 (16.9%) have specific capacities between 5-10 L/min/m, 4,293 (23.9%) have specific capacities between 10.0-50.0 L/min/m, and 1,527 (8.5%) have specific capacities more than 50.0 L/min/m.

The Oak Ridges Moraine Hydrogeologic System: Within the basin, the Oak Ridges Moraine acts a topographic divide and as a source of baseflow for several rivers and creeks. A small number of wells have been drilled within the central parts of the Moraine. Nevertheless, a few of these wells are deep enough to provide a relatively good insight into the geologic profile of this aquifer system.

A review of the geologic logs of wells constructed in the Moraine indicates the presence of extensive of sequences of sand and gravel between elevations of 300.0 and 360.0 m (a.s.l.). In places, these sequences contain discrete units of low permeable deposits (silt, clay, and/or till) at elevation intervals of about 250.0-260.0, 275.0-285.0, and above 300.0 m (a.s.l.) which create local aquifers. The sequences of the sand and gravel deposits together with the low permeable deposits are part of the Upland Aquifer Complex of the Oak Ridges Moraine (see Section 8.2.1.2).

The review also indicates the presence of discrete layers of sand at elevation intervals between 195.0-215.0, 225.0-235.0, and 245.0-265.0 m (a.s.l.). These deposits act as discrete aquifers and are part of the Lowland Aquifer Complex within the Oak Ridges Moraine (see Section 8.2.1.3).

The geologic logs of a few wells also show the presence of deep layers of sand at elevations between 165.0 and 185.0 m (a.s.l.) which are part of the Basal Aquifers within the Oak Ridges Moraine (see Section 8.2.1.5).

Aquifers within the Till of Map Unit 19: The Till of Map Unit 19 covers a very large area within the basin including the northern and northeastern flanks of the Moraine. A review of the geologic logs of several hundred wells constructed in the till indicates the presence of extensive layers of sand deposits at discrete elevation intervals that continue beneath the Oak Ridges Moraine. The top aquifer is within an elevation range from 245.0 to 265.0 m (a.s.l.), the second aquifer is within a range of 225.0-235.0 m (a.s.l.), the third aquifer is within a range of 195.0 to 215.0 m (a.s.l.), and the fourth aquifer is within a range of 175.0 to 185.0 m (a.s.l.). As the overburden thickness decreases toward the north and northeast, the number the aquifers below the till start also to decrease.

The Stirling Aquifer: This name is suggested for an aquifer that extends from Stirling to the eastern boundary of the Lower Trent River watershed. The aquifer consists of sands that range in thickness between 30.0 and 60.0 m along the eastern topographic divide. Their thickness in the vicinity of Stirling, however, has decreased to between 5.0 and 15.0 m due to erosion. The surface elevation of these sands is between 190 and 210 (a.s.l.) along the topographic divide and drops to between 110 and 125 m (a.s.l.) in the vicinity of Stirling. In places, the sands are covered by silt, clay, or till deposits. Where the sands are at the surface, the aquifer is unconfined. A large number of high capacity wells obtain water from the aquifer. The specific capacities of most wells are between 10.0 and more than 50.0 L/min/m.

Local Aquifers within the Kawartha Region and the Otonabee River Watershed: A local aquifer occurs along the northwestern shore of Sturgeon Lake between Bobcaygeon and Sturgeon Point. The aquifer consists of sands up to 20.0 m thick. The surface elevation of the aquifer ranges between 250.0 and 260.0 m (a.s.l.). Water in the aquifer is mostly unconfined except where it is covered by till or clay deposits. The static water levels are a few metres below the surface. A large number of wells obtain water from this aquifer. The specific capacities of many of these wells range from about 10.0 L/min/m to more than 50.0 L/min/m.

A second local aquifer occurs along the southeastern shore of Pigeon Lake. The aquifer consists of sands that are covered by till deposits toward the northeast. In many wells, the sands rest on top of the bedrock. Their top elevation is between 245.0 and 260.0 m (a.s.l.) and their thickness may reach 30.0 m. Where the sands are at the surface, the aquifer is unconfined. The specific capacities of many wells are between 10.0 L/min/m and more than 50.0 L/min/m.

A third local aquifer occurs along the southeastern shore of Chemong Lake and extends southwest. The aquifer consists of sands that range in thickness from a few metres up to 25.0 m. Toward the northeast, the sands are covered by a till. Their top elevation is between 255.0 and 265.0 m (a.s.l.). Where the sands are at the surface, the aquifer is unconfined. The specific capacities of many wells tapping the aquifer range from about 5.0 L/min/m to more than 50.0 L/min/m.

Local Aquifers within the Iroquois Plain: Several local aquifers occur within the Iroquois Plain in the Lower Trent. One aquifer is located in the southwestern part of the plain to the west of Colborne. It consists of glaciolacustrine sands that rest on top of the bedrock. The surface elevation of these sands is between 90.0 and 110.0 m (a.s.l.) and their thickness is between 5.0 and 25.0 m. Where the sands are exposed at the surface, the aquifer is unconfined. The depths to the water table are mostly a few metres below the surface. The specific capacities of the wells tapping the aquifer range between 1.0 and more than 50.0 L/min/m.

A second aquifer is located to the northeast of Colborne where glaciolacustrine sands occur at the surface. In places, the sands are covered by till deposits. The elevation of the sands is between 100.0 and 130.0 m (a.s.l.) and their thickness is between 5.0 and 65.0 m. Where the sands are exposed at the surface, the aquifer is unconfined. The depths to the water table are mostly a few metres below the surface. The specific capacities of the wells tapping the aquifer are mostly between 10.0 and more than 50.0 L/min/m.

A third aquifer occurs to the north of Trenton where glaciolacustrine sands are at the surface. The surface elevation of these sands is between 130.0 and 160.0 m (a.s.l.) and their thickness is between 5.0 and 25.0 m. The logs of several wells show the sands rest on top of the bedrock. In places, the sands are overlain by clay deposits. Where the sands are exposed at the surface, the aquifer is unconfined. The depths to the water table range from a few metres to more than 20.0 m, and the specific capacities of most wells are between 10.0 and more than 50.0 L/min/m.

A fourth aquifer occurs in the vicinity of Frankford. The aquifer consists of glaciolacustrine sands that are partially covered by clay and till deposits. The elevation of the sands is mainly between 90.0 and 100.0 m (a.s.l.) and their thickness is between 5.0 and 20.0 m. The logs of several wells show that the sands rest on top of the bedrock. Where the sands are exposed at the surface, the aquifer is unconfined. The depths to the water table are mostly a few metres below the surface, and the specific capacities of the most wells are between 10.0 and more than 50.0 L/min/m.

8.2.3 The Ganaraska Region Conservation Authority

Location: The Ganaraska Region Conservation Authority (the Authority) covers an area of about 935.0 km^2 extending from the Wilmot Creek watershed in the west to the Cobourg and Baltimore Creeks watershed in east, and from Lake Ontario in the south to the Oak Ridges Moraine and Rice Lake in the north. The Authority includes seven municipalities in whole or in part, including the City of Kawartha Lakes, the Town of Cobourg, the Municipalities of Hope and Port Hope, and Clarington, and the Townships of Alnwick Haldimand, Cavan-Millbrook-North Monaghan, and Hamilton. The three main urban centres within the Authority are Cobourg, Clarington, and Port Hope (Figure 27).

Drainage: The main streams within the Authority are the Ganaraska River and the Wilmot, Graham, Gage, Cobourg, and Baltimore Creeks. All these streams flow into Lake Ontario. In addition, a number of small streams flow into Lake Ontario or into Rice Lake.

Physiography: According to Chapman and Putnam (1984), the Authority contains parts of three physiographic regions, namely, the Oak Ridges Moraine, the South Slope, and the Iroquois Plain.

The Northern part of the Authority is occupied by the Oak Ridges Moraine. The Moraine's surface has a hilly, knob-and-basin relief. Its southern flank is covered by the Halton Till on the west, by the till of Map Unit 19 on the east, and by outwash deposits in between.

The South Slope extends from the abandoned Lake Iroquois shoreline in the south to the Oak Ridges Moraine in the north. It contains numerous drumlins that point southwest and stand about 60.0 to 100.0 m above the surrounding lowlands.

A belt about 8.0 to 12.0 km wide extends along the north shore of Lake Ontario and is part of the Iroquois Plain physiographic region. Chapman and Putnam (1984) indicated that several branches of the Ganaraska River that originated in the Oak Ridges Moraine, acted as separate creeks and carried large amounts of sand into glacial Lake Iroquois. As a result, a large delta was built in the plain. They also indicated that the Iroquois Plain contains large drumlins, some of which stood out as islands in the glacial lake. According to Chapman and Putnam (1984), the waves bouncing against the exposed ends of these drumlins cut steep shore cliffs and spread the debris to form broad offshore terraces. A few kilometers to the north of Port Hope and Cobourg the abandoned Lake Iroquois shoreline is well defined by cliffs and beach materials, but in certain areas its position must be inferred from the presence of lacustrine materials and the altitude.

<u>Bedrock Topography and Geology</u>: The bedrock within the Authority is completely covered by a mantle of Quaternary deposits. The bedrock elevation ranges from about 40.0 to 80.0 m (a.s.l.) along the shore of Lake Ontario to about 160.0 to 200.0 m (a.s.l.) in the Oak Ridges Moraine. The Authority is underlain by the Simcoe Group of Middle Ordovician age. The group includes the Gull River, Bobcaygeon, Verulam, and Lindsay Formations.

<u>Overburden Thickness and Geology</u>: The thickness of the overburden is between10.0 m and 70.0 m within the Iroquois plain, 50.0 and 90.0 m within the South Slope, and reaches more than 110.0 m within the Oak Ridges Moraine. As in other areas, the thickness of the overburden dictates the distribution of the overburden and bedrock wells and the specific importance of each type of deposits as a source of water supply.

The overburden consists of glacial, glaciofluvial, and glaciolacustrine deposits of Pleistocene age and alluvial and swamp deposits of Recent age. According to Barnett (1992), the glacial deposits consist of two tills, the Halton Till and the undifferentiated till of Map Unit 19. The Halton Till is found in the western parts of the Authority south of the Moraine. The till of Map Unit 19, on the other hand, occurs in the eastern parts of the Authority south of the Moraine and also within the Iroquois Plain.

Ice-contact deposits of sand and gravel occur within the Moraine. Also, outwash deposits of sand and gravel occur along the southern flank of the Moraine. Sand, silt, and clay deposits of glaciolacustrine origin occur within the Iroquois plain.

<u>Overburden Aquifers</u>: The sand and gravel deposits of glaciofluvial and glaciolacustrine origins are the main aquifers within the Authority. A total of 3,916 overburden wells has been identified in it as compared to 864 bedrock wells indicating that the overburden is more important as a source of water supply. Of the overburden wells, 580 (14.8%) have no specific capacity data, 375 (9.6%) have specific capacities of less than 1.0 L/min/m, 1,307 (33.4%) have specific capacities between 1.0-5.0 L/min/m, 615 (15.7%) have specific capacities between 5.0-10.0 L/min/m, 853 (21.8%) have specific capacities between 10.0-50.0 L/min/m, and 186 (4.7%) have specific capacities more than 50.0 L/min/m.

<u>The Oak Ridges Moraine Hydrogeologic System</u>: The Oak Ridges Moraine along the northern boundaries of Authority acts a topographic divide and as a source of baseflow for the Ganaraska River and the Wilmot Creek. A small number of wells have been drilled within the central parts of the Moraine and a few of these wells are deep enough to provide a full picture

of the geologic profile. Nevertheless, a few areas with high capacity wells have been selected to allow some insight into this hydrogeologic system within the Authority (see Section 8.2.1.1). The first area, which is covered mainly by ice-contact deposits, is located within Concessions 9 and 10 in Clarington Township. The records of 12 wells in this area were examined. The wells, which are between 25.0 and 105.0 m deep, penetrate successive layers of sand and gravel deposits. The geologic log of well No. 19-01058 shows about 100.0 m of sand and gravel with a few metres of what appears to be a till-like material. The wellhead elevations range between 335.0 and 358.0 m (a.s.l.). Groundwater is mainly under water table condition and is reported to have been found at elevations between 286.0 and 321.0 m (a.s.l.). The depths to the static water levels range from 22.0 to 47.0 m. Well yields are reported to range from about 35.0 to 1,725.0 L/min, and the specific capacities are mostly between 5.0 and more than 50.0 L/min/m.

The second area, which is also covered by ice-contact deposits, is within Concession 8 in Clarington Township. The records of 11 wells in this area were examined. The wells, which are between 9.0 and 42.0 m deep, penetrate successive layers of sand and gravel deposits. A few well logs, however, indicate the presence of a till-like material at depth. The wellhead elevations range between 209.0 and 255.0 m (a.s.l.). Groundwater in the aquifer is mainly under water table condition and is reported to have been found at elevations between 202.0 and 250.0 m (a.s.l.). The depths to the static water levels range from 2.0 to 21.0 m. Well yields are reported to range from about 25.0 to 180.0 L/min, and the calculated specific capacities are mostly between 10.0 and 50.0 L/min/m.

The third area is located along the southern shore of Rice Lake within Concession 8 and 9 in Hamilton Township. Most of the surface area is covered by glaciofluvial ice-contact deposits and a small portion is covered by till deposits. The records of 32 wells in this area indicate that the majority of them are between 9.0 and 55.0 m deep. The wells penetrate successive layers of sand and gravel deposits. A number of well logs, however, indicate the presence of a few metres of clay or till-like materials mainly at the surface. The wellhead elevations range between 189.0 and 232.0 m (a.s.l.). Water is reported in the aquifer at elevations between 167.0 and 221.0 m (a.s.l.). Four wells are reported as flowing and the depths to the static water levels in the remaining wells range from less than one metre to 30.0 m. Well yields range from about 15.0 to 205.0 L/min, and the specific capacities are mostly between 10.0 and 50.0 L/min/m.

<u>Local Aquifer in Areas Covered by Till Deposits</u>: As indicated above, part of the southern flank of the Moraine is covered by till. The water wells in two such areas were examined for further details.

The first area, which is covered by the Halton Till, is within Concessions 7, 8, and 9 in Clarington Township. The records of 23 wells in this area indicate that they are between 6.0 and 51.0 m deep. The wells obtain water from a confined aquifer that consists of sands and gravels that are overlain by till and/or clay deposits. The wellhead elevations range between 139.0 and 302.0 m (a.s.l.). Groundwater in the aquifer is reported to have been found at elevations between 139.0 and 281.0 m (a.s.l.). The depths to the static water levels range from 5.0 to 37.0 m. Well yields are between 20.0 and 225.0 L/min, and the specific capacities are mostly between 5.0 and 50.0 L/min/m.

The second area, which is covered by the Till of Map Unit 19, is located within Concession 8 and 9 in Hamilton Township. The records of 10 wells in this area indicate that the majority of them are between 5.0 and 50.0 m deep. The well logs indicate the presence of a till-like material on top of sands and/or gravels. The wellhead elevations range between 198.0 and 250.0 m (a.s.l.). Groundwater is confined and is reported to have been found at elevations between 141.0 and 230.0 m (a.s.l.). Three wells are reported as flowing and the depths to the static water levels in the remaining wells range from 2.0 to 17.0 m. Well yields are between 40.0 and 295.0 L/min, and the specific capacities are mostly between 5.0 and more than 50.0 L/min/m.

Local Aquifers within the Outwash Deposits: As indicated above, the outwash deposits cover parts of the southern flank of the Moraine and they appear to act as part of the Oak Ridges hydrogeologic system. Two areas, where these deposits outcrop at the surface, were examined.

The first area is within Concessions 7, 8, and 9 in the Township of Port Hope and Hope. The surface of the area is covered mainly by outwash deposits and some ice-contact deposits. The records of 24 wells in the area indicate that the majority of the wells are between 6.0 and 63.0 m deep. The well logs indicate the presence of sequences of sand and gravel deposits that are occasionally overlain by clay or till-like materials. The wellhead elevations range between 180.0 and 235.0 m (a.s.l.). Groundwater is confined or under a water table condition and is reported to have been found at elevations between 148.0 and 203.0 m (a.s.l.). The depths to the static water levels range from less than one metre to 38.0 m. Well yields are between 30.0 and 180.0 L/min, and the specific capacities are between 5.0 and more than 50.0 L/min/m.

The second area is within Concessions 7 and 8 in Hamilton Township. The surface area is covered mainly by outwash and ice-contact deposits. The records of 44 wells in this area indicate that the majority of the wells are between 10.0 and 34.0 m deep. One well, however, is 45.0 m deep and another is 63.0 m deep. The well logs indicate the presence of sequences of sand and gravel deposits extending from the surface up to 45.0 m deep. A few logs show clay or till-like materials at depth. The wellhead elevations range between 197.0 and 255.0 m (a.s.l.). Groundwater is mostly under a water table condition and is reported to have been found at elevations between 178.0 and 215.0 m (a.s.l.). The depths to the static water levels range from 3.0 to 23.0 m. Well yields are between 20 and180.0 L/min, and the calculated specific capacities are between 5.0 and more than 50.0 L/min/m.

Local Aquifers within the Iroquois Plain: As indicated above, the Iroquois Plain within the Authority is covered by glaciolacustrine sand and clay deposits and by the Till of Map Unit 19. Several areas within this plain contain water wells that have high specific capacity values.

One area is located within Concessions 1, 2, 3, 4, and 5 in Clarington Township. The records of 51 wells in this area indicate that groundwater is obtained mainly from sand and gravel deposits that range in thickness from a few metres up to 52.0 m. The wellhead elevations range between 122.0 and 185.0 m (a.s.l.) and the well depths range between 7.0 and 70.0 m. Groundwater is mostly confined and is reported to have been found at elevations between 98.0 and 180.0 m (a.s.l.). The depths to the static water levels range from 1.0 to 30.0 m. Well yields are between 5.0 and 115.0 L/min, and the specific capacities are between 1.0 and 50.0 L/min/m.

A second area is located within Concessions 2, 3, 4, and 5 in Port Hope and Hope Township. The records of 31 wells in this area indicate that groundwater is obtained from sand and gravel deposits that range in thickness from a few metres up to 10.0 m. The wellhead elevations range between 99.0 and 162.0 m (a.s.l.), and the well depths range between 6.0 and 61.0 m. Where the sand or gravel deposits are at the surface, the aquifer is unconfined. Water is reported to have been found mainly at elevations between 88.0 and 151.0 m (a.s.l.). The depths to the static water levels range from less than one metre to 37.0 m. Well yields are between 45.0 and 165.0 L/min, and the specific capacities are between 1.0 and 50.0 L/min/m.

A third area is located within Concessions 1, 2, 3, 4, and 5 in Hamilton Township. The records of 39 wells in this area indicate that groundwater is obtained from sand and gravel deposits that range in thickness from a few metres up to 20.0 m. The wellhead elevations range between 99.0

and 251.0 m (a.s.l.), and the well depths range between 3.0 and 34.0 m. Some wells, however, are much deeper. The aquifer is confined or under a water table condition, and water is reported to have been found at elevations between 67.0 and 212.0 m (a.s.l.). The depths to the static water levels range from 1.0 to 37.0 m. Well yields are between 20.0 and 135.0 L/min, and the specific capacities are between 1.0 and more than 50.0 L/min/m.

8.2.4 The Central Lake Ontario Conservation Authority

Location: The Central Lake Ontario Conservation Authority (the Authority) covers an area of 627.0 km^2 and extends from Ajax in the west to Port Darlington in the east and from Lake Ontario in the south to the Oak Ridges Moraine in the north. The Authority includes, all or in part, the Cities of Oshawa and Pickering, the Towns of Ajax and Whitby, the Municipality of Clarington, and the Townships of Scugog and Uxbridge. The Authority is a major automobile manufacturing centre in Ontario and it is also known for its agricultural production, quarry operations, woodlands, and recreational areas. The main urban centres within the Authority are Ajax, Bowmanville, Oshawa and Whitby (Figure 28).

Drainage: The Authority contains fifteen main creeks, namely, the Bennet, Black, Bowmanville, Corbett, Darlington, Farewell, Goodman, Harmony, Lynde, Oshawa, Pringle, Robinson, Soper, Tooley, and Westside Creeks. In addition, there are several minor unnamed creeks that rise within the Iroquois Plain and drain into Lake Ontario. Seven of the fifteen creeks, namely, the Black, Bowmanville, Farewell, Harmony, Lynde, Oshawa, and Soper Creeks rise on the Oak Ridges Moraine. The headwaters of the Darlington, Goodman, Pringle, and Tooley Creeks are within the South Slope, and the remaining creeks rise within the Iroquois Plain.

Physiography: The three physiographic regions within the Authority, namely, the Oak Ridges Moraine, the South Slope, and the Iroquois Plain were described by Gravenor (1957) and Chapman and Putnam (1984).

The southern flank of the Oak Ridges Moraine, which extends along the northern part of the Authority, is characterized by hilly, irregular surfaces, and marked by knolls, hummocks and closed depressions. An east-west belt of the Halton Till, which is several kilometres wide, covers the southern flank of the Moraine.

The South Slope extends over most of the central parts of the Authority. Its topography varies from regularly gentle to fairly steep slopes, yet presents a noticeable contrast to the irregular features of the Oak Ridges Moraine to the north and the flatter rolling surface of the Iroquois Plain to the south.

The Iroquois Plain forms a belt that is eight to twelve kilometres wide along the present-day shoreline of Lake Ontario. The plain is bounded on the north by an abandoned shoreline that tilts upwards to the east. Sand and gravel bars and beach terraces are well displayed at the surface along the abandoned shoreline. Large deltas were formed at the mouths of the Bowmanville, Lynde, Oshawa, and Soper Creeks as they emptied their waters into Lake Iroquois or a lower level lake, creating a belt up to 3.0 km in width to the south of the abandoned shoreline. Farther south, the Iroquois Plain is covered by silt, clay, till, and organic deposits.

Bedrock Topography and Geology: The bedrock within the Authority is completely obscured by the overburden and its elevation ranges from approximately 60.0 to 70.0 m (a.s.l.) along the Lake Ontario shoreline to more than 150.0 m (a.s.l.) in the Oak Ridges Moraine. Two bedrock valleys have been reported by Singer (1981) which appear to coincide roughly with the existing valleys of the Bowmanville and Soper Creeks.

A belt that ranges in width between 2.0 and 3.0 km is underlain by the Lindsay Formation of the Simcoe Group of Upper Ordovician age. The belt extends along the eastern boundary of the Authority and along the north shore of Lake Ontario. The rest of the Authority is underlain by the younger Blue Mountain Formation (formerly the Whitby Formation) of Middle Ordovician age (Johnson et al.1992).

Overburden Thickness and Geology: The overburden thickens from less than 6.0 m along the Lake Ontario shoreline to about 215.0 m within the Oak Ridges Moraine. It consists of glacial, glaciofluvial, and glaciolacustrine deposits of Pleistocene age with minor amounts of alluvial, beach, muck and swamp deposits of Recent age.

The glacial deposits, which are mainly in the form of a ground moraine and associated drumlins, consist of two tills, the Halton Till and the Till of Map Unit 19 (Barnett et al.1992). The Halton Till is found between the abandoned Lake Iroquois shoreline in the south and the base of the Oak Ridges Moraine to the north. Within these limits, the Halton Till is part of the South Slope. The till of Map Unit 19, on the other hand, is found in a few areas along the Lake Ontario shoreline within the Iroquois Plain. The elevation of the exposed till is equal to or lower than the elevation of the silt and clay deposits of Lake Iroquois indicating that it was flooded by water. Gravenor (1957) believes that these low lying till surfaced areas represent locations where strong currents prevented the deposition of silt and clay. A few well-formed, oval-shaped drumlins, composed of sandy till with abundant stones, are scattered within the Authority.

The glaciofluvial deposits within the Oak Ridges Moraine occur as ice-contact deposits of sand and gravel. A small area to the southwest of the Village of Enniskillen within the Bowmanville Creek watershed was identified by Gravenor (1957) as a kame. This kame area is composed of sand, gravel and minor amounts of till deposits and it was built, probably, in contact with the ice. Also, areas of fluvial sediments of sand and gravel are found immediately north of the abandoned Lake Iroquois shoreline within the Bowmanville, Harmony, and Soper Creeks watersheds. According to Gravenor (1957), these sediments represent materials deposited by streams that flowed into Lake Iroquois.

The glaciolacustrine sediments were deposited in Lake Iroquois along and to the south of its abandoned shoreline. The thickness of these deposits is generally less than 10.0 m. As indicated above, a sandy belt occurs south of the abandoned shoreline. In places, the thickness of the sand in this belt reaches 30.0 m. Further south, the offshore deposits of Lake Iroquois consist mainly of silt and clay.

Along most of the main stream valleys there are several terraces formed when the streams were flowing at higher levels. The terraces consist of a mixture of gravel, sand, silt and clay. Also, along most of the present Lake Ontario shoreline there are beaches of gravel and sand between the base of the bluffs and the lake. In several localities, sand bars have been built across bays.

Overburden Aquifers: The overburden is an important source of water for rural domestic and municipal supplies in the Authority, and the sand and gravel deposits of glaciofluvial and glaciolacustrine origins are the main aquifers. A number of aquifer systems have been identified within the Authority. To assist in the identification process, numerous well records were examined and a large number of east-west and north-south geologic cross-sections were constructed. At times, however, side by side wells showed different geologic logs or reported water being found at different depths.

A total of 5,170 overburden wells has been identified within the Authority as compared to 817 bedrock wells indicating that the overburden is more important than the bedrock as a source of water supply. Most of the overburden wells are located above the abandoned Lake Iroquois shoreline. Of the overburden wells, 1,709 (33.1%) have no specific capacity data, 374 (7.2%) have specific capacities of less than 1.0 L/min/m, 1,168 (22.6%) have specific capacities between 1.0-5.0 L/min/m, 710 (13.7%) have specific capacities between 5.0-10.0 L/min/m, 999 (19.3%) have specific capacities between 10.0-50.0 L/min/m, and 210 (4.1%) have specific capacities above 50.0 L/min/m.

The Oak Ridges Moraine Hydrogeologic System: The Oak Ridges Moraine acts as both a topographic divide and a source of baseflow for a number of major streams within the Authority. Sand and gravel deposits up to 100.0 m thick have been found in several MOE test wells constructed in the Moraine. Along the northern boundary of the Authority, where these deposits occur at the surface, groundwater is under water table condition. To the south, where these deposits are blanketed by the Halton Till, groundwater is confined.

The records of 41 high capacity wells drilled in the Moraine within the Township of Scugog were examined. The land surface where these wells are located is covered by the Halton Till. The records indicate that the wells, which are 6.0 to 81.0 m deep, penetrate medium sand and gravel deposits at elevations between 250.0 and 300.0 m (a.s.l.). These deposits are part of the Upland Aquifer Complex. The records also indicate that groundwater is confined and that the depths to static water levels are between 5.0 and 56.0 m. Well yields are between 35.0 and 255.0 L/min. The specific capacities for these wells are mostly above 10.0 L/min/m (See Section 8.2.1.2).

Local Sand and Gravel Aquifers within the South Slope: Numerous overburden wells have been constructed in the middle parts of the Authority within the South Slope. Often the geologic logs of these wells show beds of sand and/or gravel at various depths. Also often, the log of a given well shows several sand and gravel beds separated by till or clay deposits that act as confining layers. The sand and gravel deposits form local aquifers within the South Slope. The records of high capacity wells in three such aquifers were examined.

The first local aquifer is located within Concessions 7 and 8 in the Town of Whitby. The records of 32 wells tapping the aquifer indicate that the majority of them are between 4.0 and 23.0 m deep. One well, however, is 58.0 m deep and another is 78.0 m deep. Most of the wells obtain water from sand and gravel deposits that are a few metres thick and range in elevation between 175.0 and 224.0 m (a.s.l.). Groundwater is reported to be confined and the depths to the static water levels range from 1.0 to 14.0 m. Well yields are between 20.0 and 115.0 L/min, and the specific capacities are mostly between 10.0 and 50.0 L/min/m.

The second local aquifer is within Concessions 6 and 7 in the Town of Whitby. The records of 20 wells tapping the aquifer indicate that the majority of them are between 5.0 and 37.0 m deep. Three wells, however, are more than 59.0 m deep. Most of the wells obtain water from sand and gravel deposits that are a few metres thick and range in elevation between 110.0 and 172.0 m (a.s.l.). Groundwater is reported to be under confined condition. Two wells are reported as flowing, and the depths to the static water levels in the remaining wells range from about 2.0 to 12.0 m. Well yields are between 30.0 and 160.0 L/min, and the specific capacities are mostly between 10.0 and 50.0 L/min/m.

The third local aquifer is within Concessions 6 and 7 in the Municipality of Clarington. The records of 27 wells tapping the aquifer indicate that the majority of them are about 2.0 to 31.0 m deep. Three wells, however, are 42.0 to 59.0 m deep. Most of the wells obtain water from sand and gravel deposits that are a few metres thick and range in elevation between 130.0 and

180.0 m (a.s.l.). Groundwater is reported to be under confined conditions, and the depths to the static water levels range from about 1.0 to 11.0 m. Well yields are between 30.0 and 160.0 L/min, and the specific capacities are mostly between 10.0 and 50.0 L/min/m.

Local Sand and Gravel Aquifers within the Iroquois Plain: Many wells have been constructed within the Iroquois Plain. Most of these wells obtain water from local sand and gravel aquifers and are characterized by specific capacities that range between 10.0 and 50.0 L/min/m. The records of high capacity wells in nine such local aquifers were examined.

The first local aquifer is located within Concessions 7 and 8 in the Town of Whitby. The records of 32 wells tapping the aquifer indicate that the majority of them are between 4.0 and 23.0 m deep. One well, however, is 58.0 m deep and another is 78.0 m deep. Most of the wells obtain water from sand and gravel deposits that are a few metres thick and range in elevation between 175.0 and 224.0 m (a.s.l.). Groundwater is reported to be confined, and the depths to the static water levels are between 1.0 and 14.0 m. Well yields are between 20.0 and 115.0 L/min, and the specific capacities are mostly between 10.0 and 50.0 L/min/m.

The second local aquifer is within Concessions 3 and 4 in the Town of Whitby. The records of 28 wells tapping the aquifer indicate that they are about 4.0 to 23.0 m deep. Most of the wells obtain water from sand and gravel deposits that are a few metres thick and range in elevation between 108.0 and 142.0 m (a.s.l.). The depths to the static water levels range from about 2.0 to 12.0 m. Well yields are between 15.0 and 115.0 L/min, and the specific capacities are mostly between 10.0 and 50.0 L/min/m.

The third local aquifer is within Concessions 1 and 2 in the Town of Whitby. The records of 16 wells tapping the aquifer indicate that most of them are about 4.0 to 58.0 m deep. Most of the wells obtain water from sand and gravel deposits that are a few metres thick and range in elevation between 75.0 and 102.0 m (a.s.l.). Groundwater is confined. The depths to the static water levels range from about 1.0 to 23.0 m. Well yields are between 20.0 and 220.0 L/min, and the specific capacities are mostly between 10.0 and 50.0 L/min/m.

The fourth local aquifer is within Concessions 4 and 5 in the City of Oshawa. The records of 32 wells tapping this aquifer indicate that most of them are about 4.0 to 27.0 m deep. One well, however, is 41.0 m deep. Most of the wells obtain water from sand and gravel deposits that are a few metres thick and range in elevation between 127.0 and 158.0 m (a.s.l.). Groundwater is confined. The depths to the static water levels range from about 1.0 to 14.0 m. Well yields are between 5.0 and 325.0 L/min, and the specific capacities are mostly between 10.0 and 50.0 L/min/m.

The fifth local aquifer is within Concessions 2, 3, and 4 in the Municipality of Clarington. The records of 49 wells tapping the aquifer indicate that most of them are about 5.0 to 22.0 m deep. One well, however, is 40.0 m deep and another is 55.0 m deep. Most of the wells obtain water from sand and gravel deposits that are a few metres thick and range in elevation between 121.0 and 166.0 m (a.s.l.). Groundwater is confined or under water table condition. The depths to the static water levels range from about 1.0 to 7.0 m. Well yields are between 10.0 and 115.0 L/min, and the specific capacities are mostly between 10.0 and 50.0 L/min/m.

The sixth local aquifer is within Concessions 2 and 3 in the Municipality of Clarington. The records of 55 wells tapping the aquifer indicate that most of them are about 3.0 to 14.0 m deep. One well, however, is 26.0 m deep and another is 30.0 m deep. Most of the wells obtain water from sand and gravel deposits that are a few metres thick and range in elevation between 135.0 and 151.0 m (a.s.l.). Groundwater is confined or under water table condition. The depths to the static water levels range from less than one metre to 7.0 m. Well yields are between 10.0 and 180.0 L/min, and the specific capacities are mostly between 10.0 and 50.0 L/min/m.

The seventh local aquifer is within Concessions 1 in the Municipality of Clarington. The records of 19 wells tapping the aquifer indicate that most of them are about 7.0 to 28.0 m deep. Most of the wells obtain water mainly from gravel deposits that are a few metres thick and range in elevation between 75.0 and 87.0 m (a.s.l.). Groundwater is confined or under water table condition. The static water levels range from less than one metre to 9.0 m. Well yields are between 10.0 and 225.0 L/min, and the specific capacities are mostly between 10.0 and 50.0 L/min/m.

The eighth local aquifer is within Concessions 3, 4, 5, and 6 in the Municipality of Clarington. A small part of this aquifer is within the South Slope. The records of 62 wells tapping the aquifer indicate that most of them are about 4.0 to 25.0 m deep. Two wells, however, are 46.0 m deep. Most of the wells obtain water from sand and gravel deposits that are a few metres thick and range in elevation between 110.0 and 120.0 m (a.s.l.). Groundwater is confined or under water table condition. The depths to the static water levels range from about 1.0 to 18.0 m. Well yields are between 5.0 and 180.0 L/min, and the specific capacities are mostly between 10.0 and 50.0 L/min/m.

The ninth local aquifer is within Concessions 1 and 2 in the Municipality of Clarington. The aquifer is covered by glaciofluvial clay deposits. The records of 38 wells tapping this aquifer indicate that most of them are about 6.0 to 23.0 m deep. Most of the wells obtain water mainly from gravel deposits that are a few metres thick and range in elevation between 77.0 and 87.0 m (a.s.l.). Groundwater is confined. The depths to the static water levels range from about 1.0 to 9.0 m. Well yields are between 30.0 and 225.0 L/min. One well, however, is reported to yield 680.0 L/min. The specific capacities for most wells are between 10.0 and 50.0 L/min/m.

8.2.5 The Metro Toronto and Region Conservation Authority

<u>Location</u>: The Metro Toronto and Region Conservation Authority (the Authority) extends from Mississauga in the west to Ajax in the east and from Lake Ontario in the south to the Oak Ridges Moraine in the north. The Authority includes 3,467.0 square kilometres comprising six member municipalities, namely, the City of Toronto, the Regional Municipalities of Durham, Peel and York, the Township of Adjala-Tosorontio, and the Town of Mono. The Authority includes, in whole or in part, the Cities of Toronto, Mississauga, Brampton, and the Towns of Ajax, Uxbridge, Whitchurch-Stouffville, and Markham (Figure 29).

<u>Drainage</u>: The Authority contains nine main streams, including from west to east the Etobicoke Creek, the Mimico Creek, the Humber River, the Don River, the Highland Creek, the Rouge River, the Petticoat Creek, the Duffins Creek, and the Carruthers Creek. These streams trend generally in a northwest-southeast direction, and for the most part, their drainage pattern is parallel.

The Etobicoke and Mimico Creeks are at the western part of the Authority. Both creeks rise within the Halton Till Plain. Lester B. Pearson International Airport straddles the watersheds of both creeks.

The Humber River has its headwaters within the Niagara Escarpment and the Oak Ridges Moraine. It flows through forests, meadows, and agricultural areas before meandering through the City of Toronto. The Humber has an area of about 570.0 km^2 and it has several tributaries, including the West Branch which drains the Peel Plain and the East Branch which rises on the

Moraine. It is a healthy river with brook trout in its headwaters and vibrant conservation areas and wetlands along its course.

The Don River rises within the Peel Plain and the South Slope and flows through the heart of Toronto. Its watershed is about 360.0 km^2 and more than 80.0% of it is urbanized. Its waters are quite degraded.

The Highland Creek watershed, which is about 85.0% urbanized, lies between the Don and Rouge Rivers watersheds. To reduce erosion and prevent flooding, a high portion of this creek and its tributaries has been either buried underground or channelized.

The Rouge River, which is about 335.9 km^2 in size, rises at the base of the Oak Ridges Moraine and empties its water at Pickering. Its main tributaries are the Little Rouge River and the Bruce and Beaver Creeks. Urban development is small in the northern half of the watershed and begins to become more pronounced in the southern half. The watersheds of the Petticoat Creek and other small streams, which flow directly into Lake Ontario around Frenchman's Bay, are located between the watersheds of the Duffins Creek and the Rouge River.

The Duffins Creek watershed covers some 285.0 km^2. The Creek rises on the Oak Ridges Moraine which provides it with abundant baseflow. Its headwaters support brook trout and include large areas of forests and wetlands. The creek, which has a well-defined valley throughout most of its length, enters Lake Ontario through the Duffins March.

The Carruthers Creek watershed, which is about 38.0 km^2 in size, is one of the smaller watersheds within the Authority and is located along its eastern end. The headwaters of the creek are within the South Slope. The creek flows in a southerly direction and enters Lake Ontario through the Carruthers Marsh.

Physiography: Parts of five physiographic regions have been identified by Chapman and Putnam (1984) within the Authority, namely, the Niagara Escarpment, the Oak Ridges Moraine, the South Slope, the Peel Plain, and the Iroquois Plain.

A small portion of the headwater of the Humber River near Mono Mills is within the Niagara Escarpment. Also, the headwaters of several other streams are within the Oak Ridges Moraine.

A large portion of the central area of the Authority is part of the Peel Plain. The Etobicoke Creek and the Humber, Don, and Rouge Rivers have cut deep valleys across this plain.

The South Slope covers a wide area within the Authority extending from the southern flank of the Oak Ridges Moraine to the abandoned shoreline of Lake Iroquois and it is overlain mainly by the Halton Till. Within the Authority, the South Slope is faintly drumlinized and is scored at intervals by tributaries to the Rouge, Don, and Humber Rivers.

The southern part of the Authority along the shore of Lake Ontario is occupied by the Iroquois Plain. The plain is several kilometres in width within its eastern and western parts and becomes extremely narrow within in its central part along the Scarborough Bluffs.

Bedrock Topography and Geology: With the exception of two small areas within the lower part of the Etobicoke Creek watershed, the bedrock within the Authority is completely obscured by the overburden. The bedrock elevation ranges from about 60.0 m (a.s.l.) along Lake Ontario to about 200.0 m (a.s.l.) in the Oak Ridges Moraine.

The Authority is underlain by the Blue Mountain, Georgian Bay, and Queenston Formations of Upper Ordovician age. A small area extending from the north of Richmond Hill to the Oak Ridges Moraine is underlain by the rocks of the Simcoe Group of Middle Ordovician age, and another small area in the vicinity of Mono Mills is underlain by the rocks of the Clinton Group and the Amabel Formation of Middle Silurian age.

Overburden Thickness and Geology: In general, the overburden within the Authority thickens from less than 6.0 m along the Lake Ontario shoreline to about 215.0 m within the Oak Ridges Moraine. The overburden consists of glacial, glaciofluvial, and glaciolacustrine deposits of Pleistocene age with minor amounts of alluvial, beach, muck and swamp deposits of Recent age.

Karrow (1967) has identified within the geologic section of the Scarborough Bluffs the following deposits:

Deposit	Age
York Till	Illinoian
Don Formation	Sangamonian
Scarborough Formation	Early Wisconsinan
Channel sands	
Sonnybrook Till	
Lower Thorncliffe Lake Beds	Middle Wisconsinan
Seminary Till	
Middle Thorncliffe Lake Beds	
Medowcliffe Till	
Upper Thorncliffe Lake Beds	
Lower Leaside Till	
Upper Leaside Till	
Lake Iroquois Deposits	Late Wisconsinan

Sibul et al. (1977) described the overburden stratigraphy of the Duffins Creek and Rouge River watersheds. They identified the Lower Drift, the Interstadial Drift, and the Upper Drift. Their Lower Drift, which was reported in the lower part of the two watersheds and within the Oak Ridges Moraine, consists of a till that was correlated with the York Till. Their Interstadial Drift, which consists of sand, silt, and clay with lenses of tills, was correlated with the Scarborough Formation, the Sunnybrook Till, and the Thorncliffe Formation. Further, their Upper Drift, which consists mainly of a till and gravel, sand, silt, and clay, was correlated with the Halton Till and early lakes and streams.

