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Aggregate Resources Inventory of the

County of Middlesex and the City of London

Southern Ontario

Ontario Geological Survey
Aggregate Resources Inventory
Paper 78

2016

ONTARIO GEOLOGICAL SURVEY
125 ANNIVERSARY Est. 1891

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By V.L. Lee

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***Map 1 and Map 2 accompanying this report are simplified to depict information critical to the majority of users. Enhanced information on the aggregate resources for this area is provided in a compressed (*.zip*) file available for download from GeologyOntario (www.ontario.ca/geology). Additional documents in the *.zip* file provide further details on the vector ESRI® ArcGIS® files for Maps 1 and 2, Microsoft® Excel® versions of Tables 1 to 10, and other files that enhance this report.**

Abstract

This report includes an inventory and evaluation of the aggregate resources in the County of Middlesex and the City of London based on a detailed field assessment undertaken in the summer of 2013 and on previous studies related to aggregate assessment 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*.

The purpose of this study is to delineate and inventory the aggregate deposits within the County of Middlesex and the City of London and to assess the quality and quantity of sand and gravel and bedrock-derived aggregate resources. This information is required for infrastructure development and renewal, general construction applications and land use planning purposes.

Eight (8) sand and gravel resource areas have been selected at the primary resource level in the County of Middlesex and the City of London. These selected resource areas have a total unlicenced area of 4840 ha with a possible resource area of 2349 ha after considering physical, cultural and environmental constraints. These resource areas have approximately 278 million tonnes of aggregate material. The primary selected resource areas are concentrated within the glaciofluvial deposits in proximity to the urban centre of the City of London. Stone quality, specifically the presence of chert, may limit the use of this granular material for many high-specification aggregate products (e.g., asphalt and concrete products).

There are a number of sand and gravel deposits that have been selected at the secondary level of significance. These deposits add to the overall granular resources of the County of Middlesex and the City of London. Deposit thickness, the variability of the material, the lower coarse aggregate content and concerns over the stone quality of some of the deposits generally make these resource areas less attractive for development than the primary deposits. In addition, previous extraction and urban expansion impact the quantity of granular material available; however, the deposits are still a valuable resource.

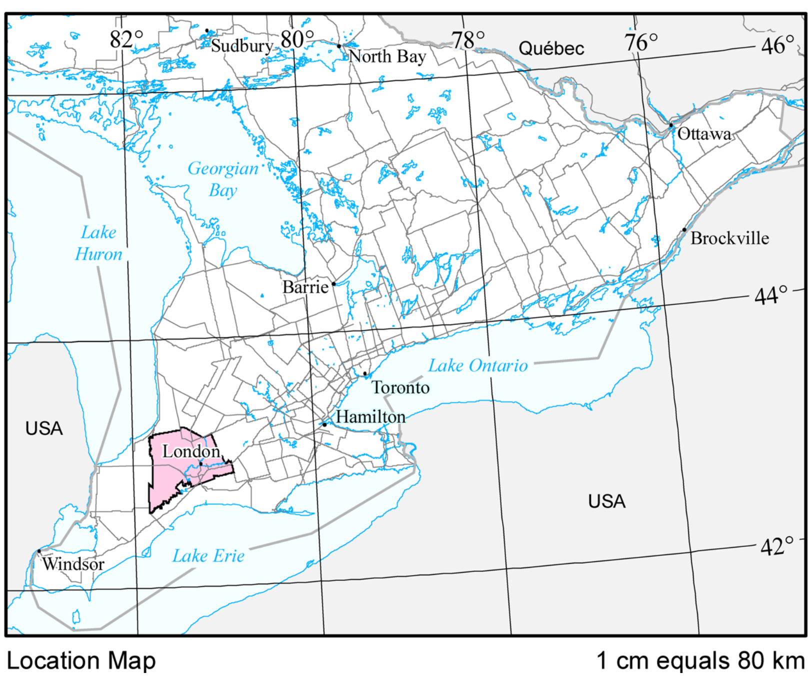

Figure 1. Map of southern Ontario showing the location of the County of Middlesex and the City of London.

No bedrock formations with physical properties suitable for typical aggregate applications are present within 8 m of ground surface. As such, there are no areas of selected bedrock resources identified within the study area.

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.

Aggregate Resources Inventory of the County of Middlesex and the City of London

By V.L. Lee[1]

Field work, map production and report by V.L. Lee[1].

Report reviewed by A.F. Bajc[1].

Manuscript accepted for publication in 2014 by J.R. Parker, Senior Manager, Earth Resources and Geoscience Mapping Section, Ontario Geological Survey. This report is published with the permission of the Director, Ontario Geological Survey.

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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 2012, the total tonnage of mineral aggregates extracted in Ontario was 152 million tonnes, greater than that of any other metallic or nonmetallic commodity mined in the Province (The Ontario Aggregate Resources Corporation 2013).

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 (MTO), by the Ontario Geological Survey (OGS), and by the Ministry of Natural Resources and Forestry (MNRF) in Regional, District and Area offices. 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 MTO. 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 MNRF regional, district and area offices. 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 MNRF, and from individuals and companies.

Aerial photographs and remotely sensed imagery at various scales were used to determine the continuity of deposits, especially in areas where information is limited. Water well records, held by the Ministry of the Environment and Climate Change (MOECC), 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 Land Information Ontario Data Warehouse, Land Information Ontario, MNRF, with modifications by staff of the Ministry of Northern Development and Mines.

Units and Definitions

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

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

DATA PRESENTATION AND INTERPRETATION

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

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

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

Map 1: Sand and Gravel Resources

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

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

SELECTED SAND AND GRAVEL RESOURCE AREAS

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

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

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

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

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

SELECTION CRITERIA

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

Site Specific Criteria

DEPOSIT SIZE AND THICKNESS

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

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

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

AGGREGATE QUALITY

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

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

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

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

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

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

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

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

Deposit Information

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

In the following example of a deposit information code,

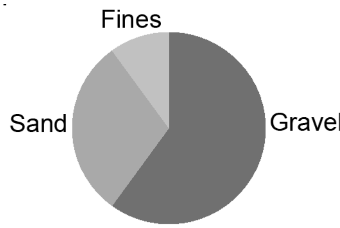
"G / 1 / OW / C",

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

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

Texture Symbol

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



LOCATION AND SETTING

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

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

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

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

Regional Considerations

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

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

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

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

SAND AND GRAVEL RESOURCE TONNAGE CALCULATIONS

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

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

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 Ministry of the Environment and Climate Change (MOECC), oil and gas well data from the Ministry of Natural Resources and Forestry (MNRF), and from geotechnical test hole data from various sources. Map 2 is based on concepts similar to those outlined for Map 1.

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

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

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

SELECTED BEDROCK RESOURCE AREAS

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

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

SELECTION CRITERIA

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

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

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

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

BEDROCK RESOURCE TONNAGE CALCULATIONS

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

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

Assessment of Aggregate Resources in the County of Middlesex and the City of London

LOCATION AND POPULATION

The County of Middlesex, including the City of London (herein jointly referred to as the County of Middlesex), is located in southwest Ontario and occupies approximately 331 754 ha (Figure 2). It is bounded to the east by the counties of Perth and Oxford, to the south by the County of Elgin, to the west by the Municipality of Chatham-Kent and the County of Lambton, and to the north by the County of Huron. The study area is covered by all or parts of the following 1:50 000 scale map sheets of the National Topographic System (NTS): Grand Bend (40 P/5), Parkhill (40 P/4), Strathroy (40 I/13), Bothwell (40 I/12), St. Mary's (40 P/6), Lucan (40 P/3), St. Thomas (40 I/14), Woodstock (40 P/2), Tillsonburg (40 I/15).

The population of the county was 439 151 in 2011 (Statistics Canada 2012), which represents a 4.0% increase from 2006 (Statistics Canada 2012) (Table A). A large part of the municipality is urban; however, land use becomes more rural, with agriculture and pasture fields more common, with distance away from the City of London.

The city is served by Provincial Highways 401 and 402, and former provincial highways 2, 4 and 7, as well as a number of well-maintained county and township roads. Provincial Highway 401 provides a direct route east to Toronto and west to Windsor. Provincial Highway 402 provides a direct route west to Sarnia.

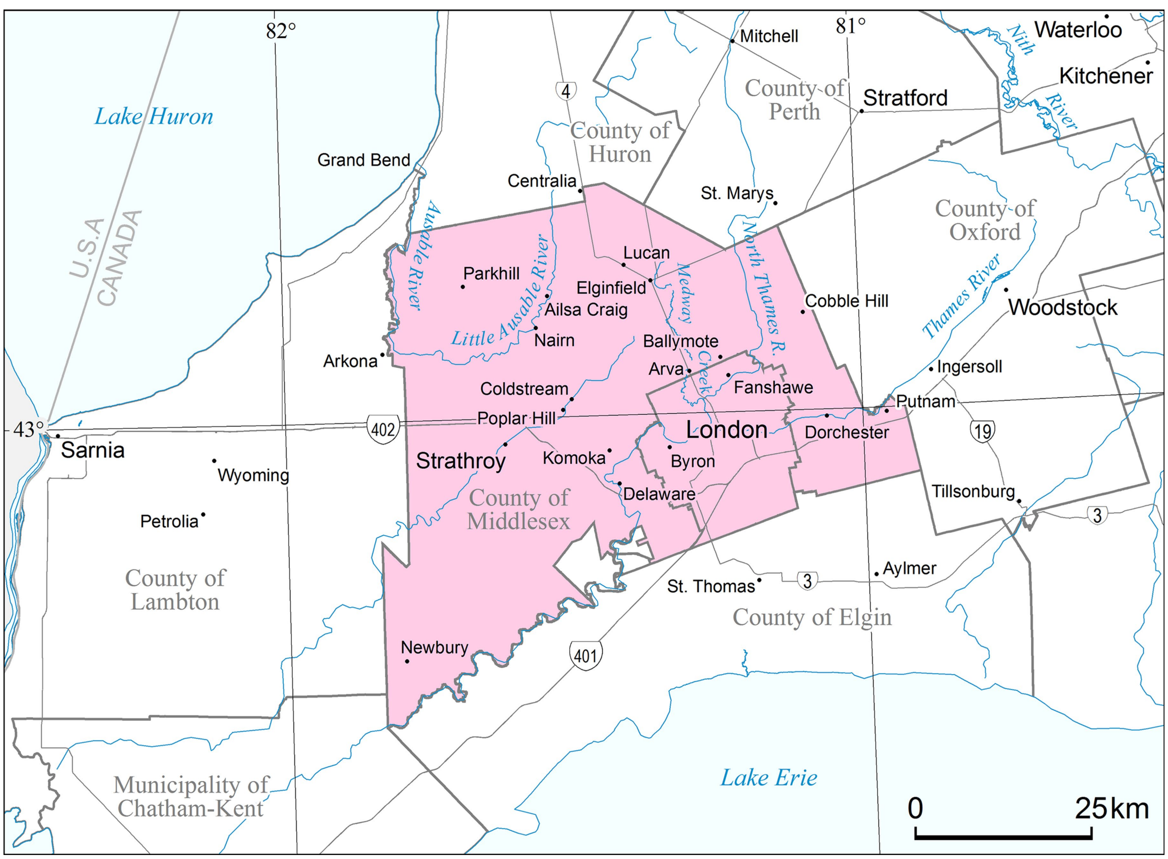


Figure 2. Detailed location map for the County of Middlesex and the City of London including the surrounding area.

Table A. Area and Population, County of Middlesex and City of London.

Municipality (Listed Alphabetically)	Land Area (Hectares)	2006 Population*	2011 Population*
Township of Adelaide Metcalfe	33 138	3135	3028
City of London	42 057	352 395	366 151
Township of Lucan Biddulph	16 915	4187	4338
Township of Middlesex Centre	58 815	15 589	16 487
Village of Newbury	185	439	447
Municipality of North Middlesex	59 790	6740	6658
Municipality of Southwest Middlesex	42 797	5980	5860
Township of Strathroy–Caradoc	27 412	19 959	20 978
Municipality of Thames Centre	43 395	13 085	13 000
First Nations communities	7249	914**	2204
TOTAL	**331 753**	**422 423***	**439 151**

** Sources: Statistics Canada (2007, 2012).*

*** Discrepancies occur because of incompletely enumerated First Nations communities.*

PREVIOUS WORK

Previous aggregate resources inventories in the County of Middlesex were completed on a lower tier (i.e., township) level. These inventories include the work by the Ontario Geological Survey (1981, 1982a, 1982b, 1982c, 1983a, 1983b, 1984 and 1991). These reports do not follow the "traditional" Aggregate Resources Inventory Paper format currently in use. Extensive borehole, geophysical and other data collected as a part of these earlier projects were incorporated into this study where applicable. These data are provided in Tables 7 and 8 (*see also* vector ESRI® ArcGIS® version).

The aggregate resources of the townships of Adelaide Metcalfe and Strathroy–Caradoc, the Municipality of Southwest Middlesex and the Town of Newbury have not been previously assessed. This is because of the known lack of aggregate resources in these regions.

EXTRACTIVE ACTIVITY

Overview

The aggregate production for the County of Middlesex from 2003 to 2012 is shown in Figure 3. There has been an overall steady decrease in the amount of aggregate produced during this time. This is primarily a result of resource depletion and resource sterilization because of urban expansion.

Poor planning is partially to blame for the lack of available aggregate resources in the study area, particularly within the City of London. Even in the 1970s when an estimated 10 year supply remained, concerns from the aggregate industry were not addressed (Sado 1976). In particular, portions of the Byron deposit, with sand and gravel material present at thicknesses greater than 30 m, have been left unutilized as a result of urban expansion.

The aggregate production in 2012 for each municipality is provided in Table B. The table does not include information for the Village of Newbury or the Municipality of Southwest Middlesex. No licenced aggregate extraction occurred in these 2 municipalities during the year of 2012. In addition, no information is provided for the First Nation communities.

The majority (~97.4%) of extractive activity occurs in the Municipality of Thames Centre, the City of London and the Township of Middlesex Centre (*see* Table B). There are 2 primary reasons for this concentration of activity: 1) these municipalities have large expanses of glaciofluvial, deltaic and outwash deposits that are known to contain large amounts of quality aggregate material, and 2) these resources are located close to where the demand for aggregate is occurring, that is, the City of London proper.

Table B. Aggregate Production by Municipality (2012), County of Middlesex and City of London.

Municipality (Listed Alphabetically)	2012 Production* (tonnes)	Percentage of the County Total
Township of Adelaide Metcalfe	42 043.00	1.1
City of London	891 426.86	23.6
Township of Lucan Biddulph	3161.10	0.1
Township of Middlesex Centre	513 580.99	13.6
Village of Newbury	–	–
Municipality of North Middlesex	42 881.80	1.1
Municipality of Southwest Middlesex	–	–
Township of Strathroy–Caradoc	9636.00	0.3
Municipality of Thames Centre	2 274 520.09	60.2
TOTAL	**3 777 249.84**	**100.0**

** Source: The Ontario Aggregate Resources Corporation (2013).*

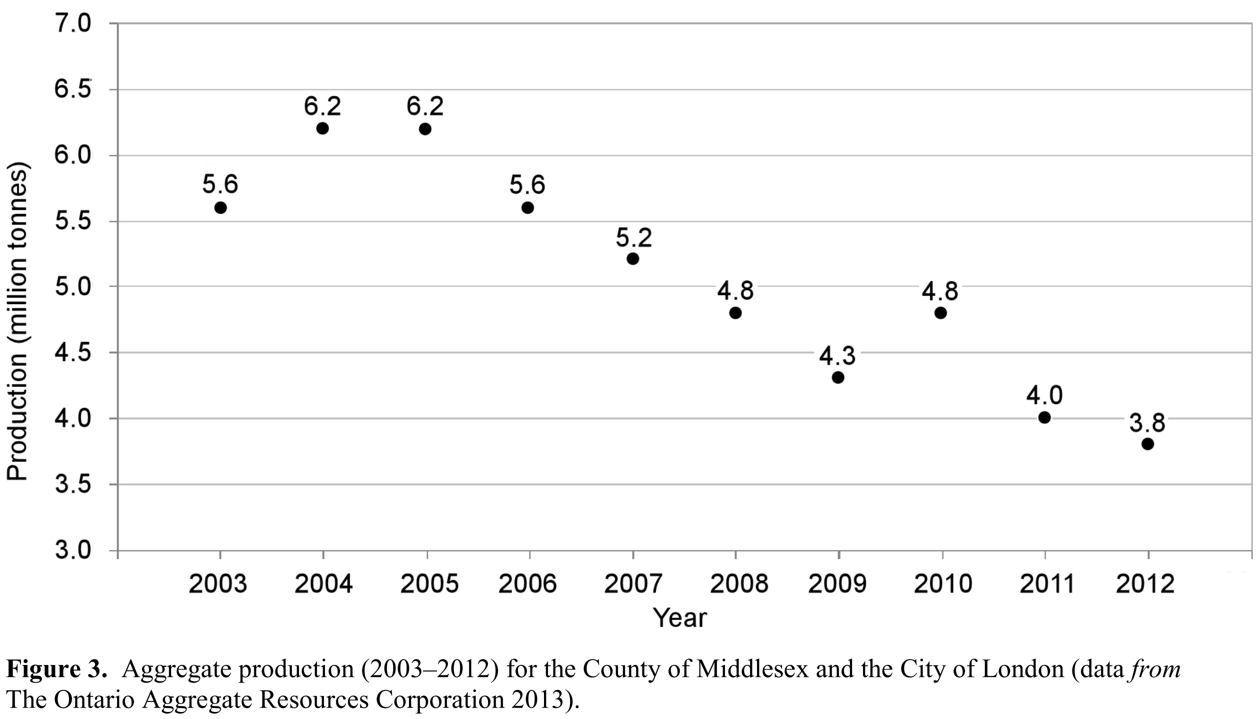


Figure 3. Aggregate production (2003–2012) for the County of Middlesex and the City of London (data *from* The Ontario Aggregate Resources Corporation 2013).

The majority (~97.4%) of extractive activity occurs in the Municipality of Thames Centre, the City of London and the Township of Middlesex Centre (*see* Table B). There are 2 primary reasons for this concentration of activity: 1) these municipalities have large expanses of glaciofluvial, deltaic and outwash deposits that are known to contain large amounts of quality aggregate material, and 2) these resources are located close to where the demand for aggregate is occurring, that is, the City of London proper.

Sand and Gravel

In total, 114 licenced and unlicenced sand and gravel pits were identified throughout the County of Middlesex during the field investigations for this study. At the time of writing, 111 pits (representing 2477 ha or 0.7% of the total land base of these municipalities) were licenced under the *Aggregate Resources Act* (Table 2). This information was provided by the Ministry of Natural Resources and Forestry (from Land Information Ontario) in the summer of 2013.

Bedrock

At the time of writing, there were 2 licenced quarries located in the County of Middlesex occupying 6.8 ha (Table 5). The quarries are not producing bedrock-derived crushed stone for use in road building and construction applications. Rather, they have been used in the past for the manufacturing of brick and tile. This information was provided by the Ministry of Natural Resources and Forestry (from Land Information Ontario) in the summer of 2013.

SURFICIAL GEOLOGY AND PHYSIOGRAPHY

The physiography and distribution of surficial material in the County of Middlesex are primarily the result of glacial activity that took place during the Late Wisconsinan approximately 23 000 to 10 000 radiocarbon years before present (Barnett 1992). The study area was subjected to oscillating ice margins and multiple ice lobes that have produced a complex suite of tills with distinct properties. The repeated advance and retreat of the ice lobes along with fluctuating lake levels and associated fluvial activity during this time are the main events that have shaped the landscape. Subsequent activity during the Holocene, or the last 10 000 years, has altered Late Wisconsinan deposits by wind and alluvial activity.

Late Wisconsinan

During the Late Wisconsinan, 3 periods of ice advance—the Nissouri, Port Bruce and Port Huron phases—are separated by 2 periods of ice-margin recession: the Erie and Mackinaw phases (Barnett 1992). Figure 4 provides a summary of glacial activity in the study area.

NISSOURI PHASE

The Nissouri Phase marks the main advance of the Laurentide Ice Sheet during the Late Wisconsinan (Barnett 1992). The ice sheet moved in a southward direction and at its furthest extent covered the entire study area, extending as far south as Indiana in the United States (Cooper 1979, 1977a, 1977b, 1977c, 1977d). The record of this advance in the study area is represented by the Catfish Creek Drift (Barnett 1992). This drift complex is composed of subglacial till, the Catfish Creek Till, with lesser amounts of glaciofluvial and glaciolacustrine stratified sediments. The Catfish Creek Till is generally a stony, overconsolidated, calcareous, sandy silt to silt till (Barnett 1992). In the latter part of the Nissouri Phase, the ice sheet thinned and lobation occurred. The Dorchester moraine may have been, in part, formed in this interlobate region (Barnett 1992). The majority of these deposits have been buried by the deposits of later glacial advances, discussed below. Surface exposures of the drift complex in the study area are limited to the area of the Dorchester moraine. The nature of these deposits and the limited surface exposure of them results in the sand and gravel material of the Nissouri Phase as not having significant potential as an aggregate resource.

ERIE PHASE

The Erie Phase represents a period of ice recession. The degree of recession is unclear. It has been suggested that the study area was free of ice during this period (Cooper 1979; Sado 1980). Proglacial lakes developed south and west of the retreating ice margin in the Huron and Erie lake basins, respectively (Barnett 1992). Fine-grained glaciolacustrine sediment was likely deposited within the study area during this interval; however, there is no direct evidence for this. It is suggested that the subsequent ice advance of the Port Bruce Phase, discussed below, overrode and reworked material deposited during the Erie Phase incorporating it into its matrix (Barnett 1992). Indirect evidence for these events is the fine-grained nature of the overlying tills. Bajc and Dodge (2011) suggest that the Erie Phase was a period of general ice recession punctuated by minor readvances of the ice margin. Complex sequences of diamicton interbedded with glaciolacustrine deposits were laid down during this period. Nevertheless, there is no aggregate potential of the sand and gravel material specific to the Erie Phase.

PORT BRUCE PHASE

During subsequent ice re-advances, the flow of ice occurred as lobes originating from the basins presently occupied by the Great Lakes (Barnett 1992). During the Port Bruce Phase, the study area was subjected to ice flowing radially outward from the Huron and Erie lake basins. The ice lobes overrode the Erie Phase glaciolacustrine sediments, discussed above, incorporating them into the tills of the re-advancing ice. This is evidenced by the fine-grained nature of both the Port Stanley Till, deposited by the Erie ice lobe, and the Tavistock Till, deposited by the Huron ice lobe (Barnett 1992).

Ice advancing from the Huron basin fluctuated depositing multiple layers of Tavistock Till interbedded with glaciolacustrine and glaciofluvial sediments (Sado 1980; *see* Figure 4). The Dorchester, Cherry Grove and Arva moraines were deposited or overridden during these events. A number of predominantly sand, ice-contact stratified deposits are associated with these moraines. These deposits include the Cobble Hills and North Dorchester ice-contact deposits located along the eastern border of the study area. These deposits have become an important aggregate resource in the study area as other resources have been depleted. The ice-contact deposits along with the associated till plain have been identified by Chapman and Putnam (1984) as the Oxford till plain physiographic region (Figure 5). The Oxford till plain is identified as an upland surface, in places drumlinized, incised by well-defined valleys (Chapman and Putnam 1984).

The Dorchester, Cherry Grove and Arva moraines were later overridden by ice that deposited additional layers of Tavistock Till (*see* Figure 4). The morphology of these moraines is subdued and likely palimpsest. They faintly extend above the general level of the till plain that extends across the northeast to central portion of the study area. This area lies within part of the region identified as the Stratford till plain physiographic region (Chapman and Putnam 1984; *see* Figure 5). The Stratford till plain is typically a flat-lying ground moraine interrupted locally by several end moraines. In the study area, these end moraine include the Arva, Cherry Grove, Mitchell and Lucan moraines.

Huron basin ice advancing from the northwest met with Erie basin ice advancing from the southeast (Sado 1980). Interbedding of Tavistock and Port Stanley tills occurred as the ice masses abutted and fluctuated against each other in this position. The Ingersoll moraine marks the position of this interaction (Sado 1980). In general, Tavistock Till is located north of the Ingersoll interlobate moraine, whereas Port Stanley Till is located to the south. It is, however, likely that the Huron and Erie ice lobes each extended beyond the Ingersoll moraine (Sado 1980).

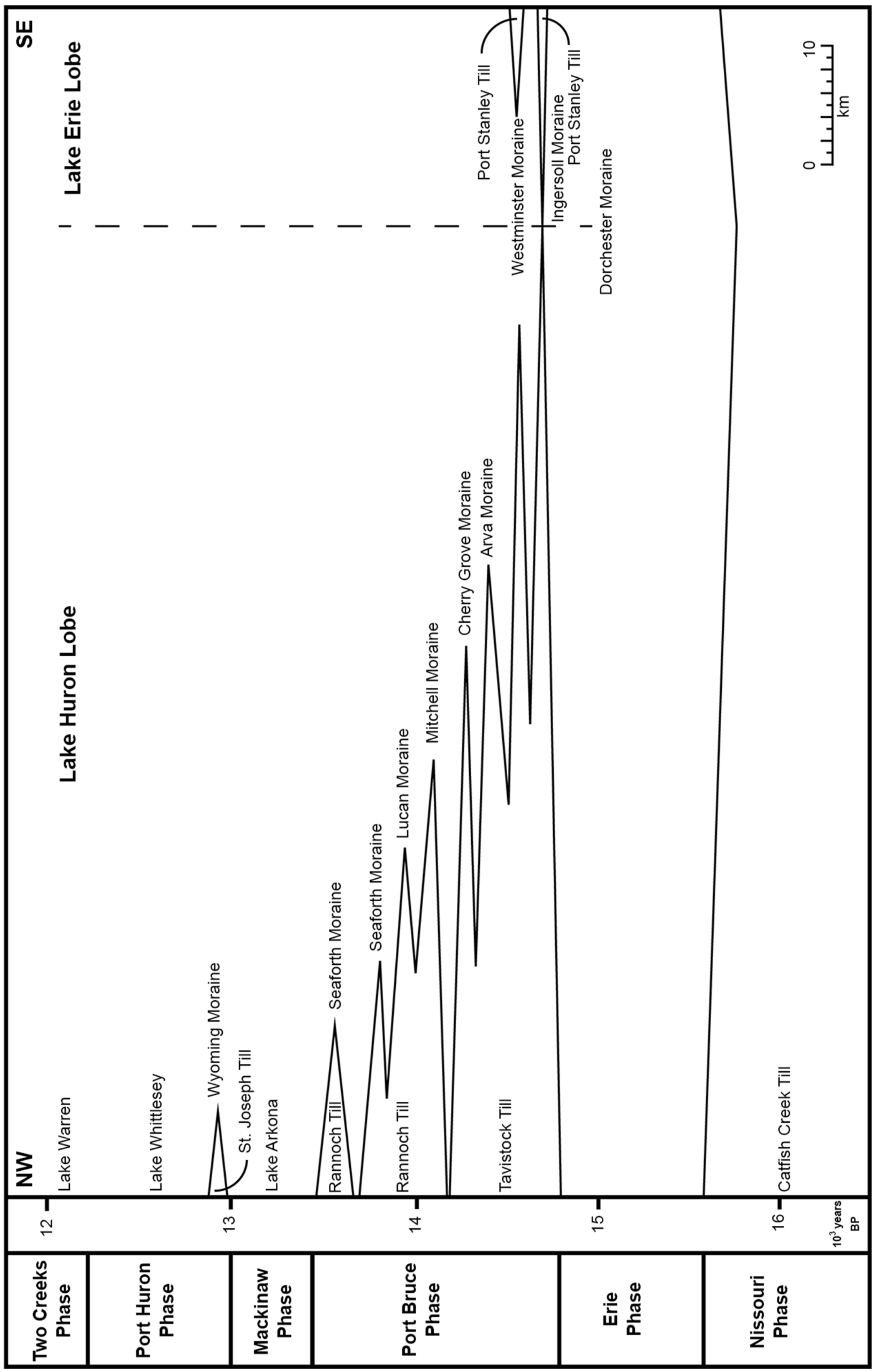


Figure 4. Simplified time–distance diagram showing the fluctuations of glacial ice lobes during the Late Wisconsinan in the study area (*modified from* Sado 1980).

The Lake Erie ice lobe advanced from the eastern end of the basin extending northwestward into the present-day City of London, meeting the Lake Huron ice lobe. The Port Stanley Drift deposited by this advance consists of several layers of till and associated waterlain sediment including glaciolacustrine sand, silt and clay (Sado 1980). The Ingersoll moraine is generally composed of a layer of Port Stanley Till overlying a core of gravel. Several kettle lakes (ponds) are present in the vicinity of the Ingersoll moraine. Directly south of the Ingersoll moraine, the Westminster moraine was deposited and, similar to the Ingersoll moraine, is composed of layers of Port Stanley Till interbedded with stratified sediment. These moraines along with the kettle lakes have resulted in a landscape with a high degree of local relief and, as a result, the area has been identified as the Mount Elgin ridges physiographic region (Chapman and Putman 1984; *see* Figure 5).

