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Aggregate Resources Inventory of the

County of Frontenac

Southern Ontario

Ontario Geological Survey
Aggregate Resources Inventory
Paper 187

2012

Ontario

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By A.S. Marich

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Abstract

This report provides an evaluation of the aggregate resources for the County of Frontenac. This report is based on a detailed field assessment undertaken in the summer of 2009 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).

Sand and gravel deposits located within the County of Frontenac are the result of glacial, glaciofluvial, glaciolacustrine and postglacial fluvial and lacustrine processes. The deposits are relatively small deposits of variable thickness and quality. Four areas have been selected at the primary significance level and a number at the secondary significance level. Protective measures should be considered for these resource areas.

Paleozoic limestones are the primary source of high-quality crushed aggregate in the County of Frontenac. Portions of the Gull River Formation and the Bobcaygeon Formation, occupying approximately 57 137 ha with an estimated aggregate resource of 22 081.6 million tonnes, have been selected for possible resource protection.

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.

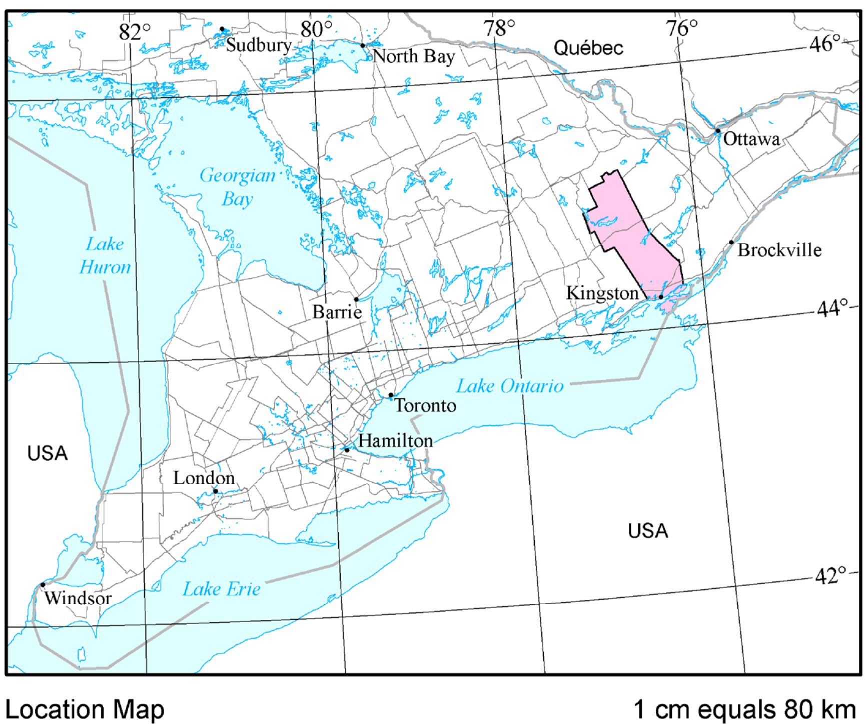


Figure 1. Map of southern Ontario showing the location of the County of Frontenac.

Aggregate Resources Inventory of the County of Frontenac

By A.S. Marich[1]

Field work, map production and report by A.S. Marich in 2009.

Updates and report additions by V.L. Lee in 2012.

Manuscript accepted for publication in 2012 by D.K. Armstrong, Manager (Acting), Sedimentary Geoscience Section, Ontario Geological Survey. This report is published with the permission of the Director, Ontario Geological Survey.

[1] Sedimentary Geoscience 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 Ontario Ministry of Natural Resources (MNR). 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 Ontario 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 MNR, 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 Ontario 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, 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

Three maps, each portraying a different aspect of the aggregate resources in the report area, accompany the report. Maps 1A and 1B, "Sand and Gravel Resources", provide an inventory and evaluation of the sand and gravel resources in the report area. Map 2, "Bedrock Resources", covering the southern portion of the study area, 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 Maps 1A, 1B and 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 Maps 1A and 1B) 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 tables for sand and gravel resources data are found in the folder "Sand_Gravel"; the data for bedrock resources data are in the folder "Bedrock". The tables are in database format (*.dbf* file) that can be opened using other software, for example Microsoft® Excel®. The cross-references include the folder, the table and the field name separated by a short vertical line; the field name is indicated by bold, small capital letters (e.g., Bedrock | Drift_Thick.dbf | **AABBCC**).

Maps 1A and 1B: Sand and Gravel Resources

Maps 1A and 1B show the extent and quality of sand and gravel deposits within the study area and an evaluation of the aggregate resources. The maps are 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 Maps 1A and 1B. 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 Maps 1A and 1B and described in Table 2. Similarly, any test locations appear on Maps 1A and 1B 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 | Sand_Gravel.dbf | **SIGN**.

Areas of primary significance are coloured red on Maps 1A and 1B and identified by a deposit number that corresponds to numbers in Table 3. The deposit number is also recorded in Sand_Gravel | Sand_Gravel.dbf | **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 Maps 1A and 1B. 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 Maps 1A and 1B. 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 | Sand_Gravel.dbf | **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 | Sand_Gravel.dbf | **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 | Sand_Gravel.dbf | **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 Ontario Ministry of Transportation (MTO) and the Sedimentary Geoscience 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 | Sand_Gravel.dbf | **DEP_ORIGIN**.

In the following example of a deposit information code,

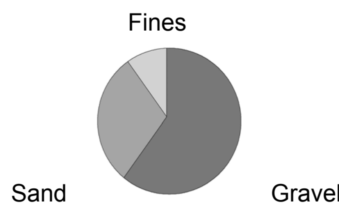
"G / 1 / OW / C",

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 | Sand_Gravel.dbf | **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 MNR, 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 | Sand_Gravel.dbf | **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.

$$\text{Tonnage} = \text{Area} \times \text{Thickness} \times \text{Density Factor}$$

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 Ontario Ministry of the Environment (MOE), oil and gas well data from the Ontario 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 Maps 1A and 1B.

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.dbf.

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 extent 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 Bedrock | Drift_Thick.dbf | 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 Bedrock | Drift_Thick.dbf | 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 Ontario Ministry of Transportation. 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 Bedrock | Drift_Thick.dbf | AREA; the favourable bedrock formations are reported in Bedrock | Drift_Thick.dbf | 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 Bedrock | Drift_Thick.dbf | 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 Frontenac

LOCATION AND POPULATION

The County of Frontenac (herein referred to as "Frontenac County") occupies an area of 367 248 ha in southeastern Ontario, on the north shore of Lake Ontario between the City of Kingston and the County of Renfrew. It is bounded to the west by the County of Lennox and Addington; to the east by the County of Lanark and the County of Leeds and Grenville; to the north by the County of Renfrew; and to the south by Lake Ontario. The county is covered by all or parts of 10, 1:50 000 scale map sheets of the National Topographic System (NTS). These maps sheets are Denbigh (31 F/3), Clyde Forks (31 F/2), Bon Echo (31 C/14), Sharbot Lake (31 C/15), Kaladar (31 C/11), Tichborne (31 C/10), Sydenham (31 C/7), Gananoque (31 C/8), Bath (31 C/2) and Wolfe Island (31 C/1).

Frontenac County consists of 4 townships and the City of Kingston (Table A). In 2006, Frontenac County was inhabited by 143 865 residents, a 3.8% increase from 2001 (Statistics Canada 2006). Much of the county is rural, with the majority of the county farmed or forested. The main urban centre, the City of Kingston, comprises 81.5% of the overall population.

Table A – Area and Population, County of Frontenac

Municipality (Listed Alphabetically)	Land Area (Hectares)	2001 Population	2006 Population
Township of Central Frontenac	97 007	4557	4665
Township of Frontenac Islands	17 499	1638	1862
City of Kingston	45 039	114 195	117 207
Township of North Frontenac	113 575	1801	1904
Township of South Frontenac	94 128	16 415	18 227
TOTAL	**367 248**	**138 606**	**143 865**

Major road access to Frontenac County is provided by Provincial Highways 401 and 7. Access to Toronto and Ottawa is via Highway 401 in the south and Highway 7 in the north. Highway 15 provides travel northeast from Kingston and Highway 41 provides travel north from Highway 401. Travel throughout the county is provided by a well-developed network of county and township roads.

SURFICIAL GEOLOGY AND PHYSIOGRAPHY

The physiography and distribution of surficial materials in Frontenac County, including the sand and gravel deposits illustrated on Maps 1A and 1B, were primarily deposited by glacial activity that occurred during the Late Wisconsinan (Barnett 1992). During the Late Wisconsinan, approximately 23 000 to 10 000 years ago, the Laurentide Ice Sheet covered all of Frontenac County and extended into New York State. The ice advanced and retreated repeatedly across the study area during the Quaternary with the last ice flow being in a generally northeast to the southwest direction. This southwest advance is evident from the orientation of striations on bedrock surfaces and other ice-flow indicators within glacial sediments (Barnett 1992).

As the ice advanced, it scoured the underlying overburden and bedrock, accumulating debris within and beneath the ice sheet. This entrained debris consisted of a mixture of boulders, stone, sand, silt and clay. Pressure at the base of the glacier melted the ice allowing debris to be released and eventually lodged onto the surface substrate. The accretion and consolidation of debris over time led to the creation of tills, which are widespread across Frontenac County (Barnett 1992). The tills present in the northern regions of Frontenac County are mostly derived from Precambrian rock and tend to be sandy. According to Barnett (1992), on average, the till matrix comprises over 70% sand with less than 5% clay particles. Crystalline clasts are common in these tills making them essentially non-calcareous (Barnett 1992). In contrast, the till derived from the erosion of carbonate rocks in the southern regions of Frontenac County is commonly silty. The till matrix grain-size distribution is usually between 25 to 40% sand, 40 to 50% silt and 15 to 30% clay (Barnett 1992).

Other landforms deposited during the advancement of the glacier include drumlins, moraines and the associated landforms (Barnett 1992). These types of deposits are not wide spread in Frontenac County, although a few examples are present.

In most of Frontenac County, as the ice advanced, it scoured, polished and rounded off erosion-resistant Precambrian bedrock accentuating structural features. As the Precambrian bedrock in these regions generally provided little debris to the glacier, surficial material deposited in these areas is generally limited to a thin veneer of till. Consequently, the area is characterized by rough rounded knobs and hills of Precambrian bedrock. Chapman and Putnam (1984) identify these areas as the Algonquin highlands and Georgian Bay fringe physiographic regions (Figure 2). Outcrops of bare bedrock are common as till over the bedrock is generally thin (<1 m) and discontinuous throughout the region. The valleys between bedrock highs or other structurally controlled valleys tend to be floored with glaciofluvial sand and gravel and are commonly filled with bogs or swamps (Chapman and Putnam 1984).

With glacial retreat, accumulated debris was deposited over portions of the county by meltwater as ice-contact deposits (e.g., eskers). These deposits lie on top of the much older Precambrian and overlying Paleozoic bedrock, which have helped shape their location and quality (Barnett 1992). There are areas in the Algonquin highlands and Georgian Bay fringe regions where the glacial drift is thicker. These significant accumulations of glacial material have occurred in and under the influence of bedrock-controlled valleys. Ice-contact and outwash deposits are present in these areas (Chapman and Putnam 1984). A belt of south-trending ice-contact and outwash materials occurs south of Mazinaw Lake running parallel to Highway 41. This glaciofluvial deposit was created in part from waters of a proglacial lake flowing south to the Lake Ontario basin. Another glaciofluvial system, near Snow Road Station, trends southwestward through hilly areas in the eastern portions of the Township of North Frontenac and the Township of Central Frontenac. Present in these deposits are eskers and outwash deposits. Finally, a large ice-contact deposit occurs north of Plevna (Ministry of Natural Resources 1987).