Four tills occur at the surface within the Authority, namely, the Newmarket Till, Kettleby Till, Halton Till, and the undifferentiated Till of Map Unit 19. The Newmarket Till, which is the oldest till, is found in two small areas, one area is at the northwestern tip of the Authority and the other is to the northeast of King City. The Kettleby Till occurs within a small area to the north of King City. The Halton Till occurs over most of the surface area of the Authority extending between the abandoned shoreline of Lake Iroquois in the south and the base of the Oak Ridges Moraine in the north. Within these limits, the Halton Till constitutes a part of the South Slope physiographic region. The undifferentiated Till of Map Unit 19 is found along the Lake Ontario shoreline within the Iroquois Plain.

Ice-contact deposits of sand and gravel are found at the surface within the Oak Ridges Moraine. Also, outwash deposits of sand are found in two small areas in the extreme northwestern part of the Authority.

Sand and clay deposits of glaciolacustrine origin are found at the surface within the Peel Plain and the Iroquois Plain. These deposits were laid down in Lake Iroquois along its abandoned shoreline where sand and gravel bars and beach terraces are common.

Within the flood plains of most streams there are several terraces that were formed when the streams were flowing at higher levels. The terraces are composed of mixtures of gravel, sand, silt and clay. Also, along most of the Lake Ontario shoreline there are beaches of gravel and sand deposits.

Overburden Aquifers: A total of 14,476 overburden wells has been identified within the Authority as compared to 3,080 bedrock wells which indicates that the overburden is more important than the bedrock as a source of water supply. Most of the overburden wells are located within the upper half of the Authority outside the limits of the City of Toronto. Of the 14,476 overburden wells, 5,488 (37.9%) have no specific capacity data, 1,072 (7.4%) have specific capacities of less than 1.0 L/min/m, 3,750 (25.9%) have specific capacities between 1.0-5.0 L/min/m, 1,626 (11.2%) have specific capacities between 5.0-10.0 L/min/m, 1,771 (12.3%) have specific capacities between 10.0-50.0 L/min/m, and 769 (5.3%) have specific capacities above 50.0 L/min/m.

Sand and gravel deposits of glaciofluvial and glaciolacustrine origins are the main aquifers within the Authority. In addition, the Halton Till could act as an aquifer of limited capacity. A number of local aquifer systems have been identified within the Authority. Thirteen of these aquifers have been named by Sibul et al. (1977) and seven new aquifers have been identified and named in this report. All the aquifers were identified based on similarities in elevations and the continuity of the sand and gravel deposits.

The Oak Ridges Moraine, which forms a broad east-west belt along the northern parts of the Authority, acts as a topographic divide and as a source of baseflow for the Humber, Don and Rouge Rivers and the Duffins Creek. A detailed description of this hydrogeologic system is given in Section 8.2.1.

In addition, Sibul et al. (1977) identified and named the following thirteen aquifers within the Duffins Creek and the Humber River watersheds:

- Upper Markham Aquifer,
- Lower Markham Aquifer,
- Upper Unionville Aquifer,
- Lower Unionville Aquifer,
- Upper Victoria Aquifer,
- Lower Victoria Aquifer,
- Upper Brougham Aquifer,
- Lower Brougham Aquifer,
- Greenwood Aquifer,
- Atha Aquifer,
- Green River Aquifer,
- Pickering Aquifer, and
- Cedar Grove Aquifer.

The locations of these aquifers are shown on Maps 7 and 8 prepared by Sibul et al. (1977).

<u>The Upper and Lower Markham Aquifers</u>: These two aquifers, which are superimposed on top of each other, are located between Markham and Stouffville at average depths of 35.0 and 50.0 m. According to Sibul et al. (1977), test wells in the upper aquifer revealed very coarsely gravel which was assumed to be of a glaciofluvial origin. Also, extensive sands were found in the lower aquifer. The average thickness of continuous sand and/or gravel in each aquifer is about 10.0 m. The elevation of the top of the upper aquifer ranges from 167.0 m to 187.0 m (a.s.l.) while the top of the lower aquifer ranges from 145.0 m to 170.0 m (a.s.l.). Both aquifers are confined and are associated with some flowing wells. Individual specific well capacities in the two aquifers are variable and the probable well yields range from about 45.0 to 225.0 L/min. The transmissivity of the upper aquifer was estimated at $6.0* 10^{-4}$ m^2/sec, and the transmissivity of the lower aquifer was estimated at $4.6* 10^{-4}$ m^2/sec.

<u>The Upper and Lower Unionville Aquifers</u>: These two aquifers are roughly located under Unionville just west of Markham. They consist mainly of sand, but gravel can be found locally. The average saturated thicknesses of both aquifers are about 6.0 m. The average elevation of the top of the upper aquifer is about 167.0 m (a.s.l.), and the average top of the lower aquifer is about 145.0 m (a.s.l.). Both aquifers are confined and some wells tapping them are reported as flowing. According to Sibul et al. (1977), the probable well yields range from 115.0 to 230.0 L/min for the upper aquifer, and from 90.0 to 115.0 L/min for the lower aquifer. Some municipal wells that obtain water from the aquifers have yields ranging from 680.0 to 3,200.0 L/min. The transmissivity of the upper aquifer was estimated at 3.4 $3.1* 0^{-4}$ m^2/sec, and the transmissivity of the lower aquifer was estimated at $6.4* 10^{-4}$ m^2/sec.

<u>The Upper and Lower Victoria Aquifers</u>: These two aquifers are located to the northeast of Richmond Hill in the vicinity of Victoria Square. According to Sibul et al. (1977), the northern boundary of the upper aquifer underlies a small part of the Oak Ridges Moraine, while the lower aquifer extends farther north under the Moraine. The aquifers consist of sand with occasional gravel. The average saturated thickness of the sand is about 4.0 m in the upper aquifer and 3.0 m in the lower aquifer. The elevation of the top of the upper aquifer ranges from 194.0 to 225.0 m (a.s.l.) and the top of the lower aquifer ranges from 166.0 to 196.0 m (a.s.l.). Both aquifers are confined and some of their wells are flowing. Whereas most of the wells in the upper aquifer have potential yields of 10.0-45.0 L/min, well yields of the lower aquifer are in the range of 45.0 to 225.0 L/min. The transmissivity of the upper aquifer was estimated at $3.1* 0^{-4}$ m^2/sec, and the transmissivity of the lower aquifer was estimated at $4.3* 10^{-4}$ m^2/sec.

<u>The Upper and Lower Brougham Aquifers</u>: These two aquifers are located in the Duffins Creek watershed in the vicinity of Brougham. According to Sibul et al. (1977), the upper aquifer has an area of about 20.0 km^2, and the lower aquifer has an area of about 30.0 km^2. The two aquifers, which consist mainly of sand, are separated by about 30.0 m of silt, clay and till deposits. The thickness of the sand is about 6.0 m in the upper aquifer and about 3.0 m in the lower aquifer. Also, the elevation of the top of the upper aquifer is about 195.0 m (a.s.l.), while the top of the lower aquifer is at about 161.0 m (a.s.l.). Sibul et al. (1977) noted that both aquifers are relatively deep and are cut partially by the Duffins Creek which leads to a considerable discharge from the aquifers to the creek. The potential well yield from each aquifer is about 45.0 to 115.0 L/min. The transmissivity of the upper aquifer was estimated at $3.1* 0^{-4}$ m^2/sec, and the transmissivity of the lower aquifer was estimated at $2.2* 10^{-4}$ m^2/sec.

<u>The Greenwood Aquifer</u>: This aquifer is located in the central part of the Duffins Creek watershed and it partially underlies the Lower Brougham Aquifer. Its top elevation is at about 135.0 m (a.s.l.). The aquifer consists of about 6.0 m of sand with occasional gravel. The aquifer is confined and its static level is at or close to the ground surface. The potential well yield from

the aquifer is about 45.0 to 115.0 L/min, and its transmissivity was estimated at $2.5 * 10^{-4}$ m^2/sec.

<u>The Atha, Green River, Pickering, and Cedar Grove Aquifers</u>: Both the Atha and the Green River Aquifers are located in the central portion of the West Duffins Creek. The Pickering Aquifer is located to the north of Pickering, and the Cedar Grove Aquifer is located within the watershed of the Little Rouge Creek. Sibul et al. (1977) noted that each of these aquifers is of local importance and covers an area of less than 25 km^2.

Geologic cross-sections and water well records were used to identify and name several local aquifers within the western part of the Authority. The locations of these aquifers are given in terms of watershed and municipality.

<u>The Upper and Lower Chinguacousy Aquifers</u>: These names are suggested for two confined aquifers that are located in the Humber River watershed. The area where these aquifers occur is covered mostly by the Halton Till. A few small areas, however, are covered by glaciofluvial and glaciolacustrine deposits.

The upper aquifer is within the Municipality of the Town of Caledon. The records of 20 wells that obtain water from the aquifer indicate that it consists of sand and gravel deposits whose thickness is between 1.0 and 30.0 m. The wellhead elevations range from 248.0 to 296.0 m (a.s.l.), and the top elevation of the aquifer is between 245.0 and 287.0 m (a.s.l.). The depths to the static water levels range from flowing to 28.0 m. The well yields range from about 20.0 to 365.0 L/min, and the specific capacities of the wells are between 5.0 and more than 50.0 L/min/m.

The lower aquifer is located within the Municipalities of Brampton City and the Town of Caledon. The records of 55 tapping the aquifer indicate that it consists of sand and gravel deposits whose thickness ranges from a few metres up to 17.0 m. The wellhead elevations range from 221.0 to 276.0 m (a.s.l.), and the top elevation of the aquifer is between 192.0 and 251.0 m (a.s.l.). The depths to the static water levels range from less than one metre to 27 m. The records also indicate that the well yields range from about 5.0 to 135.0 L/min. Fourteen wells, however, yield between 680.0 and 5,000.0 L/min, and the specific capacities are between 5.0 and more than 50.0 L/min/m.

<u>The Etobicoke Aquifer</u>: This name is suggested for a confined aquifer that is located within the headwaters of the Etobicoke Creek watershed within the Municipality of the Town of Caledon. The area where the aquifer occurs is covered by the Halton Till.

The records of 23 wells tapping the aquifer indicate that it consists of sand and gravel deposits that range in thickness from a few metres up to 12.0 m. Its top elevation ranges from 245.0 to 265.0 m (a.s.l.). The wellhead elevations range from 259.0 to 282.0 m (a.s.l.), and the depths to the static water levels range from less than 1.0 to 15.0 m. The well yields range from about 5.0 to 275.0 L/min, and the specific capacities for the wells range from about one to 50.0.

<u>The Kleinburg Aquifer</u>: This name is suggested for a local confined aquifer which is located in the vicinity of Kleinburg. The records of 27 wells tapping the aquifer indicate that it consists of sand and gravel deposits that range in thickness from a few metres up to 22.0 m. The wellhead elevations range from 158.0 to 238.0 m (a.s.l.), and the top elevation of the aquifer is between 145.0 and 205.0 m (a.s.l.). The depths to the static water levels range from flowing to about 40.0 m. Well yields range from about 20.0 to 200.0 L/min. Six wells, however, yield between 275.0 and 2,275.0 L/min. The specific capacities of the wells are between 5.0 and 50.0 L/min/m.

The Maple Aquifer: This name is suggested for a confined aquifer that is located in the northern part of the Don River watershed in the Municipalities of Vaughan and Richmond Hill. The aquifer area is covered with the Halton Till and with sand and gravel deposits of ice-contact origin.

The records of 59 wells tapping the aquifer indicate that it consists of sand and gravel deposits that range in thickness from a few metres up to 67.0 m. The wellhead elevations range from 231.0 to 290.0 m (a.s.l.), and the top elevation of the aquifer is between 219.0 and 268.0 m (a.s.l.). The depths to the static water levels range from less than one metre to about 39.0 m. Well yields range from about 15.0 to 275.0 L/min. Twelve wells, however, yield between 375.0 and 2,900.0 L/min. The specific capacities of the wells are between 5.0 and more than 50.0 L/min/m.

The Thornhill Aquifer: This name is suggested for a confined aquifer that is located in the central part of the Don River watershed, in the Municipalities of Markham, Richmond Hill, and Vaughan. The aquifer area is covered with the Halton Till and with some glaciolacustrine clay.

The records of 96 wells tapping the aquifer indicate that it consists of sand and gravel deposits that range in thickness from a few metres up to 40.0 m. The wellhead elevations range from 162.0 to 204.0 m (a.s.l.), and the top elevation of the aquifer is between 139.0 and 178.0 m (a.s.l.). Two wells are reported as flowing. The depths to the static water levels in the remaining wells range from less than one metre to about 28.0 m. Well yields range from about 10.0 to 275.0 L/min. One well, however, yields 3,250.0 L/min. The specific capacities of the wells are between 5.0 and more than 50.0 L/min/m.

The Vellore Aquifer: This name is suggested for a confined aquifer that is located in the Humber River watershed within the Municipality of Vaughan. The area where the aquifer occurs is covered by the Halton Till and some glaciolacustrine clay.

The records of 31 wells tapping the aquifer indicate that it consists mainly of sand and gravel deposits that range in thickness between 5.0 and 29.0 m. The wellhead elevations range from 208.0 to 245.0 m (a.s.l.), and the top elevation of the aquifer is between 200.0 and 237.0 m (a.s.l.). The depths to the static water levels in the range from about 1.0 to 25.0 m. Well yields range from about 15.0 to 225.0 L/min. Five wells, however, yield between 325.0 and 545.0 L/min, and the specific capacities of the wells are between 5.0 and more than 50.0 L/min/m.

The Woodbridge Aquifer: This name is suggested for a confined aquifer that is located in the Humber River watershed within the Municipality of Vaughan in the vicinity of Woodbridge. The area where the aquifer occurs is covered by glaciolacustrine clay deposits.

The records of 58 wells tapping the aquifer indicate that it consists of sand and gravel deposits that range in thickness from a few metres up to 21.0 m. The wellhead elevations range from 158.0 to 185.0 m (a.s.l.), and the elevation of the top of the aquifer is between 127.0 and 158.0 m (a.s.l.). The depths to the static water levels range from about 2.0 to 30.0 m. The records also indicate that the well yields range from about 25.0 to 225.0 L/min. Six wells, however, yield between 615.0 and 3,200.0 L/min. The specific capacities of most wells are between 10.0 and more than 50.0 L/min/m.

8.2.6 The Credit Valley Conservation Authority

Location: The Credit Valley Conservation Authority (the Authority) is located in the central part of southern Ontario on the north side of Lake Ontario. It has an area of about 795.0 km^2, a total length of about 90.0 km, and a width that varies between 9.0 and 23.0 km. Land surface elevations vary from 75.0 m (a.s.l.) at Lake Ontario to about 525.0 m (a.s.l.) in the extreme upper parts of the Authority. Most of the Authority is located in Peel County but small parts of Dufferin, Halton and Wellington Counties are also included. The City of Mississauga occupies the lower part of the Authority. Other urban centres include Acton, Caledon, Erin, Georgetown, Hillsburgh, Orangeville, and Port Credit (Figure 30).

Drainage: The Authority includes the Credit River watershed and a number of small watercourses that flow into Lake Ontario. The Credit River rises within a hilly plateau of moraines, gravel terraces, and swamps above the Niagara Escarpment at elevations between 415.0 and 480.0 m (a.s.l.), and it empties into Lake Ontario at Port Credit. The river consists of two main branches, the Credit River in the Orangeville-Alton-Cataract area and the West Credit River in the Hillsburgh-Erin-Belfountain area. The Credit River leaves the Escarpment through a deep notch at Cataract while the West Credit descends through a similar notch at Belfountain and joins the Credit River at Credit Forks. Downstream from Credit Forks, the Credit River has built a wide alluvial plain and is joined by the East Credit River at Inglewood. From Inglewood, the river flows for about 16.0 km to the vicinity of Glen Williams in a narrow valley. At Glen Williams, the river swings in a southeasterly direction and follows the slope of a till plain toward Lake Ontario.

Physiography: According to Chapman and Putnam (1984), parts of eight physiographic regions are found within the Authority, including the Iroquois Plain, the South Slope, the Peel Plain, the Niagara Escarpment, the Oak Ridges Moraine, the Horseshoe Moraines, the Guelph Drumlin Field, and the Hillsburgh Sandhills.

The Iroquois Plain is a belt that varies in width from 3.0 to 5.0 km and extends from Lake Ontario to the abandoned Lake Iroquois shoreline. For the most part, the plain is covered with a thin sheet of sand and silty sand which is less than one metre in thickness. Sand and gravel bars and beach terraces, 3.0 to 6.0 m high, are well displayed at the surface along the abandoned shoreline.

The South Slope consists of a northern part, which drapes the base of the Niagara Escarpment and extends south to Highway 7, and a southern part which extends from Highway 7 to the abandoned Lake Iroquois shoreline. Part of the Palgrave and the Cheltenham Moraines are included in the northern part, while the Trafalgar Moraine is included in the southern part.

The Peel Plain is a level to undulating tracts of clay soils that cover the central portions of Halton, Peel, and York Counties. Within the Authority, the underlying geological material of the plain is till which has been modified by a thin veneer of clay and silt.

The vertical cliffs along the brow of the Niagara Escarpment outline the dolostones of the Cataract Group and Amabel Formation while the slopes below are carved in the red shale of the Queenston Formation. The Escarpment enters the Authority at a point to the southeast of Acton where the elevation is approximately 340.0 m (a.s.l.). It stands out boldly until it reaches Credit Forks. From that point northward, the Escarpment is almost completely hidden by morainic deposits.

The extreme western end of the Oak Ridges Moraine is located within the Authority, extending from Credit Forks in a northeasterly direction toward the topographic divide. The Moraine forms the Caledon and Albion Hills and is characterized by a hilly topography with a knob-and-basin relief and surface elevations ranging from 300.0 to 350.0 m (a.s.l.).

A belt of moraines, composed mainly of till deposits, extends from Acton in the south, flanks Caledon from the east, and continues to Orangeville in the north. The belt includes Galt, Paris and Singhampton Moraines and is part of a larger physiographic region known as the Horseshoe Moraines. From Singhampton to Caledon, the moraines lie along the brow and slopes of the Escarpment.

Chapman and Putnam (1984) considered the area extending from Paris Moraine to the east, the Singhampton Moraine to the north, and the Orangeville Moraine to the west as part of the Guelph Drumlin Field physiographic region. The field consists of low rolling, streamlined drumlins that are separated from each other by numerous interconnecting meltwater channels.

The Orangeville Moraine lies to the west of a line extending from Hillsburgh in the south to Orangeville in the north. Chapman and Putnam (1984) identified this moraine as part of the Hillsburgh Sandhills physiographic region. The moraine forms a nearly flat-topped positive feature, which has been strongly dissected by fluvial erosion.

<u>Bedrock Topography and Geology</u>: The bedrock topography is similar to the present-day topography. Highest bedrock elevations between 440.0 and 460.0 m (a.s.l.) are found along the topographic divide in the Townships of Erin, Garafraxa, and Amaranth. From these highs, the bedrock surface forms a plateau, which slopes toward the well-defined Escarpment. Local bedrock topographic divides seem to coincide with present-day divides and three bedrock valleys appear to have been well established. One valley extends from Orangeville down the current Credit River Valley to the Escarpment, the second extends along the current Shaw's Creek Valley, and the third extends from Erin to Belfountain.

Below the Escarpment, the bedrock surface slopes gently toward Lake Ontario. From Credit Fork to Cheltenham, a bedrock valley appears to be slightly to the north and east of the present-day Credit River Valley. From Cheltenham to Port Credit, however, the bedrock valley appears to follow closely the present-day Credit River Valley.

The oldest Paleozoic rocks within the Authority are those of the Georgian Bay and Queenston Formations of Upper Ordovician age. The Queenston Formation is covered by the Cataract Group of Lower Silurian age. Overlying the Cataract Group is the Clinton Group of Middle Silurian age. This group, in turn, is covered by the Amabel and Guelph Formations of Middle Silurian age (Johnson et al. 1992).

<u>Overburden Thickness and Geology</u>: At the base of the Escarpment and in the lower parts of the Authority, the overburden thickness is less than one metre. Most of the area below the Escarpment, however, has an overburden thickness ranging from 10.0 to 20.0 m and can reach 50.0 m in some places. Above the Escarpment, the thickness of the overburden within Orangeville, Oak Ridges, and the lower part of Paris Moraines ranges from 40.0 to 50.0 m. The thickness of the overburden within the Singhampton Moraine is between 10.0 and 30.0 m and reaches 50.0 m in a small area. The thickness of the overburden in the areas between the moraines ranges from 20.0 to 30.0 m. At a few places, where the bedrock is close to the surface, the thickness of the overburden is limited and ranges from less than one metre to a few metres.

The Quaternary deposits consist of glacial, glaciofluvial, and glaciolacustrine deposits of Pleistocene age and fluvial and organic deposits of Recent age. The glacial deposits consist of five tills, namely, the Newmarket Till, Wentworth Till, Port Stanley Till, Tavistock Till and Halton Till (Cowan and Sharpe 1973, Cowan 1976). The first three tills are sandy silt tills, whereas the other two tills are silt to clay silt tills.

Within the Authority, the Newmarket Till is found largely within the Singhampton Moraine in Mono and Caledon Townships. The Wentworth Till forms a belt of hummocky topography extending from Acton in the southwest to the headwaters of the Caledon Creek in the northeast, and consists largely of the Paris and Galt moraines. A few drumlins are associated with the till and are located on the eastern flank of the Paris Moraine in the Town of Caledon.

The Port Stanley Till occupies a broad track of rolling ground known as the Guelph Drumlin Field east of the Orangeville Moraine in the Townships of Erin and Caledon. The Tavistock Till occurs in the Townships of East Garafraxa and Amaranth where it overlies the western part of the Orangeville Moraine. The Halton Till occurs over a large area within the Authority. The till is present as a thin strip along the edge and over the lower slopes of the Escarpment. It forms the Palgrave Moraine at the extreme northwestern corner of the Authority and the Trafalgar Moraine in its lower end. The till also forms a gently rolling till plain extending from the lower slopes of the Escarpment to the abandoned Lake Iroquois shoreline.

Most of the ice-contact deposits of glaciofluvial origin within the Authority are associated with the Orangeville and Oak Ridges Moraines. The Orangeville Moraine is located in the extreme northwestern part of the Authority and extends from the Township of Mono in the northeast to Hillsburgh in the Township of Erin in the southwest. According to Chapman and Putnam (1984), this moraine is one of the first landforms to appear in southern Ontario when the Georgian Bay and Lake Ontario lobes separated. The Orangeville Moraine consists mainly of stratified sand, silt, and gravel. The bulk of the moraine exceeds 50.0 m in thickness. Similar deposits also occur in the northeastern parts of the Authority, where deep beds of fine sand extend from the Palgrave Moraine to the Paris Moraine. These deposits constitute the extreme western tip of the Oak Ridges Moraine and their thickness ranges from 40.0 to 50.0 m. In addition, Meltwater channel deposits of gravel and sand were laid down in old glacial meltwater channels.

The glaciolacustrine deposits were laid down in Lakes Peel and Iroquois. The deposits of Lake Peel occur to the north of the Trafalgar Moraine. They were laid down in a brief stand of water referred to as the Lake Peel Ponding. The thickness of the deposits is less than a metre and they consist of clay, silt and fine sand on top of the Halton Till. The Lake Iroquois sediments were deposited along and to the south of the abandoned shoreline. For the most part, these deposits consist of sand and silty sand less than a metre thick.

Along most of the flood plain of the Credit River, there are terraces formed when the river was flowing at higher levels. These terraces are composed of a mixture of gravel, sand, silt and clay. Also, tracts of poorly drained land containing organic materials occur in the meltwater channels and shallow depressions. Most of the material consists of black muck, though peat occurs in many places.

Overburden Aquifers: The total number of water wells within the Authority is 6,012. Of these, 3,750 (62.4%) are bedrock wells, 1,652 (27.5%) are overburden wells, and the remaining wells are of unknown type. Most of the wells are used to provide rural domestic water supplies and livestock watering. The City of Mississauga obtains its water supply from Lake Ontario. In the rest of the Authority, groundwater is used to meet all the municipal water needs. The towns of Acton, Caledon, Erin, Georgetown, Hillsburgh, and Orangeville are totally dependant on groundwater supplies.

Data related to short-term pumping tests are available for 890 overburden wells. The data indicate that 274 wells (30.8%) have specific capacities ranging from 1.0 to 5.0 L/min/m, 348 wells (39.1%) have specific capacities between 5.0 and 25.0 L/min/m, 90 wells (10.1%) have specific capacities between 25.0 and 50.0 L/min/m, and the remaining 178 wells (20.0%) have specific capacities larger than 50.0 L/min/m.

Several sand and gravel aquifers have been identified within the Authority. In addition, several tills have been identified by Singer et al. (1994) as capable of acting as aquifers. Till analyses conducted on the Port Stanley, Newmarket, and Wentworth Tills in the Orangeville area (Cowan, 1976) indicate that the three tills contain a high percentage of sand and silt. Because of this similarity in composition, these tills can be viewed, from a hydrogeologic point of view, as one hydrogeologic unit that constitute an important aquifer within the Authority. Data are available on short-term pumping tests for 102 wells constructed in the tills. The specific capacity data for these wells range from 0.3 to 200.0 L/min/m. In addition, the Halton Till within the Authority is capable of providing limited water supplies to meet domestic needs. The specific capacity data for 216 wells constructed in this till range from 0.3 to 60.0 L/min/m. From a hydrogeologic point of view, however, the Halton Till is mostly an aquitard.

<u>The Orangeville Aquifer Complex</u>: This aquifer complex, which consists mainly of gravel and sand and some silt, extends along the northwestern boundary of the Authority. According to Cowan (1976), the gravel is glaciofluvial in origin and constitutes a lower unit of the Orangeville Moraine; the sand and silt, on the other hand, are glaciolacustrine in origin and constitute an upper unit of the moraine. Local variability and internal collapse structures led to the mapping of these materials as ice-contact stratified drift. About 89 overburden wells have been constructed in this moraine. The well logs show sand and gravel deposits that range in thickness from a few metres up to 55.0 m. In places, these deposits are overlain by clay and silt deposits. The specific capacities of the wells are between 1.0 and more than 50.0 L/min/m. The available information, however, is not adequate to describe this aquifer complex in more detail.

<u>Meltwater Channel Hydrogeologic Unit</u>: Five meltwater channels that act as aquifers have been identified within the Authority. One channel is known as the Hillsburgh Channel (Cowan 1976) and it extends from the south of Caledon Lakes to Hillsburgh along the southern limb of the Orangeville Moraine. The martial within this channel consist of outwash gravel and may exceed 7.0 m in thickness.

A second channel was formed when the northeasterly limb of the Orangeville Moraine was breached to initiate drainage via the Credit River from Orangeville to Alton. Further ice retreat extended the Credit River channel to Cataract. The deposits vary from sand and silty gravel to clean uniform stratified gravel with a thickness ranging from less than 8.0 m to more than15.0 m. The deposits are contiguous with the Caledon outwash deposits at Cataract.

A third channel is called the Caledon Meltwater Channel (White 1975). Within the Authority, this channel traverses the rim of the Escarpment past Caledon and Cataract to Erin. The channel forms a broad valley which has a flat floor and is underlain by gravel and well-sorted fine to medium sand. According to White (1976), these deposits were laid down as the Lake Ontario lobe stood at the Paris Moraine.

A fourth channel system occurs along the Black River and the Silver Creek and extends to Georgetown. A fifth channel, known as the Caledon East Meltwater Channel (White 1976), extends from the settlement of Albion outside the Authority to Inglewood. Below Inglewood, the channel disappears possibly beneath the present East Credit River until Terra Cotta where it appears again and continues to Glen Williams. The channel floor is relatively flat and is underlain by fine to medium sand.

Wells constructed in this hydrogeologic unit indicate the presence of gravel, coarse, medium and fine sand, and some silt and clay. The variable thickness and composition of these deposits result in highly variable well yields. Nevertheless, this hydrogeologic unit constitutes one of the best overburden aquifers in the Authority and can serve as an important source for domestic and municipal water supplies. The specific capacity data for 134 wells in this unit range from 0.1 to 2,993.0 L/min/m.

One pumping test conducted on Test Well No. 5, which is drilled in a meltwater channel in the Village of Inglewood, indicates a transmissivity value of approximately 45.0 m^2/day. Another test conducted on Alton Municipal Well No.3, which is drilled in a different meltwater channel, indicates a transmissivity of 2,382.0 m^2/day and a storage coefficient of 0.001.

Lake Peel Deltaic Aquifer: This aquifer is located in the lower part of the Authority extending from Highway 7 to Chruchville. The aquifer consists of fine sand and silt deposits that were laid down at an early stage of Lake Peel. Due to its composition and limited areal extent, it is a minor aquifer. The specific capacity data for 73 wells constructed in the aquifer range from 0.6 to 100.0 L/min/m (Singer et al. 1994).

4.2.7 The Halton Region Conservation Authority

Location: The Halton Region Conservation Authority (the Authority) is located in the central part of southern Ontario. It is bounded on the north and northeast by the Credit Valley Conservation Authority, on the west by the Grand River Conservation Authority, on the southwest by the Halton Region Conservation Authority, and on the southeast by Lake Ontario (Figure 31).

A large portion of the Authority is within the Regional Municipality of Halton. It also includes parts of Wellington and Wentworth Counties. The main urban centres are Burlington, Milton, and Oakville.

Drainage: The two main streams within the Authority are the Sixteen Mile and Bronte Creeks. The Sixteen Mile Creek and its two main tributaries, the East and Middle Sixteen Mile Creeks, rise within the bedrock plain above the Niagara Escarpment. The creek descends the Escarpment at Campbellville and then meanders through a shallow overburden plain. Its two main tributaries also descend the Escarpment through narrow bedrock cuts before they merge together south of Hornby. The combined creeks then join the main Sixteen Mile Creek in a deep valley west of Glenorchy. The Sixteen Mile Creek then flows in a southeasterly direction and enters Lake Ontario at the Town of Oakville.

The Bronte Creek also rises above the Escarpment and it descends through it via a bedrock cut at the Kilbride/Lowville area. Below the Escarpment, the creek meanders in a narrow, steep-sided valley before it empties into Lake Ontario to the southeast of Bronte. A few smaller streams, such as Joshua, Morrison and McCarney Creeks, drain the intervening areas and empty into Lake Ontario. These streams have their headwaters in the Trafalgar Moraine and drain a portion of the till plain below the Escarpment.

Physiography: Chapman and Putnam (1984) identified parts of four physiographic regions within the Authority, namely, the Niagara Escarpment, the South Slope, the Peel Plain, and the Iroquois Plain.

Within the Authority, the Niagara Escarpment is characterized by a sharp topographic break formed by cliffs of erosion-resistant Silurian dolostones overlying softer Ordovician shales. The Escarpment is veneered by hummocky accumulations of a ground moraine and outwash deposits.

The South Slope is divided by the Peel Plain into a northern portion draping the base of the Escarpment and a southern portion comprising the Trafalgar Moraine and adjacent till plain. The northern portion is an area of a ground moraine and outwash deposits. The Trafalgar Moraine is a low ridge about 5.0 to 8.0 m high formed during the retreat of the Lake Ontario ice lobe.

The Peel Plain is an area of low relief. Topographic irregularities have been obscured by a blanket of glaciolacustrine sediments that were deposited in a shallow, short lived glacial lake known as the "Peel Ponding".

A prominent shore bluff, 3.0 to 6.0 m high, marks the northern boundary of the Iroquois Plain at about the 114-metre topographic contour level. The extent of the plain is relatively uniform, with the abandoned Lake Iroquois shoreline running parallel to the Lake Ontario shoreline approximately 3.0 km inland from the lake.

Bedrock Topography and Geology: Parts of the bedrock are exposed at the surface, some are above the Escarpment and others are at or near the Lake Ontario shoreline. The bedrock elevation ranges from 80.0 m along the shore of Lake Ontario to about 350.0 m above the Escarpment. A bedrock valley cuts through the Niagara Escarpment and extends from Campbellville eastward toward the Kelso Reservoir along the present-day course of the Sixteen Mile Creek. The valley extends also southward through the Nassageweya Valley. A second bedrock valley extends from Carlisle through the Kilbride and Lowville areas and further southeastward along the present-day course of the Bronte Creek. A third bedrock valley extends along the present-day course of Grindstone Creek.

According to Johnson et al. (1992), the oldest bedrock units within the Authority are the Georgian Bay and Queenston Formations of Upper Ordovician age. Overlying the Ordovician rocks are the rocks of the Cataract Group and the Amabel, Lockport and Guelph Formations of Lower and Middle Silurian age.

Overburden Thickness and Geology: Over most of the Authority, the thickness of the overburden is between 10.0 and 30.0 m. According to Barnett (1992), the overburden consists of glacial, glaciofluvial, and glaciolacustrine deposits of Pleistocene age and fluvial and beach deposits of Recent age.

Two tills, namely, the Wentworth and Halton Tills occur within the Authority. The Wentworth Till is found over most of the northwestern area above the Escarpment as a ground moraine. The Halton Till, on the other hand, is found as a ground moraine over most of the area below the Escarpment.

Ice-contact and outwash deposits of sand and gravel are displayed at the surface in a few locations above and below the Escarpment. Some of these deposits are associated with the bedrock valleys that cut through the Escarpment in the Kilbride/Lowville and Campbellville areas.

Sand deposits of glaciolacustrine origin are found mainly within the southwestern part of the Authority. Similar deposits are also found in a few locations within the Iroquois Plain. Clay deposits of glaciolacustrine origin are found mainly to the south and east of Milton.

Overburden Aquifers: A total of 1,707 overburden wells has been identified within the Authority as compared to 6,941 bedrock wells which indicates that the overburden is not the significant source of water supply. This is specifically true above the Escarpment and in the eastern and southeastern parts of the Authority below the Escarpment.

Of the 1,707 overburden wells, 595 (34.8%) have no specific capacity data, 64 (3.7%) have specific capacity of less than 1.0 L/min/m, 215 (12.6%) have specific capacity between 1.0-5.0 L/min/m, 191(11.2%) have specific capacity between 5.0 -10.0 L/min/m, 450 (26.4%) have specific capacity between 10.0-50.0 L/min/m, and 192 (11.3%) have specific capacity above 50.0 L/min/m.

Aquifers Associated with Bedrock Valleys: Various amounts of sand and gravel occur in bedrock valleys that have been carved by meltwaters in the Kilbride/Lowville and Campbellville areas. These deposits are confined within the bedrock valleys which have limited widths and meandering profiles. They range from 1.5 to 6.0 m in thickness, and represent important overburden aquifers within the Authority (Holysh 1995).

The East and Middle Sixteen Mile Aquifer: Funk (1979) mapped large areas of outwash sand and gravel extending along the base of the Escarpment from Georgetown and Scotch Block area in the northwest to the lower parts of the East Sixteen Mile Creek as one major aquifer in this part of Ontario. The boundaries of the aquifer are presented in Map 4 (Funk 1979). Both Georgetown and Milton obtain their water supplies from thick sections of this aquifer. The groundwater in the aquifer is unconfined where the sand and gravel deposits are exposed near the base of the Escarpment, and it is confined to the east where the outwash materials pinch out under the till materials.

The results of five pumping tests are given by Funk (1979) for overburden wells within the Authority. The Hornby Well No. 1103 taps an aquifer about 10.0 m thick. It has a permeability of 45.5 m/day and a storage coefficient of 0.001. The Kelso Well TW 3/63 obtains water from two layers (aquifers) of sand. The first is 20.0 m thick and has a permeability of 225.0 m/day and a storage coefficient of 0.01, and the second is 20.0 m thick and has a permeability of 265.0 m/day and a storage coefficient of 0.001. The Campbellville Well taps an aquifer about 20.0 to 30.0 m thick. It has a permeability of 4.5 m/day and a storage coefficient of 0.0001. The Georgetown Well PW 4 taps an aquifer about 20.0 m thick. It has a transmissivity between 1,300.0 and 2,200.0 m^2/day and a storage coefficient of 0.00001. The Georgetown Well PW 5 taps an aquifer about 16.0 m thick. It has a transmissivity of 7,500.0 m^2/day and a storage coefficient of 10^{-6}.

8.2.8 The Hamilton Region Conservation Authority

Location: The Hamilton Region Conservation Authority (the Authority) is located at the western tip of Lake Ontario. Most of the Authority is within the City of Hamilton Municipality in Wentworth County. The main urban centre is the City of Hamilton which is famous for its port, manufacturing industries, and touristic attractions. Other important communities are Ancaster, Dundas, and Stoney Creek (Figure32).

Drainage: The main streams within the Authority are the Spencer, Red Hill, and Stoney Creeks. Several other small streams and the lower part of the Grindstone Creek are also within the Authority. With the exception of the Stoney Creek which drains directly into Lake Ontario, all the other streams drain into the Hamilton Harbour.

The Spencer Creek is the largest stream within the Authority. The creek rises in the vicinity of Valens where it drains the back slope of the Galt Moraine. It flows in a southeasterly direction through the Beverly Swamp and then crosses a bedrock plain to Websters Falls. From there, it spills over the Niagara Escarpment through a steep-walled gorge at the top of the preglacial Dundas Valley. The creek drops rapidly to Dundas and proceeds eastward to enter the Hamilton

Harbour at University Gardens. The main tributary to the Spencer Creek is the Coldwater Creek which joins it at McMaster University.

The Red Hill Creek originates above the Escarpment to the south of the Mount Albion Conservation Area. The creek flows north and descends the Escarpment at Albion Falls through a preglacial valley. It continues its course north and enters the Hamilton Harbour through the Windermere Basin.

The Stoney Creek originates above the Escarpment and travels westward to the Devils Punch Bowl Conservation Area. From there it turns northward, descends the Escarpment, and flows toward Lake Ontario.

Physiography: The main landforms within the Authority include an end moraine, an outwash sand plain, a preglacial lake plain, till plains, bedrock valleys, and swamps. According to Chapman and Putnam (1984), parts of the five physiographic regions are found within the Authority, namely, the Iroquois Plain, the Niagara Escarpment, the Norfolk Sand Plain, the Haldimand Clay Plain, and the Horseshoe Moraines.

The Iroquois Plain extends between Lake Ontario and the Niagara Escarpment encircling the Hamilton Harbour. The Niagara Escarpment runs through the Authority encircling Lake Ontario and the Hamilton Harbour. The Dundas Valley, which extends inland about 12.0 km from the west end of Lake Ontario, constitutes a notable break in the Escarpment. Chapman and Putnam (1984) extended the Norfolk Sand Plain northward to the Hamilton area and included the outwash plain above the Escarpment within this physiographic region. The Haldimand Clay Plain is found within the southeastern part of the Authority. Also, the headwaters of the Spencer Creek drain the southern slope of the Galt Moraine which is part of the Horshoe Moraines physiographic region.

Bedrock Topography and Geology: The bedrock is exposed at the surface along and above the Escarpment and within the Iroquois Plain. Its elevation ranges from about 80.0 m (a.s.l.) along the shore of Lake Ontario to about 275.0 m (a.s.l.) above the Escarpment. The exception is the Dundas Valley where the bedrock is believed to be 180.0 m below the level of Lake Ontario (Karrow 1987). The Dundas Valley is a major preglacial bedrock valley. An extension of the valley has been traced into the Brantford area where it was found to connect with the valley of the Grand River (Karrow 1987). Another large preglacial valley is now occupied by the Red Hill Creek.

According to Johnson et al. (1992), the oldest rocks exposed within the Authority are the shales of the Queenston Formation of Upper Ordovician age. These rocks, in turn, are overlain by the rocks of the Clinton Group and the Amabel, Lockport, and Guelph Formations of Middle Silurian age.

Overburden Thickness and Geology: The thickness of the overburden ranges from zero, in areas where the bedrock is at the surface, to more than 180.0 m in the Dundas Valley. Over most of the Authority, however, the thickness of the overburden is between 10.0 and 30.0 m. The overburden consists of glacial, glaciofluvial, and glaciolacustrine deposits of Pleistocene age and fluvial and organic deposits of Recent age (Barnett 1992).

The glacial deposits consist of two tills, namely, the Wentworth Till and the Halton Till. The Wentworth Till occurs in the northwestern parts of the Authority. The Halton Till, on the other hand, occurs as a sheet of till resting on the bedrock between the Escarpment and the abandoned Lake Iroquois shoreline.

One small area above the Escarpment to the south of the Dundas Valley is covered by ice-contact sand and gravel deposits and two small areas in the northwestern part of the Authority are covered by outwash sand deposits.

