ISSN 1917-330X (online)
ISBN 978-1-4606-0909-5 (PDF)

ISSN 0708-2061 (print)
ISBN 978-1-4606-0908-8 (print)

Ontario

Aggregate Resources Inventory of the

County of Perth

Southern Ontario

Ontario Geological Survey
Aggregate Resources Inventory
Paper 175

2013

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By D.J. Rowell

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Users of OGS products are encouraged to contact those Aboriginal communities whose traditional territories may be located in the mineral exploration area to discuss their project.

ISSN 0708-2061 (print) ISSN 1917-330X (online)
ISBN 978-1-4606-0908-8 (print) ISBN 978-1-4606-0909-5 (PDF)

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PRINT

Library and Archives Canada Cataloguing in Publication Data

Rowell, D.J.
Aggregate resources inventory of the County of Perth, southern Ontario

(Ontario Geological Survey aggregate resources inventory paper, ISSN 0708-2061 ; 175)
Includes bibliographical references.
Available also on the Internet.
ISBN 978-1-4606-0908-8

1. Aggregates (Building materials)—Ontario—Perth (County). 2. Geology—Ontario—Perth (County)—Maps. I. Ontario Geological Survey. II. Title. III. Series: Ontario Geological Survey aggregate resources inventory paper ; 175.

TN939 R68 2013 553.6'20971323 C2013-964008-8

ONLINE

Library and Archives Canada Cataloguing in Publication Data

Rowell, D.J.
Aggregate resources inventory of the County of Perth, southern Ontario [electronic resource]

(Ontario Geological Survey aggregate resources inventory paper, ISSN 1917-330X ; 175)
Includes bibliographical references.
Electronic monograph in PDF format.
Issued also in printed form.
ISBN 978-1-4606-0909-5

1. Aggregates (Building materials)—Ontario—Perth (County). 2. Geology—Ontario—Perth (County)—Maps. I. Ontario Geological Survey. II. Title. III. Series: Ontario Geological Survey aggregate resources inventory paper (Online) ; 175.

TN939 R68 2013 553.6'20971323 C2013-964009-6

Cette publication est disponible en anglais seulement.

Parts of this publication may be quoted if credit is given. It is recommended that reference be made in the following form:

Rowell, D.J. 2013. Aggregate resources inventory of the County of Perth, southern Ontario; Ontario Geological Survey, Aggregate Resources Inventory Paper 175, 75p.

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Abstract

This report includes an inventory and evaluation of the aggregate resources in the County of Perth. This report is based on a detailed field assessment undertaken in the summer of 2012 and on previous studies of the area. The investigation was conducted to delineate and determine the quantity and quality of aggregate within the area, and to help ensure that sufficient aggregate resources are available for future use. This report is part of the Aggregate Resource Inventory Program for areas designated under the *Aggregate Resources Act* (ARA).

Over 775 field station observations, 100 gradation results and 5116 other data points (e.g., water-well records, geotechnical boreholes, and oil and gas wells) were used to make the interpretations and draw the conclusions as discussed in the report.

Twelve selected sand and gravel resource areas have been chosen at the primary resource level in Perth County. These selected resource areas have a total unlicenced area of 742.4 ha (0.33% of the land base) with a possible resource area of 653.0 ha (0.29% of land base) after considering physical, cultural and environmental constraints. These resource areas have approximately 66.4 million tonnes of aggregate material. Stone quality (predominantly the presence of chert) greatly limits the use of this granular material for many high-specification aggregate products (e.g., Hot-Laid (HL) and concrete (coarse aggregate (CA)) products).

There are a number of sand and gravel deposits that have been selected at the secondary level of significance. These deposits add greatly to the overall granular resources of Perth County. A number of factors generally make these resource areas less attractive for development than the primary deposits: deposit thickness and, therefore, the quantity of granular material available; variability of the material; lower coarse aggregate content; concerns over the stone quality; and the "dirtiness" of some of the deposits. The deposits are still a valuable resource and should be considered during land-use planning discussions and decision-making processes.

Perth County is underlain by a sequence of Paleozoic rock units that have generally not been used extensively in the production of aggregate products. Some of the formations have been used for the manufacture of lime, metallurgical flux and cement, with some minor aggregate production. In addition, these formations are generally overlain by a thick sequence of Quaternary sediment, which would affect the economic decisions to develop these resources.

Selected Resource Areas are not intended to be permanent, single land use units that must be incorporated into an official planning document. They represent areas in which a major resource is known to exist. Such resource areas may be reserved wholly or partially for extractive development and/or resource protection within the context of the official plan.

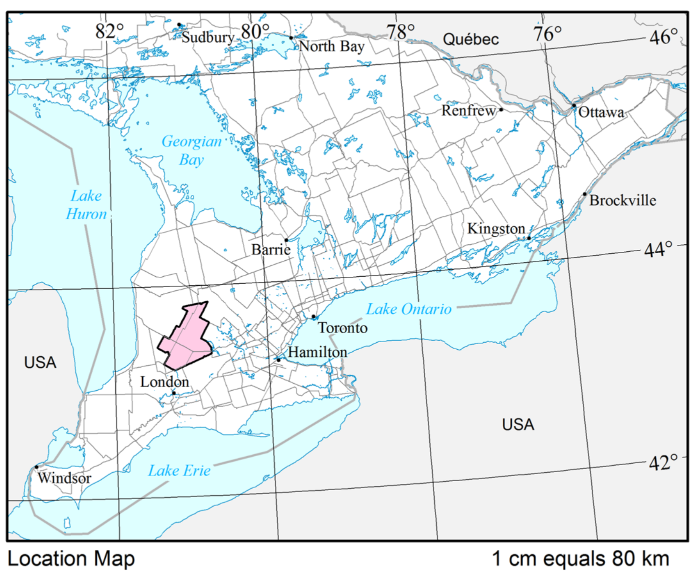

Figure 1. Map of southern Ontario showing the location of the County of Perth.

Aggregate Resources Inventory of the County of Perth

By D.J. Rowell[1]

Field work, map production and report by D.J. Rowell.

Manuscript accepted for publication in 2012 by J.R. Parker, Senior Manager, Earth Resources and Geoscience Mapping Section, Ontario Geological Survey. This report is published with the permission of the Director, Ontario Geological Survey.

[1] Earth Resources and Geoscience Mapping Section, Ontario Geological Survey

Introduction

Mineral aggregates, which include bedrock-derived crushed stone as well as naturally formed sand and gravel, constitute the major raw material in Ontario's road building and construction industries. Large quantities of these materials are used each year throughout the Province. For example, in 2010, the total tonnage of mineral aggregates extracted in Ontario was 166 million tonnes, greater than that of any other metallic or nonmetallic commodity mined in the Province (The Ontario Aggregate Resources Corporation 2011).

Although mineral aggregate deposits are plentiful in Ontario, they are fixed-location, non-renewable resources that can be exploited only in those areas where they occur. Mineral aggregates are characterized by their high bulk and low unit value so that the economic value of a deposit is a function of its proximity to a market area as well as its quality and size. The potential for extractive development is usually greatest in areas where land use competition is extreme. For these reasons, the availability of adequate resources for future development is now being threatened in many areas, especially urban areas where demand is the greatest.

Comprehensive planning and resource management strategies are required to make the best use of available resources, especially in those areas experiencing rapid development. Unfortunately, in some cases, the best aggregate resources are found in or near areas of environmental sensitivity, resulting in the requirement to balance the need for the different natural resources. Therefore, planning strategies must be based on a sound knowledge of the total mineral aggregate resource base at both local and regional levels. The purpose of the Aggregate Resources Inventory Program is to provide the basic geological information required to include potential mineral aggregate resource areas in planning strategies. The reports should form the basis for discussion on those areas best suited for possible extraction. The aim is to assist decision-makers in protecting the public well-being by ensuring that adequate resources of mineral aggregate remain available for future use.

This report is a technical background document, based for the most part on geological information and interpretation. It has been designed as a component of the total planning process and should be used in conjunction with other planning considerations, to ensure the best use of an area's resources.

The report includes an assessment of sand and gravel resources as well as a discussion on the potential for bedrock-derived aggregate. The most recent information available has been used to prepare the report. As new information becomes available, revisions may be necessary.

Inventory Methods, Data Presentation and Interpretation

FIELD AND OFFICE METHODS

The methods used to prepare the report involved the interpretation of published geological data such as bedrock and surficial geology maps and reports, as well as field examination of possible resource areas. Field methods included the examination of natural and man-made exposures of granular material. Most observations were made at quarries and sand and gravel pits located by field surveys and from records held by the Ministry of Transportation of Ontario (MTO), the Ontario Geological Survey (OGS), and by Regional, District and Area Offices of the Ministry of Natural Resources (MNR) of Ontario. Observations made at pit sites included estimates of the total face height and the proportion of gravel- and sand-sized materials in the deposit. Observations regarding the shape and lithology of the particles were also made. These characteristics are important in estimating the quality and quantity of the aggregate. In areas of limited exposure, subsurface materials may be assessed by hand augering, test pitting and drilling.

Deposits with potential for extractive development, or those where existing data are scarce, were studied in greater detail. In instances, representative sites in these deposits are evaluated by taking 11 to 45 kg samples from existing pit or quarry faces, roadcuts or other exposures. The samples may be subjected to some or all of the following tests: absorption capacity, magnesium sulphate soundness test, micro-Deval abrasion test, unconfined freeze–thaw test, and accelerated mortar bar expansion test.

The field data were supplemented by pit information on file with the Soils and Aggregates Section of the Ministry of Transportation of Ontario. Data contained in these files include field estimates of the depth, composition and "workability" of deposits, as well as laboratory analyses of the physical properties and suitability of the aggregate. Information concerning the development history of the pit and acceptable uses of the aggregate is also recorded. The locations of additional aggregate sources were obtained from records held by Regional, District and Area Offices of the Ministry of Natural Resources. In addition, testing data for type, quantity and quality of aggregates were also obtained from aggregate licence applications where these reports are on file with the Ministry of Natural Resources, and from individuals and companies.

Aerial photographs and remotely sensed imagery at various scales were used to determine the continuity of deposits, especially in areas where information is limited. Water well records, held by the Ministry of the Environment (MOE), were used in some areas to corroborate deposit thickness estimates or to indicate the presence of buried granular material. These records were used in conjunction with other evidence.

Topographic maps of the National Topographic System, at a scale of 1:50 000, were used as a compilation base for the field and office data. The information was then transferred to a base map, also at a scale of 1:50 000. These base maps were prepared using digital information taken from the Ontario Land Information Warehouse, Land Information Ontario, Ministry of Natural Resources, with modifications by staff of the Ministry of Northern Development and Mines.

Units and Definitions

The measurements and other primary data available for resource tonnage calculations are presented in metric units in the text and on the tables that accompany the report. Data are generally rounded off in accordance with the *Metric Practice Guide* (Ontario Interministerial Committee on National Standards and Specifications 1975).

The tonnage estimates for aggregate deposits are termed possible resources (*see* Appendix B – Glossary) in accordance with terminology used by the Ontario Resource Classification Scheme (Robertson 1975, p.7) and the Association of Professional Engineers of Ontario (1976).

DATA PRESENTATION AND INTERPRETATION

Two maps, each portraying a different aspect of the aggregate resources in the report area, accompany the report. Map 1, "Sand and Gravel Resources", provides an inventory and evaluation of the sand and gravel resources in the report area. Map 2, "Bedrock Resources", shows the distribution of bedrock formations and the thickness of overlying unconsolidated sediments, and identifies the Selected Bedrock Resource Areas.

The hard-copy versions of Map 1 and Map 2 (back pocket of the report) are simplified to depict information critical to the majority of users.

Enhanced information on the aggregate resources for this area (e.g., complete deposit information for Map 1) is provided in vector ESRI® ArcGIS® files available for download as a compressed (*.zip*) file from GeologyOntario (www.ontario.ca/geology). A "readme" file included in the *.zip* file provides further details regarding the contents of these vector files. In addition, cross-references to data provided in the *.zip* file are provided for clients who wish to access digital data that does not require opening the vector ArcGIS® files. The file that contains the tables for sand and gravel resources and bedrock resources data is found in the root data folder. The tables are in a database (*.mdb*) format file that can be opened using other software, for example, Microsoft® Access® (however, it is recommended the file be copied before opening to avoid creating problems with the vector ArcGIS® files). The cross-references include the table and the field name separated by a short vertical line; the field name is indicated by bold, small capital letters (e.g., | Drift_Thick | **AABBCC**).

Map 1: Sand and Gravel Resources

Map 1 shows the extent and quality of sand and gravel deposits within the study area and an evaluation of the aggregate resources. The map is derived from existing surficial geology maps of the area or from aerial photograph interpretation in areas where surficial mapping is incomplete.

The present level of extractive activity is also indicated on Map 1. Those areas licenced for extraction under the Aggregate Resources Act are shown by a solid outline and identified by a number that refers to the pit descriptions in Table 2. Each description notes the owner/operator and licenced hectarage of the pit, as well as the estimated face height and percentage gravel. A number of unlicenced pits (abandoned pits or pits operating on demand under authority of a wayside permit) are identified by a numbered dot on Map 1 and described in Table 2. Similarly, any test locations appear on Map 1 as a point symbol and the results of the test material are provided in Table 9.

SELECTED SAND AND GRAVEL RESOURCE AREAS

All the sand and gravel deposits are first delineated by geological boundaries and then classified into one of 3 levels of significance: primary, secondary or tertiary. The deposit's significance is also recorded in | Sand_Gravel | **SIGNIF**.

Areas of primary significance are coloured red on Map 1 and identified by a deposit number that corresponds to numbers in Table 3. The deposit number is also recorded in | Sand_Gravel | **SELECT_AREA**.

Selected Sand and Gravel Resource Areas of primary significance are not permanent, single land use units. They represent areas in which a major resource is known to exist, and may be reserved wholly or partially for extractive development and/or resource protection. In many of the recently approved municipal Official Plans, all or portions of resources of primary significance, and in some cases resources of secondary significance, are identified and protected.

Deposits of secondary significance are coloured orange on Map 1. Such deposits are believed to contain significant amounts of sand and gravel. Although deposits of secondary significance are not considered to be the best resources in the report area, they may contain large quantities of sand and gravel and should be considered as part of the overall aggregate supply of the area.

Deposits of tertiary significance are coloured yellow on Map 1. They are not considered to be important resource areas because of their low available resources or because of possible difficulties in extraction. Such areas may be useful for local needs or extraction under a wayside permit, but are unlikely to support large-scale development.

SELECTION CRITERIA

The process by which deposits are evaluated and selected involves the consideration of 2 sets of criteria. The main selection criteria are site specific, related to the characteristics of individual deposits. Factors such as deposit size, aggregate quality, and deposit location and setting are considered in the selection of those deposits best suited for extractive development. A second set of criteria involves the assessment of local aggregate resources in relation to the quality, quantity and distribution of resources in the region in which the report area is located. The intent of such a process of evaluation is to ensure the continuing availability of sufficient resources to meet possible future demands.

Site Specific Criteria

DEPOSIT SIZE AND THICKNESS

Ideally, selected deposits should contain available sand and gravel resources large enough to support a commercial pit operation using a stationary or portable processing plant. In practice, much smaller deposits may be of significant value depending on the overall resources in the rest of the project area.

The "thickness class" indicates a depth range, which is related to the potential resource tonnage for each deposit (*see* Table 1, Column 1: "Class Number"). Four thickness class divisions have been established: Class 1 deposits are greater than 6 m thick; Class 2 sand and gravel deposits are from 3 to 6 m thick; Class 3 represents a deposit that is from 1.5 to 3 m thick; and Class 4 represents a sand and gravel deposit that is less than 1.5 m thick. The thickness class for each deposit is also recorded in | Sand_Gravel | **DEP_THICK**.

Generally, deposits in Class 1 and containing more than 35% gravel are considered to be most favourable for commercial development. Thinner deposits may be valuable in areas with low total resources.

AGGREGATE QUALITY

The limitations of natural aggregates for various uses result from variations in the lithology of the particles comprising the deposit and from variations in the size distribution of these particles.

Four indicators of the quality of aggregate may be included in the deposit information: gravel content (G or S), fines (C), oversize (O) and lithology (L). Three of the quality indicators deal with grain size distribution.

The gravel content ("G" or "S") indicates the suitability of aggregate for various uses. Deposits containing at least 35% gravel ("G") in addition to a minimum of 20% material greater than the 26.5 mm sieve are considered to be the most favourable extractive sites, since this content is the minimum from which crushed products can be economically produced. In "sandy" deposits ("S"), the gravel-sized aggregate (greater than 4.75 mm) makes up less than 35% of the whole deposit making it difficult to produce coarse aggregate products. The gravel content is also recorded in | Sand_Gravel | **MATERIAL**.

Excess fines (high silt and clay content) ("C") may severely limit the potential use of a deposit. Fines content in excess of 10% may impede drainage in road subbase aggregate and render it more susceptible to the effects of frost action. In asphalt aggregate, excess fines hinder the bonding of particles.

Deposits containing more than 20% oversize material (greater than 10 cm in diameter) ("O") may also have use limitations. The oversize component is unacceptable for uncrushed road base, so it must be either crushed or removed during processing.

Another indicator of the quality of an aggregate is lithology ("L"). Just as the unique physical and chemical properties of bedrock types determine their value for use as crushed rock, so do various lithologies of particles in a sand and gravel deposit determine its suitability for various uses. The presence of objectionable lithologies such as chert, siltstone and shale, even in relatively small amounts, can result in a reduction in the quality of an aggregate, especially for high-quality uses such as concrete and asphalt. Similarly, highly weathered, very porous and friable rock can restrict the quality of an aggregate.

If the deposit information shows either "C", "O" or "L", or any combination of these indicators, the quality of the deposit is considered to be reduced for some aggregate uses. The deposit quality, if applicable, is recorded in | Sand_Gravel | **LIMITATION**. No attempt is made to quantify the degree of limitation imposed. Assessment of the 4 indicators is made from published data, from data contained in files of both the Ministry of Transportation of Ontario (MTO) and the Earth Resources and Geoscience Mapping Section of the Ontario Geological Survey, and from field observations.

Quality data may also appear in Table 9, where the results of quality tests are listed by test type and sample location. The types of tests conducted and the test specifications are explained in Appendixes B and E, respectively.

Deposit Information

The deposit information coding is similar to that used in soil mapping and land classification systems commonly in use in North America and indicates the gravel content, thickness of material, origin (type) and quality limitations, if applicable. The "gravel content" and "thickness class", as described above, are basic criteria for distinguishing different deposits. The geologic deposit type is also reported (the types are summarized with respect to their main geologic and extractive characteristics in Appendix C of the report). The geologic deposit type is recorded in | Sand_Gravel | **DEP_ORIGIN**.

In the following example of a deposit information code,

"G / 1 / OW / C",

where G represents gravel content, 1 represents thickness class, OW represents geological type and C represents aggregate quality, the deposit information code is interpreted as an outwash deposit greater than 6 m thick containing more than 35% gravel with excess silt and clay.

The deposit information is recorded in | Sand_Gravel | **LABEL**.

Texture Symbol

The texture symbol provides a more detailed assessment of the grain size distribution of material sampled during field study. These symbols are derived from the information plotted on the aggregate grading curves that, if available, are included with the report. The relative amounts of gravel, sand, and silt and clay in the sampled material are shown graphically in the texture symbol by the subdivision of a circle into proportional segments. The following example shows a hypothetical sample consisting of 60% gravel, 30% sand and 10% silt and clay ("fines").

LOCATION AND SETTING

The location and setting of a resource area has a direct influence on its value for possible extraction. The evaluation of a deposit's setting is made on the basis of natural, environmental and man-made features that may limit or prohibit extractive development.

First, the physical context of the deposit is considered. Deposits with some physical constraint on extractive development, such as thick overburden or high water table, are less valuable resource areas because of the difficulties involved in resource recovery. Second, permanent man-made features, such as roads, railways, power lines and housing developments, which are built on a deposit, may prohibit its extraction. The constraining effect of legally required setbacks surrounding such features is included in the evaluation. A quantitative assessment of these constraints can be made by measurement of their areal extent directly from the topographic maps. The area rendered unavailable by these features is shown for each resource area in Table 3 (Column 3).

In addition to man-made and cultural features, certain natural features, such as provincially significant wetlands, may prove to be constraints. In this report, such constraints have not been outlined and the reader is advised to consult with municipal planning staff and the local office of the MNR for information on these matters. Depending on the number and type of constraint applicable, anywhere from 15 to 85% of the total resources in a municipality may be unavailable for development (Planning Initiatives Limited 1993).

The assessment of sand and gravel deposits with respect to local land use and private land ownership is an important component of the general evaluation process. Since the approval of the Provincial Policy Statement (PPS) under the authority of the *Planning Act* in 2005, recently approved Official Plans now contain detailed policies regarding the location and operation of aggregate extraction activities. These official plans should be consulted at an early stage with regard to the establishment of an aggregate extraction operation. These aspects of the evaluation process are not considered further in this report, but readers are encouraged to discuss them with personnel of the pertinent office of the Ministry of Natural Resources, Ministry of Municipal Affairs and Housing staff, and/or regional and local planning officials.

Regional Considerations

In selecting sufficient areas for resource development, it is important to assess both the local and the regional resource base, and to forecast future production and demand patterns.

Some appreciation of future aggregate requirements in an area may be gained by assessing its present production levels and by forecasting future production trends. Such an approach is based on the assumptions that production levels in an area closely reflect the demand, and that the present production or "market share" of an area will remain roughly at the same level.

The availability of aggregate resources in the region surrounding a project area should be considered in order to properly evaluate specific resource areas and to develop optimum resource management plans. For example, an area that has large resources in comparison to its surrounding region constitutes a regionally significant resource area. Areas with large resources in proximity to high-demand centres, such as metropolitan areas, are special cases as the demand for aggregate may be greater than the amount of production in the areas close to the urban boundary.

Although an appreciation of the multitude of factors affecting aggregate availability (e.g., environmental and planning constraints) is required to develop comprehensive resource management strategies, such detailed evaluation is beyond the scope of this report. The selection of resource areas made in this study is based primarily on geological data or on considerations outlined in the preceding sections.

SAND AND GRAVEL RESOURCE TONNAGE CALCULATIONS

Once the interpretative boundaries of the aggregate units have been established, quantitative estimates of the possible resources available can be made. Generally, the volume of a deposit can be calculated if its areal extent and average thickness are known or can be estimated. The computation methods used are as follows. First, the area of the deposit, as outlined on the final base map, is calculated in hectares (ha). The deposit area is also recorded in | Sand_Gravel | **AREA**. The thickness values used are an approximation of the deposit thickness, based on the face heights of pits developed in the deposit or on subsurface data such as test holes and water well records. Tonnage values can then be calculated by multiplying the volume of the deposit by 0.01770 (the density factor). This factor is approximately the number of tonnes in a 1 m thick layer of sand and gravel, 1 ha in extent, assuming an average density of 1770 kg/m^3.

Tonnage = Area × Thickness × Density Factor

Tonnage calculated in this manner must be considered only as an estimate. Furthermore, such tonnages represent amounts that existed prior to any extraction of material (i.e., original tonnage) (Table 1, Column 4).

The Selected Sand and Gravel Resource Areas in Table 3 are calculated in the following way. Two successive subtractions are made from the total area. Column 3 accounts for the number of hectares unavailable because of the presence of permanent cultural features and their associated setback requirements. Column 4 accounts for those areas that have previously been extracted (e.g., wayside, unlicenced and abandoned pits are included in this category). The remaining figure is the area of the deposit currently available for extraction (Column 5). The available area is then multiplied by the estimated deposit thickness and the density factor (Column 5 × Column 6 × 0.01770), to give an estimate of the sand and gravel tonnage (Column 7) possibly available for extractive development and/or resource protection. It should be noted, however, that studies (Planning Initiatives Limited 1993) have shown that substantial proportions of the resources in an area may be constrained due to environmental considerations (e.g., floodplains, environmentally sensitive areas). Lack of landowner interest in development, a range of planning considerations or other matters may also reduce the available resources.

Resource estimates are calculated for deposits of primary significance. Resource estimates for deposits of secondary and tertiary significance are not calculated in Table 3; however, the aggregate potential of these deposits is discussed in the report.

Map 2: Bedrock Resources

Map 2 is an interpretative map derived from bedrock geology, drift thickness and bedrock topography maps, water well data from the Ministry of the Environment (MOE), oil and gas well data from the Ministry of Natural Resources (MNR), and from geotechnical test hole data from various sources. Map 2 is based on concepts similar to those outlined for Map 1.

Inventory information presented on Map 2 is designed to give an indication of the present level of extractive activity in the report area. Those areas licenced for extraction under the *Aggregate Resources Act* are shown by a solid outline and identified by a number that refers to the quarry descriptions in Table 5. Each description notes the owner/operator, licenced hectarage and an estimate of face height. Unlicenced quarries (abandoned quarries or wayside quarries operating on demand under authority of a permit) are also identified and numbered on Map 2 and described in Table 5. Drill hole locations or other descriptive stratigraphic sections appear as a point symbol on Map 2. Table 7 provides these descriptions. These descriptions are also recorded in | Bedrock | Add_Info table.

The geological boundaries of the Paleozoic bedrock units are shown by black dashed lines. Isolated Paleozoic and Precambrian outcrops are indicated by an "×". Three sets of contour lines delineate areas of less than 1 m of drift, areas of 1 to 8 m of drift, and areas of 8 to 15 m of drift. The extents of these areas of thin drift are indicated on Map 2 and are indicated in Table 4 (Column 1). The deposit's significance is also recorded in | Drift_Thick | **CONTOUR**. The darkest shade of blue indicates where bedrock crops out or is within 1 m of the ground surface. These areas constitute potential resource areas because of their easy access. The medium shade of blue indicates areas where drift cover is up to 8 m thick. Quarrying is possible in this depth of overburden and these zones also represent potential resource areas. The lightest shade of blue indicates bedrock areas overlain by 8 to 15 m of overburden.

Outside of these delineated areas, the bedrock can be assumed to be covered by more than 15 m of overburden, a depth generally considered to be too great to allow economic extraction. However, areas in which the bedrock is covered with greater than 8 m of overburden may constitute resources that have extractive value in specific circumstances. These circumstances include the resource being located adjacent to existing industrial infrastructure (e.g., a quarry operation or processing plant); speciality industrial mineral products (e.g., chemical lime and metallurgical rock) that can be produced from the resources; or part or all of the overburden being composed of an economically attractive deposit.

SELECTED BEDROCK RESOURCE AREAS

Selection of Bedrock Resource Areas has been restricted to a single level of significance. Three factors support this approach. First, quality and quantity variations within a specific geological formation are gradual. Second, the areal extent of a given quarry operation is much smaller than that of a sand and gravel pit producing an equivalent tonnage of material, and third, since crushed bedrock has a higher unit value than sand and gravel, longer haul distances can be considered. These factors allow the identification of alternative sites having similar development potential. The Selected Areas, if present, are shown on Map 2 by a line pattern and the calculated available tonnages are given in Table 6. The selected bedrock resource areas are also recorded in | Drift_Thick | **SELECT_AREA**.

Selected Bedrock Resource Areas shown on Map 2 are not permanent, single land use units. They represent areas in which a major bedrock resource is known to exist and may be reserved wholly or partially for extractive development and/or resource protection, within an Official Plan.

SELECTION CRITERIA

Criteria equivalent to those used for sand and gravel deposits are used to select bedrock areas most favourable for extractive development.

The evaluation of bedrock resources is made primarily on the basis of performance and suitability data established by laboratory testing at the Ministry of Transportation of Ontario. The main characteristics and uses of the bedrock units found in southern Ontario are summarized in Appendix D.

Deposit "size" is related directly to the areal extent of thin drift cover overlying favourable bedrock formations. The deposit size is recorded in | Drift_Thick | **AREA**; the favourable bedrock formations are reported in | Drift_Thick | **FORMATION**. Since vertical and lateral variations in bedrock units are much more gradual than in sand and gravel deposits, the quality and quantity of the resource are usually consistent over large areas.

Quality of the aggregate derived from specific bedrock units is established by the performance standards previously mentioned. Location and setting criteria and regional considerations are identical to those for sand and gravel deposits.

BEDROCK RESOURCE TONNAGE CALCULATIONS

The method used to calculate resources of bedrock-derived aggregate is much the same as that described above for sand and gravel resources. The areal extent of bedrock formations overlain by less than 15 m of unconsolidated overburden is determined from bedrock geology maps, drift thickness and bedrock topography maps, and from the interpretation of water well records (Table 4). The measured extent of such areas is then multiplied by the estimated quarriable thickness of the formation, based on stratigraphic analyses and on estimates of existing quarry faces in the unit. In some cases, a standardized estimate of 18 m is used for thickness. Volume estimates are then multiplied by the density factor (the estimated weight in tonnes of a 1 m thick section of rock, 1 ha in extent). The areal extent of bedrock formations is also recorded in | Drift_Thick | **AREA**.

Resources of limestone and dolostone are calculated using a density factor of 2649 kg/m^3; sandstone resources are calculated using a density estimate of 2344 kg/m^3; and shale resources are calculated with a factor of 2408 kg/m^3 (Telford et al. 1980).

Assessment of Aggregate Resources in the County of Perth

LOCATION AND POPULATION

The County of Perth (herein referred to as "Perth County") occupies 221 846 ha in southwestern Ontario (Figure 1). It is bounded to the east by the Regional Municipality of Waterloo; to the east and northeast by the County of Wellington; to the west and northwest by the County of Huron; and to the south by the counties of Middlesex and Oxford (Figure 2). The county is covered by all or parts of 7 National Topographic System (NTS) 1:50 000 scale map sheets. The 7 map sheets from north to south are Wingham (40 P/14), Palmerston (40 P/15), Seaforth (40 P/11), Conestogo (40 P/10), St. Marys (40 P/6), Stratford (40 P/7) and Lucan (40 P/3).

In 2011, the population of Perth County was 75 112 (Statistics Canada 2011), which represents a 1.03% increase from 2006 (Table A). Perth County is largely rural in character and agricultural land use activities are predominant. According to the Canada Land Inventory, approximately 90% of the total land base within the county has a soil capability rating of either Class 1, 2 or 3. The City of Stratford is an important tourist destination, hosting the Stratford Festival. Stratford and the Town of St. Marys provide important commerce, economic (i.e., manufacturing) and social services to the county. Other important, specialized services are provided by the City of London, located to the south in the County of Middlesex; and the cities of Kitchener and Waterloo, located to the east in the Regional Municipality of Waterloo (e.g., post-secondary education, specialized medical services, etc.).

There are a number of smaller, rural municipalities, including Listowel, Milverton, Mitchell, Atwood and Shakespeare, to name a few. These communities also supply important local services to the residents of Perth County. The communities of Tavistock (County of Oxford) and Palmerston (County of Wellington) lie just outside the study area.

Table A shows the municipality and township structure of Perth County. The table also indicates the wards (former townships) that comprise these municipalities and townships because much of the discussion in the report and the accompanying tables and maps refer to the individual wards.

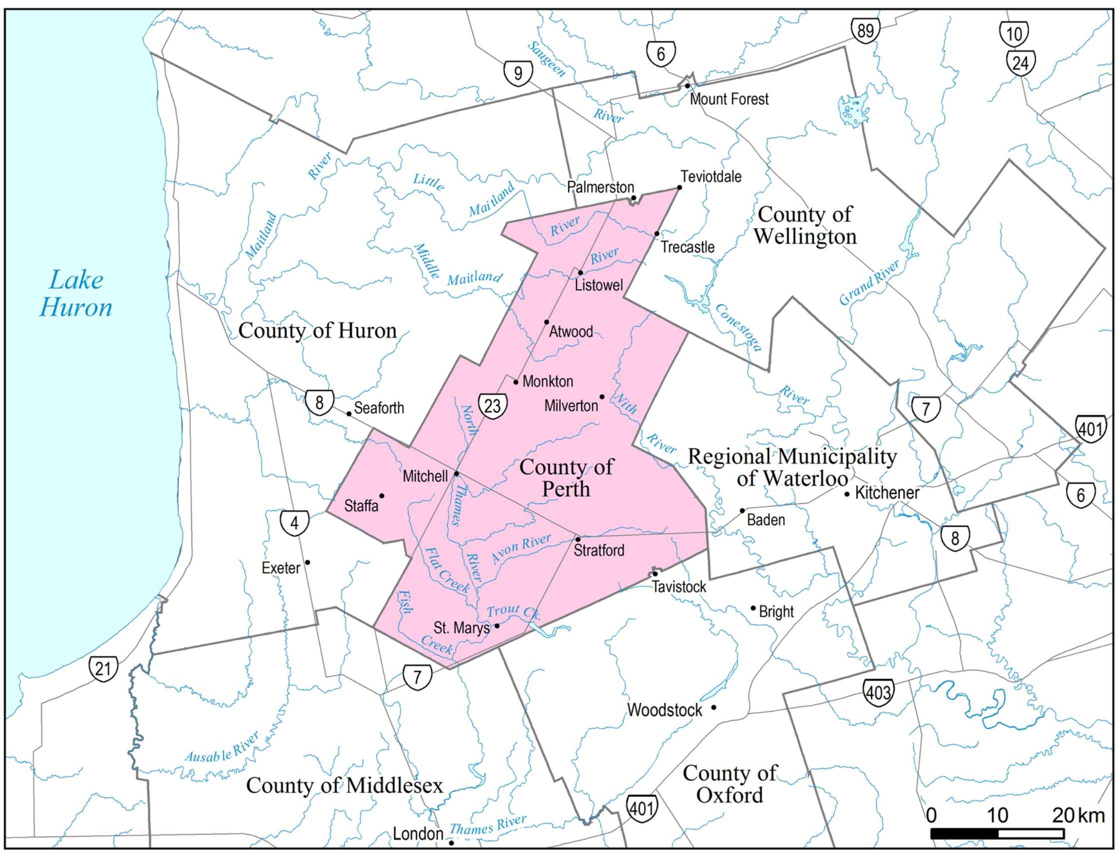

Figure 2. Detailed location map for the County of Perth including the surrounding area.