During the last glacial retreat, approximately 12 300 year ago, drainage of the St. Lawrence Valley was blocked by remaining glacial ice causing the water level in the Lake Ontario basin to rise far above present-day levels. This accumulation of water was glacial Lake Iroquois and the southern regions of Frontenac County were submerged (Barnett 1992). The southeast corner of Frontenac County, including Howe Island, is underlain by Precambrian bedrock that is part of the Frontenac Arch (sometimes referred to as the Frontenac Axis), a bedrock arch of the Canadian Shield that extends from the Thousand Islands northwest to Algonquin Provincial Park. Wave action in the lake removed sediment covering the bedrock knobs of the Frontenac Arch. Clay was deposited as bottom sediments in glacial Lake Iroquois in the lows between the exposed rock knobs. This particular region is identified and described by Chapman and Putnam (1984) as the Leeds knobs and flats and is characterized by Precambrian knobs and flat-lying clay plains.

The southwest and south-central portions of Frontenac County, including Wolfe Island, are the only regions of Frontenac County that are underlain by Paleozoic rock. This physiographic region, identified as the Napanee plain, is characterized by flat to undulating limestone with thin overburden as most of material was removed by glacial activity. In general, the till deposited in the region is thin, although some thicker drift occurs in stream valleys, and depressions commonly have thin deposits of stratified clay (Chapman and Putnam 1984).

A more detailed account of the glacial history and surficial geology of Frontenac County is provided by Barnett (1992), Chapman and Putnam (1984), Henderson (1966, 1973a, 1973b), Henderson and Kettles (1992), Kettles (1992), Kettles, Henderson and Henderson (1992), and Leyland and Russell (1983, 1984).

PREVIOUS WORK

A previous aggregate resources inventory of Frontenac County was completed in 1987 (Ministry of Natural Resources 1987: Open File Report 5581). This report differs from the “traditional” Aggregate Resources Inventory Paper content in that extensive borehole data collected during the earlier projects are included herein. These data are presented in Table 7 and in vector ESRI® ArcGIS® files.

SAND AND GRAVEL EXTRACTIVE ACTIVITY

At the time of writing, there were 105 licenced sand and gravel pits located throughout the Frontenac County. The total area licenced or permitted for sand and gravel extraction is 2943.9 ha. Some of the licenced or permitted operations are both sand and gravel and bedrock-derived (quarry) operations. This information was provided by the Ministry of Natural Resources in the fall of 2011. Updated and more detailed licence information can be obtain by contacting the Bancroft District office, Ministry of Natural Resources for the Township of North Frontenac and the Peterborough District - Kingston office, Ministry of Natural Resources for the townships of Central Frontenac, South Frontenac and Frontenac Islands and for the City of Kingston.

SAND AND GRAVEL AGGREGATE QUALITY

Test data from MTO files have been used extensively in the assessment of the resources of the county. 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 the Frontenac 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 the data 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.

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.

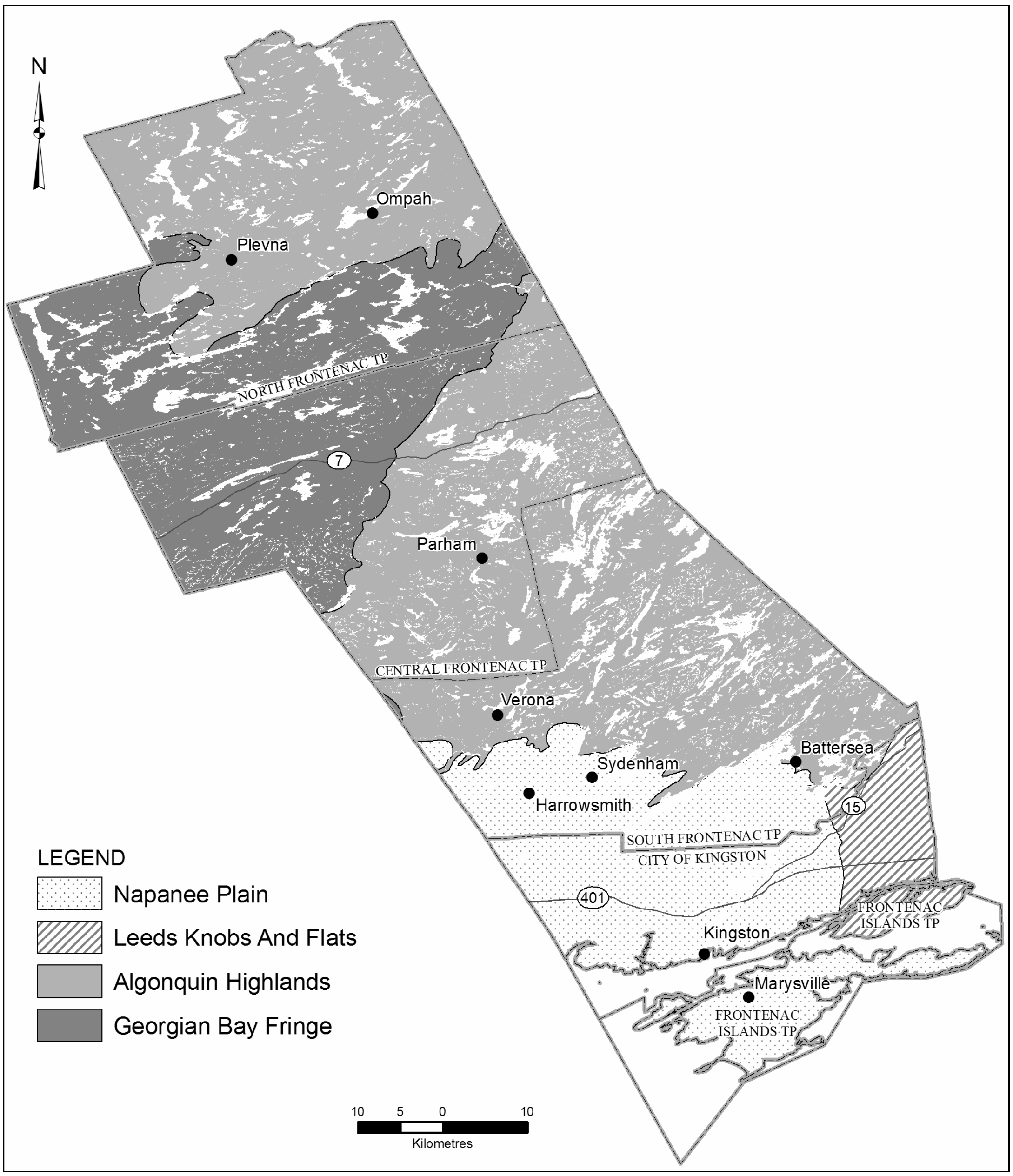


Figure 2. Physiographic regions of the County of Frontenac (*after* Chapman and Putnam 1984).

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.

It is 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

Maps 1A and 1B show the geographic distribution of sand and gravel–rich deposits in Frontenac County. The total area occupied by these deposits is 11 313.6 ha, representing 3.08% of the total area of the county (Table 1). These deposits contain an estimated 804.0 million tonnes of sand and gravel resources. The aggregate resources of Frontenac County consist mostly of sand, possess highly variable grain size distributions and, in many cases, contain high silt content. As such, the material included in the above estimates may have no aggregate production potential.

As noted previously, the northern half of the study area is blanketed predominantly by very thin till with sand and gravel deposits concentrated within bedrock valleys. Many of these deposits are currently occupied by wetlands, are located in areas of very poor access, and are located far from areas of need. Gravel content within these deposits is extremely variable, even within small individual deposits, but commonly consists of subrounded Precambrian granitic clasts, and has variable deleterious characteristics including high clast fissility.

The limited large sand and gravel deposits have, for the most part, been licenced and many are close to depletion. Large volumes of sand remain in small and discontinuous deposits that may be useful for local winter sand and rural road maintenance.

Four areas have been identified as Selected Sand and Gravel Resource Areas of primary significance and are indicated on Maps 1A and 1B in red. These 4 areas occupy an unlicenced area of 841.3 ha; this area is reduced to 775.1 ha, after considering cultural, physical and environmental constraints. These areas represent approximately 82.3 million tonnes of aggregate resources (Table 3).

Selected Sand and Gravel Resource Area 1

Selected Sand and Gravel Resource Area 1 is an ice-contact outwash deposit located along the southwest edge of the Township of North Frontenac. This deposit extends south from Lower Mazinaw Lake, trends south parallel to Highway 41 and continues southeast into the County of Lennox and Addington. This deposit includes fluvial and deltaic deposits from an ancient river channel that was the primary drainage of the proglacial Lower Mazinaw Lake (Moore and Morton 1986). This deposit thins southward as the distance from proglacial lake and glacier increased. The portions of this outwash system in the County of Lennox and Addington have been selected as an aggregate resource of secondary significance because the deposit is thinner in this region (Jagger Hims Limited and Ontario Geological Survey 1999).

The deposit consists of clean, medium- to fine-textured sand with 30 to 40% subrounded pea to cobble gravel. The gravel content of this deposit is highly variable and selective extraction maybe required. Data from previous studies indicated suitability for production of Select Subbase Material (SSM) and concrete products (Jagger Hims and Ontario Geological Survey 1999; Ministry of Natural Resources 1987). The deposit thins eastward and bedrock was observed in nearby abandoned pits and road cuts. Previous gradation results indicate a coarse aggregate content that ranges from 6.2 to 92.7%. Petrographic Number values range from 100 to 122 for Granular and 16 mm crushed and from 101.2 to 195 for hot mix and concrete. Magnesium sulphate soundness test results for coarse aggregate range from 1.2 to 12.7% and 4.6 to 21.8% for fine aggregate. The absorption value test results range from 0.6 to 1.07. Los Angeles abrasion test results range from 36 to 42.

Selected Sand and Gravel Resource Area 1 has a total unlicenced area of 796.8 ha. After considering physical and cultural constraints, the area available for possible resource protection and development is 739.0 ha. Assuming an average deposit thickness of 6 m, the area is estimated to contain a possible aggregate resource of 78.5 million tonnes (*see* Table 3). This total is independent of the material that is available in the adjacent portion of the deposit in the County of Lennox and Addington.

Selected Sand and Gravel Resource Area 2

Selected Sand and Gravel Resource Area 2 is an undifferentiated ice-contact stratified drift deposit located in the east-central part of the Township of North Frontenac close to the western border with the County of Lennox and Addington.

This resource area is an ice-contact deposit comprising medium- to fine-textured sand with minor silt and 30 to 45% gravel as estimated in the field. Clasts are granitic, are derived from Precambrian material and are subrounded. Face heights within local pits vary from 3 to 8 m, and this deposit appears to thicken eastward and likely extends to the north. Bedrock is exposed in a nearby road cut indicating the bedrock surface is highly variable at this location. Gravel in this deposit is crushable, but not likely suitable for high-quality uses such as asphalt production. Additional material testing is required to assess other possible uses of this deposit. Although this deposit does contain material of questionable aggregate quality, in comparison with other deposits in the County, this deposit contains relatively large amounts of gravel. This deposit represents an important source of aggregate in northern Frontenac County where gravel resources are limited.

Selected Sand and Gravel Resources Area 2 has a total unlicenced area of 35.9 ha. After considering physical and cultural constraints, the area available for possible resource protection and development is approximately 31.7 ha. Assuming an average thickness of 6 m, the area is estimated to contain a possible aggregate resource of 3.4 million tonnes (*see* Table 3).

Selected Sand and Gravel Resource Area 3

Selected Sand and Gravel Resource Area 3 is an undifferentiated ice-contact stratified drift deposit located in the central part of the Township of North Frontenac.

This resources area is an ice-contact deposit consisting of clean, medium- to fine-textured sand with >30% gravel in sections. Clasts are granitic Precambrian material, subrounded and granular to boulder in size, but are predominantly 3 to 5 cm in diameter. At the time of investigation, the deposit was unlicenced. Since that time, most of area of this deposit has been licenced; however, it needs to be noted that the deposit contains large amounts of gravel in sections, and contains significant amounts of gravel for the area and represents an important source of aggregate in northern Frontenac County where gravel resources are limited.