Large areas surrounding the Hamilton Harbour within the Iroquois Plain, and also surrounding the Dundas Valley above the Escarpment consist of sand deposits of glaciolacustrine origin. Also, a large plain in the southeastern part of the Authority and a few smaller areas within the Iroquois Plain and along the western boundary of the Authority are covered by clay deposits of glaciolacustrine origin.

Alluvial deposits are found along most stream courses. The most important of these deposits is the Dundas gravel fan at the mouth of the gorge which was cut into the Escarpment by the Spencer Creek. Organic marl, muck, and peat deposits are found mainly within the Beverly Swamp.

<u>Overburden Aquifers</u>: There are 4,423 bedrock wells within the Authority and 677 overburden wells indicating that the overburden is of minor importance as a source of water supply. Of the 677 overburden wells, 363 (53.6%) have no specific capacity data, 32 (4.7%) have specific capacities of less than 1.0 L/min/m, 63 (9.3%) have specific capacities between 1.0-5.0 L/min/m, 45(6.6%) have specific capacities between 5.0-10.0 L/min/m, 117 (17.4%) have specific capacities between 10.0-50.0 L/min/m, and 57 (8.4%) have specific capacities above 50.0 L/min/m.

The thickness of the overburden is generally small to allow for the development of large overburden aquifers. Nevertheless, two small aquifers have been identified within the Authority.

<u>The Valens Outwash Aquifer</u>: This name is suggested for a small aquifer that is located in the northwestern tip of the Authority within Puslinch Township. The surface area is covered mainly by outwash deposits and some Wentworth Till. The records of 34 wells tapping the aquifer indicate that the majority of them are between 10.0 and 39.0 m deep. Most of the wells obtain water from sand and gravel deposits that range from a few meters up to 15.0 m in thickness. The elevation of the top of these deposits ranges between 290.0 and 326.0 m (a.s.l.). Groundwater in the aquifer is mainly under water table condition and the depths to the static water levels range from 4.0 to 20.0 m. Well yields are between 45.0 and 450.0 L/min, and the specific capacities are mostly between 10.0 and 50.0 L/min/m.

<u>The Ancaster-West Flamborough Aquifer</u>: This name is suggested for an aquifer that is located in the glaciolacustrine sand deposits above the Escarpment. The records of wells within several areas in the aquifer were examined.

The first area is along the western boundary of the Authority within Concessions 1 and 2 (Ancaster Township). The records of 22 wells in this area indicate that the majority of them are between 10.0 and 39.0 m deep. One well, however, is 54.0 m deep and another is 73.0 m deep. Most of the wells obtain water from sand deposits with some gravel. The sand has been described as fine sand, quick sand, coarse sand, medium sand, and clay sand. Some wells penetrate a few metres of these deposits, while others penetrate more than 20.0 m. Well No. 68-01758 is reported to penetrate 73.0 m of quick sand, fine silt sand, and medium sand deposits. Clay, sandy clay, and silt deposits are also reported in several wells. The wellhead elevations range between 187.0 and 253.0 m (a.s.l.). Groundwater, which is mainly under water table condition, is reported at elevations between 206.0 and 242.0 m (a.s.l.). The depths to the static water levels range from 3.0 to 34.0 m. Well yields are between 20.0 and 225.0 L/min. The specific capacities of the wells are mostly between 10.0 and 50.0 L/min/m.

The second area is located along the southwestern boundary of the Authority within Concessions 3 and 4 (Ancaster Township). The records of 10 wells in this area indicate that the majority of them are between 5.0 and 19.0 m deep. Most of the wells obtain water from medium sand deposits that are a few metres in thickness. Clay is reported in three wells and hardpan (till) is reported in one well. The wellhead elevations range between 232.0 and 250.0 m (a.s.l.). Groundwater is reported at elevations between 226.0 and 244.0 m (a.s.l.). The depths to the static water levels range from 2.0 to 11.0 m. Well yields are between 20.0 and 200.0 L/min, and the specific capacities are mostly between 5.0 and more than 50.0 L/min/m.

The third area is located within Concessions 1 and 2 (West Flamborough Township). The records of 43 wells in this area indicate that the majority of the wells are between 7.0 and 34.0 m deep. Most of the wells obtain water from medium sand and gravel deposits that are a few metres in thickness. The logs of most wells report the presence of clay. The wellhead elevations range between 191.0 and 247.0 m (a.s.l.). Groundwater, which is mainly confined, is found at elevations between 191.0 and 228.0 m (a.s.l.). The depths to the static water levels range from 2.0 to 24.0 m. Well yields are reported to range from about 20.0 to 115.0 L/min, and the calculated specific capacities are mostly between 5.0 and more than 50.0 L/min/m.

8.3 AQUIFERS IN AREAS DRAINING INTO LAKE SIMCOE AND GEORGIAN BAY

8.3.1 The Alliston Aquifer Complex

The Alliston Aquifer Complex was first identified by Sibul and Choo-Ying (1971) as the "Alliston Aquifer." The aquifer, which is located in the eastern portion of the Upper Nottawasaga River basin, consists of medium-to coarse-grained sand and is often overlain by blue clay deposits. At many places, the sand is interbedded or replaced with sequences of silt or very fine sand. According to Sibul and Choo-Ying (1971), the majority of domestic wells penetrate only the top few metres of the aquifer and show small water yields. When the full thickness of the aquifer is considered, however, well yields of more than 500.0 L/min are feasible.

Turner(1977) published Map 77-1 of the Alliston Aquifer Complex. In the marginal notes that accompanied the map, he proposed the name: "Alliston Aquifer Complex" for the Alliston Aquifer. According to the author, the word "complex" was added because investigations, conducted outside the Upper Nottawasaga River basin, have revealed that the aquifer is part of a broader system of closely associated aquifers. Hence the word "complex" signifies a system of aquifer lenses, each of variable extent and thickness, but all related to a similar geologic environment of deposition.

According to Turner (1977), the aquifer complex covers the entire area between the Oak Ridges Moraine and Georgian Bay. It is missing in the Thornton area within the Nottawasaga River basin where a regional bedrock high appears to have been an island in an extensive lake. It is also missing in an area west of Bradford in the Lake Simcoe basin.

The aquifer complex consists of fine to coarse sand deposits that occur at variable depths in close association with silt and clay deposits. All these materials were laid down in a glaciolacustrine environment. They are 3.0 to 6.0 m thick and are usually found at elevations between 120.0 and 160.0 m (a.s.l.). In some wells, especially those located around the boundaries of the complex, water is obtained from gravel deposits. These deposits have an irregular distribution and were interpreted as to be deltaic in origin. Silt and clay deposits that are described by drillers as "blue clay" act as confining materials on top of the aquifer. Their thickness is often more than 12.0 m.

Turner (1977) indicated that high-capacity wells have been developed in many areas within the aquifer complex. Locally, however, the aquifer complex may contain materials of low permeability or may be too thin to yield large quantities of water. These conditions are usually encountered along the boundaries of the aquifer complex as at Cookstown or Holland Landing.

A north-south piezometric divide at elevations greater than 228.0 m (a.s.l.), which runs immediately west of Barrie, separates the groundwater flow within the aquifer complex into a major system that flows toward Nottawasaga Bay and a minor system that flows toward Lake Simcoe. The valleys of the Nottawasaga and Schomberg Rivers are major areas of groundwater discharge. Numerous flowing wells are found in these valleys. Groundwater discharge areas also occur at Wasaga Beach, along the Innisfil Creek, and along the western shore of Lake Simcoe where flowing wells occur.

8.3.2 The Lake Simcoe Drainage Basin

Location: The Lake Simcoe drainage basin (the basin) is located about 50.0 km north of Toronto. The basin has a total area of about 3,580.0 km^2, of which the lake occupies about 722.0 km^2. Lake Simcoe is part of the Trent-Severn Waterway which connects Lake Ontario to Georgian Bay. The main two islands in Lake Simcoe are Georgina and Thora Islands (Figure 33).

The basin includes parts of the Regional municipalities of York and Durham, the County of Simcoe, and the City of Kawartha Lakes. Local municipalities include, in whole or in part, Barrie and Orillia, the Towns of Aurora, Bradford West Gwillimbury, East Gwillimbury, Georgina, Innisfil, Newmarket, New Tecumseth, and Whitchurch-Stouffville, and the Townships of Brock, King, Oro-Medonte, Ramara, Scugog, and Uxbridge. The major urban centres within the basin are Barrie, Newmarket and Aurora. Other smaller centres include Bradford, Holland Landing, Keswick, Mount Albert, Sharon, Schomberg, and Sutton.

Drainage: The basin is drained by 35 tributary rivers, with five major tributaries that account for more than 60.0% of the total area. Most of these rivers originate along the southern boundary of the basin in the Oak Ridges Moraine and then flow in a northerly direction before discharging into Lake Simcoe. The largest streams in the basin are the Black and the Holland Rivers. Other important streams are the Beaver, Maskinonge, and Talbot Rivers, the Pefferlaw and Uxbridge Brooks, and the Hawkstone, Hewitts, Lovers, and Whites Creeks. In addition, a number of small drainage areas empty into Lake Simcoe, including the Barrie Creeks, Georgina Creeks, Innisfil Creeks, Oro Creeks South, Oro Creeks North, and Ramera Creeks. Large swamp areas occur in both the Black River and Holland River watersheds. The most famous of these areas is the Holland Marsh which is a topographic depression extending from the Lake Simcoe toward the Oak Ridges Moraine.

Physiography: According to Chapman and Putnam (1984), parts of five physiographic regions are found within the basin, namely, the Oak Ridges Moraine, Schomberg Clay Plains, Peterborough Drumlin Fields, Simcoe lowlands, Simcoe Uplands, and Carden Plain.

The Oak Ridges Moraine forms the topographic divide separating the surface flow toward Lake Simcoe and Lake Ontario. The surface is hilly with a knob-and-basin relief with the elevation in places is as much as 365.0 m (a.s.l.). The moraine contains numerous small lakes and closed depressions or kettles, of which Musselman Lake, at an elevation of about 325.0 m (a.s.l.) is the largest.

The Schomberg Clay Plains, which consist of deep deposits of stratified clay and silt, occur in two large areas around Schomberg and Newmarket. According to Chapman and Putnam (1984), the surface under the clay is that of a drumlinized till plain. Some of the larger drumlins are exposed through the clay. Since the rolling relief of the underlying till plain has not entirely been eliminated, these areas are not so flat as many lake plains. The authors note that in the area along the Holland River between Newmarket and Holland Landing considerable dissection has taken place giving rise to rough topography. The average depth of the clay deposit seems to be about 5.0 m, but deep deposits are known.

Part of the watersheds of the Black and Beaverton Rivers, the Pefferlaw and Uxbridge Brooks, and the Innisfil Creek is within the Peterborough Drumlin Field. The area is covered by a ground moraine and contains numerous drumlins that have a northeast to southwest orientation.

The Lake Simcoe Lowlands consist of Lake Simcoe and the lands surrounding it and lying between 218.0 and 260.0 m (a.s.l.). The Lowlands consist of a narrow bouldery strip along the northern and western shores of Lake Simcoe and broad plains on the south and east of it. The most prominent feature of the Lowlands is the Holland Marsh which extends southwestward for about 25.0 km between high morainic hills. Also, low, swampy, sandy plains are being drained by the Black River and the Pefferlaw Brook.

Within the basin, part of the Oro Moraine and the till plains that occur to the south of Kempenfelt Bay and to the east of Cook's Bay are part of the Simcoe Uplands. These areas were probably islands in glacial Lake Algonquin.

Most of the northeastern part of the basin is part of the Carden Plain physiographic region. It is underlain by limestone rocks with very little overburden. According to Chapman and Putnam (1984), the plain was under Lake Algonquin and contains some beaches and offshore sand deposits.

<u>Bedrock Topography and Geology</u>: With the exception of the northeastern part of the basin where the bedrock outcrops at the surface, the basin is completely covered with a mantle of overburden that increase in thickness toward the west and the south. The bedrock topography within the basin displays a prominent depression which generally follows the trend of the Holland River Valley. It is part of the Laurentian Channel which extends from Georgian Bay to Lake Ontario. Bedrock surface elevations in the depression range from about 90.0 to 120.0 m (a.s.l.). The elevation of the bedrock increases toward the south, east, and north reaching about 280.0-320.0 m (a.s.l.) in the northeastern corner of the basin. A prominent bedrock high south of Aurora has a local relief of about 60.0 m above the adjoining valley.

The Paleozoic bedrock in the basin consists primarily of limestone and shale. Four formations have been identified within the basin, namely, the Verulam and the Lindsay Formations of the Simcoe Group of Middle Ordovician age, and the Blue Mountain and Georgian Bay Formations of Upper Ordovician age (Johnson et al. 1992).

<u>Overburden Thickness and Geology</u>: In general, the overburden thickness increases from the northeastern part of the basin, where it ranges between zero and 30.0 m, to the southern part of the basin where it ranges between 100.0 and 200.0 m. Deposits that are greater than 150.0 m in thickness are also found between Lake Simcoe and the basin's western topographic divide. The overburden consists of glacial, glaciofluvial, and glaciolacustrine deposits of Pleistocene age and fluvial and organic deposits of Recent age.

Five tills are displayed at the surface within the basin, namely, the Newmarket Till, Kettleby Till, Halton Till, and the undifferentiated Tills of Map Units 19 and 20 (Barnett et al. 1991). The Newmarket Till is found at the surface along the basin's western topographic divide and forms most of the high rim surrounding the Holland Marsh. The Kettleby Till occurs over the northern flank of the Oak Ridges Moraine in the south western part of the basin, to the east of Aurora and Newmarket, and to the west of Cook's Bay. The Halton Till occurs in a small area over the northern flank of the Oak Ridges Moraine in the southeastern part of the basin. Large areas in the eastern, northeastern, and northwestern parts of the basin are covered with the sandy silt to silt Till of Map Unit 19. Also, a small area in the northeastern part of the Talbot River watershed is covered with the sandy Till of Map Unit 20.

Large areas along the southern, southeastern, and western boundaries of the basin are covered with stratified sand and gravel of glaciofluvial origin. Sediments of glaciolacustrine origin are also widespread throughout the basin. These sediments were deposited in glacial Lakes Schomberg and Algonquin. Lake Schomberg was formed within a small area between the receding Lake Simcoe ice lobe and the Oak Ridges Moraine. The lake left behind some small sand deposits between Happy Valley and Kettleby and extensive stratified to varved silt and clay deposits to the west and east of Holland Marsh. Lake Algonquin followed Lake Schomberg and occupied the Lake Simcoe basin as well as parts of Lake Huron and Lake Michigan basins. Lake Algonquin left behind extensive sand deposits within the valleys of the Holland and Black Rivers.

Fluvial deposits of silt, sand and gravel are found within the flood plains of the various streams of the basin. Peat and muck deposits are found to the south of Cook's Bay and within the Black River flood plain.

<u>Overburden Aquifers</u>: Groundwater in the basin adequately supports the provision of water supplies for both private domestic and large municipal and industrial needs. In addition, groundwater is an important source of water supply for market gardening, sod turf production, golf course irrigation, and recreation. Most of the population within the basin is served by municipal water supply systems and the remaining population is serviced by private water wells. Large capacity wells serve the municipal needs of Aurora, Barrie, Bradford, Holland Landing, Keswick, Mount Albert, Newmarket, and Sharon.

Most of the water wells in the basin are overburden wells. This is specifically true in the southern part of the basin where the overburden is thick. A total of 31,313 wells has been identified within the basin. Of these, 9,654 are bedrock wells and 21,659 are overburden wells.

Of the 21,659 overburden wells, 6,662 (30.8%) have no specific capacity data, 1,212 (5.6%) have specific capacities of less than 1.0 L/min/m, 5,989 (27.6%) have specific capacities between 1.0-5.0 L/min/m, 3,174 (14.6%) have specific capacities between 5-10 L/min/m, 3,629 (16.8%) have specific capacities between 10.0-50.0 L/min/m, and 993 (4.6%) have specific capacities more than 50.0 L/min/m.

The Upper Holland Valley Conservation Report (1953) represents the earliest attempt to identify and describe the principal overburden aquifers within the basin. The 1953 Report identified a sandy area within the eastern half of the East Holland River subwatershed as a good aquifer. The area consists of glaciolacustrine and glaciofluvial sands with layers of gravel up to 30.0 m thick. The 1953 report describes these sediments as well sorted and having a large storage space for groundwater. This conclusion was based on the observation that water levels in the wells of this area have not fluctuated very much even during the dry years or seasons, when the fluctuation was strong in the rest of the watershed. A second aquifer was identified in the same report south of Aurora. The aquifer is described as consisting of sand deposits up to

40.0 m thick. A third sandy aquifer was identified between Cook's Bay and Holland Landing and extends as a sandy terrace along the Holland River to Newmarket. According to the report, the sand of this aquifer is fine or medium-grained and well sorted, thus forming a fairly good aquifer.

Since the publication of the 1953 report, numerous groundwater investigations, which covered parts of the basin, were conducted. These investigations, however, were completed by various authors and at different times. As a result, several names were given to what seems to be the same aquifer. Luckily, the aquifers were identified by location and elevation which makes it possible to distinguish the individual aquifer.

Vallery et al. (1982) evaluated the groundwater resources of the Holland and Black River watersheds. They noted that groundwater in the two watersheds is obtained from a number of discrete water-bearing sediments that are not continuous over large areas, but rather occur as individual lenses that have limited extent. For this reason, they used the term "aquifer complex" to describe the water-bearing sediments that have similar elevations and piezometric levels. Seven such aquifer complexes were identified within the two watersheds, including Alliston, Algonquin, Holt, Kame Outwash, Mount Albert, Oak Ridges, and Schomberg (Vallery et al. 1982, Sheet 3).

The following sections provide information about the aquifers and aquifer complexes that have been identified by various investigators within the basin.

<u>The Oak Ridges Moraine Hydrogeologic System</u>: The Oak Ridges Moraine acts a topographic divide and as a source of baseflow for the Holland River, and the Pefferlaw and Beaver Brooks (see Section 8.2.1).

<u>The Yonge Street Aquifer</u>: International Water Consultants Ltd. (1991) described a lower aquifer that extends along the Yonge Street core and ranges in elevation from 150.0 to 200.0 m (a.s.l.). The aquifer is described as a channel deposit that trends generally in a north-south direction and appears to be loosely associated with bedrock valleys. Hunter et al. (1996) also indicated that bounded, channel aquifers are found at elevations below 180.0 m (a.s.l.) at many locations within the Oak Ridges Moraine and up to150.0 m (a.s.l.) or deeper south of the Moraine. These aquifers, which they named the "Bounded Channel Aquifers" include the Yonge Street Aquifer. Pumping tests of wells tapping the aquifer indicate that it is about one kilometre wide in the vicinity of Aurora and that it exhibits strong proximal boundaries.

The Young Street Aquifer provides municipal water supply to Aurora, Newmarket, and Holland Landing. Singer et al. (2000) evaluated the groundwater resources of the East Holland River subwatershed and noted that, based on 1995 data, the groundwater withdrawal from the subwatershed is more than 38,640.0 m^3/day. Most of this withdrawal, which translates to about 80.0 mm/year, is from the Yonge Street Aquifer. The withdrawal represents about 65.0% of the East Holland River flow at Holland Landing. An examination of the annual streamflow records at Holland Landing, however, indicated that, although the river flow is heavily influenced by the variations in precipitation, there was no sign of any long-term influence of the groundwater withdrawal on the amount of baseflow. It is as if the Yonge Street Aquifer is independent of the groundwater discharge into the East Holland River.

The above-described situation can be explained in a number of ways. A few points, however, need some clarification. First, water table aquifers are recharged from precipitation or snowmelt that percolates through the soil after the soil moisture deficiency is satisfied. Second, the majority of confined aquifers are being recharged from precipitation that leaks through the low permeable materials on top of them. Some of these aquifers are only partially confined and can receive an additional recharge within those areas that are under water table conditions. Third, if a confined aquifer does not receive any recharge at all, a situation that arises occasionally in desert environments, then water withdrawal will be solely from storage and mining of the aquifer occurs.

When groundwater is withdrawn through a pumping well from a water table aquifer, a lowering of the water table within and in the surrounding area of the well occurs. In three dimensions, the drawdown curve has a conic shape known as the cone of depression. The outer limit of the cone of depression defines the area of influence of the well. When groundwater is withdrawn from a confined aquifer, on the other hand, a lowering of the piezometric head occurs and also a cone of depression occurs.

The formation of the cones of depression result in increases of the recharge to the aquifers due to:

- shifting of the groundwater divides which increases the sizes of the capture zones, and
- in the case of confined aquifers, increases in the recharge from overlying aquifers through the confining materials.

The increased groundwater recharge to a confined aquifer occurs because the differences between its piezometric head and the heads of overlying aquifers increase. Without any stresses due to water withdrawals, the natural groundwater regime within the East Holland River watershed is to discharge ultimately into Lake Simcoe. The large number of flowing wells in the Holland Marsh area proves this point. Along the way to its ultimate destination, groundwater seeps into the valleys of the East Holland River and sustains its baseflow (Singer et al. 2000).

As indicated earlier, the Yonge Street Aquifer, which is a confined channel aquifer, provides most of the municipal groundwater supply within the East Holland River subwatershed. This water withdrawal leads to a decline in the piezometric level within the aquifer. International Water Consultants (1991) examined the available well production and monitoring data from the Yonge street Aquifer for the period 1981 to 1990. The water level hydrographs for the production wells showed the following ranges of elevation in metres (a.s.l.):

Well Name	**1981 - 83**	**1984 - 85**	**1987 - 88**	**1989 - 90**
Aurora Well # 1	230 - 236			212 - 224
Aurora Well # 2	228 - 234			208 - 220
Aurora Well # 3	232 - 238			219 - 226
Aurora Well # 4	232 - 236			209 - 217
Aurora Well # 5			231 - 233	220 - 228
Newmarket Well # 1	228 - 230			210 - 217
Newmarket Well # 2	230 - 240			215 - 218
Newmarket Well # 13	234 - 236			206 - 218
Newmarket Well # 16		226 - 234		209 - 217
Newmarket Well # 15	222 - 224			206 - 211
Holland Landing Well # 1	235 - 236			226 - 229
Holland Landing Well # 2	234 - 236			223 - 227

The above data indicate that the hydraulic heads of the majority of production wells at Aurora and Newmarket have decreased to about 206.0 to 220.0 m (a.s.l.). In comparison, the water level of Lake Simcoe is 219.0 m (a.s.l.). According to International Water Consultants (1991), the hydrographs of monitoring wells located within the Yonge Street Aquifer but not adjacent to individual production wells show an average water level decline of about 1.6 m/year from 1982 to 1989. During this period, water production from the municipal wells rose from about 18,000.0 m^3/day up to 31,000.0 m^3/day.

The most important groundwater recharge zone in the basin is within the Oak Ridges Moraine area where very thick deposits of sands and gravels are at or near the surface. Part of this recharge seeps into the Holland River and the Pefferlaw and Beaver Creeks and sustains their baseflow. Another part seeps further to recharge the Lowland Aquifer Complex and the Bounded Channel Aquifers including the Yonge Street Aquifer. Recharge to the Yonge Street Aquifer by infiltration through approximately 100.0 m of low permeable deposits of silt and clay that overlie the aquifer is dependent on their vertical hydraulic conductivity.

International Water Consultants (1991) applied a numerical model that simulates a single confined aquifer (the Yonge Street Aquifer) to an area that includes the East Holland River subwatershed. The model used constant recharge values for the aquifer that ranged from zero for the river valleys to 64.0 mm for the area between Aurora and Holland Landing. They also assigned a recharge value of 127.0 mm/year for the area within the Oak Ridges Moraine.

The model predicted a maximum continuous water yield from the aquifer of about 50,000.0 to 55,000.0 m^3/day. These amounts, which are based on drawdown to the top of the aquifer at the well locations, represent the maximum recoverable water before mining occurs. Based on available hydrochemical data and an analysis of the post 1980 static level data contained in the MOE water well database, Hunter et al. (1996) concluded that the Yonge Street aquifer is hydraulically connected to the Upland Aquifer Complex. The existing capture zone of the aquifer is estimated to extend from King City in the west to Lake Wilcox and the Kettle lake zone in the south and further toward Ballantrae in the east. According to Hunter et al. (1996), the recharge to the Yonge Street Aquifer through the overlying less permeable deposits is not significant and a deep lateral recharge due to an increased capture zone within the Oak Ridges Moraine dominates.

As indicated above, the groundwater withdrawal from the Yonge Street Aquifer is not being accommodated by reduced baseflow in the East Holland River. It is being balanced by increased infiltration from above and/or adjustments to the groundwater divide which result in an increase in the catchment area of the aquifer. Unfortunately, data is lacking when it comes to the exact extent of this aquifer beyond the boundaries of the East Holland River subwatershed. Further, data regarding the variations in the hydraulic head of the aquifer within the Oak Ridges Moraine, where most of the recharge originates, are insufficient to draw definite conclusions.

The Yonge St. Aquifer produces about two-thirds of the municipal groundwater production in the Oak Ridges Moraine area. Information related to the transmissivity of the Yonge Street Aquifer has been reported in a number of hydrogeologic investigations. According to International Water Consultants Ltd. (1991), testing of York Region municipal wells indicated that transmissivities within the aquifer core range from about 1,000.0 m^2/day in the Newmarket area up to about 4,000.0 m^2/day in the Holland Landing and Sharon/ Queensville areas.

<u>The Alliston Aquifer Complex</u>: Turner (1977) included the area to the northwest of Kempenfelt Bay and west of Cook's Bay within the Alliston Aquifer Complex. Vallery et al. (1982) extended the southern boundary of the aquifer to the Oak Ridges Moraine and extended its eastern boundary to the vicinity of Aurora and Newmarket.

According to Vallery et al. (1982), the Alliston Aquifer Complex within the basin consists of sand and gravel deposits with an average thickness of about 5.0 m and an average elevation of about 165.0 m (a.s.l.). Some wells that obtain water from the aquifer complex are flowing and the average depth to the static level is about 12.0 m. The transmissivity values range from 3.0 to 1,500.0 m^2/day. Well yields are good and the average probable yield is about 700.0 L/min.

<u>The Mount Albert Aquifer Complex</u>: Vallery et al. (1982) described a local aquifer complex within the Mount Albert area. It consists primarily of deep sand and gravel deposits averaging about 3.0 m in thickness at an average elevation of about 215.0 m (a.s.l.). Some wells tapping the aquifer complex are flowing and the average depth to static level is about 9.0 m. The transmissivity values for the aquifer complex range from 5.0 to 210.0 m^2/day. Well yields are generally good with one municipal well serving the community of Mount Albert and rated at about 200.0 L/min.

<u>The Holt Aquifer Complex</u>: Vallery et al. (1982) mapped this aquifer complex within an area that extends from Aurora to Mount Albert. It consists of buried sand and gravel deposits about 3.0 m thick at elevations between 205.0 and 245.0 m (a.s.l.). International Water Consultants Ltd. (1991) described an aquifer zone of sand and gravel deposits within the East Holland River subwatershed which occur at an elevation range of 180.0 to 260.0 m (a.s.l.). This aquifer zone, which was called the Intermediate Aquifers, overlaps the range of the Holt Aquifer Complex identified by Vallery et al. (1982). Hunter et al. (1996) also described an aquifer complex, which they named the Lowland Aquifer Complex, that occurs in the general elevation range from 200.0 to about 260.0 m (a.s.l.). The elevation range of this aquifer complex overlaps the elevation ranges of the Holt Aquifer Complex identified by Vallery et al. (1982) and the zone of Intermediate Aquifers identified by International Water Consultants Ltd. (1991).

According to Hunter et al. (1996), the Lowland Aquifer Complex includes sandy meltwater channel deposits which extend up gradient into the tunnel channels that cut into and through the Newmarket Till. It also extends under the Oak Ridges Moraine as deep channel deposits fanning out into the regional lowlands as discrete aquifer units between elevations from about 220.0 to 240.0 m (a.s.l.). Hunter et al. (1996) noted that many rural settlements on the lower slopes adjacent to the Oak Ridges Moraine depend on this aquifer for potable water supply. In addition, a number of golf course irrigation wells and a number of municipal production well fields are also located in this aquifer complex.

According to Vallery et al. (1986), some wells that obtain water from the Holt Aquifer Complex are flowing, and the average depth to the static level is about 12.0 m. The transmissivity values range from 1.5 to 150.0 m^2/day. Individual well yields are variable, and are generally adequate to support domestic water supplies. Several wells within the aquifer complex have estimated yields of up to 130.0 L/min. The average probable well yield is about 90.0 L/min. According to International Water Consultants Ltd. (1991), a number of municipal wells have been developed in the Intermediate Aquifers zone, including Newmarket Wells #9 and #14. The reported transmissivities for these wells are generally moderate and in the order of 100.0 to 400.0 m^2/day.

<u>The Schomberg Aquifer Complex</u>: According to Vallery et al. (1982), this aquifer complex surrounds the Holland Marsh from the east, south, and west. It consists of buried sand with minor gravel about 3.0 m thick at elevations between 205.0 and 245.0 m (a.s.l.). Some wells that obtain water from the aquifer complex are flowing wells, and the average depth to the static water level is about 15.0 m. The transmissivity values range from 1.5 to 150.0 m^2/day. Individual well yields are generally adequate to support domestic water supplies, and one municipal well serves the community of Schomberg and yields up to 175.0 L/min. The average probable well yield is about 90.0 L/min.

The Algonquin Aquifer Complex: According to Vallery et al. (1982), this aquifer complex occurs mainly within the lower part of the Black River watershed and extends from Cook's Bay to the eastern topographic boundary. It is found at shallow depths as lenses of sand and gravel. These lenses are often thin (about 4.0 m thick) and isolated. Their top surface elevations range between 215.0 and 245.0 m (a.s.l.). The transmissivity values for this aquifer complex range from 1.5 to 150.0 m^2/day. Individual well yields are generally adequate to support domestic water supplies. Yields up to 450.0 L/min, however, are obtained locally. The average probable well yield is about 70.0 L/min.

The Kame Outwash Aquifer Complex: According to Vallery et al. (1982), this aquifer complex occurs along the southwestern boundary of the basin. It consists mainly of sand and minor amounts of gravel about 5.0 m thick. The top surface elevations of these deposits range from 245.0 to 315.0 m (a.s.l.). The depths to static water levels range from 2.0 to 50.0 m with an average depth of 15.0 m. The transmissivity values range from 15.0 to 450.0 m^2/day. Individual well yields are generally adequate to support domestic water supplies and yields up to 450.0 L/min are obtained locally. The average probable well yield is about 70.0 L/min.

8.3.3 The Severn Sound Drainage Area

Location: The Severn Sound drainage area (the Sound) is a group of bays in southeast Georgian Bay. The Sound has a total drainage area of about 1,095.0 Km^2, a maximum length of about 43.0 km in a northwest-southeast direction, and a maximum width of about 46.0 Km in a northeast-southwest direction. It is bounded on the north by the Severn River basin and Georgian Bay, on the east by Lake Simcoe and Lake Couchiching basins, on the south by the Nottawasaga River basin, and on the west by Georgian Bay as well as by a narrow strip of land that drains into Georgian Bay. Land surface elevations vary from 177.0 m (a.s.l.) along the shores of Georgian Bay to 412.0 m (a.s.l.) in a small area located within the Oro Moraine along the southern topographic divide (Figure 34).

The Sound includes, in whole or in part, the Townships of Tiny, Springwater, Tay, Oro-Medonte, and Severn, and the Towns of Penetanguishene and Midland. In addition, a small area in the north is within Georgian Bay Township (Baxter Ward) in the District Municipality of Muskoka.

Drainage: The Sound contains six small watersheds draining from the south and a miscellaneous area draining land along the north shore of the Sound. The six watersheds are those of the North, Coldwater, Sturgeon and Wye Rivers and the Hog and Copeland Creeks. Due to their small gradients within their flat-floored valleys, the six streams have cut shallow channels and their flow at times is very sluggish. These small gradients explain the swampy character of many areas within their valleys.

The North River rises in a hilly plateau to the north of Bass Lake and empties into Matchedash Bay. It has three major tributaries: the Purbrook, Bear and Silver Creeks. The Coldwater River originates near Coulson and flows from south to north before it enters into Matchedash Bay. The Sturgeon River originates in a hilly plateau near Hillsdale and flows in a northerly direction before it empties into Sturgeon Bay. The Hog Creek originates in Oro-Medonte Township, flows in a northerly direction through Tay Township, and empties into Hog Bay. The Wye River originates to the north of the Cook's Hill area in Springwater Township and flows from south to north to its outlet into Georgian Bay. The Copeland Creek originates from Lalligan Lake in Tiny Township and flows in a northwesterly direction to its outlet into Penetang Harbour.

Physiography: Chapman and Putnam (1984) identified three physiographic regions in the Sound, namely, the Georgian Bay Fringe, the Simcoe Lowlands, and the Simcoe Uplands.

The Georgian Bay Fringe forms a broad belt bordering Georgian Bay and occupying large parts of Muskoka and Parry Sound. The region occupies an almost continuous strip across the northeastern parts of the Sound and extends further north along the shorelines of Georgian Bay from Matchedash Bay to Beausoleil Island. A major part of the region was covered by glacial Lake Algonquin and it is characterized by low relief, shallow soil, and bare rock knobs and ridges.

The Simcoe Lowlands extends from Georgian Bay to Lake Simcoe. The region consists mainly of flat-floored valleys, which were flooded by glacial Lake Algonquin. On both sides of the valleys, shore cliffs, beaches and terraces, left during the various stages of glacial Lake Algonquin, can be traced for long distances. The floors of the valleys are covered by glaciofluvial, glaciolacustrine and recent deposits of mud, peat, and muck. In addition, large outcrops of Ordovician limestone are found within the North River watershed and are considered part of the Simcoe Lowlands. These strata are generally flat-lying, with a low dip of about 5.0 metres per kilometre to the southwest (Deane 1950).

The Simcoe Uplands consist of a series of broad, rolling till plains separated by steep-sided, flat-floored valleys. Most of the till plains are encircled by numerous shorelines, indicating that they were islands in glacial Lake Algonquin. The till plains occur throughout the central parts of the Sound as well as in the Penetang Peninsula where they were probably submerged in glacial Lake Algonquin. The Oro Moraine is also considered a part of the Simcoe Uplands. The moraine, which consists mainly of sand and gravel with minor amounts of clay or boulders, is located along the southeastern boundaries of the Sound and is characterized by rolling, kettle and knob topography.

Bedrock Topography and Geology: According to Singer et al. (1999), the bedrock elevations within the Sound range from more than 250.0 m to less than 120.0 m (a.s.l.). Highest elevations are found in the northeastern parts of the Sound where the Paleozoic rocks are either at or very close to the surface. They are also found within three dome-like structures located immediately north of Bass Lake. The lowest bedrock elevations are found in the southwestern part of the Sound which probably contained two major drainage systems before the Quaternary Period. The two systems were separated by a series of dome-like structures that extended in an east-westerly direction immediately to the north of Bass Lake and then continued in a northwesterly direction to Sturgeon Bay. Surface water to the south and south-west of the bedrock ridge drained toward an extensive bedrock valley known as the Laurentian Channel, which extended from Georgian Bay toward Cook's Bay on Lake Simcoe and further to Lake Ontario.

The bedrock in the Sound consists of Paleozoic rocks of Middle and Upper Ordovician age resting on a Precambrian basement. Young Quaternary deposits cover most of the Paleozoic rocks. The Precambrian rocks are mostly obscured by a cover of Paleozoic and Quaternary deposits. However, these rocks occur at the surface or very close to the surface within a narrow strip that extends along the northern borders of the Sound from Maple Valley in the east to Matchedash Bay in the west, and along the eastern shores of Georgian Bay northward to Honey Harbour and Beausoleil Island.

A succession of Paleozoic rocks of Middle Ordovician age overlies the Precambrian rocks over most of the Sound. Limestones outcrop at the surface at several locations in the Oro-Medonte, Severn, and Tay Townships, and they form a narrow, limestone plain that extends along the southern rim of the Canadian Shield to Port McNicoll on Georgian Bay.

The Paleozoic rocks belong to the Basal and Simcoe Groups of the Middle Ordovician age. Four formations of Middle Ordovician age have been identified within the Sound area. These formations include the Shadow Lake Formation of the Basal Group and the Gull River, Bobcaygeon, and Verulam Formations of the Simcoe Group (Johnson et al.1992).

Overburden Thickness and Geology: The thickness of the overburden in areas where the Precambrian and Paleozoic rocks are at or close to the surface is small and ranges from zero to less than 20.0 m. The overburden thickness increases gradually along a front that extends in an easterly-northwesterly direction. This front extends from areas located to the north of Bass Lake in the east to areas located west of Midland in the northwest. The maximum thickness of the overburden (120.0 to more than 140.0 m) is found along an axis that extends from the southern boundaries of the Sound through Orr Lake until it reaches the western boundary. To the southwest of this axis, the overburden thickness starts to decrease to a range of 80.0 -120.0 m. Other thick overburden deposits are found within the Oro Moraine. The maximum thickness of the overburden in this area ranges from 80.0 to 100.0 m along an axis that extends in a north-southerly direction to the west of Bass Lake (Singer et al. 1999).

The overburden deposits within the Sound consist of glacial, glaciofluvial, glaciolacustrine, of Pleistocene age and fluvial and organic deposits of Recent age. Most of the glacial deposits within the Sound were mapped by Barnett et al.(1991) as part of the undifferentiated Till of Map Unit 19. A second till, which outcrops at the surface in a few small locals was mapped by Barnett (1991) as part of the undifferentiated Till of Map Unit 21. The two tills occur as broad rolling plains, a ground moraine, and drumlins. Available data indicate that additional tills occur under the surface within the Sound. Barnett (1991), in a preliminary report on the stratigraphic drilling of Quaternary sediments in Barrie area, Simcoe County, described the geologic logs of five deep boreholes drilled in Oro-Medonte Township. Three of these boreholes (OGS-90-5, OGS-90-7 and OGS-90-14) reached the bedrock and provide complete profiles of the Quaternary section. Till-like, diamicton materials, separated by thick sequences of gravel, sand, silt and clay, were found at different depths in all the boreholes. The exact number of buried tills within the Sound, however, is not known.

One of the most important ice-contact deposits within the Sound area is the Oro Moraine. The moraine, which occupies the southern half of the Sound and continues beyond its boundaries, is about 25.0 km long with a maximum width of about 8.0 km. It is characterized by a hummocky topography with extensive kettles and knolls, tunnel channels, small dunes, and steep ice-contact slopes along its northern boundaries. The materials of the moraine are mainly sand and gravel deposits with minor amounts of clay or boulders. Other ice-contact deposits are found to the north of Warminster and south of Fair Valley in the Coldwater River watershed, at various locations within the Sturgeon River watershed, and around Midland Park Lake. These deposits consist of fine to coarse-grained sand, gravelly sand and gravel with minor amounts of silt, clay, and till.

A small outwash deposit of well-sorted, fine to coarse-grained sand with minor gravel, silt and clay is found in the headwaters of the Coldwater River adjacent to the Oro Moraine. Other outwash deposits, consisting mainly of medium to coarse sand with some boulders, occur to the south and north of Orr Lake around earlier "Algonquin Islands," and also west of Midland Park Lake. The Coldwater River, the Hog Creek, and the Wye River have cut channels through these outwash deposits. The origin of the outwash deposits is fluvial or deltaic. As the glacier melted, streams loaded with sediment flowed away and deposited their load of sand and gravel in valleys or in deltas. Compared to the ice-contact deposits, the outwash deposits are generally more uniform by texture. Their texture varies from silt to fine sand to coarse gravel, and their bedding is generally horizontal. The flat to undulating topography of the outwash deposits has been modified by subsequent actions of the waters of Lake Algonquin producing boulder strips and some depressions on the surface. According to Burwasser and Boyd (1974), much of the outwash sand between the "Algonquin Islands" in the Orr Lake area has been reworked so completely that it is mapped as lacustrine sand. On the edges of the "Islands" and below the Algonquin bluff is a deposit, mapped as winnowed outwash, of medium to fine sand. These sands contain numerous boulders, some exceeding two metres in their longest dimension.

Extensive deposits of glaciolacustrine origin occur at the surface within the Sound. They consist of very fine to medium-grained sand with silt and minor clay. These horizontally bedded deposits are found mainly in the headwaters of the North and Coldwater Rivers, over most of the valley of the Sturgeon River, around Orr Lake, and along the western boundaries of the Sound. The thickness of the glaciolacustrine deposits is highly variable. Within northern parts of the Sound, these deposits are generally thin, but can vary greatly within short distances. In areas, where the Paleozoic rocks are close to the surface, these deposits are thin and uniform. In other areas, where deep boreholes were drilled in Medonte and Severn Townships, the total thickness of these deposits is more than 60.0 m.