Road access to Perth County is provided by Provincial Highways 7, 8 and 23. Highway 23 trends northeasterly through the western and central part of the county, extending from the Kirkton–Mount Pleasant area in the south to Palmerston along the northern boundary. Highway 8 trends in a northwesterly direction through the City of Stratford and continues to Goderich, along the Lake Huron shoreline. Highway 7 enters Perth County from the Regional Municipality of Waterloo and heads in a generally westward direction to the City of Stratford. At Stratford, Highway 7 heads southward to the St. Marys area. In addition to these Provincial Highways, there are a number of well-maintained paved and gravel county and lower-tier municipal roads that provide an extensive transportation network throughout the county. There is a municipal airport at Stratford and other smaller airports are located throughout the county (e.g., Listowel). The Goderich–Exeter Railway (GEXR) operates between Kitchener–Waterloo–Stratford–London and Goderich. Where communities and other geographic features are referenced in this report, one is referred to Maps 1 and 2 since they provide greater detail than the accompanying figures.

Over 775 field station observations, 100 gradation results and 5116 other data points (e.g., water-well records, geotechnical boreholes, and oil and gas wells) were used to make the interpretations and draw the conclusions as discussed below.

SURFICIAL GEOLOGY AND PHYSIOGRAPHY

The physiography and distribution of surficial materials in Perth County, including the sand and gravel deposits illustrated on Map 1, are primarily the result of glacial activity that took place in the Late Wisconsinan (Barnett 1992). This period, which lasted from approximately 23 000 to 10 000 years BP, was marked by the repeated advance and retreat of glacial ice originating in the Huron–Georgian Bay and the Erie–Ontario basins (Cowan 1979a; Karrow 1977a, 1993a). The direction of ice movement in the study area is generally recorded by depositional forms (drumlins, moraines and fluted ground moraine). As the ice advanced across the study area, debris from the underlying soil and bedrock accumulated within and beneath the ice. The debris—a mixture of stones, sand, silt and clay—was deposited over large areas of Perth County as till plains, drumlins and moraines.

The bedrock topography underlying the area represented by Perth County is generally flat lying with a gentle regional dip to the southwest. The bedrock surface elevation varies from about 400 m in the northeast to about 265 m in the southwest. Water-well data and previously drilled boreholes indicate a few notable buried-bedrock valleys. The deepest and most noticeable is located in the northwest corner of Perth County, trending from the Atwood–Newry area southeastward toward the Milverton area (Figure 3, dark blue shading). This buried valley feature is about 91 m deep and continues northwestward to Seaforth and Lake Huron. This buried valley also continues southeastward beyond Milverton where it divides into 2 branches: one in an easterly direction to the City of Kitchener and a second branch that trends southeasterly to the Baden area (Regional Municipality of Waterloo). These branches appear to rejoin south of Kitchener–Waterloo and continue toward Dundas (Karrow 1993a). A buried valley of about 30 m deep trends northwestward from the Rannoch–St. Marys area to Russeldale, Munro and north of Dublin (Karrow 1977a). This buried valley appears to join another buried valley running from Exeter (outside the map area to the southwest) to Mount Pleasant and is estimated to be 46 m deep. The thick overburden cover in the eastern part of Perth County is mainly due to the presence of large, thick morainic deposits. More details on the bedrock geology underlying Perth County are provided in “Bedrock Geology and Resource Potential”.

Table A – Area and Population, County of Perth

Municipality (Wards)	Land Area (Hectares)	2001 Population	2006 Population	2011 Population
Municipality of Perth North (Wallace Ward, Elma Ward)	49 319	12 055	12 254	12 631
Municipality of Perth West (Logan Ward, Hibbert Ward, Fullarton Ward)	57 942	9129	8839	8919
Township of East Perth (Mornington Ward, Ellice Ward, North Easthope Ward, South Easthope Ward)	71 339	12 119	11 986	12 028
Township of South Perth (Blanshard Ward, Downie Ward)	39 303	4299	4132	3993
City of Stratford	2695	29 780	30 516	30 886
Town of St. Marys	1248	6293	6617	6655
TOTAL	**221 846**	**73 675**	**74 344**	**75 112**

Till

Overlying the Paleozoic bedrock is a complex sequence of unconsolidated Quaternary sediments. Because the area has been affected by multiple ice lobes over an extended period of time, the area has a rather complicated depositional history. One of the oldest buried till units in the study area is the Catfish Creek Till. Its presence has been widely documented in water-well records, boreholes and subsurface exposures (e.g., deeply cut river valleys) throughout a large portion of the study area. The till was deposited during the Nissouri Phase (Stadial) approximately 23 000 to 17 000 years BP. It is an extremely compact, moderately to very stony to bouldery (up to 15%), sandy silt to silty sand

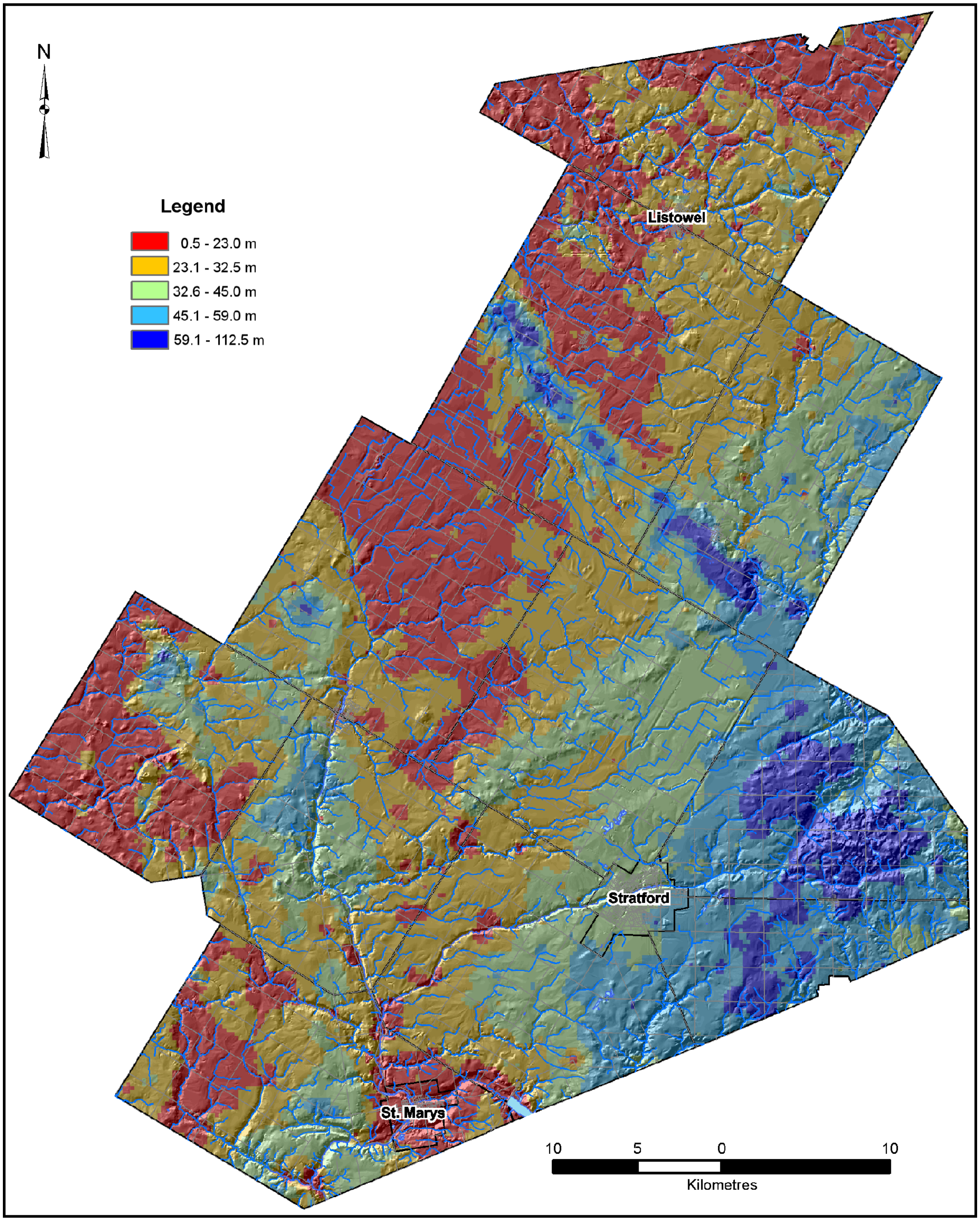

Figure 3. Bedrock topography of the County of Perth illustrating the general location of buried-bedrock valleys.

till that can range from 3 to 6 m thick in the study area. The till appears yellow to buff to olive in colour when oxidized and grey when unoxidized. Pebble lithology and till fabric analysis suggests that the till was deposited by ice advancing into the area from the north-northeast (Georgian Bay lobe). The initial movement of the ice sheet during the Nissouri Phase (Stadial) was controlled by the orientation of the Great Lakes basins, but changed to a more regional flow from the north-northeast (Barnett 1992; Brown 1985). Table 10 provides some of the physical characteristics of the Catfish Creek Till as noted by Karrow (1977a, 1993a), Cowan (1975, 1979a) and A.J. Cooper (OGS, unpublished report, 1981). There are areas where the Catfish Creek Till lies directly on the bedrock surface. In other areas, the Catfish Creek Till overlies older unconsolidated sediments including older till units.

The only named pre-Catfish Creek Till in the study area is the Canning Till (Karrow 1993a; Figure 4). The till is described as a reddish, clayey to silty, nearly stone-free till. The reddish colour of this till, and the presence of granules of red shale, are indicative of the Queenston Formation located along the base of the Niagara Escarpment suggesting that this till was deposited by ice moving from the Erie–Ontario basin (i.e., the ice advanced to the north-northwest). The Canning Till is believed to have been deposited during the Early Wisconsinan (Bajc and Shirota 2007; Barnett 1992; Cowan 1975), although A.J. Cooper (OGS, unpublished report, 1981) had correlated the Canning Till as Middle Wisconsinan. Fine-textured glaciolacustrine or lacustrine sediments have been recorded overlying the Canning Till. Analyses of some of the key physical properties of the Canning Till are provided in Table 10.

Overlying the Catfish Creek Till in the study area is the Stirton Till. The till has been described as a dolomitic, strongly calcareous, stiff, very dark grey to greyish brown, silty to silty clay till with low to moderate plasticity (*see* Table 10). Where the till exists, the unit is generally from 1 to 3 m thick. Cowan (1979a) reports a very limited distribution

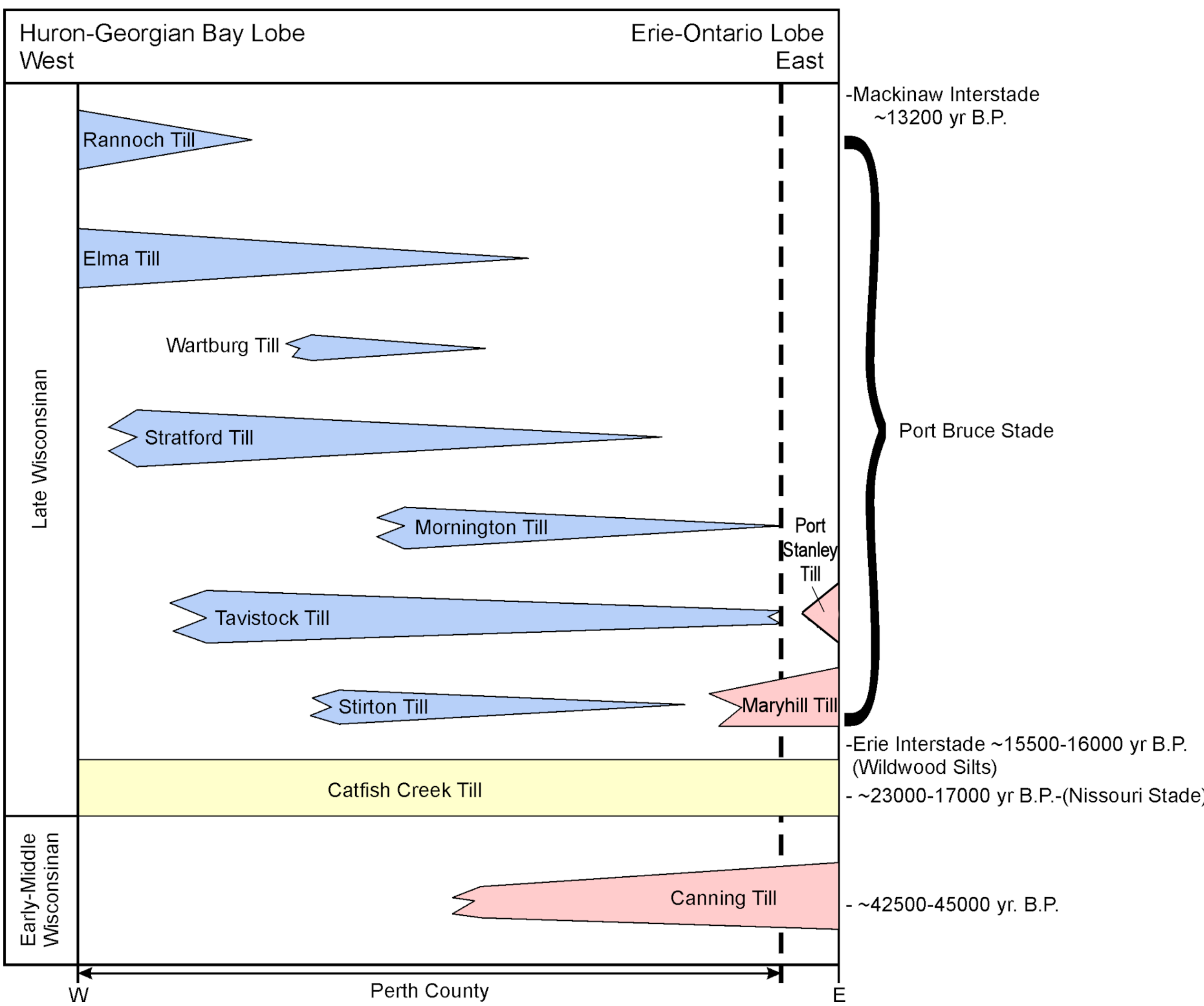

Figure 4. Buried and surface tills in the County of Perth; the relative position of till is shown in an east-west direction.

of the Stirton Till in the northern part of Perth County. Pebble lithology and fabric analysis conducted by Cowan (1979a) and Karrow (1993a) suggest that the till was deposited by the Georgian Bay lobe at approximately 15 000 years BP (Port Bruce Phase (Stadial)). Feenstra (1975) suggests that the Stirton Till is generally a basal till and an ablation till locally. The Stirton Till can lie directly on top of the Catfish Creek Till or overlie a thin sequence of glaciolacustrine or lacustrine sediments (laminated sand, silt and clay) deposited over the Catfish Creek Till. The Stirton Till does not appear as a surface till in the study area. It is believed that the Stirton Till is correlative to the Maryhill Till deposited by the Erie–Ontario lobe (*see* Figure 4).

Overlying the Stirton Till is the Tavistock Till. The Tavistock Till has been described as a dolomitic, highly calcareous, stiff to very stiff, brown to yellowish-brown, silt to clayey silt till (*see* Table 10) (Cowan 1979a). The clast content is low, usually less than 5%, and is dominated by carbonate and shale clasts. It has been suggested that the Tavistock Till was deposited by a major readvance of the Huron–Georgian Bay lobe during the Port Bruce Phase (Stadial), and is correlative with the Port Stanley Till of the Erie–Ontario lobe (*see* Figure 4). The till has a thickness that varies from 1 to 9 m in the study area. The till has been identified in the subsurface along the Middle Maitland River near Listowel and is present as a surface till in other areas of the study area (southeast corner of the study area near the community of Tavistock). The Tavistock Till can be overlain by glaciolacustrine or lacustrine sediments, the Stratford or Mornington tills or, in some locations, directly overlain by the Elma Till. Where glaciolacustrine or lacustrine sediments appear between the Tavistock and Mornington tills, they have been described as 0.5 to 2 m of rhythmitic, laminated, sand, silt and clay. The till is generally a basal till and an ablation till locally (Feenstra 1975).

Overlying the Tavistock Till is the Mornington Till. This till is named after the former Township of Mornington, Perth County. The till has been observed in the subsurface near Drayton (just east of the study area in the County of Wellington) with a thickness of about 1 m, and has been mapped as a surface till near the eastern boundary of Perth County in North Easthope Ward. It is described as a dark grey to grey, mottled, strongly calcareous, clay till with rare pebbles, which is believed to be derived from underlying glaciolacustrine silt and clay, and older till units (*see* Table 10). It is believed to have been deposited by a minor readvance or oscillation of the Georgian Bay lobe, after the deposition of the Tavistock Till (Cowan 1979a; Karrow 1993a). Feenstra (1975) suggests that the Mornington Till is a basal till.

Generally located south of the Milverton moraine and north of the community of Harmony, and westward to the North Thames River and east to the Easthope moraine is the strongly calcareous, stony, sandy silt Stratford Till (*see* Table 10). It is generally a thin till often lying directly on the Tavistock Till in the south and the Mornington Till in the north (Karrow 1993a). Based on the general thickness of this till unit, it has been suggested that the Stratford Till represents a minor readvance or oscillation of the Huron–Georgian Bay lobe ice. (Photo 01 shows a picture of the Stratford Till just north of the City of Stratford (ESRI® ArcGIS® version only).)

Overlying the Stratford Till, only in a small portion of the study area, is the Wartburg Till. The till lies on surface in an area near the Milverton moraine and from Brunner to Fullarton. The till has been described as a strongly calcareous, almost stone-free clay till (*see* Table 10). It represents a very brief and minor readvance or oscillation of the Huron–Georgian Bay lobe ice during the Port Bruce Phase (Stadial) (*see* Figure 4).

The Elma Till is one of the youngest tills in the study area and, as such, is located on the surface over a large portion of Perth County. The till is generally located in the northwest corner of the county and extends southeastward to the central part of the county (Cowan 1979a; A.J. Cooper, OGS, unpublished report, 1981). The till has been estimated as being up to 9 m thick. It is described as a stony (5 to 7%), sandy silt to silt till with low plasticity that can be very stiff at depth. It is generally yellowish brown, and the colour can range from brown to light yellowish brown (*see* Table 10). It has a high total carbonate content and is strongly dolomitic. In the northern part of Perth County (Wallace Ward), the chert content can be up to 17% (Cowan 1979a). The till was deposited by the Georgian Bay lobe and is middle to late Port Bruce Phase (Stadial) in age. The till continues to the north into Huron, Wellington and Bruce counties. It is drumlinized and fluted. Average grain size analysis of the matrix indicates approximately 30% sand, 53% silt and 17% clay (*see* Table 10). (Photo 02 shows the Elma Till in the northwest corner of Logan Ward (ESRI® ArcGIS® version only).)

The Rannoch Till was deposited by ice of the Huron lobe. It is characterized by a strongly calcareous, silt to silty clay matrix, except where deposited over sand, when the matrix may become quite loose and exhibit a sandy silt texture (Karrow 1977a; A.J. Cooper, OGS, unpublished report, 1981). The till is found in the southwest corner of Perth County and along the western part of the study area. Average grain size analysis of the till matrix is approximately 20% sand, 52% silt and 28% clay (*see* Table 10).

Some of the till units described above are actually quite similar and their physical properties can, and do, overlap. This similarity prompted A.J. Cooper (OGS, unpublished report, 1981) to suggest that, to make a proper distinction between some of these till units, one has to examine the geomorphic features and landform associations as well as the physical properties of the till. For example, to distinguish between the Rannoch and Elma tills, A.J. Cooper (OGS, unpublished report, 1981) considered the relationship between the till units, deposition along moraines and the relationship to esker deposits. Eskers that are associated with the Elma ice (Georgian Bay lobe) trend northwest-southeast, whereas Rannoch ice (Huron lobe) eskers generally trend east-west.

Till is generally not suitable for the production and manufacture of aggregate products because it often has a high fines content (therefore considered “dirty”) and may have a high percentage of oversize material (cobbles, boulders). Therefore, to manufacture granular material would require significant handling and processing, which can be uneconomical.

Moraines

Older landforms are often difficult to recognize in the study area because of the obscuring effects of subsequent geological events. There are a number of older landforms that have been partially obscured and buried, and which affect the present assemblage of surface landforms. The term “palimpsest” has been applied to these landforms, which include a number of large moraines in, and to the east of, the study area (Karrow 1993a). An example of a palimpsest landform in the study area is the Easthope moraine, the origin of which remains largely undetermined because of a younger till unit that covers the older sediments.

The Gads Hill moraine consists of 2 surface tills: the Tavistock and Stratford tills. Within this morainic area are about 20 ice-marginal positions (Karrow 1993a). The Milverton moraine is a narrow but well-defined ridge approximately 6 to 9 m high and is composed predominantly of Elma Till; therefore, the Milverton moraine is believed to be associated with the Georgian Bay lobe. Few pebbles or boulders are present and the ridge contains little granular material.

The Mitchell, Dublin and Lucan moraines are composed of, or capped by, Rannoch Till and are associated with the Huron lobe. The North Thames River flows along the front of the Mitchell moraine and, therefore, is assumed to be an ice-marginal drainage system.

Glaciofluvial Deposits

In addition to these glacial deposits noted above, there are a number of glaciofluvial ice-contact deposits located throughout the study area. As the ice retreated, sediment-laden meltwater flowing within and beneath the ice deposited numerous esker ridges or segments, particularly in the north and western part of Perth County (Map 1). West of the North Thames River, these eskers generally trend easterly, whereas morainic ridges trend in a north-south direction (Rannoch ice from the Huron lobe). On the east side of the North Thames River, these esker ridges trend more northwest-southeast. Granular material within eskers and other ice-contact deposits is generally clean and varies from sand to gravel to crushable sized clasts. The aggregate potential of these types of deposits is generally good, although lithological constraints may limit usage. In Perth County, these deposits have been extracted extensively in the past.

Glaciofluvial outwash deposits occur as meltwater channel fills, small outwash plains and outwash terraces throughout much of the county. Sand and gravel-rich channel-fill and terrace deposits are observed south of the community of Palmerston, along the Little Maitland and Middle Maitland river systems and from Trecastle to Teviotdale (*see* Map 1, Wallace Ward). Many of these deposits are limited in size or thickness, and may lack desirable gradation for high-specification aggregate products. The outwash deposits are generally 1 to 5 m thick. The lithology of some of the coarse aggregate clasts may limit the suitability of these granular resources for the production of high-specification aggregate products, and these deposits have been extracted extensively in the past. A complex of glaciofluvial ice-contact and outwash deposits are observed near Staffa in Hibbert Ward, Municipality of Perth West. This complex hosts a number of licenced aggregate operations.

Because of the number of references in this document to moraines and eskers, these linear features are shown on Map 1, which is not normally the case for ARIP maps. These features are also provided in the | Sand_Gravel | Linear table in the ESRI® ArcGIS® version.

Glaciolacustrine and/or Lacustrine Deposits

Unlike many areas of southwestern Ontario, there is a general lack of surface glaciolacustrine or lacustrine sand deposits located throughout the study area, other than a small area to the north of the City of Stratford. The study area has a reasonably high surface elevation and, therefore, was less susceptible to being inundated by glacial lake waters. Fine-grained glaciolacustrine or lacustrine deposits (silt and clay) do exist, but these were generally deposited in small, isolated, low-lying “ponds” that were not part of a much larger proglacial lake. Older glaciolacustrine or lacustrine deposits (laminated or rhythmites of sand, silt and clay) occur sporadically between the till sheets (as noted earlier), which suggests that perhaps older proglacial lakes or ponds did exist in the study area. No glaciolacustrine beach deposits were mapped in the study area, although Karrow (1993a) noted that a small lake formed north of the City of Stratford at an elevation of about 372 m asl. A similar lake formed west of the Milverton moraine at approximately the same elevation.

General Glacial History

The deposition of the Catfish Creek Till represents a major advance of glacial ice from the north-northeast. This advance during the Nissouri Phase (Stadial) covered all of southwestern Ontario and extended into Ohio at approximately 23 000 to 17 000 years BP. Approximately 16 000 years ago, the ice retreated north of the study area, at least as far as the present-day Mount Forest (Cowan 1979a), during the Erie Phase (Interstadial). This was followed by a readvance of the Huron–Georgian Bay ice across Perth County depositing the Stirton Till (approximately 15 000 years BP), followed by the deposition of the Tavistock Till. It has been suggested that the ice margin was at its maximum extent and, as a result, the thin ice lacked the energy to scour and remold the landscape. In fact, just to the east of Perth County near the community of Bright, the Catfish Creek Till is exposed at the surface, suggesting that this particular area was not covered by glacial ice during this time (Karrow 1993a). Because of the high elevation of the area, the thin ice conditions and the general lack of evidence to suggest the presence of major proglacial lakes, Taylor (1913) has referred to this area as the Ontario "Island". The tills that are younger than the Tavistock Till represent minor readvances or oscillations of the glacial ice. The readvance of the Georgian Bay lobe (Elma Till) and the Huron lobe (Rannoch Till) are considered strong readvances (A.J. Cooper, OGS, unpublished report, 1981). Between till sheets there may, or may not, be thin glaciolacustrine or lacustrine deposits.

PHYSIOGRAPHIC REGIONS

The area represented by Perth County is covered by 5 physiographic regions as defined by Chapman and Putnam (1984). From north to south, these include the Teeswater drumlin field, Dundalk till plain, Stratford till plain, Waterloo hills and the Oxford till plain (Figure 5). The Horseshoe moraines physiographic region is located just southwest of Perth County, outside the study area.

Teeswater Drumlin Field

The Teeswater drumlin field lies in the northwestern part of the county, in a triangular shaped wedge just west of Palmerston (*see* Figure 5). The surface till that comprises the ground moraine and drumlins within this physiographic region is the Elma Till. The drumlins in this field are characteristically low, broad, oval-shaped hills with gentle slopes. The drumlins are approximately 1.5 km long and 0.5 km wide, with a height of about 15 m (Photo 03, ESRI® ArcGIS® version only). Their orientation is variable, but is generally south-southeastward (120 to 155°) (Cowan 1979a). Ground fluting within the physiographic region is generally 1.5 km long, and is represented by about 2 m of negative relief. They trend in a 135 to 160° direction. Toward the outer margins of the field, the drumlins become less noticeable and gradually merge into an undulating till plain (Photo 04, ESRI® ArcGIS® version only).

Dundalk Till Plain

Just south of the Teeswater drumlin field is the Dundalk till plain physiographic region trending in a generally northeast-southwest direction (*see* Figure 5). The physiographic region continues into the counties of Huron, Wellington, Grey and Dufferin. The physiographic region is characterized by a gently undulating topography with some relief provided by fluted ground moraine and low drumlinoid ridges or features (Chapman and Putnam 1984). Numerous, small, flat-floored valleys form a network over the plain. (Photos 05 and 06 (ESRI® ArcGIS® version only) provide a general view of the Dundalk till plain in the study area.) The physiographic region is the source of the headwaters of the Saugeen, Maitland and Grand rivers. Once again, the Elma Till is the predominant surface till in the physiographic region in Perth County. Within the Dundalk till plain, localized deposits of sand and gravel occur as ice-contact stratified deposits and eskers.

Stratford Till Plain

The Stratford till plain lies south of the Dundalk till plain and is a broad till plain extending from London in the south to Listowel in the north (*see* Figure 5). It is an area where gently rolling till plains are intermixed with glaciolacustrine and lacustrine fine-grained sediments (silt and clay). Some topographic relief is provided by a series of terminal moraines. Sand and gravel deposits are present in the intermorainal valleys south of St. Marys. The highest part of the physiographic region is drained by the Conestogo and Nith rivers (just east of the study area), which are tributaries of the Grand River. The Maitland River serves another part of the drainage pattern, with the central and southern portions of the physiographic region drained by the Thames River. The surface tills within the physiographic region include the Tavistock, Mornington, Stratford, Wartburg, Elma and Rannoch. (Photo 07 shows an area of the Stratford till plain (ESRI® ArcGIS® version only).)

Oxford Till Plain

Located south of the Stratford till plain and covering an area of approximately 1550 km^2 is the Oxford till plain (Chapman and Putnam 1984). The surface is gently rolling and drumlinized, with well-developed drumlins located south of the City of Woodstock (County of Oxford). The surface till in this physiographic region within the study area is the Tavistock Till. Trout Creek and the south branch of the Thames River have their headwaters about 6.5 km west of the community of Tavistock. Ancient glacial rivers have deeply downcut the sediments along Trout Creek and have exposed the underlying bedrock, which is and has been extracted in the St. Marys area (*see* Map 2, Licenced Quarry No. 1).

Waterloo Hills

The Waterloo hills physiographic region is predominantly located east of the study area, but there is a small portion of this physiographic region situated along the eastern part of Perth County, in North Easthope Ward (Chapman and Putnam 1984). The surface is generally an area of gently rolling hills. Some hills are composed of sand, whereas others are predominantly a sandy till. Ice-contact deposits are intermixed with these sandy sediments, and outwash sand occupies many of the intervening hollows. The till units located in this physiographic region include the Mornington and Maryhill tills.

Drainage

Drainage in the northern part of the study area is provided by the Maitland River system and its tributaries (south of Palmerston and in the Listowel area), ultimately draining toward Lake Huron. Drainage for the central and southern portion of the study area is provided by the Thames River system and its tributaries, including the North Thames River, Trout Creek and Avon River, which drain westward to Lake St. Clair. The Ausable River system is located in the very southwestern part of the study area and drains westward. The Saugeen and Grand (including its tributaries the Conestogo and Nith rivers) river systems are located just north and east of the study area, respectively.

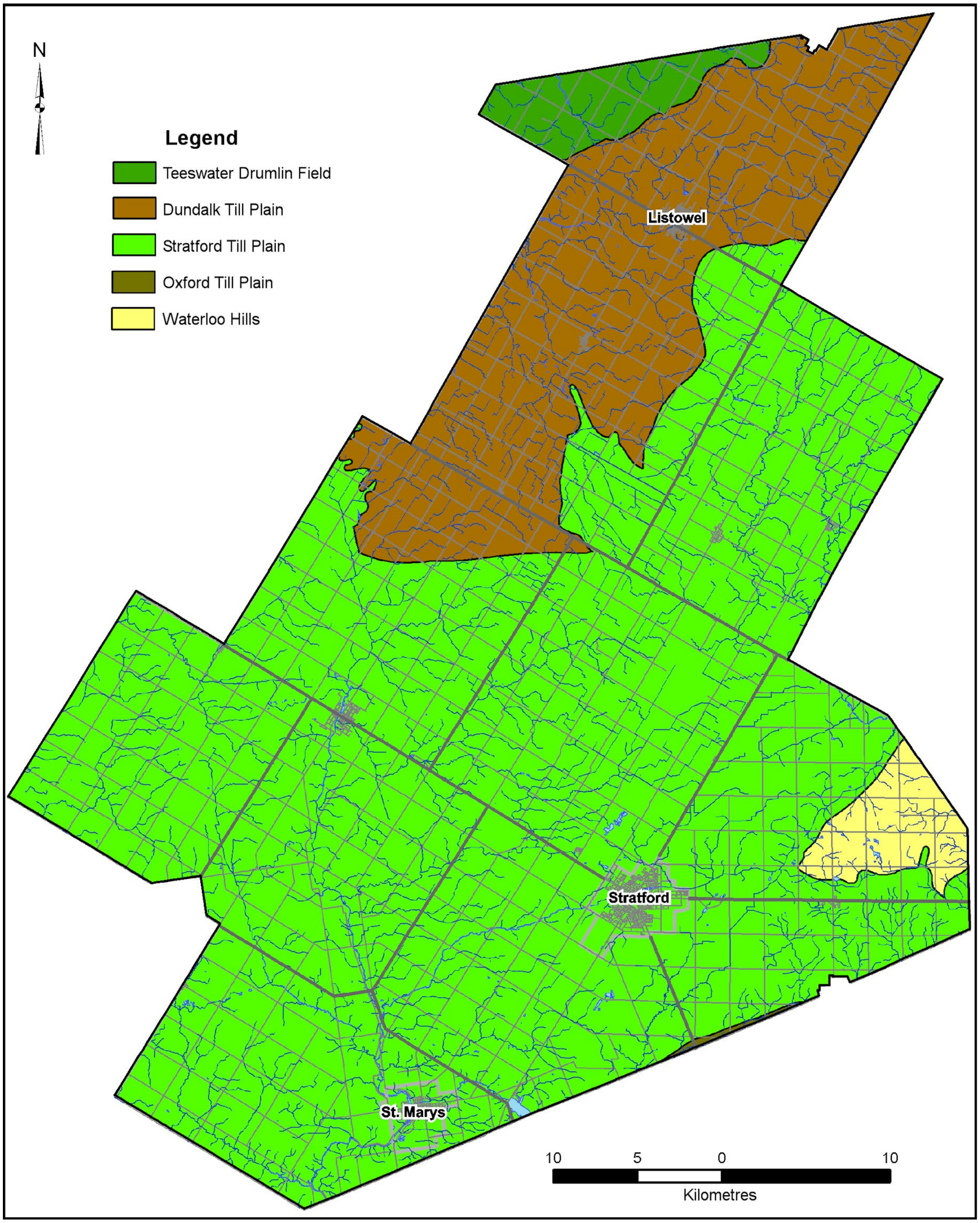

Figure 5. Physiographic regions of the County of Perth (*modified from* Chapman and Putnam 2007).

SAND AND GRAVEL EXTRACTIVE ACTIVITY

The sand and gravel deposits of Perth County are shown on Map 1, which accompanies this report. Sand and gravel deposits occupy approximately 18 635 ha (roughly 8.4% of the county), and contain an original resource tonnage of 1024.9 million tonnes (Table 1). **These figures represent a comprehensive inventory of all granular material in Perth County, although much of the material included in the estimate has no potential for use in aggregate products**.

At the time of writing, 43 pits (representing 1637.38 ha or 0.7% of the county's total land base) were licenced for operation under the *Aggregate Resources Act*. These licenced areas include 1 operation that is licenced as both a sand and gravel operation and a quarry (Pit No. 77 and Quarry No. 1), which accounts for greater than 25% of the licenced area. This information was provided by the Ministry of Natural Resources, Land Information Ontario Warehouse in the summer of 2012. The majority of these operations have been developed in ice-contact, ice-contact esker ridges, glaciofluvial outwash and morainic deposits. In general, many of the pits are small operations capable of meeting local demand for low-specification aggregate, whereas a few operations can meet the requirements for higher specification aggregate products. The average annual production for the period from 2006 to 2010 for Perth County was approximately 2.190 million tonnes (Table B), with the majority of the production coming from the Township of South Perth (Table C). Pit locations are shown on Map 1, and individual descriptions are provided in Table 2.