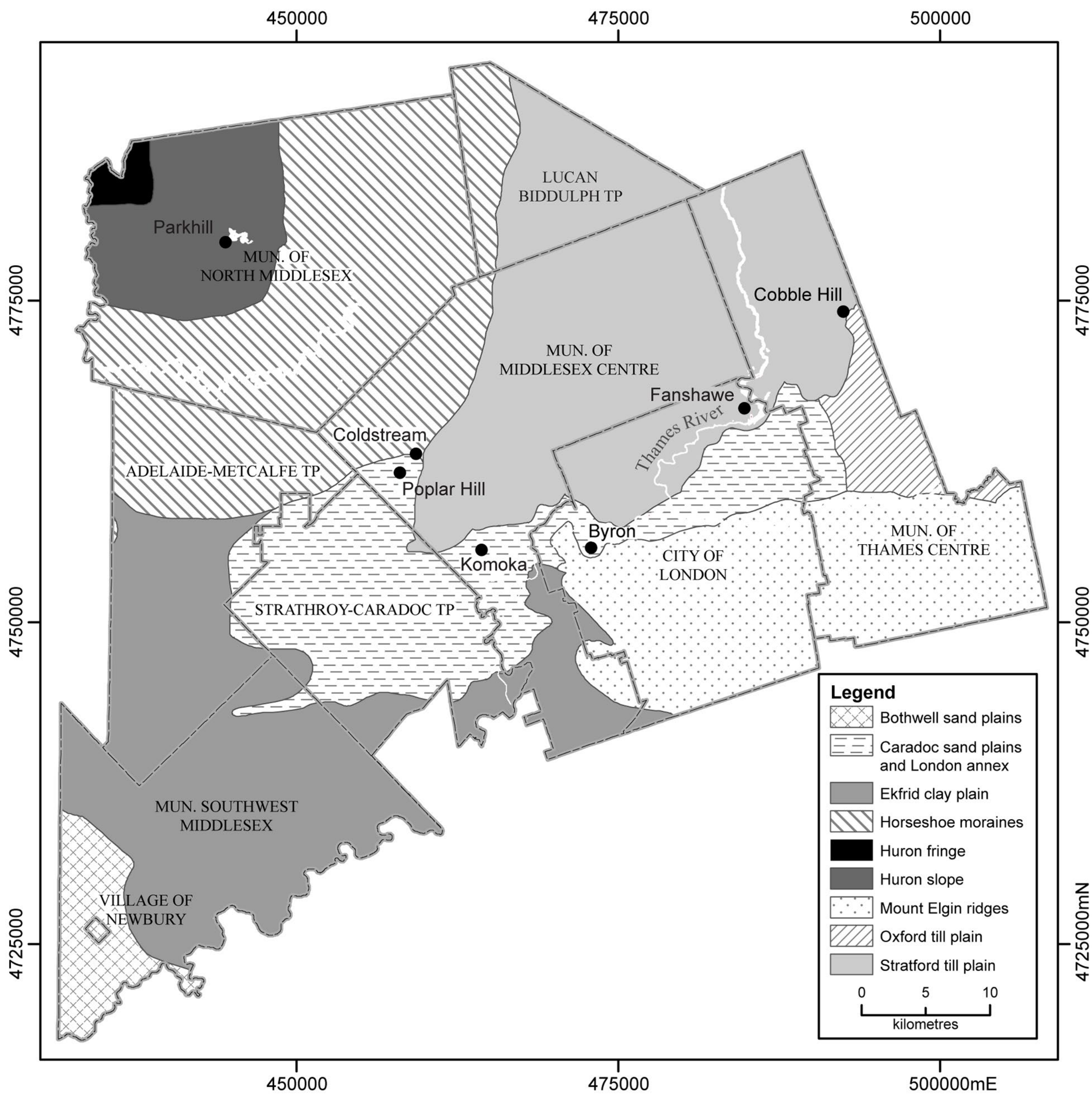


Figure 5. Physiographic regions of the County of Middlesex and the City of London (*modified from* Chapman and Putnam 2007).

A later re-advance of the Huron ice lobe during the latter part of the Port Bruce Phase resulted in the deposition of the Rannoch Till (Sado 1980). This till is present both in till plains and as end moraines including the Mitchell, Lucan, Seaforth and Centralia moraines in the study area (Barnett 1992; *see* Figure 4). The Huron ice lobe advanced from the northwest forming the Mitchell moraine, then shifted to a more westerly direction forming the Lucan, Seaforth and Centralia moraines (Sado 1980). Ice-contact stratified sediment associated with these moraines may occur beneath fine-grained till (e.g., Vanderveer 1989). A number of buried sand and gravel deposits have been identified on the till plain west of the Seaforth moraine. Deposits of similar character and with limited surface exposure also occur along the trends of the moraines and provide additional aggregate resources to the region. The Mitchell and Lucan moraines and associated till plains comprise the remaining portion of the Stratford till plain (discussed previously). The Seaforth and Centralia moraines and associated till plains lie within a portion of the Horseshoe moraines physiographic region (Chapman and Putnam 1984; *see* Figure 5). The Horseshoe moraines physiographic region is a large horseshoe-shaped region located on the uplands west of the Niagara Escarpment. In the study area, the region consists of a simple landscape consisting of till plains and moraines (Chapman and Putnam 1984).

The ice-contact stratified drift deposits exposed east of Arkona, along the western boundary of the study area, were deposited during the Port Bruce Stadial. The sands and gravels of the ice-contact deposits are similar to those forming the core of the Seaforth moraine (discussed previously) and were likely deposited along the same ice margin (Cooper 1979). This deposit, which extends into the County of Lambton, is a significant source of sand and gravel for the county.

The last incursion of ice from the Lake Huron basin during the Port Bruce Phase resulted in the deposition of a silty clay to clay till that contains numerous inclusions of glaciolacustrine sediments and overlies the Rannoch Till (Cooper 1979). Some researchers have considered this till to be an upper member of the Rannoch Till (discussed previously) (Barnett 1992). This till, informally referred to as the "southern till", can be found as a veneer in the southern part of the Seaforth moraine. As a result, the Seaforth moraine is noticeably less rugged than other moraines in the area (Cooper 1979). In the Strathroy area (east-central portion of the county), lacustrine deposits merge with and are gradational with the "southern till". This till is limited in its extent and does not represent a major event (Cooper 1979).

Throughout the Port Bruce Phase, ponded meltwater fronted the ice margins, resulting in a series of discrete lake phases associated with changing water levels in the Great Lakes basins. Meltwater collected in the western end of the Lake Erie basin and in the southern end of the Lake Huron basin, forming glacial Lake Maumee I (Barnett 1992). Falling water levels and the establishment of glacial Lake Maumee II occurred as the Huron ice lobe retreated northward. The delta and outwash complex located at Coldstream and Poplar Hill, another significant aggregate resource, are believed to have been deposited at this time (Terasmae, Karrow and Dreimanis 1972). Glacial Lake Maumee III formed following a re-advance of the Huron ice lobe and the blockage of meltwater channels, raising the water level of the lake. Subsequent ice retreat resulted in the opening of the meltwater channel once again and the establishment of glacial Lake Maumee IV (Barnett 1992).

During the fluctuating levels of glacial Lake Maumee, large amounts of sediments were carried by meltwater channels into the glacial lakes abutting the ice margins. Numerous outwash and deltaic deposits were laid down along the developing Thames River and its tributaries. Large deposits extend from Fanshawe southwest to Byron and Komoka. These 3 deposits in particular contribute significantly to the amount of aggregate resources available in the study area. These deposits largely compose the physiographic regions identified as the Caradoc sand plains and London annex (Chapman and Putnam 1984; *see* Figure 5). These plains differ from the surrounding till and clay plains in that they are composed of waterlaid sand and gravel. The London annex was largely created during the Port Bruce Phase and the Caradoc sand plains during the subsequent Port Huron Phase (discussed later).

MACKINAW PHASE

Possible warmer climate during the Mackinaw Phase caused the further retreat of the ice margins. Lake levels in the lakes Huron and Erie basins lowered forming glacial Lake Arkona (Cooper 1979). Exposed Arkona beach deposits are present in the northwest portion of the study area (Cooper 1979). Possible Lake Arkona beach deposits are buried beneath till and glaciolacustrine sediments deposited during the subsequent Port Huron Phase (Cooper 1979). The beach deposits are relatively small and thin, are not well developed and, therefore, have limited potential as an aggregate resource.

PORT HURON PHASE

The last major ice advance into the study area occurred during the Port Huron Phase. The Huron ice lobe extended into the northwest corner of the study area. The St. Joseph Till was deposited at this time coincident with the Wyoming moraine being constructed at the outer limits of the advance (Cooper 1979). The Wyoming moraine is a prominent feature in the northwest portion of the study area because it is juxtaposed against a predominantly flat terrain. It is a hummocky belt of land rising 30 to 60 m above the surrounding till plains. It is approximately 8 km wide and runs parallel to Lake Huron (Cooper 1979). The outer edges of the till tend to be clast free and are enriched in glaciolacustrine sediments because of the influence of glacial Lake Whittlesey (discussed below) (Cooper 1979). The Wyoming moraine and associated St. Joseph till plain comprise the remainder of the Horseshoe moraines physiographic region (described previously), and a portion of the Huron slope (Chapman and Putnam 1984; *see* Figure 5). The Huron slope physiographic region is a clay plain that slopes gently down from the Wyoming moraine toward Lake Huron (Chapman and Putnam 1984).

During and continuing until shortly after the Port Huron Phase, glacial Lake Whittlesey developed in the Lake Erie basin south and west of the retreating Huron and Erie ice lobes, respectively (Barnett 1992). Glacial Lake Whittlesey water levels began to recede a short time after the Port Huron ice advance (Cooper 1979). Although glacial Lake Whittlesey was a relatively short-lived lake, it deposited up to 10 m or more of sediments in the Ausable River valley (Cooper 1979). In addition, the delta deposit at Komoka was partially constructed into glacial Lake Whittlesey by extensive streams flowing down the valley of the Thames River (Barnett 1992).

TWO CREEKS PHASE

Following the Port Huron Phase, the study area became ice free and lake levels fell to the glacial Lake Warren shoreline (Barnett 1992). In the northwest part of the study area, glacial Lake Warren abutted the Wyoming moraine. Wave action reworked the St. Joseph Till and developed a relatively large beach deposit. It is approximately 1.5 km at is widest and 20 km long. The deposit is not significant to the county as a whole, but is an important resource to municipalities in the northwest part of the county. These glacial Lake Warren beach deposits, along with deeper glaciolacustrine sediments, comprise the remainder of the Huron slope physiographic region (Chapman and Putnam 1984; *see* Figure 5).

During the numerous postglacial lake stages, thick sequences of clay, silt and sand were deposited in the Huron and Erie lake basins. The low-lying area along the southwest corner of the study area contains a thick sequence of these fine-grained deposits. These areas are located within the physiographic regions of the Ekfrid clay plain and Bothwell sand plain (Chapman and Putnam 1984; *see* Figure 5). The fine-grained deposits within these regions have limited aggregate potential. The Ekfrid clay plain is present in the southwest portion of the study area between and around the Caradoc sand plains and Bothwell sand plain. The clay was carried down the Thames River valley and deposited in the deep, glacial lake basins. The clay plain consists of a flat surface incised by a number of rivers. The Bothwell sand plain is located in the southwestern corner of the study area adjacent to the Caradoc sand plains (discussed previously).

The genesis of the plain is similar to that of the Caradoc sand plains. The plain was also formed when the early Thames River discharged sediment into a glacial lake, this time glacial Lake Warren. The plain consists of a thin veneer of sand overlying a predominantly clay substrate. With the retreat of glacial lakes, the fine sand material of the Bothwell sand plain was left exposed and susceptible to reworking by wind. A number of sand dunes have been identified in the extreme southwest corner of the study area.

Continued evolution of the Great Lakes basins occurred with the establishment of early Lake Erie which failed to extend into the study area and glacial Lake Algonquin in the Huron basin (Barnett 1992). Glacial Lake Algonquin extended into the northwest corner of the study area and was followed by Lake Nipissing. In the study area, the extent of glacial Lake Algonquin and Lake Nipissing are identical with both lakes extending into only the very northwest corner of the county. As a result, the beach deposits of glacial Lake Algonquin and Lake Nipissing are difficult to differentiate. The small beach deposits of glacial Lake Algonquin–Lake Nipissing are located along the edge of the Huron fringe physiographic region (Chapman and Putnam 1984; *see* Figure 5). This region comprises features created by the actions of glacial Lake Algonquin and Lake Nipissing. None of the deposits associated with glacial Lake Algonquin or Lake Nipissing have significant potential as an aggregate resource.

Sediments

TILL

As discussed in "Surficial Geology and Physiography", till in the study area is present as till plains and as end or recessional moraines. Till is generally not regarded as having potential for use in aggregate products because it generally contains significant amounts of fine-textured material (silts and clays). Table 10 provides the analysis of the till samples in the study area. Till in the study area can possibly be used as fill.

GLACIOFLUVIAL DEPOSITS

Undifferentiated Ice-Contact Stratified Drift

Undifferentiated ice-contact stratified drift deposits are found scattered throughout the study area, often in close proximity to moraines. The deposits are typically composed of stratified gravel, sand, silt and till and often are a significant source of sand and gravel material for aggregate applications. In the study area, these deposits are often overlain by till or fine-grained glaciolacustrine sediment. The surface exposures of these deposits can be limited and the extraction of such material may include significant amount of stripping and/or dredging to access sand and gravel material.

Subaqueous Fans

A number of deposits in the study area mapped as undifferentiated ice-contact stratified drift may be more accurately described as subaqueous fans. Formed in proximity to the mouths of meltwater conduits as they are discharged into a standing body of water, subaqueous fans typically consist of stratified sands and gravel with wide variations in the material distribution. As with the undifferentiated ice-contact stratified drift deposits in the region, these fans can be buried, requiring stripping and/or dredging to access the sand and gravel material.

Outwash

Outwash deposits within the study area are restricted to areas of former glacial meltwater channels. These channels generally occur within the valleys of modern rivers including the Ausable, North Thames and

Thames rivers. The coarseness of the outwash deposits varies depending on their proximity to source. In the study area, these deposits are composed primarily of sand, although coarser sections were observed.

Alluvial Deposits

Alluvial deposits in the study area are predominantly homogeneous clay and silt, but may contain amounts of stratified gravel, sand and organic matter. These deposits occur along stream channels that may or may not be presently active. These deposits were, and continue to be, laid down adjacent to and within active streams. Older and present-day alluvial deposits have similar lithologies and gradations, with older alluvial deposits usually being identified by the lack of organic material. The character of the alluvial deposits is greatly controlled by the underlying material.

GLACIOLACUSTRINE DEPOSITS

As discussed in "Surficial Geology and Physiography", a number of proglacial lakes formed in the study area throughout the late-glacial period. Fine-grained sediments (sand, silt and clay) were deposited in the deep basins of these lakes, whereas coarser grained sediments (sand and gravel) were deposited in the littoral zone.

Glaciolacustrine Delta

Coarse-grained sediments were deposited in the meltwater channels following the present-day valleys of the Thames River and its tributaries. The deposits become finer textured toward the west (i.e., downstream of the mouth of the delta). These deltas (at London, Fanshawe, Byron and Komoka) are terraced and graded to a succession of proglacial lakes that developed in the Erie and Huron basins. The significant size and thickness of these deposits makes them a significant source of aggregate in the study area.

Glaciolacustrine Beach

A number of beach deposits were mapped throughout the study area. The majority of these deposits are relatively small (e.g., <10 ha) and thin (e.g., <1.5 m thick). As such, they do not contain significant amounts of aggregate. A few rare exceptions exist and include beaches with significantly larger areal extent (i.e., the large beach east of Parkhill). However, because these deposits are still relatively thin, their resource significance on a regional scale is limited.

Glaciolacustrine Plain

Glaciolacustrine deposits cover much of the southwest portion of the study area where proglacial lakes were present. These deposits consist primarily of sand, silt and clay and cover much of the Municipality of Southwest Middlesex and the townships of Adelaide Metcalfe and Strathroy–Caradoc. Only those deposits that contain significant amounts of sand are shown on Map 1 (*see* back pocket).

Those glaciolacustrine deposits that are predominantly silt and clay are not identified on Map 1 because there is little potential to use these resources in typical aggregate applications. These deposits have been used in the past in the manufacture of brick and tile, in particular from the following locations.

1. In proximity to the community of Parkhill in the Municipality of North Middlesex, clay has been used in the manufacturing of brick (Guillet 1967).
2. West of the community of Delaware, clay attributed to glacial Lake Maumee located has been utilized for the manufacturing of brick (Guillet 1967).

3. North of the community of Strathroy, a pit and plant for the manufacturing of tile has operated. The clay is believed to be deposited in the basin of an early glacial lake (i.e., before that of glacial Lake Whittlesey) (Guillet 1967).
4. At the community of Elginfield, glaciolacustrine clay has been used to manufacture tile. The clay is believed to have been deposited in an early glacial lake (i.e., before that of glacial Lake Whittlesey) in a depression in the Rannoch Till plain (Guillet 1967).

EOLIAN DEPOSITS

Eolian deposits occur in the southwest portion of the study area generally in the townships of Adelaide Metcalfe and Strathroy–Caradoc, the Municipality of Southwest Middlesex and the Village of Newbury. The material was originally deposited as basinal glaciolacustrine sediment and subsequently reworked by wind following the drop in lake levels. Dunes are scattered throughout these glaciolacustrine deposits, but are concentrated in the extreme southwest corner of the county. Material is largely fine to medium sand and has limited potential as an aggregate resource. Licenced operations developed within these types of deposits have the potential to produce sand-specific products (i.e., septic sands, mortar sand, and sand for winter sanding).

SAND AND GRAVEL AGGREGATE QUALITY

Test data from the Ministry of Transportation (MTO) files have been used extensively in the assessment of the resources of the county (Table 9). However, significant changes have occurred in the testing and specifications applied to aggregates since the original Aggregate Resources Inventory Papers (ARIPs) were completed (1979 to 2000). 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 County of Middlesex commonly contain test results for the Los Angeles abrasion and magnesium sulphate soundness tests. These data are extensive and they are still useful in assessing the general quality of the material, so they have been included in the current assessment. For example, a Los Angeles abrasion test loss of 35% or less generally indicates good physical quality in an aggregate.

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

Care should be exercised, however, in extrapolating the quality test data for individual samples contained in this report to the entire deposit because of 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 ESRI® 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.

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

Restricted Resources

The sand and gravel resources map (Map 1) that accompany Aggregate Resource Inventory Papers (ARIPs) usually displays only primary (red), secondary (orange) and tertiary (yellow) shading as discussed earlier in this report. The County of Middlesex is no different from other areas in southern Ontario where many of the important sand and gravel resource areas have become restricted because of previous extraction and human activity. As a result, these activities may have totally removed segments of sand and gravel resources (i.e., surrendered licences), beyond what would normally be represented by the abandoned pit symbol. Therefore, this report identifies restricted resources (green) that represent areas of sand and gravel resources that are substantially removed or areas where the only remaining aggregate resources may be below the water table. These restricted resource areas (shown on Map 1 in green) have not been included in resource calculation because it would be difficult to assess the remaining quantity or quality of the granular material.

In this report, the use of the abandoned pit symbol has been limited to identifying unlicenced pits where exposed sand and gravel material was observed and studied during the field investigations. Many unlicenced pits are difficult to identify and only the very obvious unlicenced pits are shown on Map 1. This is because of a variety of reasons, including 1) many of the unlicenced pits were small to begin with and have left a small "footprint"; 2) many have been fully or partially rehabilitated following extractive activities; 3) many pit faces have been sloped and revegetated naturally; 4) many pits may be hard to identify from the natural rolling topography of the area; and, 5) the *Pits and Quarries Control Act* (1971) and the *Aggregate Resources Act* (1989) have been effective in preventing the establishment of new unlicenced pits.

SELECTED SAND AND GRAVEL RESOURCES AREAS

The sand and gravel deposits of the County of Middlesex are shown on Map 1 that accompanies this report. Sand and gravel deposits occupy approximately 89 759 ha (roughly 27% of the area of the municipality) and contain an original resource tonnage of 5653 million tonnes (Table 1). **These figures represent a comprehensive inventory of all the granular material in the County of Middlesex, although much of the material included in the estimate has no potential for use in aggregate products.**

For this study, the criteria for Selected Sand and Gravel Resources include 1) quality of the material in the deposit suitable for producing Granular A and/or hot mix asphalt (HMA) and concrete aggregate products, 2) sand and gravel material present at surface with a thickness of at least 6 m, and 3) at least 1 million tonnes of virgin material estimated to be available for future extraction. In total, 8 areas have been chosen as Selected Sand and Gravel Resource Areas of primary significance; these areas are indicated on Map 1 in red. These areas occupy an unlicenced area of about 4839.6 ha, which is reduced to 2349.0 ha after considering previous extraction and cultural, physical and environmental constraints. These areas represent a possible aggregate resource of 278.1 million tonnes (Table 3).

Selected Sand and Gravel Resource Area 1

Selected Sand and Gravel Resource Area 1 is located in the western portion of the County of Middlesex along the borders of the Municipality of North Middlesex and the Township of Adelaide Metcalfe and extends into the County of Lambton. This selected resource is composed of 4 undifferentiated ice-contact stratified drift segments separated and possibly overlain by fine glaciolacustrine and modern alluvial material. At the time of writing, 1 licenced pit (Pit No.6) was developed in the deposit. A number of pits opened in the past have been depleted and rehabilitated into ponds or for agricultural use (Ontario Geological Survey 1991).

These undifferentiated ice-contact stratified drift deposits are located between the Seaforth and Wyoming moraines and likely represent the deposits laid down during a pause in the retreat of the Huron ice lobe. Pit faces expose highly varied material, largely sand material consisting of well-sorted, cross-bedded sand with minor gravel and massive, poorly sorted sand and gravel beds. Some crushable material was observed during the field investigation. Clast lithology is principally limestone, dolostone and Precambrian with minor chert (1 to 2%) (Cooper 1979).

Up to 1 m of silt and clay was observed overlying portions of these deposits. It is likely that the undifferentiated ice-contact stratified drift deposits located south and southeast in close proximity to Selected Sand and Gravel Resource Area 1 are portions of the same deposit. Water-well records in proximity to these deposits indicate up to 9 m of sand underlying 3 to 5 m of clay. Field observations suggest that these deposits are part of a subaquatic fan complex, not an undifferentiated ice-contact–stratified drift complex. These deposits likely represent a large, partially buried subaquatic fan deposited in association with the undifferentiated ice-contact stratified drift deposit to the north (Selected Sand and Gravel Resource Area 1). There are currently 4 licenced pits (Pit Nos. 17 to 20) located in the associated deposits that have been selected to be of secondary significance because of their smaller surface extent.

Previous gradation results indicate that, when present, coarse material varies from approximately 5 to 50%, fine aggregate from 50 to 95% and fines from 1.5 to 7.5%. The large range of the gradations is because of the high variability of depositional environments in the deposit. The majority of the material will meet the gradational requirements for Granular B, SSM, HMA(fine aggregate) and concrete (fine aggregate) products. If sufficient quantities of coarse material are located in the deposit, the material will be able to meet the gradational requirements for Granular A.

Limited information is available regarding the quality of the sand and gravel aggregate material. One available MTO test result suggests that the material quality is too poor for use in HMA or concrete products (*see* Table 9). The same deposit in the County of Lambton has been on the aggregate source list for concrete fine aggregate. This suggests that the material in the study area will also meet the quality requirements for use in HMA and concrete products with beneficiation.

Selected Sand and Gravel Resource Area 1 has a total unlicenced area of 345.6 ha. After considering previously extracted areas and physical, cultural and environmental constraints, the remaining area is reduced to 234.5 ha. Pit faces generally expose 3 to 8 m of granular material. Using a conservative deposit thickness of 6.0 m, 24.9 million tonnes of aggregate material are still available for extraction (*see* Table 3).

Selected Sand and Gravel Resource Area 2

Selected Sand and Gravel Resource Area 2 is a deltaic complex located in both the Municipality of Middlesex Centre and the City of London, at the community of Komoka. The material was laid down primarily in a delta of glacial Lake Maumee II with lower elevations attributed to the later glacial Lake

Whittlesey (Terasmae, Karrow and Dreimanis 1972). At the time of writing, there were 8 licenced pits (Pit Nos. 26 to 33) within this selected resource area. A number of previously operated pits have been depleted and rehabilitated mainly into ponds.

Pit faces expose 3 to 5 m of well-sorted medium sand with interbeds of fine to medium gravel. Gravel content ranges from approximately 20 to 70%. Water-well records indicate up to 12 m of sand and gravel potentially available for extraction, largely below the water table. At the time of the field investigation, operations within the deposit were dredging material from up to 7 m below the water table. Portions of the deposit are covered with a thin (1 to 2 m) veneer of silty sand. The deposit is finer in the north and likely coarsens with depth. Exposures are limited, although oversize and crushable material is located at depth below the water table. The material of this deposit will be able to meet the gradational requirements of various aggregate products including Granular A, and HMA and concrete products.

The quality of the material poses a problem that will limit the products that can be produced. Chert is present in enough quantities, 5 to 20%, to limit the potential uses of the resource (Ontario Geological Survey 1981; Ingham and Dunikowska-Koniuszy 1965). Previous MTO results (*see* Table 9) suggest that the material will be able to meet the quality requirements of Granular A. The use of the material in producing HMA and concrete aggregate products will likely be limited by the amount of deleterious lithology.

Selected Sand and Gravel Resource Area 2 has a total unlicenced area of 874.6 ha. After considering previously extracted areas and physical, cultural and environmental constraints, the remaining area is reduced to 284.5 ha. Pit faces generally exposes 3 to 5 m of granular material. Extraction below the water table (dredging) is common in the licenced pits developed within this deposit. Using a conservative deposit thickness of 6 m, 30.2 million tonnes of aggregate material are still available for extraction (*see* Table 3).

Selected Sand and Gravel Resource Area 3

Selected Sand and Gravel Resource Area 3 is primarily located in the western portion of the City of London, extending into the Municipality of Middlesex Centre. Dreimanis (1964) described this outwash deposit as a valley train, although other portions of the deposit have been identified as a glaciolacustrine delta deposit (Dreimanis 1964). At the time of writing, there were no licenced pits within the deposit. The selection of this deposit is based on information obtained from a number of rehabilitated pits within the resource area.

The material is primarily sand with pockets of gravel. Coarse material is reported to be concentrated in the northern part of the deposit along the Thames River (Sado 1976). This observation is corroborated by water-wells records that indicate the presence of gravel, but only in the north portion of the deposit, in proximity to the Thames River. Former pits developed in this deposit are reported as having a gravel content that ranged from 20 to 80% (Ontario Geological Survey 1983a). Former face heights ranged from 2 to 9 m and generally exposed horizontally bedded medium sand with layers of fine to medium gravel (Ontario Geological Survey 1982c, 1983a). There is a general trend of the material coarsening with depth. Gravel content of the upper portions of the deposit is estimated to be 10 to 30%, whereas lower portions are estimated to be 60 to 80% (Ontario Geological Survey 1982c).

The material will meet the granular requirements for Granular B and HMA and concrete products, as well as the requirements for Granular A if enough coarse material is located. Fines are present and washing will likely be required to meet the gradational requirements of these aggregate products.

No previous test results were located for material of this deposit. Previous field investigations and the field investigations completed as a part of the current study gave no indication of deleterious lithologies that would limit the usefulness of the material.

Selected Sand and Gravel Resource Area 3 has a total unlicenced area of 880.1 ha. After considering previously extracted areas and physical, cultural and environmental constraints, the remaining area is reduced to 609.5 ha. Using a conservative deposit thickness of 6 m, 64.7 million tonnes of aggregate material are still available for extraction (*see* Table 3).

Selected Sand and Gravel Resource Area 4

Located in the western portion of the City of London south of the Thames River, an impressive delta overlain and interbedded with till material near the community of Byron has been selected as having primary significance. At the time of writing, there were 8 licenced pits (Pit Nos. 60 to 67) developed in the deposit.

The origin of this deposit is complex and involves multiple deltas, glacial lakes and ice lobes. A detailed review of the geological history of the Byron deposit is provided by Terasmae, Karrow and Dreimanis (1972). Generally, the upper layers of the deposit consist of silty till interbedded with deltaic and lacustrine sands. These layers contain excess fines that should be avoided or washed out. The lower portions of the deposit consist of deltaic gravels (Terasmae, Karrow and Dreimanis 1972). The coarse gravel material commonly contains oversize, crushable material. Cementation of these gravels was noted. Face heights at the time of the field investigation were approximately 30 m. Available surface elevations indicate that over 60 m of sand and gravel available for extraction above the water table alone. Extraction below the water table was occurring at the time of the field investigation and adds to the volume of resource available.

The material will be able to meet the gradational requirements of a wide variety of products including Granular A, Granular B and HMA and concrete aggregate products. Chert was observed in the field, although there are no indications that this will limit usage of the material.

Selected Sand and Gravel Resource Area 4 has a total unlicenced area of 207.1 ha. After considering previously extracted areas and physical, cultural and environmental constraints, the remaining area is reduced to 67.4 ha. Using a conservative deposit thickness of 30 m, 35.8 million tonnes of aggregate material are still available for extraction (*see* Table 3).

The author acknowledges that detailed, site-specific, local-scale studies have been carried out and detailed planning proposals have been developed for the extraction and subsequent rehabilitation of the Byron deposit. These studies conclude that no available resource areas are remaining in the deposit. This is primarily a result of the inclusion of local zoning and planning policies not considered in the current study. Since these zoning and planning policies are subject to change, the remaining resource available for extraction is significant enough to warrant being selected as a primary resource area.

Selected Sand and Gravel Resource Area 5

Selected Sand and Gravel Resource Area 5 is located at the junction of the municipalities of Middlesex Centre, Thames Centre and the City of London. The deposit is informally named the “Fanshawe Delta” (Sado 1980). This complex includes both deltaic and glaciofluvial outwash deposits. At the time of writing, there were 26 licenced pits (Pit Nos. 42 to 59 and 75 to 87) developed in the deposit. A number of former pits have been depleted and rehabilitated.

Pit faces range from 3 to 8 m and generally expose horizontally bedded, well-sorted sand and gravel (topset), overlying inclined, well-sorted sand and gravel beds (foreset). Water-well and borehole records indicate sand and gravel material present at depths up to 20 m. Portions of these resources are located below the water table. Licenced operations were dredging for material at the time of the field investigation. The deposit material is noticeably coarser in the north. The northern portions of the deposit have higher gravel content and contain oversize material that can be crushed and utilized. Southern portions have lower gravel content and contain enough fines that washing will likely be required to produce an acceptable aggregate product. Fine sand to silty sand layers were also observed.