The glaciolacustrine deposits within the Sound include abandoned beaches, sand plains, and clay plains. Abandoned beaches consisting of gravel and sand deposits are found around the "Algonquin Islands." At some places, the abandoned beaches are poorly developed, but in many other places, one, two or three levels of well-developed beaches can be traced for long distances. These cascading beaches can be found particularly around Orr Lake, along both sides of the valleys of the Hog Creek and Wye River, and to the southwest of Midland Park Lake.

Clay flats of glaciolacustrine origin are most common in the depressions within the Sound, and are found in the middle sections of the North, Coldwater and Sturgeon Rivers and the Hog Creek. The clays also cover a large area extending from the south of Wye Marsh to the headwaters of the Wye River. Their thickness varies from less than 6.0 m to more than 20.0 m.

Accumulations of organic matter of mud, peat, muck and marl are found in many low, inadequately drained parts of the Sound. The largest such deposits are found in Tiny Marsh. Modern alluvial deposits of gravel, very fine to coarse-grained sand, silt and clay occur along stream channels within the Sound. These deposits are probably composed of reworked glaciolacustrine sediments.

Overburden Aquifers: The number of water wells within the Sound is 3,211 wells. Of these wells, 1,103 (34.3%) are bedrock wells, 1,958 (61.0%) are overburden wells, and the remaining 150 (4.7%) are of unknown type. Most of the wells are being used for domestic water supply. The remaining wells are being used for livestock watering, municipal, commercial, industrial, irrigation, cooling, and mixed use purposes.

In general, the availability of groundwater in the overburden ranges from poor to good. Locally, however, the overburden aquifers are the most productive sources of groundwater within the Sound and provide a number of urban areas with water supplies.

The Oro Moraine Aquifer Complex: The Oro Moraine, which occupies the southern half of the Sound and continues beyond its boundaries, acts as a water divide and an aquifer complex that provide baseflow to the main streams within the Sound. The aquifer complex also acts as one of the most important recharge areas within the Sound. About 50 wells tap water from the aquifer complex. The majority of these wells are more than 20.0 m deep. Three Layers (aquifers) of water-bearing sand and gravel have been reported in these wells.

Henderson, Paddon and Associates Ltd.(1990) conducted a hydrogeologic assessment of the Buffalo Springs area, which is located within the kame moraine. The assessment reported on the results of a pumping test of a deep production well (OW1) in Buffalo Springs at a rate of about 300.0 m^3/day. Seven wells (Ow2, OW3, OW4, OW5, OW6, OW7 and OW8) were monitored during the pumping test. The transmissivity coefficients for these wells range from 460.0 to 17,000.0 m^2/day and the storage coefficients range from $3.4 * 10^{-4}$ to $8.8 * 10^{-3}$. According to Henderson, Paddon and Associates Ltd. (1990), the Buffalo Springs area contains a shallow water table aquifer and a confined intermediate aquifer of variable depth and composition located 20.0 to 30.0 m below the ground surface, which supplies local domestic wells. In addition, there is a deep aquifer that underlies extensive confining layers of a sandy silty till, 50.0 to 80.0 m deep.

Unfortunately, it is not possible to provide a better hydrogeologic description of the Oro Aquifer Complex because of its large size and the lack of adequate information.

Local Aquifers within the Ice-Contact Deposits: As indicated earlier, ice-contact deposits are found to the north of Warminster and south of Fair Valley in the Coldwater River watershed, at various locations within the Sturgeon River watershed, and around Midland Park Lake. These deposits, which act as local aquifers, consist of fine to coarse-grained sand, gravelly sand and gravel with minor amounts of silt, clay, and till.

Singer et al.(1999) identified 124 wells that tap water from the ice-contact deposits including those within the Oro Aquifer Complex. The minimum and maximum values for the specific capacity distribution for these wells were 0.5 and 596.5 L/min/m, respectively. The 10 and 90 percentiles were 1.3 and 82.8 L/min/m, respectively, and the geometric mean was 9.2 L/min/m. The minimum and maximum values for the transmissivity distribution of 117 of the 124 wells were 1.0 and 10526.3 m^2/day, respectively. The 10 and 90 percentiles were 9.7 and 829.2 m^2/day, respectively, and the geometric mean was 126.36 m^2/day.

Local Outwash Aquifers: As indicated above, small outwash deposit of well-sorted, fine to coarse-grained sand with minor gravel, silt and clay is found in the headwaters of the Coldwater River adjacent to the Oro Moraine. Other outwash deposits are found to the south and north of Orr Lake, and also to the west of Midland Park Lake. The Coldwater River, the Hog Creek, and the Wye River have cut channels through these outwash deposits. When present in sufficient thickness, these deposits act as local aquifers.

According to Singer et al. (1999), a sample of 124 wells, constructed within the outwash deposits of the Sound, was identified. The sample's minimum and maximum specific capacity values were 0.12 and 298.3 L/min/m. The 10 and 90 percentiles were 1.7 and 59.6 L/min/m, respectively, and the geometric mean was 8.0 L/min/m. The sample's minimum and maximum transmissivity values were 0.2 and 1,937.4 m^2/day, respectively. The 10 and 90 percentiles were 11.8 and 600.9 m^2/day, respectively, and the geometric mean was 64.5 m^2/day.

Local Glaciolacustrine Sand Aquifers: As indicated above, sand deposits of glaciolacustrine origin are found over large areas within the Sound. In places, the thickness of these deposits is adequate to form important local aquifers. One such aquifer occurs within the headwaters of the Coldwater River. A second local aquifer occurs within the headwaters of the Sturgeon River. A third local aquifer is located in the vicinity of Orr Lake within the headwaters of the Why River. A forth local aquifer is located along the western boundary of the Wye River watershed. A fifth local aquifer is located to the northeast of Bass Lake within the headwater of the North River. A sixth local aquifer encircles the Penetang Bay.

A sample of 383 wells constructed within the glaciolacustrine deposits has suitable data related to short-term pumping tests. Singer et al.(1999) used these data to determine the transmissivity distribution for the sample. The sample's minimum and maximum transmissivity values were estimated to range from 0.3 to 34,800.0 m^2/day, respectively, and the sample's geometric mean was estimated to be about 75.0 m^2/day.

Based on the estimated transmissivity distributions for wells completed in the various overburden units within the Sound, Singer et al. (1999) concluded that the wells constructed in areas where ice-contact and outwash deposits outcrop at the surface have the highest water-yielding capabilities.

8.3.4 The Nottawasaga Valley Conservation Authority

Location: The Nottawasaga Valley Conservation Authority (the Authority) is located in the southwestern part of southern Ontario. It is bounded on the north by the Severn Sound drainage area and the Nottawasaga Bay, on the east by the Lake Simcoe basin, on the south by the Humber and Credit Rivers watersheds, and on the west by the basins of the Grand, Saugeen, and Beaver Rivers.

The Authority contains parts of the Counties of Simcoe, Dufferin, and Grey. Eighteen municipalities are entirely or partially within the Authority, including the City of Barrie, the Towns of Bradford West Gwillimbury, Collingwood, Innisfil, New Tecumseth, Shelburne, and Wasaga Beach, and the Townships of Adjala-Tosorontio, Amaranth, Clearview, Collingwood, Essa, Melancthon, Mono, Mulmur, Oro-Medonte, and Springwater (Figure 35).

Agriculture is the dominant land use within the Authority which is famous for its sod production, potato farming, apple orchards, and gardening crops. The Authority is also known for its recreational areas. The major urban centres are Alliston, Beeton, Collingwood, Cookstown, Tottenham, and Wasaga Beach.

Drainage: The Nottawasaga River, which has an area of about 3,360.0 km^2 and a length of about 122.0 km, is the main watercourse within the Authority. The river rises on a high plain west of the Niagara Escarpment and flows down through a deeply cut rock valley. It takes a northeasterly course through the Hockley Valley, which is noted for its rugged topography, and then it takes a northerly and a northwesterly roundabout course to its mouth at Wasaga Beach. Its main tributaries are the Boyne, Mad, and Pine Rivers and the Innisfil, Bear, and Willow Creeks. The Authority contains a number of boggy areas. The most notable of these is the Minesing Swamp. Four small streams draining directly into Georgian Bay are also within the Authority. These streams include the Pretty and Batteaux Rivers and the Silver and Black Ash Creeks.

Physiography: Chapman and Putnam (1984) identified parts of seven physiographic regions within the Authority, namely, the Horseshoe Moraines, Niagara Escarpment, Simcoe Lowlands, Simcoe Uplands, Oak Ridges Moraine, Peterborough Drumlin field, and Schomberg Clay Plains.

Part of the eastern flank of the Horseshoe Moraines extend along the western side of the Authority. It contains portions of the Gibraltar, Banks, and Corn Hill Moraines.

The vertical cliffs of the Niagara Escarpment are well displayed from the Pine River to a point above Collingwood where the Blue Mountain stands about 480.0 m (a.s.l.). Below the Pine River, however, most of the rock slopes are obscured by morainic ridges and deposits of sand and gravel. The Nottawasaga River, and its tributaries the Boyne, Mad, and Pine Rivers and other smaller streams have cut deep valleys down the Escarpment.

Small Parts of the Peterborough Drumlin Field, Oak Ridges Moraine, and Schomberg Clay Plains form an arc over the southern part of the Authority. About 100 drumlins, which have a northeast-southwest orientation, are found within the Peterborough Drumlin Field. The central part of the Authority is occupied by the Simcoe Lowlands and its eastern side is occupied by the Simcoe Uplands. A ridge of boulder clay with sand spread on the surface, known as the Edenvale Moraine, is located within the Simcoe Lowland between Jack Lake and Phelpston. The Nottawasaga River has cut a gorge 30.0 m deep through this moraine.

Bedrock Topography and Geology: The bedrock is at the surface at a number of locations above the Niagara Escarpment. In the rest of the Authority, however, the bedrock is obscured by an overburden mantle. The elevation of the bedrock ranges from more than 500.0 m (a.s.l.) above the Escarpment to about 120.0 m (a.s.l.) along the Authority's eastern boundaries and in the Wasaga Beach area. The Escarpment is a prominent topographic feature on the present land surface. A deep bedrock valley that cuts into the Escarpment occurs beneath the Nottawasaga River in the region of the Hockley Valley. Other smaller bedrock channels occur along the Escarpment to the north. Below the Escarpment, the bedrock slopes eastward toward the Laurentian Channel, a regional bedrock valley that extends from Georgian Bay to Lake Ontario.

The Paleozoic rocks consist of shales, dolomites, and limestones of Ordovician and Silurian age. The oldest Paleozoic rocks are those of the Simcoe Group of Middle Ordovician age. The group consists of the Bobcaygeon, Verulam, and Lindsay Formations. The shales of the Blue Mountain, Georgian Bay and Queenston Formations of Upper Ordovician age overly the Simcoe Group. In turn, these rocks are overlain by the Cataract Group of Lower Silurian age which includes the Whirlpool, Manitoulin, and Cabot Head Formations. The youngest Paleozoic rocks within the Authority are the dolomites of the Amabel and Guelph Formations of Middle Silurian age.

Overburden Thickness and Geology: The overburden within the Authority consists of glacial, glaciofluvial, glaciolacustrine deposits of Pleistocene age with minor amounts of alluvial and swamp deposits of Recent age. The thickness of these deposits varies from less than 10.0 m over the Niagara Escarpment plateau to more than 110.0 m along the eastern boundaries of the Authority.

The glacial deposits cover large areas within the northwestern, central, and eastern parts of the Authority. Landforms associated with these deposits include drumlins, till plains, and end moraines. Six different tills have been mapped by Bennet et al. (1991) within the Authority, including the Catfish Creek Till, Tavistock Till, Newmarket Till, Kettleby Till, and the tills of Map Unit 19 and Map Unit 21.

The Catfish Creek and Tavistock Tills are found above the Escarpment. The Newmarket Till is found mainly in the northwestern and eastern parts of the Authority. Small patches of this till also occur along the southern boundary of the Authority. The Kettleby Till is found within the central part of Adjala-Tosorontio Township. The undifferentiated Tills of Map Units 19 and 21 are found within the northern part of the Authority in the Townships of Clearview, Springwater, and Oro-Medonte.

Ice-contact deposits of glaciofluvial origin in the form of kames are found over the Escarpment and to just east of it, and also along the Authority's southern, eastern, and northeastern parts. The outwash deposits of glaciofluvial origin cover large areas within the Townships of Adjala-Tosorontio and Mulmur. They are also found near the southern boundary of the Authority southeast of Hockley, and as narrow channels in the vicinity and above the Escarpment.

Deposits of glaciolacustrine origin consisting of clay, silt, and fine sand cover a wide area within the flood plain of the Nottawasaga River. These deposits were laid down in ice-marginal lakes and ponds associated with glacial Lake Schomberg and subsequent phases of glacial Lake Algonquin. Also, thick sequences of clay and silt directly overlie part of the till plains within the Authority. Medium to coarse-grained sands, and occasionally gravel of glaciolacustrine origin is found near the Innisfil Creek and along the lower part of the Nottawasaga River. Sibul and Choo-Ying (1971) noted that as much as 15.0 m of sand, interbedded with minor beds of silt and clay, can be seen within the banks of the Nottawasaga River.

Recent deposits of beach sand and gravel as well as lacustrine silt and clay occur in the vicinity of Wasaga Beach. Also, a large area within the southwestern part of the Township of Springwater is covered by peat and Muck deposits. In addition, alluvial deposits of clay, silt, and fine sand occur within the flood plains of various streams.

Overburden Aquifers: There are 19,725 records on file with the Ministry of the Environment for water wells constructed within the Authority. Of these wells, 5,529 (28.03%) are bedrock wells and 14,196 (71.97%) are overburden wells. This indicates that the overburden is more significant than the bedrock as a source of water supply.

The well records indicate that 4,318 overburden wells do not contain any information related to pumping tests. Data related to short-term pumping tests are available for the remaining 9,878 wells. Of these wells, 750 (7.6%) have specific capacities of less than 1.0 L/min/m, 3,581 (36.2%) have specific capacities between 1.0 and 5.0 L/min/m, 2,486 (25.2%) have specific capacities between 5.0 and 10 L/min/m, 2,545 (25.8%) have specific capacities between 10.0 and 50.0 L/min/m, and the remaining 516 (5.2%) have specific capacities more than 50.0 L/min/m.

Five overburden aquifers have been identified by Sibul and Choo-Ying (1971) within the Upper Nottawasaga River watershed. Their Map 2743B-5 shows the areal distribution of the Kame Outwash Aquifer Complex, Lake Algonquin Sand Aquifer, Thornton Sand Aquifer, Alliston Sand Aquifer, and Hockley Valley Aquifer. In addition, a sixth aquifer has been identified in this report and named the Oro-Medonte Aquifer.

The Kame and Outwash Aquifer Complex: According to Sibul and Choo-Ying (1971), this aquifer occurs mostly at the surface just east of the Escarpment within a large area extending along the southern parts of the Townships of New Tecumseth and Adjala-Tosorontio, the eastern half of the Townships of Mono, and the southwestern part of the Township of Mulmur. The available data make it possible to extend the boundaries of this aquifer into the eastern part of Mulmur Township, the northwestern part of the Adjala-Tosorontio Township and a small part of Clearview Township.

The aquifer, which is mostly unconfined, consists of kame and outwash sand and gravel deposits that ranges in thickness between 10.0 and 30.0 m. The depth to the water table varies with topography. Where the relief is high, the water table is often more than 15.0 m deep, and in areas of relatively low relief, the average depth to the water table is about 6.0 m. A large number of wells draw water from the aquifer. Some of these wells have specific capacities larger than 10.0 L/min/m. The majority of the wells, however, have smaller specific capacities.

The Lake Algonquin Sand Aquifer: Extensive sand deposits, laid down in glacial Lake Algonquin, are found at the surface at elevation of 225.0 to 230.0 m (a.s.l.) within the southern, central, northeastern and northwestern parts of the Authority. Sibul and Choo-Ying (1977) named the southern part of these deposits the Lake Algonquin Sand Aquifer. The average thickness of the sands is about 10.0 m. The aquifer is unconfined, and the average depth to the water table is between 3.0 and 5.0 m. Most wells that obtain water from this aquifer have specific capacities of less than 5.0 L/min/m which is adequate for domestic water needs.

<u>The Thornton Sand Aquifer</u>: A local aquifer of medium to coarse-grained sand at about 260.0 m (a.s.l.) has been identified by Sibul and Choo-Ying under an area covered by the Newmarket Till in the Townships of Innisfil and Essa. New data indicate that the aquifer is found at an elevation range between 248.0 and 265.0 m (a.s.l.) and has a thickness that varies from a few metres up to 30.0 m. The aquifer is confined with static water levels ranging from 10.0 to 30.0 m below the surface. Some wells that obtain water from this aquifer have specific capacities larger than 10.0 L/min/m. The majority of the wells, however, have smaller specific capacities.

<u>The Glaciolacustrine Aquifer Complex</u>: A layer of glaciolacustrine fine sand is reported in wells within the Townships of Innisfil, Essa, and New Tecumseth at an elevation level between 175.0 and 205.0 m (a.s.l.).

MOE published in the mid-eighties Map 2273 showing geophysical well log correlations of twelve wells drilled within the confines of a bedrock depression between Barrie and the Oak Ridges Moraine. Of the twelve wells used in the correlation, five wells (7048, 14466, 7090, 9779, 10548) were drilled for geological mapping purposes only and do not provide any useful groundwater yield data. Another six wells (13958, 13959, 13960, 13962, 14077, 14079) were drilled as part of a groundwater availability program for the Innisfil Township, and one well (4-74) was drilled as part of a water supply exploration program for Cookstown. The latter seven wells contain some groundwater yield data. According to the summary that accompanied Map 2273, the wells are located generally in the central part of a bedrock depression where a glacial lake probably existed.

The geophysical logs show a glaciolacustrine sequence that could be correlated over much of the map area. The sequence maintains a uniform thickness with a very little slope in an east-west direction, but does slope significantly in a north-south direction. To approximate the conditions at the time of the sequence deposition in the north-south direction, elevation corrections for differential uplift were applied to each well relative well No. 9779 which is the most southern well. The elevation of the top of the sequence ranges between 175.0 and 205.0 m (a.s.l.).

The glaciolacustrine sequence consists generally of fine silty sand over clay. The formation may become coarser toward the depression boundaries. This occurs at well No. 10548 where the formation consists of about 8.0 m of coarse sand with some gravel. According to the summary that accompanied the map, the water yield of the formation is very limited, probably in the range of domestic supplies. Of the seven wells drilled for water supply purposes, pumping tests were conducted within the confines of the main formation in only three wells (13959, 14077, 14079). Well No.14077 was pumped at a rate of 45.0 L/min. The well had a maximum probable yield of between 180.0 and 365.0 L/min. The other two wells produced only small amounts (less than 10.0 L/min) of water. From the test drilling data, it would appear that most wells in this formation would produce generally sufficient quantities of water for domestic purposes only.

<u>The Alliston Aquifer Complex</u>: As indicated earlier, Sibul and Choo-Ying (1971) were the first to identify a series of water-bearing sand beds of variable thickness which they named the Alliston Sand Aquifer. This aquifer is considered now a part a regional aquifer complex which extends under large areas within the Nottawasaga watershed, the Lake Simcoe basin, and the Severn Sound drainage area (see Section 8.3.1). Within the Authority, the aquifer complex extends from the headwaters of the Innisfil Creek along the eastern topographic divide to

Wasaga Beach. It is encountered at elevations between 120.0 and 150.0 m in areas where the bedrock surface is above 150.0 m.

The aquifer complex is confined and many wells, in areas where the surface elevation is less than 230.0 m, are flowing. In areas where the ground surface is high, the average depth to the static water level is more than 30.0 m. Sibul and Choo-Ying (1971) noted that the domestic wells that penetrate a few metres of the aquifer complex show small water yields. Yields can be increased to at least 560.0 L/min when larger thickness of the aquifer complex is penetrated. One Alliston municipal well is screened more than 7.0 m in the sand and has a theoretical yield of 5,600.0 L/min. The authors also suggested that the recharge to the aquifer complex takes place either through the kame moraine and terrace areas east of the Escarpment or through the Oak Ridges Moraine at the southeastern boundary of the Authority.

The Hockley Valley Aquifer: Sibul and Choo-Ying (1971) suggested the presence of a confined aquifer consisting of gravel within the bedrock valley underlying the Nottawasaga River in the area of Hockley Valley. The thickness of the overburden in this area ranges from zero, where the bedrock outcrops along the banks of the Nottawasaga River, to more than 150.0 m in several well. The authors suggested that properly developed, fully penetrating wells drilled in the confines of the valley should yield about 560.0 L/min. It was not possible during this study to confirm the depth or the areal extent of this aquifer. Many overburden wells within the area are highly productive with specific capacities more than 10.0 L/min/m. The depths to the top of the aquifer in these wells, however, range from 30.0 to 140.0 m. Some of these wells also report extensive water-bearing sands.

The Oro-Medonte Aquifer: This name is suggested for an aquifer consisting of extensive ice-contact sand deposits that occur at the surface at elevations between 275.0 and 360.0 m (a.s.l.) within the Oro-Medonte, Springwater, and Innisfil Townships. The thickness of the aquifer varies from 25.0 m to more than 100.0 m. The aquifer is mostly unconfined with the static water levels ranging from less than 10.0 m to more than 50.0 m. Where the aquifer is overlain by till deposits, it is confined. Wells that obtain water from the aquifer have specific yield ranging from 5.0 to more than 10.0 L/min/m.

8.3.5 The Grey Sauble Conservation Authority

Location: The Grey Sauble Conservation Authority (the Authority) extends along 155.0 km of Georgian Bay and Lake Huron. It is bounded on the east by the Nottawasaga Valley Conservation Authority, on the south by the Saugeen Conservation Authority, on the west by Lake Huron, and on the north and northeast by the Bruce Peninsula and Georgian Bay.

The Authority covers about 3,146.0 km^2 in the Counties of Bruce and Grey. It encompasses all or parts of eight municipalities, including the Town of South Bruce Peninsula, the Township of Georgian Bluffs, and the Municipality of Meaford. It also includes parts of the Town of Blue Mountains, the Township of Chatsworth, and the Municipalities of Grey Highlands and Arran-Elderslie. The largest urban centre within the Authority is Owen Sound. Other urban centres are Allenford, Chatsworth, Hepworth, Meaford, Sauble Beach, Shallow Lake, Tara, and Thornbury (Figure 36).

Drainage: There are five major river systems within the Authority as well as numerous smaller streams. The Sauble River is the largest of these streams. Its main branch rises near Desboro within the Arran Drumlin Field and travels in a northwesterly direction to enter Lake Huron north of Sauble Beach. Several lakes are within the Sauble's watershed, including Lakes Gould, Chesley, and Hepworth. The two main tributaries to the Sauble are the Rankin River and the Hepworth Creek.

Other distinguished rivers within the Authority are the Pattawatomi, Sydenham, Bighead, and Beaver Rivers. The Pattawatomi River rises in the southern parts of the Township of Georgian Bluffs and flows in a northeasterly direction toward the Town of Owen Sound. The Sydenham River rises in the middle part of the Township of Chatsworth and flows mainly in northerly direction to join the Pattawatomi River in the Town of Owen Sound before emptying into Owen Sound Bay. The Bighead River rises in the northeastern part of the Township of Chatsworth. It travels mainly in a northeasterly direction and enters Georgian Bay at Meaford. Finally, the Beaver River rises in the southwestern part of the Municipality of Grey Highlands and flows in a northeasterly direction to enter Georgian Bay at Thornbury.

Physiography: Chapman and Putnam (1984) identified seven physiographic regions within the Authority, namely, the Arran Drumlin Field, Beaver Valley, Bighead Valley, Bruce Peninsula, Cape Rich Steps, Horseshoe Moraines, Huron Fringe, and Niagara Escarpment. Five of these physiographic regions, namely the Beaver Valley, Bighead Valley, Cape Rich Steps, and Bruce Peninsula, and the Niagara Escarpment are interrelated.

Immediately at Craigleith, at the northeastern end of the Authority, are the steepest and most mountainous part of the Niagara Escarpment. The brow of the Escarpment in this area is about 1.5 km off Georgian Bay. A short distance to the west, however, the edge of the Escarpment retreats southward for about 40.0 km inland and then it turns northward to form the eastern and western rims of the Beaver River Valley. A short distance farther to the west is the valley of the Bighead River. Between the two valleys stands another cliff whose cap is about 6.5 km from the shore of Georgian Bay. Further west, between the Bighead Valley and Owen Sound, the Escarpment advances to Cape Rich where it ends abruptly in a striking shale cliff, the "Clay Banks," which rises sheer from the edge of the water to a height of almost 130.0 m.

The Beaver Valley is entirely within the Authority. It occupies a sharply-cut indentation in the Niagara cuesta extending from Thornbury on Georgian Bay to Flesherton in the south. As indicated above, the Niagara Escarpment forms the upper rims of the valley and appears as almost a vertical cliff, 15.0 to 30.0 m in height. The valley, which existed in preglacial times, was overrun several times by glaciers. These glaciers served to carve the valley into an open, steep-sided, broad-bottomed structure. According to Chapman and Putnam (1984), glacial Lake Algonquin covered all the land below the 235-meter contour and left a well-developed beach at Heathcote some 7.0 km south of Thornbury. The glacial lake left also a crescent-shaped lake plain that is bounded near Georgian Bay by a steep bluff which stands about 15.0 m above Georgian Bay and marks the shoreline of the Nipissing Great Lakes.

The Bighead Valley is also an indentation in the Escarpment and it is being drained by the Bighead River. The valley was largely eroded in preglacial time and has been modified by ice erosion. Drumlins, which are oriented almost directly south, completely cover the shoulders, sides, and floor of the valley. Across the mouth of the valley, about four kilometres inland from the present shoreline of Georgian Bay and about 60.0 m higher, is an abandoned shoreline of Lake Algonquin. A terrace, which probably marks the highest water level of the Nipissing Great Lakes, is within the Town of Meaford (Chapman and Putnam 1984).

An area of about 130.0 km^2 extending from Owen Sound to Nottawasaga Bay has been identified by Chapman and Putnam (1984) as the Cape Rich Steps. According to these authors, in preglacial time, this area was the upland between two rivers that flowed down the Georgian Bay depression. From Nottawasaga Bay in the east to Owen Sound in the west, the land within this physiographic region rises about 150.0 m in five steps. The first step was left by Lake Nipissing and the second by Lake Algonquin. The third step consists of red shale of the Queenston Formation, the forth step consists of the dolostones of the Cataract Group, and the fifth step consists of the dolostones of the Amabel Formation. A long narrow lake, the Mountain Lake, lies in a preglacial valley to the west of Cape Rich.

Within the Authority, the Bruce Peninsula physiographic region extends from the vicinity of Owen Sound to the Municipality of Northern Bruce Peninsula. Apart from a few drumlins, gravel bars, and sand dunes, this physiographic region has only a little overburden scattered on dolostone that dip westward. Near Georgian Bay, the rocks form a bluff about 60.0 m in height (Chapman and Putnam, 1984).

The Arran Drumlin Field forms the headwaters of the Sauble River. As the name implies, the area is almost entirely occupied with drumlins oriented almost southwest. In part of the field, lacustrine clay occurs between the drumlins. Near Tara, many thin end moraines, known as the Tara Strands, run mainly in an east-west direction. Swamps and lakes are found in the depressions between the drumlins (Chapman and Putnam, 1984).

The Horseshoe Moraines extends along the southern boundary of the Authority. It contains a shallow ground moraine and scattered groups of drumlins. Till ridges, kame moraines, outwash plains are also associated with this physiographic region.

A narrow sand plain extending along the shore of Lake Huron for about 325.0 km has been identified by Chapman and Putnam (1984) as the Huron Fringe physiographic region. This region extends from the northwestern boundary of the Authority to the south of Sauble Beach. It comprises terraces that were laid down by glacial Lakes Algonquin and Nipissing.

<u>Bedrock Topography and Geology</u>: A large portion of the bedrock within the northern parts of the Authority is exposed at the surface. The bedrock elevation ranges from about 120.0 m (a.s.l.) in the vicinity of Chief's Point on Lake Huron to about 480.0 m (a.s.l.) to the east of the Beaver River Valley. According to Johnson et al. (1992), the bedrock geology consists of the Lindsay, Georgian Bay, and Queenston Formations of Upper Ordovician age, the Manitoulin, Formation of the Cataract Group of Early Silurian age, the Amabel and Guelph Formations of Middle Silurian age, and the Salina Formation of Upper Silurian age.

<u>Overburden Thickness and Geology</u>: As indicated above, the bedrock is exposed in the northern parts of the Authority. Over the remaining parts, the overburden thickness ranges from about 10.0 m to about 70.0 m. The exception is a small area within the Bighead River Valley where the overburden thickness is more than 110.0 m.

The overburden consists mainly of glacial deposits and minor amounts of glaciofluvial, glaciolacustrine deposits of Pleistocene age and fluvial deposits of Recent age. According to Barnett (1992), four tills occur within the Authority, namely, the Catfish Creek Till, Elma Till, St. Joseph Till, and Newmarket Till.

The Catfish Creek Till occurs within two small areas along the Authority's southwestern boundary. More than half the Authority is covered by the Elma Till, which occurs as a ground moraine and in drumlins. The St. Joseph Till is found as a very narrow band along the Authority's southern boundary. It occurs mainly as a ground moraine. The Newmarket Till occurs as a long strip along the Authority's eastern boundary.

The glaciofluvial deposits of sand and gravel are associated mainly with the Elma Till. Most of these deposits are of ice-contact origin that are displayed at the surface as narrow, east-west trending, end moraines. Two small outwash plains also occur in the eastern part of the Authority.

A sand plain, laid down by glacial Lake Algonquin, occurs in the lower part of the Sauble River. The plain extends as a narrow belt parallel to the shore of Lake Huron and it is separated from it by a second belt of lacustrine sand deposits. Sand deposits of glaciolacustrine origin are also found in the lower parts of the Beaver and Bighead Rivers. Silt and clay deposits of glaciolacustrine origin are found at several locations mainly to the east and south of Severn Sound. In addition, a long, narrow body of fluvial deposits is found within the flood plain of the Beaver River.

Overburden Aquifers: A total of 12,543 bedrock wells has been identified within the Authority as compared to 1,169 overburden wells which indicates that the overburden is less important as a source of water supply. Of the overburden wells, 257 (22.0%) have no specific capacity data, 102 (8.7%) have specific capacities of less than 1.0 L/min/m, 260 (22.2%) have specific capacities between 1.0-5.0 L/min/m, 143 (12.3%) have specific capacities between 5.0-10.0 L/min/m, 257 (22.0%) have specific capacities between 10.0-50.0 L/min/m, and 150 (12.8%) have specific capacities that exceed above 50.0 L/min/m.

The main overburden aquifers within the Authority are the sand and gravel deposits that are either exposed at the surface or exist at various depths within the overburden. Three such aquifers have been identified and named. In addition, several minor aquifers have been identified to the south of Chatsworth, in the vicinity of Sauble Beach, and in the vicinity of Dobbinton.

The Meaford Aquifer: This name is suggested for a local, confined aquifer that occurs in the vicinity of the Town of Meaford. It consists mainly of coarse sand and gravel deposits that range in thickness from several metres up to 24.0 m. The area where the aquifer occurs is covered mainly with deposits of glaciolacustrine sand and clay. These deposits together with a till-like deposit are reported on top of the aquifer. The records of 29 wells tapping the aquifer indicate that the wellhead elevations are between 181.0 and 259.0 m (a.s.l.), the elevation of the top of the aquifer in the majority of the wells is between 182.0 and 194.0 m (a.s.l.), and the depths to the static water levels are between 1.0 and 32.0 m. The well yields range from 5.0 to 100.0 L/min. One well, however, is reported to yield 450.0 L/min.

The Thornbury Aquifer: This name is suggested for an aquifer that is located in the vicinity and to the south of the Town of Thornbury. It consists of gravel and sand deposits that range in thickness from several metres up to 32.0 m. The area where the aquifer occurs is covered mainly with deposits of till, glaciolacustrine sand, and ice-contact sand and gravel. Where the aquifer is exposed at the surface, it is under a water table condition, otherwise it is confined. The records of 106 wells tapping the aquifer indicate that the wellhead elevations are between 180.0 and 265.0 m (a.s.l.), the reported elevation of the top of the aquifer in most wells is between 190.0 and 222.0 m (a.s.l.), and the depths to the static water levels range from less than one metre to 24.0 m. The well yields range from 15.0 to 225.0 L/min. The specific yields of many wells are more than 10.0 L/min/m.

The Flesherton Aquifer: This name is suggested for an aquifer that is located in the vicinity and to the south of the Village of Flesherton. It consists of gravel and sand deposits that range in thickness from several metres up to 23.0 m. The area where the aquifer occurs is covered mainly with ice-contact sand and gravel, outwash sand, and till deposits. Where the aquifer is exposed at the surface, it is under a water table condition, otherwise it is confined. The records of 60 wells tapping the aquifer indicate that the wellhead elevations are between 427.0 and 482.0 m (a.s.l.), the reported elevation of the top of the aquifer is between 403.0 and 443.0 m (a.s.l.), and the depths to the static water levels range from less than one metre to 12.0 m. The well yields range from 20.0 to 225.0 L/min. The specific yields of many wells are mostly between 10.0 and more than 50.0 L/min/m.

8.4 OVERBURDEN AQUIFERS IN AREAS DRAINING INTO LAKE HURON

8.4.1 The Saugeen Conservation Authority

Location: The Saugeen Conservation Authority (the Authority) is bounded on the north by the Grey Sauble Conservation Authority, on the east by the Grand River Conservation Authority, on the south by the Maitland Conservation Authority, and on the west by Lake Huron. The Authority covers 4,675.0 km^2 and encompasses all or parts of 15 municipalities. The main urban centres are Hanover, Kincardine, Mount Forest, Port Elgin, Teeswater, and Walkerton (Figure 37).

Drainage: The Saugeen River is the major river system within the Authority. The main branch of the Saugeen River rises near Dundalk at an elevation of about 520.0 m (a.s.l.) and flows about 195.0 km to enter Lake Huron at Southampton. The river flows in a southwesterly direction from its source to a point at the south of Walkerton before it turns sharply northwest toward Lake Huron. Its main tributaries are the North Branch, the Rocky Saugeen, the South Saugeen, and the Teeswater Rivers.

The North Branch rises to the northeast of Holland Centre and flows mainly in a southwesterly direction to meet the Saugeen River at Paisley. The Rocky Saugeen rises to the northeast of Markdale and flows mainly in a southwesterly direction to join the Saugeen River at Hanover. The South Saugeen rises to the northeast of Dundalk. It flows in a southwesterly direction to a point at the southwest of Mount Forest before it turns sharply northwest toward Hanover. The Beatty Saugeen River joins the South Saugeen at the south of Hanover and the combined rivers join the Saugeen River to the west of Hanover. The Teeswater River rises in the southern part of the Authority near Belmore. It flows in a westerly direction to a point at the southwest of Teeswater before it turns north toward Paisley where it joins the Saugeen River.

Numerous small streams drain into Lake Huron between Port Elgin and Lurgan Beach and are part of the Authority. The most important of these streams are the Little Sauble, North Penetangore, Pine, and South Pine Rivers.

Physiography: The landforms within Authority include drumlins, a ground moraine, moraines, sand and clay plains, glacial beaches, and swamps. The Saugeen Kame Moraines, the Walkerton Moraine, and parts of the Wyoming and Banks Moraines are within the Authority. According to Chapman and Putnam (1984), parts of seven physiographic regions occur in the Authority, including the Huron Fringe, Huron Slope, Arran Drumlin Field, Saugeen Clay Plain, Horseshoe Moraines, Teeswater Drumlin Field, and Dundalk Till Plain.

The Huron Fringe extends as a narrow band along Lake Huron and comprises the wave-cut terraces of glacial Lakes Algonquin and Nipissing with their boulders, gravel bars, and sand dunes. Across the mouth of the Saugeen Valley, Lake Algonquin built a massive beach of sand and gravel.

The Huron Slope extends parallel to the Huron Fringe from Port Elgin to the south of Kincardine. This physiographic region has been modified by a narrow strip of sand and by the twin beaches of glacial Lake Warren which flank the Wyoming Moraine. It is covered by lacustrine clay, which is one meter thick, on top of till deposits.

An area lying mainly in the northern part of the Authority contains numerous long narrow drumlins and is part of the Arran Drumlin Field physiographic region. According to Chapman and Putnam (1984), these drumlins, which are oriented almost southwest, have been formed by the advance of an ice from the basin now occupied by Georgian Bay.

The Saugeen Clay Plain is located completely within the Authority north of the Walkerton Moraine. It is underlain by deep stratified clay deposited in a bay of glacial Lake Warren. The Saugeen and Teeswater Rivers have cut deep valleys in these deposits.

Within the Authority, the Horseshoe Moraines have two main components. One component consists of irregular, stony knobs and ridges, and the other consists of gravel or swamp-floored valleys.

The Teeswater Drumlin Field occupies parts of the counties of Bruce, Grey, Huron, Wellington, and Perth. The field lies in front of the northwestern limb of the Horseshoe Moraine system. Within the Authority, the drumlins are low, broad oval hills with gentle slopes and an orientation which varies from almost north and south to almost northwest-southeast. Broad terraces of sand and gravel deposits fill much of the low ground between the drumlins

The headwater area of the Saugeen River is part of the Dundalk Plain which includes also the headwater areas of the Grand, Maitland, and Nottawasaga Rivers. Within the Authority, the Dundalk Plain is a till plain which is characterized by swamps and by poorly drained depressions.

<u>Bedrock Topography and Geology</u>: Within the Authority, the bedrock is exposed at the surface at the Bruce Nuclear Power Station on Lake Huron. Its surface elevation ranges from about 120.0 m (a.s.l.) at the mouth of the Saugeen River to more than 480.0 m (a.s.l.) within its headwaters near Dundalk. A large bedrock valley underlies the lower part of the Saugeen River.

The bedrock contains successive bands of different ages and widths that extend from the northwest to the southeast and dip to the southwest. It consists of the Amabel and Guelph Formations of Middle Silurian age, the Salina and Bass Island Formations of Upper Silurian age, the Bois Blanc Formation of Lower Devonian age, and the Detroit River Group of Middle Devonian age.

<u>Overburden Thickness and Geology</u>: The thickness of the overburden ranges from less than 10.0 m to more than 110.0 m. Within the central parts of the Authority the thickness of the overburden ranges between 30.0 and 90.0 m. It is less than 10.0 m within a narrow strip along Lake Huron and increases immediately to more than 110.0 m within a wide strip that runs parallel to Lake Huron. Another wide strip of thick overburden deposits extends from the Priceville area along the eastern boundary of the Authority to the Arthur area along its southern boundary.

The overburden consists of glacial, glaciofluvial, and glaciolacustrine deposits of Pleistocene age and alluvial and swamp deposits of Recent age. According to Barnett (1992), the glacial deposits contain four tills, namely, the Catfish Creek Till, Elma Till, Dundalk Till, and St. Joseph Till.

The Catfish Creek Till occurs within a small band along the Authorities northeastern boundaries. The Elma Till occurs as a ground moraine and in the drumlins of the Teeswater Drumlin Field. It is overlain in many places by glaciofluvial sand and gravel, glaciolacustrine silts, and younger tills. The Dundalk Till is found as a ground moraine in the Walkerton area. The St. Joseph Till occurs within the Wyoming Moraine which parallels the shore of Lake Huron and also within the Banks Moraine.

The glaciofluvial deposits, which consist of ice-contact and outwash sand and gravel, are found the central parts of the Authority within the Walkerton Moraine. They also occur south of Walkerton primarily as terrace and channel deposits and north of Hanover as deltaic deposits. Extensive deposits of glaciolacustrine sands, silt and clay occur at the surface at several locations. The largest of these deposits (more than 25.0 m thick) occur beneath the Greenock Swamp. Similar deposits occur north of the Walkerton Moraine and also north of Hanover.

Overburden Aquifers: A total of 11,735 bedrock wells has been identified within the Authority as compared to 1,354 overburden wells which indicates that the overburden is of limited importance as a source of water supply. The sand and gravel deposits of glaciofluvial and glaciolacustrine origin are the main local aquifers within the Authority. In addition, some sandy till deposits could act as aquifers.

Of the 1,354 overburden wells, 342 (25.3%) have no specific capacity data, 23 (1.7 %) have specific capacities less than 1.0 L/min/m, 161 (11.9%) have specific capacities between 1.0-5.0 L/min/m, 151 (11.1%) have specific capacities between 5.0-10.0 L/min/m, 443 (32.7%) have specific capacities between 10.0-50.0 L/min/m, and 234 (17.3%) have specific capacities above 50.0 L/min/m.