Many of the best granular resource areas have been licenced and significant portions of these deposits have been extracted. In some cases, all or most of the existing deposit has been licenced meaning that little of the resource area lies outside of the licenced area. In addition, many of the licenced operations are using dredging or dragline techniques to recover aggregate material from below the water table and, therefore, are extending the life of the operation.

Most of the unlicenced pits have been abandoned for some time and, as a result, some are substantially overgrown. (Photo 08 (ESRI® ArcGIS® version only) shows an unlicenced pit that has been naturally rehabilitated.) Many unlicenced pits have reached the water table and are now ponds (Photo 09 (ESRI® ArcGIS® version only)). Many unlicenced pits are difficult to identify and only the very obvious unlicenced pits may appear on Map 1. This happens for a variety of reasons, including 1) many of the unlicenced pits were small to begin with and have left a small "footprint"; 2) many have been fully or partially rehabilitated following extractive activities; 3) many pit faces have been sloped and re-vegetated naturally; 4) many older pits may be hard to identify from the natural rolling topography of the area; and 5) the *Pits and Quarries Control Act* (1971) and the *Aggregate Resources Act* (1989) have been effective in preventing the establishment of new unlicenced pits.

In addition to aggregate production as noted above, Perth County has a historical record for the production of brick and tile from fine-grained Quaternary sediments (clay). These operations were generally small and there is little evidence today of these past industrial mineral activities (Guillet 1977).

Restricted Resources

The Sand and Gravel Resources Map (Map 1) that accompanies an Aggregate Resources Inventory Paper (ARIP) usually displays only primary (red), secondary (orange) and tertiary (yellow) levels of deposit significance, as discussed

Table B – Aggregate Production (2006–2010), County of Perth

Year	Production (×10^3 tonnes)
2006	2388
2007	2112
2008	1856
2009	1867
2010	2729
Average	***2190***

Source: The Ontario Aggregate Resources Corporation (2011).

Table C – Aggregate Production (2010) by Municipality, County of Perth

Municipality	Production (tonnes)	Percentage of the County Total
Municipality of Perth North	38 750	1.42
Municipality of Perth West	207 554	7.61
Township of East Perth	549 890	20.15
Township of South Perth* (*includes the Town of St. Marys)	1 932 592	70.82
TOTAL	**2 728 786**	

Source: The Ontario Aggregate Resources Corporation (2011).

earlier in this report. Perth County is rather unusual in that many of the important sand and gravel resource areas are either short (e.g., small esker segments), thin (e.g., a narrow esker ridge) or shallow (e.g., some glaciofluvial outwash deposits). As a result, previous extractive activity may have totally removed segments of the deposit, beyond what would normally be represented by the abandoned pit symbol. Therefore, this report introduces a fourth colour (green) to Map 1, which represents areas of sand and gravel deposits that are substantially extracted or areas where the only remaining aggregate resources may be below the water table. These green-shaded resource areas have not been included in resource calculations, since it would be difficult to assess the remaining quantity or quality of the granular material.

SAND AND GRAVEL AGGREGATE QUALITY

Significant changes have occurred in the testing and specifications applied to aggregates since the original Aggregate Resources Inventory Papers (ARIPs) were completed. The Los Angeles abrasion test (LS-603) is no longer used in the Ontario Provincial Standard Specifications (OPSS) and the magnesium sulphate soundness test (LS-606) has been reduced to an alternate test. Two newer tests, the micro-Deval abrasion test (LS-618 and LS-619) and the unconfined freeze–thaw test (LS-614) have been added. The accelerated mortar bar expansion bar test (LS-620) has also become a standard test for the determination of potential alkali–silica reactivity in concrete aggregate.

The MTO files for Perth County commonly contain test results for the Los Angeles abrasion and magnesium sulphate soundness tests. These data are extensive and are still useful in assessing the general quality of the material, so they have been included in the current assessment. For example, a Los Angeles abrasion test loss of 35% or less generally indicates good physical quality in an aggregate.

Many former sources of sand and gravel are now depleted; however, the data compiled when they were operating are useful in indicating the potential of adjacent properties within the same deposit.

Care should be exercised in extrapolating the quality test data for individual samples contained in this report to the entire deposit due to the inherent variability of sand and gravel deposits, particularly large and extensive deposits. Where possible, a range of test results have been provided, which represent a number of sample locations distributed throughout the deposit from samples collected over a long period of time. Where aggregate test results and photos (vector ArcGIS® version only) have been included for the selected deposit, the position of these photos and test results have been re-positioned to ensure the privacy of property owners. These photos and results are often placed near the centre of the deposit.

Discussion on what specifications the granular material within a deposit or selected resource area may be suitable for only relate to aggregate products that are generally used by the MTO. Other aggregate products, such as winter road sand, fill, septic and mortar sand, to name a few, are not discussed; therefore, many licenced operations are economically viable and are successfully producing these other valuable aggregate products.

The granular material that is found in a particular deposit is a reflection of the glacial activity that occurred within an area. Generally, it is also a reflection of the local bedrock units since the glacier would easily crush, grind and transport broken pieces of bedrock. Meltwater coming from the glacier would also transport these local bedrock clasts. Therefore, it is not surprising that a sand and gravel deposit that is down ice from a poor aggregate-producing bedrock unit may have limited use as a high-specification granular source due to the lithology of the clasts within the deposit.

This is particularly important in Perth County where many of the underlying bedrock formations contain deleterious lithologies (e.g., chert, shale, siltstone). Therefore, many of the granular deposits with a good percentage of crushable and gravel-size clasts may be limited in the production of high-specification coarse aggregate products by poor stone quality. Ingham and Dunikowska-Koniuszy (1965) reviewed the distribution, character and basic properties of chert in southwestern Ontario, including their use in asphalt and concrete. Chert particles and clasts have a higher porosity than other rock type clasts resulting in higher absorption. Ingham and Dunikowska-Koniuszy (1965) also concluded that chert failed the asphalt stripping tests and, therefore, should not be used in asphalt products. Chert clasts had greater breakage in freeze–thaw testing and are highly reactive for alkali-reactivity (an alkali–silica reaction) and, therefore, should be avoided in the production of concrete. Areas of the Bois Blanc Formation can be from 30.3 to 62.3% chert, by volume, and some gravel deposits in southwestern Ontario can be up to 50% chert (Ingham and Dunikowska-Koniuszy 1965). This stone quality may also affect the fine aggregate material rendering it unsuitable for the production of fine aggregate products such as Hot-Laid (HL) and concrete fine aggregate (FA). Table 9 of this report provides the results of extensive aggregate quality testing completed throughout the study area.

Finally, it must be stated that coarse-grained granular deposits (sand and gravel) are often derived from, and a product of, coarse-grained glacial deposits (e.g., till); therefore, an area that is dominated by fine-grained tills (silty, silty clay) often lack large, significant coarse aggregate deposits. This statement is applicable to the study area.

It is therefore highly recommended that where sand and gravel extraction and development is contemplated that extensive testing be conducted to verify aggregate quality and quantity. Site-specific investigations provide greater detail on the nature of the local deposit.

SELECTED SAND AND GRAVEL RESOURCES AREAS

As noted in "Surficial Geology and Physiography", ice-contact deposits, morainic ridges and glaciofluvial outwash deposits are the predominant source of sand and gravel in Perth County. Many of these deposits have supplied aggregate to the county for a number of years and many are either depleted or nearing depletion. Dredging and dragline operations are extending the extraction life of some of these deposits.

Because of the palimpsest nature of sediment deposited in this area (*see* "Moraines"), a great deal of time was spent examining boreholes and water-well records to try to identify and delineate buried aggregate deposits. Some of the Selected Sand and Gravel Resource Areas of both primary and secondary significance are either buried or partially buried. Unfortunately, no real pattern or well-defined areas of buried granular material could be established. (However, as a result of these detailed examinations, additional information is provided in the | Sand_Gravel | BURIED table (Map 1, ESRI® ArcGIS® version only).) Buried granular material is often a "dirty" material having an excess of fines (material passing the #200 or 75 μm sieve). Generally, fines in excess of 10% render material unsuitable for use in HL and structural concrete mixes. It can be used for granular base and subbase material when properly screened, washed or blended with coarser clean aggregate.

Selected Sand and Gravel Resource Area 1

Selected Sand and Gravel Resource Area 1 is located along the northern boundary of Wallace Ward, west of Palmerston, in the Municipality of Perth North. The selected resource area comprises the southern extension of 2 esker segments that trend south-southeasterly from the County of Wellington (herein referred to as "Wellington County"). Not much of the selected resource area actually lies within Perth County (both in terms of surface area and quantity of material), but the esker ridges are more extensive in Wellington County.

Planning and Engineering Initiatives Limited and the Ontario Geological Survey (1999) reported 6 licenced operations within this selected resource area in Wellington County. Pit faces reveal sand and gravel material suitable for the production of granular base and subbase aggregate. The stone quality is generally too poor for the production of HL and concrete aggregate products due to the presence of chert. The deposits have generally been described as single, sharply defined esker ridges with local relief of 6 to 15 m. The eskers were deposited directly on a till plain. Paleocurrent flow has been measured to the southeast (Planning and Engineering Initiatives Limited and Ontario Geological Survey 1999), which is consistent with the information provided in "Surficial Geology and Physiography".

The coarse aggregate content of this selected resource area varies from 35% to 80%, with crushable material ranging from 6 to 37%. The sand content varies from 20 to 65%. The lithology of the clasts range from 3 to 15% limestone, 76 to 89% dolostone, 6 to 12% Precambrian clasts and 0 to 2% chert.

The esker segments located in Perth County occupy an area of 6.6 ha, which is reduced to 5.4 ha after considering previously extracted areas and physical, cultural and environmental constraints. Assuming a conservative deposit thickness of 4.5 m, there are approximately 0.4 million tonnes of aggregate located in Wallace Ward (Table 3); however, this relatively small resource needs to be considered with the 7.4 million tonnes identified in Wellington County (Planning and Engineering Initiatives Limited and Ontario Geological Survey 1999), thereby making the deposits more worthy of the primary designation.

Selected Sand and Gravel Resource Area 2

Selected Sand and Gravel Resource Area 2 is located in the northwest corner of Logan Ward, Municipality of Perth West, approximately 7 km west of the community of Monkton. The selected resource area comprises a series of ice-contact esker segments that, generally, are already licenced for extraction (Pit Nos. 15 to 19, inclusive). The primary esker segments are surrounded or flanked by sandy ice-contact material, which has been selected as a resource of secondary significance and adds greatly to the overall granular resource within this selected area. The secondary resource continues northwestward into the County of Huron (herein referred to as "Huron County") (Ontario Geological Survey 2004).

Granular material within the esker core is variable and can be described as interbedded, finely laminated rippled sand with fine gravelly sand; fine rippled sand with thin silt and clay seams; well-sorted, moderately graded, stratified fine gravel interbedded with fine to coarse, well-laminated silty sand; and very coarse boulder gravel. The flanks are predominantly sand with seams of silt and clay and, in some areas, covered by Elma Till. Aggregate material is available below the water table and dredging operations are in progress along the deposit. Dredging along some sections of the deposit are now recovering fines and boulders, suggesting that the granular material has "bottomed out" and dredging is actually removing the underlying till material.

Gradation results for Selected Sand and Gravel Resource Area 2 indicate a coarse aggregate content that varies from 4.1 to 78.2%, a sand content ranging from 18.9 to 93.6% and fines from 1.5 to 24.9%. Crushable material varies from 6.8 to 49.5% of the coarse aggregate fraction. Lithological results vary from 79 to 94% limestone, 1 to 16% dolostone, 3 to 5% Precambrian clasts, 0 to 1% siltstone and 1 to 2% chert. The chert content of this deposit is generally lower than the chert content of granular resources in other areas of the county (Petrographic Number test results for HL and concrete (coarse aggregate (CA)) products are generally lower and the absorption test results are acceptable). Other aggregate test results for this selected area are presented in Table 9.

The aggregate test results presented in Table 9 would suggest that the granular material in this selected resource area would be suitable for the production of Granular A and B, and SSM products with proper beneficiation. The coarse aggregate (CA) fraction may be suitable for the production of small quantities of HL (CA) products, although stone quality will have to be monitored. Hot-Laid (CA) has been produced from this area in the past. The coarse aggregate is borderline for concrete as indicated by the aggregate test results in Table 9.

Most of Selected Sand and Gravel Resource Area 2 is already under licence for extraction of granular material, except for approximately 8.9 ha. Assuming a conservative deposit thickness of 4.5 m (some areas will be thicker and dredging is possible), there are approximately 0.7 million tonnes of aggregate material available for extraction (*see* Table 3). The secondary ice-contact deposits that flank the esker core and continue northwestward into Huron County provide additional granular material.

Selected Sand and Gravel Resource Area 3

Selected Sand and Gravel Resource Area 3 is located along the western boundary of Logan Ward, Municipality of Perth West, just southwest of Selected Sand and Gravel Resource Area 2. Selected Sand and Gravel Resource Area 3 comprises the northeastern extension of a glaciofluvial esker deposit that trends northeasterly from Huron County. Not much of the selected resource area lies within Perth County (both in terms of surface area and quantity of material), but the esker ridge is substantially longer and more prominent in Huron County.

The Ontario Geological Survey (2004) reported a licenced pit operation and a number of unlicenced pits in Huron County. Pit faces and roadcuts expose predominantly sand and gravel material with minor seams of fine sand and silt. The coarse aggregate content was estimated at between 30 and 70% with an average of 40%. The material has been used to produce Granular A and B, SSM and some HL (CA) products. Beneficiation is required for some aggregate products and stone quality will have to be monitored. The deposit has generally been described as a single, sharply defined esker ridge with local relief of 5 to 8 m. Paleocurrent flow is to the northeast.

The esker segment located in Perth County occupies an area of 13.2 ha, which is reduced to 10.0 ha after considering previously extracted areas and physical, cultural and environmental constraints. Assuming a conservative deposit thickness of 4.5 m, there are approximately 0.8 million tonnes of aggregate located in Logan Ward (*see* Table 3). This relatively small resource needs to be considered with the 4.4 million tonnes identified in Huron County (Ontario Geological Survey 2004).

Selected Sand and Gravel Resource Area 4

A large glaciofluvial ice-contact deposit situated west of Dublin in Hibbert Ward, Municipality of Perth West, has been chosen as Selected Sand and Gravel Resource Area 4. A.J. Cooper (OGS, unpublished report, 1981) believes that the deposit was formed during the retreat of the Huron lobe; specifically, that the granular material was transported and washed out of the Huron ice during deposition of the Dublin moraine. A later readvance or oscillation of the ice deposited a 1 to 1.5 m cover of Rannoch Till.

Two licenced (Pit Nos. 23 and 24) and 1 unlicenced pit (Pit No. 32) have been developed within the selected resource area. Exposures within the deposit reveal well-stratified, coarse cobbly gravel with a clean, medium to coarse sand matrix; thin-bedded, well-stratified, sandy gravel and gravelly sand with some small-scale cross-beds; and well-stratified, poorly sorted gravel with coarse sand layers.

The coarse aggregate content varies from 38.3 to 59.9%, with crushable material ranging from 15.8 to 38.0%. The sand content varies from 29.8 to 61.2% with a 0.5 to 13.3% fines fraction. Granular material extracted from the deposit has generally been acceptable for the production of Granular A and B, SSM, 16 mm crushed stone, and HL4 and HL8 (CA) products. Sand control, selection and blending may be necessary in some sections of the deposit.

Selected Sand and Gravel Resource Area 4 occupies approximately 205.2 ha after considering previously extracted areas and other planning constraints. Assuming a conservative average deposit thickness of 6 m, approximately 21.8 million tonnes of granular material would be available for extraction (*see* Table 3). Transportation to and from this deposit is provided by county and lower-tier municipal roads.

Selected Sand and Gravel Resource Area 5

Selected Sand and Gravel Resource Area 5 consists of a glaciofluvial ice-contact–ice-contact esker complex surrounding the community of Staffa (Hibbert Ward, Municipality of Perth West). A small ice-contact esker segment located to the southwest of this complex has been designated as a resource area of secondary significance, as has the glaciofluvial outwash deposit located along the northeastern corner of the complex. There are currently 5 licenced pits within this combined primary and secondary resource area (Pit Nos. 25 to 29, inclusive) as well as 1 unlicenced pit (Pit No. 36) and numerous areas of obvious previous extractive activity (*see* Map 1, green shading). Pit faces range from 1 to 9 m in height.

The deposit is an upland area with hummocky topography and some notable small kettle features. Material exposed in these pit faces can be described as well-stratified, gravelly sand and sandy gravel with lens of cross-bedded, laminated sand; massive, boulder-cobble gravel supported in a clean coarse sand matrix; and a thick, massive sequence of unsorted cobbles, boulders and gravel in a clast-supported sand matrix (boulders can exceed 70 cm). Areas of unsorted, dirty coarse gravel suggest rapid deposition, and A.J. Cooper (OGS, unpublished report, 1981) has suggested that the deposit represents an infilling of a re-entrant into the Huron lobe. Glacial meltwater flowing from the retreating ice formed the outwash deposit to the north-east of the ice-contact complex.

The coarse aggregate content varies from 28.8 to 89.8%, with 13.3 to 53.8% crushable. Sand varies from 10.0 to 63.5% and fines range from 0.2 to 18.1%. Lithological results for this selected area range from 31 to 91% limestone, 5 to 67% dolostone, 0 to 1% siltstone, 1 to 6% Precambrian clasts and 0 to 1% chert. Material from this deposit can produce Granular A and B, SSM, 16 mm crushed stone, and HL4 and HL8 (CA) products. Because of the variability, selective extraction procedures may be required. Oversize material will need to be separated, removed or crushed. Sand control and blending may be required to meet HL (FA) requirements.

Selected Sand and Gravel Resource Area 5 has a resource area of 239.1 ha. Previous extractive activity, cultural and environmental constraints reduce this area to 214.9 ha. Assuming a conservative deposit thickness of 6 m, there are approximately 22.8 million tonnes of aggregate available for extraction (*see* Table 3).

Selected Sand and Gravel Resource Area 6

Selected Sand and Gravel Resource Area 6 is a small glaciofluvial ice-contact deposit that crosses over the Perth County–Regional Municipality of Waterloo (herein referred to as the "Region of Waterloo") boundary in Mornington Ward, Township of East Perth. The portion of the deposit in Perth County is actually very small (both in terms of surface area and quantity of available material) and the majority of the deposit is located in the Region of Waterloo.

There is currently no granular resource extraction within this particular deposit in either municipality. The selection of this resource area in the Region of Waterloo appears to be based on the similarity of this deposit with other hummocky ice-contact deposits within this portion of the Region of Waterloo (Ontario Geological Survey and Planning and Engineering Initiatives Limited 1998). A similar deposit located slightly to the southeast of this deposit in the Region of Waterloo currently hosts 3 licenced pits with a gravel content estimated at 35% and a thickness of up to 20 m. It is expected that this selected primary resource area will have similar physical characteristics. It is also expected that this deposit will have seams of silt and clay, granular material interbedded with till, and chert clasts; all of which are characteristic of other surrounding granular deposits.

The granular resource has been estimated at 3.2 million tonnes in the Region of Waterloo. Based on approximately 1.7 ha of resource area in Perth County, and assuming a deposit thickness of 6 m, the granular resource available in Perth County would add an additional 0.2 million tonnes to the Region of Waterloo resource (*see* Table 3). Another important reason for selecting this deposit in the Region of Waterloo was the general lack of granular resources in that part of the Region (Ontario Geological Survey and Planning and Engineering Initiatives Limited 1998). A general lack of granular material in this part of Perth County is also true.

Selected Sand and Gravel Resource Area 7

Selected Sand and Gravel Resource Area 7 is located in Ellice Ward, Township of East Perth, just northwest of the City of Stratford. There are currently 2 licenced properties (Pit Nos. 44 and 45) located and developed within this deposit. The deposit is a partially buried glaciofluvial ice-contact deposit that may be part of, or associated with, the Gads Hill moraine. The extraction operation is a dredging operation and the only granular face is located along the eastern side of the licenced property; therefore, no mappable resource unit is identified on Map 1. The granular material along this face can generally be described as horizontally bedded, fine to coarse, poorly sorted clean gravel in a clean sandy matrix. Cobbles and some boulders occur in the northern part of the pit face. On the western side of the operation, silty clay Stratford Till was observed.

Gradation results indicate 24.2 to 77.1% coarse aggregate with 6.5 to 41.0% crushable. The sand content ranges from 22.7 to 74.0% and the fines vary from 0.2 to 15.3%. The lithology ranges from 46 to 53% limestone, 27 to 36% dolostone, 0 to 2% siltstone, 8 to 9% Precambrian clasts and 7 to 12% chert. Other test results are provided in Table 9. The high Petrographic Number test results for HL (CA) and concrete (161.8 to 201.0) and the high absorption test results (2.100, 2.300 and 2.370%) can generally be attributed to the chert content.

Based on the above information, the granular material should be suitable for the production of Granular A and B, and SSM products. Hot-Laid and concrete (CA) should be monitored. Hot Laid and concrete sand would require screening, blending and other necessary beneficiation.

It is difficult to calculate the remaining granular resources within Selected Sand and Gravel Resource Area 7, since the deposit is buried and dredging operations are being carried out within the licenced operation. Previously drilled boreholes and water-well records failed to provide a general trend or outline of a potential buried deposit beyond the licenced property. An application for an aggregate licence, for an area south of the existing licenced property, was submitted to the Ministry of Natural Resources during the summer of 2012. Therefore, it is possible that site-specific drilling has indicated that the buried granular material extends southward from Pit Nos. 44 and 45.

Selected Sand and Gravel Resource Area 8

Selected Sand and Gravel Resource Area 8 is a glaciofluvial outwash–terrace deposit located along Flat Creek in Blanshard Ward, Township of South Perth, just northwest of the Town of St. Marys near Science Hill. Glacial meltwater flowing from the west, during the formation of Dublin moraine, would have deposited these outwash and terrace deposits. The deposit currently hosts 3 licenced pits (Pit Nos. 70, 71 and 72). Pit faces range from 3.5 to 5 m; dredging is being done in the licenced area.

Granular material ranges from well-stratified, well-sorted, horizontally bedded, clean sand and gravel with cobbles and boulders; to thin-bedded, laminated silty fine sand and silt layers. The coarse aggregate content ranges from approximately 30 to 50%, with some sections of the deposit being approximately 70% coarse aggregate, with 22 to 45% crushable. (Photo 10 (ArcGIS® version only) illustrates the subrounded to subangular nature of some of the cobbly-bouldery material within this deposit.)

The granular material within this deposit has been used for the production of Granular A and B, SSM, HL (CA) and HL (FA) products. In some areas of the deposit, selection and sand control will have to be implemented to meet aggregate specifications; and some of the cobbles and boulders will have to be separated, removed or crushed.

Selected Sand and Gravel Resource Area 8 occupies 12.9 ha after considering the licenced operations. The area is further reduced to 11.1 ha after previously extracted areas and physical, cultural and environmental constraints are considered. Assuming a conservative deposit thickness of 6 m (not including the potential for dredging operations), there are 1.2 million tonnes of aggregate still available for resource extraction (*see* Table 3).

Selected Sand and Gravel Resource Area 9

A glaciofluvial outwash–terrace deposit located along the western boundary of the Town of St. Marys and along the north shore of the Thames River has been selected as a resource of primary significance. (Photo 11 (ESRI® ArcGIS® version only) shows the terrace ridge located along the northern part of this deposit.) Three licenced pit operations (Pit Nos. 75, 76 and 77) have been developed along the full length of this deposit. Pit No 77 is licenced as both a pit and quarry operation with the main extractive activity being the quarry operation.

The pit exposures reveal a moderately stratified, moderately to well-sorted, granular material with 40 to 50% coarse aggregate (gravel and crushable). Granular material from this deposit should be suitable for the production of Granular A and B, SSM and HL (CA) and HL (FA) products. Beneficiation will be required in order to meet the specifications for some aggregate products.

Selected Sand and Gravel Resource Area 9 has an area of 34.7 ha, exclusive of the licenced operations. This area is reduced to 23.9 ha after considering previous extraction and physical, cultural and environmental constraints. Assuming a conservative deposit thickness of 6 m, there would be approximately 2.5 million tonnes available for extraction. An area of glaciofluvial outwash located to the west of this selected resource area, and identified as a secondary resource area on Map 1, could also add to the granular material available for extraction in this area.

Selected Sand and Gravel Resource Area 10

Selected Sand and Gravel Resource Area 10 comprises 2 glaciofluvial ice-contact deposits, located south of the City of Stratford, and buried granular material that appears to surround and join these 2 surface deposits. Three licenced pit operations (Pit Nos. 55, 56 and 57) have been developed within these deposits and all 3 operations are being dredged for granular material.

A 3 to 4.5 m pit face along the eastern boundary of the deposit reveals a variety of granular material. The material varies from very well-stratified, well-sorted, fine gravel with cross-bedding and a paleocurrent flow to the south; to thick, horizontally bedded, well-stratified, thin-bedded, fine sandy gravel and coarse gravelly sand. Some areas are covered by about 1 m of thick-bedded, moderately stratified, fining-upward, cross-bedded, coarse to fine gravel with a clean sand matrix. (Photo 12 (ESRI® ArcGIS® version only) illustrates the type of material found in this deposit.) A layer of silt till was noted during field investigation covering some sections of the deposit (Photo 13, ESRI® ArcGIS® version only). Current dredging operations are removing granular material from about 8.2 m below the water surface. Karrow (1977a) suggests that this area may be associated with the Gads Hill moraine complex.

The coarse aggregate content varies from 36.6 to 89.6%, with a crushable fraction that ranges from 24.9 to 53.9%. The sand content ranges from 8.1 to 58.4% and the fines vary from 0.8 to 17.6%. Lithological results indicate 56% limestone, 37% dolostone, 5% Precambrian clasts and 2% chert. Other test results for this selected resource area are provided in Table 9, and generally indicate granular material that is suitable for the production of Granular A and B, SSM and HL (CA) products with sand control and beneficiation. The Petrographic Numbers for HL (CA) and concrete will need to be monitored and reflect the presence of chert clasts.

Selected Sand and Gravel Resource Area 10 occupies 17.3 ha after considering previously extracted areas and other planning constraints. Assuming a conservative deposit thickness of 6 m, although this would not include the potential for dredging operations as is happening now, there would be 1.8 million tonnes of aggregate resource available for extraction (*see* Table 3).

Selected Sand and Gravel Resource Area 11

Selected Sand and Gravel Resource Area 11 is located to the southwest of Selected Sand and Gravel Resource Area 10, both of which are in Downie Ward, Township of South Perth. The deposit has been mapped as a glaciofluvial ice-contact–ice-contact esker deposit. There is currently a single licenced pit operation (Pit No. 58) located within this resource area; however, previous extractive activity has occurred as illustrated on Map 1 by the green shading and by the unlicenced pit symbols. In some of the previously extracted areas, the water table has been exposed.

Gradation results for this deposit indicate a coarse aggregate content that varies from 0 to 77.3%. The sand fraction varies from 15.0 to 93.2% and the fines content ranges from 1.2 to 12.7%. Lithological results indicate 67 to 76% limestone, 16 to 21% dolostone, 0 to 1% siltstone, 7 to 8% Precambrian clasts and 0 to 4% chert. The Petrographic Number test results for HL (CA) and concrete reflect the siltstone and chert content (*see* Table 9). Other test results are provided in Table 9. Granular material from this deposit can be used for the production of Granular A and B, SSM and HL (CA) products with proper beneficiation, selection and blending.

Selected Sand and Gravel Resource Area 11 occupies 136.1 ha exclusive of the licenced property. Previously extracted areas and physical, cultural and environmental constraints reduce this area to approximately 129.3 ha. Assuming a conservative deposit thickness of 5 m (which would not consider the potential for dredging operations), the selected resource area should have approximately 11.4 million tonnes available for extractive activity. A glaciofluvial outwash deposit located just south of this selected area has been selected at the secondary level of significance. There is generally less information available for this deposit, although field observations suggest that this deposit has a good percentage of coarse aggregate. This deposit would add to the granular resources of this particular selected area.

Selected Sand and Gravel Resource Area 12

Located to the southeast of Selected Sand and Gravel Resource Area 11, and straddling the boundary between Perth County–County of Oxford (herein referred to as "Oxford County") is an ice-contact deposit that has been chosen as Selected Sand and Gravel Resource Area 12. Little of this particular deposit is located in Downie Ward (Township of South Perth) and most of the deposit lies in the County of Oxford where it has been selected as a resource of primary significance (Ontario Geological Survey 1986). There is a licenced pit operation on the south side of the boundary road in Oxford County and 1 unlicenced pit (Pit No. 64) was noted in Perth County.

Cowan (1975) suggests that the sediments within this selected resource area were deposited at or near an ice margin, and represent a period of stagnant ice with considerable subglacial drainage. The material has been described as quite varied ranging from fine sand interspersed with till, to sand and coarse gravel with significant commercial value. In Oxford County, there were 10 licenced and 4 unlicenced properties in this selected resource area (Ontario Geological Survey 1986).

The coarse aggregate content varies from 35 to 60%, including crushable material that ranges from 5 to 22%. A coarse aggregate content in excess of 75% has also been reported. Lithological results indicate 40% limestone, 41% dolostone, 1% sandstone, 8% Precambrian clasts and 9% chert. The deposits have been used for the production of Granular A and B, SSM and HL4 (CA) products with proper processing and beneficiation. The sand fraction may require blending for the production of HL (FA) products.

Based on aggregate test results and the size of the deposits in Oxford County, the northern extension of these deposits have been selected as a primary resource in Perth County. Selected Sand and Gravel Resource Area 12 has an area of 25.3 ha after considering previously extracted areas and other planning constraints. Assuming a conservative deposit thickness of 6 m (estimated to be 6 to 9 m in Oxford County), there would be approximately 2.7 million tonnes of granular material in Perth County (*see* Table 3). This is in addition to the 62 million tonnes identified in Oxford County (Ontario Geological Survey 1986).

Resource Areas of Secondary Significance

There are numerous secondary deposits throughout Perth County that add significantly to the overall aggregate resource supply in the study area. The following factors make these resource areas less attractive for development than primary deposits: deposit thickness and, therefore, the quantity of granular material available; variability of the material; lower coarse aggregate content; concerns over the stone quality; the "dirtiness" of some of the deposits (percentage of fines); and, in some cases, the lack of geological information. However, many of these secondary resource areas could be used locally to supply lower specification aggregate products and could be used as a wayside permit, which is a time-limited, project-specific extraction activity. Given the previous and current extractive activities, and the limited nature of primary resource areas within the study area, secondary resource areas should be considered during land-use planning discussions and decision-making processes.

MUNICIPALITY OF PERTH NORTH

Surrounding and south of Selected Sand and Gravel Resource Area 1, in the north-central portion of Wallace Ward, are a series of glaciofluvial ice-contact and outwash deposits, which are identified as resource areas of secondary importance. Licenced Pit Nos. 1 and 2, as well as a number of unlicenced pits are located within these deposits. The deposits are generally up to 6 m thick; however, there may be segments of these deposits that are thinner, as well as areas that are substantially thicker. Granular material within these deposits range from well-stratified, thin- to thick-bedded, interbedded sand, silty sand to gravelly sand and sandy gravel; to finely laminated and rippled cross-bedded, fine- to medium-grained sand; to stratified, moderately sorted fine gravel with cobbles, overlain by thin sandy-silt beds with some fine gravel. The coarse aggregate content varies from 21.2 to 77.9% with crushable material ranging from 8 to 19%. The sand content varies from 12.7 to 63.0% and fines vary from 7.2 to 15.8%. Lithology is variable from 7 to 12% limestone, 64 to 67% dolostone, 9 to 11% Precambrian clasts, 0 to 1% siltstone and 15 to 17% chert. The granular material is generally acceptable for the production of granular base and subbase material. The chert content restricts the use of the aggregate for the production of HL (CA) and concrete products, which is reflected in the Petrographic Numbers (169.6 to 217.0), magnesium sulphate soundness (up to 16.3%) and absorption values (3 of 4 test results are >2.5) shown in Table 9. Sections of the deposits are “dirty” for the production of granular material and appropriate beneficiation procedures will be required to meet specification.

In the eastern part of Wallace Ward are 2 small esker segments that have been identified as secondary resource areas. No licenced pits are currently developed in this area, but previous extractive activity has occurred. The coarse aggregate content ranges from 42.8 to 70.8% with crushable material as high as 33.0%. The sand content varies from 17.7 to 28.3%, with fines ranging from 2.0 to 39.5%. Lithological results indicate 5 to 16% limestone, 64 to 66% dolostone, 4 to 5% Precambrian clasts and 13 to 24% chert. The granular material can be used for the production of Granular A and B, and SSM products. Stone quality (i.e., a high chert content) and the “dirtiness” of some sections of these deposits limit the use of this material. Beneficiation procedures are required to meet some specifications. Other test results for this resource area are provided in Table 9. A single exposure within this selected resource area revealed a moderately stratified, unsorted to moderately sorted, fine to coarse gravel in a clean sand matrix. The esker core has a higher percentage of coarse aggregate, whereas the flanks tend to be sandy. The esker continues southeasterly into Wellington County where some segments of the esker have been selected as primary and other sections as secondary.

In the southwest portion of Wallace Ward and extending into the northwestern part of Elma Ward are a series of glaciofluvial outwash deposits that have been selected as secondary resource deposits. These deposits currently host licenced Pit No. 3, unlicenced Pit Nos. 9 and 10, a number of unlicenced pits and previously extracted areas (*see* Map 1, green shading). The granular material can generally be described as well-stratified, fining-upward, coarse clean sandy gravel with cobbles overlain by laminated, medium-grained sand. Small-scale cross-bedding is observed within some of the sand layers. Other exposures reveal a fine, clast-supported, well-sorted gravel with interbedded sand. Gradation results for these deposits indicate a coarse aggregate content of 56.1 to 61.3%, with 25.2 to 37.8% crushable, 37.9 to 41.0% sand and 1.1 to 3.0% fines. Lithology is variable, but is approximately 6 to 10% limestone, 66 to 76% dolostone, 4 to 10% Precambrian clasts and 8 to 20% chert. Other aggregate test results for these deposits are reported in Table 9. The material is generally acceptable for the production of Granular A and B, and SSM products. The high chert content generally restricts the use of this granular material for the production of HL (CA) and concrete aggregate, and is reflected in the Petrographic Number (154.7, 167.5) and absorption values (2.810, 2.950) as listed in Table 9. Similar outwash deposits located in Huron County have been selected at the secondary level of significance and host licenced operations (Ontario Geological Survey 2004).