Selected Sand and Gravel Resources Area 3 has a total unlicenced area of 25.1 ha. After considering physical and cultural constraints, the area available for possible extraction is approximately 20.7 ha. Assuming an average thickness of 6 m, the area is estimated to contain a possible aggregate resource of 2.2 million tonnes (*see* Table 3). As the deposit is now mostly licenced, there is no area available for possible resource protection and development. All of the potential resource material is located within the licence.

Selected Sand and Gravel Resource Area 4

Selected Sand and Gravel Resources Area 4 is an undifferentiated ice-contact stratified drift deposit located in the northwest corner of the Township of Central Frontenac along the northern border. There are 3 licenced pits operating within this deposit, which account for the majority of the deposit.

Test results from a sample, AM-01-09, collected within this selected area as part of the present study, are provided in Table 9 and Figures 3A and 3B. Results of the gradation test indicate a coarse aggregate content of 29.2%. Micro-Deval abrasion test results for the fine aggregate fraction is 11.47%. Previous gradation results indicate a coarse aggregate content that ranges from 0.3 to 74.6%. Petrographic Number values range from 100 to 127.1 for Granular and 16 mm crushed and from 101 to 140 for hot mix and concrete. Magnesium sulphate soundness test results for coarse aggregate range from 0.4 to 6.4% and from 4.4 to 19.4% for fine aggregate. Los Angeles abrasion test results range from 16.4 to 27.5. These data suggest that the material in this deposit, with processing, can be used in the production of SSM and HL asphalt and concrete products.

Selected Sand and Gravel Resources Area 4 has a total unlicenced area of 8.6 ha. After considering physical and cultural constraints, the area available for possible resource protection and development is approximately 4.4 ha. Assuming an average thickness of 6 m, the area is estimated to contain a possible resource of 0.5 million tonnes (*see* Table 3). The amount of available tonnage within this selected resource is relatively low for a selected resource because the majority of the deposit is licenced. This deposit still represents an important source of high-quality aggregate because of the limited amount available in Frontenac County.

Resource Areas of Secondary Significance

Resources of secondary significance are, in some cases, high-quality, but low volume deposits. These deposits can contain excess fines or perhaps require further testing to assess potential use as aggregate. These deposits contain a large enough tonnage for local extraction, but may be lacking sufficient volume of material for commercial use.

A number of undifferentiated ice-contact stratified drift deposits located in the central part of the Township of North Frontenac have been selected as sand and gravel resources areas of secondary significance. The first is a broad, flat-lying deposit located in the northwest corner, south of Buckshot Lake Road within a bedrock valley. This is an ice-contact deposit consisting of medium-textured sand with 20 to 30% gravel. Clasts are predominantly Precambrian and include crushable sized material. Previous studies indicated that this material is suitable for Granular B and SSM products. The deposit depth is highly variable; faces within pits indicate 2 m to greater than 6 m of granular material. The material in this deposit could be used under a wayside permit for local construction road projects.

The second ice-contact deposit within the Township of North Frontenac selected as sand and gravel resource area of secondary significance is located in the central region of the Township of North Frontenac. It is a 2 km long, linear ice-contact deposit trending northeast. The material consists of medium- to fine-textured sand with gravel and crushable material in varying proportions. A gravel pit located within this deposit exhibited 5 to 10 m faces, and the deposit depth is highly variable. Additional data collection is required to assess the true volume and quality of the deposit. Testing by the Ministry of Transportation (MTO) found parts of this deposit suitable for Granular A and B base courses, asphalt and concrete aggregate with some crushable gravel. This deposit is located along Road 506 and could provide an easily accessible source of sand and gravel to reconstruction projects along the road.

A small ice-contact deposit located in the central part of the Township of North Frontenac on Road 509 just west of Selected Sand and Gravel Resource Area 3 has been selected as a sand and gravel resource of secondary significance. The deposit covers an area of 4.0 ha and is predominantly sand. Face heights of an abandoned pit located within the deposit range from 4 to 10 m. This deposit can provide quality sand for construction projects in northern Frontenac and along the Road 509 corridor.

An ice-contact deposit located in the central part of the Township of North Frontenac on Road 509 just west of Selected Sand and Gravel Resource Area 3 has been selected as a sand and gravel resource area of secondary significance. This deposit contains at least 30% gravel with the presences of a significant amount of fines. Face height ranges from 8 to 10 m in the 2 licenced pits that have been developed in the deposit. Material from this deposit can be used in local construction projects along Road 509 corridor.

A series of related glaciolacustrine delta and ice-contact deposits located in the southeast corner of the Township of North Frontenac have been selected as a resource area of secondary significance. These southwest-trending deposits comprise part of a larger complex that extends into the northeast portion of the Township of Central Frontenac and includes Selected Sand and Gravel Resource Area 4. The series of deposits includes 7 deposits that are a combination of glaciolacustrine delta and ice-contact deposits that contain different amounts of gravel. There are 2 abandoned pits within these deposits with a face height of 6 to 15 m and 6 licenced pits located within these deposits with face heights of 4 to 15 m. Although portions of this deposit contain material acceptable for the production of Granular A and B products, these deposits are, for the most part, small (4 to 25 ha) and highly variable in material size and distribution. This deposit extends to either side of Road 509 in the Township of North Frontenac and could provide an easily accessible source of sand and gravel for construction projects located along Road 509.

A glaciolacustrine deltaic and ice-contact deposit located in the northwest portion of the Township of Central Frontenac have been selected as a sand and gravel resource area of secondary significance. These deposits are related to those deposits located in the southeast corner of the Township of North Frontenac identified and discussed above. There are 2 abandoned pits located within these deposits; currently, no licenced operations are present. Face heights in the abandoned pits range from 8 to 12 m in height. Material in these deposits varies from cobbly medium-textured sand to sandy cobble gravel, with some very silty sections. The deposits contain up to 30% gravel in some sections and less than 10% in other sections. The Precambrian clasts contained in these deposits may limit use for Granular A and B products. These deposits become very thin locally and Precambrian bedrock is exposed in places.

A linear cluster of glaciolacustrine deltaic and ice-contact deposits located in the centre of the Township of Central Frontenac have been selected as a sand and gravel resource area of secondary significance. This series consists of 3 deposits, relatively small in size, covering an area that varies from 12 to 38 ha. There is 1 abandoned pit and 1 active aggregate licence located within these deposits. Face heights observed in the abandoned and licenced pit range from 4 to 10 m. The deposit thickness is highly variable and difficult to estimate in some areas. Thickness can reach 10 m in areas, whereas bedrock is near the surface in other parts. These deposits consist mainly of sand, but gravel (upward of 30% gravel in isolated pockets) was also observed. Some sections are extremely silty and should be avoided. Previous gradation results indicate a coarse aggregate content that ranges from 36.7 to 74.7%. Petrographic Number values range from 100 to 102.5 for Granular and 16 mm crushed and from 103.3 to 121.4 for hot mix and concrete. Magnesium sulphate soundness test results for coarse aggregate range from 0.9 to 2.9% and from 6.7 to 16.3% for fine aggregate. The absorption value test results range from 0.8 to 1.12. Los Angeles abrasion test results range from 20.5 to 22.7. These deposits are in proximity to Highway 7 and could provide an easily accessible source of sand and gravel for construction projects along the provincial highway.

Another ice-contact deposit located along western boundary of the Township of Central Frontenac has been selected as a resource area of secondary significance. The deposit is long and narrow with an approximate length of 4.5 km. It covers an area of 109 ha, although there are 2 licences that occupy the majority of the deposit. Face heights within the deposit are variable and range from 2 to 8 m. Previous gradation results indicate a coarse aggregate content that ranges from 24.5 to 74.7 %. Petrographic Number values range from 102.4 to 125 for Granular and 16 mm crushed and from 112.1 to 132 for hot mix and concrete. Magnesium sulphate soundness test results for coarse aggregate range from 3.7 to 4.1% and from 7.8 to 11.3% for fine aggregate. Los Angeles abrasion test results range from 24.5 to 25.4. The deposit contains medium-textured sand to gravel and is acceptable for Granular B, SSM and HL products; however, blending or washing may be required to produce some of these products. The deposit is located directly south of Highway 7 and can provide quality aggregate for construction projects along the corridor.

An ice-contact deposit located in the north-central part of the Township of South Frontenac has been selected as a sand and gravel resource area of secondary significance. This deposit forms part of a series of ice-contact deposits that trend southwest through the southern part of the Township of Central Frontenac and the western part of the Township of South Frontenac. This deposit marks the northeastern extent of the series. The deposit is relatively small comprising less than 12 ha of unlicenced area. There is 1 active licenced pit located within the deposit; this licenced pit has face heights ranging from 6 to 15 m. Although the deposit does contain a significant amount of gravel, it is a relatively small deposit and contains a significant amount of fines. Further testing may be required to determine whether, with processing of the material, it is a viable resource for Granular A and B products.

An ice-contact deposit located in the central part of the Township of South Frontenac along the southern border has been selected as a sand and gravel resource of secondary significance. The deposit is predominantly sand and is quite large, covering an area larger than 100 ha. A number of licenced pits have been developed within this deposit. A previous gradation result indicates a coarse aggregate content of 13.4%. Petrographic Number values range from 104 to 274.5 for Granular and 16 mm crushed and from 114.1 to 348.3 for hot mix and concrete. Magnesium sulphate soundness test results for fine aggregate range from 5.6 to 17.3%. The absorption value test results range from 0.3 to 2.46%. A Los Angeles abrasion test result is 21.6. Of the licenced areas, only one is currently extracting material, whereas the other areas are being used for waste disposal. Face heights within the deposit range from 3 to 4 m. Although the deposit is predominantly sand, the extent of its area and its proximity to the City of Kingston increases the significance of the deposit.

A pair of deposits from an ice-contact kame–moraine complex located in the northeast of the City of Kingston has been selected as a sand and gravel resource of secondary significance. These 2 deposits have been interpreted as evidence of a temporary stillstand of the ice front during deglaciation (Ministry of Natural Resources 1987). There is 1 abandoned pit and a number of licenced pits that have been developed within these deposits. Face heights within the deposit are variable ranging from 3 to 20 m. Test results from a sample, AM-02-09, collected within this deposit and as part of this study, are provided in Table 9 and Figures 3A and 3B. Previous gradation results indicate a coarse aggregate content that ranges from 0.2 to 67.3%. Petrographic Number values range from 101 to 166 for Granular and 16 mm crushed and from 111 to 202.3 for hot mix and concrete. Magnesium sulphate soundness test results for coarse aggregate range from 6.2 to 25.4% and from 5.6 to 29.1% for fine aggregate. The absorption value test results range from 0.76 to 2.24%. Los Angeles abrasion test results range from 28.3 to 35.1. Material in these deposits can be used in the production of Granular B products. Because these deposits are located just east of Highway 15, they are ideal for construction projects along the highway corridor.

Lastly, an ice-contact deposit located in the southwestern part of the Township of Frontenac Islands on Wolfe Island has been selected as a sand and gravel resource area of secondary significance. This linear deposit is located along the shore of Lake Ontario and is approximately 3 km in length. There is 1 licenced pit located within this deposit. Face heights range from 6 to 12 m. Previous gradation results indicate a coarse aggregate content that ranges from 2.0 to 5.4%. Magnesium sulphate soundness test results for fine aggregate range from 8.6 to 11.9%. The absorption value test results range from 0.91 to 1.13%. This moraine-like deposit has a high gravel content (>30%), but has a high fines content and is variable in nature. Given the high transportation cost associated with transporting material from the mainland, this deposit represents a significant resource for Wolfe Island.