Previous gradation results indicate that, when present, crushable material varies from 3.1 to 53.3%, coarse aggregate from 1.4 to 74.4%, fine aggregate from 24.4 to 98.2% and fines from 0.4 to 6.1%. The material will be able to meet the gradational requirements for Granular A, Granular B and HMA and concrete aggregate products with relative ease.

Previous MTO aggregate test results provide the following results (*see* Table 9). Petrographic Number values vary from 100.0 to 119.1 for Granular and 16 mm crushed and from 103.0 to 175.8 for HMA and concrete stone. Magnesium sulphate soundness test results range from 0.4 to 13.4% for coarse aggregate and from 8.4 to 21.2% for fine aggregate. Los Angeles abrasion values vary from 19.0 to 32.0%. Micro-Deval abrasion test results vary from 8.5 to 16.8% for coarse aggregate and from 13.0 to 25.0% for fine aggregate. Absorption values range from 0.584 to 2.040% and bulk relative density values range from 2.430 to 2.748. Few test results (approximately 10 out of 171) fall outside of the acceptable values for Granular A and HMA and concrete products. The quality of the material is acceptable for producing a wide range of aggregate products.

Although chert was observed in the deposit during the field investigation and was noted in past investigations (Ontario Geological Survey 1983b; Ingham and Dunikowska-Koniuszy 1965), it does not seem to impact the overall quality of the material. Cementation was also observed, although again, it does not seem to impact the quality of the material.

Selected Sand and Gravel Resource Area 5 has a total unlicenced area of 1773.2 ha. After considering previously extracted areas and physical, cultural and environmental constraints, the remaining area is reduced to 650.7 ha. Pit faces generally expose 3 to 8 m of granular material. Using a conservative deposit thickness of 6.0 m, 69.1 million tonnes of aggregate material are still available for extraction (*see* Table 3).

Selected Sand and Gravel Resource Area 6

Selected Sand and Gravel Resource Area 6 is a large expanse of undifferentiated ice-contact stratified drift terrain located in the east-central portion of the Municipality of Thames Centre, extending into the County of Oxford. At the time of writing, 17 licenced pits (Pit Nos. 88 to 94 and 96 to 104) had been developed in the deposit. A number of former pits previously developed in this deposit have been depleted and rehabilitated.

This deposit is associated with the Dorchester moraine, a feature suggested as being interlobate in origin (Barnett 1992). Sand and gravel deposits are often overlain by or interbedded with till. Face heights range from 2 to 6 m and expose material that varies considerably. Poorly sorted medium sand with medium to coarse gravel was commonly observed in pit sections. Pockets of material with higher gravel content were also observed and tended to contain cobble material. This deposit may also be more accurately described as a subaqueous fan. Water-well and borehole records indicate up to 20 m of material. Portions of these resources will be below the water table. A number of licenced operations were dredging material from below the water table at the time of the field investigation.

The high degree of variability of the material means that a variety of aggregate products can be produced. As gravel and crushable material tends to occurs in pockets, the ability to produce Granular A and related products will be dependent on locating these pockets.

Previous aggregate test results provide the following results (*see* Table 9). Petrographic Number values vary from 100.0 to 203.2 for Granular and 16 mm crushed and from 117.0 to 230.8 for HMA and concrete stone. Magnesium sulphate soundness test results range from 2.0 to 12.4% for coarse aggregate and from 8.8 to 17.4% for fine aggregate. Los Angeles abrasion values varied from 22.0 to 35.0%. Micro-Deval abrasion test results vary from 10.3 to 14.6% for coarse aggregate and from 9.9 to 15.2% for fine aggregate. Absorption values range from 0.750 to 2.300% and bulk relative density values range from 2.274 to 2.627. Petrographic Number values confirm quality problems with the material of the deposit. The stone quality of material from this deposit is generally too poor for use in HMA (coarse aggregate) and concrete (coarse aggregate) products. The material will still meet the requirements for Granular A and related products and HMA and concrete (fine aggregate) products.

Selected Sand and Gravel Resource Area 6 has a total unlicenced area of 675.8 ha. After considering previously extracted areas and physical, cultural and environmental constraints, the remaining area is reduced to 465.6 ha. Pit faces generally expose 3 to 6 m of granular material. Using a deposit thickness of 6.0 m, 49.4 million tonnes of aggregate material are still available for extraction (*see* Table 3).

Selected Sand and Gravel Resource Area 7

Selected Sand and Gravel Resource Area 7 is located along the eastern portion of the Municipality of Thames Centre bordering the County of Oxford. At the time of writing, there were no licenced pits in the deposit. At least 1 former pit has left the deposit largely depleted with a large pond marking the former location of extraction. This deposit has been selected at the primary significance in part to be consistent with the aggregate resource mapping in the County of Oxford to the east (Rowell 2014).

Previous investigation indicated face heights of 3 to 5 m and a gravel content of 50 to 60%. One water-well record in the deposit indicates 9.5 m gravel present. More detailed information of this deposit is provided by Rowell (2014).

Previous aggregate test results provide the following results (*see* Table 9). Petrographic Number values vary from 102.8 to 119.6 for Granular and 16 mm crushed and from 126.3 to 167.7 for HMA and concrete stone. Magnesium sulphate soundness test results range from 3.7 to 8.0% for coarse aggregate and from 10.2 to 15.8% for fine aggregate. Los Angeles abrasion values varied from 21.8 to 25.7%. Absorption values range from 1.360 to 1.730% and bulk relative density values range from 2.605 to 2.646. Petrographic Number values are typically out of range for HMA and concrete indicating that the stone quality is too poor for use in HMA (coarse aggregate) and concrete (coarse aggregate) products.

Selected Sand and Gravel Resource Area 7 has a total unlicenced area of 43.7 ha. After considering previously extracted areas and physical, cultural and environmental constraints, the remaining area is reduced to 7.0 ha. Using a conservative deposit thickness of 6.0 m, 0.7 million tonnes of aggregate material are still available for extraction (*see* Table 3). The extension of this deposit into the County of Oxford will greatly add to the amount of material available for extraction.

Selected Sand and Gravel Resource Area 8

Selected Sand and Gravel Resource Area 8 is an outwash deposit located in along the eastern border of the Municipality of Thames Centre south of the Thames River. At the time of writing, there were 3 licenced pits (Pit Nos. 106 to 108) developed in this deposit. It has been selected at the primary level in part to be consistent with the continuation of this deposit into the County of Oxford (Rowell 2014).

Pit faces expose 3 to 6 m of poorly sorted medium to coarse sand with gravel and cobbles up to 20 cm in diameter. Water-well records indicate up to 15 m of sand and gravel material is present. Much of these resources are likely located below the water table. Dredging for material below the water table was carried out in the licenced operations at the time of the field investigation.

Previous aggregate test results provide the following results for this selected area (*see* Table 9). Petrographic Number values vary from 100.0 to 150.4 for Granular and 16 mm crushed and from 123.0 to 184.3 for HMA and concrete stone. Magnesium sulphate soundness test results range from 1.5 to 12.5% for coarse aggregate. Los Angeles abrasion values varied from 24.1 to 29.7%. The more modern micro-Deval abrasion values range from 9.6 to 18.9% for coarse aggregate and from 10.1 to 19.7% for fine aggregate. Unconfined freeze–thaw test results vary from 3.4 to 5.5%. Accelerated mortar bar expansion test results range from 0.108 to 0.412%. Values of Petrographic Number, micro-Deval abrasion and absorption fall out of range of those values typically acceptable for aggregate products. Minor cementation was noted in the field and is a likely contributor to the slightly reduced quality of the stone.

Selected Sand and Gravel Resource Area 8 has a total unlicenced area of 44.8 ha. After considering previously extracted areas and physical, cultural and environmental constraints, the remaining area is reduced to 29.7 ha. Pit faces generally expose 4 to 6 m of granular material. Using a conservative deposit thickness of 6.0 m, 3.2 million tonnes of aggregate material are still available for extraction (*see* Table 3).

Resource Areas of Secondary Significance

Sand and gravel resources selected at the secondary level typically have lower gravel content (<35%), contain significant amounts of fines or deleterious material (i.e., chert) that limit uses for the material, and are present with thicknesses less than 6 m. Other resources that contain quality material and are present with thicknesses greater than 6 m have been selected as a secondary resource because their aerial extent, and thus available tonnage, is limited. In the study area, this is often because of urban expansion or resource depletion (i.e., previous and current sand and gravel resource extraction).

MUNICIPALITY OF NORTH MIDDLESEX

Glacial Lake Warren Beach Deposit

A long beach deposit centrally located in the Municipality of North Middlesex has been selected as having secondary significance. The deposit abuts the Wyoming moraine and was deposited along the shores of glacial Lake Warren. The beach is approximately 19 km long and up to 1.5 km wide. At the time of writing, 4 licenced pits and 1 unlicensed pit (Pit Nos. 2 to 5, and 12) were present in the deposit. A number of formerly producing pits have been depleted and rehabilitated. Face heights range from 2 to 3 m and water was observed on pit floors indicating that the water table is relatively shallow. Fine-grained material was also observed underlying the sand and gravel material. The deposit consists primarily of gravelly sand. Previous gradation results indicate that, when present, gravel material varies from approximately 11 to 25%, sand aggregate from 50 to 95% and fines from 1 to 4.5%. Clasts consist predominantly of limestone, dolostone or Precambrian material. Chert content varies from 3 to 19% and occurs at levels high enough to limit the potential uses of the deposit without significant beneficiation (Cooper 1979). Material from this deposit can be used in the production of Granular B, SSM and general pit-run applications. The previous ARIP (Ontario Geological Survey 1991) was completed on the township level and selected this deposit as having primary significance. On the township level, this author agrees with the assessment in the previous ARIP because sand and gravel deposits are limited in this municipality. When considering this deposit on a county scale, its significance is reduced as there are other deposits within the county with significantly more resources and a higher quality of material. However, this deposit is significant for the northwest portion of the study area and steps should be taken to protect the resource for local use.

Ausable River Outwash Deposit

A series of outwash deposits along the Ausable River in the eastern portion of the Municipality of North Middlesex has been selected as having secondary significance. These outwash deposits were formed in front of the Wyoming moraine as meltwater drained away from the retreating Huron ice lobe. At the time of writing, 2 licenced pits (Pit Nos. 7 and 8) were developed in the deposits. A number of previously operated pits have been rehabilitated. Field observations indicate that face heights range from 1 to 3 m and sediments generally fine upward with coarse material being predominantly fine gravel with subordinate coarse gravel observed. Previous gradation results indicate that coarse material varies from approximately 20 to 50% in the northern portion of the deposit and up to 20% in the southern portion (Cooper 1979). Information from a number of test holes and geophysical traverse lines, completed as part of the previous ARIP (Ontario Geological Survey 1991), are presented in Tables 7 and 8. These data confirm recent field observations. As with the beach deposit discussed above, the previous ARIP (Ontario Geological Survey 1991) was completed on the township level and selected this deposit as having primary significance. When considering this deposit on a county scale, its significance is reduced as there are other deposits with significantly more resources and a higher quality of material located in other portions of the study area. However, this deposit is significant for the northwest portion of the study area and steps should be taken to protect the resource for local use.

A number of shoreline deposits are present between Arkona, east of the study area, and Ailsa Craig. These deposits, in the southeast portion of the Municipality of North Middlesex, are discontinuous, shallow beach deposits of glacial lakes Arkona and Whittlesey. Portions of these beach deposits are buried under glaciolacustrine silt and clay (Cooper 1979). The deposits are on average 2 m thick and consist mostly of medium to coarse sand. The quality of the material is of concern because of a high content of deleterious material, primarily chert and shale (Cooper 1979). Between Ailsa Craig and Nairn, the beach deposits are associated with a delta of glacial Lake Whittlesey. The beach and deltaic deposits are only distinguished by their morphology. It is likely that the beach deposits are formed by reworking of the delta deposit as a result of wave action.

TOWNSHIP OF LUCAN BIDDULPH

Only 2 resources of secondary significance are located in the Township of Lucan Biddulph. Both of these are outwash deposits and are associated with former meltwater channels. Located west of Lucan along the Little Ausable River, pit faces expose 2 to 3 m of poorly sorted medium to coarse sand with gravel, cobble and boulders. Clay is present intermixed with the coarse material and a high degree of calcium carbonate cementation was observed. The larger clasts (i.e., cobbles and boulders) are predominantly limestone and dolostone and could be crushed to increase the application of the deposit.

The second outwash deposit is located along the southern border of the township within the valley of Medway Creek and extends to the south into the Municipality of Middlesex Centre where it is also selected at the secondary resource level. No exposures of the deposit could be examined during field investigations because the pits have been rehabilitated. The selection of this deposit is based on previous field investigations. Past pit faces exposed 2 to 3 m of medium to coarse sand underlain by fine to medium gravel (Ontario Geological Survey 1982a). The thickness of associated deposits in the Municipality of Middlesex Centre suggests that more material will be present at depth. Much of the resource is believed to be located below the water table.

MUNICIPALITY OF MIDDLESEX CENTRE

Sandy Peripherals of Komoka

The peripheries of the Komoka delta have been selected as a resource of secondary significance. These deposits are located north and south of Selected Sand and Gravel Resources 2 and 3, respectively. They are primarily sand. Water-well records indicate up to 13.5 m of sand with pockets of gravel with thicknesses ranging from 0.5 to 1 m. Past investigations (Ontario Geological Survey 1981) noted that old MTO records also indicated pockets of gravel. The material of this deposit is thought to be able to meet the gradational requirements of Granular B. No quality concerns have been observed or noted.

Coldstream and Poplar Hill Outwash Deposit

In the western portion of the Municipality of Middlesex Centre, a northeast-trending outwash deposit at the communities of Coldstream and Poplar Hill has been selected as having secondary significance. This deltaic deposit has a similar history as the Komoka deposit previously discussed. The material, laid down in a delta of glacial Lake Maumee, is smaller and sandier than the Komoka deposit. At the time of writing, there were 3 licenced pits (Pit Nos. 34 to 36) developed in the deposit. The material is mostly sand, although up to approximately 65% coarse material was observed by Cooper (1979). The field investigation for the current study noted significant amounts of oversize material being dredged from below the water table. The variability of the amount of granular material present within the deposit is thought to be a result of braided streams that are partially responsible for the deposition of material (Ontario Geological Survey 1981). The silt content of the deposit is high enough to limit the usefulness of the deposit without major mitigation.

The few previous aggregate test results (*see* Table 9) available for this deposit largely indicate that the quality of the material is sound. The single Petrographic Number test result is out of range to be used in Granular A or in HMA and concrete products. In addition, a single accelerated mortar bar expansion test result was also outside the range for those high-quality end-member aggregate products. Further testing may be required to confirm the quality of the material.

Undifferentiated Ice-Contact Stratified Drift Deposit Northwest of Ilderton

Northwest of Ilderton, an undifferentiated ice-contact stratified drift deposit has been selected as having secondary significance. The deposit is located along the trend of the Seaforth moraine and was laid down in close proximity to the ice margin. Till partially overlies the undifferentiated ice-contact stratified drift deposits with fines intermixed with the upper layers of the deposit. At the time of writing, there were no active pits developed in the deposit. A number of previously operated pits have been rehabilitated into ponds. Past aggregate investigations indicate that face heights ranged from 2 to 5 m and exposed medium sand with beds of fine-to-medium gravel. Up to 8 m of coarse aggregate material, with gravel content estimates ranging from 50 to 70%, is believed to be present (Ontario Geological Survey 1981). Dredging will likely have to occur to attain the full potential of the deposit. Available previous test results (*see* Table 9) give no indication of quality concerns for this deposit.

Medway Creek Outwash Deposits

A series of gravelly and sandy outwash deposits are located in the north-central portion of the Municipality of Middlesex Centre. This meltwater channel is now occupied by the present-day Medway River. At the time of writing, there were 3 licenced pits (Pit Nos. 39 to 41) developed within the deposit. A number of pits that were opened in the past have been rehabilitated into ponds. Pits faces expose 2 to 5 m of sand with fine-to-coarse gravel. Gravel content is estimated to be between 30 and 60% (Ontario Geological Survey 1983b). Dredging is required to extract the deposit because of a high water table.

Previous MTO test results (*see* Table 9) completed on the material of this deposit indicate that the material is of acceptable quality for use in a number of aggregate products including Granular A, Granular B, and HMA and concrete products. One micro-Deval abrasion value was just out of specification for use in some HMA surface paving products.

Outwash Deposit West of Ballymote

Located to the west of Ballymote, a gravelly outwash deposit has been selected as having secondary significance. One water-well record indicates 7.5 m of sand and gravel overlying clay. No information is available on the quality of the material and no data are available to confirm the quantities present. This deposit has been selected in part because of its proximity to Selected Sand and Gravel Resource Area 5.

CITY OF LONDON

Glaciolacustrine Delta, North-Central City of London

Located in the north-central part of the City of London, underlying the urbanized portions of the city, a large glaciolacustrine delta has been mapped. The delta is located adjacent to the Thames River and is similar to those located at Fanshawe and Komoka to the east and west, respectively. A number of previously operated pits have been rehabilitated. This deposit contains significant amounts of sand and gravel material with the potential to produce a wide variety of aggregate products. Extraction of the resource is limited by the urban centre of the City of London.

Undifferentiated Ice-Contact Stratified Drift Deposit in South-Central City of London

An undifferentiated ice-contact stratified drift deposit on the northern flank of the Westminster moraine in south-central City of London has been selected at the secondary level of significance. At the time of writing, there were 5 licenced pits (Pit Nos. 68 to 72) developed within the deposit. The majority of the deposit is licenced or has been previously licenced and extracted. As a result, limited amounts of the deposit remain for future extraction. The amount of material remaining for future extraction is inadequate (<1 million tonnes) to be selected at the primary significance level as it was in previous assessments (Ontario Geological Survey 1982c).

Previous aggregate test results provide the following results (*see* Table 9). Petrographic Number values vary from 104.7 to 172.7 for Granular and 16 mm crushed and from 157.8 to 197.1 for HMA and concrete stone. Micro-Deval abrasion values for fine aggregate ranges from 14.2 to 16.5%. Absorption values range from 0.746 to 2.828% and bulk relative density values range from 2.506 to 2.660. The estimated 0.5 million tonnes of material remaining should be protected for future extraction.

MUNICIPALITY OF THAMES CENTRE

Outwash Deposit Located on the Northern Border

A small gravel outwash deposit located along the North Thames River on the boundary of Middlesex County has been selected as a secondary resource area. The 2 pits developed in the deposit (Pit Nos. 73 and 74) occupy the majority of the deposit, and are in the final stages of rehabilitation. It is expected that no further extraction will be of value in this portion of this deposit. The deposit has been selected to be of secondary significance to remain consistent with the aggregate mapping in the County of Perth (Rowell 2013).

Gravel Outwash Deposit Associated with the "Fanshawe Delta"

A relatively small gravel outwash deposit located in close proximity to Selected Sand and Gravel Resource Area 5 has been selected as a secondary resource area. The deposit is an extension of those materials forming the "Fanshawe Delta". The material is likely similar, but is present in lesser quantities (i.e., thinner). At the time of writing, there were no licenced pits operating in the deposit and limited information is available. This deposit has been selected in part because it has been identified in previous aggregate assessments (Ontario Geological Survey 1984). A former licenced pit, which is currently rehabilitated, contained approximately 4 m of "moderately bedded, poorly sorted, fine to coarse gravel mixed with dirty, coarse sand" (Ontario Geological Survey 1984, p.12). This pit, as well as a number of adjacent pits, have been previously dredged for material. Extraction below the water table is likely required to obtain the full potential of the deposit. Sands and gravels from this deposit are likely acceptable for producing Granular B and HMA fine aggregate products.

Ice-Contact Stratified Drift Deposit Associated with the "Fanshawe Delta"

An undifferentiated ice-contact stratified drift deposit located in close proximity to Selected Sand and Gravel Area 5 has been selected as a secondary resource area. Limited information is available for this deposit. It has been selected in part because of its close proximity to the "Fanshawe Delta". Field investigation of a roadcut in the deposit exposed 2 m of coarse sand to fine gravel.

Ice-Contact Stratified Drift Deposits North of the Thames River

These sandy undifferentiated ice-contact stratified drift deposits are located in proximity to Selected Sand and Gravel Resource Area 6. At the time of writing, there was 1 licenced pit (Pit No. 95) completely within the deposit and 2 licenced pits (Pit Nos. 88 and 91) partially developed within the deposit. A limited amount of information is available on this deposit. Geotechnical records indicate that the deposit is composed predominantly of fine sand with some clay, coarse sand and fine gravel present.

Sandy Outwash Deposits South of the Thames River

The sandy outwash deposits, located immediately south of the Thames River, have been selected as having secondary significance. At the time of writing, there were no licenced pits developed in this deposit. A number of past-producing pits have been rehabilitated into ponds. As with the outwash deposit discussed above, the material is predominantly sandy with clay, coarse sand and fine gravel (Ontario Geological Survey 1982b).

Gravel Outwash Deposit South of Provincial Highway 401

A gravelly outwash deposit, located in the southern portion of the Municipality of Thames Centre immediately south of Highway 401, has been selected at the secondary level of significance. This outwash deposit is located on the north side of the Ingersoll moraine and is capped by till. There are currently 3 licenced pits (Pit Nos. 110 to 112) developed in this deposit and 1 unlicenced pit (Pit No. 113). The majority of the deposit is licenced and only a small portion remains for future extraction. The amount of material remaining for future extraction is inadequate (<1 million tonnes) to be selected at the primary significance level as it has in previous assessments (Ontario Geological Survey 1982b).

Previous aggregate test results provide the following results (*see* Table 9). Petrographic Number values vary from 104.7 to 172.7 for Granular and 16 mm crushed and from 157.8 to 197.1 for HMA and concrete stone. Micro-Deval abrasion values for fine aggregate ranges from 14.2 to 16.5%. Absorption values range from 0.746 to 2.828% and bulk relative density values range from 2.506 to 2.660.

Outwash Deposit South of Putnam

An outwash deposit located south of the community of Putnam has been selected as a sand and gravel resource of secondary significance. This deposit is located within the Reynolds Creek meltwater channel. Water-well records indicate that approximately 20 m of sand and gravel are present within this deposit. Related deposits in the County of Oxford have also been selected as having secondary significance (Rowell 2014).

Undifferentiated Ice-Contact Stratified Drift Deposit on the East Border

An undifferentiated ice-contact stratified drift deposit located along the eastern border of the Municipality of Thames Centre south of the Thames River has been selected as having secondary significance. The deposit is associated with the Seaforth moraine. The limited aggregate test result data (*see* Table 9) suggest that the quality of the material is acceptable for a variety of products.

BURIED SAND AND GRAVEL RESOURCES

As discussed in the "Surficial Geology and Physiography", because of multiple readvances of the Laurentide Ice Sheet, there are a number of buried sand and gravel deposits identified throughout the study area. Some of these buried granular deposits are identified on Map 1 (dashed boundary line).

The deposits located along the eastern border of the Municipality of North Middlesex were identified by Vanderveer (1989) as part of a detailed electromagnetic conductivity survey. These aggregate resources are classified as undifferentiated ice-contact stratified drift deposits associated with the Seaforth moraine and are located 2 to 5 m beneath till. One licenced pit (Pit No. 11) developed in these buried deposits exposes material with a high percentage of granular material, much of which is crushable, under approximately 2 m of till.

Water-well and borehole records included in this report (vector ESRI® ArcGIS® version only) help to confirm the presence of buried resources throughout the study area. Several other potential buried sand and gravel resources have been identified and are discussed briefly in this report.

These buried deposits can add substantially to the sand and gravel resources available in the study area, although they have not been quantified or delineated during this study. The density of water-well and borehole records in the study area is not sufficient to delineate these buried resources. Only smaller scale detailed investigations, similar to that completed by Vanderveer (1989), as mentioned previously, are capable of producing a useable resource delineation. Detailed geotechnical studies including drilling should be completed on these potential resources before they are included in any aggregate resource plan.

BEDROCK GEOLOGY

The County of Middlesex is underlain by a thick succession of Paleozoic bedrock consisting primarily of dolostones, limestones and shales (Figure 6) (Sanford 1967; Sanford and Baer 1981; Johnson et al. 1992; Birchard, Rutka and Brunton 2004; Armstrong and Carter 2010). Outcrops of these formations are limited and are only found in rivers valleys within the county.

The Lucas Formation is the oldest Paleozoic unit underlying the study area. This Middle Devonian unit consists of limestone, dolostone, anhydrite and locally sandy limestone (Birchard, Rutka and Brunton 2004; Armstrong and Carter 2010). The formation is the uppermost member of the Detroit River Group and overlies, in descending order, the Amherstburg and Sylvania formations (Birchard, Rutka and Brunton 2004; Armstrong and Carter 2010). The Lucas Formation is subdivided into 3 lithological units:

the Lucas Formation undifferentiated, the Anderdon Member limestone and the Anderdon Member sandy limestone. The Lucas Formation undifferentiated consists of thin- to medium-bedded, light to grey-brown, fine-crystalline, poorly fossiliferous, laminated dolostone and limestone (Armstrong and Carter 2010). 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. The Anderdon Member sandy limestone consists of medium- to massive-bedded, medium- to coarse-grained, fossiliferous sandy limestones. This member is located in the subsurface of the study area as a capping member or interbedded with the uppermost strata of the Lucas Formation. The member is sometimes referred to as the "Columbus" or "Columbus Sands" or "Columbus Sandstone" (Armstrong and Carter 2010).

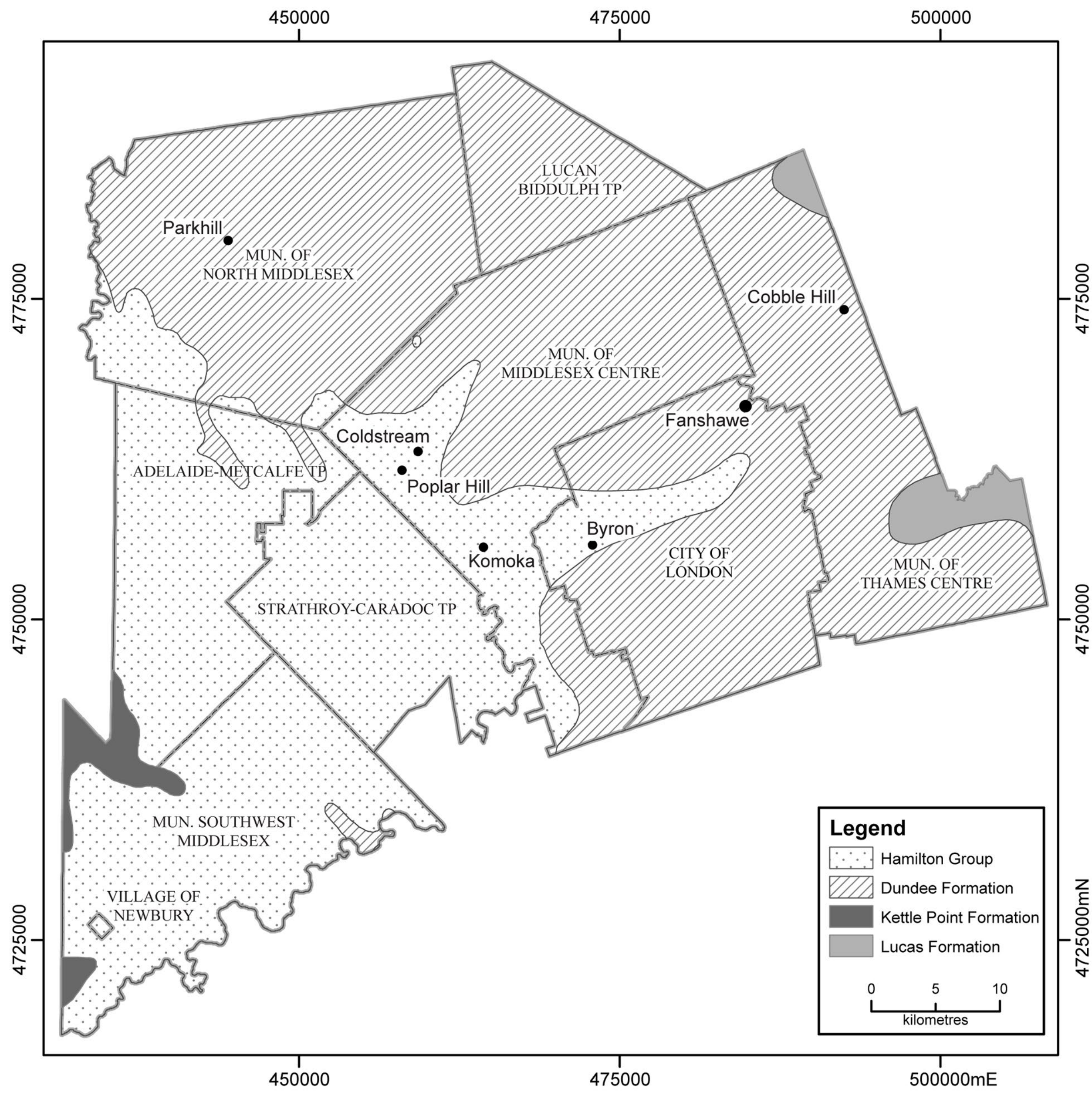


Figure 6. Bedrock geology of the County of Middlesex (*modified from* Armstrong and Dodge 2007).

The Lucas Formation is disconformably overlain by limestones of the Dundee Formation. This Middle Devonian formation consists of grey to tan to brown, fossiliferous, medium- to thick-bedded limestones and minor dolostones (Armstrong and Carter 2010). Oil staining and chert nodules are commonly observed in the formation (Armstrong and Carter 2010). This formation is quarried near St. Mary's in the County of Perth for the manufacturing of Portland cement (Rowell 2013).