In the northwestern part of Elma Ward (west of the Listowel) is a glaciofluvial ice-contact–esker complex that trends in a southeast direction. One recognizable unlicenced pit (Pit No. 13) is still present within this complex; however, a number of other areas have been extracted in the past (*see* Map 1, green shading). The coarse aggregate content within this complex is variable from 5.9 to 71.4% with 20.1 to 41.9% crushable. The sand content is also quite variable ranging from 20.7 to 88.2%. Fines range from 5.1 to 9.8%. Petrographic Numbers for HL (CA) and concrete (*see* Table 9) indicate poor stone quality (Petrographic Number test results vary from 223.1 to 345.7), which relate to a high percentage of chert. This high chert content is also reflected in the absorption results (3.250 and 4.470%). The granular material within this complex can be used for the production of Granular A and B, and SSM products with proper beneficiation.

Located in the west-central part of Elma Ward and extending southeastward toward the community of Newry is the Newry esker, portions of which have been selected as a resource of secondary significance. The Newry esker continues into Huron County where it has also been selected as a resource of secondary significance (Ontario Geological Survey 2004). There are currently 2 licenced pits (Pit Nos. 11 and 12) located within this deposit, both are located along the western boundary of Elma Ward and both are dredging granular material. A number of sections of the esker ridge (Photo 14, ESRI® ArcGIS® version only) have been extracted in the past (*see* Map 1, green shading). Limited gradation results for this area indicate a content of

65.8% coarse aggregate, 32.6% sand and 1.6% fines with 32.4% of the coarse aggregate content being crushable. Lithological results indicate 35% limestone, 50% dolostone, 10% Precambrian clasts and 5% chert. These test results, as well as others provided in Table 9, would suggest that the granular material is acceptable for the production of Granular A and B, SSM and some lower specification HL (CA) products in limited quantities with appropriate beneficiation. Stone quality is still a concern for the production of high-specification concrete aggregate (Petrographic Number is 146.9).

Another small esker segment located along the western boundary of Elma Ward, and located south of the Newry esker, has also been selected as a resource of secondary importance. Similar to Selected Sand and Gravel Resource Area 1, there is very little of the esker ridge located in Perth County. Much of what is present within Elma Ward has been extensively extracted. (Photo 15 (ESRI® ArcGIS® version only) shows a previously extracted portion of the esker deposit.) The esker ridge is more prominent in Huron County, and has been selected there as a resource of secondary importance (Ontario Geological Survey 2004).

These secondary deposits can add to the overall granular resources of the Municipality of Perth North and can be utilized for local construction, infrastructure renewal projects or wayside operations. Many of the small esker segments have been extracted in the past and will only provide limited quantities of granular material.

The Atwood esker, located just north of the community of Atwood and trending in a southeasterly direction, has not been selected as a resource of secondary importance. The esker ridge has been extensively extracted in the past and the remaining ice-contact esker segments tend to be thin (generally <3 m thick) and predominantly sand.

MUNICIPALITY OF PERTH WEST

Northeast-trending glaciofluvial ice-contact esker segments have been selected as a resource of secondary significance. These esker segments are located in the northern part of Hibbert Ward and cross over into the southern part of Logan Ward, just west of the community of Mitchell. Sections of these esker ridges have been extracted (Pit Nos. 21, 22, 33; *see also* Map 1, green shaded areas); however, there are still portions of these deposits that are available for extractive activity. Material is quite variable with one sample having a gradation of 78.7% coarse aggregate (including 48.1% crushable), 13.8% sand and 7.5% fines. Another sample along the same deposit was 89.9% sand, 0% coarse aggregate and 10.1% fines. These deposits are not expected to provide large quantities of granular material, but may be suitable for small, local construction projects or wayside operations. Aggregate test results for a small deposit just northeast of these esker segments, and for esker segments located in Hibbert Ward, are presented in Table 9.

Two glaciofluvial ice-contact deposits located just southwest of Selected Sand and Gravel Resource Area 5 have been selected as secondary resource areas. Licenced Pit No. 31 has been developed in this selected area.

One glaciofluvial ice-contact deposit located along the southwestern boundary of Hibbert Ward has been selected as a secondary resource. The deposit currently has a single licenced operation (Pit No. 30); however, this pit has been completely rehabilitated. Coarse aggregate material ranges from 18.7 to 62.9%, with 5.0 to 36.8% crushable. The sand content varies from 33.1 to 77.0%, with fines varying from 4.0 to 14.3%. Lithology varies from 81 to 94% limestone, 3 to 14% dolostone, 2 to 3% Precambrian clasts and 1 to 2% chert. The granular material from this deposit has been used for the production of Granular A and B, SSM, HL (CA) and HL (FA) products with fines control and blending of the sand fraction. As noted in Table 9, the Petrographic Numbers for HL and concrete (CA) are borderline acceptable (137.6, 140.2). The deposit continues into Huron County where the deposit has been selected as a secondary resource.

TOWNSHIP OF EAST PERTH

The advance and retreat of glacial ice left few glaciofluvial ice-contact or outwash deposits on the ground surface in Mornington and Ellice wards because of the nearly stone-free nature of the local tills (therefore, leaving little granular material to rework), and the absence of a sufficient gradient to allow for rapid run-off and material sorting.

Numerous glaciofluvial ice-contact deposits, located throughout North Easthope Ward, have been selected as resource areas of secondary importance. There are currently 4 licenced operations within these selected areas (Pit Nos. 47 to 50 inclusive). There are also a number of unlicenced pits and areas where extraction has taken place in the past (*see* Map 1, green shading). Granular material within these deposits is quite variable with the coarse aggregate content ranging from 0.2 to 76.6%, with a crushable component ranging from 0 to 43.3%. The sand content varies from 21.9 to 96.5% and the fines from 1.3 to 14.7%. Lithology ranges from 36 to 79% limestone, 6 to 59% dolostone, 4 to 14% Precambrian clasts and 1 to 5% chert. Other aggregate test results for these glaciofluvial ice-contact deposits are provided in Table 9. High Petrographic Numbers for HL and concrete (CA) generally reflect the chert content within the coarse aggregate fraction of the granular material (120.8 to 277.0). Some magnesium sulphate soundness and absorption test results do not meet specification and will require close monitoring. Granular A and B, SSM, HL4 (CA) and HL4 (FA) products have been produced from these deposits in the past. Screening, blending and other beneficiation measures would be required to meet some specifications. These deposits are associated with the Easthope and Gads Hill moraines, which as stated earlier are unresolved in terms of their genesis.

The material in these secondary resource areas vary from horizontal, uniform, clean coarse gravel overlain by sand and silt; to well-sorted, horizontally bedded fine to coarse, clast-supported gravel with a clean sand matrix; to thin-bedded, fine to coarse sand to fine gravel with cross-bedding and ripple formation covered by thin bedded, silt fine sand and clay (Photo 16, ESRI® ArcGIS® version only); to coarse, massive, clast-supported gravel overlain by fine gravel; to well-stratified, unsorted matrix-supported, coarse gravelly sand with cobbles; to poorly stratified, massive, cobble-boulder with unsorted, dirty, clast-supported matrix of sand, silt and clay (Photo 17, ESRI® ArcGIS® version only); to 2 m thick, interbedded, laminated clay and silty sand layers (Photo 18, ESRI® ArcGIS® version only).

TOWNSHIP OF SOUTH PERTH

A series of glaciofluvial outwash deposits located along Flat Creek, Fish Creek and the North Thames River have all been designated as secondary aggregate resource areas. These areas should provide reasonably good quality aggregate that can be used for local construction projects or as a wayside operation. Aggregate quality will be variable, but previous test results for outwash deposits near the community of Kirkton indicate 40 to 70% coarse aggregate. Petrographic Number test results for HL and concrete (CA) range between 127 and 162, and absorption values range between 1.56 and 2.07%. These deposits should be able to produce Granular A and B, and SSM products and may provide limited quantities of HL4 (FA) products. Site-specific and detailed testing would be required. Many areas of these deposits have been extracted in the past, and land-use planning constraints were noted during field work (i.e., a conservation area). The deposit thickness is variable; however, the deposits are generally 3 to 6 m thick.

Small glaciofluvial ice-contact deposits distributed throughout Blanshard Ward have also been selected as sand and gravel deposits of secondary importance. Many of these deposits currently have small licenced operations (e.g., Pit Nos. 65 to 68 and 73) or have had previous extractive activity. The material can be quite variable from a good mixture of sand and gravel to areas that are predominantly silt and silty fine sand. In areas where the material is generally a silty fine sand, the water table is generally high. These deposits will be limited in their ability to provide aggregate material; however, they may be able to supply limited quantities of granular material to local projects either through the current licenced operations or through a wayside operation.

Glaciofluvial outwash deposits located at the confluence of Fish Creek and the North Thames River, just southwest of Selected Sand and Gravel Resource Area 9 have been selected as secondary resource areas. Exposures reveal between 3 and 8 m of well-sorted, thin- to thick-bedded, interbedded sand, silty sand to gravelly sand and sandy gravel; finely laminated and rippled cross-bedded, fine- to medium-grained sand; stratified, moderately sorted fine gravel with cobbles overlain by thin sandy-silt horizons with some fine gravel; and a thick, massive sequence of unsorted cobbles, boulders and gravel in a clast-supported sand matrix. Oversize material is available for crushing. (Photo 19 (ESRI® ArcGIS® version only) illustrates the type of material located within this deposit.) Part of the resource area is almost completely covered by licenced Pit No. 74. Other previous extractive activity has occurred in this secondary outwash area (*see* Map 1, unlicenced Pit No. 78; *see also* green shading). The deposit has been selected as a secondary resource in Middlesex County.

In Downie Ward, the St. Marys esker deposit has been selected at the secondary level of significance. This relatively narrow ice-contact ridge has a low profile and is almost indiscernible in some areas along its length. Some minor dredging operations have occurred along the esker ridge. The sandy flanks of the esker are often interbedded with Tavistock Till. Field lithology results indicate 72% limestone, 17% dolostone, 1% siltstone, 7% Precambrian clasts and 3% chert. The gradation results for a sample collected along the esker ridge indicates 62.8% coarse aggregate with 22% crushable, 36.4% sand and only 0.8% fines. The Petrographic Number test results for HL (CA) and concrete was slightly above acceptable for this particular sample, which is a reflection of the chert and siltstone content. The material is generally acceptable for Granular A and B, SSM and HL4 (CA) products with sand fraction control, blending and beneficiation. Hot-Laid (FA) production may be possible.

BEDROCK GEOLOGY AND RESOURCE POTENTIAL

The oldest Paleozoic rocks in Perth County are the buff, fine crystalline dolostones; greenish grey and reddish shales; and evaporites of the Upper Silurian Salina Formation (Group), which are located in the northeast corner of the study area. The Salina Formation (Group) has not been utilized for the production of aggregate due to a thick overburden cover, poor accessibility, a high shale content and poor physical properties (Hewitt 1960). The Salina Formation (Group) is believed to have formed due to uplift along the Algonquin Arch and reasonably rapid basin subsidence, drastically changing the depositional environment (Johnson et al. 1992). Repeated carbonate, evaporite and argillaceous sedimentation characterize the Salina Formation (Group) as represented by the various rock units. For greater detail on these units, one is referred to Armstrong and Carter (2010). Salt is extracted from the Salina Formation (Group) in southwestern Ontario near Windsor and Goderich, as well as a number of salt brine wells. A significant thickness of 205.2 m of Salina Formation (Group) was intersected at the Bruce Nuclear site (Raven et al. 2009), northwest of the study area.

The Upper Silurian Bass Islands Formation conformably overlies the Salina Formation (Group). The lithology of the Bass Islands strata consists of buff to brown, fine-grained dolostone in even, vertically jointed, thin to medium beds

(Johnson et al. 1992). Locally, thick beds up to 60 cm are present. The formation is generally nonfossiliferous. The Bass Islands Formation has not been utilized for aggregate in the study area; however, some strata have historical use for the manufacture of lime (Hewitt 1960). The formation is overlain by a thick overburden cover and does not crop out in the study area. A sample of Bass Islands Formation rock was submitted for standard aggregate testing (Rowell 2012). The results have been included in Table 9. A drill hole at the Bruce Nuclear site intersected 45.3 m of Bass Islands Formation (Raven et al. 2009). The Bass Islands Formation is roughly equivalent to the Bertie Formation located in the Niagara Peninsula (Johnson et al. 1992).

Disconformably overlying the Bass Islands Formation are the greenish-grey to grey-brownish, thin- to medium-bedded, fine- to medium-grained, fossiliferous, bioturbated, cherty limestones and dolostones of the Lower Devonian Bois Blanc Formation (Johnson et al. 1992). The unit is locally very fossiliferous containing rugose and tabulate corals, brachiopods and some amphipora. Perhaps most characteristic of this unit is the presence of abundant nodules and lenses of white weathered chert. In some exposures, the chert can form up to 90% of the rock. The formation is between 3 and 50 m thick and is generally thicker toward the centre of the Michigan Basin (Johnson et al. 1992). At the Bruce Nuclear site, drill holes intersected approximately 49 m of the Bois Blanc Formation (Raven et al. 2009). The formation is covered by a thick and extensive overburden cover and does not crop out in the study area. South of the study area, the formation has been quarried at Hagersville, Cayuga and Port Colborne for crushed stone suitable for base course. The high chert content of this unit makes it unsuitable for asphalt and concrete aggregate.

The Amherstburg Formation is a Middle Devonian formation with the lower part of the formation quite possibly Lower Devonian in age (Johnson et al. 1992). The formation varies from 0 to 50 m thick and consists of tan to grey-brown to dark brown, fine- to coarse-grained, bituminous, bioclastic, fossiliferous, commonly cherty limestones and dolostones. Drill holes at the Bruce Nuclear site have intersected 44.6 m of Amherstburg Formation (Raven et al. 2009). Fossils that have been noted in the formation include rugose and tabulate corals, brachiopods, crinoids, cephalopods and trilobites. In the Teeswater–Formosa area of southern Bruce County, biohermal limestone and dolostone units are considered to belong to the Amherstburg Formation (Uyeno, Telford and Sanford 1982). This biohermal facies is known as the Formosa Reef Limestone or Formosa reef facies. The formation is covered by thick overburden and does not crop out in the study area. Historically, the main utility of the strata has been for the production of cement, metallurgical flux, agricultural lime and chemical stone (Hewitt 1960). Use of the stone for aggregate is less likely, due to the porous and sometimes soft nature of the rock (Hewitt 1960).

Conformably overlying the Amherstburg Formation in the study area is the Lucas Formation. The formation consists of brownish-grey, brown and cream, thin- to thick-bedded, fine crystalline dolostone. Minor interbeds of limestone occur in association with small bioherms and brecciated beds (Johnson et al. 1992). Locally, the strata contain chert nodules, bituminous streaks and algal laminae. Anhydritic beds have also been observed and recorded within the formation. Rutka and Birchard (1993) and Birchard, Rutka and Brunton (2004) have proposed 4 depositional environments for the various lithologies noted within the Lucas Formation in the Michigan Basin. These include upper sabkha mud-flat evaporate, lower sabkha mud-flat evaporate, supratidal–shallow intertidal and subtidal depositional environments. The formation is exposed along Trout Creek and the North Thames River near St. Marys, and in the subsurface at the St. Marys quarry site. Drill holes at the Bruce Nuclear site intersected 10.4 m of Lucas Formation (Raven et al. 2009). Historically, the Lucas Formation has been used for chemical and metallurgical stone, especially in the Ingersoll area of southern Ontario. Within the study area, the formation has been utilized for lime production, aggregate for road construction and the manufacture of cement.

Disconformably overlying the Lucas Formation are the grey to tan to brown, fossiliferous, medium- to thick-bedded limestone and minor dolostone of the Dundee Formation. The formation is approximately 35 to 45 m thick and displays bituminous partings and oil staining in more porous segments and along fractures. Chert nodules are locally abundant. Fossils are generally abundant and include crinoid debris, brachiopods, rugose and tabulate corals, trilobites and algal cysts. The Dundee Formation is an oil-bearing formation. It has been quarried near Port Dover and on Pelee Island for crushed stone. It is also extracted near St. Marys for the manufacture of cement. In a previously extracted portion of the St. Marys quarry operation, 11.1 m of the basal part of the Dundee Formation sharply overlies 8.1 m of the Lucas Formation (Derry Michener Booth and Wahl and Ontario Geological Survey 1989).

Karst Features

Karrow (1977b) mapped a number of sinkhole features in the southwest corner of Hibbert Ward. A group of about 15 sinkholes were mapped in the Cromarty area in a till unit that lies in front of the Lucan moraine. A second group of about 10 sinkholes were mapped near Chiselhurst in front of the Seaforth moraine. Most of the sinkholes are less than 5 m deep and 9 m in diameter. The deepest sinkhole was measured at 7.6 m deep and approximately 30 m in diameter. The largest sinkhole was located near the Ausable River west of Cromarty and is approximately 46 m wide and over 122 m long. Some sinkholes have a noticeable opening at the bottom of the feature, which allows them to drain a substantial amount of water in a short period of time. Other sinkhole features appear to be closed and appear to retain water before seepage slowly drains them. All of the sinkhole features are underlain by Quaternary sediments over the Dundee Formation.

BEDROCK AGGREGATE QUALITY AND SUITABILITY

A sample of the Bass Islands and Lucas formations were collected and tested as part of the project to inventory the aggregate resources of Bruce County (Rowell 2012). The test results for the Bass Islands Formation sample would appear to indicate that the formation is suitable for the production of Granular A and B, and SSM products, but unsuitable for the production of HL (CA) and concrete products (Petrographic Number = 145.7; Absorption = 2.836%). The aggregate quality test results for the Lucas Formation sample indicates that the rock is unsuitable for aggregate production (*see* Table 9).

The Dundee Formation is generally not used in the production of aggregate products. It has been quarried and crushed near Port Dover and on Pelee Island as a source of granular base and subbase material, and is used to produce rock for shoreline protection. The Dundee Formation is extracted by St. Marys Cement Incorporated in the study area for the manufacture of cement.

The lithology of the Salina Formation (Group) is such that it has not been used in the production of aggregate products. The Salina Formation (Group) is still a valuable resource in Ontario since facies of this formation have been mined extensively for gypsum (Caledonia and Hagersville area) and salt (Windsor, Sarnia and Goderich). Salt from the Salina Formation (Group) has been extracted as a traditional mining operation (underground mining) and as salt brine.

Selected Bedrock Resource Area

There are no Selected Bedrock Resource Areas in Perth County despite the following information: 1) St. Marys Cement Incorporated has a large quarry and processing facility along the southern boundary of the Town of St. Marys; 2) bedrock crops out along Trout Creek and the North Thames River; 3) surrounding these outcrops is a reasonably thin overburden cover as indicated on Map 2; and 4) extraction activities have occurred around the Town of St. Marys for many years.

The reason is that the Lucas and Dundee formations that are exposed in this area are generally not a source of high-quality bedrock-derived aggregate. St. Marys Cement Incorporated is extracting these formations for the manufacture of cement, an industrial mineral. In addition, many of the outcrops as noted above are located within the waterways.

It would be reasonable to expect that, during land-use planning discussions and decision-making processes, land-use planners would take into consideration the St. Marys cement quarry and processing facility, and the valuable economic impact that this operation has had to the local economy. The operation has been extremely important.

SUMMARY

Twelve selected sand and gravel resource areas have been chosen at the primary resource level in Perth County. These selected resource areas have a total unlicenced area of 742.4 ha (0.33% of the land base) with a possible resource area of 653.0 ha (0.29% of land base) after considering physical, cultural and environmental constraints. These resource areas have approximately 66.4 million tonnes of aggregate material. Stone quality (predominantly the presence of chert) greatly limits the use of this granular material for many high-specification aggregate products (e.g., HL and concrete (CA) products).

There are a number of sand and gravel deposits that have been selected at the secondary level of significance. These deposits add greatly to the overall granular resources of Perth County. Deposit thickness and, therefore, the quantity of granular material available, variability of the material, lower coarse aggregate content, concerns over the stone quality and the “dirtiness” of some of the deposits generally make these resource areas less attractive for development than the primary deposits. The deposits are still a valuable resource and should be considered during land-use planning discussions and decision-making processes.

Perth County is underlain by a sequence of Paleozoic rock units that have generally not been used extensively in the production of aggregate products. Some of the formations have been used for the manufacture of lime, metallurgical flux and cement, with some minor aggregate production. In addition, these formations are generally overlain by a thick sequence of Quaternary sediment, which would affect the economic decisions to develop these resources. The bedrock has been used for the manufacture of cement in the St. Marys area, which has provided significant economic benefits to the local community and the surrounding area.

As a result of the limited quantities of granular material available and the constraints on the bedrock-derived resources that are present in the study area, Perth County has greatly limited potential for aggregate development and production.

Enquiries regarding the Aggregate Resources Inventory of the County of Perth may be directed to the Earth Resources and Geoscience Mapping Section, Ontario Geological Survey, Mines and Minerals Division, Ministry of Northern Development and Mines, 933 Ramsey Lake Road, Sudbury, Ontario P3E 6B5 [Tel: (705) 670-5758]; or to the Owen Sound District Office, Ministry of Natural Resources, Owen Sound, Ontario [Tel: (519) 371-8470].

Table 1 - Total Identified Sand and Gravel Resources, County of Perth

1 Class Number	2 Deposit Type	3 Areal Extent (Hectares)	4 Original Tonnage (Million Tonnes)
Municipality of North Perth			
1	G-OW	52.35	5.6
	S-OW	45.60	4.8
2	G-IC	335.18	26.7
	G-IC-E	91.54	7.3
	G-OW	913.35	72.7
	S-IC	501.95	40.0
	S-LP	130.30	10.4
	S-OW	238.86	19.0
3	G-IC	127.59	4.5
	G-IC-E	140.94	5.0
	G-OW	247.90	8.8
	S-AL	959.09	34.0
	S-IC	65.06	2.3
	S-LP	436.04	15.4
	S-OW	1273.96	45.1
4	G-OW	12.94	0.2
	S-IC	1.02	0.0
	S-LP	20.00	0.4
	S-OW	20.30	0.4
Subtotal		**5613.97**	**302.6**
Municipality of West Perth			
1	G-IC	612.15	65.0
	G-IC-E	29.99	3.2
	S-IC	154.24	16.4
2	G-IC	7.98	0.6
	G-IC-E	60.38	4.8
	G-OW	31.45	2.5
	S-IC	359.18	28.6
	S-IC-E	8.27	0.7
3	G-IC	80.32	2.8
	G-IC-E	55.92	2.0
	G-OW	281.34	10.0
	S-AL	1301.55	46.1
	S-IC	47.88	1.7
	S-IC-E	76.34	2.7
	S-LP	10.37	0.4
4	G-IC	2.95	0.1
	G-IC-E	6.20	0.1
	G-OW	109.24	1.9
	S-AL	32.16	0.6
	S-IC	5.51	0.1
	S-LP	7.25	0.1
Subtotal		**3280.67**	**190.3**

Table 1 - Total Identified Sand and Gravel Resources, County of Perth			
1 Class Number	**2 Deposit Type**	**3 Areal Extent (Hectares)**	**4 Original Tonnage (Million Tonnes)**
Township of Perth East			
1	G-IC	199.14	21.1
	S-IC	657.08	69.8
	S-OW	30.62	3.3
2	G-IC	164.17	13.1
	G-OW	79.26	6.3
	S-IC	222.99	17.8
	S-OW	300.42	23.9
3	G-IC	142.65	5.0
	G-IC-E	52.06	1.8
	G-OW	99.14	3.5
	S-AL	2395.07	84.8
	S-IC	260.99	9.2
	S-IC-E	14.80	0.5
	S-OW	329.62	11.7
4	G-IC	86.21	1.5
	G-IC-E	3.79	0.1
	S-AL	3.56	0.1
	S-IC	36.16	0.6
	S-OW	31.29	0.6
Subtotal		**5109.02**	**274.7**
Township of Perth South			
1	G-IC	137.37	14.6
	G-IC-E	148.46	15.8
	G-IC-OW	7.57	0.8
	G-OW	381.39	40.5
	S-IC	151.15	16.1
	S-OW	36.29	3.9
2	G-IC	40.22	3.2
	G-IC-E	79.38	6.3
	G-OW	572.86	45.6
	S-IC	161.36	12.9
3	G-IC	33.76	1.2
	G-IC-E	31.13	1.1
	G-OW	151.13	5.4
	S-AL	2311.40	81.8
	S-IC	22.57	0.8
	S-OW	56.22	2.0

Table 1 - Total Identified Sand and Gravel Resources, County of Perth			
1 Class Number	**2 Deposit Type**	**3 Areal Extent (Hectares)**	**4 Original Tonnage (Million Tonnes)**
4	G-IC	8.11	0.1
	G-IC-E	11.41	0.2
	G-OW	12.08	0.2
	S-IC	277.79	4.9
Subtotal		**4631.65**	**257.3**
TOTAL		**18 635.31**	**1024.9**

Minor variations in all tables are caused by the rounding of data.

* The above figures represent a comprehensive inventory of all granular materials in the map area. Some of the material included in the estimate has no aggregate potential and some is unavailable for extraction due to land use restrictions.

Explanation of Deposit Type:

First letter denotes gravel content:
G = >35% gravel; S = generally "sandy", gravel-size (>4.75 mm) aggregate <35% gravel.

Letters after hyphen denote the geologic deposit type (*see also* Appendix C):
AL = alluvium; IC = ice-contact stratified drift, includes esker (E) and kame (K) deposits; LP = glaciolacustrine plains; OW = outwash.

Table 2 - Sand and Gravel Pits, County of Perth

Pit No.	Owner/Operator	Licenced Area (Hectares)	Face Height (Metres)	% Gravel	Remarks
Municipality of North Perth					
Wallace Ward					
Licenced					
1	Larry Kraus	8.40	Variable, ~3.5 - 4.5	40 - 60	Ice-contact / ice-contact esker deposit
2	Brenda Koenig	10.82	Variable	Variable	Ice-contact / outwash complex
3	Anthony Fay	20.20	~3 - 4	~35 - 55	Outwash deposit. Dredging operation
Unlicenced					
4	-	-	~4 - 5.5	~35 - 55	Ice-contact deposit. Predominantly overgrown, but still noticeable
5	-	-	~3.5 - 4	~35 - 55	Predominantly overgrown - located just southeast of landfill site
6	-	-	~2 - 3	~30 - 45	Ice-contact deposit. Predominantly overgrown, but still noticeable
7	-	-	~2 - 4	~15 - 25	Predominantly overgrown - ponds present - still noticeable
8	-	-	~2.5 - 4.5	~10 - 25	Ice-contact deposit. Predominantly overgrown, but still noticeable
9	-	-	~3 - 4	~35 - 55	Outwash deposit. Face is still noticeable
10	-	-	~3 - 4	~35 - 55	Outwash deposit. Face is still noticeable
Elma Ward					
Licenced					
11	Hanna and Hamilton Construction Co. Limited	11.18	-	-	Dredging operations - hard to determine depth or percent gravel
12	Donegan's Haulage Limited	6.00	-	-	Dredging operations - hard to determine depth or percent gravel
Unlicenced					
13	-	-	~2 - 3.5	~25 - 40	Predominantly overgrown, but still noticeable
14	-	-	~2 - 3.5	~10 - 25	Small ice-contact deposit. Predominantly overgrown, but still noticeable. Other former pits in the area are now ponds
Municipality of West Perth					
Logan Ward					
Licenced					
15	Machan Construction Limited	42.50	3 - 6	Variable	Ice-contact esker deposit. Dredging operations in the north end of the pit
16	Strat-Con Construction Ltd.	2.51	1.5 - 3.5	20 - 50	Pit has been developed along an ice-contact esker ridge
17	Machan Construction Limited	40.50	1.5 - 7.5	15 - 50	Pit has been developed along an ice-contact esker ridge
18	Irvin Scherbarth	7.50	5 - 7	35 - 60	Pit has been developed along an ice-contact esker ridge
19	Machan Construction Limited	25.00	1.5 - 4.5	10 - 60	Pit has been developed along an ice-contact esker ridge
Unlicenced					
20	-	-	~1 - 1.5	-	Small, shallow pit
21	-	-	~1 - 2	-	Badly overgrown, but noticeable
22	-	-	3	-	Badly overgrown, but noticeable. Water in pit floor

Table 2 - Sand and Gravel Pits, County of Perth

Pit No.	Owner/Operator	Licenced Area (Hectares)	Face Height (Metres)	% Gravel	Remarks
Hibbert Ward					
Licenced					
23	Josephine A. Van Loon	51.10	~5.5 - 7.5	~35 - 65	Pit has not been active in a while
24	Josephine A. Van Loon	22.10	~4.5 - 6	~35 - 65	Pit has not been active in a while
25	Municipality of West Perth	62.00	~4.5 - 5.5	~25 - 45	North end of ice-contact/outwash (Staffa) complex
26	The Warren Paving & Materials Group Limited	13.20	~1.5 - 3	~30 - 55	Pit has not been active for some time and is badly overgrown
27	David Gardiner	4.30	~4 - 8	~30 - 50	Pit has not been active in a while
28	Jennison Construction Ltd.	37.90	~4 - 9	~35 - 65	Ice-contact/outwash (Staffa) complex
29	Maurice Ruston	5.26	~1 - 2	~35 - 55	Pit has not been active in a while
30	Jay Hayden	36.40	-	-	Pit has been rehabilitated
31	1028094 Ontario Inc.	26.60	Variable	Variable	Pit is split into 2 parcels
31	1028094 Ontario Inc.	10.10	Variable	Variable	Pit is split into 2 parcels
Unlicenced					
32	-	-	~4 - 6	~30 - 60	Ice-contact deposit
33	-	-	~1 - 2.5	~25 - 40	Ice-contact deposit. Partially water filled
34	-	-	~1 - 3	~20 - 30	Ice-contact deposit. Old pit is still noticeable
35	-	-	~1.5 - 2.5	~35 - 55	Ice-contact deposit. Old pit is still noticeable
36	-	-	~2 - 3.5	~30 - 50	Ice-contact deposit. Old pit is still noticeable
37	-	-	~1.5 - 2.5	-	Till material
38	-	-	~1.5 - 3	~25 - 35	Ice-contact deposit. Old pit is still noticeable
39	-	-	~1.5 - 2.5	~30 - 45	Outwash deposit
Fullarton Ward					
Licenced					
Unlicenced					
40	-	-	~1 - 2.5	~15 - 30	Ice-contact deposit. Old pit is still noticeable
Township of Perth East					
Mornington Ward					
Licenced					
Unlicenced					
41	-	-	~1 - 2.5	Variable	Pit has been developed in a small esker ridge
42	-	-	~6	Variable	The height of the pit face is probably slightly exaggerated because of the natural topography
43	-	-	~6	Variable	The height of the pit face is probably slightly exaggerated because of the natural topography
Ellice Ward					
Licenced					
44	McCann Construction Inc.	101.96	-	-	Dredging operations - hard to determine depth or percent gravel
45	McCann Construction Inc.	26.50	-	-	Dredging operations - hard to determine depth or percent gravel
46	Casey Gansevles Excavating Ltd.	15.70	-	-	Pit has been essentially rehabilitated. Only a pond and stockpiles remain

Pit No.	Owner/Operator	Licenced Area (Hectares)	Face Height (Metres)	% Gravel	Remarks
Table 2 - Sand and Gravel Pits, County of Perth					
North Easthope Ward					
Licenced					
47	Floyd and Ruth Lantz	18.00	Variable, up to 20	Variable, ~40 - 60	Ice-contact deposit
48	Bell Sand Farms Inc.	53.00	Variable, up to 6	Variable, ~0 - 35	Ice-contact deposit
49	Michael Wilhelm Excavating Ltd.	46.40	Variable, 2.5 - 7	Variable, ~30 - 55	Dredging operations - hard to determine depth or percent gravel
50	Corporation of the Township of Perth East	23.70	Variable, 5.5 - 7	Variable, ~35 - 50	Dredging operations - hard to determine depth or percent gravel
Unlicenced					
51	-	-	~2.5 - 4	Variable, ~0 - 40	Ice-contact deposit
52	-	-	~5 - 6.5	Variable, ~0 - 40	Ice-contact deposit
53	-	-	Variable, up to 8	Variable, ~25 - 40	Ice-contact deposit. Partially rehabilitated
54	-	-	Variable	Variable, ~0 - 15	Ice-contact deposit
South Easthope Ward					
Licenced					
Unlicenced					
Township of Perth South and the Town of St. Marys					
Downie Ward					
Licenced					
55	The Warren Paving & Materials Group Limited	49.60	-	~30 - 60	Ice-contact deposit. Dredging operation
56	The Warren Paving & Materials Group Limited	72.10	Variable, 1.5 - 3	~30 - 60	Ice-contact deposit. Dredging operation
57	McCann Construction Inc.	55.40	Variable, 2.5 - 5	~30 - 60	Ice-contact deposit. Dredging operation
58	Kevin Allman	21.10	Variable, 1 - 3	Variable, ~30 - 50	Ice-contact deposit. Dredging operation
Unlicenced					
59	-	-	~1 - 2	Variable	Outwash deposit
60	-	-	~1.5 - 3	~30 - 50	Ice-contact deposit. Pit generally overgrown, but noticeable
61	-	-	~1.5 - 3	~30 - 50	Ice-contact deposit. Pit generally overgrown, but noticeable
62	-	-	~1.5 - 3	~30 - 50	Ice-contact deposit. Pit generally overgrown, but noticeable
63	-	-	~1.5 - 3	~30 - 50	Ice-contact deposit. Pit generally overgrown, but noticeable
64	-	-	~1.5 - 3.5	~15 - 35	Ice-contact deposit. Pit is just noticeable; appears to be partially rehabilitated

Table 2 - Sand and Gravel Pits, County of Perth

Pit No.	Owner/Operator	Licenced Area (Hectares)	Face Height (Metres)	% Gravel	Remarks
Blanshard Ward					
Licenced					
65	Murray Shier	16.20	~2 - 2.5	~30 - 50	Ice-contact deposit
66	Murray Shier	13.80	Variable, 1.5 - 4.5	~25 - 45	Outwash deposit; overgrown
67	Graham D. Ross	37.00	Variable, 1.5 - 3.5	~0 - 40	Ice-contact deposit
68	T & S Bickell Farms Ltd.	12.08	~1.5 - 4.5	~0 - 40	Ice-contact deposit
69	J. Edwin Robinson	34.20	~2 - 3	Variable	Ice-contact/outwash deposit. Till present
70	McCann Redi-Mix Inc.	9.20	~3.5 - 5	~30 - 50	Outwash deposit
71	McCann Redi-Mix Inc.	15.50	~3.5 - 5	~30 - 50	Outwash deposit
72	Margaret Toews	21.00	~3.5 - 5	~30 - 50	Outwash deposit
73	419599 Ontario Limited	11.00	-	-	Outwash deposit. Rehabilitated
74	The Warren Paving & Materials Group Limited	47.79	~3 - 8	~30 - 60	Outwash deposit
75	Jack Pickel	38.90	Variable, up to 5	~30 - 50	Outwash deposit
76	The Corporation of the Town of St. Marys	3.94	~2 - 3.5	-	Outwash deposit. Pit now being used for disposal of excess dirt and other material
77	St. Marys Cement Inc.	449.74	Variable	~30 - 45	Pit is licenced as both a pit and quarry operation. The quarry operation is the main focus of the extractive activity
Unlicenced					
78	-	-	Variable	Variable	Outwash deposit. Pit is still noticeable

Table 3 - Selected Sand and Gravel Resource Areas, County of Perth

1 Deposit No.	2 Unlicenced Area* (Hectares)	3 Cultural Setbacks** (Hectares)	4 Extracted Area*** (Hectares)	5 Possible Resource Area (Hectares)	6 Estimated Deposit Thickness (Metres)	7 Possible Aggregate Resources**** (Million Tonnes)
Municipality of North Perth						
1	6.6	1.2	0.0	5.4	4.5	0.4
Municipality of West Perth						
2†	8.9	0.0	0.0	8.9	4.5	0.7
3	13.2	3.2	0.0	10.0	4.5	0.8
4	244.3	39.1	0.0	205.2	6	21.8
5	239.1	18.9	5.3	214.9	6	22.8
Municipality of Perth East						
6	2.6	0.9	0.0	1.7	6	0.2
7‡	-	-	-	-	-	-
Municipality of Perth South						
8	12.9	1.8	0.0	11.1	6	1.2
9	34.7	10.8	0.0	23.9	6	2.5
10‡	17.3	0.0	0.0	17.3	6	1.8
11	136.1	6.8	0.0	129.3	5	11.4
12	26.7	0.8	0.6	25.3	6	2.7
TOTAL	**742.4**	**83.5**	**5.9**	**653.0**		**66.4**

Minor variations in the tables are caused by the rounding of the data.