There are numerous deposits of tertiary significance within Frontenac County. Many are isolated pockets of material within bedrock valleys, which have variable sorting and gravel content. Some of these pockets of material may be extracted and used locally for fill and rural road maintenance. These deposits are mainly of glaciolacustrine and glaciofluvial origins. All of these deposits are of variable thickness, as well as having fines and deleterious lithology content. These deposits can be used for local purposes, but, due to the lack of high-quality naturally occurring granular material in the county, it is suggested here that these deposits be considered for future use. Further testing is required to determine additional uses of this material.

BEDROCK GEOLOGY AND RESOURCE POTENTIAL

The majority of Frontenac County is underlain by Precambrian (Mesoproterozoic to Neoproterozoic) metamorphic and igneous rock of the Grenville Province of the Canadian Shield. The southwest part of Frontenac County, including Wolfe Island and Howe Island, is underlain by Paleozoic sandstone, dolostone, limestone and shale (Map 2).

The Precambrian rocks, assigned to the Central Metasedimentary Belt, consist of a combination of volcanic and clastic metasedimentary rocks, intruded by plutonic rocks and metamorphosed to varying degrees *circa* 1300 to 1070 Ma (Easton 1992). Detailed mapping and discussion of the Precambrian bedrock geology of Frontenac County is provided by Easton (1990, 1994, 2001a, 2001b, 2001c, 2006), Easton et al. (2001), Moore and Morton (1986), Pauk (1987, 1989a, 1989b) and Wolff (1982, 1985).

The Precambrian bedrock is overlain by several Paleozoic units ranging from Cambrian to Ordovician in age. These formations crop out in the townships of South Frontenac and Frontenac Islands and the City of Kingston, and are most continuous in the southwest part of the county. An overview of the Paleozoic bedrock formations is provided below. Detailed mapping and discussion of the Paleozoic bedrock of Frontenac County is provided by Carson (1981, 1982a, 1982b), Armstrong and Carter (2010), Armstrong and Dodge (2007), Johnson et al. (1992), Sanford (1993) and Williams and Wolf (1984).

The oldest Paleozoic bedrock formation in Frontenac County is the Covey Hill Formation. This formation unconformably overlies the Precambrian basement. This Cambrian unit is the basal formation of the Potsdam Group and the unit was laid down in a non-marine, alluvial fan and braided fluvial environment (Johnson et al. 1992). As such, the unit consists of interbedded non-calcareous feldspathic conglomerate and impure sandstones. It is present in a limited number of outcrops near the east-central boundary of the county (Carson 1981; Armstrong and Carter 2010; Armstrong and Dodge 2007).

Unconformably overlying the Precambrian basement and the Covey Hill Formation, where present, is the Nepean Formation, the upper formation of the Potsdam Group. In general, the Nepean Formation is a thin- to massive-bedded quartz sandstone with minor conglomerate beds, and rare shaly partings (Carson 1981, 1982a, 1982b; Armstrong and Carter 2006). The lower disconformable contact represents the first appearance of feldspar-free sandstone in the Paleozoic succession (Johnson et al. 1992). This unit crops out primarily in southeastern Frontenac County, but small outcrops exist in the southeast corner of the Township of South Frontenac. The Nepean Formation has been used as building stone and for silica (LeBaron et al. 1990; Hewitt 1963). Neither formation of the Potsdam Group has potential for use as an aggregate resource.

The Upper Ordovician Shadow Lake Formation disconformably overlies the Potsdam Group. The Shadow Lake Formation forms the lowest member of the Simcoe Group and consists of red and green sandy shales, argillaceous and arkosic sandstones and minor sandy argillaceous dolostones. Basal conglomerate beds have been seen locally in outcrops throughout southern Ontario (Armstrong and Carter 2010). Minor scattered outcrops of this formation occur across the southern portion of the Township of South Frontenac (Armstrong and Carter 2006; Armstrong and Dodge 2007). This bedrock unit is of very limited value as an aggregate.

Conformably overlying the Shadow Lake Formation is the Upper Ordovician Gull River Formation. This Simcoe Group formation generally consists of limestone with lesser amounts of dolostone, shale and argillaceous sandstone and has been subdivided into 3 members (Carson 1981, 1982a, 1982b; Armstrong and Carter 2010). The lower member consists of medium to thick beds of medium to dark grey-brown, lithographic to finely crystalline limestone. The middle member consists of thin to medium interbedded pale green and buff siltstone, pale grey-green and buff siltstone, pale grey-green and buff, finely crystalline dolomitic limestone and medium to dark brown lithographic limestone. The upper member consists of medium to dark brown, lithographic to sublithographic limestone (Carson 1981, 1982a, 1982b). Fossils are common throughout the formation. The Gull River Formation is the most extensive Paleozoic unit within Frontenac County and occurs in the southeast, on Howe Island and northeast Wolfe Island. The formation is quarried for granular course aggregate, building stone and sand. Some beds, particularly those in the lower and middle members, may be alkali–carbonate reactive, causing expansion and cracking when used in Portland cement (Rogers 1985).

The Bobcaygeon Formation of the Simcoe Group conformably overlies the Gull River Formation. This Upper Ordovician formation consists of 2 members. The lower member consists of thin- to medium-bedded and locally massive pale to dark brown and grey crystalline limestone interbedded with pale brown, fine- to medium-grained calcarenite. The upper member of the formation consists of thinly bedded medium to dark grey and brown, finely crystalline to sublithographic limestone. Fossils are common throughout both members (Carson 1981, 1982a, 1982b). In Frontenac County, the formation occurs in central Wolfe Island and can be quarried for crushed stone and granular base course aggregate. Certain beds of the Bobcaygeon Formation in the Ottawa area have been found to be alkali–silica reactive when used in Portland cement (Rogers 1985).

The Upper Ordovician Verulam Formation of the Simcoe Group conformably overlies the Bobcaygeon Formation. This formation consists of pale to dark brown and grey, medium- to coarse-grained bioclastic limestone, interbedded with crystalline limestone and shale seams (Carson 1981, 1982a, 1982b). The formation occurs in the southeast portion of Wolfe Island. The formation has been quarried for aggregate in the past, but shale beds may be problematic for widespread use. The Verulam Formation is used by the cement manufacturing industry west of the study area to produce Portland cement (Derry Michener Booth and Wahl and Ontario Geological Survey 1989a).

BEDROCK AGGREGATE QUALITY AND SUITABILITY

Precambrian bedrock may exhibit wide variations with respect to aggregate quality over relatively short distances. Consequently, any site proposed for quarry development should be tested in detail before extraction occurs. Highly weathered, brittle and friable Precambrian bedrock, which is unacceptable for aggregates use, may occur in the study area. There are also areas underlain by more massive, hard and durable rock, which appears suitable for a variety of aggregate applications. However, some of the massive, coarse-grained felsic igneous rock and gneisses with high mica, feldspar and quartz content may have bonding problems because the smooth cleavage and fracture surfaces of these minerals hinder the adhesion of asphalt and cement mixes. This problem may be circumvented by weathering rocks for a period of time in stockpiles or by adding chemicals (anti-stripping agents) that corrode the smooth surfaces and allow better adhesion.

No areas of Precambrian bedrock in Frontenac County have been selected for possible resource protection as the Paleozoic bedrock in the southern region of the county is the preferred source of bedrock-derived aggregates in the area. With this said, there are areas where the Precambrian bedrock is suitable for extraction. Three areas along Highway 7 are licenced to extract Precambrian bedrock in Frontenac County. The amount and type of extraction at these sites is undetermined.

Of the Paleozoic bedrock formations present in the county, the Gull River and Bobcaygeon formations are best suited for aggregate extraction and production. The feldspar, conglomerate and sandstones of the Covey Hill and Nepean formations are unsuitable for most aggregates uses. The high shale content of the Shadow Lake Formation makes it unsuitable for use as aggregate. The Verulam Formation can be used in the production of some aggregate products and is used to produce Portland cement west of the study area.

The Gull River and Bobcaygeon formations are extracted and crushed for a variety of aggregate uses including concrete, asphalt and granular base. Certain beds from the Gull River Formation have been shown to be alkali–carbonate reactive when used in Portland cement. When used in Portland cement, expansion and cracking can occur leading to deterioration of the concrete. Although rocks from these beds are acceptable for use as granular base or in asphalt, selective quarrying in the Gull River Formation can be employed to obtain aggregates that are not alkali–reactive (Rogers 1985). Previous test results indicate Petrographic Number values range from 100 to 643 for Granular and 16 mm crushed and from 100 to 658 for hot mix and concrete. Magnesium sulphate soundness test results for coarse aggregate range from

0.5 to 92.6% and from 8.3 to 75.7% for fine aggregate. The absorption value test results range from 0.03 to 3.4%. Los Angeles abrasion test results range from 14.7 to 51.9. The bulk relative density test results range from 2.69 to 2.72.

Certain beds of the Bobcaygeon Formation are alkali–silica reactive. These beds contain small amounts of black chert and microscopic chalcedony in the limestone that reacts with the Portland cement. Selective quarrying can be employed to avoid the use of these beds in the production of concrete (Rogers 1985). Previous test results indicate Petrographic Number values range from 102.1 to 127 for Granular and 16 mm crushed and from 104.5 to 144.4 for hot mix and concrete. Magnesium sulphate soundness test results for coarse aggregate range from 4.2 to 10.9%. The absorption value test results range from 0.46 to 0.73%. Los Angeles abrasion test results range from 20.5 to 23.4.

SELECTED BEDROCK RESOURCE AREAS

Areas where the Gull River and Bobcaygeon formations have less than 8 m of overburden have been chosen as selected bedrock resources areas. These specific formations have been chosen as selected bedrock resource areas because of their suitability in producing aggregate products. These areas are identified on Map 2, which covers the southern portion of Frontenac County (the corresponding map for the northern portion of Frontenac County is not included with this report as there are no areas of Paleozoic bedrock). They occupy a possible resource area of 57 137.1 ha representing a possible aggregate resource of 14 754.4 million tonnes assuming an average deposit thickness of 15 m and 10 m for the Gull River and Bobcaygeon formations, respectively (Table 6).

Paleozoic units are generally thinner in Frontenac County than they are elsewhere in Ontario. This is due to the proximity of the Frontenac Arch, a Precambrian paleotopographic high located in the eastern half of Frontenac County. The Paleozoic bedrock thins as it approaches the Frontenac Arch. Variations in formation thickness were observed during this study, with formation thickness typically increasing toward the west. Based on field observations in this study, an average deposit thickness of 15 m was selected as the thickness of the Gull River Formation and a thickness of 10 m was selected as the thickness of the Bobcaygeon Formation.

Selected Bedrock Resource Area 1

Selected Bedrock Resource Area 1 stretches across the southeast mainland corner of Frontenac County in an area of the Napanee plain (*see* Figure 2) where overburden thickness is less than 8 m. The total available area of the selected resource, after considering licenced areas and cultural limitations, is 52 442.1 ha. Based upon an average deposit thickness of 15 m, this area represents a potential of 20 837.9 million tonnes of aggregate resource (*see* Table 6).

Selected Bedrock Resource Area 2

Selected Bedrock Resource Area 2 stretches across the northwest portion of Wolfe Island and represents an area of the Napanee plain (*see* Figure 2) where overburden thickness is less than 8 m. The total available area of this selected resource, after considering licenced areas and cultural limitations, is 4695.0 ha. Based upon a average deposit thickness of 10 m, this area represents a potential 1243.7 million tonnes of aggregate (*see* Table 6).

SUMMARY

Naturally occurring sand and gravel deposits occur throughout Frontenac County, although they are relatively small deposits commonly located within valleys between bedrock knobs. They are primarily of glaciolacustrine and glaciofluvial origin. Four deposits have been identified as Selected Sand and Gravel Resource Areas of primary significance, and a number of secondary and tertiary deposits have been identified as potential sources of aggregate that require additional testing, or are of limited extent. These latter deposits should be considered in land use planning exercises as they provide material for local uses. Those deposits selected as having primary significance represent a total unlicenced area of 841.3 ha with a possible resource area of 775.1 ha after considering cultural and physical constraints. These possible resource areas have approximately 139.9 million tonnes of aggregate material (*see* Table 3).