Calcareous shales with limestones interbeds of the Hamilton Group disconformably overlie the Dundee Formation. The group consists of 6 formations; in ascending stratigraphic order (i.e., oldest to youngest) (Armstrong and Carter 2010), these formations are the following.

- The Bell Formation consists of blue-grey, soft, calcareous shales with abundant fossils. The basal contact with the Dundee Formation is commonly marked by the presence of pyrite.
- The Rockport Quarry Formation consists of grey to brown, fine-grained, argillaceous limestone. The basal contact with the underlying Bell Formation is sharp.
- The Arkona Formation conformably overlies the Rockport Quarry Formation, with a gradational contact between the 2 formations. The formation consists of blue-grey, soft, calcareous shale, with thin argillaceous limestone beds.
- Disconformably overlying the Arkona Formation is the Hungry Hollow Formation. The formation consists of an upper coral-rich, calcareous, shale-dominated interval and a lower fossiliferous, bioclastic limestone. Bedding contacts are sharp and often pyritized.
- Conformably overlying the Hungry Hollow Formation is the Widder Formation. This formation consists of calcareous, grey to brown-grey shale interbedded with bioturbated, fine-grained, argillaceous, nodular limestone and coarse-grained bioclastic limestones.
- Sharply, but conformably, overlying the Widder Formation is the Ipperwash Formation. The formation consists of grey-brown, fine- to coarse-grained, argillaceous and bioclastic limestone with shaly interbeds.

Disconformably overlying the Hamilton Group shales is the Upper Devonian Kettle Point Formation. This formation consists of dark brown to black organic-rich shales and siltstone. Beds of organic-poor, grey-green silty shale and siltstone interbeds are common. The Kettle Point Formation is named for its large round concretions or "kettles".

BEDROCK AGGREGATE QUALITY AND SUITABILITY

As mentioned in "Bedrock Geology", the Dundee Formation is extracted north of the study area in the County of Perth for the manufacturing of Portland cement (Rowell 2013). In addition, the Lucas Formation is extracted east of the study area in the County of Oxford, primarily for the manufacturing of cement, and production of chemical and metallurgical stone (Rowell 2014). These products are considered industrial minerals and are not typically used in the production standard aggregate products. Additionally, no outcropping of the Dundee or Lucas formations, or areas where the overburden drift is thin (<8 m), occur in the study area. As such, these formations are not discussed further in this report.

The Arkona Formation of the Hamilton Group has been extracted in the study area in the past for brick and tile manufacturing (Rowell 2009, 2012). Rowell (2012) does not recommend the protection of the Arkona Formation for future extractive opportunities.

SELECTED BEDROCK RESOURCE AREAS

The only bedrock outcrops in the study area occur in the western portion along the Ausable River; thus, the only licenced quarries in the study area (Quarry Nos. 1 and 2) are located there. All other areas with less than 8 m of overburden, and therefore economical for bedrock extraction, generally occur in areas along deep river valley cuts. The limited size of these areas, along with a number of planning and environmental constraints that would be imposed on any extraction, makes these areas unsuitable for future extraction. For these reasons above, there are no Selected Bedrock Resource Areas in the County of Middlesex.

SUMMARY

Eight selected sand and gravel resource areas have been chosen at the primary resource level in the County of Middlesex and the City of London. These selected resource areas have a total unlicenced area of 4839 ha with a possible resource area of 2349.0 ha after considering physical, cultural and environmental constraints. These resource areas have approximately 278.1 million tonnes of aggregate material. Stone quality (predominantly the presence of chert) limits the use of this granular material for many high-specification aggregate products (e.g., HMA and concrete products).

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

The County of Middlesex is underlain by a sequence of Paleozoic rock units that have generally not been used extensively in the production of aggregate products. Some of the formations have been used elsewhere for the manufacture of lime, metallurgical flux and cement, with some minor aggregate production. In addition, these formations are generally overlain by a thick sequence of Quaternary sediment, which would affect the economics of developing these resources. Shale of the Arkona Formation has been used for the manufacture of brick and tile.

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

Enquiries regarding the Aggregate Resources Inventory of the County of Middlesex and the City of London may be directed to the Earth Resources and Geoscience Mapping Section, Ontario Geological Survey, Mines and Minerals Division, Ministry of Northern Development and Mines, 933 Ramsey Lake Road, Sudbury, Ontario P3E 6B5 [Tel: (705) 670-5758].

Table 1. Total Identified Sand and Gravel Resources, County of Middlesex and City of London.

1 Class Number	2 Deposit Type	3 Areal Extent (Hectares)	4 Original Tonnage (Million Tonnes)
Municipality of North Middlesex			
1	S-IC	10.58	1.1
	S-IC/SF	262.91	27.9
2	G-IC	3.59	0.3
3	G-OW	139.99	5.6
	S-OW/LB	170.10	6.8
	S-LB	1666.48	66.4
	S-OW	323.90	12.9
	S-OW/LD	819.96	32.7
4	G-OW	85.92	1.5
	S-AL	2906.95	51.5
	S-LB	199.84	3.5
	S-OW	737.42	13.1
Subtotal		**7327.63**	**223.2**
Township of Lucan Biddulph			
1	G-OW	23.43	2.5
	S-OW	28.24	3.0
2	G-IC	18.17	1.4
3	G-OW	16.54	0.7
	G-IC	36.85	1.5
	S-AL	25.76	1.0
4	S-AL	450.90	8.0
	S-IC	7.62	0.1
Subtotal		**607.51**	**18.2**
Township of Adelaide Metcalfe			
1	G-IC	155.28	16.5
	S-LB/WD	335.51	35.6
	S-IC	8.34	0.9
	S-IC/SF	165.23	17.5
2	S-LP/WD	848.00	67.5
	S-LB/WD	1705.93	135.9
3	S-LB/WD	641.89	25.6
	S-OW	168.12	6.7
	S-IC	100.74	4.0
4	S-AL	1286.94	22.8
	S-LB	108.45	1.9
	S-LB/WD	63.75	1.1
	S-OW	4.10	0.1
Subtotal		**5592.26**	**336.1**
Village of Newbury			
3	S-LB/WD	186.30	7.4
Subtotal		**186.30**	**7.4**

1 Class Number	2 Deposit Type	3 Areal Extent (Hectares)	4 Original Tonnage (Million Tonnes)
Township of Southwest Middlesex			
2	S-LB	666.01	53.0
	S-LP/LB	27.15	2.2
	S-LB/WD	2493.14	198.6
3	S-AL	194.41	7.7
	S-LB	259.89	10.4
	S-LB/WD	9377.31	373.5
	S-OW	1979.62	78.8
4	S-AL	1151.03	20.4
	S-LB	128.23	2.3
	S-LB/WD	21.77	0.4
	S-OW	33.46	0.6
Subtotal		**16 332.02**	**747.8**
Township of Strathroy–Caradoc			
1	S-LP/LB	19.53	2.1
	S-LB/WD	10 136.75	1076.5
2	S-LB	102.79	8.2
	S-LP/LB	84.80	6.8
	S-LB/WD	6042.57	481.3
3	S-AL	728.18	29.0
	S-LB	18.88	0.8
	S-LD	296.08	11.8
	S-LB/WD	275.66	11.0
	S-OW	28.92	1.2
4	S-AL	824.86	14.6
	S-LB	210.13	3.7
	S-LB/WD	17.56	0.3
Subtotal		**18 786.71**	**1647.1**
Township of Middlesex Centre			
1	G-LD	1167.39	124.0
	G-OW	34.02	3.6
	S-LD	1226.54	130.3
	S-LB/WD	533.83	56.7
	S-OW	194.12	20.6
2	G-OW	142.32	11.3
	G-IC	125.72	10.0
	S-LD	897.85	71.5
	S-LB	562.85	44.8
	S-OW	117.16	9.3
	S-IC	194.16	15.5
3	G-LB/OW	55.00	2.2
	G-OW	122.95	4.9
	G-IC	213.77	8.5
	S-AL	2344.96	93.4

1 Class Number	2 Deposit Type	3 Areal Extent (Hectares)	4 Original Tonnage (Million Tonnes)
	S-LB	55.66	2.2
	S-LD	277.27	11.0
	S-OW	67.83	2.7
	S-IC	60.19	2.4
4	S-AL	1093.84	19.4
	S-LB	12.42	0.2
	S-LD	58.83	1.0
	S-LB	909.68	16.1
Subtotal		**10 468.37**	**661.7**
City of London			
1	G-LD	4948.03	525.5
	G-OW	9.76	1.0
	S-IC	80.94	8.6
2	G-LB	399.20	31.8
	G-LD	189.25	15.1
	G-OW	31.73	2.5
	G-OW/LB	34.18	2.7
	S-LB	10.79	0.9
	S-LD	2949.61	234.9
	S-LB	201.88	16.1
	S-OW	319.77	25.5
	S-IC	56.57	4.5
3	G-LB	44.87	1.8
	G-LD	28.72	1.1
	G-OW	22.34	0.9
	G-IC	5.09	0.2
	S-AL	3008.02	119.8
	S-LB	92.49	3.7
	S-LD	11.69	0.5
	S-LB	1432.02	57.0
	S-OW	252.04	10.0
	S-IC	517.98	20.6
4	S-AL	486.89	8.6
	S-LB	37.11	0.7
	S-LD	61.30	1.1
	S-LB	1495.58	26.5
	S-OW	3.21	0.1
Subtotal		**16 731.07**	**1121.6**

1 Class Number	2 Deposit Type	3 Areal Extent (Hectares)	4 Original Tonnage (Million Tonnes)
Municipality of Thames Centre			
1	G-LD	774.22	82.2
	G-OW	271.15	28.8
	G-OW/LD	30.12	3.2
	G-IC	987.57	104.9
2	G-LD	310.45	24.7
	G-OW	25.55	2.0
	G-IC	566.32	45.1
	S-LD	508.73	40.5
	S-OW	731.13	58.2
	G-OW/LD	1418.31	113.0
	S-IC	2748.37	218.9
3	G-LB	23.53	0.9
	G-LD	29.95	1.2
	G-OW	377.90	15.0
	G-IC	24.17	1.0
	S-AL	2303.25	91.7
	S-LD	34.70	1.4
	S-LB	1.22	0.0
	S-OW	48.08	1.9
	S-IC	468.86	18.7
4	S-AL	474.80	8.4
	S-LB	927.59	16.4
	S-OW	465.56	8.2
	S-IC	175.69	3.1
Subtotal		**13 727.19**	**889.7**
TOTAL		**89 759.07**	**5652.9**

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

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

Explanation of Deposit Type:

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

*Letters after hyphen denote the geologic deposit type (*see also *Appendix C):*
AL = alluvium; IC = ice-contact stratified drift, includes esker (E) and kame (K) deposits; ICT = ice-contact terraces; LB = glaciolacustrine beach deposits; LD = glaciolacustrine deltas; LP = glaciolacustrine plains; OW = outwash; SF = subaqueous fans; WD = windblown deposits

Table 2. Sand and Gravel Pits, County of Middlesex and City of London.

Pit No.	Licencee	Licenced Area (Hectares)	Face Height (Metres)	% Gravel	Remarks
Municipality of North Middlesex					
Licenced					
1	Dan Masfrankc	3.7	3 - 4	0 - 10	Pit has been developed in an ice-contact stratified drift deposit
2	McCann Redi-Mix Inc.	5.1	2 - 3	0 - 20	Glaciolacustrine beach deposit
3	Municipality of North Middlesex	10.1	2 - 3	0 - 20	Glaciolacustrine beach deposit
4	Ken Valley Farms Ltd.	29.0	-	0 - 20	Glaciolacustrine beach deposit. Pit is largely rehabilitated
5	McCann Redi-Mix Inc.	20.2	2 - 3	0 - 20	Glaciolacustrine beach deposit
6	Grant M. Herrington	18.3	2 - 3	20 - 50	Subaqueous fan deposit. Dredging of material occurring
7	Charles P. Corbett	48.1	2 - 3	20 - 50	Outwash deposit
8	Lawrence E. Amos	29.3	1	20 - 50	Outwash deposit
9	Paul Vanneste and Sarah Bassett	21.1	1 - 2	0 - 10	Alluvial deposit
10	James A. Scott	39.6	1.5 - 2	0 - 10	Alluvial deposit
11	Municipality of North Middlesex	10.3	5 - 6	60 - 80	Gravel deposit buried by till
Unlicenced					
12	-	-	2 - 3	0 - 20	Glaciolacustrine beach deposit
13	-	-	2 - 3	0 - 20	Glaciolacustrine beach deposit
Township of Lucan Biddulph					
Licenced					
14	Clarence Carter and Sons Ltd.	4.5	2	30 - 50	Outwash deposit
15	C. James Thomas	25.5	2 - 3	60 - 70	Outwash deposit
16	Dennis Maguire	6.8	2 - 3	10 - 50	Pit has been developed in an ice-contact stratified drift deposit
Unlicenced					
Township of Adelaide Metcalfe					
Licenced					
17	John van den Eynden	11.3	1 - 2	0 - 10	Subaqueous fan deposit
18	V.B. Sand & Gravel Ltd.	26.7	1 - 2	0 - 10	Subaqueous fan deposit
19	Jeff and Maria Maes	13.7	5 -8	10 - 50	Subaqueous fan deposit
20	J. van Bree Holdings Ltd.	16.5	5 - 8	10 - 50	Subaqueous fan deposit
Unlicenced					
Village of Newbury					
Licenced					
Unlicenced					
Municipality of Southwest Middlesex					
Licenced					
Unlicenced					
Township of Strathroy–Caradoc					
Licenced					
21	Zwart Excavating Ltd.	12.1	2 - 3	0 - 10	Glaciolacustrine plain deposit reworked by eolian processes
22	Gary Falconer Transport Ltd.	15.9	2 - 3	0 - 10	Glaciolacustrine plain deposit reworked by eolian processes

Pit No.	Licencee	Licenced Area (Hectares)	Face Height (Metres)	% Gravel	Remarks
23	Gary Falconer Transport Ltd.	20.5	2 - 3	0 - 10	Glaciolacustrine plain deposit reworked by eolian processes
24	Gary Falconer	5.4	2 - 3	0 - 10	Glaciolacustrine plain deposit reworked by eolian processes
25	Donald L. Young	3.4	2 - 3	0 - 10	Glaciolacustrine plain deposit reworked by eolian processes
Unlicenced					
Township of Middlesex Centre					
Licenced					
26	Middlesex Stone Limited	21.0	1 - 3	50 - 70	Glaciolacustrine plain and delta deposits. Extraction primarily via dredging
27	Johnston Bros. (Bothwell) Limited	18.9	1 - 3	50 - 70	Glaciolacustrine delta deposit
28	Johnston Bros. (Bothwell) Limited	27.3	1 - 2	50 - 70	Glaciolacustrine delta deposit. Extraction primarily via dredging
29	South Winds Development Co. Inc.	20.9	3 - 6	60- 70	Glaciolacustrine delta deposit
30	South Winds Development Co. Inc.	24.9	3 - 5	60- 70	Glaciolacustrine delta deposit
31	Huron Construction Co. Limited	60.7	1 - 2	50 - 60	Pit has been developed in a glaciolacustrine plain and delta deposit. Extraction primarily via dredging
32	Township of Strathroy-Caradoc	8.2	1 - 2	50 - 60	Glaciolacustrine delta deposit. Extraction primarily via dredging
33	Johnston Bros. (Bothwell) Limited	8.0	5 - 6	40 - 50	Glaciolacustrine delta deposit. Licence in the final stages of rehabilitation
34	1142059 Ontario Limited	2.4	3 - 6	10 - 30	Glaciolacustrine delta deposit. Extraction primarily via dredging
35	1142059 Ontario Limited	12.3	3 - 6	10 - 30	Glaciolacustrine delta deposit. Extraction primarily via dredging
36	1142059 Ontario Limited	78.9	3 - 6	10 - 30	Glaciolacustrine delta deposit. Extraction primarily via dredging
37	Township of Middlesex Centre	13.1	1 - 3	-	Undifferentiated ice-contact stratified drift deposit. Appears to be in the final stages of rehabilitation
38	McCann Redi-Mix Inc.	14.9	3 - 6	60- 70	Undifferentiated ice-contact stratified drift deposit. Appears to be in the final stages of rehabilitation
39	Corporation of the County of Middlesex	14.2	2 - 3	50 - 60	Undifferentiated ice-contact stratified drift deposit. Extraction occurring via dredging
40	Lafarge Canada Inc.	8.7	2 - 3	50 - 60	Undifferentiated ice-contact stratified drift deposit. Extraction occurred via dredging. Licence in the final stages of rehabilitation
41	Township of Middlesex Centre	40.5	2 - 3	50 - 60	Undifferentiated ice-contact stratified drift deposit. Extraction occurring via dredging
42	TRY Recycling Inc.	5.8	3 - 5	60- 70	Glaciolacustrine delta deposit. Licence partially rehabilitated; and used as a recycling depot
43	Lafarge Canada Inc.	3.4	-	-	Glaciolacustrine delta deposit. Licence in the final stages of rehabilitation
44	St. Marys Cement Inc. (Canada)	0.7	5 - 6	60- 70	Glaciolacustrine delta deposit. Licence in the final stages of rehabilitation
45	St. Marys Cement Inc. (Canada)	8.8	5 - 6	60- 70	Glaciolacustrine delta deposit
46	Township of Middlesex Centre	25.4	3 - 6	60- 70	Glaciolacustrine delta deposit
47	Demar Aggregates Inc.	15.9	4 - 6	60- 70	Glaciolacustrine delta deposit
Unlicenced					

Pit No.	Licencee	Licenced Area (Hectares)	Face Height (Metres)	% Gravel	Remarks
City of London					
Licenced					
48	Lafarge Canada Inc.	62.7	6 - 8	60 - 70	Glaciolacustrine delta deposit. Licence partially rehabilitated; and used for processing plant
49	Lafarge Canada Inc.	20.0	5 - 6	60 - 70	Glaciolacustrine delta deposit
50	Lafarge Canada Inc.	1.2	5 - 6	60 - 70	Glaciolacustrine delta deposit
51	Lafarge Canada Inc.	42.1	4 - 5	60 - 70	Glaciolacustrine delta deposit. Some extraction occurring via dredging
52	Township of Middlesex Centre	21.5	3 - 4	30 - 60	Glaciolacustrine delta deposit
53	J-AAR Excavating Limited	40.5	3 - 6	-	Licence is partially rehabilitated. Primarily used for processing plant
54	Dufferin Construction Company, A Division of Holcim (Canada) Inc.	18.6	2 - 3	50 - 60	Glaciolacustrine delta deposit. Licence partially rehabilitated; and used as a processing plant
55	Dufferin Construction Company, A Division of Holcim (Canada) Inc.	41.7	3 - 4	50 - 60	Glaciolacustrine delta deposit. Licence appears to be in the final stages of rehabilitation
56	St. Marys Cement Inc. (Canada)	26.1	6 - 8	40 - 50	Glaciolacustrine delta deposit. Licence partially rehabilitation; and used primarily as a processing plant
57	Lafarge Canada Inc.	37.6	6 - 8	50 - 60	Glaciolacustrine delta deposit
58	Lafarge Canada Inc.	36.5	5 - 6	60 - 70	Glaciolacustrine delta deposit
59	Lafarge Canada Inc.	47.5	5 - 6	60 - 70	Glaciolacustrine delta deposit
60	Spivak Partnership	1.6	23 - 30	50 - 60	Glaciolacustrine delta deposit
61	Highcrest Properties (London) Limited	6.6	23 - 30	50 - 60	Glaciolacustrine delta deposit
62	South Winds Development Co. Inc.	4.1	23 - 30	50 - 60	Glaciolacustrine delta deposit
63	South Winds Development Co. Inc.	12.8	23 - 30	50 - 60	Glaciolacustrine delta deposit
64	South Winds Development Co. Inc.	1.2	23 - 30	50 - 60	Glaciolacustrine delta deposit
65	Lafarge Canada Inc.	34.2	23 - 30	50 - 60	Glaciolacustrine delta deposit
66	Lafarge Canada Inc.	2.9	-	-	Unopened
67	Lafarge Canada Inc.	6.6	8 - 15	50 - 60	Glaciolacustrine delta deposit
68	AAROC Aggregates Ltd.	6.2	3 - 8	10 - 30	Undifferentiated ice-contact stratified drift deposit
69	L. McDonnel Brown	30.9	3 - 11	10 - 30	Undifferentiated ice-contact stratified drift deposit
70	AAROC Aggregates Ltd.	37.6	3 - 8	10 - 30	Undifferentiated ice-contact stratified drift deposit
71	Westcliff Aggregates Ltd.	18.6	3 - 5	10 - 30	Undifferentiated ice-contact stratified drift deposit
72	Bre-Ex Limited	29.4	3 - 9	10 - 30	Undifferentiated ice-contact stratified drift deposit
Unlicenced					
Municipality of Thames Centre					
Licenced					
73	Dufferin Aggregates, A Division of Holcim (Canada) Inc.	15.4	-	-	Outwash deposit. Licence in the final stages of rehabilitation
74	Dufferin Aggregates, A Division of Holcim (Canada) Inc.	8.7	-	-	Outwash deposit. Licence in the final stages of rehabilitation
75	Demar Aggregates Inc.	31.4	3 - 6	40 - 60	Glaciolacustrine delta deposit
76	St. Marys Cement Inc. (Canada)	25.2	3 - 6	60 - 85	Glaciolacustrine delta deposit
77	St. Marys Cement Inc. (Canada)	8.3	-	-	Glaciolacustrine delta deposit

Pit No.	Licencee	Licenced Area (Hectares)	Face Height (Metres)	% Gravel	Remarks
78	St. Marys Cement Inc. (Canada)	4.9	3 - 6	60 - 85	Glaciolacustrine delta deposit
79	St. Marys Cement Inc. (Canada)	7.6	3 - 6	40 - 60	Glaciolacustrine delta deposit
80	Tridon Construction Ltd.	27.0	2 - 3	40 - 70	Glaciolacustrine delta deposit
81	Lafarge Canada Inc.	101.4	2 - 3	40 - 80	Glaciolacustrine delta deposit. Extraction partially via dredging
82	Lafarge Canada Inc.	72.6	-	-	Glaciolacustrine delta deposit. Licence in the final stages of rehabilitation
83	Corporation of the County of Middlesex	20.2	4 - 8	60 - 70	Glaciolacustrine delta deposit
84	The Municipality of Thames Centre	4.0	1.5 - 3	60 - 70	Outwash deposit. Extraction occurring via dredging
85	The Municipality of Thames Centre	29.7	1.5 - 3	60 - 70	Outwash deposit. Extraction occurring via dredging
86	L82 Construction Limited	31.9	2 - 3	60 - 70	Outwash deposit. Extraction occurring via dredging
87	L82 Construction Limited	14.8	2 - 3	60 - 70	Outwash deposit. Extraction occurring via dredging
88	St. Marys Cement Inc. (Canada)	36.7	3 - 5	10 - 30	Undifferentiated ice-contact stratified drift deposit
89	St. Marys Cement Inc. (Canada)	4.6	3 - 5	70 - 80	Undifferentiated ice-contact stratified drift deposit
90	St. Marys Cement Inc. (Canada)	2.4	3 - 5	70 - 80	Undifferentiated ice-contact stratified drift deposit
91	Thames Valley Resources Corporation	22.7	-	-	Undifferentiated ice-contact stratified drift deposit. Licence in the final stages of rehabilitation
92	Murray Pucula	7.6	2 - 3	30 - 50	Undifferentiated ice-contact stratified drift deposit. Extraction primarily via dredging
93	St. Marys Cement Inc. (Canada)	49.7	3 - 5	30 - 50	Undifferentiated ice-contact stratified drift deposit. Extraction primarily via dredging
94	Lafarge Canada Inc.	39.5	-	-	Unopened
95	Lafarge Canada Inc.	39.9	-	-	Undifferentiated ice-contact stratified drift deposit. Licence in the final stages of rehabilitation
96	St. Marys Cement Inc. (Canada)	41.6	-	-	Unopened
97	Corporation of the Municipality of Thames Centre	2.0	3 - 5	50 - 60	Undifferentiated ice-contact stratified drift deposit
98	AAROC Aggregates Ltd.	21.0	2 - 3	-	Undifferentiated ice-contact stratified drift deposit. Licence in the final stages of rehabilitation
99	N-J Spivak Limited	42.4	2 - 3	20 - 50	Undifferentiated ice-contact stratified drift deposit
100	Nicli Aggregates Inc.	39.5	2 - 3	20 - 50	Undifferentiated ice-contact stratified drift deposit. Extraction partially via dredging
101	Lafarge Canada Inc.	28.4	3 - 6		Undifferentiated ice-contact stratified drift deposit. Extraction partially via dredging
102	Corporation of the Municipality of Thames Centre	5.7	3 - 6	20 - 50	Undifferentiated ice-contact stratified drift deposit
103	Lafarge Canada Inc.	12.1	3 - 6	20 - 50	Undifferentiated ice-contact stratified drift deposit. Extraction partially via dredging
104	Johnston Bros. (Bothwell) Limited	18.5	3 - 6	20 - 50	Undifferentiated ice-contact stratified drift deposit
105	Walmsley Bros. Limited	30.6	3 - 6	50 - 60	Outwash deposit. Licence partially rehabilitated; and used primarily as a processing site

Pit No.	Licencee	Licenced Area (Hectares)	Face Height (Metres)	% Gravel	Remarks
106	Dufferin Aggregates, A Division of Holcim (Canada) Inc.	81.7	4 - 6	20 - 65	Outwash deposit. Licence partially rehabilitated. Extraction via dredging
107	Johnston Bros. (Bothwell) Limited	17.7	3.5 - 4	20 - 40	Outwash deposit
108	Dufferin Aggregates, A Division of Holcim (Canada) Inc.	47.6	4 - 6	20 - 65	Outwash deposit. Licence partially rehabilitated. Extraction via dredging
109	E. & E. McLaughlin Ltd.	28.5	3 - 6	20 - 50	Undifferentiated ice-contact stratified drift deposit
110	St. Marys Cement Inc. (Canada)	11.1	6 - 8	30 - 70	Outwash and glaciolacustrine delta deposits
111	St. Marys Cement Inc. (Canada)	14.1	6 - 8	30 - 70	Outwash and glaciolacustrine delta deposits. Extraction partially via dredging
112	Corporation of the Municipality of Thames Centre	7.7	6 - 8	30 - 70	Outwash and glaciolacustrine delta deposits
Unlicenced					
113	-	-	3 - 5	10 - 30	Outwash and glaciolacustrine delta deposits

Table 3. Selected Sand and Gravel Resource Areas, County of Middlesex and City of London.

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	345.6	104.3	6.8	234.5	6	24.9
2	874.6	317.3	272.9	284.5	6	30.2
3	880.1	242.6	28.1	609.5	6	64.7
4	201.7	103.8	30.5	67.4	30	35.8
5	1773.2	663.9	458.6	650.7	6	69.1
6	675.8	184.8	25.4	465.6	6	49.4
7	43.7	2.1	34.5	7.0	6	0.7
8	44.8	15.1	0.0	29.7	6	3.2
TOTAL	**4839.6**	**1633.9**	**856.7**	**2349.0**		**278.1**

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

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

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

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

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

Table 4. Total Identified Bedrock Resources, County of Middlesex and City of London.

1 Drift Thickness (Metres)	2 Formation	3 Estimated Deposit Thickness (Metres)	4 Areal Extent (Hectares)	5 Original Tonnage (Million of Tonnes)
8-15	Dundee Formation	15	927.19	368.4
Subtotal			**927.19**	**368.4**
<1	Hamilton Group	15	29.09	10.5
1-8		15	368.47	133.1
8-15		15	1587.31	573.3
Subtotal			**1984.88**	**716.9**
1-8	Kettle Point Formation	15	43.07	17.1
8-15		15	696.73	276.8
Subtotal			**739.80**	**294.0**
8-15	Lucas Formation	15	311.58	123.8
Subtotal			**311.58**	**123.8**
TOTAL			**3963.45**	**1503.1**

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 Middlesex and City of London.

Quarry No.	Licencee	Licenced Area (Hectares)	Face Height (Metres)	Remarks
Municipality of North Middlesex				
Licenced				
1	Brampton Brick Limited	5.14	7 - 10	Has been used in the manufacture of bricks and tiles
2	Brampton Brick Limited	1.66	7 - 10	Has been used in the manufacture of bricks and tiles
Unlicenced				
Township of Lucan Biddulph				
Licenced				
Unlicenced				
Township of Adelaide Metcalfe				
Licenced				
Unlicenced				
Village of Newbury				
Licenced				
Unlicenced				
Municipality of Southwest Middlesex				
Licenced				
Unlicenced				
Township of Strathroy–Caradoc				
Licenced				
Unlicenced				
Municipality of Middlesex Centre				
Licenced				
Unlicenced				
City of London				
Licenced				
Unlicenced				
Municipality of Thames Centre				
Licenced				
Unlicenced				

Table 6. Selected Bedrock Resource Areas, County of Middlesex and City of London.

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

* *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 Test Hole Data, County of Middlesex and City of London.