The Arthur-Mount Forest Aquifer: This name is suggested for a local aquifer that occurs within the Arthur-Mount Forest area in the southeastern part of the Authority. The records of 28 wells tapping this aquifer indicate that it consists of sand and gravel deposits that occur at the surface or are overlain by till or clay deposits up to 47.0 m in thickness. The thickness of the sand and gravel deposits range from 20.0 to 45.0 m. Where these deposits are at the surface, the aquifer is unconfined.

The elevation of the top of the unconfined part of the aquifer ranges from 381.0 to 438.0 m (a.s.l.), and the elevation of the top of its confined part ranges from 363.0 to 426.0 m (a.s.l.). The depths to the static water levels range from 2.0 to 18.0 m. Also, well yields range from 15.0 to 130.0 L/min. A few wells, however, report yields between 340.0 and 360.0 L/min. The specific capacities of most wells range between 10.0 and 50.0 L/min/m.

The Chesley Aquifer: This name is suggested for a local aquifer that occurs in the vicinity of Chesley and to the north of it along the northern boundary of the Authority. The records of 27 wells tapping this aquifer indicate that it consists of gravel and sand deposits that range in thickness from 10.0 to 44.0 m. In places these deposits are overlain by up to 21.0 m of clay and till. Where the sand and gravel deposits are at the surface, the aquifer is unconfined.

The elevation of the top of the unconfined part of the aquifer ranges from 282.0 to 309.0 m (a.s.l.), and the elevation of the top of the confined part ranges from 262.0 to 303.0 m (a.s.l.). Water is found at elevations between 253.0 and 295.0 m (a.s.l.), and the depths to the static water levels range from 1.0 to 12.0 m. Well yields range from 15.0 to 130.0 L/min, and the specific capacities of most wells range between 10.0 and 50.0 L/min/m.

The Dundalk Aquifer: This name is suggested for a local aquifer that occurs within the northeastern part of the Authority in the vicinity of Dundalk. The records of 21 wells that obtain water from this aquifer indicate that it consists of gravel and sand deposits that range in thickness from 7.0 to 15.0 m. In places, the aquifer is overlain by up to 18.0 m of a till-like deposit. Where the sand and gravel deposits are at the surface, the aquifer is unconfined.

The elevation of the unconfined part of the aquifer ranges from 518.0 to 525.0 m (a.s.l.) and the elevation of the confined part ranges from 501.0 to 512.0 m (a.s.l.). Water is found at elevations between 458.0 and 512.0 m (a.s.l.), and the depths to the static water levels range from 2.0 to

11.0 m. Well yields range from 20.0 to 120.0 L/min, and the specific capacities of most wells range between 5.0 and 50.0 L/min/m.

The Durham Aquifer: This name is suggested for a local aquifer that occurs in the vicinity of Durham. The records of 44 wells tapping the aquifer indicate that it consists of sand and gravel deposits that occur at the surface and range in thickness from13.0 to 42.0 m.

The elevation of the top of the aquifer range from 290.0 to 389.0 m (a.s.l.), the water is found at elevations between 268.0 and 352.0 m (a.s.l.), and the depths to the static water levels range from 2.0 to 34.0 m. Well yields range from 25.0 to 130.0 L/min, and the majority of wells have specific capacities ranging between 10.0 and 50.0 L/min/m.

The Elgin-Southampton Aquifer: This name is suggested for a local aquifer that occurs within the lower part of the Saugeen River basin in the vicinity of Elgin and Southampton. The records of 27 wells that obtain water from this aquifer indicate that it consists of sand and gravel deposits that range in thickness from 6.0 to 20.0 m. In places, the aquifer is overlain by up to 13.0 m of clay deposits. Where the sand and gravel deposits are at the surface, the aquifer is unconfined.

The elevation of the unconfined part of the aquifer ranges from 183.0 to 206.0 m (a.s.l.) and the elevation of the confined part ranges from 191.0 to 197.0 m (a.s.l.). Water is found at elevations between 173.0 and 207.0 m (a.s.l.), and the depths to the static water levels range from 1.0 to 8.0 m. Well yields range from 15.0 to 90.0 L/min, and the specific capacities of most wells range between 10.0 and 50.0 L/min/m.

The Hanover Aquifer: This name is suggested for a local aquifer that occurs in the vicinity of Hanover. The records of 52 wells that obtain water from this aquifer indicate that it consists of sand gravel deposits that range in thickness from a few metres up to 33.0 m. The aquifer is mainly confined by up to 35.0 m of till and clay deposits. In places, however, the sand and gravel deposits are at the surface where the aquifer is unconfined.

The elevation of the unconfined part of the aquifer ranges from 259.0 to 306.0 m (a.s.l.) and the elevation of the confined part ranges from 231.0 to 288.0 m (a.s.l.). Water is found at elevations between 219.0 and 306.0 m (a.s.l.), and the depths to the static water levels range from less than one metre to 17.0 m. Well yields range from 20.0 to 225.0 L/min. Two wells, however, are reported to yield 3,180.0 and 3,190.0 L/min, respectively. The majority of wells have specific capacities that range between 10.0 and 50.0 L/min/m.

The Holstein Aquifer: This name is suggested for an aquifer that extend between Durham and Mount Forest. The records of 57 wells tapping the aquifer indicate that it consists of gravel and sand deposits that range in thickness from 14.0 to 68.0 m. The aquifer is mainly unconfined. In places, however, the sand and gravel deposits are overlain by up to 35.0 m of till and clay deposits.

The wellhead elevations range from 351.0 to 451.0 m (a.s.l.), and the elevation of the top of the confined part of the aquifer ranges from 352.0 to 393.0 m (a.s.l.). Water is found at elevations between 325.0 and 432.0 m (a.s.l.), and the depths to the static water levels range from 2.0 to 37.0 m. Well yields range from 20.0 to 180.0 L/min. One well, however, is reported to yield 450.0 L/min. The majority of wells have specific capacities that range between 10.0 and 50.0 L/min/m.

The Markdale Aquifer: This name is suggested for a local aquifer that occurs in the vicinity of Markdale in the northeastern part of the Authority. The records of 22 wells that obtain water from this aquifer indicate that it consists of gravel and sand deposits that range in thickness from 18.0 to 41.0 m. In places these deposits are overlain by up to 25.0 m of clay and till. Where the sand and gravel deposits are at the surface, the aquifer is unconfined.

The elevation of the top of the unconfined part of the aquifer ranges from 396.0 to 426.0 m (a.s.l.), and the elevation of the top of the confined part ranges from 408.0 to 430.0 m (a.s.l.). Water is found at elevations between 358.0 and 421.0 m (a.s.l.), and the depths to the static water levels range from 1.0 to 18.0 m. Well yields range from 15.0 to 90.0 L/min. One well, however, is reported to yield 1,800.0 L/min. The majority of wells have specific capacities that range between 10.0 and 50.0 L/min/m.

The Priceville Aquifer: This name is suggested for a local aquifer that occurs in the vicinity of Priceville in the eastern part of the Authority. The records of 31 wells tapping this aquifer indicate that it consists of gravel and sand deposits that range in thickness from 21.0 to 71.0 m. In places these deposits are overlain by up to 30.0 m of a till-like deposit. Where the sand and gravel deposits are at the surface, the aquifer is unconfined.

The elevation of the top of the unconfined part of the aquifer ranges from 456.0 to 494.0 m (a.s.l.), and the elevation of the top of the confined part ranges from 431.0 to 472.0 m (a.s.l.). Water is found at elevations between 404.0 and 459.0 m (a.s.l.), and the depths to the static water levels range from less than one metre to 17.0 m. Well yields range from 25.0 to 160.0 L/min. The majority of wells have specific capacities that range between 5.0 and 50.0 L/min/m.

The Walkerton Aquifer: This name is suggested for a local aquifer that occurs in the vicinity of Walkerton. The records of 21 wells tapping this aquifer indicate that it consists of gravel and sand deposits that range in thickness from 1.0 to 12.0 m. In places the aquifer is overlain by clay and till deposits that can reach 15.0 m in thickness.

The elevation of the top of the unconfined part of the aquifer ranges from 247.0 to 288.0 m (a.s.l.), and the elevation of the top of the confined part ranges from 236.0 to 295.0 m (a.s.l.). Water is found at elevations between 230.0 and 285.0 m (a.s.l.), and the depths to the static water levels range from 2.0 to 17.0 m. Well yields range from 25.0 to 225.0 L/min. Two wells, however, report yields of 500.0 and 1,150.0 L/min, respectively. The specific capacities of most wells range between 10.0 and 50.0 L/min/m.

8.4.2 The Maitland Valley Conservation Authority

Location: The Maitland Valley Conservation Authority (the Authority) is bounded on the north by the Saugeen Valley Conservation Authority, on the east by the Grand River Conservation Authority, on the south by the Ausable Bayfield and Upper Thames River Conservation Authorities, and on the west by Lake Huron. The Authority includes parts of the Counties of Bruce, Huron, Perth, and Wellington. Many small urban centres are within the Authority, including Blyth, Brussels, Goderich, Harrison, Listowel, Lucknow, Kinloss, Palmerston, Wallace, West Wawanosh, and Wingham (Figure 38).

Drainage: The Maitland River, which drains about 2,540.0 km^2, is the largest stream within the Authority. The main branch of the river rises within a swampy, flat area near Harriston and flows westward through the Teeswater Drumlin Field to Wingham where it is joined from the south by the Little and the Middle Maitland Rivers. From Wingham the river flows in a southwesterly direction through a deep valley until it reaches Holmesville and from there it flows in a northwesterly direction to enter Lake Huron at Goderich. A few tributaries enter the lower stretches of the river. The largest of these tributaries is the South Maitland River which rises within a clay plain north and east of Seaforth and flows in a northwesterly direction to join the Maitland River from the south at Benmiller. The Sharpes Creek also joins the Maitland River from the north at the same point.

The Nine Mile River is the second largest stream within the Authority. A part of the headwaters of this river is within the Saugeen Conservation Authority. The river flows through Lucknow and enters Lake Huron at Port Albert.

Physiography: The Wyoming and Wawanosh Moraines are two prominent landforms within the Authority. The Wyoming Moraine runs from Kinloss in the north through Lucknow to Goderich in the south. The Wawanosh Moraine, on the other hand, runs to the east of the Wyoming Moraine as a belt, about eight kilometres wide, which consists of low till ridges and hills of sand and gravel. Other landforms include drumlins, a ground moraine, sand and clay plains, spillways, beaches, and swamps. Chapman and Putnam (1984) identified parts of five physiographic regions within the Authority, including the Huron Slope, Horseshoe Moraines, Teeswater Drumlin Field, Dundalk Till Plain, and Stratford Till Plain.

The land extending between Lake Huron on the west and the Wyoming Moraine on the east is part of the Huron Slope physiographic region. Within the Authority, this region is essentially a clay plain, modified by a narrow strip of sand and by the twin beaches of glacial Lake Warren which flank the moraine.

A strip of land extending to the east of the Huron Slope is part of the Horseshoe Moraines physiographic region. Within the Authority, this region includes the Wyoming and Wawanosh Moraines. Also, associated with this region are the gravel spillways and the swamp-floored valleys of the Maitland River system.

The Teeswater Drumlin Field occupies the northeastern part of the Authority from Wingham in the west to Harrison, Palmerston, and Wallace in the east lying in front of the limb of the Horseshoe Moraines. The region contains numerous drumlins which gradually fade out toward the outer margins of the field. Most of the drumlins are low, oval hills with gentle slopes. Orientation of their axes varies from almost north and south in the Wingham area to almost northwest-southeast in the country between Palmerston and Harriston. Broad large valleys have been cut by the Maitland River system throughout this physiographic region.

A gently undulating plain with a few low drumlins to the south of the Teeswater Drumlin Field is part of the Dundalk Till Plain. Most of the headwaters of the Maitland River are in this region and they form a network of small flat-floored valleys which connect with the Maitland spillway systems. The valleys are frequently swampy, and contain small streams or no streams at all.

A portion of the Authority, sandwiched among the Horseshoe Moraines to the west and the Teeswater Drumlin Field and the Dundalk Till Plain to the north and east, is occupied by the Stratford Till Plain. This region is mostly a level area of a ground moraine modified by a few small moraines.

Bedrock Topography and Geology: No part of the bedrock within the Authority is exposed at the surface. The bedrock elevation ranges from about 160.0 m (a.s.l.) along Lake Huron to more than 360.0 m (a.s.l.) along the Authority's eastern boundary.

According to Johnson et al. (1992), the bedrock geology consists of the Salina and the Bass Island Formations of Upper Silurian age, the Bois Blanc Formation of Lower Devonian age, and the Detroit River Group and the Dundee Formation of Middle Devonian age.

Overburden Thickness and Geology: The overburden thickness ranges from about 10.0 m to more than 70.0 m. According to Barnett (1992), the overburden consists of glacial, glaciofluvial, glaciolacustrine deposits of Pleistocene age and alluvial deposits of Recent age.

Five tills occur within the Authority, namely, the Tavistock Till, Mornington Till, Elma Till, Rannoch Till, and St. Joseph Till. The Tavistock Till is found within a very small locale in the northeastern tip of the Authority and the Mornington Till occurs along the southeastern corner of the Authority to the east of Mornington and Milverton.

Most of the eastern half of the Authority is covered by the Elma Till which occurs as a ground moraine and within drumlins. The Rannoch Till is found in the vicinity of West Wawanosh in the north and within an area extending from McKillop to the Authority's southern boundary. The St. Joseph Till occurs as a wide band extending along the shore of Lake Huron from the northern boundary of the Authority to its southern boundary.

Sand and gravel deposits of glaciofluvial origin are displayed at the surface over large areas. Most of these deposits are associated with the Wawanosh Moraine. Ice-contact deposits occur over large areas extending from the vicinity of Blyth to the Authority's southern boundary and east to the vicinity of Brussels. Also, smaller bodies of ice-contact deposits occur to the east of Kinloss, in the vicinity of Grey, and to the northeast of Howick. The outwash deposits, on the other hand, occur within the central and northern parts of the Authority.

A few narrow glaciolacustrine sand plains occur within the Huron Slope physiographic region. These deposits are bounded on the east by the abandoned shore bluffs left by glacial Lake Warren. Silt and clay deposits of glaciolacustrine origin are found at several locations mainly within the southeastern parts of the Authority. In addition, fluvial deposits of recent origin are found within the flood plain of the Maitland River system.

Overburden Aquifers: A total of 8,805 bedrock wells has been identified within the Authority as compared to 237 overburden wells which indicates that the overburden is of minor importance a source of water supply. Of the 237 overburden wells, 91 (38.4%) have no specific capacity data, 5 (2.1%) have specific capacities of less than 1.0 L/min/m, 26 (11.0%) have specific capacities between 1.0-5.0 L/min/m, 25 (10.5%) have specific capacities between 5.0-10.0 L/min/m, 55 (23.2%) have specific capacities between 10.0-50.0 L/min/m, and 35 (14.8%) have specific capacities above 50.0 L/min/m.

No major overburden aquifers have been identified within the Authority. Two local aquifers, however, have been identified. One aquifer is located within the northeastern tip of the Authority to the northeast of Palmerston and the other is located within the southeastern tip of the Authority in the vicinity of Milverton.

The records of six wells, which tap the first aquifer, indicate that it consists of up to 14.0 m of sand and gravel under a till-like deposit. The wellhead elevations range from 415.0 to 430.0 m (a.s.l.), and the elevations at which water was found range from 357.0 to 406.0 m (a.s.l.). The depth of the wells ranges from 14.0 to 60.0 m and the depths to the static water levels range from 5.0 to 19.0 m. The records also indicate that the aquifer is confined and yields from 45.0 to 115.0 L/min. The specific capacities for the wells range from about 10.0 to 50.0 L/min/m.

The records of six wells, which tap the second aquifer, indicate that it consists of a few metres of sand and gravel under a till-like deposit. The wellhead elevations range from 374.0 to 383.0 m (a.s.l.), and the elevations at which water was found range from 320.0 to 375.0 m (a.s.l.). The depth of the wells ranges from 17.0 to 57.0 m and the depths to the static water levels range from 3.0 to 14.0 m. The records also indicate that the aquifer is confined and yields from

45.0 to 135.0 L/min. The specific capacities for the wells range from about 10.0 to more than 50.0 L/min/m.

8.4.3 The Ausable-Bayfield Conservation Authority

Location: The Ausable-Bayfield Conservation Authority (the Authority) is located in the southwestern part of southern Ontario and covers about 2,440.0 km^2. It is bounded on the north by the Maitland Conservation Authority, on the east by the Upper Thames Conservation Authority, on the south by the St. Clair Region Conservation Authority, and on the west by Lake Huron. The Authority includes parts of the Counties of Huron, Lambton, Middlesex, and Perth. Many small urban centres are within the Authority, including Alisa Craig, Bayfield, Clinton, Dashwood, East Williams, Exeter, Grand Bend, Hensall, Lucan, Parkhill, Port Franks, Stanley , and West Williams (Figure 39).

Drainage: The Authority encompasses the drainage watersheds of the Ausable River, the Bayfield River, the Parkhill Creek and the small streams between Bayfield and Grand Bend that drain directly to Lake Huron. The Ausable River, which drains about 415.0 km^2, originates along the front of the Wyoming Moraine as well as within the clay plain to the north and east of Exeter. The river follows the depression in front of the moraine as far as Arkona where it cuts a 30-meter deep valley through the overburden and the bedrock. From Arkona the river flows in a northerly direction cutting through the Wyoming Moraine until it reaches the Thedford Marsh, a shallow bay formed by glacial Lakes Algonquin and Nipissing. Once the river crosses this depression, it turns southwestward and makes its way through sand dunes before entering Lake Huron at Port Franks. According to Chapman and Putnam (1984), in 1875 a canal was cut through the dunes, draining the swamp and providing a direct route to Lake Huron. Between the head of the cut and the mouth of Parkhill (Mud) Creek, the Ausable is dead.

The Parkhill Creek and the Little Ausable are the main tributaries of the Ausable River. The Parkhill Creek rises east of Dashwood and flows through a deep valley in a southerly direction to Parkhill. From there, the creek turns westward until it joins the canal built in 1875. The Little Ausable, on the other hand, rises to the east of Exeter and flows in a southerly direction to a point west of Lucan. From there, the tributary turns west to enter the Ausable north of Alisa Craig.

The Bayfield River is located between the Maitland River in the north and the Ausable River in the south. The river, which drains an area of about 520.0 km^2, rises within a till plain in the vicinity of Dublin and in the vicinity of Brandy Point outside the Authority. The river flows in a northwesterly direction until it reaches a point to the south of Clinton where it turns southwest for about seven kilometres. From there, the river starts to flow in a northwesterly direction until it enters Lake Huron at Bayfield. The lower Bayfield valley is about 30.0 m deep and about 600.0 m wide.

Physiography: Landforms within the Authority include moraines, a ground moraine, clay plains, sand dunes, and spillways. The Wyoming and Seaforth Moraines run in parallel through the Authority from north to south while the Centralia Moraine trends south through Centralia. Chapman and Putnam (1984) identified parts of four physiographic regions within the Authority, including the Huron Fringe, Huron Slope, Horseshoe Moraines, and Stratford Till Plain.

A narrow strip of land that extends along Lake Huron from north to south is part of the Huron Fringe. Between the northern boundary of the Authority and Grand Bend, the Huron Fringe is very narrow and is bordered by a shorecliff 15.0 to 30.0 m high. Below Grand Bend, the strip becomes wider and consists of sand dunes, a clay plain, and lagoons including the Thedford Marsh.

The land extending between the Huron Fringe on the west and the Wyoming Moraine on the east is part of the Huron Slope. Within the Authority, the Huron Slope is essentially a clay plain, modified by a narrow strip of sand and by the twin beaches of glacial Lake Warren.

A wide strip of land extending along the Huron Slope from the east is part of the Horseshoe Moraines. Within the Authority, this physiographic region includes parts of the Wyoming and Seaforth Moraines and the associated gravel or swamp-floored valleys.

In addition, a portion of Stratford Till Plain covers the eastern part of the Authority. It is mostly a level plain that is covered by a ground moraine.

<u>Bedrock Topography and Geology</u>: No part of the bedrock within the Authority is exposed at the surface. The bedrock elevation ranges from about 160.0 m (a.s.l.) along the shore of Lake Huron to more than 320.0 m (a.s.l.) along the Authority's eastern boundary.

According to Johnson et al. (1992), the bedrock geology consists of the Detroit River Group, the Dundee Formation, and the Hamilton Group of Middle Devonian age. The Detroit River Group is found within two small areas; one area is to the southeast of Dublin and the second is between Stanley and Hensall. Most of the Authority is covered with the Dundee Formation. A narrow strip of land extending along the southern and southwestern boundaries of the Authority is underlain by the Hamilton Group.

<u>Overburden Thickness and Geology</u>: As indicated above, the overburden covers all the bedrock within the Authority. Its thickness ranges from about 10.0 m to more than 70.0 m. According to Barnett (1992), the overburden consists mainly of glacial, glaciofluvial, and glaciolacustrine deposits of Pleistocene age and some fluvial and lacustrine deposits of Recent age.

Two tills occur within the Authority, namely, the Rannoch Till and St. Joseph Till. The Rannoch Till is found within a band extending from the northern to the southeastern boundaries of the Authority. The St. Joseph Till, on the other hand, is found as a wide band extending along the shore of Lake Huron from north to south.

The ice-contact deposits of sand and gravel are displayed at the surface in a few locations within the northeastern parts of the Authority and at one location close to its southern boundary. The outwash deposits, on the other hand, are found as narrow bands within the central and northern parts of the Authority extending from the vicinity of Clinton in the north to the west of Centralia in the south. They are also found in the vicinity of Alisa Craig in the south.

A few narrow sand plains of glaciolacustrine origin are found within the Huron Slope physiographic region. They are bounded on the east by the abandoned shore bluffs left by glacial Lake Warren. Silt and clay deposits of glaciolacustrine origin are found at several locations mainly along the Lake Huron shoreline in the north, in the vicinity of Parkhill and Thedford, and to the south of Alisa Craig and East Williams.

In addition, a belt of lacustrine sand dunes occurs south of Grand Bend. Also, fluvial deposits are found as beaches along Lake Huron and as fluvial deposits within the flood plains of various streams.

Overburden Aquifers: A total of 3,879 bedrock wells has been identified within the Authority as compared to 2,786 overburden wells indicating that the overburden is a significant source of water supply. This is specifically true in the eastern and southern parts of the Authority where a highly productive aquifer occurs below the Rannoch Till.

Of the 2,786 overburden wells, 818 (29.4%) have no specific capacity data, 267 (9.6%) have specific capacities of less than 1.0 L/min/m, 637 (22.8%) have specific capacities between 1.0 - 5.0 L/min/m, 252 (9.0%) have specific capacities between 5.0-10.0 L/min/m, 540 (19.4%) have specific capacities between 10.0-50.0 L/min/m, and 272 (9.8%) have specific capacities above 50.0 L/min/m.

The Ausable Aquifer: This name is suggested for what appears to be the most productive overburden aquifers within the Lake Huron basin. This confined aquifer occurs as a band extending along the eastern and southern half of the Authority. The surface deposits consist mainly of the Rannoch Till, and small amounts of glaciofluvial sand and glaciolacustrine clay. The glaciofluvial deposits at the southwestern end of the aquifer provide the opportunity for some recharge. The source of the recharge to the remaining parts of the aquifer is not clear.

The records of 367 wells that obtain water from the aquifer were examined. They indicate that the aquifer consists mainly of gravel deposits with some medium sand in the north that change into medium and fine sand toward the south. Most of the wells penetrate one or a few metres of this aquifer. The wells can be classified into three groups based on location and wellhead elevation.

The first group, which is located within the northern part of the aquifer extending from Seaforth to Exeter, has wellhead elevations between 282.0 and 347.0 m (a.s.l.) and the well depths range from 4.0 to 25.0 m. Water is found at elevations between 271.0 and 345.0 m (a.s.l.), and the depths to the static water levels are between 1.0 and 13.0 m. Well yields range from 20.0 to 250.0 L/min and some wells yield up to1,590.0 L/min. The thickness of the aquifer in this area is less than 10.0 m and the aquifer material is mostly gravel.

The second group, which is located within the central part of the aquifer extending from Exeter to East Williams and Lobo, has wellhead elevations between 238.0 and 299.0 m (a.s.l.) and well depths that range from 3.0 to 28.0 m. Water is found at elevations between 230.0 and 292.0 m (a.s.l.), and the depths to the static water levels range from less than one metre to 21.0 m. Well yields range from 15.0 to 225.0 L/min. The thickness of the aquifer in this area is also less than 10.0 m and the aquifer material is sand and gravel.

The third group, which is located within the southern part of the aquifer extending from East Williams and Lobo to the vicinity of Warwick, has wellhead elevations between 221.0 and 264.0 m (a.s.l.) and depths that range from 7.0 to 41.0 m. Water is found at elevations between 211.0 and 248.0 m (a.s.l.), and the depths to the static water levels range from l2.0 to 27.0 m. Well yields range from 5.0 to 275.0 L/min. The thickness of the aquifer in this area is also less than 15.0 m and the aquifer material is mostly sand.

The Sand Dunes Aquifer: This name is suggested for a local water table aquifer that occurs within the sand dunes south of Grand Bend. The records of 30 wells that obtain water from this aquifer indicate that it consists of medium sand that ranges in thickness from 1.0 to 23.0 m. One well, however, penetrates 50.0 m of sand and gravel.

The wellhead elevations range from 181.0 to 201.0 m (a.s.l.) and the well depths range from 5.0 to 23.0 m. Two wells, however, have depths of more than 52.0 m. Water is found at elevations between 173.0 and 193.0 m (a.s.l.). Well yields range from 15.0 to 180.0 L/min. One well, however yields 455.0 L/min.

8.5 OVERBURDEN AQUIFERS IN AREAS DRAINING INTO LAKE ST. CLAIR

8.5.1 The St. Clair Region Conservation Authority

Location: The St. Clair Region Conservation Authority (the Authority) is located in the southwestern part of southern Ontario. It is bounded on the east and southeast by the Thames River basin, on the south by Lake St. Clair, on the west by the Detroit River, on the northwest by Lake Huron, and on the northeast by the Ausable Bayfield Conservation Authority. The Authority includes parts of Kent, Lambton, and Huron Counties. The largest urban centre within the Authority is Sarnia. Other important urban centres are Alvinston, Brigden, Dresden, Forest, Florence, Mount Bridges, Petrolia, Strathroy, Wallaceburg, Warwick, and Wyoming (Figure 40).

Drainage: With the exception of the small streams that drain directly into the Detroit River and Lake Huron, drainage within the Authority is nearly all southward through the Sydenham River system. The Sydenham River drains an area of about 2,900.0 km^2 and empties into Lake St. Clair. Its watershed is mostly a clay plain of little relief in which poor drainage prevails. The river consists of two main branches, the Main Sydenham River and the North Sydenham River. The Main Sydenham River rises between the Lucan and Seaforth Moraines to the northeast of Strathroy. The North Sydenham River, on the other hand, rises between the Wyoming and Seaforth Moraines to the northeast of Warwick. The two branches join at Wallaceburg and from that point, the Sydenham moves toward Lake St. Clair and enters it at Mitchell Bay. Due to the prevalence of shallow valleys and low gradients, the Sydenham watershed is prone to floods.

Physiography: Landforms within the Authority include the southern tips of the Wyoming, Seaforth and Lucan Moraines. It also includes extensive clay plains, till plains, sand dunes, abandoned beaches, and swamps. Chapman and Putnam (1984) identified five physiographic regions within the Authority, namely, the Bothwell Sand Plain, Ekfrid Clay Plain, Horseshoe Moraines, Huron Slope, and St. Clair Clay Plains.

According to Chapman and Putnam (1984), the Bothwell Sand Plain is the delta of the Thames River in glacial Lake Warren. The plain occurs within the northeastern tip of the Authority and along its southeastern boundary.

The Ekfrid Clay Plain occurs in the northeastern parts of the Authority as a nearly level area consisting of stratified clays. Here and there, low smooth ridges are superimposed on the clay plain.

Within the Authority, the Horseshoe Moraines contain parts of three moraines, the Wyoming, Seaforth, and Lucan Moraines. The Wyoming Moraine, which consists of clay till, forms a single broad ridge which fades out about six kilometres west of Wyoming. The Seaforth Moraine extends between Watford and Arkona as a broad ridge. The southern reaches of this moraine, however, beyond Watford are too faint to be mapped. The Lucan Moraine can be traced in the northeastern part of the Authority. Compared to the Seaforth Moraine, it is somewhat weaker and less bulky.

A narrow strip of land extending along Lake Huron from Sarnia to the northern boundary of the Authority is part of the Huron Fringe physiographic region. It comprises terraces and beach deposits.

According to Chapman and Putnam (1984), glacial Lakes Whittlesey and Warren, which covered all of the St. Clair Clay Plains, failed to leave deep stratified beds of sediment on the underlying clay till. Therefore, this physiographic region is essentially a till plain smoothed by shallow deposits of lake origin (lacustrine clay).

Bedrock Topography and Geology: All the bedrock within the Authority is obscured by a mantle of overburden deposits. Most of the bedrock elevation is between 120.0 and 200.0 m (a.s.l.). A bedrock ridge ranging in elevation from 200.0 to 240.0 m (a.s.l.) is located in the upper parts of the Authority.

According to Johnson et al. (1992), the bedrock geology consists of the Hamilton Group of Middle Devonian age, the Kettle Point Formation of Upper Devonian age, and the Port Lambton Group of Mississippian age.

Overburden Thickness and Geology: Over most of the western part of the Authority the overburden ranges from 30.0 to 50.0 m. An exception is a small area along the Detroit River between Port Lambton and Courtright where the thickness of the overburden is between 50.0 and 70.0 m. The thickness of the overburden within the eastern and northeastern parts of the Authority ranges between 30.0 and more than 70.0 m.

The overburden consists mainly of glacial and glaciolacustrine deposits and a minor amount of glaciofluvial ice contact deposits of Pleistocene age. It also contains alluvium, beach, muck and swamp deposits of Recent age.

Two tills have been identified within the Authority, the Rannoch Till and the St. Joseph Till (Barnett 1992). The Rannoch Till occurs mainly to the east and southeast of the North Sydenham River as a ground moraine. It is also found in the Lucan and Seaforth Moraines. The St. Joseph Till, on the other hand, occurs to the west and northwest of the North Sydenham River. It also occurs within the Wyoming Moraine.

Sand and gravel deposits of glaciolacustrine origin are found mainly in the northeastern part of the Authority and along its southeastern boundary. Deposits of glaciolacustrine clay are found within the flood plains of the two branches of the Sydenham River as well as to the southeast of the Main Branch.

In addition, recent lacustrine sand, gravelly sand and gravel as well as beach deposits are found within the Sarnia and the St. Clair Lake areas. Also, organic deposit of peat, muck and marl are found along the shore of Lake St. Clair.

Overburden Aquifers: A total of 7,452 bedrock wells has been identified within the Authority as compared to 4,165 overburden wells indicating that the overburden is an important source of water supply. Of the 4,165 overburden wells, 1,471 (35.3%) have no specific capacity data, 268 (6.4%) have specific capacities of less than 1.0 L/min/m, 677 (16.2%) have specific capacities between 1.0-5.0 L/min/m, 461(11.1%) have specific capacities between 5.0-10.0 L/min/m, 815 (19.6%) have specific capacities between 10.0-50.0 L/min/m, and 473 (11.4%) have specific capacities above 50.0 L/min/m.

The main overburden aquifers are the sand deposits that are either exposed at the surface or exist at various depths within the overburden. Some overburden wells have water of poor natural quality (salty, sulphurous or containing gas).

The Bothwell Aquifer: This name is suggested for an aquifer that is located in the northeastern part of the Authority within the Bothwell Sand Plain physiographic region. It consists of deltaic sand deposits that are mostly exposed at the surface and range in thickness from several metres up to 28.0 m. In places, the aquifer is covered by a few metres of clay. The records of 370 wells penetrating the aquifer indicate that the wellhead elevations range from 226.0 to 263.0 m (a.s.l.), and the elevation of the top of the aquifer ranges from 214.0 to 252.0 m (a.s.l.).

Where the aquifer is exposed at the surface, it is unconfined. The depths to the static water levels range between 1.0 and 27.0 m. For the majority of wells, however, the depths are less than 10.0 m. The reported well yields range between 15.0 and 350.0 L/min. Several wells, however, report yields between 450.0 and 900.0 L/min. The majority of the wells have specific capacities between 10.0 and more than 50.0 L/min/m.

The Coldstream Aquifer: This name is suggested for a confined aquifer that is located within the northeastern tip of the Authority. The aquifer consists of sand and gravel deposits that range in thickness from about one to 11.0 m. The aquifer is overlain by till deposits that are up to 10.0 m in thickness. The records of 154 wells penetrating the aquifer indicate that the wellhead elevations range from 245.0 to 283.0 m (a.s.l.), and the elevation of the top of the aquifer ranges from 230.0 to 270.0 m (a.s.l.).

The depths to the static water levels range from less than one metre to 20.0 m. The reported well yields range between 5.0 and 275.0 L/min. Many wells have specific capacities between 10.0 and more than 50.0 L/min/m.

The Alvinston- Rutherford Aquifer: This name is suggested for a confined aquifer that extends from the vicinity of Alvinston in the northeast to the vicinity of Rutherford in the southwest. The aquifer consists mainly of gravel with some sand deposits that are about one metre thick. The aquifer is overlain by clay and till deposits that range in thickness from several metres to more than 20.0 m. The records of 125 wells penetrating the aquifer indicate that the wellhead elevations range from 182.0 to 224.0 m (a.s.l.), and the elevation of the top of the aquifer ranges from 165.0 to 202.0 m (a.s.l.).

The depths to the static water levels range from less than one metre to 14.0 m. The reported well yields range between 15.0 and 115.0 L/min. Many wells have specific capacities between 10.0 and more than 50.0 L/min/m.

The Wallaceburg Aquifer: This name is suggested for a confined aquifer that occurs within an area that extends from vicinity of Wallaceburg in the east to the Detroit River in the west. The aquifer consists of gravel and sand deposits that are about one metre in thickness.

The aquifer is overlain by sand, clay and till-like deposits that range in thickness from several metres to more than 30.0 m. The records of 93 wells penetrating the aquifer indicate that the wellhead elevations range from 176.0 to 182.0 m (a.s.l.), and the elevation of the top of the aquifer ranges from 134.0 to 167.0 m (a.s.l.). The depths to the static water levels range from 2.0 to 14.0 m, but these depths in most wells are less than 10.0 m. The reported well yields range between 10.0 and 100.0 L/min. Many wells have specific capacities between 10.0 and 50.0 L/min/m.

In addition, a number of small local aquifers occur in the vicinity of Sarnia, in the vicinity of Bridges, and along the southeastern boundary of the Authority.

8.5.2 The Thames River Basin

Location: The Thames River basin (the basin) is located in southwestern part of southern Ontario. It is bounded on the northeast by the Maitland and Grand River basins; on the southeast by the Long Point Authority, the Catfish and Kettle Creek watersheds and small catchments draining into Lake Erie; and on the northwest by the Ausable and Sydenham River basins (Figure 41).

The basin includes parts of Elgin, Essex, Huron, Kent, Lambton, Middlesex, Oxford, and Perth Counties. It has a total area of about 5,700.0 km^2, and a length of about 200.0 km from its headwaters in Oxford and Perth Counties to its mouth at Lake St. Clair near Tilbury. Two conservation authorities operate in the basin, the Upper Thames Conservation Authority and the Lower Thames Conservation Authority.

The most important component of the basin's economy is agriculture. Agricultural activities include livestock raising, dairying, production of corn, soybeans, mixed grains, oats, tobacco, wheat, and hay. The agricultural base is complemented by industry and commerce in several urban centres, including London, Ingersoll, Woodstock, Chatham, and Stratford. Other smaller urban centres are Bothwell, Innerkip, Mitchell, St. Mary's, Tavistock, and Thamesford.

Drainage: The basin can be divided into two main parts, the Upper Thames and the Lower Thames. The Upper Thames basin is almost round in shape and has an area about 3,575.0 km^2. It is being drained by the North Thames River, the Middle Branch, and the South Branch. The North Thames rises to the north of Mitchell and flows south toward London. It has several tributaries, including the Avon and the Medway Rivers, and the Flat, Trout, and Fish Creeks. The Middle Thames rises in the East Zorra-Tavistock Township and flows southwesterly to meet the South Thames near Putnam. The South Branch rises west of Tavistock and travels in a southeasterly direction to Innerkip. From there, it swings southwest toward Woodstock, Ingersoll and London. Its main tributaries are the Cedar Creek, which joins it at Woodstock, and the Middle Thames and the Reynolds Creek which join it at Putnam.

The Lower Thames River basin is about 2,250.0 km^2 and extends from London to Lake St. Clair. The basin is roughly rectangular in shape, with a length of about 137.0 km and a maximum width of about 22.0 km. There are numerous short tributaries to the Lower Thames. Those tributaries entering the main stream from the north are generally less than 15.0 km long, and those tributaries entering it from the south are generally longer and drain larger areas.

Physiography: The topography of the basin is relatively flat and the main landforms are moraines, a ground moraine, and clay and sand plains. The most prominent moraines within the basin are the Ingersoll, Lucan, Milverton, and Mitchell Moraines. Chapman and Putnam (1984) identified parts of seven physiographic regions within the basin, namely, the Stratford Till Plain, Oxford Till Plain, Mount Elgin Ridges, Caradoc Sand Plains, Ekfrid Clay Plain, Bothwell Sand Plain, and St. Clair Clay Plains.

Most of the central and southern portions of the Stratford Till Plain is within the basin, extending from the northwestern boundary to London. The region is covered by a ground moraine interrupted by several terminal moraines.

The Oxford Till Plain occurs within the upper part of the basin in Oxford County. It is a drumlinized till plain, with well-formed drumlins appearing south of Woodstock and faint drumlins and flutings farther north. Both the drumlins and flutings have a northwest alignment. A group of kames, around Lakeside in the northwest corner of Oxford County, is also included in this region.

A small area along the southeastern boundary of the basin is occupied by the Mount Elgin Ridges. The Ingersoll Moraine is part of this region and its northern slope drains directly into the Thames River.

The Caradoc Sand Plains occur in the vicinity of London. It consists of a series of small plains which are covered mainly with sand deposits. The surface of this physiographic region is nearly level and its sand deposits thin out toward the west until the underlying clay deposits appear at the surface.

The Ekfrid Clay Plain is located west and south of the Caradoc Sand Plain and consists of stratified clays. The surface is nearly level except where it is cut by gullies near the Thames River. Chapman and Putnam (1984) indicated that here and there, knolls or low smooth ridges of sand and gravel are superimposed on the clay.

According to Chapman and Putnam (1984), the Bothwell Sand Plain was a delta of the Thames River in glacial Lake Warren. The sands, which are about one metre in thickness, were spread thinly over a clay floor. The sand plain is cut in two by the Thames River.

The Lake St. Clair Clay Plains physiographic region is located in the vicinity of Lake St. Clair in Essex and Kent Counties. It consists of extensive clay plains and has little relief. According to Chapman and Putnam (1984), glacial Lake Whittlesey, which deeply covered all of these lands, and glacial Lake Warren, which subsequently covered nearly the whole area, failed to leave deep stratified beds of sediment on the underlying clay till.

<u>Bedrock Topography and Geology</u>: The bedrock elevation within the Upper Thames basin ranges from 200.0 to more 320.0 m (a.s.l.), with a general gradient of about 2.0 m per km. Within the Lower Thames basin, the bedrock elevation ranges from120.0 to 200.0 (a.s.l.), with a gradient of about 0.6 m per km. These differences in gradients between the two main parts of the Thames River basin are reflected in the surface topography of the basin.

According to Johnson et al. (1992), the bedrock geology is represented by the Salina and Bass Island Formations of Upper Silurian age; the Bois Blanc Formation of Lower Ordovician age; the Detroit River Group, the Dundee Formation, and the Hamilton Group of Middle Devonian age; and the Kettle Point Formation of Upper Devonian age.

<u>Overburden Thickness and Geology</u>: The overburden thickness within the basin ranges from less than 10.0 m to more than 90.0 m. Small areas with an overburden thickness of less than 10.0 m are found along the basin's northeastern boundaries. Throughout most of the Upper Thames basin, the thickness of the overburden is between 10.0 and 30.0 m. However, in areas located to the east of Stratford and along the southwestern topographic divide, the overburden thickness increases to 70.0 m and it reaches about 90.0 m in a few places. Over most of the Lower Thames basin, the thickness of the overburden is between 10 and 70 m. However, it increases to more than 90.0 m in the vicinity of London and along the southeastern topographic divide.