The Paleozoic Bobcaygeon and Gull River formations provide large volumes of bedrock suitable for aggregate use in the southern portions of Frontenac County. The total unlicenced area is 68 253.0 ha with a possible resource area of 57 137.1 ha after physical and cultural constraints have been considered. This represents a bedrock resource of approximately 22 081.6million tonnes (*see* Table 6). Care should be taken to ensure the continued availability of as much as possible of these selected resources areas.

Enquiries regarding the Aggregate Resources Inventory of the County of Frontenac may be directed to the Sedimentary Geoscience 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 Bancroft District Office, Ministry of Natural Resources, 106 Monck Street, Bancroft, Ontario K0L 1C0 [Tel: (613) 332-3940] and Peterborough District – Kingston Office, Ministry of Natural Resources, 51 Heakes Lane, Kingston, Ontario L0L 1X0 [Tel: (613) 531-5700].

Table 1 – Total Identified Sand and Gravel Resources, County of Frontenac

1 Class Number	2 Deposit Type	3 Areal Extent (Hectares)	4 Original Tonnage (Million Tonnes)
Township of North Frontenac			
1	G-IC	1110.55	117.9
	G-LD	3.49	0.4
	S-IC	143.35	15.2
	S-LD	212.69	22.6
2	G-IC	47.99	3.8
	G-LD	29.70	2.4
	S-IC	585.66	46.6
	S-LD	52.72	4.2
	S-LD	45.57	3.6
	S-OW	3.16	0.3
3	S-IC	531.93	18.8
	S-LD	417.01	14.8
	S-LP	9.06	0.3
4	S-IC	64.45	1.1
	S-LD	22.11	0.4
Subtotal		**3279.5**	**252.5**
Township of Central Frontenac			
1	G-IC	64.9	6.9
	G-LD	18.8	2.0
	G-LP	13.9	1.5
	S-IC	161.1	17.1
	S-LD	15.4	1.6
	S-LP	29.3	3.1
2	G-IC	281.7	22.4
	G-LD	10.3	0.8
	G-LP	48.2	3.8
	S-IC	553.4	44.1
	S-LD	134.9	10.7
	S-LP	204.4	16.3
3	S-IC	488.3	17.3
	S-LD	1096.5	38.8
	S-LP	92.5	3.3
	S-OW	2.4	0.1
4	S-LD	23.3	0.4
Subtotal		**3239.3**	**190.3**
Township of South Frontenac			
1	G-IC	12.3	1.3
	S-IC	742.4	78.8
	S-OW	389.3	41.3
2	S-IC	339.9	27.1
	S-LD	12.4	1.0
	S-LP	69.5	5.5
	S-OW	390.5	33.7

Table 1 – Total Identified Sand and Gravel Resources, County of Frontenac			
1 Class Number	**2 Deposit Type**	**3 Areal Extent (Hectares)**	**4 Original Tonnage (Million Tonnes)**
3	S-IC	49.1	1.7
	S-LD	15.0	0.5
	S-LP	132.7	4.7
	S-OW	808.2	28.6
4	S-IC	62.2	1.1
	S-LD	20.4	0.4
	S-OW	85.9	1.5
Subtotal		**3129.8**	**227.3**
City of Kingston			
1	G-IC	80.0	8.5
	S-IC	751.2	79.8
	S-LP	8.4	0.9
2	S-IC	139.1	11.1
	S-LP	30.6	2.4
	S-OW	52.5	4.2
3	S-IC	264.3	9.4
	S-LP	79.6	2.8
	S-OW	95.9	3.4
4	S-LP	6.7	0.1
Subtotal		**1508.3**	**122.6**
Township of Frontenac Islands			
1	G-IC	75.2	8.0
2	G-IC	4.5	0.4
	S-IC	6.4	0.5
3	S-IC	61.2	2.2
	S-LP	9.5	0.3
Subtotal		**156.7**	**11.3**
TOTAL		**11 313.6**	**804.0**

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", <35% gravel (gravel-size (>4.75 mm) aggregate).

Letters after hyphen denote the geologic deposit type (*see also* Appendix C):
IC = undifferentiated ice-contact stratified drift; LD = glaciolacustrine delta; LP = glaciolacustrine plain; OW = outwash.

Table 2 – Sand and Gravel Pits, County of Frontenac
Township of North Frontenac Licence information can be obtained from the Bancroft District Office, Ministry of Natural Resources, 106 Monck Street, Bancroft, Ontario K0L 1C0 [Tel: (613) 332-3940]
Township of Central Frontenac Licence information can be obtained from the Peterborough District – Kingston Office, Ministry of Natural Resources, 51 Heakes Lane, Kingston, Ontario L0L 1X0 [Tel: (613) 531-5700].
Township of South Frontenac Licence information can be obtained from the Peterborough District – Kingston Office, Ministry of Natural Resources, 51 Heakes Lane, Kingston, Ontario L0L 1X0 [Tel: (613) 531-5700].
City of Kingston Licence information can be obtained from the Peterborough District – Kingston Office, Ministry of Natural Resources, 51 Heakes Lane, Kingston, Ontario L0L 1X0 [Tel: (613) 531-5700].
Township of Frontenac Islands Licence information can be obtained from the Peterborough District – Kingston Office, Ministry of Natural Resources, 51 Heakes Lane, Kingston, Ontario L0L 1X0 [Tel: (613) 531-5700].

Table 3 – Selected Sand and Gravel Resource Areas, County of Frontenac

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)
1	796.8	57.8	—	739.0	6	78.5
2	35.9	4.3	—	31.7	6	3.4
3♦	0.0	4.4	—	0.0	6	0.0
4	8.6	4.2	—	4.4	6	0.5
TOTAL	**841.3**	**70.7**		**775.1**		**82.3**

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.

♦ Selected Sand and Gravel Resource Area 3 has a total area of 25.1 ha. After considering physical and cultural constraints, the area available for possible extraction is approximately 20.7 ha. Assuming an average thickness of 6 m, the deposit is estimated to contain a possible aggregate resource of 2.2 million tonnes. All of this potential resource is currently located within licenced areas.

Table 4 – Total Identified Bedrock Resources, County of Frontenac				
1 Drift Thickness (Metres)	**2 Formation**	**3 Estimated Deposit Thickness (Metres)**	**4 Areal Extent (Hectares)**	**5 Original Tonnage (Million of Tonnes)**
Township of South Frontenac				
1 - 8	Covey Hill	10	22.48	5.3
< 1	Nepean	10	2677.99	627.7
1 - 8	Nepean	10	3051.16	715.2
< 1	Shadow Lake	10	124.98	33.1
1 - 8	Shadow Lake	10	5.29	1.4
< 1	Gull River	10	37637.50	9970.2
1 - 8	Gull River	10	6708.68	1777.1
1 - 8	Bobcaygeon	10	93.67	24.8
Subtotal			**50 321.76**	**13 154.8**
City of Kingston				
< 1	Nepean	10	3591.22	841.8
1 - 8	Nepean	10	1797.33	421.3
< 1	Shadow Lake	10	37.93	10.0
1 - 8	Shadow Lake	10	2.78	0.7
< 1	Gull River	10	44 123.29	11 688.3
1 - 8	Gull River	10	9398.62	2489.7
8 - 15	Gull River	10	211.33	56.0
> 15	Gull River	10	223.00	59.1
Subtotal			**59 385.50**	**15 566.9**
Township of Frontenac Islands				
< 1	Nepean	10	288.42	67.6
1 - 8	Nepean	10	0.09	0.0
< 1	Gull River	10	5585.40	1479.6
1 - 8	Gull River	10	2868.44	759.8
< 1	Bobcaygeon	10	1463.82	387.8
1 - 8	Bobcaygeon	10	3585.69	949.9
< 1	Verulam	10	798.32	211.5
1 - 8	Verulam	10	2778.11	735.9
Subtotal			**17 368.29**	**4592.1**
TOTAL			**127 075.54**	**33 313.7**

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 Frontenac
Township of North Frontenac Licence information can be obtained from the Bancroft District Office, Ministry of Natural Resources, 106 Monck Street, Bancroft, Ontario K0L 1C0 [Tel: (613) 332-3940]
Township of Central Frontenac Licence information can be obtained from the Peterborough District – Kingston Office, Ministry of Natural Resources, 51 Heakes Lane, Kingston, Ontario L0L 1X0 [Tel: (613) 531-5700].
Township of South Frontenac Licence information can be obtained from the Peterborough District – Kingston Office, Ministry of Natural Resources, 51 Heakes Lane, Kingston, Ontario L0L 1X0 [Tel: (613) 531-5700].
City of Kingston Licence information can be obtained from the Peterborough District – Kingston Office, Ministry of Natural Resources, 51 Heakes Lane, Kingston, Ontario L0L 1X0 [Tel: (613) 531-5700].
Township of Frontenac Islands Licence information can be obtained from the Peterborough District – Kingston Office, Ministry of Natural Resources, 51 Heakes Lane, Kingston, Ontario L0L 1X0 [Tel: (613) 531-5700].

Table 6 – Selected Bedrock Resource Areas, County of Frontenac

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)
1	0 - 8	63 116.4	10 135.0	539.3	52 442.1	15.0	20 837.9
2	0 - 8	5136.7	441.7	0.0	4695.0	10.0	1243.7
TOTAL		**68 253.0**	**10 576.6**	**539.3**	**57 137.1**		**22 081.6**