Test Hole Number	Reference	Depth From (m)	Depth To (m)	Description
BH-2	Sado (1980)			*UTM: 488480m E 4765593m N, NAD83, Zone 17*
				Elevation: 274 m
		0.0	5.3	moderately stony, gritty sandy silt till (Tavistock Till) contains red shale chips, layer of silty fine sand at 2.8 m
		5.3	12.5	very compact, stony sandy till (Catfish Creek Till)
BH-3	Sado (1980)			*UTM: 490102m E 4784198m N, NAD83, Zone 17*
				Elevation: 323 m
		0.0	9.8	stony, gritty clayey silt till (Tavistock Till) contains red shale chips and lenses of sand
		9.8	10.8	silty fine sand
		10.8	14.0	stony, gritty sand silt till (Tavistock Till)
		14.0	21.6	very stony, very compact, sandy silt till (Catfish Creek Till), silt layer at 19 m
		21.6	22.1	limestone bedrock (Dundee Fm.)
BH-5	Sado (1980)			*UTM: 471200m E 4778900m N, NAD83, Zone 17*
				Elevation: 296 m
		0.0	6.1	massive to laminated clayey silt to clay few grits and pebbles
		6.1	7.9	fine sand
		7.9	11.5	gritty pebbly sand containing silt clay layers
		11.5	14.0	sand to fine gravel
		14.0	30.0	clayey silt till (Rannoch Till), very stony near base
		30.0	30.8	limestone bedrock (Dundee Fm.)
BH-6	Sado (1980)			*UTM: 463800m E 4772105m N, NAD83, Zone 17*
				Elevation: 274 m
		0.0	7.3	clay till (southern till) very few grits and pebbles
		7.3	7.8	pebbly sand
		7.8	12.4	moderately stony, clay silt till (Rannoch Till)
		12.4	15.8	fine sand
BH-7	Sado (1980)			*UTM: 484800m E 4765200m N, NAD83, Zone 17*
				Elevation: 274 m
		0.0	19.8	stony, sand silt till (Tavistock Till) grades coarser with depth, exposed river cut
		19.8	25.6	as above, stony, sand silt till (Tavistock Till)
		25.6	27.7	violet, sandy silt till (Port Stanley Till ?)
		27.7	28.0	cobbly gravel
		28.0	28.3	compact, stony sand silt till (Catfish Creek Till)
		28.3	28.8	limestone bedrock (Dundee Fm.)
BH-8	Sado (1980)			*UTM: 486400m E 4766200m N, NAD83, Zone 17*
				Elevation: 277 m
		0.0	5.5	moderately stony, sandy silt till (Tavistock Till) contains red shale chips
		5.5	7.6	silt grading to silty fine sand with depth
		7.6	23.2	moderately stony, sandy silt till (Tavistock Till) contains blocks of older till (Catfish Creek Till)
		23.2	24.3	massive silt
		24.3	28.9	silty fine sand containing lenses of older till (Catfish Creek Till)
		28.9	31.4	very compact, stony, sandy silt till (Catfish Creek Till)
		31.4	32.2	limestone bedrock (Dundee Fm.)

Test Hole Number	Reference	Depth From (m)	Depth To (m)	Description
BH-9	Sado (1980)			*UTM: 484504m E 4777497m N, NAD83, Zone 17*
				Elevation: 305 m
		0.0	4.0	moderately stony, gritty clayey silt till (Tavistock Till)
		4.0	6.1	laminated silt and clay with pebbly layers
		6.1	10.4	moderately stony, gritty clayey to sandy silt till (Tavistock Till) contains red shale chips
		10.4	12.0	laminated silt and clay
		12.0	15.2	very stony, sandy silt till (Catfish Creek Till)
		15.2	16.0	silty fine sand
		16.0	21.8	very compact, very stony, sandy silt till (Catfish Creek Till)
BH-10	Sado (1980)			*UTM: 486200m E 4771305m N, NAD83, Zone 17*
				Elevation: 293 m
		0.0	2.0	stony, gritty clayey silt till (Tavistock Till) contains red shale chips
		2.0	3.0	silty fine sand grading to clean, stratified sand
		3.0	5.3	stony, gritty clayey to sand silt till (Tavistock Till)
		5.3	6.0	well-stratified medium to coarse sand
		6.0	9.1	very stony, compact, sandy silt till (Tavistock Till)
		9.1	17.3	very compact, very stony sandy silt till (Catfish Creek Till)
		17.3	18.0	limestone bedrock (Dundee Fm.)
BH-11	Sado (1980)			*UTM: 486100m E 4771005m N, NAD83, Zone 17*
				Elevation: 271 m
		0.0	3.0	cobbly gravel
		3.0	5.0	stony, gritty clayey silt till (Tavistock Till)
		5.0	7.9	laminated silt and clayey silt containing pebbly lenses
		7.9	19.0	very compact, very stony sandy silt till (Catfish Creek Till)
		19.0	20.5	limestone bedrock (Dundee Fm.)
BH-12	Sado (1980)			*UTM: 475200m E 4762605m N, NAD83, Zone 17*
				Elevation: 262 m
		0.0	6.1	stony, gritty, clayey silt till (Tavistock Till) contains red shale chips
		6.1	8.5	laminated silt-clay
		8.5	10.4	stony, gritty, clayey silt till (Tavistock Till) contains red shale chips
		10.4	11.5	massive silt
		11.5	21.3	stony, gritty, clayey to sandy silt till (Tavistock Till) with depth contains red shale chips
		21.3	33.5	clean, laminated fine sand, artesian water pressure
BH-14	Sado (1980)			*UTM: 501202m E 4756707m N, NAD83, Zone 17*
				Elevation: 292 m
		0.0	10.9	clay silt till (Port Stanley Till) few pebbles, contains lenses of older till (Tavistock Till)
		10.9	15.5	gritty, sand silt till (Tavistock Till) contains silt layer
		15.5	23.8	finely laminated, cross-bedded sand
BH-19	Sado (1980)			*UTM: 499897m E 4761200m N, NAD83, Zone 17*
				Elevation: 277 m
		0.0	3.7	gritty, stony, sandy silt till (Tavistock Till) contains red shale chips
		3.7	4.5	gritty, stony, sandy silt till (Tavistock till)
		4.5	17.4	clean gravely sand
		17.4	21.3	very stony, very compact, sandy silt till (Catfish Creek Till)

Test Hole Number	Reference	Depth From (m)	Depth To (m)	Description
BH-20	Sado (1980)			*UTM: 498295m E 4760200m N, NAD83, Zone 17*
				Elevation: 271 m
		0.0	4.0	gritty, sandy silt till (Tavistock Till) contains red shape chips
		4.0	10.3	sand with gravel
		10.3	11.9	gritty, silty sand till (Tavistock Till)
		11.9	15.5	very compact, very stony silt sand till (Catfish Creek Till)
BH-21	Sado (1980)			*UTM: 498391m E 4760396m N, NAD83, Zone 17*
				Elevation: 277 m
		0.0	4.2	gritty, sandy silt till (Tavistock Till) contains red shale chips
		4.2	11.5	gravelly sand contains red clay layer
		11.5	14.6	compact, stony, silty sand till (Tavistock Till?) contains red shale chips
		14.6	18.0	very compact, very stony, sandy silt till (Catfish Creek Till)
EW-TH-1	OGS (1991)			*UTM: 457270m E 4781863m N, NAD83, Zone 17*
				Elevation: 229 m
		0.0	0.3	black, organic topsoil
		0.3	1.4	moist, buff clay
		1.4	1.7	wet, silty medium to coarse sand
		1.7	2.0	wet, dirty fine to medium sand and gravel
EW-TH-2	OGS (1991)			*UTM: 456851m E 4778801m N, NAD83, Zone 17*
				Elevation: 229 m
		0.0	0.3	black, organic topsoil
		0.3	0.6	wet, buff sandy silt
		0.6	1.5	wet, buff grey clayey silt
		1.5	1.8	moist, buff clayey silt
EW-TH-3	OGS (1991)			*UTM: 456122m E 4775782m N, NAD83, Zone 17*
				Elevation: 229 m
		0.0	0.3	dark, loamy topsoil
		0.3	1.0	buff sandy silt
		1.0	1.2	dirty fine to coarse sand and fine gravel (subrounded stones)
		1.2	1.5	bluish grey silty clay
EW-TH-4	OGS (1991)			*UTM: 461129m E 4775090m N, NAD83, Zone 17*
				Elevation: 252 m
		0.0	3.7	buff clayey silt till, occasionally consolidated stony material
EW-TH-5	OGS (1991)			*UTM: 455835m E 4775470m N, NAD83, Zone 17*
				Elevation: 229 m
		0.0	0.3	dark, loamy topsoil
		0.3	1.0	dirty, wet sandy gravel
		1.0	3.0	buff, wet fine silt and sand
EW-TH-6	OGS (1991)			*UTM: 456009m E 4774597m N, NAD83, Zone 17*
				Elevation: 229 m
		0.0	0.3	loamy topsoil
		0.3	0.6	buff, dirty sandy silt
		0.6	1.0	wet, buff silty sand
		1.0	2.1	moist, blue-grey silty clay
EW-TH-7	OGS (1991)			*UTM: 455835m E 4773718m N, NAD83, Zone 17*
				Elevation: 229 m
		0.0	0.3	dark, loamy topsoil
		0.3	0.6	buff, silty clay
		0.6	3.0	buff to grey, moist silty clay till

Test Hole Number	Reference	Depth From (m)	Depth To (m)	Description
EW-TH-8	OGS (1991)			*UTM: 452635m E 4771859m N, NAD83, Zone 17*
				Elevation: 232 m
		0.0	0.3	loamy topsoil
		0.3	3.0	fine to medium sand becoming silty and wet at 1.5 m
		3.0	3.7	moist, bluish-grey clay
EW-TH-9	OGS (1991)			*UTM: 453877m E 4769221m N, NAD83, Zone 17*
				Elevation: 221 m
		0.0	0.3	dark, loamy topsoil
		0.3	1.0	buff, wet silty clay
		1.0	2.1	dirty, fine to medium sand and gravel (rounded stones)
ND-TH-1	OGS (1982b)			*UTM: 499881m E 4761413m N, NAD83, Zone 17*
				Elevation: 273 m
		0.0	3.5	gritty silty sand till (Tavistock Till)
		3.5	17.4	clean medium to coarse sand, well graded, contains gravelly layers
		17.4	21.3	compact, stony silty sand till (Catfish Creek Till)
ND-TH-2	OGS (1982b)			*UTM: 498464m E 4760378m N, NAD83, Zone 17*
				Elevation: 271 m
		0.0	1.8	gritty silty sand till (Tavistock Till)
		1.8	16.5	silty fine sand grading to clean coarse sand containing gravelly layers
		16.5	18.0	silty sand till
		18.0	20.1	compact, stony silty sand till (Catfish Creek Till)
ND-TH-3	OGS (1982b)			*UTM: 498496m E 4760737m N, NAD83, Zone 17*
				Elevation: 270 m
		0.0	4.3	gritty silty sand till (Tavistock Till)
		4.3	8.5	clean, well-sorted sand grading to gravel and gravelly sand with depth
		8.5	17.7	gravelly silty sand
		17.7	20.1	compact, stony silty sand till (Catfish Creek Till)
ND-TH-4	OGS (1982b)			*UTM: 500467m E 4757235m N, NAD83, Zone 17*
				Elevation: 274 m
		0.0	0.9	gritty sandy silt till (Tavistock Till)
		0.9	10.1	cobbly gravels and coarse sand, well sorted, clean
		10.1	22.9	clean, well-sorted sand and some bouldery to cobbly gravel
ND-TH-5	OGS (1982b)			*UTM: 500785m E 4756917m N, NAD83, Zone 17*
				Elevation: 282 m
		0.0	16.8	clean, well-sorted sand and gravel materials
ND-TH-6	OGS (1982b)			*UTM: 502177m E 4757153m N, NAD83, Zone 17*
				Elevation: 288 m
		0.0	7.6	gritty clay silt till (Port Stanley Till)
		7.6	11.3	gritty clayey silt till (Tavistock Till)
		11.3	32.0	clean, well-sorted sand with some gravel
WT-TH-1	OGS (1982c)			*UTM: 491004m E 4757017m N, NAD83, Zone 17*
				Elevation: 267 m
		0.0	4.0	gritty sandy silt till (Tavistock Till)
		4.0	8.5	silty fine sand grading to clean gravelly coarse sand
		8.5	22.9	compact, stony silty sand till (Catfish Creek Till)

Table 8. Summary of Geophysical Data, County of Middlesex and City of London.

Geophysical Test Location	Description
Line Number: EW-GT-1	*UTM: 457281m E 4781828m N, NAD83, Zone 17*
Line Direction:	north to south
Elevation:	229 m
Seismic Data:	Number of layers: 3
Layer Velocity:	V_1 = 365 m/s
	V_2 = 1770 m/s
	V_3 = 2440 m/s
Layer Thickness:	D_1 = 2 m
	D_2 = 3 m
Interpretation:	Layer 1: 2 m sandy, clayey silt
	Layer 2: 3 m cemented sand and gravel
Line Number: EW-GT-2	*UTM: 461392m E 4775250m N, NAD83, Zone 17*
Line Direction:	west to east
Elevation:	250 m
Seismic Data:	Number of layers: 3
Layer Velocity:	V_1 = 365 m/s
	V_2 = 5000 m/s
	V_3 = 10 000 m/s
Layer Thickness:	D_1 = 2 m
	D_2 = 7 m
Interpretation:	Layer 1: 2 m silty, sandy material (ablation till)
	Layer 2: 7 m sand and gravel capped by a cemented layer of consolidated material, till
Line Number: EW-GT-3	*UTM: 456313m E 4775142m N, NAD83, Zone 17*
Line Direction:	west to east
Elevation:	229 m
Seismic Data:	Number of layers: 2
Layer Velocity:	V_1 = 400 m/s
	V_2 = 2040 m/s
Layer Thickness:	D_1 = 2 m
	D_2 = 9 m
Interpretation:	Layer 1: 2 m silty sand
	Layer 2: consolidated material, till or clay
Line Number: EW-GT-4	*UTM: 457562m E 4774996m N, NAD83, Zone 17*
Line Direction:	west to east
Elevation:	365 m
Seismic Data:	Number of layers: 2
Layer Velocity:	V_1 = 365 m/s
	V_2 = 2950 m/s
Layer Thickness:	D_1 = 3 m
	D_2 = 9 m
Interpretation:	Layer 1: 3 m silty sand
	Layer 2: consolidated material, till or clay

Geophysical Test Location	Description
Line Number: EW-GT-5	*UTM: 452464m E 4771859m N, NAD83, Zone 17*
Line Direction:	northeast to southwest
Elevation:	221 m
Seismic Data:	Number of layers: 3
Layer Velocity:	V_1 = 380 m/s
	V_2 = 1390 m/s
	V_3 = 1770 m/s
Layer Thickness:	D_1 = 1.5 m
	D_2 = 1.7 m
Interpretation:	Layer 1: 1.5 m dry sand
	Layer 2: 1.5 m wet silty sand
	Layer 3: clay
Line Number: EW-GT-6	*UTM: 453652m E 4769338m N, NAD83, Zone 17*
Line Direction:	northeast to southwest
Elevation:	232 m
Seismic Data:	Number of layers: 2
Layer Velocity:	V_1 = 1200 m/s
	V_2 = 4900 m/s
Layer Thickness:	D_1 = 3 m
	D_2 = 9 m
Interpretation:	Layer 1: 3 m sand and gravel
	Layer 2: 9 m consolidated material, till
Line Number: EW-GT-7	*UTM: 451776m E 4767887m N, NAD83, Zone 17*
Line Direction:	northeast to southwest
Elevation:	232 m
Seismic Data:	Number of layers: 2
Layer Velocity:	V_1 = 340 m/s
	V_2 = 1710 m/s
Layer Thickness:	D_1 = 3 m
	D_2 = 9 m
Interpretation:	Layer 1: 3 m sand and gravel
	Layer 2: 9 m consolidated material, till
Line Number: EW-GT-8	*UTM: 452243m E 4767413m N, NAD83, Zone 17*
Line Direction:	northeast to southwest
Elevation:	232 m
Seismic Data:	Number of layers: 2
Layer Velocity:	V_1 = 455 m/s
	V_2 = 1740 m/s
Layer Thickness:	D_1 = 1.5 m
	D_2 = 11 m
Interpretation:	Layer 1: 1.5 m sand and gravel
	Layer 2: consolidated material, till

* *For source of geophysical data,* see *"References": Ontario Geological Survey (1991)*

Table 9. Aggregate Quality Test Data, County of Middlesex and City of London.

Sample Number	COARSE AGGREGATE: Petrographic Number – Granular and 16 mm	Petrographic Number – Hot Mix and Concrete	$MgSO_4$ (%)	Micro-Deval Abrasion (% Loss)	Los Angeles Abrasion Test (% Loss)	Freeze–Thaw (% Loss)	Absorption (%)	Bulk Relative Density	Accelerated Mortar Bar (14 days) (% Loss)	FINE AGGREGATE: $MgSO_4$ (%)	Micro-Deval Abrasion (% Loss)
Generally Acceptable Values:	*<125–140*		*<12–15%*	*<14–17%*	*<35–45%*	*<6%*	*<2%*	*>2.5*	*<0.150%*	*<25%*	*<15–25%*
Municipality of North Middlesex											
Selected Sand and Gravel Resources Area 1											
	119	164	7.9	-	-	-	1.580	2.610	-	-	-
Township of Lucan Biddulph											
Township of Adelaide Metcalfe											
Village of Newbury											
Municipality of Southwest Middlesex											
Township of Strathroy–Caradoc											
Municipality of Middlesex Centre											
Selected Sand and Gravel Resources Area 2											
* 85-A-17058	-	-	4.5	-	-	-	-	-	-	5.6	-
* 85-A-17059	-	-	4.2	-	-	-	-	-	-	9.2	-
* 85-A-17060	105.3	180	3.3	-	-	-	1.138	2.644	-	14.5	-
Secondary Resource Area - Glaciolacustrine Delta at Poplar Hill and Coldstream											
	-	-	-	-	-	-	-	-	0.097	-	14.7
	-	-	-	-	-	-	-	-	0.174	-	4.4
	-	-	-	-	-	-	-	-	-	-	15.5
	-	-	-	-	-	-	1.100	2.620	-	-	-
	-	-	-	-	-	-	1.110	2.656	0.053	-	13.1
	-	-	-	-	-	-	1.600	2.592	-	-	13.0
	-	-	-	-	-	-	1.070	2.618	0.141	-	-
	-	-	-	-	-	-	1.260	2.624	-	-	-
	-	-	-	-	-	-	-	-	0.108	-	15.1
	-	-	-	-	-	-	1.130	2.630	-	-	-
	-	-	-	-	-	-	0.990	2.640	-	-	-
	-	-	-	-	-	-	1.510	2.600	-	-	-
	-	-	-	-	-	-	1.260	2.620	-	-	-
	138.4	231.4	-	-	-	-	1.833	2.581	-	-	13.5
	-	-	-	-	-	-	1.051	2.632	-	-	15.4
	-	-	-	-	-	-	1.338	2.617	0.118	-	16.9
Minimum	-	-	-	-	-	-	*0.990*	*2.581*	*0.053*	-	*4.4*
Maximum	-	-	-	-	-	-	*1.833*	*2.656*	*0.174*	-	*16.9*
Median	-	-	-	-	-	-	*1.195*	*2.620*	*0.113*	-	*14.7*
Secondary Resource Area - Ice-Contact Deposit Northwest of Ilderton											
	-	-	-	10.5	-	-	-	-	-	-	18.9
	-	-	-	12.2	-	-	-	-	-	-	22.8
	-	-	-	12.6	-	-	-	-	-	-	19.6
	101.8	112.7	-	-	-	-	0.735	2.662	-	-	-
	104.6	112.7	-	13.6	-	6.0	1.142	2.631	-	-	-

Sample Number	COARSE AGGREGATE: Petrographic Number: Granular and 16 mm	COARSE AGGREGATE: Petrographic Number: Hot Mix and Concrete	COARSE AGGREGATE: $MgSO_4$ (%)	COARSE AGGREGATE: Micro-Deval Abrasion (% Loss)	COARSE AGGREGATE: Los Angeles Abrasion Test (% Loss)	COARSE AGGREGATE: Freeze–Thaw (% Loss)	COARSE AGGREGATE: Absorption (%)	COARSE AGGREGATE: Bulk Relative Density	COARSE AGGREGATE: Accelerated Mortar Bar (14 days) (% Loss)	FINE AGGREGATE: $MgSO_4$ (%)	FINE AGGREGATE: Micro-Deval Abrasion (% Loss)
Generally Acceptable Values:	*<125–140*		*<12–15%*	*<14–17%*	*<35–45%*	*<6%*	*<2%*	*>2.5*	*<0.150%*	*<25%*	*<15–25%*
Secondary Resource Area - Medway Creek Outwash Deposit											
	110.7	119.9	-	-	-	-	-	-	-	-	-
	-	-	-	18.6	-	-	-	-	-	14.6	-
	-	-	-	15.7	-	-	-	-	-	-	18.8
	102.9	111.1	2.0	-	21.1	-	0.934	2.659	-	-	-
	107.0	117.7	-	-	-	-	0.936	2.663	-	-	-
	-	-	-	-	-	-	1.276	2.629	-	-	16.2
	101.5	123.9	-	-	-	-	1.320	2.635	-	-	-
	107.2	118.0	2.8	-	26.0	-	0.940	2.670	-	-	-
	105.0	133.4	-	-	-	-	-	-	-	-	-
	100.8	117.5	5.0	-	25.0	-	-	-	-	-	-
	100.0	105.4	-	-	25.0	-	0.900	2.660	-	-	-
	-	-	-	-	-	-	1.310	2.640	-	11.5	-
	-	-	-	-	-	-	1.133	2.647	-	12.0	-
	-	-	-	-	-	-	1.110	2.630	-	6.6	-
	-	-	-	-	-	-	1.260	2.640	-	3.4	-
	100.0	119.2	-	14.3	24.0	4.0	1.138	2.636	-	-	18.8
	110.6	120.5	-	14.4	24.0	5.0	1.139	2.634	-	-	-
Minimum	*100.0*	*105.4*	-	*14.3*	*21.1*	-	*0.900*	*2.629*	-	*3.4*	-
Maximum	*110.7*	*133.4*	-	*18.6*	*26.0*	-	*1.320*	*2.670*	-	*14.6*	-
Median	*104.0*	*118.6*	-	*15.1*	*24.5*	-	*1.136*	*2.640*	-	*11.5*	-
City of London											
Selected Sand and Gravel Resources Area 4											
* 85-A-17061	113.8	149.2	2.1	-	-	-	0.833	2.666	-	8.3	-
* 85-A-17032	101.5	134.7	2.0	-	-	-	1.001	2.664	-	11.4	-
	102.0	105.9	2.7	-	22.5	-	0.800	2.670	-	-	-
	108.0	125.9	1.3	-	21.0	-	1.000	2.660	-	-	-
	113.7	122.3	1.8	-	23.0	-	1.170	2.650	-	-	-
	114.4	150.3	-	-	-	-	1.070	2.650	-	-	-
	102.0	112.0	6.3	-	22.0	-	0.960	2.660	-	-	-
	107.2	135.0	-	-	-	-	1.170	2.640	-	-	-
	104.9	138.2	2.2	-	21.0	-	0.969	2.650	-	-	-
	104.9	130.4	-	-	-	-	1.171	2.652	-	-	11.5
	106.3	134.3	-	11.5	23.0	-	1.171	2.652	-	-	-
Minimum	*101.5*	*105.9*	*1.3*	-	*21.0*	-	*0.800*	*2.640*	-	-	-
Maximum	*114.4*	*150.3*	*6.3*	-	*23.0*	-	*1.171*	*2.670*	-	-	-
Median	*106.3*	*134.3*	*2.1*	-	*22.3*	-	*1.001*	*2.652*	-	-	-
Selected Sand and Gravel Resources Area 5											
	-	-	-	-	-	-	0.766	2.622	-	-	13.0
	-	-	-	-	-	-	1.235	2.627	-	-	16.0
	100.9	117.7	2.3	-	22.0	-	1.000	2.650	-	-	-

Sample Number	COARSE AGGREGATE: Petrographic Number: Granular and 16 mm	COARSE AGGREGATE: Petrographic Number: Hot Mix and Concrete	COARSE AGGREGATE: $MgSO_4$ (%)	COARSE AGGREGATE: Micro-Deval Abrasion (% Loss)	COARSE AGGREGATE: Los Angeles Abrasion Test (% Loss)	COARSE AGGREGATE: Freeze–Thaw (% Loss)	COARSE AGGREGATE: Absorp-tion (%)	COARSE AGGREGATE: Bulk Relative Density	COARSE AGGREGATE: Accelerated Mortar Bar (14 days) (% Loss)	FINE AGGREGATE: $MgSO_4$ (%)	FINE AGGREGATE: Micro-Deval Abrasion (% Loss)
Generally Acceptable Values:		*<125–140*	*<12–15%*	*<14–17%*	*<35–45%*	*<6%*	*<2%*	*>2.5*	*<0.150%*	*<25%*	*<15–25%*
	100.0	115.0	-	-	22.0	-	0.935	2.650	-	-	-
	100.0	108.0	2.7	-	22.0	-	0.800	2.680	-	-	-
	103.9	129.2	3.0	-	-	-	1.040	2.660	-	-	-
	101.2	112.6	-	-	-	-	-	-	-	-	-
	102.3	136.1	5.0	-	-	-	1.270	2.640	-	-	-
	103.2	136.1	2.0	-	-	-	0.960	2.430	-	-	
	102.2	128.6	2.0	-	-	-	1.200	2.640	-	-	-
	100.0	126.0	4.4	10.7	-	3.5	1.090	2.649	0.140	-	-
	-	-	-	-	-	-	-	-	0.090	11.0	14.4
	-	-	-	-	-	-	-	-	0.158	-	13.9
	-	-	-	-	-	-	-	-	0.158	-	13.9
	-	-	3.2	-	-	-	1.150	-	-	-	17.3
	-	112.0	-	10.5	-	4.4	1.220	2.680	0.091	-	-
	-	-	-	-	-	-	-	-	0.158	-	13.9
	100.0	124.0	2.6	10.1	-	-	1.170	2.644	0.170	-	-
	-	-	-	-	-	-	-	-	0.120	-	13.6
	105.8	130.8	-	-	-	-	1.350	2.630	-	-	-
	104.7	147.3	3.1	-	-	-	1.170	2.630	-	-	-
	100.0	122.0	-	-	-	-	1.400	2.620	-	-	-
	103.2	123.0	5.0	-	25.0	-	1.350	2.640	-	-	-
	100.7	124.4	3.0	-	22.0	-	1.100	2.640	-	-	-
	106.4	119.7	4.0	-	25.0	-	1.190	2.650	-	-	-
	103.6	125.2	5.0	-	22.0	-	1.270	2.620	-	-	-
	102.6	125.1	-	11.0	23.0	3.0	1.270	2.638	-	-	-
	-	-	-	-	-	-	0.949	2.651	-	-	13.7
	107.5	129.8	-	-	-	-	1.504	2.620	-	-	-
	101.5	124.2	-	-	21.0	-	1.504	2.620	-	-	-
	-	120.0	-	12.8	-	5.8	-	2.654	0.051	-	-
	-	-	-	8.5	-	0.9	1.230	-	-	-	-
	-	-	-	-	-	-	-	-	0.400	-	13.7
	-	-	-	-	-	-	0.584	2.726	0.113	-	13.7
	-	-	-	8.5	-	0.9	1.225	2.650	-	-	-
	-	115.0	1.8	10.9	-	3.2	0.840	-	0.112	-	-
	-	-	6.3	9.9	-	4.1	1.450	-	0.112	-	-
	-	116.0	3.0	9.5	-	1.8	0.940	2.659	0.136	-	-
	-	-	-	-	-	-	1.030	2.682	0.202	-	14.3
	-	130.0	6.4	10.0	-	3.2	1.350	2.638	-	-	-
	-	-	-	-	-	-	1.170	2.661	-	-	14.3
	-	-	-	10.1	-	1.4	1.230	-	-	-	-
	-	121.0	5.2	10.1	-	1.4	1.230	2.632	-	-	-
	-	116.0	-	10.1	-	3.6	0.930	-	0.054	-	-
	-	-	-	9.5	-	4.7	0.880	-	0.087	-	-

	COARSE AGGREGATE									FINE AGGREGATE	
Sample Number	Petrographic Number: Granular and 16 mm	Petrographic Number: Hot Mix and Concrete	$MgSO_4$ (%)	Micro-Deval Abrasion (% Loss)	Los Angeles Abrasion Test (% Loss)	Freeze–Thaw (% Loss)	Absorp-tion (%)	Bulk Relative Density	Accelerated Mortar Bar (14 days) (% Loss)	$MgSO_4$ (%)	Micro-Deval Abrasion (% Loss)
Generally Acceptable Values:		*<125–140*	*<12–15%*	*<14–17%*	*<35–45%*	*<6%*	*<2%*	*>2.5*	*<0.150%*	*<25%*	*<15–25%*
	-	108.0	-	9.6	-	4.5	0.970	-	0.097	-	-
	101.0	123.0	-	10.6	-	3.1	1.120	-	0.072	-	-
	-	-	-	9.9	-	3.0	1.120	-	0.099	-	-
	-	-	-	9.8	-	4.8	1.080	-	0.118	-	-
	-	-	-	11.0	-	2.2	1.110	-	0.048	-	-
	-	-	-	10.4	-	2.6	1.030	-	0.088	-	-
	-	-	-	15.6	-	19.5	0.760	2.672	0.437	-	-
	-	-	-	-	-	-	-	-	0.446	-	19.5
	-	118.0	-	14.5	-	3.5	1.370	-	0.050	-	-
	-	-	-	-	-	-	-	-	-	-	13.0
	-	111.8	0.8	12.5	-	1.9	1.160	-	-	-	15.2
	-	-	-	-	-	-	1.220	-	-	-	-
	-	117.9	2.6	10.7	-	3.2	-	-	-	-	-
	-	117.0	-	11.6	-	2.5	1.270	2.680	0.104	-	-
	-	-	-	-	-	-	1.280	2.648	-	-	15.4
	-	120.0	-	10.0	-	3.6	1.400	2.729	0.104	-	-
	-	111.8	0.8	12.5	-	1.9	1.160	2.702	0.091	-	-
	-	-	-	-	-	-	1.300	2.650	-	-	15.2
	-	117.9	2.6	10.7	-	3.2	1.220	2.727	0.091	-	-
	-	111.8	0.8	12.5	-	1.9	1.160	-	-	-	15.8
	-	117.9	2.6	10.7	-	3.2	1.220	-	-	-	-
	-	111.8	0.8	12.5	-	1.9	1.160	2.702	0.091	-	-
	106.0	118.0	3.0	-	23.9	-	0.935	2.652	-	-	-
	100.7	104.9	0.4	-	23.1	-	0.735	2.680	-	-	-
	101.0	120.4	4.0	-	22.0	-	2.000	2.650	-	-	-
	100.0	103.0	1.5	-	22.0	-	0.770	2.680	-	-	-
	100.0	109.0	3.3	-	24.0	-	0.770	2.670	-	-	-
	100.0	120.8	3.0	-	22.0	-	1.040	2.650	-	-	-
	100.0	124.3	6.2	-	26.0	-	1.330	2.640	-	-	-
	100.5	118.6	0.9	-	21.0	-	1.040	2.660	-	-	-
	100.0	120.8	3.0	-	22.0	-	1.040	2.650	-	-	-
	104.8	128.7	2.0	-	21.0	-	1.020	2.660	-	-	-
	100.0	128.2	3.8	-	-	-	1.000	2.660	-	-	-
	-	-	-	-	-	-	1.193	2.642	0.279	11.0	14.2
	103.4	112.7	-	12.6	21.0	6.0	0.935	2.657	-	-	-
	100.8	114.6	1.0	-	21.0	-	0.819	2.683	0.089	-	-
	-	125.3	-	10.2	-	3.1	1.230	2.681	0.099	-	-
	-	129.3	-	10.2	-	4.4	1.360	2.662	0.089	-	-
	100.0	122.2	7.3	-	22.0	-	0.870	2.680	-	-	-
	101.4	113.8	2.1	-	24.0	-	0.800	2.620	-	-	-
	102.0	115.9	2.8	-	-	-	1.000	2.650	-	-	-
	100.9	113.8	4.0	-	23.0	-	1.060	2.660	-	-	-