* Excludes areas licenced under the *Aggregate Resources Act.*

** Cultural setbacks include heavily populated urban areas, roads (including a 100 m wide strip centred on each road), water features (e.g., lakes, streams), 1 ha for individual houses. NOTE: This provides a preliminary and generalized constraint application only. Additional environmental and social constraints will further reduce the deposit area.

*** Extracted area is a rough estimate of areas that are not licenced, but, due to previous extractive activity, are largely depleted.

**** Further environmental, resource, social and economic constraints will greatly reduce the selected resource quantity realistically available for potential extraction.

† Surrounding secondary area will add to the total granular resources of the area.

‡ Difficult to calculate the granular resource because the deposit is buried.

Table 4 - Total Identified Bedrock Resources, County of Perth

1 Drift Thickness (Metres)	2 Formation	3 Estimated Deposit Thickness (Metres)	4 Areal Extent (Hectares)	5 Original Tonnage (Million Tonnes)
8-15	Bass Islands	15	73.95	29.4
8-15	Bois Blanc	15	29.79	11.8
8-15	Amherstburg	15	615.38	244.5
<1	Lucas	15	2.67	1.1
1-8	Lucas	15	238.47	94.8
8-15	Lucas	15	4006.31	1591.9
<1	Dundee	15	12.07	4.8
1-8	Dundee	15	77.35	30.7
8-15	Dundee	15	2438.18	968.8
TOTAL			**7494.17**	**2977.8**

Minor variations in the tables are caused by the rounding of data.

The above figures represent a comprehensive inventory of all bedrock resources in the map area. Some of the material included in the estimate has no aggregate potential and some is unavailable for extraction due to land use restrictions.

Table 5 - Quarries, County of Perth

Quarry No.	Owner/Operator	Licenced Area (Hectares)	Face Height (Metres)	Remarks
Licenced				
1	St. Marys Cement Incorporated	449.74	Variable	The Dundee Formation, as well as the underlying Lucas Formation, are being used to manufacture cement. The property is licenced as both a pit and quarry
Unlicenced				
2	-	-	2	Old Cromarty Quarry; Dundee Formation
3	-	-	13	Old Thames Quarry; Dundee Formation. Now a swimming pool
4	-	-	Variable	Old St. Mary’s Quarry; Dundee Formation
5	-	-	2	Old St. Mary’s Quarry; Lucas Formation
6	-	-	3	Old Wildwood Lake quarry; Lucas Formation

Table 6 - Selected Bedrock Resource Areas, County of Perth

1 Area Number	2 Depth of Overburden (Metres)	3 Unlicenced Area* (Hectares)	4 Cultural Setbacks** (Hectares)	5 Extracted Area*** (Hectares)	6 Possible Resource Area (Hectares)	7 Estimated Workable Thickness (Metres)	8 Possible Bedrock Resources**** (Million Tonnes)
– There are no Selected Bedrock Resource Areas –							

Minor variations in the tables are caused by the rounding of the data.

* Excludes areas licenced under the *Aggregate Resources Act* (1989).

** Cultural setbacks include heavily populated urban areas, roads (including a 100 m wide strip centred on each road), water features (e.g., lakes, streams), 1 ha for individual houses. NOTE: This provides a preliminary and generalized constraint application only. Additional environmental and social constraints will further reduce the deposit area.

*** Extracted area is a rough estimate of areas that are not licenced, but, due to previous extractive activity, are largely depleted.

**** Further environmental, resource, social and economic constraints will greatly reduce the selected resource quantity realistically available for potential extraction.

Table 7 - Summary of Borehole Data, County of Perth

Borehole or Reference Number *	Generalized Description of Material
Geocres 01	*UTM: 471049m E 4789842m N, NAD83, Zone 17* *Elevation: not available* ~2.0′ (0.61 m) of organic, clayey silt ~11.0′ (3.35 m) of grey-brown, gravelly, clayey silt till ~7.0′ (2.14 m) of cobble, boulder material
Geocres 02	*UTM: 480768m E 4785342m N, NAD83, Zone 17* *Elevation: not available* ~8.5′ (2.59 m) of silty sand till ~3.5′ (1.07 m) of clayey silt with minor sand ~8.0′ (2.44 m) of silty sand till **At ~20′ (6.10 m) hit bedrock**
Geocres 03	*UTM: 489143m E 4786475m N, NAD83, Zone 17* *Elevation: ~1068.8′ (325.8 m)* ~2.0′ (0.61 m) of topsoil ~14.0′ (4.27 m) of dense, grey silt till ~3.5′ (1.07 m) silt with occasional fine gravel layers ~13.5′ (4.11 m) of till ~2.0′ (0.61 m) of silty sand with minor gravel
Geocres 04	*UTM: 484850m E 4812296m N, NAD83, Zone 17* *Elevation: not available* ~15.6′ (4.75 m) of clay till

Table 7 - Summary of Borehole Data, County of Perth	
Borehole or Reference Number *	**Generalized Description of Material**
Geocres 05	*UTM: 483612m E 4812548m N, NAD83, Zone 17* *Elevation: ~1139.9′ (347.4 m)* ~10.9′ (3.32 m) of brown, silty clay till ~15.5′ (4.72 m) of grey, silty clay till with minor sand layers ~13.6′ (4.15 m) of hard, grey, silty clay till with boulders
Geocres 06	*UTM: 495836m E 4800703m N, NAD83, Zone 17* *Elevation: ~1115.4′ (339.9 m)* ~16.5′ (5.03 m) of well-graded, silty sand and gravel ~3.5′ (1.07 m) of sandy silt till
Geocres 07	*UTM: 475670m E 4814929m N, NAD83, Zone 17* *Elevation: not available* ~4.0′ (1.22 m) of silty sand ~69.0′ (21.03 m) of silty clay to clayey silt till ~3.7′ (1.13 m) of sandy silt with minor gravel **At ~76.7′ (23.38 m) hit bedrock**
Geocres 08	*UTM: 484370m E 4814993m N, NAD83, Zone 17* *Elevation: ~1110.6′ (338.5 m)* ~8.0′ (2.44 m) of dark brown, clayey silt till fill ~3.5′ (1.07 m) of hard, grey silty clay ~0.5′ (0.15 m) of sand ~14.1′ (4.30 m) of grey, sandy clayey silt till
Geocres 09	*UTM: 469523m E 4809548m N, NAD83, Zone 17* *Elevation: not available* ~53.0′ (16.15 m) of clayey silt till with minor sand and trace gravel
Geocres 10	*UTM: 483892m E 4812877m N, NAD83, Zone 17* *Elevation: ~1105.3′ (336.9 m)* ~12.0′ (3.66 m) of brown, silty clay with minor gravel ~8.0′ (2.44 m) of compact, brown, fine sand with trace silt ~8.0′ (2.44 m) of dense, brown silty sand till ~6.0′ (1.83 m) of brown, fine to medium sand ~2.0′ (0.61 m) hard, grey clayey silt till
Geocres 11	*UTM: 495381m E 4805823m N, NAD83, Zone 17* *Elevation: ~1157.8′ (352.9 m)* ~1.2′ (0.37 m) of silty clay till ~0.9′ (0.27 m) of sandy gravel with some silt and trace clay ~10.5′ (3.20 m) of silty clay till
Geocres 12	*UTM: 487971m E 4810397m N, NAD83, Zone 17* *Elevation: ~1144.4′ (348.8 m)* ~1.3′ (0.40 m) of sand with some gravel (fill) ~1.6′ (0.49 m) of silty clay ~5.8′ (1.77 m) of hard, clayey silt till ~5.3′ (1.62 m) of very dense till

Table 7 - Summary of Borehole Data, County of Perth

Borehole or Reference Number *	Generalized Description of Material
Geocres 13	*UTM: 506709m E 4801935m N, NAD83, Zone 17* *Elevation: ~1178.5′ (359.2 m)* ~28.0′ (8.53 m) of very loose, black peat ~6.0′ (1.83 m) of soft, grey organic-rich clayey silt ~8.0′ (2.44 m) of compact, sandy silt to silt
Geocres 14	*UTM: 502987m E 4802722m N, NAD83, Zone 17* *Elevation: not available* ~9.2′ (2.80 m) of alluvium ~12.8′ (3.90 m) of silty sand till ~3.0′ (0.91 m) of sandy silt
Geocres 15	*UTM: 516582m E 4812770m N, NAD83, Zone 17* *Elevation: not available* ~10.5′ (3.20 m) of dark brown sandy silt with trace ~1.5′ (0.46 m) of gravel seam ~19.0′ (5.79 m) of stiff, grey clay with silt seams ~10.0′ (3.05 m) of brown, gravelly silt till
Geocres 16	*UTM: 501532m E 4791589m N, NAD83, Zone 17* *Elevation: not available* ~1.5′ (0.46 m) of gravel fill ~3.5′ (1.07 m) of sand and silty clay fill ~1.5′ (0.46 m) of loose, grey organic silt ~2.0′ (0.61 m) of grey, organic fine sand ~5.0′ (1.52 m) of gravel cobbles in sandy silt ~13.0′ (3.96 m) of dense silty sand till
Geocres 17	*UTM: 504928m E 4843802m N, NAD83, Zone 17* *Elevation: ~1281.5′ (390.6 m)* ~6.0′ (1.83 m) of loose, brown silty sand/sandy silt ~9.0′ (2.74 m) of silty sand till ~15.5′ (4.72 m) of dense, grey silty fine sand ~5.0′ (1.52 m) of coarse sandy gravel
Geocres 18	*UTM: 508996m E 4820989m N, NAD83, Zone 17* *Elevation: ~1193.7′ (363.8 m)* ~2.0′ (0.61 m) of organic topsoil ~7.0′ (2.13 m) of dense, brown till ~1.0′ (0.30 m) of hard, brown silty clay ~25.0′ (7.62 m) of grey sandy silt till
Geocres 19	*UTM: 507519m E 4843057m N, NAD83, Zone 17* *Elevation: ~1274.0′ (388.3 m)* ~1.5′ (0.45 m) of ballast ~8.5′ (2.59 m) of loose, brown silty sand fill ~9.5′ (2.90 m) of still, grey clayey silt till ~2.0′ (0.61 m) of compact, grey silty fine sand
Geocres 20	*UTM: 514316m E 4835999m N, NAD83, Zone 17* *Elevation: ~1303.0′ (397.2 m)* ~7.0′ (2.13 m) of gravelly fill ~33.0′ (10.06 m) of clayey silt till ~1.5′ (0.45 m) of silty sand and gravel

Table 7 - Summary of Borehole Data, County of Perth

Borehole or Reference Number *	Generalized Description of Material
Geocres 21	*UTM: 502218m E 4841571m N, NAD83, Zone 17* *Elevation: ~1225.3′ (375.5 m)* ~4.0′ (1.22 m) of loose, sandy silty topsoil ~31.2′ (9.51 m) of stiff, dark brown silty clay till ~5.8′ (1.77 m) of dense, light grey clayey silt till
Geocres 22	*UTM: 503092m E 4825441m N, NAD83, Zone 17* *Elevation: not available* ~4.0′ (1.22 m) of topsoil ~7.5′ (2.29 m) of black peat ~4.5′ (1.37 m) of grey, organic silt ~9.5′ (2.90 m) of clayey silt/silty clay till
Geocres 23	*UTM: 489865m E 4818909m N, NAD83, Zone 17* *Elevation: not available* ~1.0′ (0.30 m) of granular fill ~6.0′ (1.83 m) of clayey, sandy silt till ~21.0′ (6.40 m) of dense, hard, sandy clayey silt till
Geocres 24	*UTM: 484145m E 4824810m N, NAD83, Zone 17* *Elevation: not available* ~2.4′ (0.73 m) of soft, brown silty clay ~6.3′ (1.92 m) of firm, stiff, brown silty clay ~1.6′ (0.49 m) of brown medium sand ~9.7′ (2.96 m) of dense, grey silt till
Geocres 25	*UTM: 485181m E 4819341m N, NAD83, Zone 17* *Elevation: ~1123.9′ (342.6 m)* ~4.0′ (1.22 m) of brown, clayey silt ~4.0′ (1.22 m) of hard, brown, clayey silt till ~12.5′ (3.81 m) of hard, grey silty clay till
Geocres 26	*UTM: 487177m E 4817986m N, NAD83, Zone 17* *Elevation: ~1136.0′ (346.3 m)* ~11.0′ (3.35 m) of sand and gravel fill ~25.5′ (7.77 m) of clayey silt till with occasional thin silt layers and occasional boulders
Geocres 27	*UTM: 495929m E 4830508m N, NAD83, Zone 17* *Elevation: ~1178.4′ (359.2 m)* ~4.5′ (1.37 m) of loose, light brown gravelly sand fill ~7.5′ (2.29 m) of soft, sandy silt clay fill ~1.0′ (0.30 m) of firm sandy silt clay ~11.5′ (3.51 m) of compact, grey silty clay till ~32.0′ (9.75 m) of stiff, grey-brown clayey silt till
Geocres 28	*UTM: 497434m E 4829274m N, NAD83, Zone 17* *Elevation: not available* ~1.0′ (0.30 m) of gravel ~4.5′ (1.37 m) of brown sand fill ~2.5′ (0.76 m) of loose, brown sandy silt ~13.5′ (4.11 m) of hard, grey silty clay till

Table 7 - Summary of Borehole Data, County of Perth

Borehole or Reference Number *	Generalized Description of Material
Geocres 29	*UTM: 474334m E 4816651m N, NAD83, Zone 17* *Elevation: ~1069.7′ (326.0 m)* ~2.5′ (0.76 m) of sand and gravel ~12.0′ (3.66 m) of stiff, silty clay to clayey silt till ~2.5′ (0.76 m) of compact, silty fine sand ~14.0′ (4.27 m) of stiff, grey, sandy silty clay till
Geocres 30	*UTM: 498483m E 4848141m N, NAD83, Zone 17* *Elevation: ~1189.4′ (362.5 m)* ~14.5′ (4.42 m) of sandy silt with minor gravel ~7.5′ (2.29 m) of till ~8.5′ (2.59 m) of fine to medium sand with trace silt and gravel ~4.8′ (1.46 m) of hard, grey silty clay
Geocres 31	*UTM: 508650m E 4850565m N, NAD83, Zone 17* *Elevation: ~1262.0′ (384.7 m)* ~28.0′ (8.53 m) of silty sand/sandy silt ~2.0′ (0.61 m) of till

*** Source:** Geotechnical studies completed for the Ministry of Transportation of Ontario (MTO) and provided to OGS staff.

Table 8 - Summary of Geophysical Data, County of Perth

— NONE —

Table 9 - Results of Aggregate Quality Tests, County of Perth

Sample Information	COARSE AGGREGATE								FINE AGGREGATE
	Petrographic Number		$MgSO_4$ (%)	Micro-Deval Abrasion (% Loss)	Los Angeles Abrasion Test (% Loss)	Freeze–Thaw (% Loss)	Absorption (%)	Bulk Relative Density	$MgSO_4$ (%)
	Granular and 16 mm	Hot Mix and Concrete							
Generally Acceptable Values:		*125–140*	*<12–15%*	*<14–17%*	*<35–45%*	*<6%*	*<2%*	*>2.5*	*<25%*
Municipality of North Perth									
Wallace Ward									
North-central secondary deposits									
Sand and gravel	100.0	169.6	5.8	-	22.8	-	1.960	2.632	6.8
Sand and gravel	100.7	170.5	9.5	-	-	-	2.540	2.560	6.6
Sand and gravel	105.6	217.0	10.4	-	22.3	-	2.570	2.586	9.6
Sand and gravel	100.0	196.9	16.3	-	-	-	2.680	2.520	6.7
Sand and gravel	101.7	202.3	15.7	-	-	-	-	-	13.8
Sand and gravel	-	-	-	-	-	-	-	-	5.7
Eastern secondary deposits									
Sand and gravel	160.5	220.8	11.9	-	23.2	-	2.640	2.528	8.0
Sand and gravel	102.6	217.3	10.7	-	-	-	2.640	2.561	7.2
Sand and gravel	102.1	144.3	13.5	-	-	-	2.300	2.590	12.4
Southwestern secondary deposits									
Sand and gravel	121.6	167.5	9.4	-	25.8	-	2.950	2.540	4.6
Sand and gravel	102.8	154.7	16.7	-	-	-	2.810	2.560	12.0
Elma Ward									
Northwestern secondary deposits									
Sand and gravel	105.2	243.8	-	-	-	-	-	-	-
Sand and gravel	103.6	223.1	-	-	-	-	-	-	-
Sand and gravel	132.6	345.7	11.2	-	28.2	-	3.250	2.500	8.5
Sand and gravel	134.5	237.4	15.7	-	-	-	-	-	12.9
Sand and gravel	110.7	249.4	13.3	-	-	-	4.470	2.410	9.6
Newry Esker									
Sand and gravel	101.7	146.9	12.1	-	-	-	2.610	2.580	13.2
Eastern deposits									
Sand and gravel	-	-	-	-	-	-	-	-	20.8
Municipality of West Perth									
Logan Ward									
Selected Sand and Gravel Resource Area 2									
Sand and gravel	163.3	208.2	11.9	-	-	-	1.770	2.600	10.6
Sand and gravel	-	-	-	-	-	-	-	-	8.9
Sand and gravel	-	-	-	-	-	-	-	-	-
Sand and gravel	-	-	-	-	-	-	-	-	13.0

Table 9 - Results of Aggregate Quality Tests, County of Perth

	COARSE AGGREGATE								FINE AGGREGATE
	Petrographic Number								
Sample Information	Granular and 16 mm	Hot Mix and Concrete	$MgSO_4$ (%)	Micro-Deval Abrasion (% Loss)	Los Angeles Abrasion Test (% Loss)	Freeze–Thaw (% Loss)	Absorption (%)	Bulk Relative Density	$MgSO_4$ (%)
Generally Acceptable Values:		*125–140*	*<12–15%*	*<14–17%*	*<35–45%*	*<6%*	*<2%*	*>2.5*	*<25%*
Sand and gravel	105.1	135.6	3.3	-	-	-	-	-	15.8
Sand and gravel	100.0	119.3	2.1	-	-	-	1.210	2.630	8.1
Sand and gravel	106.8	140.9	3.1	-	22.1	-	1.400	2.625	10.7
Sand and gravel	100.7	130.0	5.0	-	-	-	1.200	2.620	6.6
Sand and gravel	103.5	117.2	4.0	-	22.6	-	1.550	2.620	6.2
Sand and gravel	104.3	125.4	-	-	-	-	-	-	9.6
Sand and gravel	100.0	121.7	2.6	-	-	-	1.030	2.640	11.4
Sand and gravel	104.1	138.8	7.1	-	-	-	1.430	2.640	12.0
Sand and gravel	119.2	150.9	2.3	-	21.2	-	1.200	2.635	6.6
Sand and gravel	118.2	140.0	2.9	-	23.9	-	1.470	2.621	11.0
Sand and gravel	101.0	136.7	4.0	-	-	-	1.100	2.620	6.3
Sand and gravel	117.0	192.0	-	-	-	-	-	-	-
South-central secondary deposits									
Sand and gravel	121.5	148.1	-	-	22.3	-	-	-	-
Sand and gravel	125.4	184.4	8.4	-	27.6	-	1.860	2.569	18.0
Hibbert Ward									
Selected Sand and Gravel Resource Area 4									
Sand and gravel	110.0	117.0	6.2	-	22.5	-	1.040	2.700	12.7
Sand and gravel	107.6	150.0	5.2	-	-	-	1.690	2.590	7.9
Sand and gravel	100.0	114.8	3.8	-	-	-	-	-	11.5
Sand and gravel	102.4	121.3	5.8	-	-	-	1.740	2.600	9.9
Selected Sand and Gravel Resource Area 5									
Sand and gravel	114.3	136.8	3.5	-	23.0	-	1.500	2.610	-
Sand and gravel	100.0	133.9	1.8	-	-	-	1.500	2.600	11.4
Sand and gravel	100.0	108.3	2.1	-	-	-	1.330	2.620	11.6
Sand and gravel	101.1	119.4	3.6	-	23.4	-	1.170	2.642	11.6
Sand and gravel	102.0	128.8	-	-	-	-	1.900	2.560	16.7
Sand and gravel	101.6	130.2	3.5	-	-	-	1.580	2.600	9.9
Sand and gravel	107.7	123.1	5.3	-	-	-	1.540	2.610	6.7
Sand and gravel	116.5	152.5	9.3	-	-	-	1.980	2.510	15.3
Sand and gravel	100.0	116.0	-	-	-	-	-	-	11.0
Sand and gravel	139.0	162.2	6.8	-	-	-	1.780	2.590	10.9
Sand and gravel	100.0	114.2	3.3	-	-	-	1.350	2.600	8.5
Northeastern secondary deposits									
Sand and gravel	146.4	183.2	-	-	-	-	-	-	-
Sand and gravel	-	135.2	3.7	-	24.5	-	1.680	2.600	-

Table 9 - Results of Aggregate Quality Tests, County of Perth

Sample Information	Petrographic Number: Granular and 16 mm	Petrographic Number: Hot Mix and Concrete	Coarse Aggregate: $MgSO_4$ (%)	Coarse Aggregate: Micro-Deval Abrasion (% Loss)	Coarse Aggregate: Los Angeles Abrasion Test (% Loss)	Coarse Aggregate: Freeze–Thaw (% Loss)	Coarse Aggregate: Absorption (%)	Coarse Aggregate: Bulk Relative Density	Fine Aggregate: $MgSO_4$ (%)
Generally Acceptable Values:		*125–140*	*<12–15%*	*<14–17%*	*<35–45%*	*<6%*	*<2%*	*>2.5*	*<25%*
Southwestern secondary deposits									
Sand and gravel	116.4	137.6	6.4	-	-	-	1.860	2.570	10.2
Sand and gravel	103.9	140.2	6.7	-	-	-	1.700	2.590	11.6
Sand and gravel	-	-	-	-	-	-	-	-	7.9
Township of Perth East									
Mornington Ward									
Sand and gravel	100.0	162.9	7.4	-	-	-	2.010	2.610	7.8
Ellice Ward									
Selected Sand and Gravel Resource Area 7									
Sand and gravel	-	162.3	-	-	-	-	2.370	-	10.6
Sand and gravel	100.0	161.8	7.5	-	-	-	2.300	2.570	15.2
Sand and gravel	101.6	191.6	3.2	-	-	-	2.100	2.570	11.9
Sand and gravel	153.6	196.9	-	-	-	-	-	-	8.8
Sand and gravel	104.6	201.0	4.7	-	-	-	1.730	2.600	15.6
Sand and gravel	-	129.5	-	-	-	-	-	-	-
Sand and gravel	100.0	144.3	3.3	-	-	-	1.430	2.630	8.9
North Easthope Ward									
Secondary deposits									
Sand and gravel	101.4	146.5	6.0	-	22.7	-	1.670	2.622	11.2
Sand and gravel	101.9	141.6	7.8	-	23.6	-	2.030	2.466	8.6
Sand and gravel	122.1	166.2	16.1	-	-	-	2.450	2.580	11.7
Sand and gravel	100.0	120.8	2.5	-	-	-	0.960	2.700	9.5
Sand and gravel	117.4	148.4	-	-	-	-	-	-	11.8
Sand and gravel	183.2	211.1	-	-	-	-	-	-	6.3
Sand and gravel	133.8	191.6	6.6	-	-	-	1.110	2.670	8.5
Sand and gravel	100.0	131.0	6.0	-	-	-	1.470	2.630	7.2
Sand and gravel	100.0	147.9	7.0	-	22.0	-	1.370	2.660	8.5
Sand and gravel	120.6	175.1	9.4	-	-	-	2.800	2.530	8.5
Sand and gravel	164.4	277.0	16.3	-	-	-	-	-	-
Sand and gravel	101.6	125.3	2.4	-	-	-	1.570	2.630	7.1
Sand and gravel	102.1	179.3	12.7	-	-	-	2.050	2.580	6.3
Township of Perth South									
Downie Ward									
Selected Sand and Gravel Resource Area 10									
Sand and gravel	-	143.5	4.4	-	-	-	-	-	10.1
Sand and gravel	-	163.0	-	-	-	-	-	-	-

Table 9 - Results of Aggregate Quality Tests, County of Perth

Sample Information	COARSE AGGREGATE: Petrographic Number: Granular and 16 mm	Petrographic Number: Hot Mix and Concrete	$MgSO_4$ (%)	Micro-Deval Abrasion (% Loss)	Los Angeles Abrasion Test (% Loss)	Freeze–Thaw (% Loss)	Absorption (%)	Bulk Relative Density	FINE AGGREGATE: $MgSO_4$ (%)
Generally Acceptable Values:		*125–140*	*<12–15%*	*<14–17%*	*<35–45%*	*<6%*	*<2%*	*>2.5*	*<25%*
Sand and gravel	116.7	151.9	5.5	-	26.2	-	1.970	2.590	14.5
Sand and gravel	100.0	133.9	3.2	-	-	-	1.370	2.650	10.7
Sand and gravel	108.5	167.3	3.6	-	-	-	1.370	2.610	6.3
Sand and gravel	118.9	151.0	4.7	-	28.0	-	-	-	14.1
Sand and gravel	100.0	121.0	3.8	-	-	-	1.030	2.660	9.5
Sand and gravel	102.7	130.0	2.4	-	-	-	1.540	2.620	10.2
Selected Sand and Gravel Resource Area 11									
Sand and gravel	100.0	145.6	2.7	-	-	-	1.200	2.630	7.1
Sand and gravel	-	133.4	4.9	-	-	-	-	-	5.5
Sand and gravel	100.0	132.1	2.8	-	-	-	1.070	2.660	6.9
Sand and gravel	-	119.7	5.3	-	22.2	-	1.640	-	6.0
Sand and gravel	-	124.2	-	-	-	-	-	-	-
Sand and gravel	-	118.5	-	-	-	-	1.400	3.100	9.5
Sand and gravel	-	107.4	-	-	22.0	-	1.070	2.600	7.3
Sand and gravel	-	123.5	-	-	-	-	-	-	9.4
Southwestern secondary deposits									
Sand and gravel	-	123.2	2.4	-	-	-	1.440	-	13.0
Sand and gravel	-	130.9	-	-	27.0	-	-	2.680	-
Bedrock Results									
Bass Islands Fm **	120.2	145.7	1.0	-	31.0	-	2.836	2.595	-
Lucas Fm **	153.6	243.4	-	24.6	44.5	-	5.152	2.401	-
Dundee Fm	-	123.0	2.6	14.8	-	6.0	1.000	2.639	-

Note - The quality test data refer strictly to a specific sample. Because of the inherent variability of sand and gravel deposits, care should be exercised in extrapolating such information to the rest of the deposit, particularly where some of the deposits may be quite large.

** Samples collected as part of the aggregate resources inventory for the County of Bruce.

Table 10 – Till Analysis – Physical Properties, County of Perth

Till Unit [Source*]	Texture			Pebble Lithology							Carbonates				Heavy Minerals	
	Clay (%)	Silt (%)	Sand (%)	Limestone (%)	Dolostone (%)	Chert (%)	Sandstone (%)	Siltstone (%)	Shale (%)	Precambrian Clasts (%)	Calcite (%)	Dolomite (%)	Total (%)	Cal/Dol (ratio)	Total (%)	Magnetics (%)
Canning Till																
[3]	23	54	23	-	-	-	-	-	-	-	-	-	36.0	1.8	6.0	-
[3]	17	61	22	-	-	-	-	-	-	-	-	-	37.0	2.1	8.0	-
[3]	23	54	23	13	67	3	3	-	-	14	-	-	-	-	5.3	-
[3]	19	49	32	20	61	11	-	-	-	8	-	-	44.0	0.8	6.0	-
[3]	30	50	20	-	-	-	-	-	-	-	-	-	37.0	1.4	4.7	-
[3]	29	50	21	-	-	-	-	-	-	-	-	-	32.0	1.0	4.3	-
[3]	19	54	27	-	-	-	-	-	-	-	-	-	39.0	0.6	-	-
[3]	21	53	26	-	-	-	-	-	-	-	-	-	40.0	0.7	-	-
[3]	25	55	20	-	-	-	-	-	-	-	-	-	40.0	0.3	-	-
[3]	30	55	15	-	-	-	-	-	-	-	-	-	28.0	1.0	-	-
	23.6	**53.5**	**22.9**													
Catfish Creek Till																
[1]	14	48	38	25	59	-	4	-	-	12	11.1	40.7	51.8	0.3	1.1	5.4
[1]	10	53	37	11	77	-	-	-	-	12	13.7	46.8	60.5	0.3	2.0	6.1
[1]	21	50	29	14	79	-	-	-	-	6	15.4	40.5	55.9	0.4	2.3	6.1
[1]	19	49	33	14	82	-	-	-	-	4	16.3	41.7	58.0	0.4	2.4	7.6
[1]	13	49	38	18	73	-	-	-	-	9	16.5	38.8	55.3	0.4	1.7	8.6
[1]	10	41	49	15	69	-	-	-	-	16	19.2	42.9	62.1	0.4	1.6	10.6
[1]	16	46	38	9	84	2	-	-	-	6	14.5	40.0	54.5	0.4	2.4	4.8
[1]	12	49	39	17	74	-	-	-	-	9	16.8	35.6	52.4	0.5	3.1	6.5
[1]	12	44	44	13	71	2	-	-	-	12	15.5	47.6	63.1	0.3	1.4	10.6
[1]	14	56	30	13	82	-	-	-	-	5	18.7	38.5	57.2	0.5	1.6	9.5
[3]	11	38	51	-	-	-	-	-	-	-	-	-	51.0	0.5	-	-
[3]	12	58	30	-	-	-	-	-	-	-	-	-	36.0	0.6	-	-
[3]	13	45	42	-	-	-	-	-	-	-	-	-	45.0	0.6	2.77	-
[3]	7	47	46	-	-	-	-	-	-	-	-	-	43.0	0.6	4.86	-
[3]	12	37	51	-	-	-	-	-	-	-	-	-	46.0	0.9	4.85	-
[3]	13	50	37	-	-	-	-	-	-	-	-	-	45.0	0.6	4.69	-
[3]	7	41	52	-	-	-	-	-	-	-	-	-	46.0	0.5	5.26	-
[3]	12	54	34	-	-	-	-	-	-	-	-	-	47.0	0.5	5.61	-
[3]	7	45	48	-	-	-	-	-	-	-	-	-	39.0	0.5	5.33	-
[3]	9	47	44	-	-	-	-	-	-	-	-	-	51.0	0.5	-	-
	12.2	**47.4**	**40.5**										**51.0**	**0.5**		
Stirton Till																
[1]	40	47	13	-	-	-	-	-	-	-	16.7	30.0	46.7	0.6	3.5	7.7
[1]	30	57	13	-	-	-	-	-	-	-	18.1	41.4	59.5	0.4	2.5	8.6
[1]	47	51	2	-	-	-	-	-	-	-	23.9	30.0	53.9	0.8	2.6	10.9
[1]	33	59	8	-	-	-	-	-	-	-	22.8	24.8	47.6	0.9	3.5	10.3