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 Frontenac		
Borehole Number	**Depth (m)**	**Generalized Description of Material**
1	13.1	topsoil 0.9, msand cgravel layers 3.0, msand cgravel 7.6, msand cgravel layers 13.1
2	9.1	msand 1.5, cmsand mgravel 9.1
3	9.4	topsoil 0.6, cmsand cgravel layers 7.6, msand stones 9.4
4	14.0	topsoil 0.9, msand fgravel 3.7, msand mgravel layers 7.3, msand stones 10.4, msand mgravel layers 14.0
5	5.5	msand mgravel 1.5, cmsand cgravel 3.0, msand 3.7, msand cgravel layers 5.5
6	8.4	msand mgravel 2.3, csand stones 4.6, mgravel boulders 5.6, csand 6.1, mgravel boulders msand layers 8.4
7	9.8	topsoil 0.8, msand mgravel layers 3.4, fmsand mgravel layers 5.2, mcsand stones 9.8
8	5.3	topsoil 1.1, fmsand 2.7, csand 5.3
9	13.4	topsoil 0.9, mgravel 1.5, cmsand fgravel 11.3, cmsand mgravel layers 12.9, boulders 13.4
10	5.2	msand 1.2, msand stones 3.7, cgravel boulders 5.2
11	9.4	msand gravel 1.5, msand mgravel cgravel layers 3.1, msand stones 4.3, mgravel cgravel layers 5.8, msand fgravel 9.4
12	15.2	topsoil 1.0, fsand 13.7, cmsand stones 15.24
13	14.0	fgravel 1.3, msand mgravel cgravel layers 4.3, msand stones 5.2, cmsand mgravel 6.1, cmsand fgravel 14.0
14	7.9	topsoil 0.9, msand fgravel 3.5, msand mgravel 4.6, cgravel 7.9
15	8.4	msand mgravel cgravel layers 3.7, msand stones 8.4
16	16.8	msand mgravel layers cgravel layers 4.0, msand stones 7.3, mgravel 7.7, msand stones 11.3, msand gravel 16.8
17	8.8	topsoil 1.1, msand 2.7, csand cgravel 4.0, csand 4.6, cgravel boulders mgravel layers 7.3, cnsand fgravel 8.8
18	4.0	topsoil 1.3, cgravel boulders 4.0
19	5.8	msand 1.7, cgravel boulders 5.8
20	12.5	csand mgravel 3.7, cgravel 4.6, cgravel mgravel fgravel layers 7.3, msand fgravel 8.8, cgravel 10.77, mgravel cgravel boulders 12.5
21	15.2	cmsand stones 1.6, mcsand fgravel 4.9, fgravel mgravel layers 8.8, cmsand stones 15.24
22	6.4	csand gravel 4.0, mcsand 6.4
23	7.6	fsand silt layers 6.7, csand 7.6
24	4.6	cmsand mgravel 2.1, msand 4.6
25	12.2	csand stones 3.4, mcsand fgravel 5.5, cmsand fsand layers 9.4, mcsand stones 11.0, cgravel boulders 12.2
26	12.2	fsand 4.9, msand mgravel boulders 7.9, fmsand fgravel mgravel layers 12.2
27	13.7	csand fgravel 3.0, mgravel fgravel layers 10.7, cmsand stones 13.7
28	8.2	topsoil 1.4, mfsand fgravel mgravel layers 4.0, mgravel 4.1, csand fgravel 8.2
29	4.6	fsand 2.3. msand fgravel 3.7, boulders 4.6
30	12.5	topsoil 1.1, csand gravel mgravel layers 4.0, msand stones 4.6, mgravel msand layers cmsand fgravel 12.5
31	7.9	topsoil 1.0, csand cgravel mgravel layers 7.9
32	10.7	topsoil 1.2, csand mgravel cgravel layers boulders 5.2, fgravel sand layers 10.7
33	9.1	topsoil 0.9, msand stones 2.7, msand fgravel layers 6.4, cmsand cgravel 9.1
34	3.0	cmsand stones 1.3, fgravel mgravel layers 2.7, cgravel 3.0
35	4.9	cmsand stones 2.0, cmsand cgravel boulders 4.9
36	6.1	fgravel 1.5, cgravel boulders 5.2, mgravel 5.8, boulders 6.1
37	3.0	cgravel boulders 3.0
38	13.7	msand stones 2.3, mgravel fgravel layers 3.3, mcsand stones fgravel layers 7.0, csand mfsand layers stones 13.7
39	4.9	topsoil 0.9, mgravel 2.3, mcsand 4.3, mgravel 4.9
40	13.7	topsoil 0.8, msand gravel 2.3, msand stones 4.3, mcsand fgravel layers mgravel layers 9.4, cmsand stones 13.7
41	12.2	fmsand fgravel 4.3, fmsand fgravel layers 12.2
42	9.1	topsoil 1.0, msand stones fgravel layers 5.9, fsand 9.1
43	4.3	cmsand mgravel 1.8, cmsand fgravel layers 3.0, cgravel 4.3
44	10.7	fmsand 1.8, cmsand fgravel layers 6.1, csand mgravel 7.0, csand gravel mgravel layers 10.7
45	9.1	mfsand stones 4.6, cmsand fgravel 7.0, csand stones 9.1

Table 7 – Summary of Borehole Data, County of Frontenac

Borehole Number	Depth (m)	Generalized Description of Material
46	1.2	cgravel boulders 1.2
47	2.7	boulders gravel 1.8, mgravel boulders 2.7
48	13.7	cmsand mgravel layers 6.7, cmsand 11.3, fsand 13.7
49	12.2	topsoil 1.1, fsand 2.35, mfsand 12.2
50	8.2	msand stones 1.6, msand fsand layers 7.9, msand gravel boulders 8.2
51	2.7	cgravel boulders 2.7
52	4.3	topsoil 0.6, msand stones fgravel layers 2.0, mgravel 3.3, cgravel boulders 4.3
53	9.8	msand mgravel 3.0, cgravel mgravel layers 4.6, mgravel 6.4, msand gravel 9.8
54	7.6	boulders gravel 1.5, mcsand cgravel 3.0, mgravel 3.6, cmsand fgravel layers 6.1, till 7.6
55	6.4	fsand 5.5, mfsand stones 6.4
56	24.4	fsand 5.2, mfsand fgravel layers 7.9, msand stones fsand layers 19.8, csand 22.9, silt 24.4
57	19.8	fsand 7.3, fmsand stones csand layers 19.8
58	6.1	fsand 3.5, fsand silt 6.1
59	14.0	topsoil 1.1, msand fgravel 3.0, fmsand fgravel layers 5.5, fsand 12.2, fsand silt clay layers 14.0
60	5.5	topsoil 1.3, fsand 3.6, mfsand stones fgravel layers 5.5
61	51.2	csand gravel 1.4, csand fgravel layers 7.6, mcsand fgravel mgravel layers 15.2
62	12.2	csand 1.2, csand gravel layers 3.1, msand stones 4.5, msand fgravel layers 8.2, csand mgravel layers 12.2
63	17.7	cmsand 1.8, fmsand 3.0, msand 3.9, fmsand stones 13.7, msand fgravel layers 16.8, till 17.7
64	6.1	fmsand 4.3, msand gravel 6.1
65	6.7	msand 3.3, msand stones 6.7
66	6.1	msand stones 2.1, fsand silt 4.9, silt 6.1
67	4.6	boulders gravel cgravel 3.4, cgravel mgravel layers 4.6

* For source of borehole data, *see* "References": Ministry of Natural Resources (1987)
Descriptors: c = coarse; cm = coarse to medium; f = fine; fm = fine to medium; m = medium; mc = medium to coarse.

Table 8 – Summary of Geophysical Data, County of Frontenac
— NONE —

Table 9 – Results of Aggregate Quality Tests, County of Frontenac

Sample Number	Sample Information	COARSE AGGREGATE							FINE AGGREGATE
		Petrographic Number		Micro-Deval Abrasion (% Loss)	Freeze–Thaw (% Loss)	Absorption (%)	Bulk Relative Density	Accelerated Mortar Bar (14 days) (% Loss)	Micro-Deval Abrasion (% Loss)
		Granular and 16 mm Crushed	Hot Mix and Concrete						
Generally Acceptable Values:			*125–140*	*<14–17%*	*<6%*	*<2%*	*>2.5*	*<1.150%*	*<15–25%*
AM-01-09		—	—	—	—	0.999	2.701	0.133	11.47
AM-02-09		—	—	—	—	0.915	2.651	0.098	5.94
AM-03-09A		—	—	—	—	0.411	2.733	—	10.45
AM-03-09B		—	—	—	—	0.411	2.72	—	7.24

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.

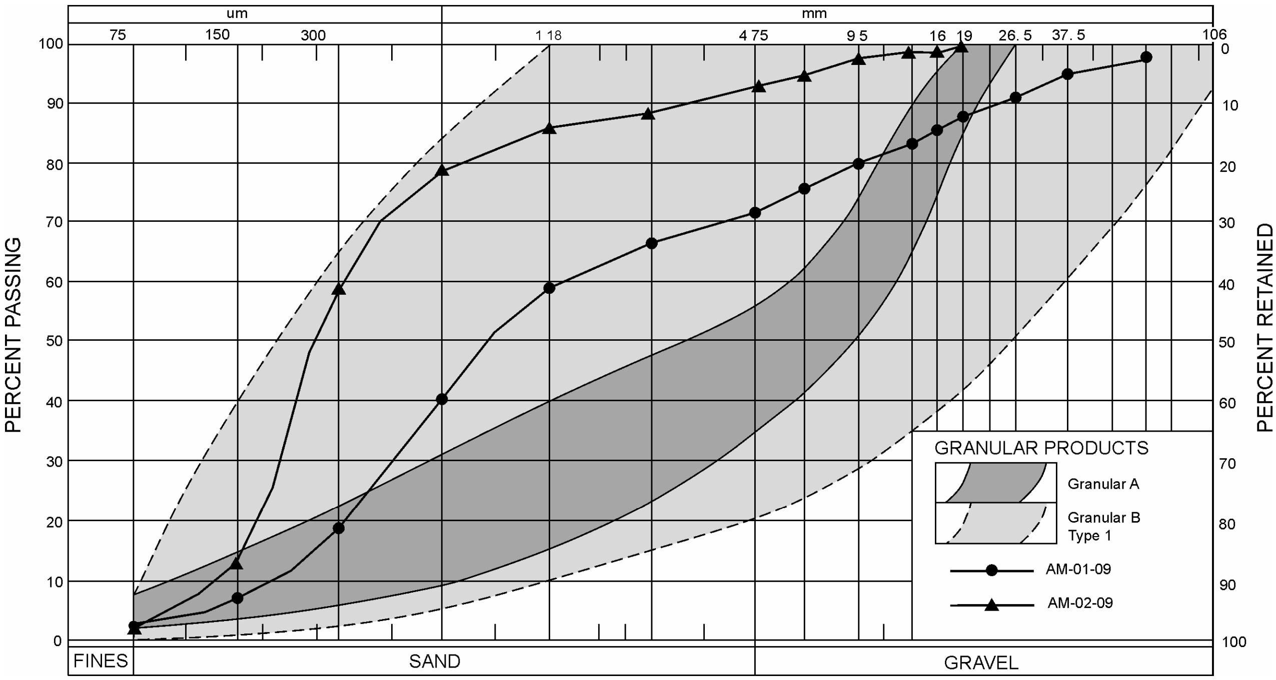


Figure 3A. Aggregate Grading Curves, County of Frontenac – Total Aggregate.
Based on analysis of the total aggregate contained in unprocessed samples (gradation envelopes adapted from the Ontario Provincial Standard Specifications OPSS 1010 (1988)).

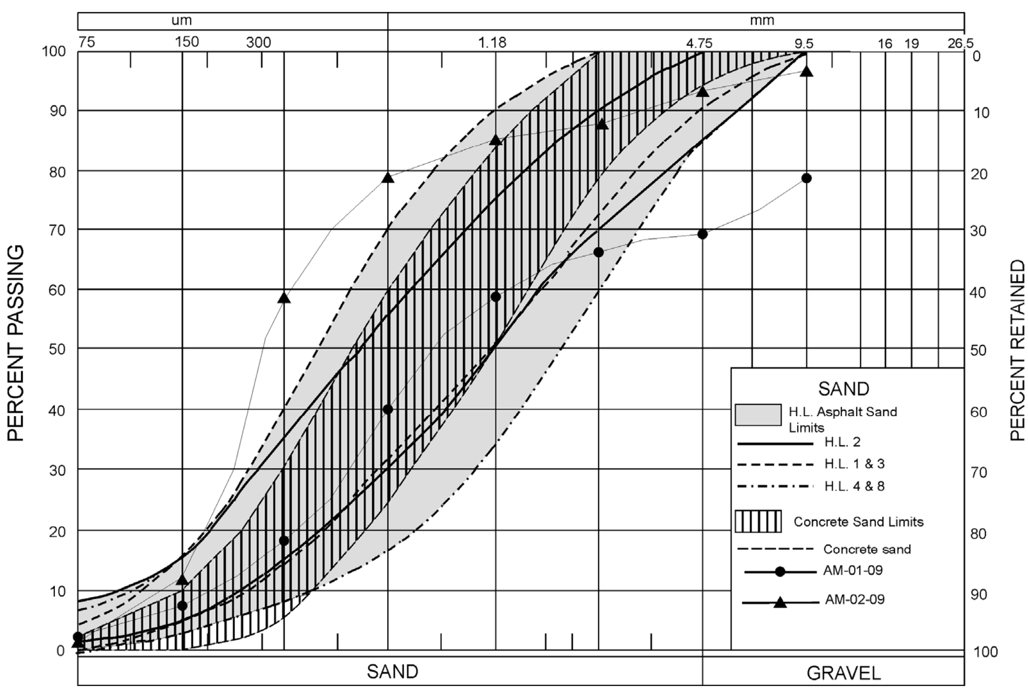


Figure 3B. Aggregate Grading Curves, County of Frontenac – Sand Fraction.
Based on analysis of the sand fraction of the aggregate contained in unprocessed samples (gradation envelopes adapted from the Ontario Provincial Standard Specifications OPSS 1002 (1988) and 1003 (1988)).

Note: Information portrayed by grading curves refers strictly to a specific sample taken at the time of field investigation. Because of the inherent variability of sand and gravel deposits, care should be exercised in extrapolating such information to the rest of the deposit.