	COARSE AGGREGATE									FINE AGGREGATE	
Sample Number	**Petrographic Number**										
	Granular and 16 mm	**Hot Mix and Concrete**	**$MgSO_4$ (%)**	**Micro-Deval Abrasion (% Loss)**	**Los Angeles Abrasion Test (% Loss)**	**Freeze–Thaw (% Loss)**	**Absorp-tion (%)**	**Bulk Relative Density**	**Accelerated Mortar Bar (14 days) (% Loss)**	**$MgSO_4$ (%)**	**Micro-Deval Abrasion (% Loss)**
Generally Acceptable Values:		*<125–140*	*<12–15%*	*<14–17%*	*<35–45%*	*<6%*	*<2%*	*>2.5*	*<0.150%*	*<25%*	*<15–25%*
	100.8	121.6	1.7	-	21.0	-	1.068	2.650	-	-	-
	103.5	124.6	6.5	-	23.0	-	1.340	2.620	-	-	-
	100.2	119.4	3.0	-	22.0	-	0.970	2.650	-	-	-
	100.9	123.0	2.0	-	23.0	-	1.240	2.630	-	-	-
	102.5	121.3	4.0	-	22.0	-	1.140	2.640	-	-	-
	102.7	119.1	5.0	-	20.2	-	1.104	2.644	-	-	-
	101.7	123.5	6.0	-	-	-	1.236	2.631	-	-	-
	102.2	117.8	-	-	22.2	-	1.236	2.631	-	-	-
	104.5	135.0	5.0	-	22.0	-	1.240	2.630	-	-	-
	-	131.6	5.0	-	23.0	-	1.124	2.660	-	-	-
	107.4	127.1	3.0	-	22.0	-	0.940	2.670	-	-	-
	103.7	122.9	-	14.2	22.0	-	1.306	2.639	-	-	-
	111.8	134.3	-	14.6	-	8.0	1.208	2.632	-	-	-
	106.9	127.1	-	15.4	-	8.0	1.175	2.641	-	-	-
	-	-	-	-	-	-	1.440	2.619	-	-	14.6
	-	-	-	-	-	-	1.420	2.614	-	-	13.7
	-	-	-	-	-	-	1.461	2.620	-	-	15.1
	-	-	-	-	-	-	0.847	2.673	-	-	23.0
	-	-	-	-	-	-	1.338	2.622	-	-	14.4
	-	-	-	-	-	-	1.297	2.621	-	-	15.3
	-	-	-	-	-	-	1.419	2.626	-	-	14.2
	-	-	-	-	-	-	1.153	2.649	-	-	25.0
	101.1	110.4	-	12.5	23.0	4.0	0.986	2.650	-	-	-
* 85-A-17012	104.8	159.5	1.9	-	-	-	1.370	2.610	-	10.0	-
* 85-A-17013	-	-	-	-	-	-	-	-	-	15.1	-
* 85-A-17014	108.7	175.8	1.2	-	-	-	-	-	-	17.4	-
* 85-A-17015	-	-	-	-	-	-	-	-	-	15.8	-
* 85-A-17016	-	-	-	-	-	-	-	-	-	21.2	-
* 85-A-17017	100.0	136.8	5.7	-	-	-	1.037	2.645	-	21.0	-
* 85-A-17018	101.6	130.4	3.3	-	-	-	1.069	2.645	-	16.1	-
* 85-A-17019	101.6	114.3	4.6	-	-	-	1.009	2.631	-	14.5	-
* 85-A-17020	101.4	119.1	1.9	-	-	-	-	-	-	12.9	-
Minimum	*100.0*	*103.0*	*0.4*	*8.5*	*20.2*	*0.9*	*0.584*	*2.430*	*0.048*	*10.0*	*13.0*
Maximum	*111.8*	*175.8*	*7.3*	*15.6*	*26.0*	*19.5*	*2.000*	*2.729*	*0.446*	*21.2*	*25.0*
Median	*101.6*	*120.8*	*3.0*	*10.7*	*22.0*	*3.2*	*1.160*	*2.650*	*0.104*	*15.1*	*14.4*
Average		*122.3*									
<140		*76.0*									
>140		*3.0*									

Sample Number	COARSE AGGREGATE									FINE AGGREGATE	
	Petrographic Number										
	Granular and 16 mm	Hot Mix and Concrete	$MgSO_4$ (%)	Micro-Deval Abrasion (% Loss)	Los Angeles Abrasion Test (% Loss)	Freeze–Thaw (% Loss)	Absorption (%)	Bulk Relative Density	Accelerated Mortar Bar (14 days) (% Loss)	$MgSO_4$ (%)	Micro-Deval Abrasion (% Loss)
Generally Acceptable Values:	*<125–140*		*<12–15%*	*<14–17%*	*<35–45%*	*<6%*	*<2%*	*>2.5*	*<0.150%*	*<25%*	*<15–25%*
Secondary Resource Area - Ice-Contact Deposit in Central City of London											
	140.3	175.8	-	-	-	-	2.828	2.506	-	-	15.6
	-	-	-	-	-	-	1.564	2.611	-	-	15.7
	-	-	-	-	-	-	1.564	2.611	1.564	-	-
	-	-	-	-	-	-	0.746	2.655	-	-	14.2
	-	-	-	-	-	-	1.379	2.642	-	-	16.5
	-	-	-	-	-	-	1.378	2.622	-	-	14.3
	113.5	168.7	2.8	-	-	-	0.940	2.660	-	-	-
	172.7	197.1	10.4	-	25.0	-	-	-	-	-	-
	104.7	157.8	5.9	-	-	-	1.220	2.610	-	10.3	-
Minimum	*104.7*	*157.8*	-	-	-	-	*0.746*	*2.506*	-	-	*14.2*
Maximum	*172.7*	*197.1*	-	-	-	-	*2.828*	*2.660*	-	-	*16.5*
Median	*126.9*	*172.3*	-	-	-	-	*1.379*	*2.617*	-	-	*15.6*
Municipality of Thames Centre											
Selected Sand and Gravel Resources Area 5											
	100.6	104.9	2.9	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	0.830	2.670	-	-	-
	104.0	116.8	-	-	-	-	-	-	-	-	-
	108.5	122.5	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	1.370	2.630	-	15.0	-
	100.0	103.7	2.0	-	21.0	-	0.770	2.670	-	-	-
	100.0	110.2	7.0	-	22.0	-	0.970	2.650	-	-	-
	103.4	114.2	-	-	-	-	-	-	-	-	-
	102.1	107.0	6.0	-	26.0	-	1.140	2.640	-	-	-
	100.0	106.3	-	16.0	32.0	-	1.070	2.643	-	-	-
	-	-	-	15.6	23.0	-	-	-	-	-	-
	104.5	121.5	-	16.5	-	-	1.407	2.623	-	-	-
	100.0	106.9	-	-	23.0	4.0	1.087	2.655	-	-	-
	-	112.0	9.4	13.4	-	-	0.985	-	-	-	-
	-	113.0	13.4	-	-	-	1.315	-	-	-	-
	-	114.0	11.3	-	-	-	1.042	-	-	-	-
	105.6	118.8	-	10.2	-	3.1	1.100	2.748	0.093	-	-
	-	122.9	-	10.3	-	2.4	1.230	2.646	-	-	-
	-	128.6	-	10.9	-	2.6	0.890	2.668	0.131	-	-
	-	-	-	16.8	-	20.4	0.760	2.666	-	-	-
	108.0	119.0	2.3	-	-	-	0.960	2.660	-	-	-
	117.9	132.7	3.0	-	22.7	-	0.930	2.661	-	-	-
	119.1	145.0	5.6	-	19.0	-	1.310	2.635	-	-	-
	102.5	141.6	13.0	-	29.0	-	2.040	2.580	-	-	21.0
	-	117.0	3.4	10.7	-	3.0	1.380	2.658	0.124	-	-
	-	116.0	3.8	11.0	-	3.6	0.970	2.664	0.060	-	-

	COARSE AGGREGATE									FINE AGGREGATE	
Sample Number	**Petrographic Number: Granular and 16 mm**	**Petrographic Number: Hot Mix and Concrete**	**$MgSO_4$ (%)**	**Micro-Deval Abrasion (% Loss)**	**Los Angeles Abrasion Test (% Loss)**	**Freeze–Thaw (% Loss)**	**Absorption (%)**	**Bulk Relative Density**	**Accelerated Mortar Bar (14 days) (% Loss)**	**$MgSO_4$ (%)**	**Micro-Deval Abrasion (% Loss)**
Generally Acceptable Values:		*<125–140*	*<12–15%*	*<14–17%*	*<35–45%*	*<6%*	*<2%*	*>2.5*	*<0.150%*	*<25%*	*<15–25%*
* 85-A-17023	101.7	144.4	5.4	-	-	-	1.200	2.630	-	13.1	-
* 85-A-17024	100.0	127.6	1.5	-	-	-	0.700	2.680	-	11.9	-
* 85-A-17027	101.8	120.0	2.5	-	-	-	1.035	2.646	-	14.1	-
* 85-A-17028	100.7	128.8	1.2	-	-	-	1.167	2.608	-	17.6	-
* 85-A-17029	109.3	143.7	4.9	-	-	-	1.236	2.619	-	12.1	-
* 85-A-17030	100.6	124.5	2.4	-	-	-	0.968	2.650	-	11.6	-
* 85-A-17031	100.0	111.4	5.5	-	-	-	1.303	2.678	-	12.6	-
* 85-A-17052	101.6	126.0	2.1	-	-	-	1.104	2.648	-	9.8	-
* 85-A-17053	100.9	129.7	2.1	-	-	-	1.167	2.635	-	9.8	-
* 85-A-17054	105.0	151.6	4.0	-	-	-	1.202	2.632	-	13.8	-
* 85-A-17055	107.0	142.7	1.4	-	-	-	1.103	2.656	-	17.1	-
* 85-A-17056	104.2	118.4	2.4	-	-	-	0.900	2.692	-	8.4	-
* 85-A-17057	102.1	128.4	2.5	-	-	-	1.302	2.627	-	11.9	-
Minimum	*100.0*	*103.7*	*1.2*	*10.2*	*19.0*	*2.4*	*0.700*	*2.580*	*0.060*	*8.4*	*21.0*
Maximum	*119.1*	*151.6*	*13.4*	*16.8*	*32.0*	*20.4*	*2.040*	*2.748*	*0.131*	*17.6*	*21.0*
Median	*102.1*	*120.0*	*3.2*	*12.2*	*23.0*	*3.1*	*1.102*	*2.650*	*0.109*	*12.4*	*21.0*
Average		*122.6*									
<140		*81.0*									
>140		*16.0*									
Selected Sand and Gravel Resources Area 6											
	113.0	162.0	4.0	-	26.8	-	1.514	2.615	-	-	-
	-	-	-	-	-	-	1.307	2.631	-	-	13.9
	-	-	-	-	-	-	1.256	2.624	-	-	13.0
	-	-	-	-	-	-	1.370	2.630	-	12.0	-
	-	-	-	-	-	-	-	-	-	-	9.9
	101.0	136.6	2.8	-	22.0	-	1.040	2.660	-	-	-
	-	-	-	-	-	-	1.210	2.640	-	12.3	-
	109.1	149.7	-	-	-	-	-	-	-	-	-
	104.2	138.6	4.0	-	22.0	-	1.170	2.650	-	-	-
	108.5	140.4	-	-	-	-	1.436	2.622	-	-	11.6
	111.1	148.3	-	10.3	24.0	-	1.353	2.626	0.127	-	-
	108.5	140.4	-	11.6	24.0	-	1.436	2.622	-	-	-
	103.6	132.6	3.1	-	23.2	-	-	2.274	-	-	-
	120.4	134.9	6.7	-	26.2	-	-	2.743	-	-	-
	123.9	146.3	-	-	-	-	-	-	-	-	-
	116.0	152.1	-	-	-	-	-	-	-	-	-
	111.7	128.3	4.7	-	26.0	-	-	-	-	-	-
	114.8	134.1	-	-	-	-	-	-	-	-	-
	130.7	161.8	8.4	-	26.1	-	-	2.741	-	-	-
	109.9	138.8	-	-	-	-	-	-	-	-	-
	121.5	138.0	5.1	-	26.1	-	-	2.732	-	-	-
	108.5	153.9	3.8	-	25.0	-	-	2.745	-	-	-

	COARSE AGGREGATE									FINE AGGREGATE	
Sample Number	**Petrographic Number**										
	Granular and 16 mm	**Hot Mix and Concrete**	**$MgSO_4$ (%)**	**Micro-Deval Abrasion (% Loss)**	**Los Angeles Abrasion Test (% Loss)**	**Freeze–Thaw (% Loss)**	**Absorption (%)**	**Bulk Relative Density**	**Accelerated Mortar Bar (14 days) (% Loss)**	**$MgSO_4$ (%)**	**Micro-Deval Abrasion (% Loss)**
Generally Acceptable Values:		*<125–140*	*<12–15%*	*<14–17%*	*<35–45%*	*<6%*	*<2%*	*>2.5*	*<0.150%*	*<25%*	*<15–25%*
	108.9	-	-	11.0	-	-	1.430	2.632	0.201	-	-
	-	-	-	-	-	-	1.640	2.611	0.151	-	15.2
	165.9	190.7	5.1	-	29.1	-	1.530	2.623	-	11.5	-
	124.3	153.6	6.4	-	27.1	-	1.530	2.632	-	15.6	-
	117.5	163.7	5.2	-	26.7	-	1.870	2.635	-	13.4	-
	151.7	230.2	6.7	-	25.0	-	1.400	2.627	-	11.6	-
	108.8	147.1	4.1	-	25.0	-	1.400	2.627	-	11.6	-
	114.7	139.8	4.8	-	25.9	-	1.470	2.611	-	12.7	-
	107.2	121.9	3.6	-	23.5	-	1.530	2.627	-	8.8	-
	105.0	135.0	5.7	-	23.5	-	1.530	2.656	-	-	-
	107.1	147.2	6.2	-	27.7	-	1.770	2.612	-	11.3	-
	109.8	159.3	6.2	-	27.7	-	1.600	2.623	-	-	-
	147.9	163.3	7.6	-	27.6	-	2.130	2.594	-	12.4	-
	136.4	188.7	3.9	-	26.7	-	1.820	2.598	-	9.2	-
	203.2	227.7	-	-	-	-	-	-	-	8.8	-
	193.0	230.8	8.2	-	-	-	-	-	-	-	-
	186.5	230.3	8.7	-	-	-	2.070	2.587	-	11.5	-
	100.0	117.0	2.0	-	22.0	-	0.940	2.660	-	-	-
	110.0	144.6	-	-	35.0	-	-	-	-	-	-
	147.7	208.6	8.7	-	-	-	1.670	2.611	-	17.4	-
	125.8	164.2	7.4	-	-	-	1.630	2.633	-	16.2	-
	106.9	126.0	5.3	-	24.3	-	-	-	-	-	-
	111.7	169.5	4.8	-	24.8	-	1.700	2.612	-	11.4	-
	129.0	158.5	6.7	-	24.6	-	1.460	2.643	-	14.0	-
	108.2	134.0	4.7	-	23.7	-	1.330	2.645	-	13.9	-
	102.0	118.9	4.0	-	24.2	-	1.360	2.664	-	14.6	-
	154.0	222.5	8.0	-	-	-	2.300	2.561	-	13.2	-
	131.5	172.0	6.1	-	26.1	-	1.700	2.603	-	-	-
	124.0	202.7	8.1	-	-	-		2.598	-	15.4	-
	142.9	199.4	8.4	-	29.1	-		2.584	-	11.5	-
	109.6	139.3	5.4	-	26.6	-	1.770	2.606	-	-	-
	109.1	161.4	7.5	-	27.4	-	1.630	2.614	-	13.4	-
	105.9	129.0	2.4	-	25.4	-	1.370	2.638	-	-	-
	154.0	204.5	7.0	-	-	-	-	-	-	-	-
	137.1	198.0	10.3	-	-	-	-	-	-	12.5	-
	123.2	147.9	5.9	-	27.3	-	1.570	2.622	-	12.3	-
	131.0	178.0		-		-	-	-	-	-	-
	118.2	142.4	5.3	-	26.4	-	-	2.613	-	14.1	-
	106.8	159.5	3.0	-	24.0	-	1.440	2.620	-	-	-
	105.6	185.7	4.0	-	-	-	1.740	2.590	-	-	-
	116.2	154.5	-	12.3	-	-	-	-	-	-	-
	106.3	132.1	-	-	22.9	-	1.271	2.633	-	-	-

Sample Number	Petrographic Number: Granular and 16 mm	Petrographic Number: Hot Mix and Concrete	COARSE AGGREGATE: $MgSO_4$ (%)	Micro-Deval Abrasion (% Loss)	Los Angeles Abrasion Test (% Loss)	Freeze–Thaw (% Loss)	Absorp-tion (%)	Bulk Relative Density	Accelerated Mortar Bar (14 days) (% Loss)	FINE AGGREGATE: $MgSO_4$ (%)	Micro-Deval Abrasion (% Loss)
Generally Acceptable Values:		*<125–140*	*<12–15%*	*<14–17%*	*<35–45%*	*<6%*	*<2%*	*>2.5*	*<0.150%*	*<25%*	*<15–25%*
	-	-	-	-	-	-	1.626	2.611	-	14.8	-
	116.8	154.4	-	12.3	-	-	-	-	-	-	-
	102.8	139.5	5.0	-	24.0	-	1.340	2.640	-	-	-
	102.2	143.5	8.0	-	28.0	-	1.330	2.640	-	-	-
	106.7	143.7	3.0	-	-	-	1.890	2.590	-	-	-
	102.3	121.5	6.0	-	23.8	-	1.303	2.636	-	-	-
	107.5	134.6	6.0	-	-	-	1.505	2.619	-	-	-
	100.8	130.6	-	14.6	22.0	4.0	-	-	-	-	-
	110.4	149.3	-	13.1	-	-	1.811	2.584	-	-	-
	-	-	-	-	-	-	-	2.631	0.201	-	-
	-	-	-	12.3	-	-	0.750	2.689	0.220	-	-
	-	-	-	11.3	-	-	0.990	2.658	0.233	-	-
	-	-	12.4	-	-	-	1.020	2.662	0.267	-	-
Minimum	*100.0*	*117.0*	*2.0*	*10.3*	*22.0*	-	*0.750*	*2.274*	*0.127*	*8.8*	*9.9*
Maximum	*203.2*	*230.8*	*12.4*	*14.6*	*35.0*	-	*2.300*	*2.745*	*0.267*	*17.4*	*15.2*
Median	*111.4*	*148.3*	*5.6*	*12.3*	*25.4*	-	*1.470*	*2.627*	*0.201*	*12.5*	*13.0*
Average	*120.8*	*157.7*	*5.8*	*12.1*	*25.5*	*4.0*	*1.5*	*2.6*	*0.2*	*12.8*	*12.7*
<140	*56.0*	*22.0*									
>140	*10.0*	*43.0*									
Selected Sand and Gravel Resources Area 7											
	114.0	167.1	5.0	-	24.1	-	1.700	2.605	-	12.0	-
	116.9	144.5	6.8	-	25.2	-	1.700	2.614	-	14.6	-
	105.8	149.7	5.2	-	23.1	-	1.700	2.614	-	14.6	-
	110.5	161.0	4.2	-	25.2	-	1.500	2.642	-	12.5	-
	114.0	156.0	8.0	-	25.7	-	1.730	2.611	-	15.8	-
	102.8	128.7	5.4	-	22.7	-	1.400	2.637	-	10.2	-
	119.6	167.7	3.7	-	23.1	-	1.500	2.628	-	13.0	-
	113.0	126.3	4.7	-	24.9	-	1.500	2.628	-	13.9	-
	109.5	146.6	6.1	-	25.0	-	1.700	2.621	-	13.5	-
	105.4	165.0	6.3	-	21.8	-	1.360	2.646	-	11.5	-
Minimum	*102.8*	*126.3*	*3.7*	-	*21.8*	-	*1.360*	*2.605*	-	*10.2*	-
Maximum	*119.6*	*167.7*	*8.0*	-	*25.7*	-	*1.730*	*2.646*	-	*15.8*	-
Median	*111.8*	*152.9*	*5.3*	-	*24.5*	-	*1.600*	*2.625*	-	*13.3*	-
Selected Sand and Gravel Resources Area 8											
	125.3	184.3	-	15.8	-	-	1.608	2.630	-	-	-
	105.9	156.0	-	12.4	-	-	1.271	2.650	-	-	-
	100.0	149.5	8.0	-	26.0	-	1.600	2.620	-	-	-
	107.9	144.1	7.0	-	27.0	-	1.470	2.620	-	-	-
	103.6	138.3	5.0	-	-	-	1.565	2.616	-	-	-
	-	-	-	11.5	-	-	1.441	2.649	-	-	12.6
	105.9	156.0	-	12.4	-	-	1.271	2.650	-	-	-

	COARSE AGGREGATE									FINE AGGREGATE	
Sample Number	Petrographic Number		MgSO$_4$ (%)	Micro-Deval Abrasion (% Loss)	Los Angeles Abrasion Test (% Loss)	Freeze–Thaw (% Loss)	Absorp-tion (%)	Bulk Relative Density	Accelerated Mortar Bar (14 days) (% Loss)	MgSO$_4$ (%)	Micro-Deval Abrasion (% Loss)
	Granular and 16 mm	Hot Mix and Concrete									
Generally Acceptable Values:		*<125–140*	*<12–15%*	*<14–17%*	*<35–45%*	*<6%*	*<2%*	*>2.5*	*<0.150%*	*<25%*	*<15–25%*
	-	130.6	-	10.2	-	4.0	1.230	2.661	0.205	-	-
	-	-	-	14.2	-	-	-	-	0.188	-	-
	-	135.2	9.0	10.7	-	-	1.380	2.622	0.412	-	-
	-	-	-	-	-	-	-	-	-	-	14.6
	-	129.4	4.4	9.8	-	-	1.280	2.649	0.132	-	-
	101.9	132.6	6.0	12.6	-	3.4	1.400	2.623	0.111	-	-
	-	123.0	-	9.6	-	4.1	1.530	2.628	0.108	-	-
	-	129.0	-	11.1	-	4.4	1.030	2.663	0.119	-	-
	-	-	-	14.0	-	-	1.410	2.632	0.140	-	-
	-	-	-	-	-	-	1.170	2.650	-	-	12.5
	-	-	-	12.4	-	-	-	-	-	-	14.1
	113.2	152.0	-	12.2	25.3	-	-	-	-	-	-
	115.6	154.1	-	12.3	-	-	-	-	-	-	-
	103.6	149.2	-	11.6	25.7	-	1.895	2.599	-	-	17.0
	-	-	-	-	-	-	2.244	2.568	-	-	18.0
	123.2	171.9	-	14.4	26.4	-	2.402	2.545	-	-	19.7
	150.4	183.3	-	15.6	28.5	-	1.482	2.632	-	-	17.6
	106.7	141.6	-	12.1	24.1	-	1.709	2.600	-	-	19.3
	113.3	170.2	-	-	29.7	-	1.534	2.619	-	-	18.9
	104.0	139.0	-	18.9	29.7	-	1.543	2.619	-	-	-
	-	-	11.6	16.9	-	-	1.720	2.665	0.372	-	-
	-	-	-	11.1	-	5.5	1.440	2.612	0.156	-	-
	105.9	138.7	12.5	10.9	-	-	1.600	3.573	0.167	-	-
	-	-	-	-	-	-	-	-	0.176	-	12.8
	-	138.7	10.5	10.9	-	-	1.600	2.598	0.167	-	-
	-	135.0	1.5	-	-	-	1.320	2.628	0.137	-	10.6
	-	133.3	4.8	-	-	3.8	1.290	2.633	0.119	-	10.1
	-	-	-	-	-	-	1.430	2.633	0.164	-	15.3
	-	130.0	-	-	-	3.9	1.460	2.614	0.115	-	10.7
	-	-	-	-	-	-	1.470	2.627	0.135	-	-
Minimum	*100.0*	*123.0*	*1.5*	*9.6*	*24.1*	*3.4*	*1.030*	*2.545*	*0.108*	-	*10.1*
Maximum	*150.4*	*184.3*	*12.5*	*18.9*	*29.7*	*5.5*	*2.402*	*3.573*	*0.412*	-	*19.7*
Median	*106.3*	*139.0*	*7.0*	*12.3*	*26.4*	*4.0*	*1.470*	*2.628*	*0.148*	-	*14.6*
Secondary Resource Area - Outwash Deposit Located on North Border											
	100.9	121.0									
		103.0	114.0		12.4		5.400	1.076	2.709	0.0	
			112.0		12.2		1.600	1.018	2.658	0.1	

	COARSE AGGREGATE									FINE AGGREGATE	
Sample Number	**Petrographic Number: Granular and 16 mm**	**Petrographic Number: Hot Mix and Concrete**	**$MgSO_4$ (%)**	**Micro-Deval Abrasion (% Loss)**	**Los Angeles Abrasion Test (% Loss)**	**Freeze–Thaw (% Loss)**	**Absorp-tion (%)**	**Bulk Relative Density**	**Accelerated Mortar Bar (14 days) (% Loss)**	**$MgSO_4$ (%)**	**Micro-Deval Abrasion (% Loss)**
Generally Acceptable Values:	*<125–140*		*<12–15%*	*<14–17%*	*<35–45%*	*<6%*	*<2%*	*>2.5*	*<0.150%*	*<25%*	*<15–25%*
Secondary Resource Area - Gravel Outwash Deposit in South of Provincial Highway 401											
	100.4	128.0	2.0	11.0	-	-	1.000	2.656	-	-	-
	147.1	170.6	6.0	10.5	22.8	-	0.999	2.664	-	-	-
	-	-	-	-	-	-	0.604	2.681	-	-	11.0
	105.0	127.0	-	12.3	-	8.0	1.040	2.665	-	-	-
	111.9	131.0	5.1	-	-	-	1.330	2.633	-	10.0	-
	-	-	-	-	-	-	-	-	0.278	-	9.0
	-	138.5	-	10.1	-	2.8	1.490	2.637	-	-	-
	-	110.5	-	10.8	-	4.6	1.100	2.652	0.202	-	-
	-	109.4	4.3	10.7	-	-	1.300	-	0.149	-	-
	-	-	4.6	12.6	-	-	1.150	2.650	-	-	-
Minimum	*100.4*	*109.4*	*2.0*	*10.1*	-	*2.8*	*0.604*	*2.633*	*0.149*	-	-
Maximum	*147.1*	*170.6*	*6.0*	*12.6*	-	*8.0*	*1.490*	*2.681*	*0.278*	-	-
Median	*108.5*	*128.0*	*4.6*	*10.8*	-	*4.6*	*1.100*	*2.654*	*0.202*	-	-
Secondary Resource Area - Gravel Outwash Deposit South of Thames River											
	104.0	146.0	2.4	-	29.0	-	1.230	2.640	-	-	-
	103.7	143.0	1.9	-	22.0	-	1.370	2.640	-	-	-
	106.1	129.8	11.0	-	-	-	1.670	2.580	-	-	-
	101.7	132.6	6.0	-	-	-	1.380	2.640	-	-	-
	120.9	175.6	-	-	-	-	1.505	2.631	-	-	16.2
	109.2	130.4	-	15.9	-	9.0	1.671	2.624	-	-	-
	118.2	178.5	-	16.2	-	-	1.505	2.631	-	-	-
Minimum	*101.7*	*129.8*	*1.9*	-	-	-	*1.230*	*2.580*	-	-	-
Maximum	*120.9*	*178.5*	*11.0*	-	-	-	*1.671*	*2.640*	-	-	-
Median	*106.1*	*143.0*	*4.2*	-	-	-	*1.505*	*2.631*	-	-	-
Secondary Resource Area - Ice-Contact Deposit on East Border											
	-	-	-	-	-	-	1.244	2.637	0.289	-	12.7
	-	-	-	-	-	-	1.153	2.633	-	-	12.6
	-	-	-	-	-	-	0.867	2.649	-	-	9.3

Sources: Test results identified with an asterisk (*) have been collected during past OGS or MNRF investigations. All other test results have been obtained from MTO aggregate source files.