Table 10 – Till Analysis – Physical Properties, County of Perth

Till Unit [Source*]	Texture			Pebble Lithology							Carbonates				Heavy Minerals	
	Clay (%)	Silt (%)	Sand (%)	Limestone (%)	Dolostone (%)	Chert (%)	Sandstone (%)	Siltstone (%)	Shale (%)	Precambrian Clasts (%)	Calcite (%)	Dolomite (%)	Total (%)	Cal/Dol (ratio)	Total (%)	Magnetics (%)
[1]	46	45	9	8	87	-	-	-	-	5	23.2	20.7	43.9	1.12	2.9	6.8
[1]	45	53	2	-	-	-	-	-	-	-	20.7	20.4	41.1	1.0	3.4	5.8
[1]	30	60	10	-	-	-	-	-	-	-	23.7	24.7	48.4	1.0	3.4	6.3
[3]	51	43	6	-	-	-	-	-	-	-	-	-	37.0	1.3	5.78	-
[3]	50	38	12	-	-	-	-	-	-	-	-	-	33.0	3.3	-	-
[3]	67	26	7	-	-	-	-	-	-	-	-	-	29.0	1.8	-	-
[3]	48	37	15	-	-	-	-	-	-	-	-	-	36.0	1.4	-	-
[3]	49	42	9	-	-	-	-	-	-	-	-	-	35.0	2.1	-	-
[3]	36	49	15	-	-	-	-	-	-	-	-	-	35.0	1.4	-	-
[3]	54	36	10	-	-	-	-	-	-	-	-	-	32.0	3.0	-	-
	44.7	**45.9**	**9.4**										**41.3**	**1.4**		
Tavistock Till																
[1]	31	47	22	30	58	-	1	-	2	9	16.4	23.2	39.6	0.7	2.7	7.8
[1]	47	43	10	13	80	-	-	1	-	6	18.2	27.5	45.7	0.7	2.2	10.0
[1]	25	50	25	11	84	1	-	-	-	4	10.5	34.6	45.1	0.3	1.9	6.8
[1]	24	51	25	12	82	-	-	-	-	6	13.4	34.2	47.6	0.4	2.3	7.3
[1]	37	48	15	17	73	1	-	-	-	9	17.9	27.9	45.8	0.6	1.8	4.1
[1]	34	58	8	19	64	1	7	-	-	10	21.0	16.5	37.5	1.3	2.8	8.9
[1]	36	43	21	17	73	2	1	-	-	6	16.6	30.0	46.6	0.6	2.4	4.0
[1]	36	44	20	33	56	-	-	-	-	11	18.8	18.4	37.2	1.0	2.8	4.8
[1]	34	52	14	11	77	-	-	1	-	11	17.0	23.5	40.5	0.7	2.0	8.8
[3]	23	50	27	-	-	-	-	-	-	-	-	-	33.0	1.4	5.79	-
[3]	18	50	32	-	-	-	-	-	-	-	-	-	26.0	1.5	-	-
[3]	8	52	40	-	-	-	-	-	-	-	-	-	35.0	0.7	4.78	-
[3]	18	56	26	-	-	-	-	-	-	-	-	-	42.0	1.1	-	-
[3]	24	46	30	32	32	10	9	-	-	17	-	-	30.0	1.6	-	-
[3]	21	50	29	-	-	-	-	-	-	-	-	-	30.0	0.6	-	-
[3]	22	45	33	-	-	-	-	-	-	-	-	-	39.0	1.7	7.03	-
[3]	28	56	16	-	-	-	-	-	-	-	-	-	36.0	1.3	-	-
[3]	43	43	14	-	-	-	-	-	-	-	-	-	37.0	1.8	-	-
[3]	29	49	22	-	-	-	-	-	-	-	-	-	35.0	1.6	4.01	-
	28.3	**49.1**	**22.6**										**38.3**	**1.0**		
Mornington Till																
[3]	62	34	4	-	-	-	-	-	-	-	-	-	39.0	1.7	3.00	-
[3]	51	44	5	-	-	-	-	-	-	-	-	-	35.0	3.0	3.78	-
[3]	52	43	5	-	-	-	-	-	-	-	-	-	35.0	2.6	3.66	-
[3]	46	45	9	44	30	4	7	-	-	15	-	-	41.0	1.7	4.61	-
[3]	39	44	17	51	33	3	1	-	-	12	-	-	39.0	1.8	3.97	-
[3]	36	51	13	49	37	2	-	-	-	12	-	-	37.0	1.4	4.16	-
[3]	48	38	14	-	-	-	-	-	-	-	-	-	32.0	2.4	4.51	-

Table 10 – Till Analysis – Physical Properties, County of Perth

Till Unit [Source*]	Texture			Pebble Lithology							Carbonates				Heavy Minerals	
	Clay (%)	Silt (%)	Sand (%)	Limestone (%)	Dolostone (%)	Chert (%)	Sandstone (%)	Siltstone (%)	Shale (%)	Precambrian Clasts (%)	Calcite (%)	Dolomite (%)	Total (%)	Cal/Dol (ratio)	Total (%)	Magnetics (%)
[3]	47	45	8	-	-	-	-	-	-	-	-	-	32.0	2.2	5.93	-
[3]	46	43	11	-	-	-	-	-	-	-	-	-	26.0	1.7	-	-
[3]	52	37	11	-	-	-	-	-	-	-	-	-	36.0	1.1	-	-
	47.9	**42.4**	**9.7**										**35.2**	**2.0**		
Stratford Till																
[3]	17	55	28	41	46	3	4	-	-	6	-	-	44.0	1.0	4.88	-
[3]	25	50	25	52	33	3	1	-	-	11	-	-	40.0	1.5	-	-
[3]	16	54	30	-	-	-	-	-	-	-	-	-	42.0	1.0	4.07	-
[3]	15	47	38	-	-	-	-	-	-	-	-	-	49.0	0.9	2.85	-
[3]	12	49	39	-	-	-	-	-	-	-	-	-	36.0	1.0	3.57	-
[3]	14	59	27	-	-	-	-	-	-	-	-	-	32.0	1.5	6.29	-
[3]	14	52	34	-	-	-	-	-	-	-	-	-	51.0	1.0	-	-
[3]	16	56	28	-	-	-	-	-	-	-	-	-	40.0	1.1	-	-
[3]	20	39	41	-	-	-	-	-	-	-	-	-	55.0	1.9	-	-
[3]	11	40	49	-	-	-	-	-	-	-	-	-	48.0	0.8	-	-
	16.0	**50.1**	**33.9**										**43.7**	**1.2**		
Wartburg Till																
[3]	42	45	13	-	-	-	-	-	-	-	-	-	48.0	0.9	4.18	-
[3]	51	39	10	-	-	-	-	-	-	-	-	-	43.0	1.2	-	-
[3]	56	43	1	-	-	-	-	-	-	-	-	-	33.0	3.9	4.90	-
[3]	**49.7**	**42.3**	**8.0**										**41.3**	**2.0**		
Elma Till																
[1]	26	58	16	8	73	10	2	-	-	7	13.7	32.7	46.4	0.4	2.2	7.6
[1]	22	57	21	8	77	2	3	2	2	6	10.6	38.8	49.4	0.3	1.5	6.0
[1]	30	56	14	15	78	-	1	5	-	1	16.1	28.9	45.0	0.6	2.0	3.4
[1]	27	58	15	7	85	-	-	-	-	8	9.6	34.6	44.2	0.3	3.8	3.8
[2]	11	43	46	-	-	-	-	-	-	-	19.0	41.1	60.1	0.5	13.3	31.0
[2]	11	54	35	40	51	3	-	1	-	4	17.4	58.9	76.3	0.3	2.7	8.9
[2]	12	52	36	34	55	2	-	1	-	8	18.0	43.6	61.6	0.4	2.3	10.5
[2]	9	56	35	-	-	-	-	-	-	-	14.7	41.7	56.4	0.4	2.4	10.2
[2]	10	46	44	50	41	3	-	1	1	4	25.3	42.5	67.8	0.6	2.6	10.4
[2]	8	51	41	26	48	10	1	3	-	12	14.7	40.9	55.6	0.4	3.2	9.1
[2]	6	45	49	16	61	7	2	5	1	8	9.8	43.6	53.4	0.2	3.0	10.1
[2]	7	52	41	23	51	9	3	8	-	6	10.2	44.8	55.0	0.2	2.8	10.9
[2]	12	58	30	15	69	-	1	6	-	8	3.9	45.7	49.6	0.1	3.9	16.5
[2]	9	53	38	16	72	3	4	1	-	4	16.4	40.6	57.0	0.4	2.5	10.4
[3]	21	57	22	-	-	-	-	-	-	-	-	-	50.0	0.6	3.3	-
[3]	25	49	26	-	-	-	-	-	-	-	-	-	40.0	0.6	-	-
[3]	16	54	30	-	-	-	-	-	-	-	-	-	48.0	0.7	-	-
[3]	24	50	26	-	-	-	-	-	-	-	-	-	46.0	0.6	-	-

Table 10 – Till Analysis – Physical Properties, County of Perth

Till Unit [Source*]	Texture			Pebble Lithology							Carbonates				Heavy Minerals	
	Clay (%)	Silt (%)	Sand (%)	Limestone (%)	Dolostone (%)	Chert (%)	Sandstone (%)	Siltstone (%)	Shale (%)	Precambrian Clasts (%)	Calcite (%)	Dolomite (%)	Total (%)	Cal/Dol (ratio)	Total (%)	Magnetics (%)
[3]	35	45	20	-	-	-	-	-	-	-	-	-	42.0	0.9	-	-
[3]	39	42	19	-	-	-	-	-	-	-	-	-	45.0	0.7	-	-
[3]	10	65	25	-	-	-	-	-	-	-	-	-	50.0	0.3	-	-
[4]	15	58	27	80	10	2	-	-	-	8	-	-	63.8	0.8	2.5	9.5
[4]	22	51	27	74	11	3	-	-	-	12	-	-	55.0	0.9	2.5	12.8
[4]	13	56	31	90	8	1	-	-	-	1	-	-	67.5	1.1	1.8	7.1
[4]	8	56	36	59	23	2	2	-	-	14	-	-	56.2	0.4	2.9	12.7
[4]	15	47	38	76	12	6	3	-	-	3	-	-	53.2	0.5	3.0	11.3
[4]	13	55	32	81	14	2	1	-	-	2	-	-	73.2	0.3	2.0	11.8
[3]	21	45	34	-	-	-	-	-	-	-	-	-	37.0	0.1	-	-
[3]	14	48	38	-	-	-	-	-	-	-	-	-	57.0	0.3	3.4	-
[3]	13	66	21	-	-	-	-	-	-	-	-	-	47.0	0.3	-	-
	16.8	**52.8**	**30.4**										**53.6**	**0.5**		
Rannoch Till																
[2]	11	49	40	38	56	-	1	-	-	5	12.3	47.3	59.6	0.3	2.7	11.0
[2]	23	62	15	40	41	3	2	3	-	11	16.1	34.4	50.5	0.5	2.5	9.4
[2]	15	52	33	33	51	1	3	2	-	10	11.9	44.2	56.1	0.3	2.7	8
[2]	18	63	19	37	57	1	-	2	-	3	16.2	39.4	55.6	0.4	2.6	10.4
[2]	29	53	18	-	-	-	-	-	-	-	12.6	33.7	46.3	0.4	2.2	8.8
[2]	14	64	22	-	-	-	-	-	-	-	16.8	32.3	49.1	0.5	2.3	9.4
[4]	33	55	12	-	-	-	-	-	-	-	-	-	56.4	0.8	2.9	12.1
[4]	34	52	14	-	-	-	-	-	-	-	-	-	56.2	1.1	3.1	8.9
[4]	44	35	21	-	-	-	-	-	-	-	-	-	61.1	1.2	2.0	8.8
[4]	36	52	12	-	-	-	-	-	-	-	-	-	54.9	1.1	1.9	8.0
[4]	17	53	30	78	10	-	3	2	-	6	-	-	65.5	0.9	2.1	12.3
[4]	24	49	27	75	9	-	2	-	-	14	-	-	65.2	1.1	1.5	10.9
[4]	28	48	24	77	11	1	4	1	-	4	-	-	65.3	0.9	1.7	8.6
[4]	11	56	33	72	6	2	5	-	-	15	-	-	59.2	0.6	2.5	13.3
[4]	9	62	29	89	5	1	1	1	-	3	-	-	64.2	0.5	2.5	10.8
[4]	27	58	15	75	9	11	-	-	-	5	-	-	63.7	0.8	1.5	16.0
[4]	39	44	17	-	-	-	-	-	-	-	-	-	52.7	0.9	3.0	11.4
[4]	39	51	10	-	-	-	-	-	-	-	-	-	53.3	1.3	1.7	4.5
[4]	41	40	19	-	-	-	-	-	-	-	-	-	52.9	1.6	2.2	10.5
[4]	41	47	12	-	-	-	-	-	-	-	-	-	55.4	1.5	2.2	16.7
[4]	38	43	19	-	-	-	-	-	-	-	-	-	55.5	1.6	1.7	6.3
[4]	30	67	3	-	-	-	-	-	-	-	-	-	56.6	0.6	2.1	16.7
[4]	36	45	19	-	-	-	-	-	-	-	-	-	54.2	1.6	2.4	9.3
	27.7	**52.2**	**20.1**								**14.3**	**38.6**	**56.9**	**0.9**	**2.3**	**10.5**

* **Sources of Data:** [1] Cowan (1979a); [2] Rowell (2012); [3] Karrow (1993a); [4] A.J. Cooper (OGS, unpublished report, 1981).

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Appendix B – Glossary

Abrasion Resistance: Tests such as the Los Angeles abrasion test (*see* Appendix E) are used to measure the ability of aggregate to resist crushing and pulverizing under conditions similar to those encountered in processing and use. Measuring resistance is an important component in the evaluation of the quality and prospective uses of aggregate. Hard, durable material is preferred for road building.

Acid-Soluble Chloride Ion Content: This test measures total chloride ion content in concrete and is used to judge the likelihood of re-bar corrosion and susceptibility to deterioration by freeze–thaw in concrete structures. There is a strong positive correlation between chloride ion content and depassivation of reinforcing steel in concrete. Depassivation permits corrosion of the steel in the presence of oxygen and moisture. Chloride ions are contributed mainly by the application of de-icing salts.

Aggregate: Any hard, inert, construction material (sand, gravel, shells, slag, crushed stone or other mineral material) used for mixing in various-sized fragments with a cement or bituminous material to form concrete, mortar, etc., or used alone for road building or other construction. Synonyms include mineral aggregate and granular material.

Alkali–Aggregate Reaction: A chemical reaction between the alkalis of Portland cement and certain minerals found in rocks used for aggregate. Alkali–aggregate reactions are undesirable because they can cause expansion and cracking of concrete. Although perfectly suitable for building stone and asphalt applications, alkali-reactive aggregates should be avoided for structural concrete uses.

Beneficiation: Beneficiation of aggregates is a process or combination of processes that improves the quality (physical properties) of a mineral aggregate and is not part of the normal processing for a particular use, such as routine crushing, screening, washing, or classification. Heavy media separation, jigging, or application of special crushers (e.g., "cage mill") are usually considered processes of beneficiation.

Blending: Required in cases of extreme coarseness, fineness, or other irregularities in the gradation of unprocessed aggregate. Blending is done with approved sand-sized aggregate in order to satisfy the gradation requirements of the material.

Cambrian: The first period of the Paleozoic Era, thought to have covered the time between 540 and 500 million years age. The Cambrian precedes the Ordovician Period.

Chert: Amorphous silica, generally associated with limestone. Often occur as irregular masses or lenses, but can also occur finely disseminated through limestones. It may be very hard in unleached form. In leached form, it is white and "chalky" and is very absorptive. It has deleterious effect for aggregates to be used in Portland cement concrete due to reactivity with alkalis in Portland cement.

Clast: An individual constituent, grain or fragment of a sediment or rock, produced by the mechanical weathering of larger rock mass. Synonyms include particle and fragment.

Crushable Aggregate: Unprocessed gravel containing a minimum of 35% coarse aggregate larger than the No. 4 sieve (4.75 mm) as well as a minimum of 20% greater than the 26.5 mm sieve.

Deleterious Lithology: A general term used to designate those rock types that are chemically or physically unsuited for use as construction or road-building aggregates. Such lithologies as chert, shale, siltstone and sandstone may deteriorate rapidly when exposed to traffic and other environmental conditions.

Devonian: A period of the Paleozoic Era thought to have covered the span of time between 410 and 355 million years ago, following the Silurian Period. Rocks formed in the Devonian Period are among the youngest Paleozoic rocks in Ontario.

Dolostone: A carbonate sedimentary rock consisting chiefly of the mineral dolomite and containing relatively little calcite (dolostone is also known as dolomite).

Drift: A general term for all unconsolidated rock debris, transported from one place and deposited in another, distinguished from underlying bedrock. In North America, glacial activity has been the dominant mode of transport and deposition of drift. Synonyms include overburden and surficial deposit.

Drumlin: A low, smoothly rounded, elongated hill, mound or ridge composed of glacial materials. These landforms were formed beneath an advancing ice sheet and were shaped by its flow.

Eolian: Pertaining to the wind, especially with respect to landforms the constituents of which were transported and deposited by wind activity. Sand dunes are an example of an eolian landform.

Fines: A general term used to describe the size fraction of an aggregate which passes (is finer than) the No. 200 mesh screen (0.075 mm). Also described informally as "dirt", these particles are in the silt and clay size range.

Glacial Lobe: A tongue-like projection from the margin of the main mass of an ice cap or ice sheet. During the Pleistocene Epoch, several lobes of the Laurentide continental ice sheet occupied the Great Lakes basins. These lobes advanced then melted back numerous times during the Pleistocene, producing the complex arrangement of glacial material and landforms found in Ontario.

Gneiss: A coarse-textured metamorphic rock with the minerals arranged in parallel streaks or bands. Gneiss is relatively rich in feldspar. Other common minerals found in this rock include quartz, mica, amphibole and garnet.

Gradation: The proportion of material of each particle size, or the frequency distribution of the various sizes, which constitute a sediment. The strength, durability, permeability and stability of an aggregate depend to a great extent on its gradation. The size limits for different particles are as follows:

Boulder	more than 200 mm
Cobbles	75–200 mm
Coarse Gravel	26.5–75 mm
Fine Gravel	4.75–26.5 mm
Coarse Sand	2–4.75 mm
Medium Sand	0.425–2 mm
Fine Sand	0.075–0.425 mm
Silt, Clay	less than 0.075 mm

Granite: A coarse-grained, light-coloured rock that ordinarily has an even texture and is composed of quartz and feldspar with either mica, hornblende or both.

Granular Base and Subbase: Components of a pavement structure of a road, which are placed on the subgrade and are designed to provide strength, stability and drainage, as well as support for surfacing materials. Granular A consists of crushed and processed aggregate and has relatively stringent quality standards in comparison to Granular B, which is usually pit-run or other unprocessed aggregate. Granular M is a shouldering and surface dressing material with quality requirements similar to Granular A. Select Subgrade Material (SSM) has similar quality requirements to Granular B and it provides a stable platform for the overlying pavement structure. (For more specific information, the reader is referred to Ontario Provincial Standard Specification (OPSS) 1010 and Appendix E).

Heavy Duty Binder: Second layer from the top of hot mix asphalt pavements used on heavily travelled (especially by trucks) expressways, such as Highway 401. Coarse and fine aggregates are to be produced from high-quality bedrock quarries, except when gravel is permitted by special provisions.

Hot-Laid (or Asphaltic) Paving Aggregate: Bituminous, cemented aggregates used in the construction of pavements either as surface or bearing course or as binder course used to bind the surface course to the underlying granular base.

Limestone: A carbonate sedimentary rock consisting chiefly of the mineral calcite. It may contain the mineral dolomite up to about 40%.

Lithology: The description of rocks on the basis of such characteristics as colour, structure, mineralogic composition and grain size. Generally, the description of the physical character of a rock.

Medium Duty Binder: Second layer from the top of hot mix asphalt pavements used on heavily travelled, usually four-lane, highways and municipal arterial roads. It may be constructed with high-quality quarried rock or high-quality gravel with a high percentage of fractured faces or polymer modified asphalt cements.

Meltwater Channel: A drainage way, often terraced, produced by water flowing away from a melting glacier margin.

Ordovician: An early period of the Paleozoic Era thought to have covered the span of time between 500 and 435 million years ago.

Paleozoic: One of the major divisions of the geologic time scale thought to have covered the time period between 540 and 250 million years ago, the Paleozoic Era (or Ancient Life Era) is subdivided into 6 geologic periods, of which only 4 (Cambrian, Ordovician, Silurian and Devonian) can be recognized in southern Ontario.

Pleistocene: An epoch of the recent geological past including the time from approximately 1.75 million years ago to 7000 years ago. Much of the Pleistocene was characterized by extensive glacial activity and is popularly referred to as the “Great Ice Age”.

Possible Resource: Reserve estimates based largely on broad knowledge of the geological character of the deposit and for which there are few, if any, samples or measurements. The estimates are based on assumed continuity or repetition for which there are reasonable geological indications, but do not take into account many site-specific natural and environmental constraints that could render the resource inaccessible.

Precambrian: The earliest geological period extending from the consolidation of the Earth’s crust to the beginning of the Cambrian Period.

Sandstone: A clastic sedimentary rock consisting chiefly of sand-sized particles of quartz and minor feldspar, cemented together by calcareous minerals (calcite or dolomite) or by silica.

Shale: A fine-grained, sedimentary rock formed by the consolidation of clay, silt or mud and characterized by well-developed bedding planes, along which the rock breaks readily into thin layers. The term shale is also commonly used for fissile claystone, siltstone and mudstone.

Siltstone: A clastic sedimentary rock consisting chiefly of silt-sized particles, cemented together by calcareous minerals (calcite and dolomite) or by silica.

Silurian: An early period of the Paleozoic Era thought to have covered the time between 435 and 410 million years ago. The Silurian follows the Ordovician Period and precedes the Devonian Period.

Soundness: The ability of the components of an aggregate to withstand the effects of various weathering processes and agents. Unsound lithologies are subject to disintegration caused by the expansion of absorbed solutions. This may seriously impair the performance of road-building and construction aggregates.

Till: Unsorted and unstratified rock debris, deposited directly by glaciers, and ranging in size from clay to large boulders.

Wisconsinan: Pertaining to the last glacial period of the Pleistocene Epoch in North America. The Wisconsinan began approximately 100 000 years ago and ended approximately 7000 years ago. The glacial deposits and landforms of Ontario are predominantly the result of glacial activity during the Wisconsinan Stage.

Appendix C – Geology of Sand and Gravel Deposits

The type, distribution and extent of sand and gravel deposits in Ontario are the result of extensive glacial and glacially influenced activity in Wisconsinan time during the Pleistocene Epoch, approximately 100 000 to 7000 years ago. The deposit types reflect the different depositional environments that existed during the melting and retreat of the continental ice masses, and can readily be differentiated on the basis of their morphology, structure and texture. The deposit types are described below.

GLACIOFLUVIAL DEPOSITS

These deposits can be divided into 2 broad categories: those that were formed in contact with (or in close proximity to) glacial ice, and those that were deposited by meltwaters carrying materials beyond the ice margin.

Ice–Contact Terraces (ICT): These are glaciofluvial features deposited between the glacial margin and a confining topographic high, such as the side of a valley. The structure of the deposits may be similar to that of outwash deposits, but, in most cases, the sorting and grading of the material is more variable and the bedding is discontinuous because of extensive slumping. The probability of locating large amounts of crushable aggregate is moderate, and extraction may be expensive because of the variability of the deposits both in terms of quality and grain size distribution.

Kames (K): Kames are defined as mounds of poorly sorted sand and gravel deposited by meltwater in depressions or fissures on the ice surface or at its margin. During glacial retreat, the melting of supporting ice causes collapse of the deposits, producing internal structures characterized by bedding discontinuities. The deposits consist mainly of irregularly bedded and cross-bedded, poorly sorted sand and gravel. The present forms of the deposits include single mounds, linear ridges (crevasse fillings) or complex groups of landforms. The latter are occasionally described as "undifferentiated ice-contact stratified drift" (IC) when detailed subsurface information is unavailable. Since kames commonly contain large amounts of fine-grained material and are characterized by considerable variability, there is generally a low to moderate probability of discovering large amounts of good quality, crushable aggregate. Extractive problems encountered in these deposits are mainly the excessive variability of the aggregate and the rare presence of excess fines (silt- and clay-sized particles).

Eskers (E): Eskers are narrow, sinuous ridges of sand and gravel deposited by meltwaters flowing in tunnels within or at the base of glaciers, or in channels on the ice surface. Eskers vary greatly in size. Many, though not all, eskers consist of a central core of poorly sorted and stratified gravel characterized by a wide range in grain size. The core material is often draped on its flanks by better sorted and stratified sand and gravel. The deposits have a high probability of containing a large proportion of crushable aggregate and, since they are generally built above the surrounding ground surface, are convenient extraction sites. For these reasons, esker deposits have been traditional aggregate sources throughout Ontario, and are significant components of the total resources of many areas.

Some planning constraints and opportunities are inherent in the nature of the deposits. Because of their linear nature, the deposits commonly extend across several property boundaries leading to unorganized extractive development at numerous small pits. On the other hand, because of their form, eskers can be easily and inexpensively extracted and are amenable to rehabilitation and sequential land use.

Undifferentiated Ice-Contact Stratified Drift (IC): This designation may include deposits from several ice-contact, depositional environments which usually form extensive, complex landforms. It is not feasible to identify individual areas of coarse-grained material within such deposits because of their lack of continuity and grain size variability. They are given a qualitative rating based on existing pit and other subsurface data.

Outwash (OW): Outwash deposits consist of sand and gravel laid down by meltwaters beyond the margin of the ice lobes. The deposits occur as sheets or as terraced valley fills (valley trains) and may be very large in extent and thickness. Well-developed outwash deposits have good horizontal bedding and are uniform in grain size distribution. Outwash deposited near the glacier's margin is much more variable in texture and structure. The probability of locating useful crushable aggregates in outwash deposits is moderate to high depending on how much information on size, distribution and thickness is available.

Subaqueous Fans (SF): Subaqueous fans are formed within or near the mouths of meltwater conduits when sediment-laden meltwaters are discharged into a standing body of water. The geometry of the resulting deposit is fan or lobe shaped. Several of these lobes may be joined together to form a larger, continuous sedimentary body. Internally, subaqueous fans consist of stratified sands and gravels that may exhibit wide variations in grain size distribution. As these features were deposited under glacial lake waters, silt and clay that settled out of these lakes may be associated in varying amounts with these deposits. The variability of the sediments and presence of fines are the main extractive problems associated with these deposits.

Alluvium (AL): Alluvium is a general term for clay, silt, sand, gravel, or similar unconsolidated material deposited during postglacial time by a stream as sorted or semi-sorted sediment, on its bed or on its floodplain. The probability of locating large amounts of crushable aggregate in alluvial deposits is low, and they have generally low value because of the presence of excess silt- and clay-sized material. There are few large postglacial alluvium deposits in Ontario.

GLACIOLACUSTRINE DEPOSITS

Glaciolacustrine Beach Deposits (LB): These are relatively narrow, linear features formed by wave action at the shores of glacial lakes that existed at various times during the deglaciation of Ontario. Well-developed lacustrine beaches are usually less than 6 m thick. The aggregate is well sorted and stratified and sand-sized material commonly predominates. The composition and size distribution of the deposit depends on the nature of the source material. The probability of obtaining crushable aggregate is high when the material is developed from coarse-grained materials such as a stony till, and low when developed from fine-grained materials. Beaches are relatively narrow, linear deposits, so that extractive operations are often numerous and extensive.

Glaciolacustrine Deltas (LD): These features were formed where streams or rivers of glacial meltwater flowed into lakes and deposited their suspended sediment. In Ontario, such deposits tend to consist mainly of sand and abundant silt. However, in near-ice and ice-contact positions, coarse material may be present. Although deltaic deposits may be large, the probability of obtaining coarse material is generally low.

Glaciolacustrine Plains (LP): The nearly level surface marking the floor of an extinct glacial lake is called a glaciolacustrine plain. The sediments that form the plain are predominantly fine to medium sand, silt and clay, and were deposited in relatively deep water. Lacustrine deposits are generally of low value as aggregate sources because of their fine grain size and lack of crushable material. In some aggregate-poor areas, lacustrine deposits may constitute valuable sources of fill and some granular subbase aggregate.

GLACIOMARINE DEPOSITS

Glaciomarine Beach Deposits (MB): Similar to glaciolacustrine beach deposits, glaciomarine beach deposits are formed in a glaciomarine environment (i.e., ocean rather than lake environment).

Glaciomarine Deltas (MD): Similar to glaciolacustrine deltas, glaciomarine deltas are the result of a glaciomarine environment.

Glaciomarine Plains (MP): Similar to glaciolacustrine plains, glaciomarine plains are the result of a glaciomarine environment.

GLACIAL DEPOSITS

End Moraines (EM): These are belts of glacial drift deposited at, and parallel to, glacier margins. End moraines commonly consist of ice-contact stratified drift and, in such instances, are usually called kame moraines. Kame moraines commonly result from deposition between 2 glacial lobes (interlobate moraines). The probability of locating aggregates within such features is moderate to low. Exploration and development costs are high. Moraines may be very large and contain vast aggregate resources, but the location of the best areas within the moraine is usually poorly defined.

EOLIAN DEPOSITS

Windblown Deposits (WD): Windblown deposits are those formed by the transport and deposition of sand by winds. The form of the deposits ranges from extensive, thin layers to well-developed linear and crescentic ridges known as dunes. Most windblown deposits in Ontario are derived from, and deposited on, pre-existing lacustrine sand plain deposits. Windblown sediments almost always consist of fine to coarse sand and are usually well sorted. The probability of locating crushable aggregate in windblown deposits is very low.

Appendix D – Geology of Bedrock Deposits

The purpose of this appendix is to familiarize the reader with the general bedrock geology of southern Ontario (Figure D1) and, where known, the potential uses of the various bedrock formations. The reader is cautioned against using this information for more specific purposes. The stratigraphic chart (Figure D2) is intended only to illustrate the stratigraphic sequences in particular geographic areas and should not be used as a regional correlation table.

The following description is arranged in ascending stratigraphic order, on a group and formation basis. Precambrian rocks are not discussed. Additional stratigraphic information is included for some formations where necessary. The publications and maps of the Ontario Geological Survey (e.g., Johnson et al. 1992 and Armstrong and Carter 2010) and the Geological Survey of Canada should be referred to for more detailed information. The lithology, thickness and general use of rocks from these formations are noted. If a formation may be suitable for use as aggregate and aggregate suitability test data are available, the data have been included in the form of ranges.

The following short forms have been used in presenting these data:

AAV = aggregate abrasion value,
Absn = absorption (percent),
BRD = bulk relative density,
LA = Los Angeles abrasion and impact test (loss in percent),
$MgSO_4$ = magnesium sulphate soundness test (loss in percent),
PN (A-C) = PN (Asphalt & Concrete) = petrographic number for asphalt (“A”) and concrete (“C”) use,
PSV = polished stone value.

The ranges are intended as a guide only and care should be exercised in extrapolating the information to specific situations. Aggregate suitability test data have been provided by the Ministry of Transportation of Ontario. Aggregate suitability tests are defined in Appendix E. Aggregate product specifications are also provided in Appendix E.

Covey Hill Formation (Cambrian)

STRATIGRAPHY and/or OCCURRENCE: Lower formation of the Potsdam Group.
LITHOLOGY: Interbedded noncalcareous feldspathic conglomerate and sandstone.
THICKNESS: 0 to 14 m.
USES: Has been quarried for aggregate in the United Counties of Leeds and Grenville.

Nepean Formation (Cambrian)

STRATIGRAPHY and/or OCCURRENCE: Upper formation of the Potsdam Group.
LITHOLOGY: Thin- to massive-bedded quartz sandstone with some conglomerate interbeds and rare shaly partings.
THICKNESS: 0 to 30 m.
USES: Suitable as dimension stone; quarried at Philipsville and Forfar for silica sand; alkali–silica reactive in Portland cement concrete.
AGGREGATE SUITABILITY TESTING: PSV = 54-68, AAV = 4-15, $MgSO_4$ = 9-32, LA = 44-90, Absn = 1.6-2.6, BRD = 2.38-2.50, PN (A-C) = 130-140.

March Formation (Lower Ordovician)

STRATIGRAPHY and/or OCCURRENCE: Lower formation of the Beekmantown Group.
LITHOLOGY: Interbedded quartz sandstone, dolomitic quartz sandstone, sandy dolostone and dolostone.
THICKNESS: 6 to 64 m.
USES: Quarried extensively for aggregate in areas of outcrop and subcrop; alkali–silica reactive in Portland cement concrete; lower part of formation is an excellent source of skid-resistant aggregate. The formation is suitable for use as facing stone and paving stone.
AGGREGATE SUITABILITY TESTING: PSV = 55-60, AAV = 4-6, $MgSO_4$ = 1-17, LA = 15-38, Absn = 0.5-0.9, BRD = 2.61-2.65, PN (A-C) = 110-150.

Oxford Formation (Lower Ordovician)

STRATIGRAPHY and/or OCCURRENCE: Upper formation of the Beekmantown Group.
LITHOLOGY: Thin- to thick-bedded, microcrystalline to medium-crystalline, grey dolostone with thin shaly interbeds.
THICKNESS: 61 to 102 m.
USES: Quarried in the Brockville and Smith Falls areas and south of Ottawa for use as aggregate.
AGGREGATE SUITABILITY TESTING: PSV = 47-48, AAV = 7-8, $MgSO_4$ = 1-4, LA = 18-23, Absn = 0.7-0.9, BRD = 2.74-2.78, PN (A-C) = 105-120.

Rockcliffe Formation (Lower Ordovician)

STRATIGRAPHY and/or OCCURRENCE: Divided into a lower member and an upper (St. Martin) member.
LITHOLOGY: Interbedded quartz sandstone and shale; interbedded shaly bioclastic limestone and shale predominate in the upper member.
THICKNESS: 0 to 125 m.
USES: Upper member has been quarried east of Ottawa for aggregate; lower member has been used as crushed stone; some high-purity limestone beds in upper member may be suitable for use as fluxing stone and in lime production.

AGGREGATE SUITABILITY TESTING: PSV = 58-63, AAV = 10-11, $MgSO_4$ = 12-40, LA = 25-28, Absn = 1.8-1.9, BRD = 2.55-2.62, PN (A-C) = 122-440.

Shadow Lake Formation (Upper Ordovician)

STRATIGRAPHY and/or OCCURRENCE: The basal unit of the Black River Group. Informally, the formation is known as the basal unit of the Ottawa Group in eastern Ontario and the basal unit of the Simcoe Group in central Ontario.

LITHOLOGY: Poorly sorted, red and green sandy shales; argillaceous and arkosic sandstones; minor sandy argillaceous dolostones and rare basal arkosic conglomerate.

THICKNESS: 0 to 15 m.

USES: Potential source of decorative stone; very limited value as aggregate source.

Gull River Formation (Upper Ordovician)

STRATIGRAPHY and/or OCCURRENCE: Part of the Black River Group. Informally, the formation is part of the Simcoe Group in central Ontario and the Ottawa Group in eastern Ontario. In eastern Ontario, the formation is subdivided into upper and lower members; in central Ontario, it is presently subdivided into upper, middle and lower members.