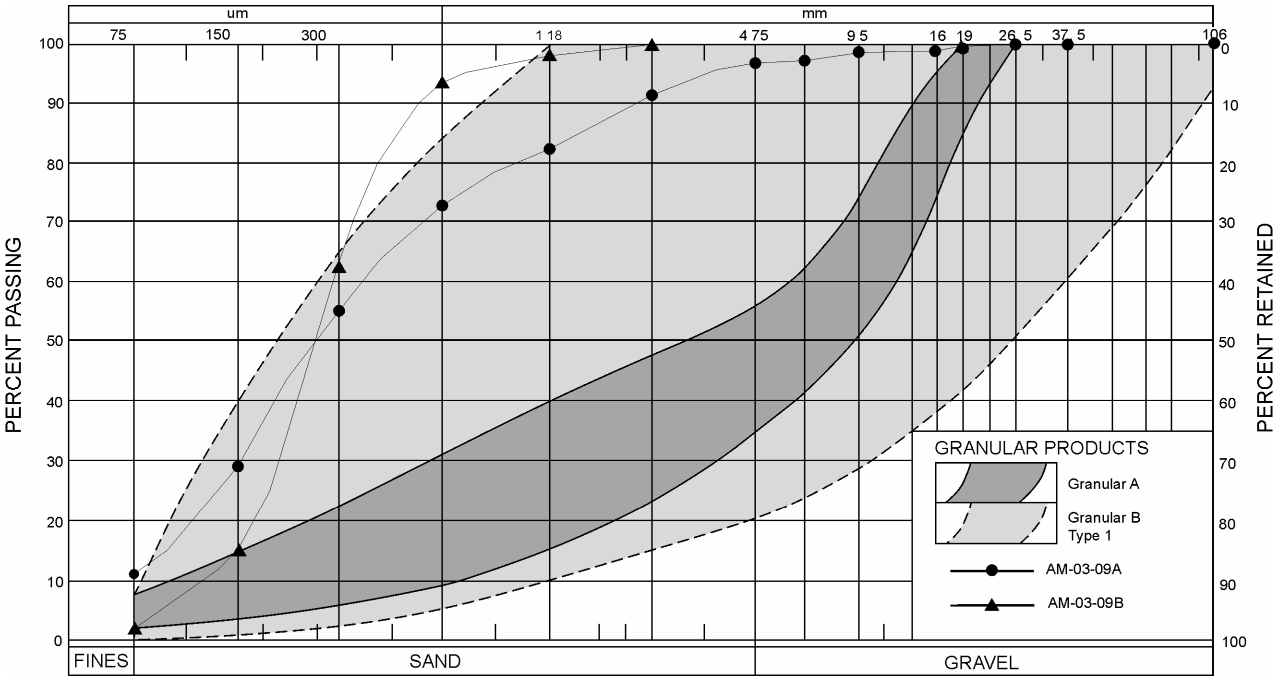


Figure 4A. Aggregate Grading Curves, County of Frontenac – Total Aggregate.
Based on analysis of the total aggregate contained in unprocessed samples (gradation envelopes adapted from the Ontario Provincial Standard Specifications OPSS 1010, 1988).

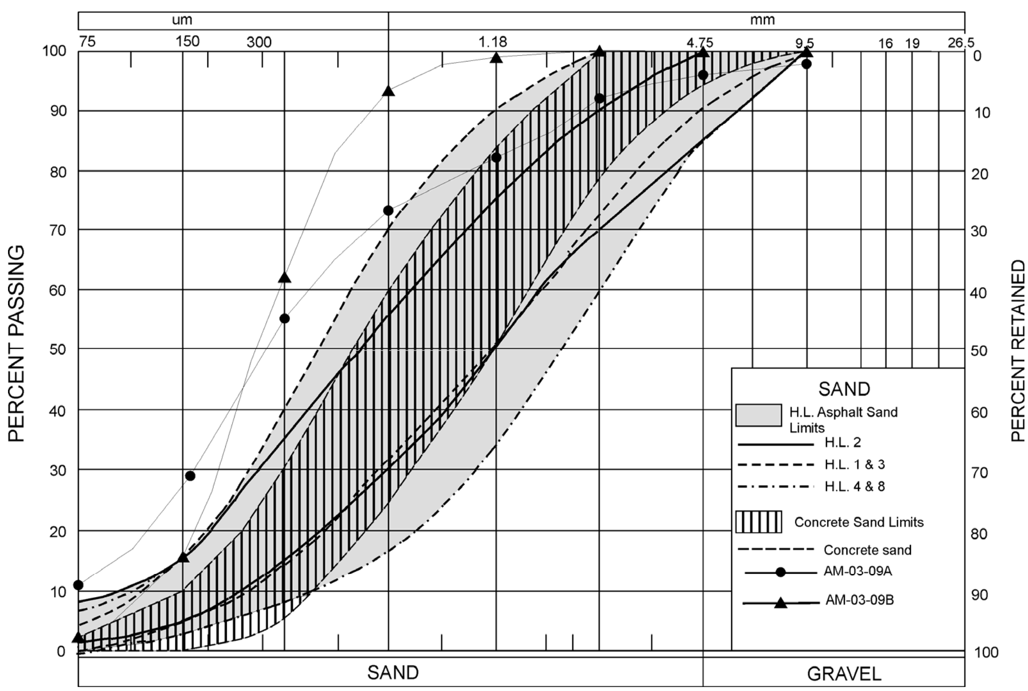


Figure 4B. Aggregate Grading Curves, County of Frontenac – Sand Fraction.
Based on analysis of the sand fraction of the aggregate contained in unprocessed samples (gradation envelopes adapted from the Ontario Provincial Standard Specifications OPSS 1002 (1988) and 1003 (1988)).

Note: Information portrayed by grading curves refers strictly to a specific sample taken at the time of field investigation. Because of the inherent variability of sand and gravel deposits, care should be exercised in extrapolating such information to the rest of the deposit.

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Appendix A – Suggested Additional Reading and References

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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 con stitute 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 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 Ontario Ministry of Transportation. 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–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.

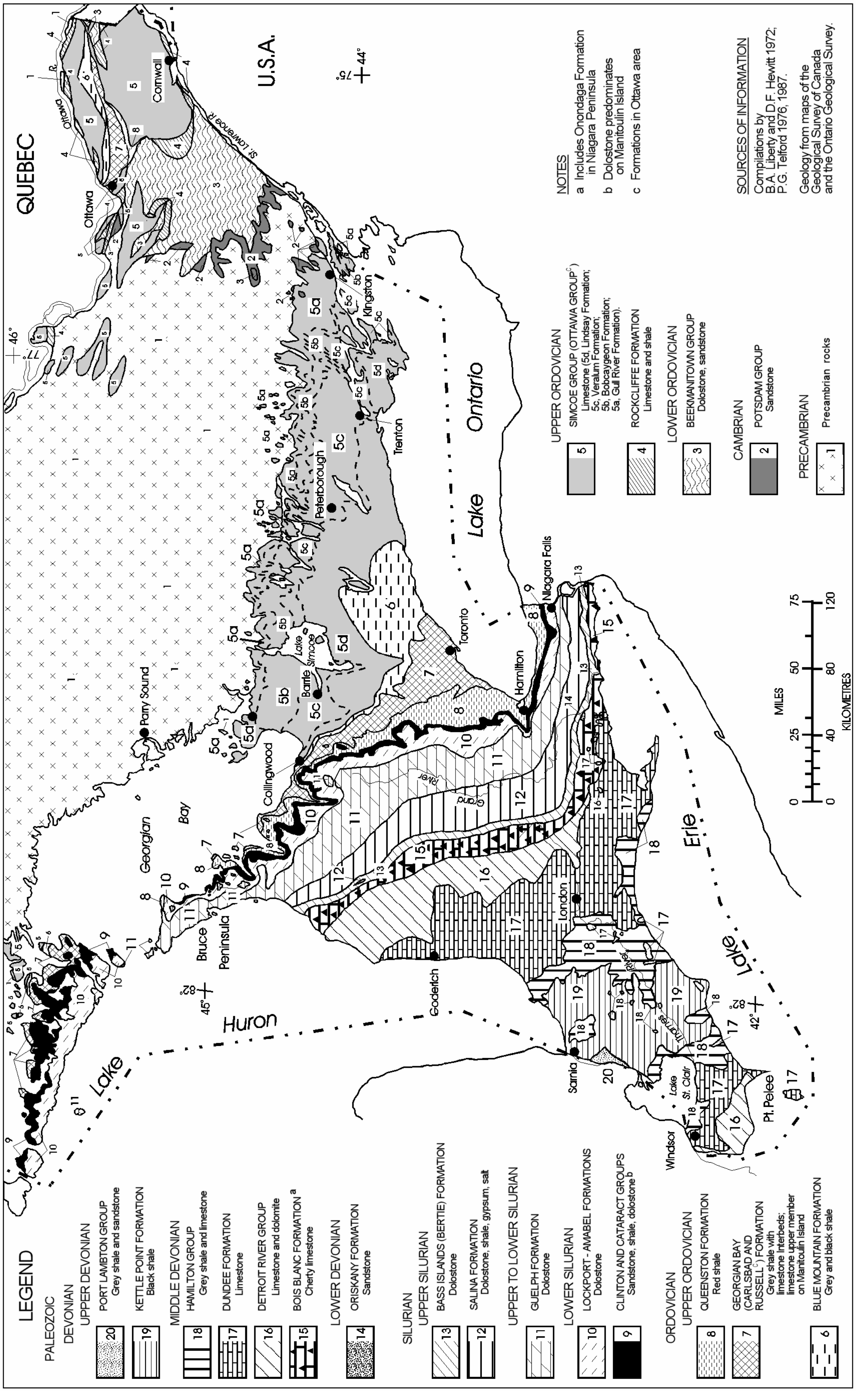

Figure D1. Bedrock geology of southern Ontario.