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.

Table 10. Results of Till Analysis (Physical Properties), County of Middlesex and the City of London.

Till Unit	Texture			Pebble Lithology						Carbonates		Heavy Minerals		Location (NAD83, Zone 17)		
Sample ID	Clay (%)	Silt (%)	Sand (%)	Limestone (%)	Dolostone (%)	Chert (%)	Sandstone (%)	Shale (%)	Precambrian (%)	Carbonates (%)	Calcite/Dolomite (ratio)	Total (%)	Magnetics (%)	Easting (m)	Northing (m)	Source
Catfish Creek Till																
BH 10003	18	48	34	-	-	-	-	-	-	47.1	0.57	3.9	10.8	486197	4771306	Sado (1980)
BH 11001	13	38	49	-	-	-	-	-	-	45.3	0.70	3.9	9.1	486097	4771000	Sado (1980)
BH 11004.5	12	41	47	-	-	-	-	-	-	48.0	0.78	4.1	9.9	486097	4771000	Sado (1980)
BH 19012	9	46	45	-	-	-	-	-	-	58.4	0.52	-	-	499897	4761200	Sado (1980)
BH 20008	8	44	48	-	-	-	-	-	-	50.3	0.54	2.9	12.7	498295	4760200	Sado (1980)
BH 2005	14	48	38	-	-	-	-	-	-	52.8	0.35	3.6	10.3	488497	4765603	Sado (1980)
BH 21010	17	47	36	-	-	-	-	-	-	59.7	0.45	3.1	12.1	498391	4760396	Sado (1980)
BH 22005	12	41	47	-	-	-	-	-	-	60.3	0.63	2.7	13.2	491100	4756800	Sado (1980)
BH 3010	13	49	38	-	-	-	-	-	-	51.2	0.32	3.7	9.7	490100	4784203	Sado (1980)
BH 8010.5	20	38	42	-	-	-	-	-	-	60.8	2.00	4.2	14.5	486400	4766200	Sado (1980)
BH 9003	11	49	40	-	-	-	-	-	-	49.6	0.50	3.3	9.0	484503	4777497	Sado (1980)
BH 9008	19	48	33	-	-	-	-	-	-	47.6	0.54	3.2	9.7	484503	4777497	Sado (1980)
N 133 C	13	37	50	51	33	4	5	-	7	45.0	0.88	4.6	11.5	486095	4770805	Sado (1980)
N 138 B	5	48	47	-	-	-	-	-	-	45.2	0.67	4.8	11.4	486395	4766405	Sado (1980)
N 94 B	11	54	35	57	24	2	3	-	4	50.8	0.49	2.9	11.8	485595	4772005	Sado (1980)
ST 1 E	11	46	43	41	37	3	-	-	19	54.4	0.68	4.2	11.1	489300	4758500	Sado (1980)
ST 2 B	16	36	48	45	39	4	-	-	12	66.4	0.68	4.0	14.2	489700	4760527	Sado (1980)
T14	10	45	45	57	29	2	1	1	9	43.8	0.69	4.9	11.2	504950	4753007	Barnett (1982a)
T3	11	44	46	38	36	5	-	-	21	32.8	1.17	3.8	11.8	500560	4756804	Barnett (1982a)
Minimum	*5*	*36*	*33*	*38*	*24*	*2*	*1*	-	*4*	*32.8*	*0.32*	*2.7*	*9.0*			
Maximum	*20*	*54*	*50*	*57*	*39*	*5*	*5*	-	*21*	*66.4*	*2.00*	*4.9*	*14.5*			
Average	*13*	*45*	*43*	*48*	*33*	*3*	*3*	-	*12*	*51.0*	*0.69*	*3.8*	*11.3*			
Port Stanley Till																
BH 14003	41	52	7	-	-	-	-	-	-	39.5	1.53	4.3	12.5	501202	4756707	Sado (1980)
BH 7004	15	62	27	-	-	-	-	-	-	30.7	1.01	4.5	14.5	484800	4765200	Sado (1980)
BH 7004.5	23	50	37	-	-	-	-	-	-	28.6	0.96	5.0	11.1	484800	4765200	Sado (1980)
ST 1 A	35	60	5	-	-	-	-	-	-	52.7	0.60	3.9	12.0	489300	4758500	Sado (1980)
ST 1 B	36	49	15	-	-	-	-	-	-	45.8	0.80	3.7	11.0	489300	4758500	Sado (1980)
T16	38	54	9	-	-	-	-	-	-	37.9	1.71	4.2	14.0	504680	4757539	Barnett (1982a)
T17	39	52	9	65	18	9	-	2	6	37.5	1.36	4.8	16.0	501235	4756803	Barnett (1982a)
T20	30	51	20	-	-	-	-	-	-	38.6	1.13	4.8	14.8	502950	4751322	Barnett (1982a)
Minimum	*15*	*49*	*5*	-	-	-	-	-	-	*28.6*	*0.60*	*3.7*	*11.0*			
Maximum	*41*	*62*	*37*	-	-	-	-	-	-	*52.7*	*1.71*	*5.0*	*16.0*			
Average	*32*	*54*	*16*	-	-	-	-	-	-	*38.9*	*1.14*	*4.4*	*13.2*			

	Texture			Pebble Lithology						Carbonates		Heavy Minerals		Location (NAD83, Zone 17)		
Till Unit **Sample ID**	**Clay (%)**	**Silt (%)**	**Sand (%)**	**Limestone (%)**	**Dolostone (%)**	**Chert (%)**	**Sandstone (%)**	**Shale (%)**	**Precambrian (%)**	**Carbonates (%)**	**Calcite/Dolomite (ratio)**	**Total (%)**	**Magnetics (%)**	**Easting (m)**	**Northing (m)**	**Source**
Tavistock Till																
BH 12004	38	38	24	-	-	-	-	-	-	44.1	1.26	5.3	12.3	475200	4762600	Sado (1980)
BH 12006	18	39	43	-	-	-	-	-	-	45.2	1.04	4.6	11.2	475200	4762600	Sado (1980)
BH 12008	17	41	42	-	-	-	-	-	-	48.9	1.13	4.7	11.4	475200	4762600	Sado (1980)
BH 14007	17	60	23	-	-	-	-	-	-	44.4	0.69	4.6	16.8	501201	4756706	Sado (1980)
BH 19001	10	48	42	-	-	-	-	-	-	41.9	1.03	-	-	499897	4761200	Sado (1980)
BH 19002	15	47	38	-	-	-	-	-	-	44.5	0.80	-	-	499897	4761200	Sado (1980)
BH 20001	13	46	41	-	-	-	-	-	-	44.7	0.68	2.8	10.1	498295	4760200	Sado (1980)
BH 2002	18	50	32	-	-	-	-	-	-	41.8	0.78	4.5	10.3	488497	4765603	Sado (1980)
BH 2004	21	46	33	-	-	-	-	-	-	44.9	0.73	4.5	11.5	488497	4765603	Sado (1980)
BH 21001	12	51	37	-	-	-	-	-	-	46.7	0.69	2.2	9.6	498391	4760396	Sado (1980)
BH 22002	14	49	37	-	-	-	-	-	-	41.1	0.49	2.4	11.1	491100	4756800	Sado (1980)
BH 3002	28	46	26	-	-	-	-	-	-	46.7	0.97	4.4	10.7	490100	4784200	Sado (1980)
BH 8001	27	45	28	-	-	-	-	-	-	26.7	0.87	4.0	10.5	486400	4766200	Sado (1980)
BH 8003	29	47	24	-	-	-	-	-	-	38.0	0.90	4.6	10.4	486400	4766200	Sado (1980)
BH 8005	13	55	32	-	-	-	-	-	-	45.6	0.73	3.7	9.6	486400	4766200	Sado (1980)
BH 9001	26	50	24	-	-	-	-	-	-	31.8	0.52	4.1	13.7	484503	4777497	Sado (1980)
E 612	31	53	16	-	-	-	-	-	-	31.7	0.83	5.0	9.0	485900	4771400	Sado (1980)
E 638	20	52	28	-	-	-	-	-	-	43.5	1.10	4.5	9.3	489000	4772703	Sado (1980)
E 661	22	59	19	-	-	-	-	-	-	38.3	0.90	3.8	9.0	493800	4771200	Sado (1980)
E 962	25	49	26	-	-	-	-	-	-	45.7	1.29	2.3	8.2	487297	4783000	Sado (1980)
J 546	22	56	22	-	-	-	-	-	-	41.0	0.76	4.0	10.3	493897	4769400	Sado (1980)
LS-10 B	27	44	29	53	32	3	-	2	10	38.6	1.51	4.9	10.9	484300	4765302	Sado (1980)
LS-9 A	21	60	19	55	32	3	-	-	10	39.2	1.27	4.5	8.2	475200	4762709	Sado (1980)
LS-9 B	27	51	22	47	36	5	-	1	11	43.2	1.26	5.0	9.6	475200	4762708	Sado (1980)
N 133 A	22	61	17	-	-	-	-	-	-	37.2	1.45	5.4	12.8	486095	4770805	Sado (1980)
N 134	15	53	32	40	30	-	1	-	29	49.2	0.37	3.4	11.4	486105	4770905	Sado (1980)
N 138 A	22	57	21	-	-	-	-	-	-	42.7	1.36	5.6	12.5	486395	4766405	Sado (1980)
N 139	17	65	18	53	25	-	1	-	19	41.3	0.80	4.0	14.4	491195	4756800	Sado (1980)
N 34 A	20	47	33	-	-	-	-	-	-	38.8	0.97	4.7	12.0	491400	4770305	Sado (1980)
N 76 A	31	54	15	63	13		11	-	13	25.5	0.80	4.7	16.9	482600	4783700	Sado (1980)
N 76 B	25	63	12	78	6	2	2	2	11	44.2	1.30	3.8	12.7	482600	4783700	Sado (1980)
N 85	26	55	22	-	-	-	-	-	1	44.9	1.14	4.6	12.4	481200	4764005	Sado (1980)
N 90 A	32	58	20	-	-	-	-	-	-	44.4	0.62	3.8	12.5	485500	4774205	Sado (1980)
N 90 B	22	53	25	58	19	3	7	-	13	44.2	0.87	3.3	11.9	485500	4774205	Sado (1980)
N 94 A	23	49	28	59	18	1	-	-	22	43.2	0.95	4.1	12.7	485595	4772005	Sado (1980)
S 608	25	49	26	-	-	-	-	-	-	37.7	1.28	2.6	7.9	477700	4775506	Sado (1980)
S 610	5	48	47	-	-	-	-	-	-	38.5	0.69	7.8	10.5	494300	4772800	Sado (1980)
S 613	32	47	21	-	-	-	-	-	-	39.0	0.86	3.6	8.2	480994	4767000	Sado (1980)
S 615	20	44	36	-	-	-	-	-	-	18.9	0.67	7.7	9.1	483994	4760994	Sado (1980)
S 617	17	63	20	-	-	-	-	-	-	37.6	0.98	4.2	11.5	490100	4761400	Sado (1980)

Till Unit	Texture			Pebble Lithology						Carbonates		Heavy Minerals		Location (NAD83, Zone 17)		
Sample ID	**Clay (%)**	**Silt (%)**	**Sand (%)**	**Limestone (%)**	**Dolostone (%)**	**Chert (%)**	**Sandstone (%)**	**Shale (%)**	**Precambrian (%)**	**Carbonates (%)**	**Calcite/Dolomite (ratio)**	**Total (%)**	**Magnetics (%)**	**Easting (m)**	**Northing (m)**	**Source**
ST 1 D	21	54	25	54	27	2	-	-	17	40.1	1.20	-	-	489300	4758500	Sado (1980)
ST 2 A	18	52	30	47	36	3	-	-	14	40.4	1.00	-	-	489700	4760527	Sado (1980)
T 1 10	23	48	29	52	35	2	-	1	10	48.3	2.60	-	-	501199	4756699	Sado (1980)
V 137	13	43	44	-	-	-	-	-	-	47.5	0.61	3.2	9.2	484500	4780604	Sado (1980)
V 276	15	61	24	-	-	-	-	-	-	37.8	0.88	3.8	7.6	496600	4762304	Sado (1980)
BH 20006	16	45	39	-	-	-	-	-	-	45.1	0.77	3.0	8.7	498295	4760200	Sado (1980)
BH 3009	29	39	32	-	-	-	-	-	-	48.2	1.02	4.6	10.9	490100	4784200	Sado (1980)
LS-10 A	12	45	43	41	38	6	2	-	13	42.2	0.86	5.2	10.9	484300	4765302	Sado (1980)
Minimum	*5*	*38*	*12*	*40*	*6*	*1*	*1*	*1*	*1*	*18.9*	*0.37*	*2.2*	*7.6*			
Maximum	*38*	*65*	*47*	*78*	*38*	*6*	*11*	*2*	*29*	*49.2*	*2.60*	*7.8*	*16.9*			
Average	*21*	*51*	*28*	*54*	*27*	*3*	*4*	*2*	*14*	*41.1*	*0.96*	*4.3*	*10.9*			
Rannoch Till																
2468A	41	40	19	-	-	-	-	-	-	52.5	1.60	2.2	10.5	457888	4784687	Cooper (1979)
3050C	29	43	28	-	-	-	-	-	-	63.2	1.60	2.3	9.5	457688	4784205	Cooper (1979)
3050I	30	67	3	-	-	-	-	-	-	56.6	0.60	2.1	16.7	457688	4784205	Cooper (1979)
3050J	38	43	19	-	-	-	-	-	-	55.5	1.60	1.7	6.3	457688	4784205	Cooper (1979)
3050L	41	47	12	-	-	-	-	-	-	55.4	1.50	2.2	16.4	457688	4784205	Cooper (1979)
3078	42	49	9	-	-	-	-	-	-	47.1	1.80	2.9	4.7	457841	4782128	Cooper (1979)
3133	44	50	6	-	-	-	-	-	-	44.0	1.50	3.2	7.7	456783	4777871	Cooper (1979)
3370A	36	45	19	-	-	-	-	-	-	54.2	1.60	2.4	9.3	457775	4783698	Cooper (1979)
993	39	51	10	-	-	-	-	-	-	53.3	1.30	1.7	4.5	458236	4788368	Cooper (1979)
A 841	37	52	11	-	-	-	-	-	-	46.2	1.76	2.1	11.5	467700	4763110	Sado (1980)
BH 5010	31	49	20	-	-	-	-	-	-	60.1	1.28	2.3	5.9	471203	4778903	Sado (1980)
BH 6007	38	52	10	-	-	-	-	-	-	53.9	0.95	2.8	11.8	463797	4772100	Sado (1980)
E 901 A	29	53	18	-	-	-	-	-	-	54.9	1.14	2.5	10.6	467300	4785200	Sado (1980)
E 901 B	22	60	18	-	-	-	-	-	-	51.5	0.81	2.1	8.1	467297	4785200	Sado (1980)
J 576	33	49	18	-	-	-	-	-	-	53.6	1.21	2.0	10.3	465497	4768003	Sado (1980)
J 941	11	34	55	-	-	-	-	-	-	44.6	0.61	3.4	9.7	463569	4780900	Sado (1980)
J 964	43	47	10	-	-	-	-	-	-	45.9	1.09	2.3	13.0	464900	4782900	Sado (1980)
LS-11 A	39	55	6	88	7	1	1	1	2	42.2	1.43	2.3	8.9	461500	4765602	Sado (1980)
LS-11 C	41	55	8	91	3	1	1	-	4	40.2	1.39	3.7	11.6	461500	4765602	Sado (1980)
N 10	42	48	10	-	-	-	-	-	-	51.0	1.58	2.1	8.3	469194	4778502	Sado (1980)
N 11	20	45	35	-	-	-	-	-	-	56.5	1.38	2.9	8.8	472300	4779700	Sado (1980)
N 135	35	58	7	-	-	-	-	-	-	47.7	0.96	1.8	10.3	461895	4765205	Sado (1980)
N 136	39	48	13	78	6	1	5	-	10	32.2	1.33	3.4	9.6	463700	4771400	Sado (1980)
N 137	37	45	18	-	-	-	-	-	-	47.5	0.97	2.6	9.6	464095	4777500	Sado (1980)
N 79	38	52	12	96	3	-	-	-	1	54.9	1.46	2.1	8.3	470700	4789900	Sado (1980)
N 95	35	54	11	83	9	2	6	-		40.5	0.53	2.8	16.2	477400	4785700	Sado (1980)
N 98	33	58	9	98	1	-	-	-	1	47.5	1.99	1.8	15.0	462700	4780405	Sado (1980)
N 99	29	57	14	91	2	-	-	5	2	54.0	1.08	2.0	8.8	477300	4782600	Sado (1980)
R 331	25	48	27	-	-	-	-	-	-	50.4	1.63	2.7	4.4	471295	4764895	Sado (1980)
R 332	27	53	20	-	-	-	-	-	-	46.4	1.38	2.2	9.8	465795	4762000	Sado (1980)

Till Unit Sample ID	Texture			Pebble Lithology						Carbonates		Heavy Minerals		Location (NAD83, Zone 17)		Source
	Clay (%)	Silt (%)	Sand (%)	Limestone (%)	Dolostone (%)	Chert (%)	Sandstone (%)	Shale (%)	Precambrian (%)	Carbonates (%)	Calcite/Dolomite (ratio)	Total (%)	Magnetics (%)	Easting (m)	Northing (m)	
R 334 B	25	51	24	-	-	-	-	-	-	50.8	1.40	2.6	6.7	459795	4763105	Sado (1980)
S 165	30	50	20	-	-	-	-	-	-	51.7	1.27	2.1	10.5	467095	4767995	Sado (1980)
S 604	37	50	13	-	-	-	-	-	-	51.2	1.23	1.0	15.4	469093	4771103	Sado (1980)
S 605	40	52	8	-	-	-	-	-	-	45.3	1.65	2.1	8.1	464600	4776806	Sado (1980)
S 606	34	47	19	-	-	-	-	-	-	49.4	1.15	1.2	12.0	470800	4783800	Sado (1980)
S 607	28	48	24	-	-	-	-	-	-	47.0	1.36	1.1	12.9	474200	4782106	Sado (1980)
BH 5013	37	57	6	-	-	-	-	-	-	56.6	0.86	1.9	12.5	471203	4778903	Sado (1980)
Minimum	*11*	*34*	*3*	*78*	*1*	*1*	*1*	*1*	*1*	*32.2*	*0.53*	*1.0*	*4.4*			
Maximum	*44*	*67*	*55*	*98*	*9*	*2*	*6*	*5*	*10*	*63.2*	*1.99*	*3.7*	*16.7*			
Average	*34*	*50*	*16*	*89*	*4*	*1*	*3*	*3*	*3*	*50.1*	*1.30*	*2.3*	*10.1*			
"southern till"																
2324	46	49	5	-	-	-	-	-	-	44.2	1.10	3.1	2.4	448864	4779190	Cooper (1979)
2468B	47	50	3	-	-	-	-	-	-	46.7	1.00	3.4	5.6	457888	4784687	Cooper (1979)
2574	50	47	3	-	-	-	-	-	-	40.4	1.30	3.3	5.9	455287	4775511	Cooper (1979)
2682	44	41	15	-	-	-	-	-	-	36.4	1.00	3.8	8.1	442850	4767012	Cooper (1979)
2683	39	53	8	-	-	-	-	-	-	37.0	0.90	3.4	7.3	442449	4767030	Cooper (1979)
2700	45	51	7	-	-	-	-	-	-	35.2	1.00	3.8	6.3	442307	4769310	Cooper (1979)
2705	46	48	6	-	-	-	-	-	-	36.6	1.00	3.5	5.7	441086	4768740	Cooper (1979)
2710A	30	61	9	-	-	-	-	-	-	41.1	0.80	3.8	4.8	440997	4770406	Cooper (1979)
3015A	37	50	13	-	-	-	-	-	-	46.8	1.80	1.8	6.5	457318	4779386	Cooper (1979)
3015B	45	51	4	-	-	-	-	-	-	44.4	1.50	2.2	8.3	457318	4779386	Cooper (1979)
3016A	40	54	6	-	-	-	-	-	-	43.9	1.30	2.7	5.3	455634	4777756	Cooper (1979)
3016B	47	49	4	-	-	-	-	-	-	40.4	1.60	2.3	12.5	455634	4777756	Cooper (1979)
3370B	46	51	3	-	-	-	-	-	-	43.9	1.10	2.9	8.7	457775	4783698	Cooper (1979)
3793	44	53	3	-	-	-	-	-	-	40.5	1.60	2.3	10.0	455732	4772241	Cooper (1979)
3801	43	54	3	-	-	-	-	-	-	40.9	1.80	2.2	8.8	456347	4770561	Cooper (1979)
3824A	42	55	3	-	-	-	-	-	-	41.3	1.40	2.2	11.5	452650	4767787	Cooper (1979)
3824B	41	56	3	-	-	-	-	-	-	42.3	1.50	2.4	12.0	452650	4767787	Cooper (1979)
3842A	47	50	3	-	-	-	-	-	-	38.4	1.30	3.1	8.6	447937	4769497	Cooper (1979)
3842B	45	53	2	-	-	-	-	-	-	35.7	1.30	3.6	9.1	447937	4769497	Cooper (1979)
3842C	44	51	5	-	-	-	-	-	-	37.3	1.10	3.4	6.7	447937	4769497	Cooper (1979)
3842D	46	51	3	-	-	-	-	-	-	36.3	1.00	3.5	5.6	447937	4769497	Cooper (1979)
3842E	46	50	4	-	-	-	-	-	-	35.9	1.10	3.7	6.7	447937	4769497	Cooper (1979)
3842F	42	54	4	-	-	-	-	-	-	36.2	1.10	3.6	7.1	447937	4769497	Cooper (1979)
3842G	47	49	4	-	-	-	-	-	-	36.0	1.20	3.5	8.5	447937	4769497	Cooper (1979)
3842H	46	50	4	-	-	-	-	-	-	37.4	1.10	3.2	8.1	447937	4769497	Cooper (1979)
3842I	45	51	4	-	-	-	-	-	-	34.2	1.50	3.5	11.5	447937	4769497	Cooper (1979)
3842J	46	50	4	-	-	-	-	-	-	36.8	1.00	3.3	6.5	447937	4769497	Cooper (1979)
3842K	45	51	4	-	-	-	-	-	-	36.3	0.90	3.2	4.9	447937	4769497	Cooper (1979)
3842L	46	50	4	-	-	-	-	-	-	37.6	1.20	2.3	8.6	447937	4769497	Cooper (1979)
3885	33	57	10	-	-	-	-	-	-	53.3	1.80	2.3	16.4	452579	4772375	Cooper (1979)

Till Unit Sample ID	Texture			Pebble Lithology						Carbonates		Heavy Minerals		Location (NAD83, Zone 17)		Source
	Clay (%)	Silt (%)	Sand (%)	Limestone (%)	Dolostone (%)	Chert (%)	Sandstone (%)	Shale (%)	Precambrian (%)	Carbonates (%)	Calcite/Dolomite (ratio)	Total (%)	Magnetics (%)	Easting (m)	Northing (m)	
3902	33	61	4	-	-	-	-	-	-	31.7	1.10	3.4	8.9	446948	4769524	Cooper (1979)
4639A	36	57	7	-	-	-	-	-	-	34.5	1.30	2.9	5.8	440890	4764562	Cooper (1979)
4639B	30	60	10	-	-	-	-	-	-	38.5	1.00	2.9	5.9	440890	4764562	Cooper (1979)
4639C	39	56	5	-	-	-	-	-	-	39.2	1.20	2.9	7.7	440890	4764562	Cooper (1979)
4639D	43	53	4	-	-	-	-	-	-	37.5	1.00	2.7	7.3	440890	4764562	Cooper (1979)
4752	39	53	7	-	-	-	-	-	-	38.5	0.90	3.0	6.3	441398	4766691	Cooper (1979)
988	43	54	3	-	-	-	-	-	-	50.2	0.70	3.8	10.0	457187	4788027	Cooper (1979)
BH 6002	44	48	8	-	-	-	-	-	-	43.0	1.28	2.8	0.0	463797	4772100	Sado (1980)
BH 6004	45	48	7	-	-	-	-	-	-	44.8	1.89	2.8	8.7	463797	4772100	Sado (1980)
E 867	43	51	6	-	-	-	-	-	-	45.6	1.19			458697	4772803	Sado (1980)
LS-11 B	44	53	3	-	-	-	-	-	-	41.4	1.76	3.5	8.9	461500	4765602	Sado (1980)
N 69 A	41	51	8	-	-	-	-	-	-	29.6	1.69	2.6	7.3	461500	4765600	Sado (1980)
N 69 B	45	50	5	-	-	-	-	-	-	40.9	1.23	2.5	8.6	461500	4765600	Sado (1980)
Minimum	*30*	*41*	*2*	-	-	-	-	-	-	*29.6*	*0.70*	*1.8*	*0.0*			
Maximum	*50*	*61*	*15*	-	-	-	-	-	-	*53.3*	*1.89*	*3.8*	*16.4*			
Average	*43*	*52*	*5*	-	-	-	-	-	-	*39.7*	*1.25*	*3.0*	*7.7*			
St. Joseph Till																
2127	43	41	16	-	-	-	-	-	-	43.4	0.50	1.6	7.1	451173	4785201	Cooper (1979)
2170	47	44	9	-	-	-	-	-	-	38.9	0.60	2.2	11.5	451474	4783992	Cooper (1979)
2234	40	48	12	-	-	-	-	-	-	43.7	0.50	1.8	13.3	448514	4784960	Cooper (1979)
2315	45	49	6	-	-	-	-	-	-	37.1	0.80	2.4	7.7	444632	4780925	Cooper (1979)
2368	43	43	14	-	-	-	-	-	-	41.4	0.70	1.5	12.5	441144	4780925	Cooper (1979)
2422B	42	47	11	-	-	-	-	-	-	38.9	0.50	1.8	13.3	446601	4779644	Cooper (1979)
2525	38	45	17	-	-	-	-	-	-	43.4	0.50	1.5	14.6	451307	4780811	Cooper (1979)
2710B	37	47	16	-	-	-	-	-	-	42.7	0.40	1.7	10.5	440997	4770406	Cooper (1979)
2747	42	47	11	-	-	-	-	-	-	43.0	0.50	1.4	8.7	441158	4773221	Cooper (1979)
2892	43	44	19	-	-	-	-	-	-	42.7	0.40	1.6	7.1	438815	4777275	Cooper (1979)
3016C	40	52	8	-	-	-	-	-	-	40.5	0.50	1.5	11.8	455634	4777756	Cooper (1979)
3016D	39	51	4	-	-	-	-	-	-	39.8	0.50	1.2	16.7	455634	4777756	Cooper (1979)
4015	39	51	10	-	-	-	-	-	-	44.4	0.60	1.9	10.7	451487	4783310	Cooper (1979)
4329	44	45	11	-	-	-	-	-	-	38.4	0.40	1.3	21.1	436062	4776517	Cooper (1979)
784	40	43	17	-	-	-	-	-	-	49.3	0.50	1.2	19.2	439897	4786895	Cooper (1979)
791	42	44	14	-	-	-	-	-	-	49.5	0.30	1.3	14.3	441441	4784433	Cooper (1979)
800	45	45	10	-	-	-	-	-	-	44.6	0.60	1.4	13.6	440904	4781339	Cooper (1979)
805	33	49	18	-	-	-	-	-	-	44.1	0.40	1.2	18.2	439507	4781306	Cooper (1979)
859	23	53	24	-	-	-	-	-	-	51.7	0.30	1.2	15.8	437320	4785339	Cooper (1979)
935	19	49	32	-	-	-	-	-	-	58.2	0.40	1.0	14.6	439129	4785940	Cooper (1979)
Minimum	*19*	*41*	*4*	-	-	-	-	-	-	*37.1*	*0.30*	*1.0*	*7.1*			
Maximum	*47*	*53*	*32*	-	-	-	-	-	-	*58.2*	*0.80*	*2.4*	*21.1*			
Average	*39*	*47*	*14*	-	-	-	-	-	-	*43.8*	*0.50*	*1.5*	*13.1*			

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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 541 and 485 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 419 and 359 million years ago, following the Silurian Period. Rocks formed in the Devonian Period are among the youngest Paleozoic rocks in Ontario.

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

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

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

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

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

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

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

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

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

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

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

Heavy Duty Binder: Second layer from the top of hot mix asphalt (HMA) 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 Mix Asphalt (HMA) 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. (For more specific information, refer to Ontario Provincial Standard Specification (OPSS) 1003 and Appendix E.)

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 485 and 444 million years ago.

Paleozoic: One of the major divisions of the geologic time scale thought to have covered the time period between 541 and 252 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 (at 541 million years).

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 444 and 419 million years ago. The Silurian follows the Ordovician Period and precedes the Devonian Period.

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

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

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

Appendix C – Geology of Sand and Gravel Deposits

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

GLACIOFLUVIAL DEPOSITS

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

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

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

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

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

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

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

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

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

GLACIOLACUSTRINE DEPOSITS

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

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

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

GLACIOMARINE DEPOSITS

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

Glaciomarine Deltas (MD): Similar to glaciolacustrine deltas, glaciomarine delta 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 Ministry of Transportation (MTO). Aggregate suitability tests are defined in Appendix E. Aggregate product specifications are also provided in Appendix E.

Covey Hill Formation (Cambrian)

STRATIGRAPHY and/or OCCURRENCE: Lower formation of the Potsdam Group.

LITHOLOGY: Interbedded noncalcareous feldspathic conglomerate and sandstone.

THICKNESS: 0 to 14 m.

USES: Has been quarried for aggregate in the United Counties of Leeds and Grenville.

Nepean Formation (Cambrian)

STRATIGRAPHY and/or OCCURRENCE: Upper formation of the Potsdam Group.