LITHOLOGY: In central and eastern Ontario, the lower member consists of alternating units of limestone, dolomitic limestone and dolostone. West of Lake Simcoe, the lower member is thin- to thick-bedded, interbedded, grey argillaceous limestone and buff to green dolostone. The upper and middle members are dense microcrystalline limestones with argillaceous dolostone interbeds. The upper member also consists of thin-bedded limestones with thin shale partings.

THICKNESS: 7.5 to 135 m.

USES: Quarried in the Lake Simcoe, Kingston, Ottawa and Cornwall areas for crushed stone. Rock from certain layers has proven to be alkali reactive when used in Portland cement concrete (alkali–carbonate reaction).

AGGREGATE SUITABILITY TESTING: PSV = 41-49, AAV = 8-12, $MgSO_4$ = 3-17, LA = 18-28, Absn = 0.3-0.9, BRD = 2.68-2.73, PN (A-C) = 100-153, micro-Deval (C) = 8.8-18.7, mortar bar (14 days) = 0.004-0.030.

Bobcaygeon Formation (Upper Ordovician)

STRATIGRAPHY and/or OCCURRENCE: Informally, the formation is part of the Simcoe Group in central Ontario and the Ottawa Group in eastern Ontario. The formation is subdivided into upper, middle and lower members. Formally, some researchers refer to the lower member as the Coboconk Formation of the Black River Group. The upper and middle members are sometimes referred to as the Kirkfield Formation, a part of the Trenton Group.

LITHOLOGY: The lower member is light grey-tan to brown-grey, medium- to very thick-bedded, fine- to medium-grained, bioturbated to current-laminated, bioclastic limestones, wackestones, packstones and grainstones. The middle member is thin- to medium-bedded, tabular-bedded, bioclastic, very fine- to fine-grained limestones with green shale interbeds and partings. The upper member is similar to the middle member, but also includes fine- to medium-grained, dark grey to light brown, thin- to medium-bedded, irregular to tabular bedded, bioturbated, horizontal to low-angle cross-laminated, bioclastic, fossiliferous limestones, wackestones, packstones and grainstones.

THICKNESS: 7 to 87 m.

USES: Quarried at Brechin, Marysville and in the Ottawa area for crushed stone. Generally suitable for use as granular base course aggregate. Rock from certain layers has been found to be alkali reactive when used in Portland cement concrete (alkali–silica reaction).

AGGREGATE SUITABILITY TESTING: PSV = 47-51, AAV = 14-23, $MgSO_4$ = 1-40, LA = 18-32, Absn = 0.3-2.4, BRD = 2.5-2.69, PN (A-C) = 100-320.

Verulam Formation (Upper Ordovician)

STRATIGRAPHY and/or OCCURRENCE: The Verulam Formation is often referred to as the Sherman Fall Formation of the Trenton Group. Informally, the formation is part of the Simcoe and Ottawa groups.

LITHOLOGY: The Verulam Formation is informally subdivided into 2 members. The lower member consists of interbedded with limestone and calcareous shale. The limestone beds are very fine to coarse grained, thin to thick bedded, nodular to tabular bedded, light to dark grey-brown and fossiliferous. The upper member is thin- to thick-bedded, medium- to coarse-grained, cross-stratified, tan to light grey, fossiliferous, bioclastic limestone.

THICKNESS: 32 to 67 m.

USES: Quarried at Picton and Bath for use in cement manufacture. Quarried for aggregate in Ramara Township, Simcoe County and in the Belleville–Kingston area. The formation may be unsuitable for use as aggregate in some areas because of its high shale content.

AGGREGATE SUITABILITY TESTING: PSV = 43-44, AAV = 9-13, $MgSO_4$ = 4-45, LA = 22-29, Absn = 0.4-2.1, BRD = 2.59-2.70, PN (A-C) = 120-255.

Lindsay Formation (Upper Ordovician)

STRATIGRAPHY and/or OCCURRENCE: The Lindsay Formation is divided into 2 members. The lower member is often referred to as the Cobourg Formation of the Trenton Group. The upper member is referred to as the Collingwood Member of the Trenton Group. In eastern Ontario, the Collingwood Member is often referred to as the Eastview Member. Informally, the Lindsay Formation is part of the Simcoe and Ottawa groups.

LITHOLOGY: The lower member is interbedded, very fine- to coarse-grained, bluish-grey to grey-brown limestone with undulating shale partings and interbeds of dark grey calcareous shale. The Collingwood Member is a black, organic-rich, petroliferous, calcareous shale with very thin, fossiliferous, bioclastic limestone interbeds.
THICKNESS: The upper member is up to 10 m thick, whereas the lower member can be up to 60 m thick.
USES: In eastern Ontario, the lower member is used extensively for aggregate production; in central Ontario, it is quarried at Picton, Ogden Point and Bowmanville for cement. The formation may be suitable or unsuitable for use as concrete and asphalt aggregate.
AGGREGATE SUITABILITY TESTING: $MgSO_4$ = 2-47, LA = 20-28, Absn = 0.4-1.3, BRD = 2.64-2.70, PN (A-C) = 110-215.

Blue Mountain and Billings Formations (Upper Ordovician)

STRATIGRAPHY and/or OCCURRENCE: The Blue Mountain Formation includes the upper and middle members of the former Whitby Formation. In eastern Ontario, the Billings Formation is equivalent to part of the Blue Mountain Formation.
LITHOLOGY: Blue-grey to grey-brown, noncalcareous shales with thin, minor interbeds of limestone and siltstone. The Billings Formation is dark grey to black, noncalcareous to slightly calcareous, pyritiferous shale with dark grey limestone laminae and grey siltstone interbeds.
THICKNESS: Blue Mountain Formation - 43 to 60 m; Billings Formation - 0 to 62 m.
USES: The Billings Formation may be a suitable source for structural clay products and lightweight expanded aggregate. The Blue Mountain Formation may be suitable for structural clay products.

Georgian Bay and Carlsbad Formations (Upper Ordovician)

STRATIGRAPHY and/or OCCURRENCE: The Georgian Bay Formation trends in a northwest direction from Lake Ontario toward Georgian Bay. The Carlsbad Formation is the equivalent of the Georgian Bay Formation in eastern Ontario.
LITHOLOGY: The Georgian Bay Formation consists of greenish to bluish-green shale interbedded with limestone, siltstone and sandstone. The Carlsbad Formation consists of interbedded shale, siltstone and bioclastic limestone.
THICKNESS: Georgian Bay Formation - 125 to 200 m; Carlsbad Formation - 0 to 186 m.
USES: Georgian Bay Formation was previously used by several producers in the Metropolitan Toronto area to produce brick and structural tile, as well as for making Portland cement. At Streetsville, expanded shale was used in the past to produce lightweight aggregate. These operations are no longer in production. The Carlsbad Formation may be used as a source material for brick and tile manufacturing and has potential as a lightweight expanded aggregate.

Queenston Formation (Upper Ordovician)

STRATIGRAPHY and/or OCCURRENCE: The Queenston Formation conformably overlies the Georgian Bay Formation and crops out along the base of the Niagara Escarpment.
LITHOLOGY: Red-maroon, thin- to thick-bedded, sandy to argillaceous shale with green mottling and banding.
THICKNESS: 45 to 335 m.
USES: There are several quarries developed in the Queenston Formation along the base of the Niagara Escarpment and one at Russell, near Ottawa. All extract shale for brick manufacturing. The Queenston Formation is the most important source of material for brick manufacture in Ontario.

Whirlpool Formation (Lower Silurian)

STRATIGRAPHY and/or OCCURRENCE: Lower formation of the Cataract Group, generally located in the Niagara Peninsula and along the Niagara Escarpment as far north as Duntroon.
LITHOLOGY: White to grey to maroon, fine-grained, orthoquartzitic sandstone with thin grey shale partings.
THICKNESS: 0 to 9 m.
USES: Building stone, flagstone.

Manitoulin Formation (Lower Silurian)

STRATIGRAPHY and/or OCCURRENCE: Part of the Cataract Group. The formation generally occurs north of Stoney Creek.
LITHOLOGY: Thin- to medium-bedded, moderately fossiliferous, fine- to medium-crystalline dolostone with minor grey-green shale. Chert nodules or lenses, and silicified fossils have also been reported within the formation.
THICKNESS: 0 to 25 m.
USES: Extracted for crushed stone in Grey County, and for decorative stone on Manitoulin Island.

Cabot Head Formation (Lower Silurian)

STRATIGRAPHY and/or OCCURRENCE: Part of the Cataract Group. The formation occurs in the subsurface throughout southwestern Ontario and crops out along the length of the Niagara Escarpment.
LITHOLOGY: Grey to green to red-maroon, noncalcareous shales with subordinate sandstone and carbonate interbeds.
THICKNESS: 12 to 40 m.
USES: Potential source of lightweight aggregate. Extraction opportunities are limited by the lack of suitable exposures.

Grimsby Formation (Lower Silurian)

STRATIGRAPHY and/or OCCURRENCE: Upper formation of the Cataract Group. The formation has been identified along the Niagara Peninsula as far north as Clappison's Corners.
LITHOLOGY: Interbedded sandstone, dolomitic sandstone and red shale. The lower part of the Grimsby Formation becomes greener and shalier as it grades into the upper Cabot Head Formation.
THICKNESS: 0 to 15 m.
USES: No present uses.

Thorold Formation (Lower Silurian)

STRATIGRAPHY and/or OCCURRENCE: Lower formation in the Clinton Group.
LITHOLOGY: Grey-green to white, fine- to coarse-grained, quartzose sandstone with minor thin grey to green shale or siltstone partings.
THICKNESS: 2 to 7 m.
USES: No present uses.

Neagha Formation (Lower Silurian)

STRATIGRAPHY and/or OCCURRENCE: Part of the Clinton Group.
LITHOLOGY: Dark to greenish grey shale, sparsely fossiliferous, fissile shale, with minor thin limestone interbeds. The base of the Neagha Formation consists of a phosphatic pebble lag that indicates an unconformable contact with the underlying Thorold Formation.
THICKNESS: 0 to 2 m.
USES: No present uses.

Dyer Bay Formation (Lower Silurian)

STRATIGRAPHY and/or OCCURRENCE: Part of the Cataract Group. Crops out on Manitoulin Island and along the east side of the Bruce Peninsula as far south as Owen Sound. In the subsurface, it underlies the Bruce Peninsula and most of Essex and Kent counties.
LITHOLOGY: Thin- to medium-bedded, fine- to medium-grained, blue-grey to brown, argillaceous, fossiliferous dolostone with green-grey shaly partings.
THICKNESS: 0 to 8 m.
USES: No present uses.

Wingfield Formation (Lower Silurian)

STRATIGRAPHY and/or OCCURRENCE: Part of the Cataract Group. Occurs on Manitoulin Island and the northernmost part of the Bruce Peninsula.
LITHOLOGY: Interbedded brown, fine- to medium-grained, argillaceous dolostone and olive-green, noncalcareous, sparsely fossiliferous shale.
THICKNESS: 0 to 15 m.
USES: No present uses.

St. Edmund Formation (Lower Silurian)

STRATIGRAPHY and/or OCCURRENCE: Part of the Cataract Group. Occurs on Manitoulin Island and the northernmost part of the Bruce Peninsula. The upper portion of the formation was previously termed the Mindemoya Formation.
LITHOLOGY: Light creamy tan, microcrystalline, thin-bedded, sparsely fossiliferous dolostone with tan to brown, fine- to medium-crystalline, thick-bedded dolostone.
THICKNESS: 0 to 25 m.
USES: Quarried for fill and crushed stone on Manitoulin Island.
AGGREGATE SUITABILITY TESTING: $MgSO_4$ = 1-2, LA = 19-21, Absn = 0.6-0.7, BRD = 2.78-2.79, PN (A-C) = 105.

Fossil Hill Formation (Lower Silurian)

STRATIGRAPHY and/or OCCURRENCE: Part of the Clinton Group. Occurs on Manitoulin Island and the northern part of the Bruce Peninsula.
LITHOLOGY: Thin- to medium-bedded, very fine- to coarse-grained, very fossiliferous dolostone. The formation also contains intervals of tan-grey, very fine-crystalline, sparsely fossiliferous dolostone.
THICKNESS: 3 to 34 m.
USES: The formation is sometimes quarried along with the overlying Amabel and Lockport formations.
AGGREGATE SUITABILITY TESTING: (Fossil Hill Formation on Manitoulin Island) $MgSO_4$ = 41, LA = 29, Absn = 4.1, BRD = 2.45, PN (A-C) = 370.

Reynales Formation (Lower Silurian)

STRATIGRAPHY and/or OCCURRENCE: Part of the Clinton Group. The Reynales Formation occurs on the Niagara Peninsula and along the Niagara Escarpment as far north as the Forks of the Credit.
LITHOLOGY: Light to dark grey, buff weathering, thin- to thick-bedded, very fine- to fine-grained, sparsely fossiliferous dolostone to argillaceous dolostone, with thin shaly interbeds and partings.
THICKNESS: 0 to 5 m.
USES: The formation is sometimes quarried along with overlying Amabel and Lockport formations.

Irondequoit Formation (Lower Silurian)

STRATIGRAPHY and/or OCCURRENCE: Part of the Clinton Group generally along the Niagara Peninsula south of Waterdown.
LITHOLOGY: Thick- to massive-bedded, light to pinkish grey, medium- to coarse-grained, crinoidal- and brachiopod-rich limestone.
THICKNESS: 0 to 10 m.
USES: Not utilized extensively.

Rochester Formation (Lower Silurian)

STRATIGRAPHY and/or OCCURRENCE: Part of the Clinton Group generally along the Niagara Peninsula.
LITHOLOGY: Dark grey to black, calcareous shale with variably abundant, thin, fine- to medium-grained calcareous to dolomitic calcisiltite to bioclastic calcarenite interbeds.
THICKNESS: 5 to 24 m.
USES: Not utilized extensively.
AGGREGATE SUITABILITY TESTING: PSV = 69, AAV = 17, $MgSO_4$ = 95, LA = 19, Absn = 2.2, BRD = 2.67, PN (A-C) = 400.

Decew Formation (Lower Silurian)

STRATIGRAPHY and/or OCCURRENCE: Part of the Clinton Group south of Waterdown along the Niagara Escarpment.
LITHOLOGY: Very fine- to fine-grained, argillaceous to arenaceous dolostone, with locally abundant shale partings and interbeds.
THICKNESS: 0 to 4 m.
USES: Too shaly for high-quality uses, but it is quarried along with the Lockport Formation in places.
AGGREGATE SUITABILITY TESTING: PSV = 67, AAV = 15, $MgSO_4$ = 55, LA = 21, Absn = 2.2, BRD = 2.66, PN (A-C) = 255.

Lockport and Amabel Formations (Lower Silurian)

STRATIGRAPHY and/or OCCURRENCE: The Lockport Formation occurs from Waterdown to Niagara Falls and is subdivided into 2 formal members: the Gasport and Goat Island members. The Amabel Formation is found from Waterdown to Cockburn Island and has been subdivided into the Lions Head and Wiarton members.
LITHOLOGY: The Gasport Member consists of thick- to massive-bedded, fine- to coarse-grained, blue-grey to white to pinkish grey dolostone and dolomitic limestone, with minor argillaceous dolostone. The Goat Island Member is dark to light grey to brown, very fine- to fine-crystalline, thin- to medium-bedded, irregularly bedded, variably argillaceous dolostone with locally abundant chert and vugs filled with gypsum, calcite or fluorite. Near Hamilton, abundant chert nodules and lenses in the Goat Island member have been informally named the Ancaster chert beds. A shaly interval, termed the Vinemount shale, occurs at the top of the Goat Island near and east of Hamilton.
The Wiarton Member consists of massive-bedded, blue-grey mottled, light grey to white, fine- to coarse-crystalline, porous crinoidal dolostone. Underlying the Wiarton Member in the Bruce Peninsula is the Colpoy Bay Member which is browner, finer grained and less fossiliferous than the Wiarton Member. The Lions Head Member consists of light grey to grey-brown, fine-crystalline, thin- to medium-bedded, sparsely fossiliferous dolostone with abundant chert nodules.
THICKNESS: (Lockport and Amabel) 3 to 40 m.
USES: Both formations have been used to produce lime, crushed stone, concrete aggregate and building stone throughout their area of occurrence, and are a resource of provincial significance.
AGGREGATE SUITABILITY TESTING: PSV = 36-49, AAV = 10-17, $MgSO_4$ = 2-6, LA = 25-32, Absn = 0.4-1.54, BRD = 2.61-2.81, PN (A-C) = 100-105.

Guelph Formation (Lower to Upper Silurian)

STRATIGRAPHY and/or OCCURRENCE: Exposed south and west of the Niagara Escarpment from the Niagara River to the tip of the Bruce Peninsula. The formation is also present in the subsurface of southwestern Ontario.
LITHOLOGY: The formation is tan- to brown-coloured, fine- to medium-crystalline, moderately to very fossiliferous, commonly biostromal to biohermal, sucrosic dolostones. In places, the formation is characterized by extensive vuggy, porous reefal facies of high chemical purity. The Eramosa Member consists of thin- to thick-bedded, tan to black, fine- to medium-crystalline, variably fossiliferous, bituminous dolostone. Locally, the Eramosa Member is argillaceous and cherty.
THICKNESS: 4 to 100 m.
USES: Some areas appear soft and unsuitable for use in the production of load-bearing aggregate. This unit requires additional testing to fully establish its aggregate suitability. The main use is for dolomitic lime for cement manufacture. The formation is quarried near Hamilton and Guelph.

Salina Formation (Group) (Upper Silurian)

STRATIGRAPHY and/or OCCURRENCE: Present in the subsurface of southwestern Ontario; only rarely exposed at surface. In southern Ontario, the succession of evaporates and evaporite-related sediments underlying the Bass Islands and Bertie formations, and overlying the reefal dolostones of the Guelph Formation, have been termed the Salina Formation. In other jurisdictions, this formation is often referred to as the Salina Group.
LITHOLOGY: Grey and maroon shale, brown dolostone and, in places, salt, anhydrite and gypsum; consists predominantly of evaporitic-rich material with up to 8 units identifiable. The Salina Group is dominated by evaporate lithologies in the Michigan Basin and become gradually shalier into the Appalachian Basin.
THICKNESS: 113 to 420 m.
USES: Gypsum mines at Hagersville, Caledonia and Drumbo. Salt is mined at Goderich and Windsor and is produced from brine wells at Amherstburg, Windsor and Sarnia.

Bertie and Bass Islands Formations (Upper Silurian)

STRATIGRAPHY and/or OCCURRENCE: The Bertie Formation is an Appalachian Basin unit found in the Niagara Peninsula. The Bertie Formation is equivalent to the Bertie Group of New York and, therefore, consists of the Oatka, Falkirk, Scajaquada, Williamsville and Akron members in Ontario. The Bass Islands Formation is a Michigan Basin equivalent of the Bertie Formation, which rarely crops out in Ontario, but is present in the subsurface in southwestern Ontario.
LITHOLOGY: The Bertie Formation consists of a succession of dark brown to light grey-tan, very fine- to fine-grained, variably laminated and bituminous, sparsely fossiliferous dolostones with argillaceous dolostones and minor shales. The Bass Islands Formation consists of dark brown to light grey-tan, variably laminated, mottled, argillaceous and bituminous, very fine- to fine-crystalline and sucrosic dolostones with minor anhydritic and sandstone beds.
THICKNESS: 10 to 90 m.
USES: Quarried for crushed stone on the Niagara Peninsula; shaly intervals are unsuitable for use as high specification aggregate because of low freeze–thaw durability. These formations have also been extracted for the production of lime.
AGGREGATE SUITABILITY TESTING: PSV = 46-49, AAV = 8-11, $MgSO_4$ = 4-19, LA = 14-23, Absn = 0.8-2.8, BRD = 2.61-2.78, PN (A-C) = 102-120.

Oriskany Formation (Lower Devonian)

STRATIGRAPHY and/or OCCURRENCE: Lower Devonian clastic unit, found in the Niagara Peninsula. The formation is equivalent to the Oriskany Formation in New York and Ohio and the Garden Island Formation of Michigan.
LITHOLOGY: Grey to yellowish white, coarse-grained, thick- to massive-bedded, calcareous quartzose sandstone.
THICKNESS: 0 to 5 m.
USES: The formation has been quarried for silica sand, building stone and armour stone. The formation may be acceptable for use as rip rap and well-cemented varieties may be acceptable for some asphaltic products.
AGGREGATE SUITABILITY TESTING: (of a well-cemented variety of the formation) PSV = 64, AAV = 6, $MgSO_4$ = 2, LA = 29, Absn = 1.2-1.3, BRD = 2.55, PN (A-C) = 107.

Bois Blanc Formation (Lower Devonian)

STRATIGRAPHY and/or OCCURRENCE: The formation disconformably overlies Silurian strata or, where present, the Lower Devonian Oriskany Formation. The Springvale Member forms the lower portion of formation.
LITHOLOGY: Greenish grey to grey-brown, thin- to medium-bedded, fine- to medium-grained, fossiliferous, bioturbated, cherty limestone and dolostone. The Springvale Member is a white to green-brown, commonly glauconitic, rarely argillaceous, quartzitic sandstone with minor sandy carbonates.
THICKNESS: 3 to 50 m. The Springvale Member is generally from 3 to 10 m thick; however, 30 m thickness has been reported.
USES: Quarried at Hagersville, Cayuga and Port Colborne for crushed stone. Material is generally unsuitable for concrete aggregate because of a high chert content.
AGGREGATE SUITABILITY TESTING: PSV = 48-53, AAV = 3-7, $MgSO_4$ = 3-18, LA = 15-22, Absn = 1.3-2.8, BRD = 2.50-2.70, PN (A-C) = 102-290.

Onondaga Formation (Middle Devonian)

STRATIGRAPHY and/or OCCURRENCE: Correlated to part of the Detroit River Group. Outcrops occur on the Niagara Peninsula from Simcoe to Niagara Falls. The formation includes the Edgecliffe, Clarence and Moorehouse members.
LITHOLOGY: Medium-bedded, fine- to coarse-grained, dark grey-brown or purplish-brown, variably cherty limestone.
THICKNESS: 8 to 25 m.
USES: Quarried for crushed stone on the Niagara Peninsula at Welland and Port Colborne. The high chert content makes much of the material unsuitable for use as concrete and asphaltic aggregate. The formation has been used as a raw material in cement manufacture.
AGGREGATE SUITABILITY TESTING: (Clarence and Edgecliffe members) $MgSO_4$ = 1-6, LA = 16.8-22.4, Absn = 0.5-1.1, PN (A-C) = 190-276.

Amherstburg Formation (Lower to Middle Devonian)

STRATIGRAPHY and/or OCCURRENCE: Part of the Detroit River Group. The formation correlates to the Amherstburg Formation of Michigan and the lower part of the Onondaga Formation in western New York. The Onondaga Formation terminology has been used in the outcrop belt of southern Ontario east of Norfolk County.
LITHOLOGY: Tan to grey-brown to dark brown, fine- to coarse-grained, bituminous, bioclastic, fossiliferous limestones and dolostone. Stromatoporoid-dominated bioherms are locally significant in Bruce and Huron counties and have been termed the Formosa Reef Limestone or Formosa reef facies.
THICKNESS: 0 to 60 m. The Formosa Reef Limestone is up to 26 m.
USES: Cement manufacture, agricultural lime, aggregate.
AGGREGATE SUITABILITY TESTING: PSV = 57, AAV = 19, $MgSO_4$ = 9-35, LA = 26-52, Absn = 1.1-6.4, BRD = 2.35-2.62, PN (A-C) = 105-300.

Lucas Formation (Middle Devonian)

STRATIGRAPHY and/or OCCURRENCE: Part of the Detroit River Group in southwestern Ontario. The formation is subdivided into 3 lithological units: the Lucas Formation undifferentiated, the Anderdon Member limestone and the Anderdon Member sandy limestone.
LITHOLOGY: The undifferentiated Lucas Formation consists of thin- to medium-bedded, light to grey-brown, fine crystalline, poorly fossiliferous dolostone and limestone. Anhydrite and gypsum beds are present near Amherstburg and Goderich. The Anderdon Member consists of light to dark grey-brown, thin- to medium-bedded, fine-grained, sparsely fossiliferous limestone, alternating with coarse-grained, bioclastic limestone.
THICKNESS: 40 to 99 m.
USES: Most important source of high-purity limestone in Ontario. Used as calcium lime for metallurgical flux and for the manufacture of chemicals. Rock of lower purity is used for cement manufacture, agricultural lime and aggregate. The Anderdon Member is quarried at Amherstburg for crushed stone.
AGGREGATE SUITABILITY TESTING: PSV = 46-47, AAV = 15-16, $MgSO_4$ = 2-60, LA = 22-47, Absn = 1.1-6.5, BRD = 2.35-2.40, PN (A-C) = 110-160.

Dundee Formation (Middle Devonian)

STRATIGRAPHY and/or OCCURRENCE: The Dundee Formation occurs between the Hamilton Group or Marcellus Formation and the limestones and dolostones of the Detroit River Group. There are few outcrops and the formation is observed mostly in the subsurface of southwestern Ontario.
LITHOLOGY: Grey to tan to brown, fossiliferous, medium- to thick-bedded limestones and minor dolostones. Bituminous partings and microstylolites are common. Chert nodules are locally abundant.
THICKNESS: 35 to 45 m.
USES: Quarried near Port Dover and on Pelee Island for crushed stone. Used at St. Marys as a raw material for Portland cement.
AGGREGATE SUITABILITY TESTING: $MgSO_4$ = 1-28, LA = 22-46, Absn = 0.6-6.8, PN (A-C) = 125-320.

Marcellus Formation (Middle Devonian)

STRATIGRAPHY and/or OCCURRENCE: Subsurface unit, mostly found below Lake Erie and extending into the eastern USA, pinches out in the Port Stanley area. The formation occurs on the southeast side of the Algonquin Arch.
LITHOLOGY: Black, organic-rich shales with interbeds of grey shale and very fine- to medium-grained, impure carbonates.
THICKNESS: 0 to 12 m.
USES: No present uses.

Bell Formation (Middle Devonian)

STRATIGRAPHY and/or OCCURRENCE: Lowest formation of the Hamilton Group, not known to crop out in Ontario.
LITHOLOGY: Blue-grey, soft, calcareous shale with thin limestone and organic-rich interbeds toward the base of the formation.
THICKNESS: 0 to 14.5 m.
USES: No present uses.

Rockport Quarry Formation (Middle Devonian)

STRATIGRAPHY and/or OCCURRENCE: Part of the Hamilton Group; not known to crop out in Ontario.
LITHOLOGY: Grey to brown, fine-grained argillaceous limestone.
THICKNESS: 0 to 6 m.
USES: No present uses.

Arkona Formation (Middle Devonian)

STRATIGRAPHY and/or OCCURRENCE: Part of the Hamilton Group.
LITHOLOGY: Blue-grey, plastic, soft, calcareous shale with minor thin and laterally discontinuous argillaceous limestone beds.
THICKNESS: 5 to 37 m.
USES: Has been extracted at Thedford and near Arkona for the production of drainage tile.

Hungry Hollow Formation (Middle Devonian)

STRATIGRAPHY and/or OCCURRENCE: Part of the Hamilton Group.
LITHOLOGY: The upper part of the formation is a coral-rich, calcareous shale-dominated unit. The lower part of the formation is predominantly fossiliferous, bioclastic limestone.
THICKNESS: 0 to 2 m.
USES: Suitable for some crushed stone and fill with very selective quarrying methods.

Widder Formation (Middle Devonian)

STRATIGRAPHY and/or OCCURRENCE: Part of the Hamilton Group.
LITHOLOGY: Calcareous, grey to brown-grey shale, bioturbated, fine-grained, argillaceous, nodular limestone and coarse-grained bioclastic limestone.
THICKNESS: 0 to 21 m.
USES: No present uses.

Ipperwash Formation (Middle Devonian)

STRATIGRAPHY and/or OCCURRENCE: Upper formation of the Hamilton Group; very limited distribution in Ontario.

LITHOLOGY: Grey-brown, fine- to coarse-grained, argillaceous and bioclastic limestone with shaly interbeds.
THICKNESS: 2 to 13 m.
USES: No present uses.

Kettle Point Formation (Upper Devonian)

STRATIGRAPHY and/or OCCURRENCE: Occurs in a northwest-trending band between Sarnia and Lake Erie; small part overlain by Port Lambton Group rocks in extreme northwest.
LITHOLOGY: Dark brown to black, highly fissile, organic-rich shale with subordinate organic-poor, grey-green silty shale and siltstone interbeds.
THICKNESS: 0 to 75 m.
USES: Possible source of lightweight aggregate or fill.

Bedford Formation (Upper Devonian)

STRATIGRAPHY and/or OCCURRENCE: Lower formation of the Port Lambton Group.
LITHOLOGY: Light grey, soft, fissile shale with silty and sandy interbeds in the upper part of the formation.
THICKNESS: 0 to 30 m.
USES: No present uses.

Berea Formation (Upper Devonian)

STRATIGRAPHY and/or OCCURRENCE: Middle formation of the Port Lambton Group; not known to crop out in Ontario.
LITHOLOGY: Grey, fine- to medium-grained sandstone with grey shale and siltstone interbeds.
THICKNESS: 0 to 60 m.
USES: No present uses.

Sunbury Formation (Lower Mississippian)

STRATIGRAPHY and/or OCCURRENCE: Upper formation of the Port Lambton Group; not known to crop out in Ontario.
LITHOLOGY: Black, organic-rich shale.
THICKNESS: 0 to 20 m.
USES: No present uses.

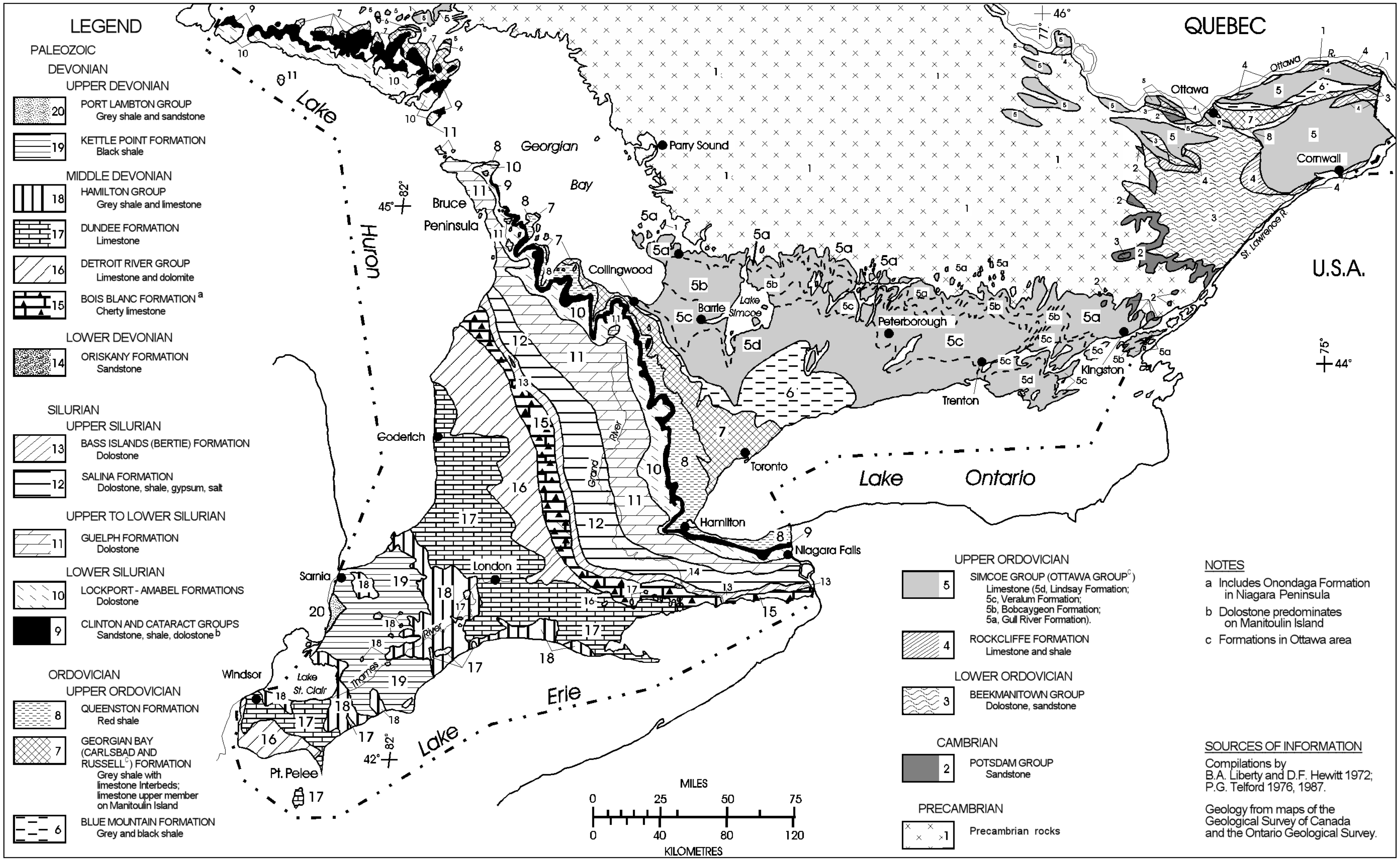


Figure D1. Bedrock geology of southern Ontario.