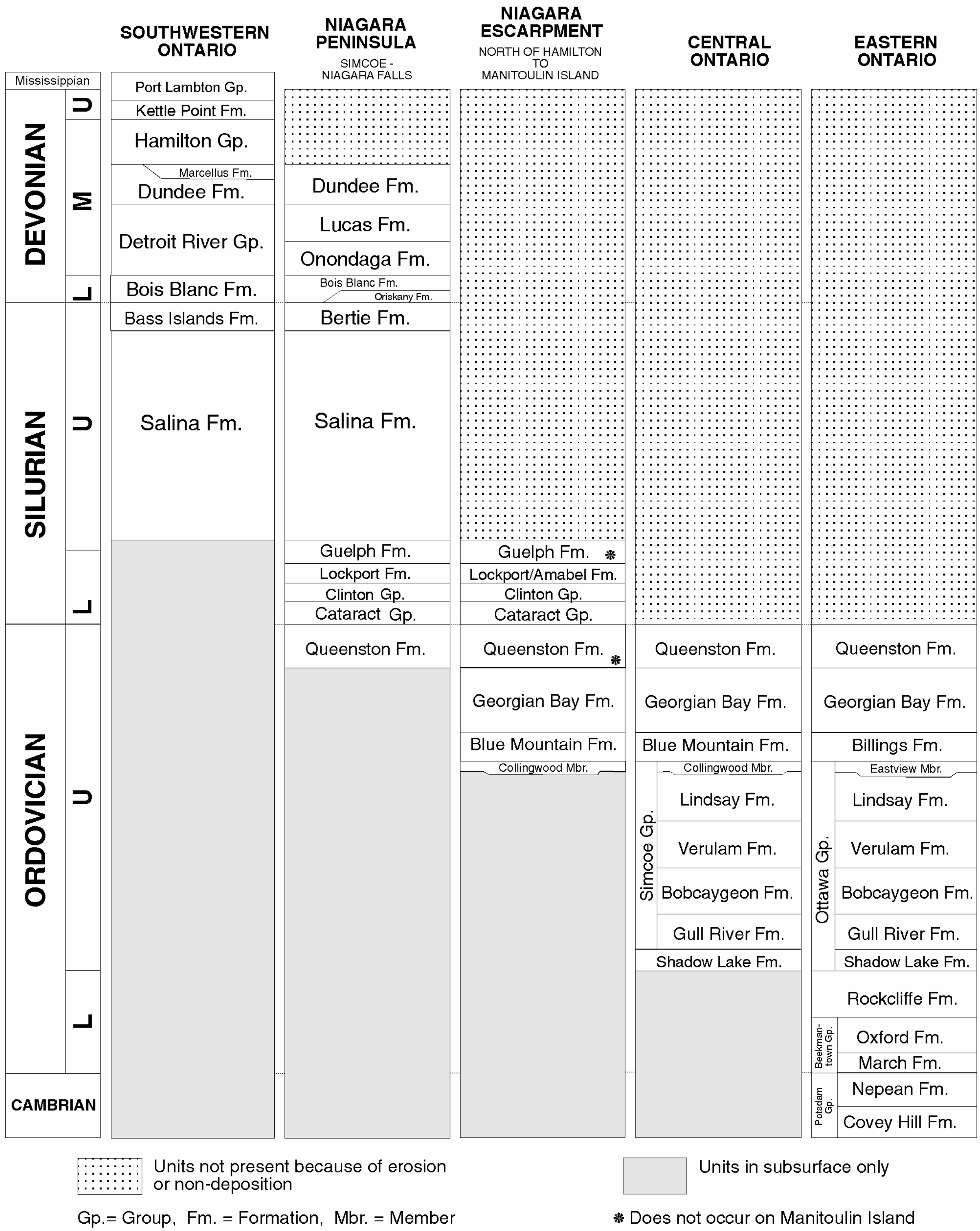

Figure D2. Exposed Paleozoic stratigraphic sequences in southern Ontario (*adapted from* Bezys and Johnson 1988 and Armstrong and Dodge 2007).

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 $>1.0\times10^{-4}$ 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	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) *[Note 13, Note 14]*	0.150 *[Note 15]*	0.150 *[Note 15]*
CSA A23.2-14A	Concrete Prism Expansion (% maximum at 1 year) *[Note 13, Note 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) *[Note 19, Note 20]*	0.150
CSA A23.2-14A	Concrete Prism Expansion (% maximum at 1 year) *[Note 19, Note 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

Conversion from SI to Imperial			Conversion from Imperial to SI		
SI Unit	*Multiplied by*	*Gives*	*Imperial Unit*	*Multiplied by*	*Gives*
		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.*

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Aggregate Resources Inventory Paper 187

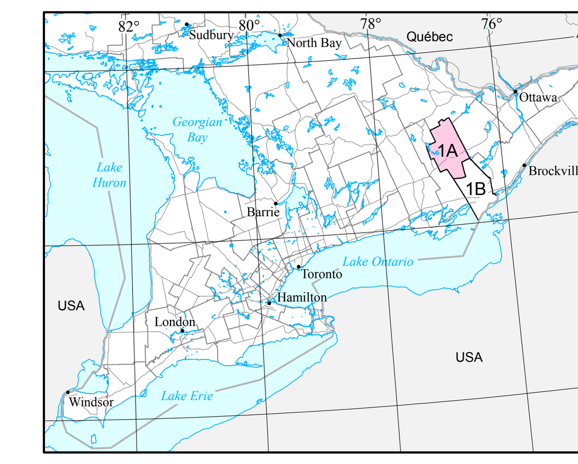
MAP 1A

Sand and Gravel Resources for the County of Frontenac

Scale 1:100 000

1000 m 0 1 2 km

NTS References: 31 C/10, 11, 14, 15; 31 F/2, 3



Location Map 1 cm equals 80 km

SAND AND GRAVEL RESOURCES

- (1) Selected Sand and Gravel Resource Area, primary significance; deposit number (*see* Table 3)
- Selected sand and gravel resource area, secondary significance
- Sand and gravel deposit, tertiary significance
- Other surficial deposits or exposed bedrock

SYMBOLS

- Geological and aggregate thickness boundary of sand and gravel deposits
- Administrative boundary

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, 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 18.

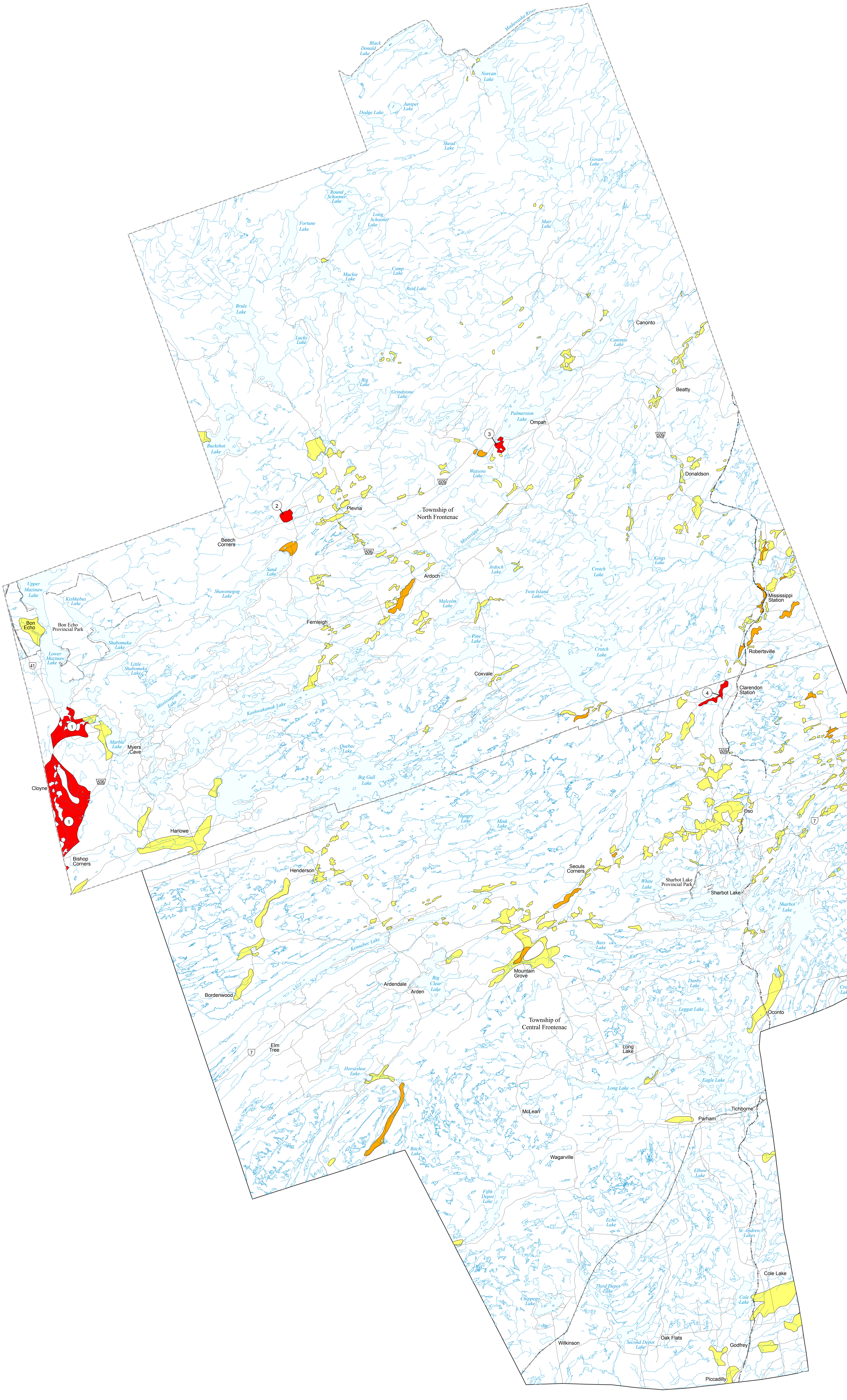
Aggregate suitability data from the Ministry of Transportation, Ontario. Selected water well data from the Ministry of the Environment, Ontario. Additional borehole data from the Ontario Geological Survey, Ministry of Northern Development and Mines.

Geology based on
- Henderson, E.P. 1966, 1973a, 1973b
- Henderson, P.J. and Kettles, I.M. 1992
- Kettles, I.M. 1992
- Kettles, I.M., Henderson, P.J. and Henderson, E.P. 1992
- Leyland, J.G. and Russell, T.S. 1983, 1984
- Ontario Geological Survey 2010

Additional geology by A.S. Marich, 2009. Compilation by A.S. Marich. 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:

Marich, A.S. 2012. Aggregate resources inventory for the County of Frontenac, southern Ontario; Ontario Geological Survey, Aggregate Resources Inventory Paper 187, Map 1A–Sand and Gravel Resources, scale 1:100 000.



Aggregate Resources Inventory Paper 187

MAP 1B

Sand and Gravel Resources for the County of Frontenac

Scale 1:100 000

1000 m 0 1 2 km

NTS References: 31 C/1, 2, 7, 8, 9, 10

Location Map 1 cm equals 80 km

SAND AND GRAVEL RESOURCES

- (1) Selected Sand and Gravel Resource Area, primary significance; deposit number (*see* Table 3)
- Selected sand and gravel resource area, secondary significance
- Sand and gravel deposit, tertiary significance
- Other surficial deposits or exposed bedrock

SYMBOLS

- Geological and aggregate thickness boundary of sand and gravel deposits
- Administrative boundary

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, 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 18.

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
- Henderson, E.P. 1966, 1973a, 1973b
- Henderson, P.J. and Kettles, I.M. 1992
- Kettles, I.M. 1992
- Kettles, I.M., Henderson, P.J. and Henderson, E.P. 1992
- Leyland, J.G. and Russell, T.S. 1983, 1984
- Ontario Geological Survey 2010

Additional geology by A.S. Marich, 2009. Compilation by A.S. Marich. 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:

Marich, A.S. 2012. Aggregate resources inventory for the County of Frontenac, southern Ontario; Ontario Geological Survey, Aggregate Resources Inventory Paper 187, Map 1B–Sand and Gravel Resources, scale 1:100 000.

Aggregate Resources Inventory Paper 187

MAP 2

Bedrock Resources for the County of Frontenac (Southern Portion)

Scale 1:100 000

1000 m 0 1 2 km

NTS References: 31 C/1, 2, 7, 8, 9, 10

Location Map 1 cm equals 80 km

LEGEND – BEDROCK UNITS

PHANEROZOIC
PALEOZOIC
ORDOVICIAN
UPPER ORDOVICIAN
Verulam Formation: Limestone and shale
Bobcaygeon Formation: Limestone
Gull River Formation: Limestone and dolostone
Shadow Lake Formation: Conglomerate, sandstone and shale

CAMBRIAN
Nepean Formation: Quartz sandstone and dolostone
Covey Hill Formation: Conglomerate and sandstone

PRECAMBRIAN
Undifferentiated Precambrian rocks

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 and Precambrian bedrock; Paleozoic bedrock covered by drift; drift thickness is generally greater than 15 m (50 feet); or areas underlain by Precambrian bedrock.

SYMBOLS

6 Selected Bedrock Resource Area; deposit number (*see* Table 6)

Geological formation and/or member boundary

Drift thickness contour

× Isolated bedrock outcrop

Administrative boundary

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, 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 18.

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
Armstrong, D.K. and Dodge, J.E.P. 2007
Carson, D.M. 1981, 1982a, 1982b
Ontario Geological Survey 1991
Williams, D.A. and Wolf, R.R. 1984

Additional geology by A.S. Marich, 2009. Compilation by A.S. Marich. 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:

Marich, A.S. 2012. Aggregate resources inventory for the County of Frontenac (southern portion), southern Ontario; Ontario Geological Survey, Aggregate Resources Inventory Paper 187, Map 2–Bedrock Resources, scale 1:100 000.