The overburden within the basin consists of glacial, glaciofluvial, and glaciolacustrine deposits of Pleistocene age with minor alluvial and swamp deposits of Recent age.

Six tills have been identified within the basin, namely, the Catfish Creek Till, Tavistock Till, Stratford Till, Port Stanley Till, Elma Till, and Rannoch Till (Barnett 1992). These tills form plains of a ground moraine and a number of end moraines.

The Catfish Creek Till occurs in a few small areas in the vicinity of Woodstock. The Tavistock Till occurs as a ground moraine in the London and Woodstock areas. The Stratford Till occurs as a thin ground moraine in the vicinity of Stratford. The Port Stanley Till occurs as a ground moraine and also occurs within the Ingersoll Moraine along the southeastern boundary of the basin. The Elma Till occurs as a ground moraine in the northwestern parts of the basin in Perth County. The Rannoch Till occurs as a ground moraine along the northwestern boundary of the basin.

Deposits of sand and gravel of glaciofluvial and glaciolacustrine origins are found at the surface as well as at various depths within the overburden. Ice-contact deposits of sand and gravel occur to the west, south and east of Thamesford. Outwash deposits of sand and gravel are found within the flood plain of the Thames River between Woodstock and London. Sand deposits of glaciolacustrine origin are displayed at the surface within the Caradoc Sand Plains and the Bothwell Sand Plain.

Clay deposits of glaciolacustrine origin are displayed at the surface within the Ekfrid Clay Plain and the St. Clair Clay Plains. Also, recent alluvial deposits are found mainly within the lower part of the Thames River flood plain.

<u>Overburden Aquifers</u>: The total number of water wells within the basin is 18,121. Of these, 8,563 (47.2%) are overburden wells, 8,149 (44.9%) are bedrock wells, and the rest are of unknown type. Most of the wells in the Upper Thames basin are drilled to rock. Toward the south, however, an increasing number of wells obtain water from the shallow and intermediate aquifers within the overburden. Nevertheless, both the overburden and the bedrock wells are common in most areas in the basin, reflecting generally an even utilization of overburden and bedrock aquifers.

Most wells tapping the surficial and shallow overburden aquifers supply adequate quantities of good quality water for domestic requirements. Higher yields are usually limited by the saturated thicknesses of the aquifers. Most of the high-capacity wells are located within the Upper Thames in an area extending between London, Ingersoll and St. Mary's. Other areas with high capacity wells are located between Stratford and Woodstock, and along the western drainage divide south of Mitchell. Most of the high capacity wells within the Lower Thames are located in an area extending from Glencoe in the north to Chatham in the south.

Specific capacity data are available for 4,943 overburden wells within the basin. Of these wells, 1,511 have specific capacities less than 5.0 L/min/m, 2,090 have specific capacities between 5.0 and 25.0 L/min/m, 593 wells have specific capacities between 25.0 and 50.0 L/min/m, and 749 wells have specific capacities higher than 50.0 L/min/m.

As part of a brief report about the groundwater resources of the Thames River basin, Goff and Brown (1981) prepared several maps showing the locations of the major overburden aquifers in the basin. The maps, with brief descriptive notes, were presented on sheets as follows:

- Sheet 6. Upper Thames River - Shallow Overburden Aquifers,
- Sheet 7. Upper Thames River - Intermediate Overburden Aquifers,
- Sheet 8. Upper Thames River - Deep Overburden Aquifers,
- Sheet 9. Lower Thames River - Shallow Overburden Aquifers,

Sheet 10. Lower Thames River - Intermediate Overburden Aquifers,
Sheet 11. Lower Thames River - Deep Overburden Aquifers.

According to Goff and Brown (1981), large parts of the Upper Thames River basin are covered with thin deposits of sand and gravel which, when saturated, act as shallow aquifers. Most of these deposits form the Caradoc Sand Plain in the vicinity of London and the spillways along stream valleys. Other minor sand and gravel deposits are found locally. In many places, these deposits are buried by a few metres of silt, clay or till.

Shallow overburden aquifers have been delineated within a large area extending from Ingersoll through Thamesford, Dorchester, London, to Mount Brydges. Similar aquifers have been also delineated to the south of Woodstock, between Woodstock and Innerkip, between Uplands and Ballymote in the east and Southgate in the west, between Thorndale and London, to the southwest of Stratford, and within several stream valleys (Sheet 6). Most wells tapping these shallow aquifers supply adequate quantities of groundwater for domestic requirements.

Sand and gravel deposits that occur at various depths within the overburden in the Upper Thames River basin form excellent intermediate aquifers that yield adequate water supplies. Such aquifers have been delineated to the east and south of Woodstock, between Woodstock and Embro, to the south and east of Ingersoll, between Ingersoll and Thamesford, between Dorchester and London, and to the northwest, west, and southwest of London (Sheet 7). Well yields from the intermediate aquifers are less than 50.0 L/min, but may exceed 250.0 L/min locally from properly constructed and developed wells.

Goff and Brown (1981) indicated that deep overburden aquifers are not common within the Upper Thames River basin, except in the vicinity of London, in the vicinity of Lambeth, between Lambeth and Komoka, to the west of Delaware, in the vicinity and to the south of Putnam, in the vicinity and to the southwest of Stratford, and in the vicinity of Mitchell (Sheet 8). Well yields from these deep aquifers are adequate or domestic and farm uses, but can be locally as high as several thousand liters per minute from properly constructed and developed wells.

According to Goff and Brown (1981), a large part of the Lower Thames River basin is covered with thin deposits of sand and gravel that are exploited by shallow wells when they are saturated. These deltaic deposits, which are most common in the central part of the Lower Thames basin, form the Bothwell Sand Plain.

Several shallow aquifers have been identified within the Lower Thames River basin. One such aquifer is located in the vicinity of Chatham where it is buried by silt, clay or till. Similar aquifers have also been delineated to the east and west of the Thames River within a band extending from the Oneida Indian Reserve in the north to the north of Tate Corners in the south, between Glencoe and Wardsville, and within a large area extending from Wardsville through Ridge Town to Chatham (Sheet 9).

Intermediate overburden aquifers have been delineated in the vicinity and to the south of Glencoe, in the vicinity and to the southwest of Bothwell, within an area extending from Thamesville and Chatham in the northwest to Durat and Blenheim in the southeast, within an area extending from Prairie Siding in the northwest to Coatsworth Station in the southeast, and to the west of Tilbury (sheet 10). These aquifers, which are protected by overlying tills, yield adequate quantities of water. Well yields are between 10.0 and 250.0 L/min.

Deep overburden aquifers are common in the southwestern and central portions of the Lower Thames River basin. Deep aquifers have been delineated in the Vicinity of Appin, to the south of Glencoe, in the vicinity and to the south of Wardsville, within a strip extending from Northwood to Kintyre, between Chatham and Merlin, to the east, west, and south of Tilbury (Sheet 11). These sand and gravel aquifers are often very thin (0.3 m) and are often located at the overburden-bedrock contact.

8.6 OVERBURDEN AQUIFERS IN THE ESSEX REGION CONSERVATION AUTHORITY

Location: The Essex Region Conservation Authority (the Authority) is located on the tip of the southwestern part of southern Ontario. It is bounded on the east by Kent County, on the north by Lake St. Clair, on the west by the Detroit River, and on the south by Lake Erie. The Authority is within Essex County and includes nine municipalities, namely, the City of Windsor; the Towns of Amherstburg, Essex, Lakeshore, LaSalle, Leamington, Kingsville, and Tecumseh; and the Township of Pelee. The main urban centres are the City of Windsor, Amherstburg, Essex, Harrow, Kingsville, LaSalle, and Leamington (Figure 42).

Drainage: The Authority contains more than 24 watersheds that are characterized by slow-moving streams. The drainage is nearly all northward to Lake St. Clair (the Ruscom River, the Belle River and the Pike Creek), but the gradient is extremely small and the drainage divide near Lake Erie is vague. The Canard River and the Turkey Creek drain toward the Detroit River, while the Cedar and Hillman Creeks drain toward Lake Erie.

Physiography: The Authority is a flat clay plain with a few small morainic hills. Chapman and Putnam (1984) identified two physiographic regions within it, namely, the St. Clair Clay Plains and Erie Spits. The St. Clay Plains is essentially a till plain that has been smoothed by shallow deposits of lake origin (lacustrine clay). It exhibits little relief and has a number of areas which are atypical of a clay plain. One area is located near Leamington where the continuity of the clay plain is broken by a small morainic hill. The hill is composed of sand and gravel and stands about 30.0 m above the general level. A second area of sandy soil is found on a slight elevation near Harrow.

The Erie Spits physiographic region is represented by Point Pelee whose surface elevation is at lake level or a few centimetres below. According to Chapman and Putnam (1984), Point Pelee juts straight out from the shore and is fabricated loosely from a succession of sand bars which run at an angle to the long axis of the spit.

Bedrock Topography and Geology: With the exception of a few bedrock outcrops within Pelee Island, all the bedrock within the Authority is obscured by a mantle of overburden deposits. Most of the bedrock elevation ranges from 120.0 to 160.0 m (a.s.l.). A bedrock ridge ranging in elevation from 160.0 to 200.0 m (a.s.l.) extends along the southern part of the Authority from Blytheswood in the east to Amherstburg in the west. According to Johnson et al. (1992), the bedrock geology consists of the Detroit River Group, the Dundee Formation, and the Hamilton Group of Middle Devonian age.

Overburden Thickness and Geology: The thickness of the overburden varies from less than 10.0 m in a small area near Amherstburg to more than 70.0 m in two small areas in the vicinity of Leamington. Over most of the southwestern part of the Authority and within Point Pelee National Park, the thickness of the overburden ranges from 10.0 to 30.0 m. Within the remaining parts of the Authority, the thickness of the overburden ranges from 30.0 to 50.0 m.

The overburden consists of glacial, glaciofluvial, and glaciolacustrine deposits of Pleistocene age as well as alluvium, beach, muck and swamp deposits of Recent age. Most of the Authority is covered by a veneer of glaciolacustrine clay deposits. At a few locations, however, glacial till and glaciolacustrine sand and gravel deposits are displayed at the surface.

Two tills have been identified within the Authority, the Port Stanley Till and Tavistock Till (Barnett 1992). The Port Stanley Till is found in the Wheatley area. It occurs as a ground moraine and is commonly interbedded with glaciolacustrine sediments. The Tavistock Till, on the other hand, is found as a series of elongated end moraines in the northeastern part of the Authority and at four small locations in its northwestern parts.

Sand and gravel deposits of glaciolacustrine origin are found in the vicinity of Leamington and at a few areas between Kingsville and Amherstburg. In addition, recent lacustrine sand, gravelly sand and gravel as well as nearshore and beach deposits are found within the La Salle area along the Detroit River. Also, organic deposit of peat, muck and marl are found within the Point Pelee area.

<u>Overburden Aquifers</u>: In general, groundwater is available in sufficient quantity and only 3.0% of the wells constructed in the Authority are reported to have insufficient water. However, the natural groundwater quality in many cases is poor and may require treatment.

A total of 3,426 bedrock wells has been identified within the Authority as compared to 1,024 overburden wells indicating that overburden is less important as a source of water supply. Of the 1,024 overburden wells, 295 (28.8%) have no specific capacity data, 25 (2.4%) have specific capacities of less than 1.0 L/min/m, 159 (15.5%) have specific capacities between 1.0-5.0 L/min/m, 128 (12.5%) have specific capacities between 5.0-10.0 L/min/m, 267 (26.2%) have specific capacity between 10.0-50.0 L/min/m, and 150 (14.6%) have specific capacities above 50.0 L/min/m.

The main overburden aquifers are the coarse, sorted sand and gravel deposits that are either exposed at the surface or exist at various depths within the overburden. These deposits are reported in some wells to overly directly the bedrock.

<u>The Leamington Aquifer</u>: This name is suggested for an aquifer that occurs within an area that extends from the vicinity of Leamington in the south to Blytheswood and Cottam in the north. The records of 214 wells tapping the aquifer indicate that it consists of gravel and sand deposits that range in thickness from 6.0 to 50.0 m. These deposits are displayed at the surface in the vicinity of Leamington and are overlain by clay and till deposits up to 32.0 m thick elsewhere. Where the sand and gravel deposits are at the surface, the aquifer is unconfined.

The elevation of the top of the unconfined part of the aquifer ranges from 182.0 to 218.0 m (a.s.l.) and the elevation of the top of the confined part ranges from 155.0 to 192.0 m (a.s.l.). Water is found at elevations between 154.0 and 215.0 m (a.s.l.), and the depths to the static water levels range from less than one metre to 11.0 m. Well yields range from 20.0 to 225.0 L/min. Several wells, however, report yields between 450.0 and 900.0 L/min. The specific capacities of most wells range between 10.0 and more than 50.0 L/min/m.

<u>The Harrow Aquifer</u>: This name is suggested for an aquifer that occurs within an area that extends from the vicinity of Harrow in the south to the vicinity of McGregor in the north. The records of 115 wells tapping the aquifer indicate that it consists of gravel and sand deposits that range in thickness from about one metre up to 36.0 m. These deposits are displayed at the surface in the vicinity of Harrow and are overlain by clay and till deposits up to 26.0 m thick elsewhere. Where the sand and gravel deposits are at the surface, the aquifer is unconfined.

The elevation of the top of the unconfined part of the aquifer ranges from 180.0 to 194.0 m (a.s.l.) and the elevation of the top of the confined part ranges from 156.0 to 187.0 m (a.s.l.). Water is found at elevations between 151.0 and 196.0 m (a.s.l.), and the depths to the static water levels range from less than one metre to 12.0 m. These depths, however, are less than 6 m in the majority of wells. Well yields range from 10.0 to 200.0 L/min. A few wells, however, have yields between 275.0 and 350.0 L/min. The specific capacities of most wells range between 5.0 and 50.0 L/min/m.

The Amherstburg Aquifer: This name is suggested for a confined aquifer that occurs to the east of Amherstburg. The records of 20 wells tapping the aquifer indicate that it consists mainly of gravel deposits that range in thickness from about one to four metres. They are overlain by clay and till deposits that range in thickness between 12.0 and 24.0 m.

The elevation of the top of this confined aquifer ranges from 156.0 to 169.0 m (a.s.l.), water is found at elevations between 156.0 and 168.0 m (a.s.l.), and the depths to the static water levels range from 3.0 to 8.0 m.Well yields range from 20.0 to 80.0 L/min, and the specific capacities of most wells range between 5.0 and 50.0 L/min/m.

The Oldcastle Aquifer: This name is suggested for a confined aquifer that occurs in the vicinity of Oldcastle to the southeast of the City of Windsor. The records of 30 wells tapping the aquifer indicate that it consists of gravel and sand deposits that range in thickness from one to four metres. Three wells, however, indicate thicknesses between 7.0 and 9.0 m. The gravel and sand deposits are overlain by clay and till deposits that range in thickness between 23.0 and 39.0 m.

The elevation of the top of this confined aquifer ranges from 149.0 to 169.0 m (a.s.l.), water is found at elevations between 149.0 and 168.0 m (a.s.l.), and the depths to the static water levels range from 3.0 to 12.0 m.Well yields range from 10.0 to 90.0 L/min, and the specific capacities of most wells range between 5.0 and 50.0 L/min/m. Based on the characteristics of this aquifer, it could be an extension of Amherstburg Aquifer.

8.7 OVERBURDEN AQUIFERS IN AREA DRAINING INTO LAKE ERIE

8.7.1 The Kettle and Catfish Creeks Drainage Area

Location: This drainage area, which is located on the north shore of Lake Erie, consists of two main watersheds, namely, the Kettle Creek and the Catfish Creek watersheds. It is bounded on the west by small catchment draining into Lake Erie, on north by the Upper Thames Conservation Authority, and on the east by the Long Point Conservation Authority. The drainage area includes parts of Elgin and Middlesex Counties (Figure 43).

The Kettle Creek watershed, which occupies the western half of the drainage area, is about 515.0 km^2 in size. The largest urban centre in the watershed is the City of St. Thomas. Other urban centres are Belmont, Port Stanley, and Union. In addition, part of the City of London is within the northern part of the watershed. The Kettle Creek Conservation Authority operates within this watershed.

The Catfish Creek watershed, which occupies the eastern half of the drainage area, is about 490.0 km^2 in size. The main urban centres within this watershed are Aylmer, Luton, Lyons, New Sarum, Orwell, Port Bruce, and Springfield. The Catfish Creek Conservation Authority operates within this watershed.

Drainage: The main streams within the drainage area are the Kettle and the Catfish Creeks. The Kettle Creek has two main branches. One branch rises to the northeast of Belmont within the southeastern flank of the St. Thomas Moraine and flows in a southwesterly direction to St. Thomas. The other branch rises to the southwest of London and flows in a southeasterly direction to meet the first branch at St. Thomas. The combined branches flow south to enter Lake Erie at Port Stanley. Below St. Thomas, the Kettle Creek has cut a deep flat-floored valley into the overburden.

The Catfish Creek drains the southeastern flank of the St. Thomas Moraine in the vicinity of Brownsville and flows mainly in southwesterly direction to a point located to northwest of Jaffa where it is joined by the combined West Catfish, East Catfish, and the Nineteen Creeks. From that point the Catfish Creek flows in a southeasterly direction and enters Lake Erie at Port Bruce. The Catfish Creek, has also cut a deep-floored valley into the overburden between New Sarum and Port Bruce.

Physiography: Landforms within the drainage area include morainic ridges, sand plains, clay plains, and deep wide-floored valleys. According to Chapman and Putnam (1984), parts of three physiographic regions are found within this drainage area, namely, the Mount Elgin Ridges, Ekfrid Clay Plain, and Norfolk Sand Plain.

Within the drainage area, the Mount Elgin Ridges are represented by part of the St. Thomas Moraine which separates the Kettle and the Catfish Creek watersheds. The moraine, which has a local relief of about 30.0 m, is covered by the Port Stanley Till.

The Ekfrid Clay Plain occupies most of the central part of the drainage area. Its surface, which is covered by stratified clays, is nearly level except where it is cut by gullies.

The Norfolk Sand Plain occupies the southeastern part of the drainage area. According to Chapman and Putnam (1984), the sand and silt deposits of this plain were laid down as a delta in glacial Lakes Whittlesey and Warren.

Bedrock Topography and Geology: All the bedrock within the drainage area is obscured by a thick mantle of overburden deposits. Its elevation ranges from 120.0 to 160.0 m (a.s.l.). According to Johnson et al. (1992), the bedrock geology is represented by the Dundee and Marcellus Formations, and the Hamilton Group of Middle Devonian age. The Hamilton Group occurs within a small pocket in the northwestern part of the drainage area. The Dundee Formation extends over most of the northern part of the drainage area, and the Marcellus Formation occurs between St. Thomas, Aylmer and Lake Erie.

Overburden Thickness and Geology: The overburden thickness is mostly between 70.0 and 90.0 m. Within the Mount Elgin Ridges physiographic region, however, it ranges between 90.0 and 110.0 m. According to Barnett (1992), the overburden consists of glacial, glaciofluvial, and glaciolacustrine deposits of Pleistocene age, and fluvial deposits of Recent age.

The glacial deposits are represented by the Port Stanley Till which covers the upper two-thirds of the drainage area. The till occurs also within small areas along the shore of Lake Erie.

Ice-contact sand and gravel deposits occur within a small area to the south of St. Thomas. Sand deposits of outwash origin are found within two small areas in the northwestern and northeastern parts of the drainage area.

Sand deposits of glaciolacustrine origin are found in the southeastern part of the drainage area and within a few small locations in its northern and northwestern parts. Clay deposits of glaciolacustrine origin occur within the lower part of the Catfish Creek watershed and also along the shore of Lake Erie.

In addition, fluvial deposits of Recent age are found in the vicinity of St. Thomas and to the southwest of it.

Overburden Aquifers: There are 3,169 overburden wells within the drainage area as compared to 187 bedrock wells, which indicates that the overburden is the main source of water supply. This is due to the fact that the overburden deposits are generally very thick which makes it impractical to drill to bedrock.

Of the 3,169 overburden wells, 4 (0.1%) have no specific capacity data, 345 (10.9%) have specific capacities less than 1.0 L/min/m, 1,176 (37.1%) have specific capacities between 1.0-5.0 L/min/m, 602 (19.0%) have specific capacities between 5.0-10.0 L/min/m, 760 (24.0%) have specific capacity between 10.0-50.0 L/min/m, and 282 (8.9%) have specific capacities above 50.0 L/min/m.

The Central Catfish Creek Aquifer: This name is suggested for an extensive aquifer that occupies a large area within the Catfish Creek watershed. The aquifer has been identified in the Springfield area, in the vicinity of Aylmer and to the east of it. It was also identified in the vicinity of Jaffa, Luton, Orwell, and New Sarum.

The records of 238 wells tapping the aquifer indicate that it is composed of sand and gravel deposits. The majority of the wells penetrate less than 10.0 m of the aquifer. Some wells, however, penetrate more than 20.0 m of continuous sand and gravel deposits. The wellhead elevations range from 192.0 to 256.0 m (a.s.l.), and the elevation of the top of the aquifer ranges from 191.0 to 239.0 m (a.s.l.).

The aquifer is mostly confined except in the vicinity of Jaffa (Malahide Township, Concessions 4, 5, 6, and 7) where sand and gravel deposits up to 35.0 m thick are displayed at the surface. The depths to the static water levels are between 2.0 and 24.0 m and the reported well yields are between 10.0 and 225.0 L/min. A few wells, however, report yields ranging from 450.0 to 2,200.0 L/min. The specific capacities of most wells are between 5.0 and 50.0 L/min/m.

The Brownsville Local Aquifer: This name is suggested for a small local aquifer that occurs in the vicinity and to the west of Brownsville in the northeastern part of the Catfish Creek watershed. The records of 14 wells tapping the aquifer indicate that it is composed of gravel and sand deposits that are up to 20.0 m thick.

The wellhead elevations range from 248.0 to 293.0 m (a.s.l.), and the elevation of the top of the aquifer ranges from 237.0 to 260.0 m (a.s.l.). The aquifer is mostly confined under till-like deposits that can reach up to 40.0 m in thickness. The depths to the static water levels range from less than one metre to 30.0 m, and the reported well yields are between 20.0 and 125.0 L/min. The specific capacities of most wells are between 10.0 and more than 50.0 L/min/m.

The South Central Elgin Aquifer: This name is suggested for a large aquifer that extends between St. Thomas and Lake Erie within the Township of Central Elgin in the Kettle Creek watershed. The records of 131 wells penetrating the aquifer indicate that it is composed of gravel and sand deposits that are mostly less than 10.0 m thick. A few wells, however, report sand and gravel deposits up to 29.0 m thick.

The wellhead elevations range from 200.0 to 235.0 m (a.s.l.), and the elevation of the top of the aquifer ranges from 183.0 to 232.0 m (a.s.l.). The northern part of the aquifer is mostly confined under up to 30.0 m of clay and till-like deposits. The southern part of the aquifer, however, is mostly unconfined. The depths to the static water levels range from less than one metre to18.0 m, and the well yields are between 20.0 and 175.0 L/min. One well however, is reported to yield 675.0 L/min and another well yields 820.0 L/min. The specific capacities of most wells are between 5.0 and 50.0 L/min/m.

<u>The South London Aquifer</u>: This name is suggested for an aquifer that is located to the south of the City of London within the Kettle Creek watershed. The records of 77 wells tapping the aquifer indicate that it is composed of gravel and sand deposits that range in thickness from several metres up to 53.0 m. The aquifer is confined under clay and till-like deposits up to 60.0 m thick.

The wellhead elevations range from 226.0 to 280.0 m (a.s.l.), and the elevation of the top of the aquifer ranges from 208.0 to 265.0 m (a.s.l.). The depths to the static water levels are between 13.0 and 42.0 m and the well yields are between30.0 and 250.0 L/min. Several wells, however, report yields ranging from 950.0 to 6,725.0 L/min. The specific capacities of most wells are between 10.0 and more 50.0 L/min/m.

In addition, two small aquifers have been identified in the northeastern part of the Kettle Creek watershed. Both aquifers are confined and obtain water from sand and gravel deposits that are less than 10.0 m thick. The elevations of the tops of the two aquifers are between 239.0 and 262.0 m (a.s.l.). Both aquifers could be part of a larger aquifer system.

8.7.2 The Long Point Region Conservation Authority

<u>Location</u>: The Long Point Conservation Authority (the Authority) is located in the southwestern part of southern Ontario. It is bounded on the west by the Catfish Conservation Authority, on the northwest by the Upper Thames Conservation Authority, on the east and northeast by the Grand River Conservation Authority, and on the south by Lake Erie. The Authority includes parts of the Counties of Elgin, Oxford, Brant, and Haldimand-Norfolk. The main urban centres are Bayham, Delhi, Langton, New Durham, Norwich, Otterville, Port Burwell, Simcoe, Tillsonburg, and Vienna (Figure 44).

<u>Drainage</u>: The Authority is drained by several streams, including the Big Otter, Big, Nanticoke and Sandusky Creeks and the Lynn River. All these streams flow into Lake Erie. The Big Otter Creek originates to the south of New Durham and flows about 77.0 km to enter Lake Erie at Port Burwell. Its initial course is controlled by the Norwich and Tillsonburg Moraines. South of Otterville, the creek passes through a gap in the Tillsonburg Moraine and flows southwest to a point three kilometres below Bayham where it turns southeast on its way to Lake Erie. The creek passes through valleys of varying depths and widths. At Vienna, the creek's streambed is about 30.0 m below the surrounding banks. The main tributaries to the creek are the Little Otter, Stony, Branch, and Spittler Creeks.

The Big Creek originates to the northwest of New Durham and flows in a general easterly direction to a point three kilometres south of Harley. From that point it starts flowing in a general southerly direction and discharges into Long Point Bay on Lake Erie about two kilometres south of Port Rowan. The creek, which is about 90.0 km long, has numerous tributaries that vary in length between 5.0 and 20.0 km. It runs through deep valleys that cut through a fairly flat landscape. Bellow Delhi the flood plain of the creek is about 30.0 m deep and up to 0.8 km wide.

Several small streams drain the eastern parts of the Authority. The most distinguished of these streams are the Nanticoke and Sandusky Creeks and the Lynn River.

Physiography: The landforms within the Authority consist of end moraines, a ground moraine, sand and clay plains, kettles, spillways, and abandoned shorelines. Chapman and Putnam (1984) identified four physiographic regions within the Authority, namely, the Mount Elgin Ridges, Norfolk Sand Plain, Horseshoe Moraines, and Haldimand Clay Plain.

The Mount Elgin Ridges, which are characterized by knob-and-kettle topography, are located in the northern and northwestern parts of the Authority. They include the St. Thomas, Norwich, and Tillsonburg Moraines. The St. Thomas Moraine forms the northwestern boundary of the Authority and extends to the southwest as a high, well-developed ridge and to the northwest as a gently rolling feature. Southeast of the St. Thomas Moraine, parallel to it, and separated from it by sand and till plains, is the Norwich Moraine. This moraine extends from Norwich to Delmer as a subdued and gently rolling ridge. The Tillsonburg Moraine is a well-developed ridge that curves west and crosses the topographic divide just north of Tillsonburg.

The Norfolk Sand Plain is a major physiographic feature of this part of Ontario. The plain has a wedge shape with a broad, curved base along the shore of Lake Erie. According to Chapman and Putnam (1984), the sand and silt deposits of this plain were laid down under deltaic conditions in glacial Lakes Whittlesey and Warren.

An area which extends from Delhi to Waterford and beyond to the Authority's northern boundary is part of the southeastern limb of the Horseshoe Moraines. This physiographic region tends to flatten out within the Authority and to disappear under the Norfolk sands.

The eastern part of the Authority is part of the Haldimand Clay Plain. According to Chapman and Putnam (1984), this plain was completely submerged under glacial Lake Warren which left a layer of glaciolacustrine clay deposits at the surface.

Bedrock Topography and Geology: There are a few small bedrock outcrops along the northeastern boundary of the Authority. Everywhere else, the bedrock surface is covered by a mantle of overburden deposits. The bedrock elevation ranges from about 250.0 m (a.s.l.) in the north to about 80.0 m (a.s.l.) in the vicinity of Long Point in the south.

According to Johnson et al. (1992), the bedrock geology consists of the Salina, the Bertie, and the Bass Island Formations of Upper Silurian age; the Bois Blanc Formation of Lower Devonian age; and the Detroit River Group, and the Dundee and Marcellus Formations of Middle Devonian age.

Overburden Thickness and Topography: The thickness of the overburden varies from less than 10.0 m in the northeastern part of the Authority to about 110.0 m in its lower part. Most areas that are located to the north of a line extending from Tillsonburg in the west to Normandale on Lake Erie have an overburden thickness of less than 50.0 m. Areas located to the south of this line, on the other hand, have an overburden thickness between 50.0 and 110.0 m. Where the overburden is thin, the bedrock is the main source of water supply.

The overburden consists of glacial, glaciofluvial, and glaciolacustrine deposits of Pleistocene age and alluvium, beach, muck and swamp deposits of Recent age. The glacial deposits predominate in the northwestern parts of the Authority where the morainic ridges occur. Deposits of glaciofluvial and glaciolacustrine deposits, on the other hand, cover most of the southeastern low, flat part of the Authority.

Two tills have been identified within the Authority, the Port Stanley Till and Wentworth Till. According to Barnett (1992) the St. Thomas, Norwich, and Tillsonburg Moraines were formed during the recession of the Erie-Ontario lobe which deposited the Port Stanley Till. The

Wentworth Till is found within a narrow area which extends from Clear Creek to St. Williams near Lake Erie. It is also found within a narrow area extending from Delhi to Scotland.

Most of the central part of the Authority is covered by glaciolacustrine sands which form the Norfolk Sand Plain. Its eastern part is covered by a thin layer of glaciolacustrine clay deposits which were formed in glacial Lake Warren (Chapman and Putnam 1984). In addition, lacustrine sediments of sand and gravel and organic deposits of peat, muck and marl are found at several locations within the Authority.

Overburden Aquifers: A total of 2,321 bedrock wells has been identified within the Authority as compared to 7,428 overburden wells indicating that the overburden is the main source of water supply. Of the 7,428 overburden wells, 2,890 (38.9%) have no specific capacity data, 137(1.8%) have specific capacities of less than 1.0 L/min/m, 723 (9.7%) have specific capacities between 1.0-5.0 L/min/m, 552 (7.4%) have specific capacities between 5.0-10.0 L/min/m, 1,337 (18.1%) have specific capacities between 10.0-50.0 L/min/m, and 1,789 (24.1%) have specific capacities above 50.0 L/min/m.

Only a few overburden wells are located within the Haldimand Clay Plain. This is due to fact that the overburden within this plain is very thin and consists mostly of clay deposits. Also, most of the wells with specific capacities of less than 10.0 L/min/m are found in areas where the Port Stanley Till occurs at the surface. On the other hand, the majority of the high productive wells with specific capacities of more than 50.0 L/min/m are associated with the Norfolk Sand Plain. The plain is permeable and thick enough in most places to provide adequate domestic supplies to water wells. The high capacity wells that are located within the morainic ridges and the intervening till plains obtain their water supplies from sand and gravel aquifers that occur at various depths within the overburden.

The Norfolk Sand Plain Aquifer: This is one of the major overburden aquifers in this part of southern Ontario. As indicated above, the aquifer was deposited under deltaic conditions in glacial Lakes Whittlesey and Warren. Most of the wells tapping the aquifer are located within an area that extends from Port Dover and St. Williams in the south to Waterford and Delhi in the north. A large number of wells are also located in the Vicinity of Tillsonburg.

The aquifer sustains the baseflow in the Big and Big Otter Creeks and in those smaller streams that drain the area enclosed between the watersheds of the two creeks. The aquifer also sustains the baseflow in the streams that drain the area located immediately to the east of the Big Creek watershed.

The well records of 1,008 wells tapping the aquifer indicates that it consists of sand and gravel deposits up to 30.0 m in thickness. Most wells penetrate less than 10.0 m of the aquifer. The sand and gravel deposits occur at the surface and slope gently from north to south. At a few places, however, the aquifer is confined by clay deposits.

The elevation of the top of the aquifer ranges from 255.0 to 264.0 m (a.s.l.) in the north to 190.0-230.0 m (a.s.l.) in the south. Water is found at elevations between 185.0 and 260.0 m (a.s.l.), and the depths to static water levels range from less than one metre to 20.0 m. These depths, however, are less than 10.0 m in most wells. Of the 1,008 wells tapping the aquifer, 53 report yields ranging from 275.0 to 2,300.0 L/min. The remaining wells have yields ranging from 20.0 to 225.0 L/min. The specific capacities of the majority of the wells range between 10.0 and more than 50.0 L/min/m.

The St. Thomas Moraine Local Aquifers: This name is suggested for four local aquifers that have been identified within the St. Thomas Moraine along the northwestern boundary of the

Authority. One aquifer is located in the vicinity of Culloden, the second is located in the vicinity of Mount Elgin, the third is located to the west of Holbrook, and the fourth is located in Burgessville area.

The records of 27 wells tapping the first aquifer indicate that it is a confined aquifer consisting of gravel and sand that range in thickness from 1.0 to 12.0 m. It is overlain by till and clay deposits that range in thickness from 5.0 to 40.0 m. The wellhead elevations are between 271.0 and 290.0 m (a.s.l.), the elevation of the top of the aquifer is between 240.0 and 269.0 m (a.s.l.), and the depths to the static water levels are from less than one metre to 34.0 m. Well yields are between 20.0 and 180.0 L/min, and the specific capacities of most wells are between 5.0 and more than 50.0 L/min/m.

The records of 18 wells tapping the second aquifer indicate that it is a confined aquifer consisting of gravel and sand that range in thickness from 1.0 to 10.0 m. It is overlain by till and clay deposits that range in thickness from 5.0 to 25.0 m. The wellhead elevations range from 273.0 to 300.0 m (a.s.l.), the elevation of the top of the aquifer is between 261.0 and 278.0 m (a.s.l.), and the depths to the static water levels range from 2.0 to 19.0 m. Well yields are between 10.0 and 100.0 L/min, and the specific capacities of most wells range from 5.0 to 50.0 L/min/m.

The records of 47 wells tapping the third aquifer indicate that it is a confined aquifer consisting of gravel and sand that range in thickness from 1.0 to 16.0 m. Most of the wells, however, penetrate one or two metres of the aquifer. Till and clay deposits that range in thickness from 6.0 to 48.0 m overlie the aquifer.

Wellhead elevations are between 267.0 and 335.0 m (a.s.l.), the elevation of the top of the aquifer is between 241.0 and 285.0 m (a.s.l.), and the depths to the static water levels range from less than one metre to 16.0 m. Well yields are between 10.0 and 125.0 L/min, and the specific capacities of most wells are between 5.0 and more than 50.0 L/min/m.

The records of 26 wells tapping the fourth aquifer indicate that it is a confined aquifer consisting of gravel and sand that range in thickness from 1.0 to 8.0 m. It is overlain by till and clay deposits that range in thickness from 4.0 to 22.0 m.Wellhead elevations are between 256.0 and 274.0 m (a.s.l.), the elevation of the top of the aquifer is between 243.0 and 261.0 m (a.s.l.), and the depths to the static water levels range from 2.0 to 17.0 m. Well yields are between 15.0 and 125.0 L/min, and the specific capacities of most wells range from10.0 to more than 50.0 L/min/m.

<u>The Tillsonburg Aquifer</u>: This name is suggested for a confined aquifer that is located to the west of Tillsonburg. The records of 113 wells taping the aquifer indicate that it consists of sand and gravel deposits up to 21.0 m in thickness. It is overlain by till and clay deposits that range in thickness from 2.0 to 56.0 m.

Wellhead elevations are between 223.0 and 280.0 m (a.s.l.), the elevation of the top of the aquifer is between 209.0 and 258.0 m (a.s.l.), and the depths to the static water levels range from less than one metre to 24.0 m. Well yields are between 10.0 and 225.0 L/min. Several wells, however, have yields ranging from 320.0 to 1,025.0 L/min. The specific capacities of most wells range from10.0 to more than 50.0 L/min/m.

8.7.3 The Grand River Conservation Authority

Location: The Grand River Conservation Authority (the Authority), which is located in the southwestern part of southern Ontario, has an area of about 6,770.0 km^2. It is bounded on the east by the Conservation Authorities of the Nottawasaga Valley, Credit Valley, Halton Region, Hamilton Region, and Niagara Region; on the northwest and west by the Severn drainage area and the Conservation Authorities of the Saugeen, Maitland Valley, and Upper Thames; and on the southwest by the Long Point Region Conservation Authority. The Authority contains the Counties of Wellington and Brand, and the Regional Municipality of Waterloo. It also contains parts of the Counties of Grey, Dufferin, Perth and Oxford, and parts of the Regional Municipalities of Hamilton-Wentworth, Halton and Haldimand-Norfolk (Figure 45).

Elevations within the Authority vary from a high of about 535.0 m (a.s.l.) near Dundalk to a low of about 174.0 m (a.s.l.) at Lake Erie. It is characterized by a variety of physiographic regions, a diversity of soils, and large differences in climatic conditions. The end result is a large variations in land capabilities and land uses. Large areas within the Authority are used for the production of row crops, cereal wheat, and specialty crops. Other large areas are devoted to fodder corn, mixed grains, hay, and livestock. Woodland, forests, idle lands, and wetlands are also found within the Authority. The four cities of Kitchener-Waterloo, Cambridge, Guelph, and Brantford are the largest urban areas within the Authority. Other important urban centres include Arthur, Ayr, Caledonia, Drayton, Dundalk, Elmira, Elora, Fergus, Grand Valley, New Hamburg, Paris, and Wellesley.

Drainage: The Grand River rises northeast of Dundalk at about 526.0 m (a.s.l.) and drains into Lake Erie at Port Maitland. Chapman and Putnam (1984) noted that the Grand may be divided into an upper part where the river and its branches flow mostly in spillways previously formed in till plains, and a lower part where the river has made its own channel across a lake plain.

The main tributaries to the Grand are the Conestoga, Nith, and Speed Rivers. Other notable but smaller tributaries are Boston, Fairchild, McKenzie, and Whiteman's Creeks. The Conestoga River rises northwest of Arthur, drains an area of about 820.0 km^2, and has a length of about 82.0 km. The Nith River rises east of the Milverton Moraine, drains an area of about 1,118.0 km^2, and has a length of about 158.0 km. The Speed River, which rises near Orton, drains an area of about 780.0 km^2 and has a length of about of 60.0 km.

Physiography: Landforms within the Authority include moraines, till plains, drumlins, kames, eskers, sand and clay plains, deep river gorges, and wetlands. The most prominent moraines in the Authority are Galt, Waterloo, Breslau, and Paris Moraines. According to Chapman and Putnam (1984), parts of ten physiographic regions are found within the Authority. These regions include the Dundalk Till Plain, Stratford Till Plain, Hillsburgh Sandhills, Guelph Drumlin Field, Waterloo Hills, Horseshoe Moraines, Oxford Till Plain, Mount Elgin Ridges, Norfolk Sand Plain, and Haldimand Clay Plain.

The Dundalk Till Plain is a gently fluted till plain which forms the headwaters of the Grand, Maitland, Nottawasaga, and Saugeen Rivers. The plain is characterized by poor drainage and swamps, bogs, and depressions are common.

The Stratford Till Plain extends as a strip south of Grand Valley and Arthur. The plain has a faint knoll and sag relief and is covered by a ground moraine which is interrupted by a few terminal moraines. It is drained by the Conestoga and Nith Rivers.

Within the Authority, the Hillsburgh Sandhills physiographic region extends on the southeastern flank of the Dundalk Till Plain from the topographic divide to the west of

Belwood. It consists of a moraine which is characterized by a rough topography and sandy materials. The Grand River cuts through this moraine at Belwood where the Shand Dam was constructed. West of Belwood the moraine is smaller and the sand gradually gives way to boulder clay.

The Guelph Drumlin Field extends between the Hillsburgh Sandhills in the north and Paris Moraine to the southeast. The region contains approximately 300 drumlins of all sizes. These drumlins are characterized by their oval shape and long axes that point due west or northwest. The intervening low ground between the drumlins is largely occupied by gravel terraces and swampy valleys in which the Speed and the Eramosa Rivers flow.

The Waterloo Hills physiographic region is located chiefly within the Regional Municipality of Waterloo. Some hills are composed mainly of sand or sandy till, while others are kames or kame moraines with outwash sands occupying the intervening hollows. Adjoining this hilly region contains an extensive area of alluvial terraces of the Grand River spillway system. A number of kettle lakes and swamps occur in the region.