LITHOLOGY: Thin- to massive-bedded quartz sandstone with some conglomerate interbeds and rare shaly partings.

THICKNESS: 0 to 30 m.

USES: Suitable as dimension stone; quarried at Philipsville and Forfar for silica sand; alkali–silica reactive in Portland cement concrete.

AGGREGATE SUITABILITY TESTING: PSV = 54-68, AAV = 4-15, $MgSO_4$ = 9-32, LA = 44-90, Absn = 1.6-2.6, BRD = 2.38-2.50, PN (A-C) = 130-140.

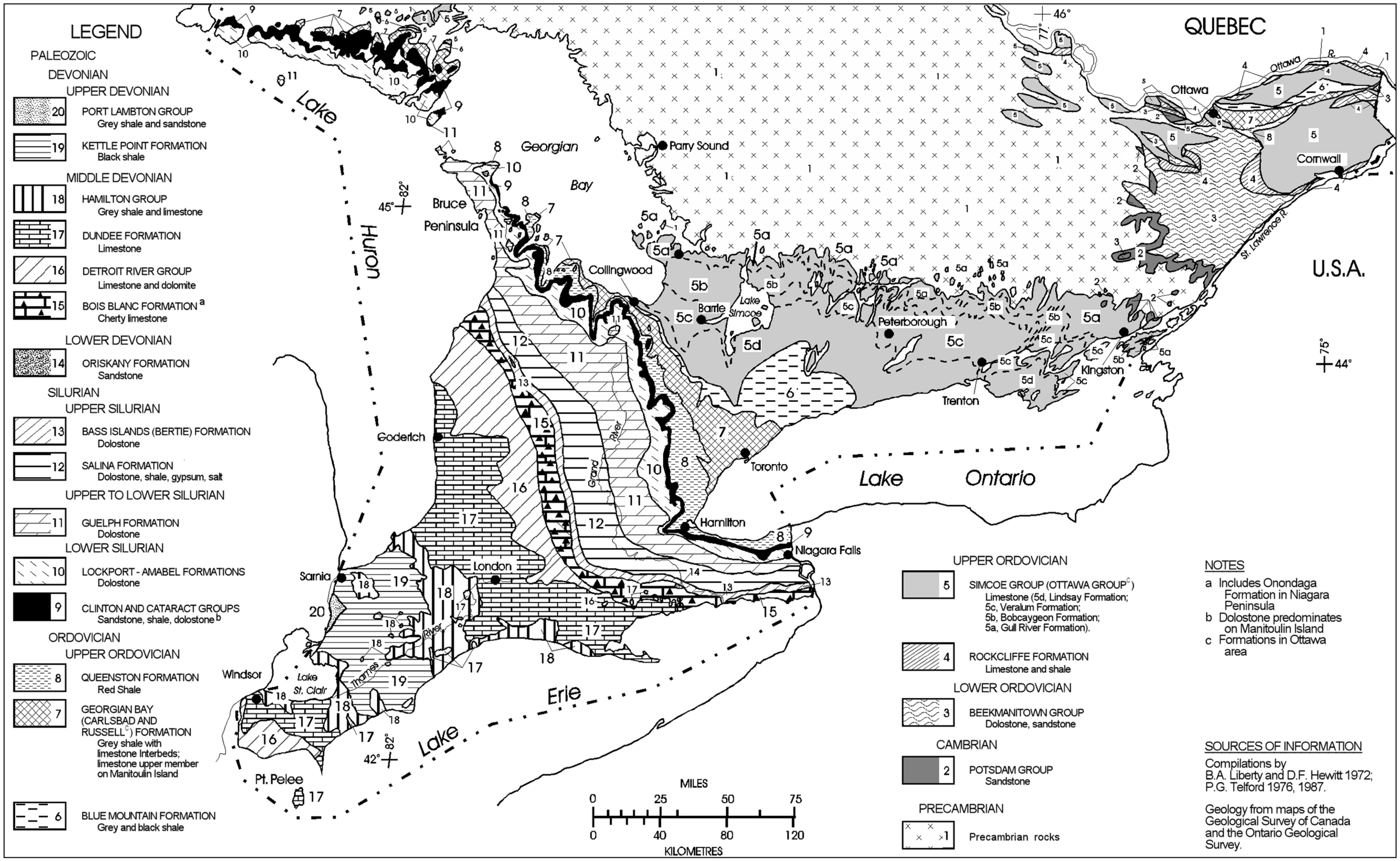

Figure D1. Bedrock geology of southern Ontario.

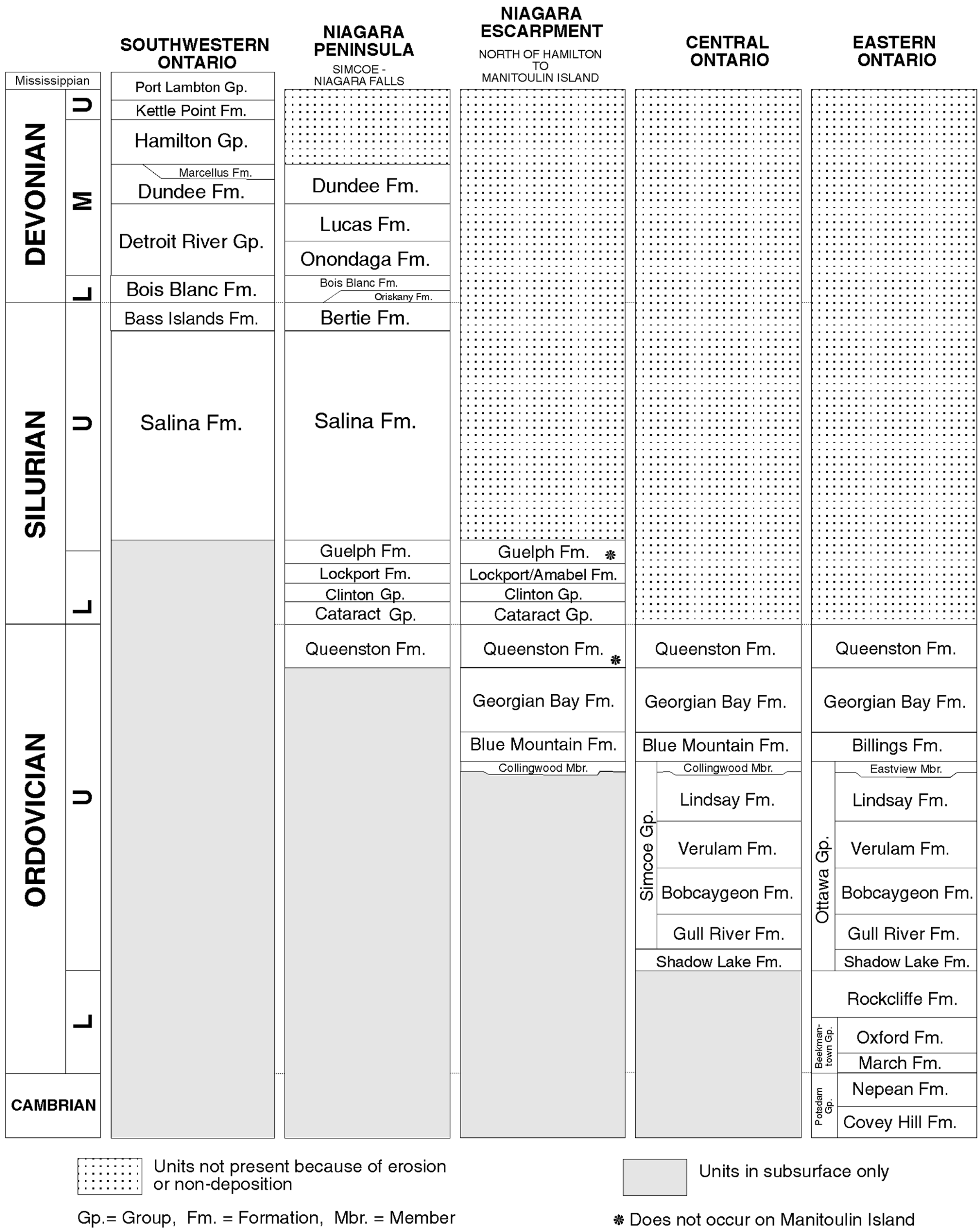

Figure D2. Exposed Paleozoic stratigraphic sequences in southern Ontario (*adapted from* Bezys and Johnson 1988 and Armstrong and Dodge 2007).

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.

Appendix E – Aggregate Quality Test Specifications

Aggregate quality tests are performed by the Ministry of Transportation (MTO), or by laboratories approved by 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 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.

Acid Insoluble Residue (LS-613): This test measures the percentage of insoluble residue in carbonate aggregate by using a hydrochloric acid (HCl) solution to dissolve the carbonate minerals. The amount and size distribution of insoluble material in carbonate aggregate is of interest when conducting investigation on the frictional properties of pavement. This test helps to distinguish those carbonate aggregates that may polish excessively and become slippery, from those that will not.

Aggregate Abrasion Value (AAV) (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 AAV (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) (LS-604 or ASTM C29): An aggregate with low relative density is lighter in weight than one with a high relative density. Low relative-density aggregates (< ~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 A	Granular B (Type I and Type III)	Granular B (Type II)	Granular M	Granular O	Select Subgrade Material
LS-607	Crushed Particles (% minimum)	60	—	100	60	100	—
LS-617	Crushed Faces, 2 or more (% minimum)	—	—	—	—	85	—
LS-614	Unconfined Freeze–Thaw Loss (% maximum)	—	—	—	—	15	—
LS-618	Micro-Deval Abrasion Loss, Coarse Aggregate (% maximum loss)	25	30 *[Note 1]*	30	25	21	30 *[Note 1]*
LS-619	Micro-Deval Abrasion Loss, Fine Aggregate (% maximum loss)	30	35	35	30	25	—
LS-630	Amount of Contamination	*[Note 2]*					
LS-631	Plastic Fines	None Permitted (non-plastic)					
LS-709	Determination of Permeability (*k*)	*[Note 3]*					

Note 1. 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 2. Granular A, B Type I, B Type III, or M may contain up to 15% by mass crushed glass or ceramic material or both. Granular A, O, B Type I, B Type III and M shall not contain more than 1.0% by mass of any combination of wood, clay brick, gypsum, gypsum wall board or plaster. Granular B Type II and SSM shall not contain more than 0.1% by mass of wood.

Note 3. For materials north of the French River and Mattawa River only: the coefficient of permeability, k, shall be greater than 1.0×10^{-4} cm/s or, alternatively, when past field experience has demonstrated satisfactory performance. Prior data demonstrating compliance with this requirement for k shall be acceptable provided such testing has been done within 5 years of the material being used and field performance has continually been shown to be satisfactory.

Greater detail, additional specifications and other aggregate product information can be obtained from the Ministry of Transportation. Details above are derived from OPS.PROV 1010 (April 2013).

MATERIAL SPECIFICATIONS FOR AGGREGATES: HOT MIX ASPHALT (HMA), SUPERPAVE™ AND STONE MASTIC ASPHALT (SMA) PRODUCTS

Table E2. Physical Property Requirements for Hot Mix Asphalt (HMA) Coarse Aggregate for Surface Course: Stone Mastic Asphalt (SMA) 9.5 and 12.5; and 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 9.5 and 12.5; and 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, Guideline B (% maximum loss)	1.3 *[Note 4]*	1.0	1.0	1.0	1.0
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 Part A	Petrographic Number (HMA) (maximum)	*[Note 5]*	120	145	120	145
LS-613	Acid Insoluble Residue Retained, 75 µm sieve (% minimum)	—	—	45	—	—
LS-614	Unconfined Freeze–Thaw Loss (% maximum loss)	6 *[Note 6]*	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 6]*	—	—	—	—

General Note:

- Percent fractured particles (i.e., crushed particles) in coarse aggregate ranges from 0 to 100% depending on the traffic category assigned to the road. Refer to OPSS.PROV 1003 for further details.

Note 4. When quarried rock is used as a source of coarse aggregate, a maximum of 2.0% passing the 75 µm sieve shall be permitted.

Note 5. The requirements listed below are only applicable for surface courses placed in the Thousand Islands Parkway; Highway 33 from west of Bath to Picton; Highway 35 from County Road 121 northerly to Norland; and in the area to the north and west of a boundary defined 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.

a) 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 types (e.g., limestone, dolostone, etc.), then blending with aggregate from non-carbonate rock types shall be required to increase the minimum non-carbonate rock type content of the coarse aggregate to 60%, as determined by petrographic examination (LS-609). In cases of dispute, LS-613 shall be used with a minimum acid insoluble residue of 60%. The method used for blending shall produce a uniform blend and be subject to approval by the Owner.

b) When the coarse aggregate for use in a surface course mix is obtained from a non-carbonate source, blending with carbonate rock types is not permitted.

Note 6. For Superpave™ 9.5 and 12.5, the Owner shall waive the requirements for LS-614, Unconfined Freeze–Thaw Loss, provided the Contractor has submitted a written request that the coarse aggregate meets the alternative requirements for LS-606, Magnesium Sulphate Soundness Loss.

Table E3. Physical Property Requirements for HMA Coarse Aggregate for Binder Course: SMA 19.0; and Superpave™ 9.5, 12.5, 19.0, 25.0 and 37.5.

MTO Test Number	Laboratory Test	SMA 19.0; and Superpave™ 9.5, 12.5, 19.0, 25.0 and 37.5
LS-601	Wash Pass, 75 µm sieve, Guideline B (% maximum loss)	1.3 *[Note 7]*
LS-604	Absorption (% maximum)	2.0
LS-608	Flat and Elongated Particles (% maximum (4:1))	20
LS-614	Unconfined Freeze–Thaw Loss (% maximum loss) *[Note 8]*	15
LS-618	Micro-Deval Abrasion Loss (% maximum loss)	21
Alternative Requirement for LS-614		
LS-606	Magnesium Sulphate Soundness Loss (% maximum loss)	15

General Note:

- Percent fractured particles (i.e., crushed particles) in coarse aggregate ranges from 0 to 100% depending on the traffic category assigned to the road. Refer to OPSS.PROV 1003 for further details.

Note 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.

Note 8. The Owner shall waive the requirements for LS-614, Unconfined Freeze–Thaw Loss, provided the Contractor has submitted a written request that the coarse aggregate meets the alternative requirements for LS-606, Magnesium Sulphate Soundness Loss.

Table E4. Physical Property Requirements for HMA Fine Aggregate:
SMA 19.0 and 12.5; and Superpave™ 9.5, 12.5, 12.5 FC1, 12.5 FC2, 19.0, 25.0 and 37.5.

MTO Test Number	**Laboratory Test**	**SMA 19.0 and 12.5; and, Superpave™ 12.5 FC2**	**Superpave™ 12.5 FC1**	**SMA 19.0; and Superpave™ 9.5, 12.5, 19.0, 25.0 and 37.5**
LS-613	Acid Insoluble Residue for retained 2.36 mm fraction (% minimum retained on 75 µm sieve)	—	—	60 *[Note 9]*
LS-619	Micro-Deval Abrasion Loss (% maximum loss) *[Note 10]*	15	20	25
LS-631	Plastic Fines	None Permitted (non-plastic)		

Note 9. The requirements listed below are only applicable for surface courses placed in the Thousand Islands Parkway; Highway 33 from west of Bath to Picton; Highway 35 from County Road 121 northerly to Norland; and in the area to the north and west of a boundary defined 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.

a) When the fine aggregate for use in a surface course mix is obtained from a gravel pit or quarry which contains any carbonate rock types (e.g., limestone, dolostone, etc.), then blending with aggregate from non-carbonate rock types shall be required to increase the acid insoluble residue to meet the minimum 60% requirement for the fraction retained on the 2.36 mm sieve. The method used for blending shall produce a uniform blend and be subject to approval by the Owner.

b) When the fine aggregate for use in a surface course mix is obtained from a non-carbonate gravel or quarry source, blending with carbonate rock types is not permitted.

Note 10. When the blending method option has been selected, this requirement applies to the total fine aggregate blend. In addition, when the blending method option has been selected, the micro-Deval abrasion loss for 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 OPS.PROV 1003 (April 2013).

MATERIAL SPECIFICATIONS FOR AGGREGATES: CONCRETE PRODUCTS

Table E5. Physical Property Requirements for Coarse Aggregate.

MTO or CSA Test Number	Laboratory Test	Acceptance Requirements *[Note 11]*	
		Pavement	Structures, Sidewalk, Curb and Gutter, and Concrete Base
LS-601	Wash Pass, 75 µm sieve, Guideline A (% maximum loss) • 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 *[Note 12]*
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 13]*	6	6
LS-618 or CSA A23.2-29A	Micro-Deval Abrasion Loss (% maximum loss)	14	17 *[Note 12]*
LS-620 or CSA A23.2-25A	Accelerated Mortar Bar Expansion (% maximum at 14 days) *[Note 14, Note 15]*	0.150 *[Note 16]*	0.150 *[Note 16]*
CSA A23.2-14A	Concrete Prism Expansion (% maximum at 1 year) *[Note 14, Note 17]*	0.040	0.040
CSA A23.2-26A	Potential Alkali–Carbonate Reactivity of Quarried Carbonate Rock *[Note 18]*	Chemical composition must plot in the non-expansive field of a specific figure used with test	
Alternative Requirement for LS-614			
LS-606	Magnesium Sulphate Soundness Loss, 5 cycles (% maximum loss) *[Note 13]*	12	12

Note 11. When a concrete surface is subject to vehicular traffic, the physical requirements for "Pavement" shall apply to the aggregate used.

Note 12. For air-cooled blast-furnace slag aggregate, the allowable maximum value for micro-Deval abrasion loss shall be 21% for structures and the allowable maximum value for Absorption shall be according to the Owner's requirements for slag aggregate.

Note 13. The Owner shall waive the requirements for LS-614, Unconfined Freeze–Thaw Loss, provided the Contractor has submitted a written request that the coarse aggregate meets the alternative requirements for LS-606, Magnesium Sulphate Soundness Loss.

Note 14. The need to demonstrate compliance with this requirement shall be waived by the Contract Administrator if the source is on the current Ministry of Transportation regional Aggregate Sources List (ASL) for Structural Concrete Fine and Coarse Aggregates or the Aggregate Sources 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 15. An aggregate that fails to meet these requirements shall be accepted by the Contract Administrator, provided the requirements of CSA A23.2-14A are met.

Note 16. 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 17. 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 1 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 18. 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 19]*	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 20, Note 21]*	0.150
CSA A23.2-14A	Concrete Prism Expansion (% maximum at 1 year) *[Note 20, Note 22]*	0.040

Note 19. 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/C87M meet the following requirements:

a) 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.

b) Setting time of the unwashed fine aggregate mortar specimens shall not differ from washed fine aggregate mortar specimens by more than 10%.

Note 20. 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 regional Aggregate Sources List for Structural Concrete Fine and Coarse Aggregates.

Note 21. An aggregate that fails this requirement may be accepted, provided the requirements of CSA A23.2-14A are met.

Note 22. 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 and 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 OPS.PROV 1002 (April 2013).

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 78

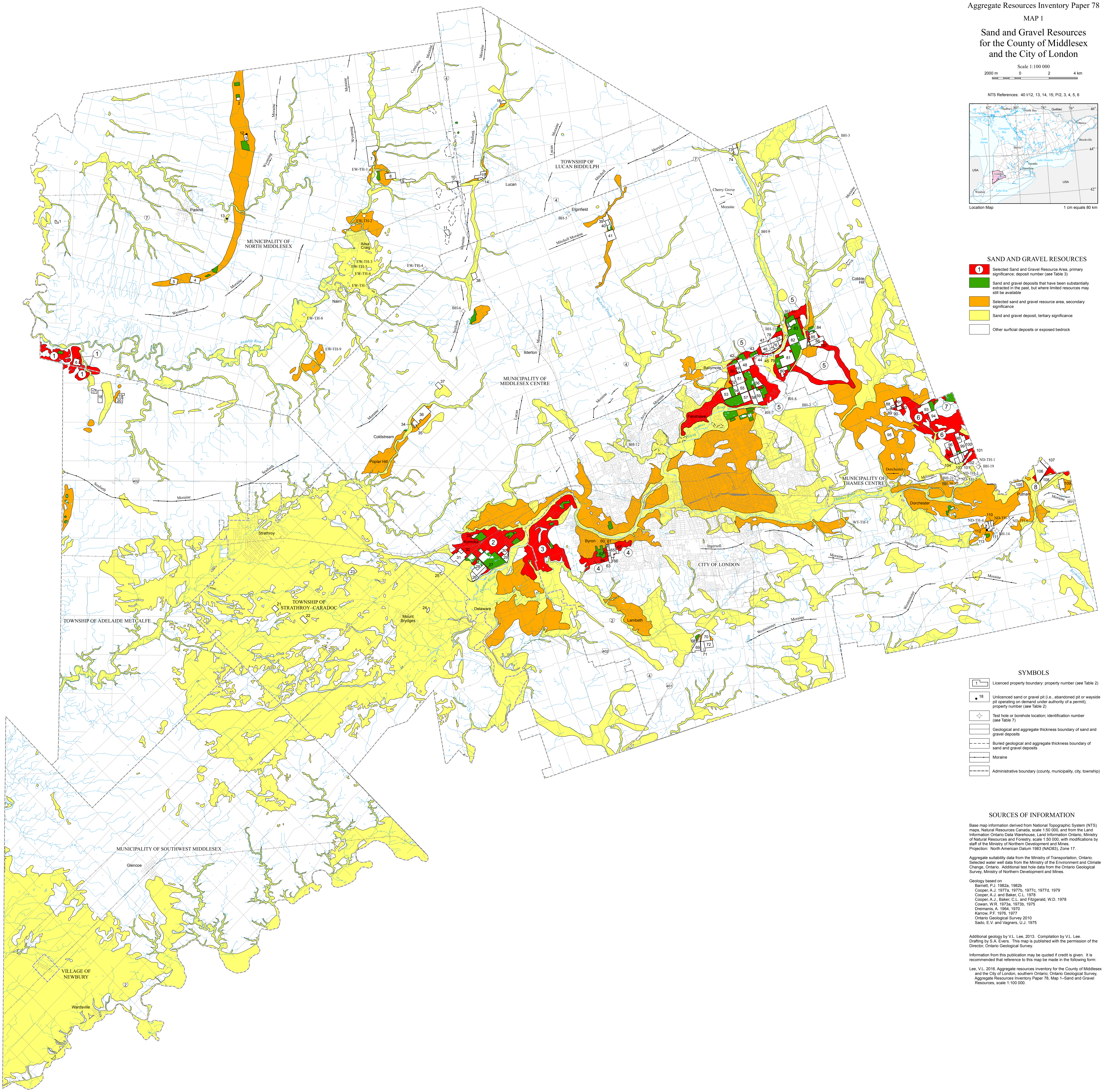
MAP 1

Sand and Gravel Resources for the County of Middlesex and the City of London

Scale 1:100 000

2000 m 0 2 4 km

NTS References: 40 I/12, 13, 14, 15; P/2, 3, 4, 5, 6



Location Map

1 cm equals 80 km

SAND AND GRAVEL RESOURCES

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

SYMBOLS

- Licenced property boundary: property number (*see* Table 2)
- Unlicenced sand or gravel pit (i.e., abandoned pit or wayside pit operating on demand under authority of a permit); property number (*see* Table 2)
- Test hole or borehole location; identification number (*see* Table 7)
- Geological and aggregate thickness boundary of sand and gravel deposits
- Buried geological and aggregate thickness boundary of sand and gravel deposits
- Moraine
- Administrative boundary (county, municipality, city, township)

SOURCES OF INFORMATION

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

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

Geology based on
Barnett, P.J. 1982a, 1982b
Cooper, A.J. 1977a, 1977b, 1977c, 1977d, 1979
Cooper, A.J. and Baker, C.L. 1978
Cooper, A.J., Baker, C.L. and Fitzgerald, W.D. 1978
Cowan, W.R. 1973a, 1973b, 1975
Dreimanis, A. 1964, 1970
Karrow, P.F. 1976, 1977
Ontario Geological Survey 2010
Sado, E.V. and Vagners, U.J. 1975

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

Lee, V.L. 2016. Aggregate resources inventory for the County of Middlesex and the City of London, southern Ontario; Ontario Geological Survey, Aggregate Resources Inventory Paper 78, Map 1–Sand and Gravel Resources, scale 1:100 000.

Aggregate Resources Inventory Paper 78

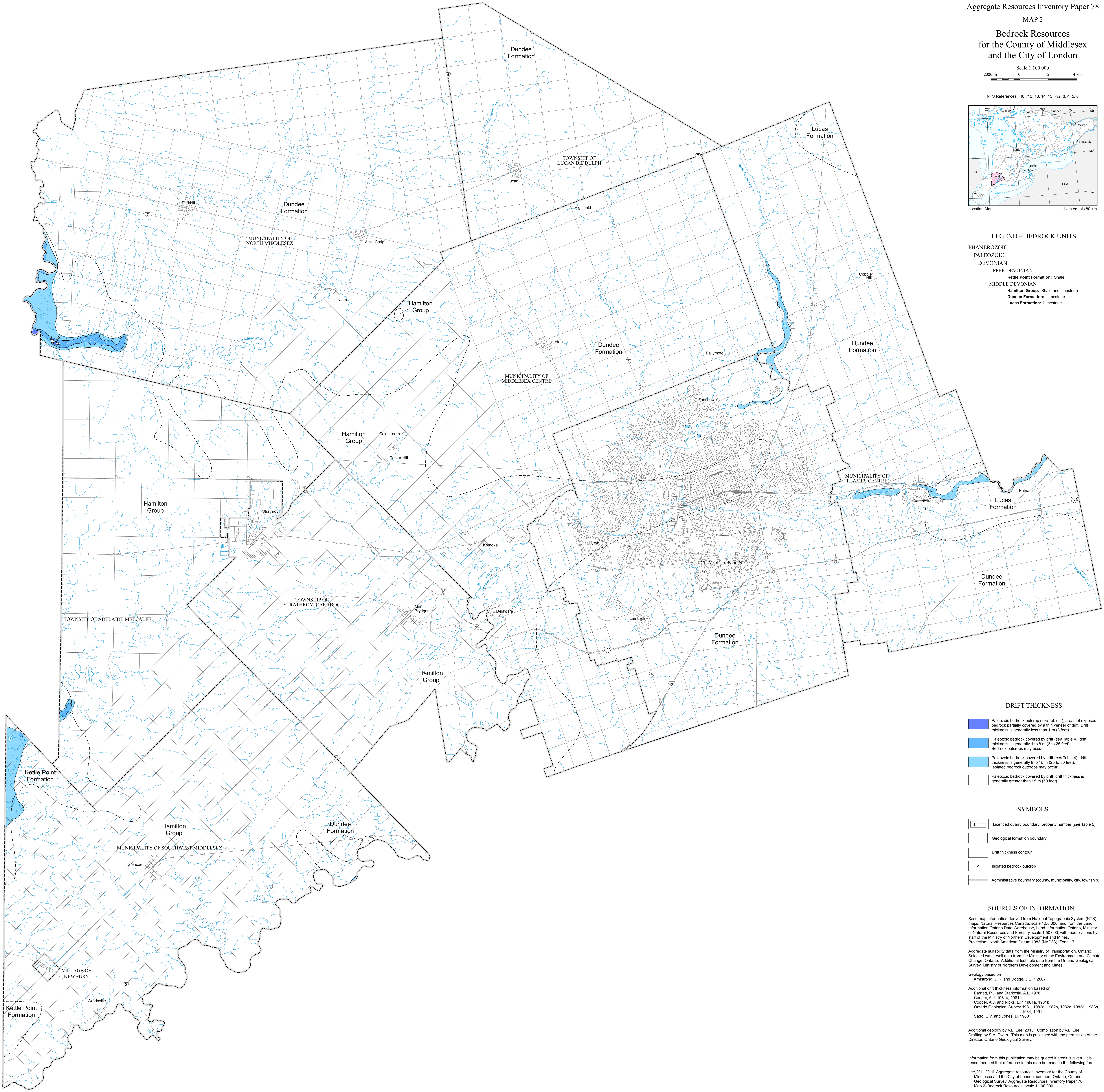
MAP 2

Bedrock Resources for the County of Middlesex and the City of London

Scale 1:100 000

2000 m 0 2 4 km

NTS References: 40 I/12, 13, 14, 15; P/2, 3, 4, 5, 6



Location Map 1 cm equals 80 km

LEGEND – BEDROCK UNITS

PHANEROZOIC

PALEOZOIC

DEVONIAN

UPPER DEVONIAN

Kettle Point Formation: Shale

MIDDLE DEVONIAN

Hamilton Group: Shale and limestone

Dundee Formation: Limestone

Lucas Formation: Limestone

DRIFT THICKNESS

Paleozoic bedrock outcrop (*see* Table 4); areas of exposed bedrock partially covered by a thin veneer of drift. Drift thickness is generally less than 1 m (3 feet).

Paleozoic bedrock covered by drift (*see* Table 4); drift thickness is generally 1 to 8 m (3 to 25 feet). Bedrock outcrops may occur.

Paleozoic bedrock covered by drift (*see* Table 4); drift thickness is generally 8 to 15 m (25 to 50 feet). Isolated bedrock outcrops may occur.

Paleozoic bedrock covered by drift; drift thickness is generally greater than 15 m (50 feet).

SYMBOLS

1 Licenced quarry boundary; property number (*see* Table 5)

Geological formation boundary

Drift thickness contour

× Isolated bedrock outcrop

Administrative boundary (county, municipality, city, township)

SOURCES OF INFORMATION

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

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

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

Additional drift thickness information based on
Barnett, P.J. and Starkoski, A.L. 1978
Cooper, A.J. 1981a, 1981b
Cooper, A.J. and Nicks, L.P. 1981a, 1981b
Ontario Geological Survey 1981, 1982a, 1982b, 1982c, 1983a, 1983b, 1984, 1991
Sado, E.V. and Jones, D. 1980

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