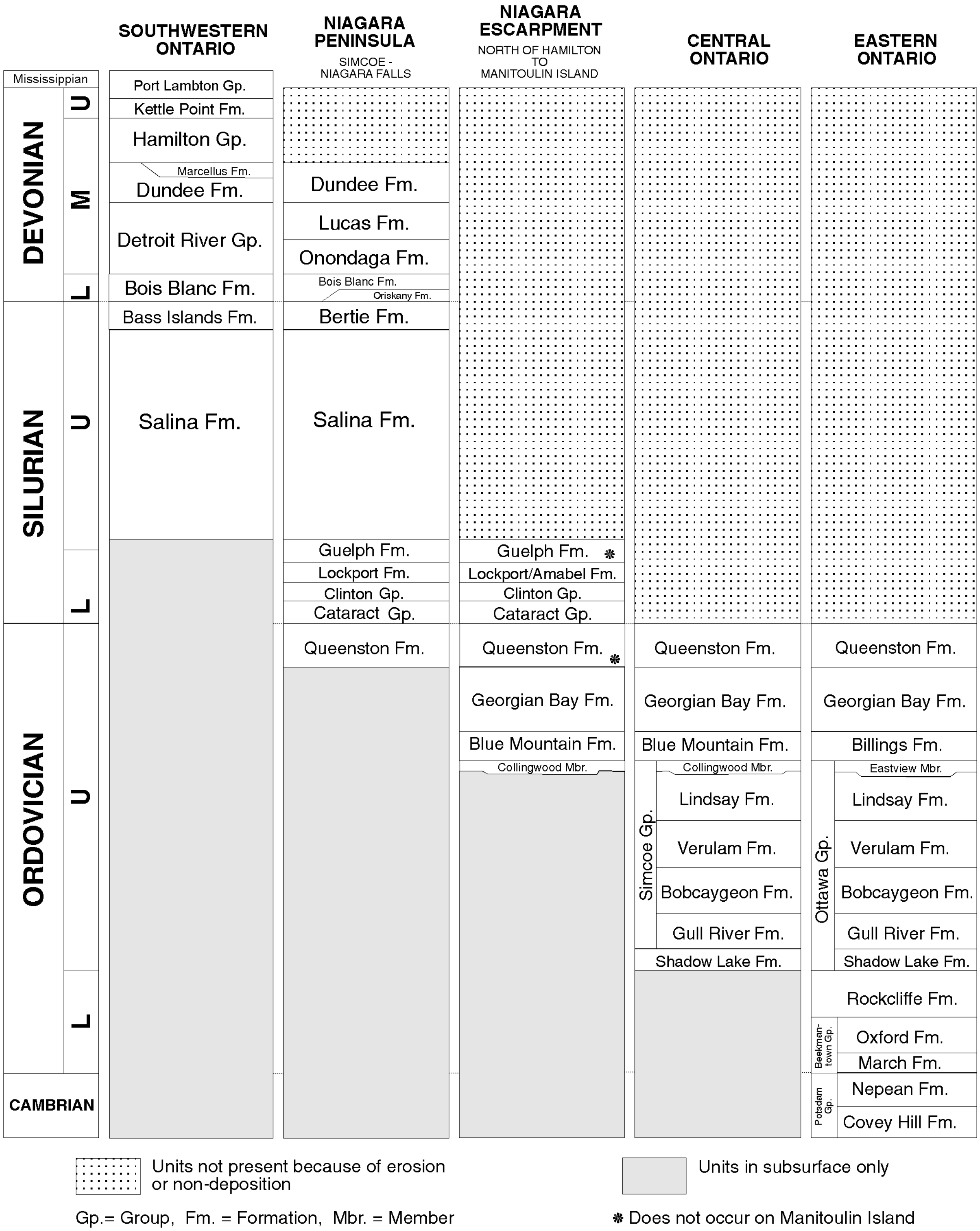


Figure D2. Exposed Paleozoic stratigraphic sequences in southern Ontario (*adapted from* Bezys and Johnson 1988 and Armstrong and Dodge 2007).

Appendix E – Aggregate Quality Test Specifications

Aggregate quality tests are performed by the Ministry of Transportation of Ontario (MTO) for the Ontario Geological Survey on sampled material. A brief description and the specification limits for each test are included in this appendix. Although a specific sample meets or does not meet the specification limits for a certain product, it may or may not be acceptable for that use based on field performance. Additional quality tests other than the tests listed in this appendix can be used to determine the suitability of an aggregate. Greater detail on the tests and aggregate specifications can be obtained from the MTO.

Absorption Capacity (LS-604): This test is related to the porosity of the rock types of which an aggregate is composed. Porous rocks are subject to disintegration when absorbed liquids freeze and thaw, thus decreasing the strength of the aggregate. This test is conducted in conjunction with the determination of the sample's relative density.

Accelerated Mortar Bar Expansion Test (LS-620): This is a rapid test for detecting alkali–silica reactive aggregates. It involves the crushing of the aggregate and the creation of standard mortar bars. For coarse and fine aggregates, suggested expansion limits of 0.10 to 0.15% are indicated for innocuous aggregates; greater than 0.10%, but less than 0.20%, indicates that it is unknown whether a potentially deleterious reaction will occur; and greater than 0.20% indicates that the aggregate is probably reactive and should not be used for Portland cement concrete. If the expansion limit exceeds 0.10% for coarse and fine aggregates, it is recommended that supplementary information be developed to confirm that the expansion is actually because of alkali reactivity. If confirmed deleteriously reactive, the material should not be used for Portland cement concrete unless corrective measures are undertaken such as the use of low- or reduced-alkali cement.

Aggregate Abrasion Value (AVV) (British Standard 812): The AAV is a measure of the resistance of aggregate to surface wear by abrasion using a standard silica sand. A low AVV (6 or less) implies good resistance to abrasion. An aggregate with good resistance to abrasion will usually give good macrotexture. This test is described in British Standard 812 (1975).

Bulk Relative Density (BRD) (ASTM C29): An aggregate with low relative density is lighter in weight than one with a high relative density. Low relative-density aggregates (less than about 2.5) are often non-durable for many aggregate uses.

Los Angeles Abrasion and Impact Test (LS-603 or ASTM C131): This test measures the resistance to abrasion and the impact strength of aggregate. This gives an idea of the breakdown that can be expected to occur when an aggregate is stockpiled, transported and placed. Values less than about 35% indicate potentially satisfactory performance for most concrete and asphalt uses. Values of more than 45% indicate that the aggregate may be susceptible to excessive breakdown during handling and placing. This test has been replaced by the micro-Deval abrasion test for coarse aggregate (see below), but, because of the large number of Los Angeles abrasion analyses that exist in historical MTO records, this test can still provide an indication of the aggregate quality.

Magnesium Sulphate Soundness Test (LS-606): This test is designed to simulate the action of freezing and thawing on aggregate. Those aggregates which are susceptible will usually break down and give high losses in this test. Values greater than about 12 to 15% indicate potential problems for concrete and asphalt coarse aggregate.

Micro-Deval Abrasion Test (LS-618 and LS-619): The micro-Deval abrasion test for fine aggregate is an accurate measure of the amount of hard, durable materials in sand-sized particles. This abrasion test is quick, cheap and more precise than the fine aggregate magnesium sulphate soundness test that suffers from a wide multi-laboratory variation. The magnesium sulphate soundness test is still considered an alternative test as indicated in many of the accompanying tables in this appendix. The micro-Deval abrasion test for coarse aggregate has replaced the Los Angeles abrasion and impact test.

Petrographic Examination (LS-609): Individual aggregate particles in a sample are divided into categories good, fair, poor and deleterious, based on their rock type (petrography) and knowledge of past field performance. A petrographic number (PN) is calculated. The higher the PN, the lower the quality of the aggregate.

Polished Stone Value (PSV) (British Standard 812): The PSV is a measure of the resistance of aggregate to the polishing action of a pneumatic tire under conditions similar to those occurring on the road surface. The actual relationship between skidding resistance and PSV varies depending on the type of road surface, age, amount of traffic and other factors. Nevertheless, an aggregate with a high PSV will generally provide higher skid resistance than one with a low PSV. This test is described in British Standard 812 (1975). Values less than 45 indicate marginal frictional properties, whereas values greater than 55 indicate excellent frictional properties (average value no less than 50).

Unconfined Freeze–Thaw Test (LS-614): This test is designed to identify aggregate material that may be susceptible to excessive damage caused by freeze–thaw cycles. Aggregates that give losses greater than about 6% have a high probability of causing "popouts" on concrete and asphalt surfaces.

MATERIAL SPECIFICATIONS FOR AGGREGATES: BASE AND SUBBASE PRODUCTS

Table E1. Physical property requirements for aggregates: base, subbase, select subgrade and backfill material.

MTO Test Number	Laboratory Test	Granular O	Granular A	Granular B (Type I and Type III)	Granular B (Type II)	Granular M	Select Subgrade Material
LS-614	Unconfined Freeze–Thaw Loss (% maximum)	15	—	—	—	—	—
LS-616 LS-709	Fine Aggregate Petrographic Requirement	*[Note 1]*					
LS-618	Micro-Deval Abrasion Loss, Coarse Aggregate (% maximum loss)	21	25	30 *[Note 2]*	30	25	30 *[Note 2]*
LS-619	Micro-Deval Abrasion Loss, Fine Aggregate (% maximum loss)	25	30	35	35	30	—
LS-630	Amount of Contamination	*[Note 3]*					
LS-631	Plastic Fines	None Permitted					
LS-704	Plasticity Index (maximum)	0	0	0	0	0	0

Note 1. For materials north of the French River and Mattawa River only: for materials with >5.0% passing the 75 µm sieve, the amount of mica retained on the 75 µm sieve (passing the 150 µm sieve) shall not exceed 10% of the material in that sieve fraction unless testing (LS-709) determines permeability values >1.0 $\times 10^{-4}$ cm/s and/or field experience show satisfactory performance (prior data demonstrating compliance with this requirement will be acceptable provided such testing has been done within the past 5 years and field performance has been satisfactory).

Note 2. The coarse aggregate micro-Deval abrasion loss test requirement will be waived if the material has more than 80% passing the 4.75 mm sieve.

Note 3. Granular A, B Type I, B Type III, or M may contain up to 15% by mass crushed glass and/or ceramic material. Granular A, O, B Type I, B Type III and M shall not contain more than 1.0% by mass of wood, clay brick, and/or gypsum, and/or gypsum wall board or plaster. Granular B Type II and SSM shall not contain more than 0.1% by mass of wood.

Greater detail, additional specifications and other aggregate product information can be obtained from the Ministry of Transportation. Details above are derived from MTO SP-110513 (August 2007).

MATERIAL SPECIFICATIONS FOR AGGREGATES: HOT MIX ASPHALT PRODUCTS

Table E2. Physical property requirements for coarse aggregate (surface course): SMA, Superpave™ 9.5, 12.5, 12.5 FC1 and 12.5 FC2.

MTO Test Number	Laboratory Test	Superpave 9.5, 12.5	Aggregate Type			
			Gravel	Quarried Rock (SMA, Superpave 12.5 FC1 and 12.5 FC2)		
			(Superpave 12.5 FC1 only)	Dolomitic Sandstone	Traprock, Diabase, Andesite	Meta-arkose, Metagabbro, Gneiss
LS-601	Wash Pass, 75 µm sieve (% maximum loss)	1.3 *[Note 4]*	1.0 *[Note 5]*	1.0 *[Note 5]*	1.0 *[Note 5]*	1.0 *[Note 5]*
LS-604	Absorption (% maximum)	2.0	1.0	1.0	1.0	1.0
LS-608	Flat and Elongated Particles (% maximum (4:1))	20	15	15	15	15
LS-609	Petrographic Number (HL) (maximum)	*[Note 6]*	120	145	120	145
LS-613	Insoluble Residue Retained, 75 µm sieve (% minimum)	—	—	45	—	—
LS-614	Unconfined Freeze–Thaw Loss (% maximum loss)	6 *[Note 7]*	6	7	6	6
LS-618	Micro-Deval Abrasion Loss (% maximum loss)	17	10	15	10	15
Alternative Requirement for LS-614						
LS-606	Magnesium Sulphate Soundness Loss (% maximum loss)	12	—	—	—	—

Note 4. When control charts (n >20) are used for LS-601, the average value shall not exceed the specification maximum (1.3%), with no single value greater than 1.7%. When quarried rock is used as a source of coarse aggregate, a maximum of 2.0% passing the 75 µm sieve shall be permitted. When control charts (n >20) are used from LS-601 for quarried rock, the average value shall not exceed the specification maximum (2.0%) with no single value greater than 2.4%.

Note 5. When control charts (n >20) are used for LS-601, the average value shall not exceed the specification maximum (1.0%), with no single value greater than 1.4%.

Note 6. For the locations listed below, Petrographic Number (HL) is replaced by the following Petrographic Examination requirements. When the coarse aggregate for use in a surface course mix is obtained from a gravel pit or quarry containing more than 40% carbonate rock type, e.g., limestone and dolostone, then blending with aggregate of non-carbonate rock type shall be required such as to increase the non-carbonate rock type content of the coarse aggregate to 60% minimum, as determined by LS-609. The method of blending shall be uniform and shall be subject to approval by the owner. In cases of dispute, LS-613 shall be used with a minimum of acid insoluble residue of 60%. When the aggregate for a surface course mix is obtained from a non-carbonate gravel or quarry source, blending with carbonate rock types shall not be permitted. This requirement is applicable to coarse aggregates used in surface course mixes in the area to the north and west of a boundary defined as follows: the north shore of Lake Superior, the north shore of the St. Mary's River, the south shore of St. Joseph Island, the north shore of Lake Huron easterly to the north and east shore of Georgian Bay (excluding Manitoulin Island), along the Severn River to Washago and a line easterly passing through Norland, Burnt River, Burleigh Falls, Madoc, and hence easterly along Highway 7 to Perth and northerly to Calabogie and easterly to Arnprior and the Ottawa River.

Note 7. For Superpave 12.5 only, the requirements will be waived by the owner when the aggregate meets the alternative requirements for LS-606.

Table E3. Physical property requirements for coarse aggregate (binder course): Superpave™ 9.5, 12.5, 19.0, 25.0 and 37.5.

MTO Test Number	Laboratory Test	Superpave 9.5, 12.5, 19.0, 25.0 and 37.5
LS-601	Wash Pass, 75 µm sieve (% maximum loss)	1.3 *[Note 8]*
LS-604	Absorption (% maximum)	2.0
LS-608	Flat and Elongated Particles (% maximum (4:1))	*
LS-614	Unconfined Freeze–Thaw Loss (% maximum loss) *[Note 9]*	15
LS-618	Micro-Deval Abrasion Loss (% maximum loss)	21
Alternative Requirement for LS-614		
LS-606	Magnesium Sulphate Soundness Loss (% maximum loss)	15

Note 8. When control charts (n >20) are used for LS-601, the average value shall not exceed the specification maximum (1.3%), with no single value greater than 1.7%. When quarried rock is used as a source of coarse aggregate, a maximum of 2.0% passing the 75 µm sieve shall be permitted. When control charts (n>20) are used for LS-601 for quarried rock, the average value shall not exceed the specification maximum (2.0%), with no single value greater than 2.4%.

Note 9. This requirement will be waived by the owner when the aggregate meets the requirements for LS-606.

* Designer fill-in, contact the MTO.

Table E4. Physical property requirements for fine aggregate: SMA, Superpave™ 9.5, 12.5, 12.5 FC1, 12.5 FC2, 19.0, 25.0 and 37.5.

MTO Test Number	Laboratory Test	SMA, Superpave 12.5 FC2	Superpave 12.5 FC1	Superpave 9.5, 12.5, 19.0, 25.0 and 37.5
LS-619	Micro-Deval Abrasion Loss (% maximum loss) *[Note 10]*	15	20	25
LS-704	Plasticity Index (maximum)	0	0	0

Note 10. Where the blending method has been selected for QC, the micro-Deval abrasion loss of each individual fine aggregate in the stockpile, prior to blending, shall not exceed 35%.

Greater detail, additional specifications and other aggregate product information can be obtained from the Ministry of Transportation. The above specifications are from MTO SP-110F12 (2007).

MATERIAL SPECIFICATIONS FOR AGGREGATES: CONCRETE PRODUCTS

Table E5. Physical property requirements for coarse aggregate.

MTO or CSA Test Number	Laboratory Test	Acceptance Requirements: Pavement	Acceptance Requirements: Structures, Sidewalk, Curb and Gutter, and Concrete Base
LS-601	Material finer than 75 µm sieve, by washing (% maximum loss) *[Note 11]* • for gravel • for crushed rock	 1.0 2.0	 1.0 2.0
LS-604 or CSA A23.2-12A	Absorption (% maximum)	2.0	2.0
LS-608	Flat and Elongated Particles (% maximum (4:1))	20	20
LS-609	Petrographic Number (Concrete) (maximum)	125	140
LS-614 or CSA A23.2-24A	Unconfined Freeze–Thaw Loss (% maximum loss) *[Note 12]*	6	6
LS-618 or CSA A23.2-29A	Micro-Deval Abrasion Loss (% maximum loss)	14	17
LS-620 or CSA A23.2-25A	Accelerated Mortar Bar Expansion (% maximum at 14 days) *[Notes 13, 14]*	0.150 *[Note 15]*	0.150 *[Note 15]*
CSA A23.2-14A	Concrete Prism Expansion (% maximum at 1 year) *[Notes 13, 16]*	0.040	0.040
CSA A23.2-26A	Potential Alkali–Carbonate Reactivity of Quarried Carbonate Rock *[Note 17]*	Chemical composition must plot in the nonexpansive field of a specific figure used with test	
Alternative Requirement for LS-614			
LS-606	Magnesium Sulphate Soundness Loss, 5 cycles (% maximum loss) *[Note 12]*	12	12

General Notes:
- Where a concrete surface is subject to vehicular traffic, the physical requirements for "Pavement" will apply to the aggregate used.
- For air-cooled blast-furnace slag aggregate, the allowable maximum value for micro-Deval shall be 21% for structures and pavements and the allowable maximum value for absorption will conform to the owner's requirements for slag aggregate.
- A coarse aggregate may be accepted or rejected by the owner based on the results of freeze–thaw testing of concrete or field performance.

Note 11. When control charts (n >20) are used for LS-601, the average value shall not exceed the specification maximum (1.3%), with no single value greater than 1.7%. When quarried rock is used as a source of coarse aggregate, a maximum of 2.0% passing the 75 µm sieve shall be permitted. When control charts (n >20) are used for LS-601 for quarried rock, the average value shall not exceed the specification maximum (2.0%), with no single value greater than 2.4%.

Note 12. The owner will waive the requirements for freeze–thaw loss when the aggregate meets the alternative magnesium sulphate soundness requirements, LS-606.

Note 13. The need to demonstrate compliance with this requirement will be waived by the Contract Administrator if the source is on the current Ministry of Transportation regional Aggregate Source List (ASL) for Structural Concrete Fine and Coarse Aggregates or the Aggregate Source List of Concrete Base/Pavement Coarse Aggregates. If the aggregate is potentially expansive due to alkali–carbonate reaction as determined by CSA A23.2-26A, the aggregate shall meet the requirements of CSA A23.2-14A, even though it may be shown as a coarse aggregate on the ASL for Structural Concrete Fine and Coarse Aggregates or the ASL for Concrete Base/Pavement Coarse Aggregates.

Note 14. An aggregate that fails to meet these requirements will be accepted by the Contract Administrator provided the requirements of CSA A23.2-14A are met.

Note 15. If the aggregate is a quarried sandstone, siltstone, granite or gneiss, the expansion shall be less than 0.080% after 14 days. For quarried aggregates of the Gull River, Bobcaygeon, Verulam and Lindsay formations, the expansion shall be less than 0.100% after 14 days.

Note 16. An aggregate needs to meet this requirement only if it fails the requirements of either CSA A23.2-25A or CSA A23.2-26A. The test data shall have been obtained within the past 18 months from aggregate from the same location within the source as that to be used in the work. If this test is conducted to show that an average deemed potentially expansive by CSA A23.2-26A does not exceed 0.040% after one year, then chemical analysis, CSA A23.2-26A, shall be provided to show that the aggregate intended for use has the same chemical composition as the material tested in CSA A23.2-14A.

Note 17. This requirement only applies to aggregate quarried from the Gull River and Bobcaygeon formations of southern and eastern Ontario. These dolomitic limestones crop out on the southern margin of the Canadian Shield from Midland to Kingston and in the Ottawa–St. Lawrence Lowlands near Cornwall.

Table E6. Physical property requirements for fine aggregate.

MTO or CSA Test Number	Laboratory Test	Acceptance Limits
LS-610	Organic Impurities, (organic plate number) *[Note 18]*	3
LS-619 or CSA A23.2-23A	Micro-Deval Abrasion Loss (% maximum loss)	20
LS-620 or CSA A23.2-25A	Accelerated Mortar Bar Expansion (% maximum at 14 days) *[Notes 19, 20]*	0.150
CSA A23.2-14A	Concrete Prism Expansion (% maximum at 1 year) *[Notes 19, 21]*	0.040

Note 18. A fine aggregate producing a colour darker than standard colour No. 3 shall be considered to have failed this requirement. A failed fine aggregate may be used if comparative mortar specimens prepared according to ASTM C87 meet the following requirements:

- Mortar specimens prepared using unwashed fine aggregate shall have a 7 day compressive strength that is a minimum of 95% of the strength of mortar specimens prepared using the same fine aggregate washed in a 3% sodium hydroxide solution. Type GU hydraulic cement shall be used.
- Setting time of the unwashed fine aggregate mortar specimens shall not differ from washed fine aggregate mortar specimens by more than 10%.

Note 19. The need for data to demonstrate compliance with this requirement shall be waived by the Contract Administrator if the aggregate source is on the current Ministry of Transportation's regional Aggregate Source List for Structural Concrete Fine and Coarse Aggregates.

Note 20. An aggregate that fails this requirement may be accepted provided the requirements of CSA A23.2-14A are met.

Note 21. An aggregate need only meet this requirement if it fails the requirements of CSA A23.2-25A. Test data shall have been obtained with the past 18 months from aggregate that is from the same source, processed in the same manner, as the material intended for use.

Greater detail, additional specifications and other aggregate product information can be obtained from the Ministry of Transportation. The above specifications are from MTO SP-110F11 (2007).

Metric Conversion Table

SI Unit	Multiplied by	Gives	Imperial Unit	Multiplied by	Gives
Conversion from SI to Imperial			**Conversion from Imperial to SI**		
		LENGTH			
1 mm	0.039 37	inches	1 inch	**25.4**	mm
1 cm	0.393 70	inches	1 inch	**2.54**	cm
1 m	3.280 84	feet	1 foot	**0.304 8**	m
1 m	0.049 709	chains	1 chain	20.116 8	m
1 km	0.621 371	miles (statute)	1 mile (statute)	**1.609 344**	km
		AREA			
1 cm^2	0.155 0	square inches	1 square inch	**6.451 6**	cm^2
1 m^2	10.763 9	square feet	1 square foot	**0.092 903 04**	m^2
1 km^2	0.386 10	square miles	1 square mile	2.589 988	km^2
1 ha	2.471 054	acres	1 acre	0.404 685 6	ha
		VOLUME			
1 cm^3	0.061 023	cubic inches	1 cubic inch	**16.387 064**	cm^3
1 m^3	35.314 7	cubic feet	1 cubic foot	0.028 316 85	m^3
1 m^3	1.307 951	cubic yards	1 cubic yard	0.764 554 86	m^3
		CAPACITY			
1 L	1.759 755	pints	1 pint	0.568 261	L
1 L	0.879 877	quarts	1 quart	1.136 522	L
1 L	0.219 969	gallons	1 gallon	**4.546 090**	L
		MASS			
1 g	0.035 273 962	ounces (avdp)	1 ounce (avdp)	28.349 523	g
1 g	0.032 150 747	ounces (troy)	1 ounce (troy)	**31.103 476 8**	g
1 kg	2.204 622 6	pounds (avdp)	1 pound (avdp)	**0.453 592 37**	kg
1 kg	0.001 102 3	tons (short)	1 ton(short)	**907.184 74**	kg
1 t	1.102 311 3	tons (short)	1 ton (short)	**0.907 184 74**	t
1 kg	0.000 984 21	tons (long)	1 ton (long)	**1016.046 908 8**	kg
1 t	0.984 206 5	tons (long)	1 ton (long)	**1.016 046 9**	t
		CONCENTRATION			
1 g/t	0.029 166 6	ounce (troy) / ton (short)	1 ounce (troy) / ton (short)	34.285 714 2	g/t
1 g/t	0.583 333 33	pennyweights / ton (short)	1 pennyweight / ton (short)	1.714 285 7	g/t

OTHER USEFUL CONVERSION FACTORS

	Multiplied by	
1 ounce (troy) per ton (short)	31.103 477	grams per ton (short)
1 gram per ton (short)	0.032 151	ounces (troy) per ton (short)
1 ounce (troy) per ton (short)	20.0	pennyweights per ton (short)
1 pennyweight per ton (short)	0.05	ounces (troy) per ton (short)

Note: Conversion factors in ***bold*** *type are exact. The conversion factors have been taken from or have been derived from factors given in the* Metric Practice Guide for the Canadian Mining and Metallurgical Industries, *published by the Mining Association of Canada in co-operation with the Coal Association of Canada.*

ISSN 0708-2061 (print)
ISBN 978-1-4606-0908-8 (print)

ISSN 1917-330X (online)
ISBN 978-1-4606-0909-5 (PDF)

Aggregate Resources Inventory Paper 175

MAP 1

Sand and Gravel Resources for the County of Perth

Scale 1:100 000

2000 m 0 2 4 km

NTS References: 40 P/3, 6, 7, 10, 11, 14, 15

Location Map 1 cm equals 80 km

SOURCES OF INFORMATION

Base map information derived from National Topographic System (NTS) maps, Natural Resources Canada, scale 1:50 000, and from the Ontario Land Information Warehouse, Land Information Ontario, Ministry of Natural Resources, scale 1:50 000, with modifications by staff of the Ministry of Northern Development and Mines.
Projection: North American Datum 1983 (NAD83), Zone 17.

Aggregate suitability data from the Ministry of Transportation, Ontario. Selected water well data from the Ministry of the Environment, Ontario. Additional borehole data from the Ontario Geological Survey, Ministry of Northern Development and Mines.

Geology based on
- Cooper, A.J., Fitzgerald, W.D. and Clue, J. 1977
- Cowan, W.R. 1979b
- Cowan, W.R., Cooper, A.J. and Pinch, J.J. 1986
- Karrow, P.F. 1977b, 1993b, 1993c
- Sado, E.V. and Vagners, U.J. 1975

Additional geology by D.J. Rowell, 2012. Compilation by D.J. Rowell. Drafting by S.A. Evers. This map is published with the permission of the Director, Ontario Geological Survey.

Information from this publication may be quoted if credit is given. It is recommended that reference to this map be made in the following form:

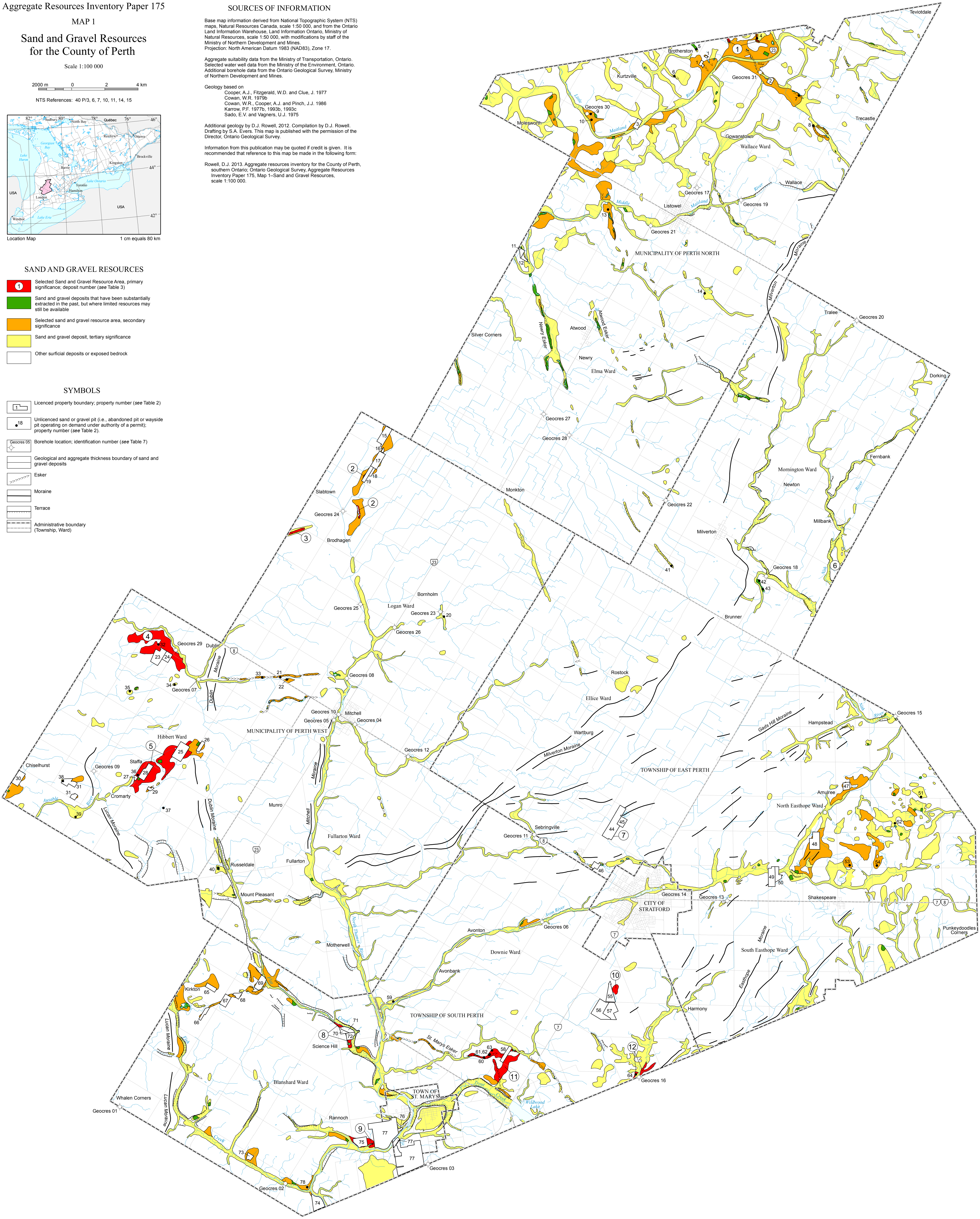
Rowell, D.J. 2013. Aggregate resources inventory for the County of Perth, southern Ontario; Ontario Geological Survey, Aggregate Resources Inventory Paper 175, Map 1–Sand and Gravel Resources, scale 1:100 000.

SAND AND GRAVEL RESOURCES

- Selected Sand and Gravel Resource Area, primary significance; deposit number (*see* Table 3)
- Sand and gravel deposits that have been substantially extracted in the past, but where limited resources may still be available
- Selected sand and gravel resource area, secondary significance
- Sand and gravel deposit, tertiary significance
- Other surficial deposits or exposed bedrock

SYMBOLS

- Licenced property boundary; property number (*see* Table 2)
- Unlicenced sand or gravel pit (i.e., abandoned pit or wayside pit operating on demand under authority of a permit); property number (*see* Table 2).
- Borehole location; identification number (*see* Table 7)
- Geological and aggregate thickness boundary of sand and gravel deposits
- Esker
- Moraine
- Terrace
- Administrative boundary (Township, Ward)



Aggregate Resources Inventory Paper 175

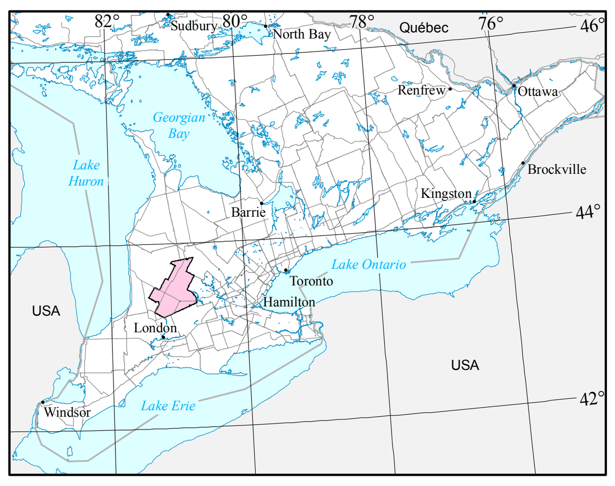
MAP 2

Bedrock Resources for the County of Perth

Scale 1:100 000

2000 m 0 2 4 km

NTS References: 40 P/3, 6, 7, 10, 11, 14, 15



Location Map 1 cm equals 80 km

SYMBOLS

- Licenced quarry boundary; property number (*see* Table 5)
- Unlicenced quarry (i.e., abandoned quarry or wayside quarry operating on demand under authority of a permit); property number (*see* Table 5).
- Geological formation and/or member boundary
- Drift thickness contour
- Isolated bedrock outcrop
- Administrative boundary (Township, Ward)

SOURCES OF INFORMATION

Base map information derived from National Topographic System (NTS) maps, Natural Resources Canada, scale 1:50 000, and from the Ontario Land Information Warehouse, Land Information Ontario, Ministry of Natural Resources, scale 1:50 000, with modifications by staff of the Ministry of Northern Development and Mines.
Projection: North American Datum 1983 (NAD83), Zone 17.

Aggregate suitability data from the Ministry of Transportation, Ontario. Selected water well data from the Ministry of the Environment, Ontario. Additional drill hole data from the Ontario Geological Survey, Ministry of Northern Development and Mines.

Geology based on
Armstrong, D.K. and Dodge, J.E.P. 2007

Additional drift thickness information based on
Cooper, A.J. 1978
Davies, L.L. and McClymont, W.R. 1962
Holden, K.M., Thomas, J. and Karrow, P.F. 1993a, 1993b
Karrow, P.F. and Ferguson, A.J. 1975
Kelly, R.I. and Carter, T.R. 1993
Sado, E.V. and Jones, D. 1980

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Information from this publication may be quoted if credit is given. It is recommended that reference to this map be made in the following form:

Rowell, D.J. 2013. Aggregate resources inventory for the County of Perth, southern Ontario; Ontario Geological Survey, Aggregate Resources Inventory Paper 175, Map 2–Bedrock Resources, scale 1:100 000.

LEGEND – BEDROCK UNITS

PHANEROZOIC
PALEOZOIC
DEVONIAN
MIDDLE DEVONIAN
Dundee Formation: Limestone and dolostone
Lucas Formation: Dolostone and limestone
Amherstburg Formation: Dolostone and limestone
LOWER DEVONIAN
Bois Blanc Formation: Limestone and dolostone
SILURIAN
UPPER SILURIAN
Bass Islands Formation: Dolostone
Salina Formation (Group): A variety of rock units

DRIFT THICKNESS

- Paleozoic bedrock outcrop (*see* Table 4); areas of exposed bedrock partially covered by a thin veneer of drift. Drift thickness is generally less than 1 m (3 feet).
- Paleozoic bedrock covered by drift (*see* Table 4); drift thickness is generally 1 to 8 m (3 to 25 feet). Bedrock outcrops may occur.
- Paleozoic bedrock covered by drift (*see* Table 4); drift thickness is generally 8 to 15 m (25 to 50 feet). Isolated bedrock outcrops may occur.
- Paleozoic bedrock covered by drift; drift thickness is generally greater than 15 m (50 feet); or areas underlain by Precambrian bedrock.