A small area to the southwest of the Waterloo Hills is part of the Oxford Till Plain which extends over most of Oxford County. The plain is composed of calcareous loam till.

A small area of the Mount Elgin Ridges is within the Authority. It is wedged between the Oxford Till Plain to the northwest and the Norfolk Sand Plain to the east and southeast. Two small watersheds within these ridges are drained by the Kenny and Homer Creeks, both tributaries of the Grand.

The Norfolk Sand Plain is a part of a larger wedge-shaped plain that extends from Lake Erie northward to Brantford on the Grand River. The plain is composed of sands and silts that were deposited as a delta in glacial Lakes Whittlesey and Warren.

Part of the eastern arm of the Horseshoe Moraines is within the Authority extending as a strip in a southwesterly direction along the Guelph Drumlin Field, the Waterloo Hills, and through the Norfolk Sand Plain from the vicinity of Acton to the southwest of Paris. The region is hilly and contains numerous gravel terraces.

The lower part of the Authority is occupied by the Haldimand Clay Plain. The plain is covered mostly by clay and silt sediments which were deposited when the area was submerged in glacial Lake Warren. The Grand River has cut a deep valley in the clay and silt below Brantford. To the east and west of Caledonia and Cayoga, a number of drumlins are scattered over the plain.

Bedrock Topography and Geology: Most of the bedrock within the Authority is obscured by the overburden. In the western parts of the Authority, the overburden is generally thick whereas in its eastern parts, it is thin and bedrock outcrops reveal a rough, gently-sloping surface. Outcrops of bedrock can be seen along the Fairchild Creek, Speed River, and Grand River. Also, a low-relief bedrock outcrop, known as the Onondaga Escarpment, occurs in the lower part of the Authority.

The bedrock surface has a regional slope from about 500.0 m (a.s.l.) in the northern part of the Authority to less than140.0 m (a.s.l.) near Lake Erie. Superimposed on the regional slope are many rises and depressions. The most notable of these are the buried valleys which appear to be abandoned valleys of earlier water courses. By far the most prominent of these is the Dundas Valley, the lower portion of which extends from southwest of Dundas to south of Burlington. The valley was probably cut by an earlier Grand River and deepened by glacial action. A prominent valley, probably the ancestral Speed River, can also be traced from east of Eramosa south to the Reformatory where it jogs southwest and joins the Eramosa River at Victoria Street in Guelph. The valley was probably cut by an earlier Grand River and deepened by glacial action. Also, a bedrock valley occurs in the Elora-Fergus area north of Kitchener-Waterloo.

According to Johnson et al. (1992), the rocks of the Queenston Formation of Upper Ordovician age are the oldest rocks within the Authority. They are exposed in a small area within the Dundas Valley west of Hamilton. The Whirlpool, Manitoulin, and Cabot Head Formations of the Cataract Group of Lower Silurian age overlie the Queenston Formation and also outcrop within the Dundas Valley.

The Amabel-Lockport Formations of Middle Silurian age occur in the extreme eastern portions of the Authority. The Amabel Formation is the northward equivalent of the Lockport Formation, and is distinguished from it by the presence of numerous reef structures. Overlying the Amabel Formation and extending under most of the eastern parts of the Authority is the Guelph Formation of Middle Silurian age.

The Salina Formation of Upper Silurian age underlies a large portion of the western half of the Authority. Overlying the Salina Formation, is the Bass Island Formation of Upper Silurian age. It occurs as a narrow band in the extreme western part of the Authority.

The Oriskany Formation of Lower Devonian age occurs within a small area in the Townships of Oneida and North Cayuga. Overlying the Bass Island Formation with unconformity is the Bois Blanc Formation of Middle Devonian age. The next younger rocks that occur in the extreme western part of the Authority are those of the Amherstburg-Onondaga Formations of Middle Devonian age.

<u>Overburden Thickness and Geology</u>: In general, the thickness of the overburden increases from east to west. Areas, where the overburden thickness is less than 30.0 m, are found within the Dundalk Till Plain, Guelph Drumlin Field, and Haldimand Clay Plain. Overburden deposits, which range in thickness between 50.0 and 110.0 m, are found within the Waterloo Hills.

The overburden geology consists of glacial, glaciofluvial, and glaciolacustrine deposits of Pleistocene age and fluvial and organic deposits of Recent age. Several tills have been identified within the Authority, all are believed to be Wisconsinan in age. From oldest to youngest, they are known as the Lower Beds, Canning Till, Pre-Catfish Creek tills, Catfish Creek Till, Stirton Till, Maryhill Till, Tavistock Till, Port Stanley Drift, Mornington Till, Stratford Till, Wartburg Till, Elma Till, Wentworth Till, and Halton Till.

According to Karrow (1987), the Lower Beds unit, includes all the unclassified sediments below the Canning Till. These beds occur along the Nith River. Also, parts of some of the lower layers in some geologic sections near Kitchener are probably of similar age. The Lower Beds were tentatively considered to be of early Wisconsinan age.

The Canning Till is known to be exposed only in sections along the Nith River and possibly the Grand River (Karrow 1987). It was also reported in two boreholes drilled in the Waterloo area (Karrow et al. 1993). A similar fine-grained till occurs beneath the Catfish Creek Till in the Brantford area (Cowan 1975).

Pre-Catfish Creek tills have been identified in a number of boreholes in the Waterloo area where the Catfish Creek Till lies directly on bedrock (Karrow et al. 1993). Also, on the east side of Belwood Lake, an exposure of a possible Catfish Creek Till was found overlying stratified sands containing clayey silt till. This may represent a till older than the Catfish Creek till or it may be a lens within it (Cowan 1976).

The Catfish Creek Till is usually covered by younger deposits and, therefore, has limited exposure at the surface within the upper part of the Authority. Other outcrops of this till occur in deeply eroded sections along the Conestogo, Nith, and Grand Rivers (Cowan 1976 and1979). The till has been also encountered in deep wells in the Waterloo area (Karrow 1987).

The Stirton Till has been observed along the Conestogo Valley between Arthur and Drayton. It is thought to be limited to the Conestogo watershed area.

The Maryhill Till occurs along the banks of the Grand River, in the watersheds of some of its tributary streams such as the Laurel Creek, and in the Guelph area along the Breslau Moraine (Karrow 1987). Drilling in the Waterloo area indicates that the Maryhill Till overlies the Catfish Creek Till and is associated with glaciofluvial and glaciolacustrine sediments as well as with local tills (Karrow et al. 1993).

The Tavistock Till frequently overlies the Catfish Creek Till within the Authority. It was formerly mapped as the "Northern Till" in the Guelph area (Karrow 1968) and as "Till C" in the Conestogo area (Karrow 1971). Drilling in the Waterloo area indicates that the Tavistock Till directly overlies the Catfish Creek Till where the Maryhill Till is not present. Otherwise, it overlies the Maryhill Till (Karrow et al. 1993). With the exception of a small area along the western boundary of the Authority to the southwest of New Hamburg, the geologic logs of the majority of water wells that have been constructed in areas where this till outcrops at the surface do not show any sand or gravel deposits at depth.

The Port Stanley Till occurs at the surface within the Guelph Drumlin Field. It is also exposed along the Nith River (Karrow 1963 and Cowan 1976), and between Ayr, Paris and the western boundary of the Authority.

The Mornington Till occurs as a thin ground moraine and is considered by some to be an upper member of the Tavistock Till (Cowan 1979). The till outcrops over an area extending between New Hamburg and Milverton and the Authority's western boundary. The geologic logs of the majority of water wells that have been constructed in areas where this till outcrops at the surface do not show any sand or gravel deposits at depth.

The Stratford Till occurs as a thin ground moraine sheet to the west of Wellesley and New Hamburg. The till is commonly overlain by thin deposits of glaciolacustrine silt and clay. The geologic logs of the majority of water wells that have been constructed in areas where this till outcrops at the surface do not show any sand or gravel deposits at depth.

The Wartburg Till forms the core of the Milverton Moraine and occurs as a ground moraine that is largely buried by the Elma Till. A very small outcrop of this till is located to the south of Milverton.

The Elma Till occurs as a ground moraine to the southwest of Dundalk and between Milverton and Drayton. In other locations, the till is overlain by glaciofluvial sand and gravel, glaciolacustrine silt, and younger tills. The geologic logs of the majority of water wells that have been constructed in areas where this till outcrops at the surface do not show any sand or gravel deposits at depth.

According to Karrow (1987), Paris, Galt, and Moffat Moraines were built by Wentworth Till. The till is also found as small drumlins in the southern part of the Authority. The geologic logs of the majority of water wells that have been constructed in areas where this till outcrops at the surface do not show any sand or gravel deposits at depth.

The Halton Till occurs as a low-relief ground moraine along the topographic divide north west of Hamilton and in small areas in the southern part of the Authority.

Large areas within the Authority are covered with sand and gravel deposits of glaciofluvial or glaciolacustrine origins. The most extensive sequences of these deposits occur throughout most of the Regional Municipality of Waterloo and in the Counties of Wellington, Brant and Oxford. The glaciofluvial deposits are found as ice-contact stratified drift, outwash plains or meltwater channels.

The ice-contact stratified drift consists primarily of glaciofluvial sediments but may contain lacustrine sediments and till locally. They are characterized by great variability, collapse features, and hummocky topography. Kames, eskers, and end moraines are considered ice-contact deposits. The kames are found between Doon and Centreville, northwest of Glen Morris, east of Fergus, and southeast of Guelph. Extensive kames of sand with some gravel also occur within the Easthope, Waterloo, and Elmira Moraines.

Three prominent eskers extend obliquely across the Guelph Drumlin Field from the Eramosa Valley to the Grand Valley. Their length varies from 15.0 to 20.0 km and their height varies from zero to nearly 15.0 m. Several smaller eskers may be seen east of Fergus and within the Paris and Galt Moraines (Karrow 1987). According to Sibul et al. (1980), the most extensive surficial deposits of sand and gravel occur within the Regional Municipality of Waterloo. Their thickness throughout the area ranges from about 5.0 to 15.0 m and can reach locally up to 40.0 m. For the most part, the Waterloo and the Elmira Moraines are composed of these deposits.

The outwash deposits are found as channel fills, terraces, sand plains, and they also occur in association with the ice-contact deposits. The outwash deposits are characterized by level to undulating surfaces marked here and there by stream channels and sometimes by kettles. A large area of outwash deposits appears to be associated directly or indirectly with Paris and Galt Moraines. Prominent outwash terraces exist along the Grand and Speed Rivers, and an outwash plain separates Paris and Galt Moraines between Killean Station and Aberfoyle.

Intimately associated with the outwash deposits are the meltwater channel deposits that are sometimes referred to as spillways. The channel of the Grand River is the largest present-day stream. The channel originated during the retreat of the Tavistock ice from the Orangeville Moraine. A second channel is about 7.0 km long and is occupied by a tributary of the Schneider Creek. A third channel came down the Speed River Valley and joined with the Grand River at Preston, as it does today, but then continued southwest to the Nith River valley along a valley now occupied by the Cedar Creek. A fourth channel follows the Conestogo River south of Highway 9. In addition, numerous small channels occur within the Guelph Drumlin Field.

Almost all of the southern parts of the Authority from Brantford to Port Maitland are covered with glaciolacustrine sediments consisting of clay, silt, shallow water sand, beach bars, and nearshore deposits. Small areas of stratified silt, with some clay and sand are also found to southeast of Guelph within Paris and Galt Moraines. Subsurface occurrences of such sediments are found in three stratigraphic positions along the Conestogo River. The oldest occurs between the Catfish Creek and the Stirton Tills, the next oldest occurs between the Stirton and the Tavistock Tills, and the youngest occurs between the Tavistock and the Mornington Tills (Cowan 1979).

Alluvial deposits of stratified gravel, sand, and silt, border most of the streams within the Authority. Extensive alluvial terraces occur along the portion of the Grand River between Inverhaugh and Bloomingdale. Swamps and bogs, filled into varying depth by organic soil, peat, and muck, are numerous within the Authority. The largest swamp is the Beverly Swamp which is found east of Galt and Moffat Moraines. Smaller swamps are found west of Mill Grove, south of Campbellville, north of Lake Medad, between Ayr and Blair, east of Kitchener, within the belt occupied by Paris Moraine, and within the outwash in front of Galt Moraine.

Overburden Aquifers: Groundwater is the most important source for municipal water supplies within the Authority. The megalopolis area of Kitchener-Waterloo, Cambridge and Guelph is the largest urban area in the province that depends almost exclusively on groundwater for municipal supplies. In addition, other small communities within the Authority depend wholly on groundwater for their domestic, commercial and industrial needs. These communities are Arthur, Ayr, Baden-New Hamburg, Caledonia, Dundalk, Elmira-St. Jacobs, Elora, Fergus, Kitchener-Waterloo, Maryhill, Milverton, Paris, Plattsville, Rookwood, and St. George.

There are 26,323 records on file with the MOE for wells constructed within the Authority. Of these, 12,666 are bedrock wells, 9,796 are overburden wells, and the remaining wells are of unknown type. The majority of these wells are used to meet the needs of rural domestic supplies and livestock watering. Data related to short-term pumping tests are available for 6,762 overburden wells in the Authority. Of these wells, 1,065 (15.7%) have specific capacities ranging from 1.0 to 5.0 L/min/m, 3,156 (46.7%) have specific capacities between 5.0 and 25.0 L/min/m, 1,145 (16.9%) have specific capacities between 25.0 and 50.0 L/min/m, and 1,396 (20.7%) have specific capacities larger than 50.0 L/min/m.

Numerous studies have been carried out to evaluate the groundwater resources of the Authority in general and of the Regional Municipality of Waterloo in particular. The following is a brief summary of some of these investigations.

Pawley et al. (1976) conducted an investigation within the flood plains of the Grand and Conestogo Rivers to locate any river-connected aquifers and to identify sites for induced infiltration by vertical wells. Some 160 test holes were drilled as part of the investigation. The results indicated that in most places adjacent to the Grand River, the saturated deposits of sand and gravel are less than 4.5 m in thickness and are underlain by a relatively impermeable till. Such deposits were considered unsuitable for induced infiltration by vertical wells. Only four sites, where the thickness of the saturated sand and gravel was about six metres, were deemed acceptable for further testing.

Coward and Barouch (1978) conducted an investigation of the hydrogeology of the Blue Springs watershed within the Authority. The report identified two overburden units in the watershed. One unit consists of kame, outwash, and alluvial deposits, and the second unit consists of a sandy till. According to these authors, the kame, outwash, and alluvial deposits occur generally as lenses and pockets overlying the sandy till, however, they form only minor groundwater aquifers.

Sibul et al. (1980) prepared a report about the Authority's groundwater resources with special emphasis on the availability of groundwater supplies for municipal uses. Among other things, these authors described the sequences of sand and gravel deposits within the Authority and mapped their locations (Map 3.5).

Woeller (1982) conducted a study of the Greenbrook well field within the Regional Municipality of Waterloo. The study examined issues related to the municipal water takings, declining well levels, and groundwater recharge. Lotimer (1985) described the groundwater flow in the aquifer system at Kitchener, and Rudolph (1985) built a quasi three-dimensional finite element model for a steady-state analysis of the system.

Golder Associates Ltd. (1992) prepared a report regarding the implementation of a comprehensive strategy for the Regional Municipality of Waterloo to protect its local groundwater resources. The two basic objectives of the strategy were to limit the risk from historic or existing land use practises and to minimize the risk from future land uses. The report included background information related to the geology and hydrogeology of the municipality.

Karrow et al. (1993) conducted a study in the Regional Municipality of Waterloo in order to complete a stratigraphic cross-section through the Waterloo Moraine. The study included drilling of a series of boreholes that were continuously cored to bedrock and performing grain size analyses on collected samples. Seismic profiles of the boreholes and natural gamma, conductivity, neutron, and density geophysical logs were obtained. The geologic settings of two aquifers within the area were also described.

Johnston and Blackport (1995) conducted an assessment of the Wilmot Centre well field as part of the Baden-New Hamburg Water Supply Master Plan and Project. The assessment contained a summary of the hydrogeology of the area.

<u>Aquifers within the Regional Municipality of Waterloo (the Region)</u>:

Sibul et al. (1980) described several sequences of sand and gravel deposits within the Region, including:

- complex sequences of inter-glacial materials (5.0 to 20.0 m thick) that occur throughout much of Waterloo Township and are thickest to the west of Kitchener-Waterloo and in the vicinity of Baden,
- a sequence of sand and gravel (3.0 to 10.0 m thick and 15.0 to 50.0 m deep) extending from the southern part of Waterloo Township through much of North Dumfries Township to Ayr,
- A sequence of gravel at depths between 35.0 and 53.0 m in the vicinity of Ayr,
- a sequence, confined by lacustrine clays and till(s), of sand and gravel (8.0 to 9.0 m thick and 25.0 to 35.0 m deep) to the east of Cambridge,
- sequences of sand and gravel up to 25.0 m thick in the immediate vicinity of Elmira, and
- a sequence of sand, confined by tills and inter-glacial sediments, in the vicinity of St. Clements.

Numerous high-capacity wells have been constructed in the above sequences of sand and gravel. Unfortunately, the lateral and vertical continuity of these deposits remains a complex issue. From a regional point of view, the groundwater flow within the Region is toward the Grand River and its tributary the Nith River. Locally, however, the groundwater flow feeds numerous springs in the low areas adjacent to the Waterloo Moraine.

Two aquifer complexes have been identified within the Region (Woeller 1982, Golder Associates Ltd. 1992, and Karrow et al. 1993). The Upper Aquifer Complex consists of sand and gravel of ice-contact and outwash origins. These deposits form two aquifer units (Unit 1 and Unit 2) that are separated by silt and clay tills (possibly the Maryhill Till) that act as an aquitard (Aquitard 1). This aquitard, which is 3.0 to 15.0 m thick, is missing in certain locations which has implication with regard to groundwater recharge and contaminant transport.

The ice-contact and outwash deposits of Unit 1 make up the surficial materials over large areas of the Region. In places, however, particularly along the eastern flank of the Waterloo Moraine, these deposits are covered by fine-grained tills. Because of this geologic setting, groundwater within Unit 1 is confined only in those areas where it is covered by the tills.

Unit 2 represents a semi-continuous deposit of outwash sands and gravels extending from the Strange Street and Greenbrook well fields to the Mannheim East well field. Groundwater in this unit is confined. The Mannheim, Wilmot, and Erb Street well fields and part of the Strange Street well field obtain water from the Upper Aquifer Complex.

A clay till that act as an aquitard (Aquitard 2) separates the Upper Aquifer Complex from the Lower Aquifer Complex. This aquitard is thin and discontinuous.

The Lower Aquifer Complex consists of glaciofluvial sand and gravel deposits that are between zero and 25.0 m in thickness. These deposits, which overlie either the bedrock or a basal till, are associated with the Catfish Creek Till. This aquifer complex is highly productive and is being utilised at the Greenbrook, Lancaster, Parkway, Strange Street, and William Street well fields in Kitchener-Waterloo, and at the Shades Mill well field in Cambridge.

<u>The Puslinch Aquifer</u>: This confined aquifer occurs in Puslinch Township. It consists of outwash sand and gravel that range in thickness from 5.0 to 10.0 m. The aquifer, which overlies the bedrock in many places, is confined by up to 35.0 m of lacustrine sediments and till that appear to pinch out to the north and south. Many wells that obtain water from this aquifer have specific capacities of more than 50.0 L/min/m (Sibul et al. 1980).

<u>The Paris Aquifer</u>: This aquifer that is located to the northeast of Paris along the Grand River. It consists of up to 6.0 m of sand and gravel deposits that occur at a depth of about 15.0 to 25.0 m. Two municipal wells, which yield up to 3,500.0 L/min, obtain water from this aquifer (Sibul et al. 1980).

<u>The St. George Aquifers:</u> Two local aquifers have been identified to the north of St. George. A deep aquifer consisting of gravel deposits about 3.0 to 5.0 m thick that appears to overlie the bedrock, and a shallow aquifer of sand and gravel. The estimated yields of wells developed in these aquifers range from 225.0 to 900.0 L/min. Also, a local confined aquifer occurs to the south of St. George. It consists of sand and gravel deposits that are about 3.0 m thick and 17.0 to 40.0 m deep. The sand and gravel deposits are overlain by clay. The estimated well yields range from 450.0 to 900.0 L/min (Sibul et al. 1980).

<u>The Norfolk Sand Plain Aquifer</u>: This is part of the Norfolk Sand Plain Aquifer which was identified within Long Point Conservation Authority. The aquifer extends between Branford, Boston and Cathcart. The area is covered by sand and gravel of ice-contact and outwash origins and by some Port Stanley Till.

The records of 355 wells tapping the aquifer indicate that it consists of sand and gravel deposits that extend from the surface to a depth of up to 40.0 m. The wellhead elevations within the central part of the aquifer range from 240.0 to 268.0 m (a.s.l.). Toward the north, the elevation of the top of the aquifer ranges from 251.0 to 275.0 m (a.s.l.), and toward the southwest, the elevation of the top of the aquifer ranges from 188.0 to 233.0 (a.s.l.).

The depths to the static water levels range from less than one metre to 23.0 m, and the well yields range from 2.0 to 50.0 L/min. Of the 355 wells, however, 34 wells have yields ranging from 450.0 L/min to 2,725.0 L/min.

8.8 OVERBURDEN AQUIFERS IN THE NIAGARA PENINSULA CONSERVATION AUTHORITY

The Niagara Peninsula Conservation Authority (the Authority) is bounded on the north and northwest by Lake Ontario and the Hamilton Region Conservation Authority, on the west by the Grand River Conservation Authority, on the south by Lake Erie, and on the east by the Niagara River. The Authority is within the Counties of Niagara, Lincoln, and Haldimand. The main urban centres are St. Catharines, Niagara Falls, Port Colborne, Welland, Fort Erie, and Niagara-on-the-Lake (Figure 46).

Drainage: Drainage within the Authority is toward Lake Ontario, the Niagara River, and Lake Erie. The Niagara River, which is about 58.0 km long, connects Lake Erie and Lake Ontario. It stars at Fort Erie and travels northward for about 16.0 km as a broad calm river before it reaches Niagara Falls. Beyond the falls, the river flows in a deep gorge until it enters Lake Ontario at Queenston.

A large portion of the Authority is drained by the Welland River which rises near Ancaster in the west and meanders across a clay plain toward the Niagara River in the east. The river has a drainage area of about 880.0 km^2. Along most of its course, it is very sluggish due to its very small gradient. It has been forced to pass under the Welland Canal through two inverted syphons and the last six kilometres of its channel are being used as the intake for the Chippawa-Queenston power canal.

A number of small streams descend the Niagara Escarpment through narrow notches and flow northward into Lake Ontario. Among these are the Four Mile Creek which enters the lake at Niagara-on-the-Lake, the Twelve Mile Creek which enters the Lake at St. Catharines, the Twenty Mile Creek which enters the lake at Jordan Harbour, and the Forty Mile Creek which enters the lake at Grimsby. A number of small streams also drain southward into Lake Erie and westward into the Niagara River.

Physiography: Landforms within the Authority include rocky escarpments, clay plains, a large kame, and several small moraines of minor local relief. Chapman and Putnam (1984) identified parts of three physiographic regions within the Authority, namely, the Iroquois Plain, Niagara Escarpment, and Haldimand Clay Plain.

The Iroquois Plain is the low land extending between Lake Ontario and the Niagara Escarpment that was inundated in late Pleistocene times by glacial Lake Iroquois. The plain is flat and is covered by lacustrine deposits of sand, silt, and clay overlying the Halton Till.

The Niagara Escarpment extends from the Niagara River in the east to Ancaster in the west and separates the Iroquois Plain in the north from the Haldimand Clay Plain in the south. It is characterized by a sharp topographic break formed by cliffs of erosion-resistant Silurian dolostones overlying softer Ordovician shales.

The Haldimand Clay Plain covers most of the Authority area and extends between the Niagara Escarpment and Lake Erie. Local relief on the plain, which is associated with several small moraines, is limited to a few meters. One major topographic feature of the plain is the Onondaga Escarpment. Within the Authority, this escarpment runs north of Lake Erie from

Ridgeway in the east to Port Colborne in the west. It consists of areas of exposed bedrock and others with a thin veneer of overburden deposits. The Fonthill Kame in the vicinity of Fonthill is another major topographic feature of the plain. The kame, which rises about 60.0 m above the surrounding plain, is nearly circular in shape and measures about 6.0 km in diameter.

Bedrock Topography and Geology: The bedrock is exposed at the surface along the Niagara Escarpment and the Onondaga Escarpment. The bedrock elevation ranges from 60.0 to 80.0 m within the Iroquois Plain, from 80.0 to 180.0 within the Welland River basin, and from 180.0 to 200.0 m along Lake Erie. Figure 7 is a map of the bedrock topography in southern Ontario. The map shows a wide bedrock depression running in an east-west direction through the Haldimand Clay Plain between the Niagara and Onondaga Escarpments. It also shows two major bedrock valleys, one emptying into Lake Ontario between Fonthill and St. Catharines and the second emptying into the Niagara River. In addition, the map indicates a buried connection to Lake Erie west of Port Colborne.

According to Johnson et al. (1992), the bedrock geology consists of:

- the Queenston Formation of Upper Ordovician age,
- the Cataract Group of Lower Silurian age,
- the Clinton Group and the Lockport and the Guelph Formations of Middle Silurian age,
- the Salina and the Bertie Formations of Upper Silurian age, and
- the Oriskany, the Bois Blanc, and the Onondaga Formations of Lower and Middle Devonian age.

Overburden Thickness and Geology: A thin cover of overburden occurs on top of the Niagara and Onondaga Escarpments. Over most of the Authority, however, the thickness of the overburden ranges from 10.0 to 50.0 m. Overburden deposits up to 100.0 m in thickness are found within the Fonthill Kame.

The overburden consists of glacial, glaciofluvial, glaciolacustrine of Pleistocene age and lacustrine and organic deposits of Recent age. The Halton Till has been mapped at the surface within the Iroquois Plain and along the Niagara Escarpment (Barnett et al. 1991). Feenstra (1981) identified a second lower till which occurs as a buried ground moraine and overlies the bedrock at many locations. The till is believed to be equivalent to Wentworth Till.

Most of the Authority is covered by a mantle of glaciolacustrine silt and clay. In addition, sand and gravel deposits of glaciolacustrine origin are displayed at the surface within the Lake Iroquois plain and along the Authority's southwestern boundary.

Thick deposits of sand, gravel, silt, and till occur within the Fonthill Kame. The origin of this kame is not clear and it could have been deposited at the edge of the ice sheet that dumped the Halton Till. Similar deposits have also been reported within the St. Davids Gorge which is an abandoned channel of the Niagara River (Gartner Lee Limited 1987).

In addition, recent lacustrine and organic deposits are found mainly in the vicinity of the Onondaga Escarpment.

Overburden Aquifers: A total of 1,663 bedrock wells has been identified within the Authority as compared to 8,916 overburden wells which indicates that the overburden is the main source of water supply. Of 8,916 overburden wells, 1,209 (13.6%) have no specific capacity data, 969 (10.9%) have specific capacities of less than 1.0 L/min/m, 1,678 (18.8%) have specific capacities between 1.0 -5.0 L/min/m, 967(10.8%) have specific capacities between 5.0-10.0

L/min/m, 2,329 (26.1%) have specific capacities between 10.0-50.0 L/min/m, and 1,764 (19.8%) have specific capacities above 50.0 L/min/m.

The Fonthill Aquifer Complex: This aquifer complex is located mainly in Pelham Township within the Fonthill Kame. Its central parts are covered by glaciolacustrine sand and by ice-contact sand and gravel, while its outside edges are covered by glaciolacustrine clay. Therefore, one part of the aquifer complex is unconfined and the other is confined.

The well records of more than 100 wells tapping the aquifer complex indicate that the sand and gravel deposits within the central parts of the aquifer complex can reach up to 60.0 m in thickness. Some wells show thick clay deposits at depth resting on a hollow bedrock surface. Wells that obtain water from the outside rim of the aquifer complex show clay deposits that increase in thickness away from the centre.

Most of the well records indicate that the depths to static water levels range from one to 20 m. Some wells, however, show lower depths. Well yields range from 15.0 to 1,335.0 L/min, and the specific yields are mostly in range of 10.0 to 50.0 L/min/m. A few wells, however, have specific yields above 50.0 L/min/m.

The Lincoln Aquifer: This name is suggested for an aquifer that has been identified within the western half of the Authority in the Townships of Ancaster, Glanford, Seneca, Binbrook, West Lincoln, Saltfleet, North Cayuga, and Canborough. The aquifer is covered by thick deposits of glaciolacustrine clay and by some till deposits.

The aquifer consists mainly of gravel deposits with minor amounts of sand. The origin of these deposits, which range in thickness from a few metres up to ten metres, is unclear. Their surface elevation increases from a range of 150.0 to 160.0 m (a.s.l.) in the eastern part of the aquifer within the Townships of Canborough and West Lincoln to a range of about 225.0-250.0 in the western part of the aquifer within the Townships of Ancaster and Glanford.

The aquifer is confined and the depths to static water levels range from less than one metre to more than 17.0 m. The well yields range from 15.0 to 300.0 L/min, and the specific capacities are mostly between 10.0 and 50.0 L/min.

The Wainfleet Aquifer: This name is suggested for a local aquifer within the Townships of Moulton and Wainfleet. The land surface where the aquifer occurs is covered by a thin layer of glaciolacustrine sand. The aquifer itself consists of medium sand and gravel deposits which are a few metres in thickness. It is overlain by up to ten metres of blue clay deposits. The elevation of the top of the aquifer ranges from 140.0 to 160.0 m (a.s.l.).

The aquifer is confined and the depths to the static water levels are between 2.0 and 7.0 m. The well yields range from 25.0 to 180.0 L/min, and the specific capacities range between 10.0 and 50.0 L/min/m.

The Port Colborne Aquifer: This name is suggested for a local aquifer in the vicinity of Port Colborne. The land surface where the aquifer occurs is covered by glaciolacustrine clay. The aquifer itself consists of gravel with some medium sand deposits which are a few metres in thickness. It is overlain by up to 25.0 m of clay and till deposits. The elevation of the top of the aquifer ranges from 156.0 to 177.0 m (a.s.l.).

The aquifer is confined and the depths to the static water levels are between 3.0 and 11.0 m. The well yields range from 15.0 to 65.0 L/min, and the specific capacities for most wells are more than 50.0 L/min/m.

The St. Catharines Aquifer: This name is suggested for a local aquifer in the vicinity of St. Catharines. The land surface where the aquifer occurs is covered by till and glaciolacustrine sand. The aquifer itself consists of a few metres of medium sand and gravel. It is overlain by up to 22.0 m of clay. The elevation of the top of the aquifer ranges from 61.0 to 76.0 m (a.s.l.).

The aquifer is confined and the depths to the static water levels are between 3.0 and 11.0 m. The well yields range from 35.0 to 890.0 L/min, and the specific capacities for most wells are between 10.0 and 50.0 L/min/m.

The Niagara-on- the- Lake Aquifer: This name is suggested for a local aquifer in the vicinity of Niagara-on-the-Lake. The land surface where the aquifer occurs is covered by till and glaciolacustrine sand. The aquifer itself consists of a few metres of fine and medium sand and/or gravel. It is overlain by up to 25.0 m of clay and till deposits. The elevation of the top of the aquifer ranges from 72.0 to 86.0 m (a.s.l.).

The aquifer is confined and the depths to the static water levels are between 3.0 and 7.0 m. The well yields range from 15.0 to 175.0 L/min, and the specific capacities for most wells are between 10.0 and 50.0 L/min/m.

9. GROUNDWATER FLOW SYSTEMS

Groundwater is subject to continuous movement, the rate of which is a function of the hydrogeologic characteristics of the material in which it moves, the existing hydraulic gradients and temperature. The existence of a three-dimensional, continuous groundwater domain in a corresponding three-dimensional potential field has been established and developed by Hubert (1940), To'th (1962, 1963, 1972), and Freeze and Whitherspoon (1966, 1967).

The groundwater hydraulic potential at a given point in this domain where the flow is at low velocity (Darcian) is given by:

$$H = g * z + (AP - P)/d \qquad (3)$$

where

H = hydraulic potential at a given point in the field,
g = gravity acceleration,
z = elevation at the point above an assumed datum,
AP = atmospheric pressure,
P = pressure at a given point, and
d = density of water.

The hydraulic head equals the hydraulic potential divided by the gravity acceleration and is measured in metres above a datum (usually mean sea level). Because the hydraulic head is obtained by dividing the hydraulic potential by a constant, it is a potential quantity itself and obeys the laws of potential theory. The hydraulic head, therefore, can be used as a potential function to describe the groundwater flow system.

A number of piezometers can be inserted at different levels inside a monitoring well to provide the hydraulic head readings at these levels. This is usually done if the well penetrates more than one aquifer. Many monitoring wells are needed to provide readings of the hydraulic heads at a given time in order to construct an accurate map of the hydraulic head distribution within a given aquifer. This can be a very expensive operation.

The data from the MOE Water Well Monitoring Network is insufficient to provide the necessary information to delineate the groundwater flow systems within the bedrock and overburden in southern Ontario. Data on the static water levels from thousands of wells constructed in the bedrock or the overburden are available. These water level data were obtained at different times and provide mean values of the hydraulic heads in various wells. Therefore, these data cannot provide an exact picture of the hydraulic head configuration. However, given the fact that the differences in the hydraulic head readings are small within a well, the data can be used to provide a general picture of the hydraulic head or the static groundwater level distribution on a regional scale.

Knowledge of the configuration of the static water levels is of importance in groundwater investigations as it indicates the direction and rate of groundwater flow. Figure 47 shows that the configuration of the static groundwater levels within the bedrock in southern Ontario is a subdued reflection of its surface topography. Regional groundwater divides closely follow the major basin topographic divides. Groundwater appears to flow through river valleys toward the Great Lakes, and the Ottawa and St. Lawrence Rivers. Figure 47 also shows that the groundwater basin of Lake Simcoe is well defined.

Within the Laurentian Highlands physiographic region, groundwater flows radially from the north in Haliburton and Hastings Counties toward the Ottawa River, Lake Ontario and Georgian Bay. Within the central part of southern Ontario, on the other hand, a groundwater divide runs through the Oak Ridges Moraine diverting groundwater flow northward to Lake Simcoe and southward to Lake Ontario.

Above the Niagara Escarpment, the Dundalk Dome directs groundwater flow radially into Georgian Bay, Lake Huron, Lake St. Clair, Lake Erie, and Lake Ontario through a myriad of rivers and creeks. The Niagara Escarpment acts as a sink through which groundwater flows under steep slopes toward Lake Ontario.

Figure 48 shows the configuration of the static groundwater levels within the overburden. The figure shows similar patterns to those found within the bedrock, but the patterns are more pronounced. Where the overburden is missing, the groundwater flow systems in both the overburden and the bedrock become one system.

10. LONG-TERM GROUNDWATER RECHARGE AND DISCHARGE

10.1 GROUNDWATER AND THE HYDROLOGIC CYCLE

The hydrologic cycle is a concept that considers the processes of motion, loss and recharge of the Earth's water. Water, which evaporates from the land and oceans, is carried by the air masses and eventually precipitates either on land or on oceans. Some of the precipitation that falls on land may be intercepted or transpired by plants and returned back to the atmosphere, some may runoff over the land surface to streams, and the remainder may infiltrate into the ground.

Some of the infiltrated water may be temporarily retained as soil moisture or moves laterally as interflow within the soil to the nearest stream. The remainder percolates deeper to the water table to be stored as groundwater. The groundwater, in turn, may be used by plants, or it flows out as springs, or it seeps into streams as baseflow, only to eventually evaporate to the atmosphere to complete the hydrologic cycle (Gray 1970).

From the foregoing it is clear that the hydrologic cycle is made up of several interrelated components (processes). Therefore, in order to study one of these components in detail, it is necessary to consider its relationships with all the other components.

10.2 SOIL MOISTURE AND GROUNDWATER RECHARGE

The status of the soil moisture component is the decisive factor when it comes to groundwater recharge. The zone of soil moisture is at a critical juncture in the hydrologic cycle. From the initial impact of precipitation on the soil surface to the final drainage or evaporation of water from the soil, it presents many facets. Thus, the infiltration process, the storage of water within the soil profile, the transmission of water laterally as interflow or vertically as groundwater recharge, the evaporation of the stored soil moisture or its utilization by plants, and the freezing-thawing cycles, all are facets of the role the soil moisture plays.

Precipitation is the primary source of water for the replenishment of soil moisture. Lateral transfer of water over the ground surface from topographic highs to lows and the upward flow of water from the groundwater zone to the unsaturated zone provide further sources of replenishment to soil moisture.

The primary mechanisms for soil moisture depletion are through evapotranspiration and gravity drainage. The magnitude of evapotranspiration is controlled by the soil moisture availability and the climatic conditions. Gravity drainage, on the other hand, occurs in response to pressure gradients either vertically or laterally. Whereas the lateral movement of the soil moisture generates interflow, its downward vertical movement contributes to groundwater recharge (Singer 1981).

10.3 TIMING OF GROUNDWATER RECHARGE IN SOUTHERN ONTARIO

The process of groundwater recharge is completely controlled by the status of soil moisture, provided that there is no gain to the groundwater storage from outside areas. There is a confusion regarding groundwater recharge and where it takes place. Except in river and stream valleys that constitute the main groundwater discharge zones, groundwater recharge takes place almost everywhere. The rate of groundwater recharge, however, is high in certain areas and the identification of such areas is, therefore, important for the appropriate management of the groundwater resources.

Measurements of precipitation and the variations in static water levels at monitoring wells are good means to determine the periods of groundwater recharge. When discussing groundwater recharge, however, it is important to keep in mind that the groundwater storage is continually being depleted by discharge to streams. Therefore, when the water level in some monitoring well remains steady, the groundwater recharge and discharge are equal. A rise in the water level indicates that recharge is more than discharge, a fall means the reverse is true.

Groundwater recharge occurs at a maximum rate when the soil is in a state of complete saturation and diminishes when the soil is at the wet limit (field capacity). In southern Ontario, this condition is met mainly during the snowmelt and spring rainfall events, which usually extends from mid March through April and early May (Figures 49 and 50). During this period, temperature starts to rise, the soil moisture is close to saturation, evapotranspiration is low, and the snow pack starts to deplete until it vanishes completely. A vast amount of liquid water, produced by the melting snow and rainfall events, is suddenly available. Part of this water generates high flows and floods. The remaining water infiltrates through the soil and then percolates to the groundwater storage. This is the main period of groundwater recharge in southern Ontario when the water table reaches a maximum height and the groundwater storage is at its peak.

Rainfall events that occur during the period from late October to early December also contribute to groundwater recharge. During this period, the temperature is declining, the growing season is finished, evapotranspiration is low, and soil moisture is being restored to saturation level by precipitation that is mostly in the form of rain. The net result is recharge to groundwater and rising water tables. Finally, some recharge to groundwater could take place during winter warm spells (Figures 49 and 50).

During the summer and early fall, the soil moisture is utilized mainly by plants through evapotranspiration and a state of soil moisture deficiency usually prevails. Therefore, most of the infiltrated water from the rain, during this period, is used to satisfy this deficiency with little or no water left to recharge the groundwater. As a result, groundwater levels steadily decline except during heavy rainfall events (Figure 49 and 50).

10.4 QUANTITATIVE ASSESSMENT OF THE LONG-TERM GROUNDWATER DISCHARGE AND RECHARGE

It is generally recognized that streamflow consists of the following three components:

- i direct runoff, which is that part of precipitation that flows over the land surface to the streams;
- ii interflow, which is that part of precipitation that flows part of the way underground, but does not become part of the groundwater regime; and
- iii baseflow, which is that part of the precipitation that reaches the streams as natural groundwater discharge, after being a part of the groundwater regime.

One way to estimate the groundwater discharge is to separate the streamflow into different components. Unfortunately, the principles of separating the streamflow into components are not well developed, and in the case of complex streamflow events streamflow separation appears to be somewhat arbitrary. It is believed, however, that if a certain method of streamflow separation is followed consistently, the same error will be committed systematically and, therefore, useful results can be obtained for comparative purposes.

For the purpose of this report, a streamflow separation program was developed. The program separates streamflow into two components: a surface runoff component consisting of direct runoff and interflow, and a baseflow component. The program allows for the processing of a large amount of data in a very short time and ensures consistency in the application of the technique.

Six parameters are used in the program. The first parameter is used to detect the beginning of an event, the second to determine the event period, the third to detect the peak flow, the fourth to determine the value of the groundwater component under the peak, the fifth to determine the relative event limits, and the sixth to determine the absolute event limit.

Data from 33 gauging stations located in small watersheds in southern Ontario were selected to separate the streamflows. Care was taken to ensure that the size of each selected watershed is less than 200.0 km^2, streamflows at all the gauging stations are natural flows, and the period of record at each station is long enough to allow for the estimation of long-term means.

All the selected streamflow gauging stations have more than eight years of daily streamflow records. The available records were processed using the streamflow separation program. Table 5 gives the names and numbers of the gauging stations, the period of records, and the drainage area. Table 6 gives the long-term means of monthly and annual groundwater discharge, which were calculated for the 33 gauging stations. An examination of Table 6 reveals that the long-term monthly means are highest during the months of March, April and May; they decrease steadily during the period June-October and start to recover during November and December. This pattern is similar to the pattern of groundwater level fluctuations shown on Figures 49 and 50.

The long-term means of annual groundwater discharge, calculated for the 33 stations, range from 83.3 to 284.9 mm. Given that the records at these stations are long and that the change in soil moisture storage approaches zero over long periods, it is possible to assume that the long-term means of monthly and annual groundwater discharge, calculated for the 33 gauging stations, are equal to the long-term means of monthly and annual groundwater recharge.

11. GROUNDWATER QUALITY

The chemical composition of groundwater is an important consideration in any hydrogeologic study. The suitability of the groundwater for use by agriculture, commerce, industry or for drinking purposes can be assessed by a study of its chemistry.

In carrying out its responsibilities under Section 2 of the Ontario Water Resources Act, MOE applies the Ontario Drinking Water Standards (ODWS) in approving the establishment of any water works, or the extension of or change in any existing water works that are capable of supplying water at a rate greater than 50,000.0 litres per day or water works that supply drinking water to more than five private residences (MOE 2001). The primary purpose of these standards is to protect public health through the provision of safe drinking water. The standards have been derived from the best information currently available and are continually being reviewed as new and more significant data become available.

Two types of standards have been established, the Maximum Acceptable Concentration (MAC) and the Interim Maximum Acceptable Concentration (IMAC). The MAC is a health-related standard. It was established for parameters that, when present above a certain concentration, have known or suspected health effects. The IMAC is also a health-related standard. It is used when the toxicological data to establish a MAC are insufficient, or when establishing a MAC at the desired level is not feasible for practical reasons.

In addition, Aesthetic Objectives (AOs) and Operational Guidelines (OGs) were established. The AOs are for parameters that may impair the taste, odour or colour of water, or may interfere with good water quality control practices. The OGs, on the other hand, are for parameters that need to be controlled to ensure the efficient and effective treatment and distribution of the water.

Most of the parameters that are routinely found in natural groundwater are associated with chemical or physical objectives that are not health related. The following is a list of these parameters and associated objectives:

Parameter	Objective (mg/L)	Aesthetic Objective or Operational Guideline
Alkalinity (as $CaCO_3$)	30 -500	OG
Chloride	250	AO
Iron	0.3	AO
Manganese	0.05	AO
Sodium	200	AO
Sulphate	500	AO
Sulphide	0.05	AO
Total Dissolved Solids	500	AO

The AO for water colour is 5 True Colour Units and the OG for pH is 6.5 to 8.5 (no units). Further, odour and taste of the water should be inoffensive.

Arsenic and lead are found at times in natural groundwater. The IMAC for arsenic is 0.025 mg/L, and the MAC for lead at the point of consumption is 0.01 mg/L. Groundwater may become contaminated by nitrate. The MAC for nitrate (as nitrogen) is 10.0 mg/L. Where nitrate and nitrite are present, the total of the two should not exceed 10.0 mg/L (as nitrogen).

Hardness is caused by dissolved calcium and magnesium, and it is expressed as the equivalent quantity of a calcium carbonate. The OG for hardness in drinking water is set at between 80.0 and 100.0 mg/L as calcium carbonate. This range for hardness is set to provide an acceptable balance between corrosion and incrustation of pipes, and to aid in water source selection where a choice exists. Water supplies with a hardness level greater than 200.0 mg/L are considered poor but tolerable. Hardness levels more than 500.0 mg/L in drinking water are unacceptable for most domestic purposes.

In applied hydrogeology, the following classification for water hardness is often used:

Hardness Range mg/L of $CaCO_3$	Type of water
10 - 60	soft
61 - 120	moderately hard
121 - 180	hard
> 180	very hard

Since the OG for the hardness parameter is set mainly for consideration of corrosion and incrustation of pipes, the hardness levels determined through chemical analyses of samples will be described as indicated in the above classification (i.e., soft, moderately soft, hard, and very hard).

Natural groundwater has often superior quality which makes it highly attractive as a source of drinking water supply. Unfortunately, groundwater in some aquifers does not always meet all the standards, objectives or guidelines and may contain high levels of total dissolved solids, hardness, sulphate, hydrogen sulphide, or iron. Home treatment devices are available to treat these problems.

Overall, natural groundwater has very low levels of nitrate and is free from bacteria. Therefor, the detection of high levels of nitrate or any amounts of faecal or total coliform bacteria in a sample collected from a water well shows that the well has been contaminated. Most well contamination is the result of poor location, inferior construction methods, or inadequate maintenance.

Most of the MOE well records include information related to the kinds of groundwater encountered as fresh, salty, sulphurous, or containing iron or gas. This information is submitted by the well driller as part of the well record. Usually, the driller examines visually a water sample taken from the well for clarity. The driller then smells and tastes the water and enters appropriate observations into the well record. These observations are very useful especially when the water tastes salty or smells like a rotten egg showing the presence of sodium chloride or hydrogen sulphide. The driller's observations, however, are subjective and inadequate for determining the suitability of groundwater for drinking purposes.

Throughout the years, water quality analyses were carried out on many municipal and private wells. A concerted effort was made during this study to assemble all the available chemical data for further evaluation.

In order to assess the quality of groundwater within various bedrock and overburden units and determine the types of groundwater in these units, a computer program called: "Durov Water Quality Analyser" was used (Durov 1948). Water quality data in mg/L are converted by the program into equivalents per million (EPM) and percent EPM values. The EPM values are used to calculate the ion balance and determine the percent ion balance. The percent EPM values, on the other hand, are used to determine the dominant ions in each sample and generate a water type table. The percent EPM values can then be plotted on a trilinear diagram, which shows the dominant cations and anions for all the samples.

11.1 GROUNDWATER QUALITY IN THE BEDROCK

General information related to the quality of groundwater is available for 129,797 bedrock wells. The records indicate that the majority of these wells yield fresh water. A considerable number of wells, however, are reported to have some natural water quality problems. Figure 51 shows the locations of bedrock wells that have been reported to yield salty, sulphurous or mineral water as well as the locations of wells that yield water containing gas.

Figure 51 indicates that bedrock wells that yield sulphurous water are concentrated in three bands in southern Ontario. The first band extends from the Ottawa River in the north to the St. Lawrence River in the south. The second band extends along the southwestern slopes of the Canadian Shield from Addington and Prince Edward Counties to Georgian Bay. The third band extends from the Niagara River in the east to Essex County in the west.

Bedrock wells that yield salty water are concentrated to the south of the Ottawa River, and can be found in Addington, Prince Edward, Halton, Peel, Kent, Lambton, and Essex counties. Most of the bedrock wells, which yield water containing gas, are located in Kent and Lambton Counties.

The results of 533 chemical analyses for water samples collected from bedrock wells are available. Appendix III lists these results and gives the well numbers or the geographic coordinates of the wells.

Figures 52, 53, 54, 55, and 56 show the percentages of samples exceeding the AOs for sodium, iron, total dissolved solids, chloride, and sulphate, respectively. Figure 57 provides a comparison among the various bedrock units in terms of minimum, mean, and maximum levels of hardness.

11.1.1 Precambrian Hydrogeologic Unit

The well records indicate that the majority of the wells in the Precambrian hydrogeologic unit provide fresh water supplies. A very small number of records, however, show some natural water quality problems, 19 wells are reported to yield salty water, 24 yield sulphurous water, and 13 yield mineral water.

The results of eight chemical analyses, for water samples taken from wells constructed in the unit, indicate that the natural groundwater quality is generally good. The mean concentration of total dissolved solids for the samples is 412.3 mg/L. In terms of hardness, the water ranges from moderately hard to very hard. Further, 43.0% of the samples have iron levels above the AO and 25.0% of the samples have sulphate levels above the AO.

Table 9 gives the results of the water type analysis (Durov analysis) for various bedrock hydrogeologic units. The analysis was conducted on three samples obtained from wells completed in the Precambrian hydrogeologic unit. The results of the analysis indicate that two samples are of a calcium-bicarbonate type and one sample is of a bicarbonate type.

11.1.2 Nepean-March-Oxford Hydrogeologic Unit

General information related to the quality of groundwater within the Nepean-March-Oxford hydrogeologic unit is available for 17,390 wells. The majority of these wells yield fresh water. A few of the wells, however, yield sulphurous water (193 wells) or salty water (33 wells).

The results of 33 chemical analyses, for water samples taken from wells constructed in this unit, indicate that the natural groundwater quality is generally good. The concentration of total dissolved solids ranges from 486.3 to 1,380.0 mg/L and 28.0% of the samples have levels above the AO. In terms of hardness, the water ranges from moderately hard to very hard with a mean hardness concentration of 320.8 mg/L.

Iron concentrations are generally low. However, eight samples have concentrations above the AO and three samples have concentrations in excess of 5.0 mg/L.

The nitrate concentrations for the majority of the samples are much below the MAC. Nevertheless, some samples show very high nitrate levels. This is an indication that human activities are contributing significant nitrate loadings to the groundwater within this hydrogeologic unit.

Water type analysis was conducted on 28 samples. The results of the analysis indicate that most of the samples are of a bicarbonate type or of a calcium-bicarbonate type.

11.1.3 Rockcliffe Hydrogeologic Unit

General information related to the quality of groundwater in this unit is available for 2,089 wells. Of these wells, 97.0% yield fresh water, 2.0% yield sulphurous water, and 1.0% yield salty water.

The results of one chemical analysis, for a water sample taken from a well constructed in this unit, are available. The results indicate that the natural groundwater quality is good. Water hardness, however, is on the high side. The water was of a bicarbonate type.

11.1.4 Ottawa Group Hydrogeologic Unit

General information related to the quality of groundwater in the Ottawa Group hydrogeologic unit is available for 10,048 wells. Approximately 91.0% of these wells yield fresh water, 5.0% yield sulphurous water, and 4.0% yield either salty or mineral water.

The results of 39 chemical analyses, for water samples taken from wells constructed in the group hydrogeologic unit, are available. Although the water quality of the samples is generally suitable for domestic use, some samples show poor water quality.

The concentrations of total dissolved solids are high with 62.0% of the samples exceeding the AO. In terms of hardness, the water ranges from soft to very hard with a mean hardness concentration of 277.9 mg/L.

Many samples show excessive levels of iron, sodium, chloride and sulphate. The AOs are exceeded in 45.0% of the samples with respect to iron, in 21.0% of the samples with respect to sodium, in 10.0% of the samples with respect to chloride, and in 3.0% of the samples with respect to sulphate.

In addition, a number of samples show high nitrate levels. This indicates that some nitrate loadings to this hydrogeologic unit are taking place as a result of human activities.

Water type analysis was conducted on 32 samples. The analysis indicates that most samples are of a calcium-bicarbonate type (41.0%), a bicarbonate type (31.0%), or a sodium-potassium-bicarbonate type (16.0%).

11.1.5 Simcoe Group Hydrogeologic Unit

General information related to the quality of groundwater in the Simcoe Group hydrogeologic unit is available for 28,033 wells. The majority of wells (78.0%) yield fresh water. However, 5.2% yield sulphurous water and 1.4% yield salty or mineral water. No data are available for the remaining 15.4% of the wells.

The results of 38 chemical analyses, for water samples taken from wells constructed in the unit, are available. These results indicate that the suitability of groundwater within this unit for domestic use ranges from poor to good.

The mean concentration of total dissolved solids is 647.0 mg/L with 42.0% of the samples showing levels above the AO. In terms of hardness, the water ranges from soft to very hard with a mean hardness concentration of 285.9 mg/L. Some samples also show levels above the AOs for iron (37.0%), sodium (15.0%), chloride (11.0%), and sulphate (11.0%).

Water type analysis was conducted for 33 samples. The results indicate that most samples are of a calcium-bicarbonate type (36.0%), a bicarbonate type (21.0%), a sodium-potassium-bicarbonate type (15.0%), or a sodium-potassium-sulphate-nitrate type (12.0%).

11.1.6 Billings-Carlsbad-Queenston Hydrogeologic Unit

General information related to the water quality of groundwater in the Billings-Carlsbad-Queenston hydrogeologic unit is available for 1,058 wells. Approximately 80.0% of these wells yield fresh water, 14.0% yield sulphurous water, and 6.0% yield either salty or mineral water.

The results of 10 chemical analyses, for water samples taken from wells constructed in the unit, indicate that the natural groundwater quality is generally poor. The concentrations of total dissolved solids exceed the AO in 70.0% of the samples with a mean concentration of 947.1 mg/L. In terms of hardness, the water ranges from soft to very hard with a mean hardness concentration of 202.3 mg/L.

The AO for sodium is exceeded in 50.0% of the samples, and the AO for chloride is exceeded in 30.0% of the samples. High sodium concentrations in groundwater are commonly associated with shales. According to Sibul et al. (1977), the sodium occurs naturally in the shales and the ion exchange process results in the replacement of calcium with sodium in groundwater. The mean concentration of calcium in the water samples is in fact low at 49.0 mg/L.

Although the concentrations of iron are generally low, three samples have iron levels exceeding the AO. The results of the chemical analyses show no indication of any nitrate contamination.

Water type analysis was conducted for the 10 samples. The analysis indicates that most samples are of a sodium-potassium-chloride type (30.0%), a sodium-potassium-bicarbonate type (20.0%), or a bicarbonate type (20.0%).

11.1.7 Blue Mountain-Georgian Bay Hydrogeologic Unit

General information related to the quality of groundwater encountered in the Blue Mountain-Georgian Bay hydrogeologic unit is available for 1,678 wells. Of these wells, 87.0% yield fresh water, 8.0% yield salty water, and the remaining 5.0% yield sulphurous or mineral water.

The results of 13 chemical analyses for water samples, taken from wells constructed in the unit, are available. Although the natural groundwater quality is generally suitable for domestic use, some samples show poor water quality. The concentrations of total dissolved solids exceed the AO in 71.0% of the samples and the mean concentration is 686.0 mg/L. In terms of hardness, the water ranges from moderately hard to very hard with a mean hardness concentration of 262.7 mg/L.

Many samples show excessive levels of sodium and chloride, which is reflected by their mean concentrations of 109.1 and 137.3 mg/L, respectively. The AO for sodium was exceeded in three samples and the AO for chloride was exceeded in two samples. Iron concentrations are generally below the AO, however, four samples have levels above the objective.

Water type analysis, which was conducted on 12 samples, indicates that the majority of the samples are of a bicarbonate type (33.0%), a sodium-potassium-chloride type (25.0%), or a sodium-potassium-bicarbonate type (17.0%).

11.1.8 Queenston Hydrogeologic Unit

General information about the quality of groundwater in the unit is available for 3,330 wells completed in the Queenston hydrologic unit. Of these wells, 92.0% yield fresh water, 5.0% yield salty water, and 3.0% yield either sulphurous or mineral water.

The results of 12 chemical analyses for water samples, taken from wells constructed in the unit, are available. The water quality of the samples is highly variable, ranging from poor to good. The concentration of total dissolved solids exceeded the AO in five of eight samples. In terms of hardness, the water ranges from hard to very hard with a mean hardness concentration of 472.1 mg/L.

Many samples show excessive levels of sodium and chloride, which is reflected by their mean concentrations of 88.0 and 123.0 mg/L, respectively. Sulphate concentrations range from 18.0 to 1,220.0 mg/L with the mean concentration at 251.0 mg/L. Four of the 12 samples exceeded the AO for sulphate and one of five samples exceeds the AO for iron.

Water type analysis was conducted on 10 samples. The analysis indicates that three samples are of calcium-bicarbonate type, two samples are of calcium-sulphate-nitrate type, one sample is of calcium type, one sample is of sodium-potassium-chloride type, and two samples have no dominant type.

11.1.9 Clinton Group and Cataract Group Hydrogeologic Units

The results of three chemical analyses are available for three wells constructed either in the Cataract Group or the Clinton Group hydrogeologic units. The results indicate that the natural groundwater quality is within the AOs for sodium, chloride, sulphate and total dissolved solids and that the water is very hard. One sample, however, shows iron levels above the AO. The water in two samples is of a calcium-bicarbonate type and in one sample of a bicarbonate type.

11.1.10 Amabel-Lockport-Guelph Hydrogeologic Unit

General information related to the quality of groundwater in the Amabel-Lockport-Guelph hydrogeologic unit is available for 22,812 wells. Approximately 96.0% of these wells yield fresh water and the remaining 4.0% yield salty, sulphurous or mineral water.

The results of 96 chemical analyses for water samples, taken from wells constructed in the Amabel Formation, are available. Although the natural groundwater water is generally suitable for domestic use, some samples show poor water quality.

The concentrations of total dissolved solids exceed the AO in 21.0% of the samples. In terms of hardness, the water ranges from moderately hard to very hard with a mean hardness concentration of 348.9 mg/L. Iron concentrations exceed the AO in 37.0% of the samples. Sulphate concentrations range from 1.0 to 1,300.0 mg/L and 6.0% of the samples exceed the AO for sulphate.

The concentrations of sodium and chloride, however, are generally low, which is reflected by their mean concentrations of 16.0 mg/L and 28.0 mg/L, respectively. In addition, 11.0% of the samples show high nitrate levels (>5.0 mg/L). This indicates that some nitrate loadings to groundwater in this unit are occurring as a result of human activities.

Water type analysis was conducted on 69 water samples. The analysis indicates that 78.0% of the samples are of a calcium-bicarbonate type, 10.0% are of a bicarbonate type, 9.0% are of a calcium-sulphate-nitrate type, and 3.0% show no dominant type.

The results of 48 chemical analyses of water samples, taken from wells constructed in the Guelph Formation, are available. Although the quality of groundwater is generally suitable for domestic use, many samples show poor water quality. The concentrations of total dissolved solids exceed the AO in 35.0% of the samples. In terms of hardness, the water ranges from moderately hard to very hard with a mean hardness concentration of 469.4 mg/L.

Iron concentrations exceed the AO in 60.0% of the samples. Sulphate concentrations range from 2.0 to 1,600.0 mg/L and 23.0% of the samples exceed the AO for sulphate. As is the case with the Amabel Formation, the concentrations of sodium and chloride are generally low which is reflected by their mean concentrations of 36.0 and 53.0 mg/L, respectively. Again, 11.0% of the samples show high nitrate levels (>5.0 mg/L).

Water type analysis was conducted on 43 samples. The results indicate that 37.0% of the samples are of a calcium-bicarbonate type, 26.0% are of a bicarbonate type, and 16.0% are of a calcium-sulphate-nitrate type. The remaining 21.0% of the samples are of a sulphate-nitrate type, a calcium type, a sodium-potassium type, or have no dominant type.

No chemical analyses are available for water samples from the Lockport Formation.

11.1.11 Salina Hydrogeologic Unit

General information is available for 3,582 of wells completed in the Salina hydrogeologic unit. Approximately 90.0% of these wells yield fresh water, 6.0% yield sulphurous water, and the remaining 4.0% yield either salty or mineral water.

The results of 63 chemical analyses for water samples, taken from wells constructed in the unit, are available. Many of these samples show poor water quality. This is most likely due to the presence of anhydrite and gypsum in the Salina Formation.

The concentration of total dissolved solids exceeds the AO in 6.09% of the samples. In terms of hardness, the water ranges from hard to very hard with a mean hardness concentration of 1,110.5 mg/L. Sulphate concentrations range from 4.0 to 2,570.0 mg/L and the mean concentration is 975.0 mg/L. The AO for sulphate is exceeded in 65.0% of the samples and sulphate concentrations above 1,000.0 mg/L have been found in 49.0% of the samples.

Iron concentrations exceed the AO in 68.0% of the samples. The concentrations of sodium and chloride, on the other hand, are generally low, which is reflected by their mean concentrations of 68.0 and 38.0 mg/L, respectively. Nevertheless, the AO for sodium is exceeded in 11.0% of the samples. Also, 9.0% of the samples show high nitrate levels (>5.0 mg/L). This indicates that some nitrate loadings to groundwater in this hydrogeologic unit are occurring as a result of human activities.

Water type analysis was conducted on 54 water samples. The results, indicate that 61.0% of the water samples are of a calcium-sulphate-nitrate type, 22.0% are of a calcium-bicarbonate type, and 7.0% are of a sulphate-nitrate type. The remaining 10.0% of the samples are of a bicarbonate type, a calcium type, or have no dominant type.

11.1.12 Bass Island Hydrogeologic Unit

General information related to the quality of groundwater in the Bass Island hydrogeologic unit is available for 860 wells. Of these wells, 95.0% yield fresh water, 3.0% yield sulphurous water, and 2.0% yield mineral water.

The results of 19 chemical analyses for water samples, taken from wells constructed in this unit, are available. Many of these samples show poor water quality. The concentration of total dissolved solids exceeds the AO in 47.0% of the samples. In terms of hardness, the water ranges from moderately hard to very hard with a mean hardness concentration of 788.3 mg/L. The concentrations of sulphate range from 5.0 to 2,197.0 mg/L and the AO for sulphate is exceeded in 35.0% of the samples. Further, sulphate concentrations above 1,000.0 mg/L have been found in 24.0% of the samples.

Iron concentration exceeds the AO in 47.0% of the samples. However, the concentrations of sodium and chloride are generally low. This is reflected by their mean concentrations of 32.0 mg/L and 14.0 mg/L, respectively. In addition, 14.0% of the samples show high nitrate levels (>5.0 mg/L). This indicates that some nitrate loadings to groundwater in this hydrogeologic unit are occurring as a result of human activities.

Water type analysis was conducted on 12 samples. The results indicate that 42.0% of the samples are of a calcium-sulphate-nitrate type, and 33.0% are of a calcium-bicarbonate type. The remaining samples are of a bicarbonate type, a calcium type, or a sodium-potassium-bicarbonate type.

11.1.13 Bois Blanc Hydrogeologic Unit

General information related to the quality of groundwater is available for 1,232 wells. Approximately 93.0% of these wells yield fresh water. Also, 6.0% yield sulphurous water, and the remaining 1.0% yield salty or mineral water.

The results of 23 chemical analyses for water samples, taken from wells constructed in the unit, are available. Many of these samples show poor water quality. The concentration of total dissolved solids exceeds the AO in 48.0% of the samples. In terms of hardness, the water ranges from hard to very hard with a mean hardness concentration of 599.9 mg/L. The concentrations of sulphate range from 4.0 to 1,875.0 mg/L and the AO for sulphate is exceeded in 32.0% of the samples. Further, sulphate concentrations above 1,000.0 mg/L have been found in 24.0% of the samples.

Iron concentration exceeded the AO in 65.0% of the samples. However, the concentrations of sodium and chloride are generally low, which is reflected by their mean concentrations of 32.0 mg/L and 15.0 mg/L, respectively. Two samples show high nitrate levels (>5.0 mg/L). This indicates that some nitrate loadings to groundwater in this hydrogeologic unit are occurring as a result of human activities.

Water type analysis was conducted on 17 samples. The results indicate that 29.0% of the samples are of a bicarbonate type, 24.0% are of a calcium-bicarbonate type, 24.0% are of a calcium-sulphate-nitrate type, and 12.0% are of a sulphate-nitrate type. The remaining samples are of a magnesium-bicarbonate type, or a calcium type.

11.1.14 Detroit River Group Hydrogeologic Unit

General information related to groundwater in the Detroit River Group hydrogeologic unit is available for 7,573 wells. Approximately 90.0% of these wells yield fresh water, 4.0% yield sulphurous water, and the remaining 6.0% yield salty water or water containing gas.

The results of 77 chemical analyses for water samples, taken from wells drilled in the unit, are available. Many of these samples show poor water quality. The concentrations of total dissolved solids exceed the AO in 50.0% of the samples. In terms of hardness, the water ranges from soft to very hard with a mean hardness concentration of 578.5 mg/L.

The concentrations of sulphate range from 0.4 to 3,100.0 mg/L and the AO for sulphate is exceeded in 22.0% of the samples. Sulphate concentrations above 1,000.0 mg/L have been found in six samples.

Also, many samples show elevated concentrations of sodium and chloride, which is reflected by their mean concentrations of 73.0 and 112.0 mg/L, respectively. Iron concentrations exceed the AO in 64.0% of the samples. In addition, four samples show high nitrate levels (>5.0 mg/L) which indicates that some nitrate loadings to groundwater in this hydrogeologic unit are occurring as a result of human activities.

Water type analysis was conducted on 40 water samples. The results indicate that 43.0% of the samples are of a calcium-bicarbonate type, 23.0% are of a bicarbonate type, 10.0% are of a magnesium-sulphate-nitrate type, and 10.0% are of a magnesium-bicarbonate type. The remaining samples are of a calcium type, a sulphate-nitrate type, a calcium-sulphate-nitrate type, or a sodium-potassium-bicarbonate type.

11.1.15 Dundee Hydrogeologic Unit

General information related to the quality of groundwater in the Dundee hydrogeologic unit is available for 4,664 wells. Approximately 79.0% of these wells yield fresh water, 19.0% yield sulphurous water, and the remaining 2.0% yield either salty or mineral water.

The results of 78 chemical analyses of water samples, taken from wells constructed in this unit, are available. Many of these samples show poor water quality. The concentration of total dissolved solids exceeds the AO in 45.0% of the samples.

In terms of hardness, the water ranges from soft to very hard with a mean hardness concentration of 378.2 mg/L. The concentrations of sulphate range from 1.0 to 1,430.0 mg/L and the AO for sulphate is exceeded in 13.0% of the samples.

Many samples also show elevated concentrations of sodium and chloride, which is reflected by their mean concentrations of 124.0 and 175.0 mg/L, respectively. Iron concentrations exceed the AO in 59.0% of the samples. In addition, three out of 29 samples show high nitrate levels (>5.0 mg/L), which indicates that some nitrate loadings to groundwater in this hydrogeologic unit are occurring as a result of human activities.

Water type analysis was conducted on 27 water samples. The results indicate that 37.0% of the samples are of a bicarbonate type, 15.0% are of a sodium-potassium-bicarbonate type, and 11.0% are of a calcium-bicarbonate water type. The remaining 37.0% of the samples comprise eight different water types, indicating that water quality within this hydrogeologic unit is highly variable.

11.1.16 Hamilton Group Hydrogeologic Unit

General information related to the quality of groundwater in the Hamilton Group hydrogeologic unit is available for 1,364 wells. Approximately 81.0% of these wells yield fresh water, 13.0% yield sulphurous water, and the remaining 6.0% yield salty water or water containing gas.

The results of 11 chemical analyses for water samples, taken from wells constructed in the Hamilton Group hydrogeologic unit, are available. Many of the samples show poor water quality.

The concentrations of total dissolved solids exceed the AO in 75.0% of the samples. In terms of hardness, the water ranges from moderately hard to very hard with a mean hardness concentration of 197.8 mg/L.

Many samples show elevated concentrations of sodium and chloride, which is reflected by their mean concentrations of 161.3 and 350.4 mg/L, respectively. The sulphate concentrations are low, ranging from 1.0 to 85.0 mg/L. Iron concentrations, on the other hand, exceeded the AO in 64.0% of the samples.

Water type analysis was conducted on three water samples. The results indicate that one sample is of a calcium-bicarbonate type, one sample is of a sodium-potassium-chloride type, and one sample is of a sodium-potassium-bicarbonate type.

11.1.17 Kettle Point Hydrogeologic Unit

General information related to the quality of groundwater in the Kettle Point hydrogeologic unit is available for 4,006 wells. Approximately 88.0% of the wells yield fresh water, 7.0% yield sulphurous water, and the remaining 5.0% yield salty or mineral water.

The results of 22 chemical analyses for water samples, taken from wells constructed in the unit, are available. Many of these samples show poor water quality.

The concentration of total dissolved solids exceeds the AO in 60.0% of the samples. In terms of hardness, the water ranges from soft to very hard with a mean hardness concentration of 99.0 mg/L.

Many samples show elevated concentrations of sodium and chloride, which is reflected by their mean concentrations of 478.7 and 261.8 mg/L, respectively. The AO for sodium is exceeded in 33.0% of the samples and the AO for chloride is exceeded in 25.0% of the samples.

Sulphate concentrations are low, ranging from 1.0 to 82.0 mg/L. Iron concentrations, on the other hand, exceed the AO in 76.0% of the samples.

Water type analysis was conducted on six samples. In the absence of any nitrate data, a conservative nitrate value of 0.5 mg/L was substituted in the Durov analysis. The analysis indicated that three of the samples are of sodium-potassium-bicarbonate type, two are of sodium-potassium-chloride type, and one is of calcium-bicarbonate type.

11.2 GROUNDWATER QUALITY IN THE OVERBURDEN

General information related to the quality of groundwater encountered in various overburden deposits is available for 77,713 wells. Approximately 98.7% of these wells yield fresh water, and the remaining 1.3% yield sulphurous, salty or mineral water or water containing gas.

Figure 58 shows the locations of overburden wells that have been reported to have water quality problems. Most of the wells that yield sulphurous water are located in the Counties of Essex, Middlesex, Simcoe, Elgin, Lambton, Ottawa-Carleton, Norfolk, Welland (Niagara), Oxford and Lincoln (Niagara). Most of the wells that yield salty water are located in the Counties of Russell, Prescott, Ottawa-Carleton and Kent. Most of the wells that yield mineral water are located in the Counties of Simcoe, Northumberland, Dufferin and York. Finally, most of the wells that yield water containing gas are located in Kent County.

The results of 522 chemical analyses are available. These analyses are for water samples collected from wells where various overburden deposits outcrop at the surface. Appendix IV tabulates these results by well number and/or geographic coordinates. Unfortunately, it is not possible to ascribe the quality of a water sample, collected from of a well completed in an area where a given overburden deposit outcrops at the surface, to that particular unit. This is due to the fact that the well may penetrate a number of overburden units and it is not possible to determine which unit is contributing most of the water in the well.

The situation, on the other hand, is different in the case of bedrock wells. Logic dictates that the drilling process of a well would not have proceeded into the bedrock unless that was absolutely necessary, either because of lack of water within the overlying overburden deposits or because the amount of water found was totally inadequate. Although one has to allow for the possibility of some water mixing, the quality of water in a bedrock well represents, by and large, the quality of groundwater within the bedrock hydrogeologic unit, which the well taps.

Faced with these difficulties, the description of groundwater quality within the overburden will be given in terms of quality parameters and water type rather than in terms of specific overburden units. The parameters that will be considered are: sodium, iron, chloride, sulphate, nitrate, total hardness, and total dissolved solids.

11.2.1 Sodium

The concentrations of sodium range from less than 1.6 to 1,430.0 mg/L. The majority of the samples have concentrations of sodium much below the AO. However, 33.0% of the samples, collected from wells constructed in areas where the Tavistock Till outcrops at the surface, have sodium concentrations above the AO. Some of the exceedances of the AO for sodium could be the result of road deicing.

11.2.2 Iron

The concentrations of total iron range from less than 0.01 to 94.0 mg/L. The samples, collected from three wells, constructed in areas where the Till of Map Unit 21 (undifferentiated silty clay to silt till) outcrops at the surface, have concentrations of iron above the AO. Further, a percentage (8.0% to 75.0%) of the samples, collected from wells constructed in all the other overburden deposits that outcrop at the surface, exceeds the AO for iron.

11.2.3 Chloride

The concentrations of chloride range from 0.1 to 2,424.0 mg/L. The majority of the samples are much below the AO. However, about 25.0% of the samples, collected from wells constructed in areas where the Tavistock Till outcrops at the surface, have chloride concentrations above the AO. Some of the exceedances of the AO for chloride could be the result of road deicing.

11.2.4 Nitrate

The concentrations of nitrate range from less than 0.02 to 66.0 mg/L. The majority of the samples are much below the MAC for nitrate. Nevertheless, about 40.0% of the samples, collected from wells completed in areas where the Mornington Till outcrops at the surface, have nitrate concentrations above the MAC. The same is true for the samples collected from wells constructed in areas where the sand and gravel of glaciomarine and marine origins outcrop at the surface. All the exceedances of the MAC for nitrate are believed to be the result of human activities.

11.2.5 Sulphate

The concentrations of sulphate range from less than less than 0.01 mg/L, in samples collected from wells completed in areas where the Port Stanley Till outcrops at the surface, to 2,100.0 mg/L in samples collected from wells constructed in areas where the sands and gravels of a glaciolacustrine origin outcrop at the surface.

Most of the samples have sulphate concentrations below the AO. Nevertheless, 29.0% of the samples, collected from wells completed in areas where the silt and clay of a glaciolacustrine origin outcrop at the surface, exceed the AO for sulphate.

11.2.6 Hardness

Water hardness range from 40.0 to 3,260.0 mg/L and the water in the majority of the samples is either hard or very hard. The highest values are observed in samples collected from wells constructed in areas where the silt and clay of glaciomarine or marine origins outcrop at the surface.

11.2.7 Total Dissolved Solids

The concentrations of total dissolved solids range from 72.0 to 7,800.0 mg/L. All the samples collected from wells constructed in areas where the Wentworth Till or the Till of Map Unit 21 outcrop at the surface have concentrations of total dissolved solids below the AO.

Samples collected from wells completed in areas where other overburden deposits occur at the surface show various degrees of exceedance in terms of total dissolved solids. They range from 15.0% for wells constructed in areas where the Port Stanley Till outcrops at the surface to 80.0% for wells constructed in areas where sands and gravel of glaciomarine and marine origins outcrop at the surface.

11.2.8 Overburden Groundwater Types

To determine the groundwater types of the overburden wells, a Durov analysis was performed on 466 samples. The analysis indicated that approximately 64.0% of the water samples are of a calcium-bicarbonate type, 11.4% are of a bicarbonate type, 6.2% are of a sodium-potassium-bicarbonate type, 6.2% are of a calcium-sulphate-nitrate type, 4.1% are of a calcium type, 3.2% are of a sodium-potassium-chloride type, and the remaining 4.9% are mainly of a magnesium-bicarbonate type or show no dominant type.

11.3 GENERAL CHARACTERISTICS OF NATURAL GROUNDWATER QUALITY ENCOUNTERED IN BEDROCK AND OVERBURDEN WELLS

Six parameters were used to assess the general characteristics of natural groundwater quality encountered in the bedrock and overburden wells in southern Ontario. These parameters were sodium, iron, chloride, sulphate, hardness, and total dissolved solids. The nitrate parameter was not considered in this assessment because the nitrate levels in natural groundwater are usually within the MAC limits and high levels of nitrate nitrogen (>10.0 mg/L) are indicative of water contamination.

A semi-quantitative scale, which is based on the percent of samples exceeding the AOs for sodium, iron, chloride, sulphate or total dissolved solids, was adopted to characterize the general groundwater quality in the sampled wells. The scale is as follows:

Percent AO exceedance	General Water Quality
0 - 10	Excellent
10 - 20	Very Good
20 - 30	Good
30 - 40	Medium
40 - 50	Low
>50	Poor

The description "excellent" indicates that at least 90.0% of the sampled wells meet the AO in terms of a given parameter. The description "poor", on the other hand, indicates that less than 50.0% of the sampled wells have water that meets the AO for a given parameter. As indicated earlier, the various ranges of hardness will be described as soft, moderately soft, hard, and very hard.

If one to believe that the water quality variations, which were obtained from the sampled wells, are representatives of the general groundwater quality, then the above scale may be extended to describe the groundwater quality in the various bedrock hydrogeologic units and within areas where the various overburden deposits occur at the surface.

Table 10 gives the results of the assessment. The table indicates that groundwater quality in both the bedrock and the overburden is often good, very good or excellent in terms of sodium, chloride, sulphate or total dissolved solids. This confirms the information contained in the WWIS database regarding the kind of water encountered in various wells. As indicated earlier, the WWIS database indicates that approximately 98.8% of all overburden and 93.9% of bedrock wells yield fresh water. In terms of iron, however, the groundwater quality in both the bedrock and the overburden fails at times to meet the MOE AO.

12. CONCLUSIONS

This report represents an attempt to describe on a regional scale the hydrogeology of southern Ontario. It also illustrates the wealth of information contained in the MOE WWIS database and how this information can be effectively used in conjunction with a suitable GIS system.

Since the inception of the WWIS database, no hydrogeologic investigation has been conducted in Ontario without strong reliance on it. In the past, however, the analysis and interpretation of the information obtained from the WWIS database for a given area was done manually. Therefore, only a limited number of well records could be considered. In comparison, more than 215,000 records were examined in this report. Of these, more than 173,000 records that have the highest degree of accuracy in terms of well location and elevation were selected for further analysis. Given that each well record contains up to 212 parameters, the database that was considered in the preparation of this report is extremely large.

Recent advances in the area of GIS systems make it feasible to consider large databases, to present the data on thematic maps, and to conduct numerous analyses and interpretations within a relatively short time frame. RAISON and ArcView are such GIS systems, and both are suitable for use with the WWIS database.

Numerous hydrogeologic techniques were developed by MOE staff to enhance the RAISON and ArcView capabilities. These techniques were used to generate several unique maps of southern Ontario for the first time and to conduct numerous hydrogeologic analyses.

The bedrock and overburden well location maps of southern Ontario (Figures 6 and 17) show not only the areal distribution of the wells but also the areas where data are scarce. These two maps can be used to identify areas where additional well information is required and to design effective data collection and monitoring programs.

The bedrock elevation map of southern Ontario (Figure 7) shows the topography of the area during preglacial times and how similar it was to present-day topography. It also reveals the location and extent of major topographic features of significant hydrogeologic importance such as the Dundalk Dome, the Laurentian Channel, and the Dundas Valley.

The overburden thickness map of southern Ontario (Figure 18) shows the areal distribution of the overburden and the variations of its thickness. The map explains why the overburden wells are clustered in areas where the overburden deposits are thick and why the bedrock wells are clustered in areas where the overburden is thin or missing.

The significance of topography on the groundwater flow regimes is illustrated in the bedrock and overburden groundwater level maps (Figures 47 and 48). The maps reveal that groundwater regional divides coincide closely with the major basin topographic divides. It also highlights the topographic control exerted by the Laurentian Highlands physiographic region and the Dundalk Dome on the groundwater flow regimes.

Statistical techniques made it feasible to select large data sets for wells completed in various bedrock units and in areas where different overburden deposits outcrop at the surface. These techniques were used to determine the specific capacity and transmissivity distributions for the selected data sets, and to identify the water-yielding capabilities of 18 bedrock hydrogeologic units (Figure 15).

In terms of water-yielding capability, the Bois Blanc, Detroit River Group, Salina, Bass Island, Dundee, and Amabel-Lockport-Guelph hydrogeologic units have been identified as the best hydrogeologic units within the bedrock in southern Ontario. The Upland Aquifer Complex within the Oak Ridges Moraine, the Yonge Street Aquifer, the Alliston Aquifer Complex, the Norfolk Sand Plain Aquifer, and the Ausable Aquifer are the best overburden aquifer systems within southern Ontario.

A streamflow separation program was used to determine the monthly and annual groundwater recharge for 33 gauging stations located in small watersheds in southern Ontario. Care was taken to ensure that the size of the watersheds is less than 200.0 km^2, streamflows at all the stations are natural flows, and the period of record at each station is long enough to allow for the estimation of the long-term means of groundwater discharge and recharge.

The long-term means of annual groundwater discharge, calculated for the 33 stations, range from 83.3 to 284.9 mm. Given that the records at the selected stations are long enough for the change in soil moisture storage to approaches zero, it is possible to assume that the long-term means of monthly and annual groundwater discharge, calculated for the 33 gauging stations, are equal to their long-term means of monthly and annual groundwater recharge.

An evaluation of natural groundwater quality in southern Ontario revealed that it is often good within both the bedrock and the overburden in terms of sodium, total iron, chloride, sulphate and total dissolved solids. This confirms the information contained in the WWIS database regarding the kind of water encountered in various bedrock and overburden wells. The WWIS database indicates that approximately 93.9% of the bedrock wells and 98.8% of the overburden wells yield fresh water. At times, however, the groundwater quality fails to meet the Provincial Drinking Water Aesthetic Objectives for some of the above parameters.

The DUROV Water Quality Analyser computer program was used to determine the various types of groundwater encountered in bedrock and overburden wells. Most samples indicate that groundwater in both the bedrock and the overburden is of bicarbonate or calcium-bicarbonate type.

Given the complexity of the hydrogeology of southern Ontario, future researchers will no doubt make many new findings and, in doing so, improve our understanding of the groundwater regimes in this part of the province.

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