City of Ottawa Seismic Site Classification Map From Combined Geological/Geophysical Data

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The influence of local geological materials on seismically-induced ground motions is recognized in the 2005 National Building Code of Canada (NBCC2005; NRC, 2005) which introduced seismic site classifications to characterize site conditions based on the average stiffness of the upper 30 m of the ground surface (Finn and Wightman, 2003). Five of the six seismic site classes defined in NBCC2005 correspond approximately to: hard rock (class A), rock (class B), soft rock or very dense soil (class C), stiff soil (class D) and soft soil (class E); the sixth site, class (F), is discussed below. The classes are defined in terms of shear-wave velocity for classes A-E (Table 4.1.8.4.A in NRC, 2005; see also the map legend), though standard penetration resistance or undrained shear strength can be used instead for classes C, D and E. For building design, NBCC2005 provides amplification factors (Tables 4.1.8.4B and 4.1.8.4C in NRC, 2005) for each site class in order to compute the spectral accelerations of the design ground motion at a specific site. The amplification factors are functions of ground motion intensity, thus taking non-linear effects into account.

Site class F, the sixth NBCC seismic site class, defines a special case of soil conditions, including liquefiable soils, quick and highly sensitive clays, >3 m of peat, >8 m of highly plastic clays and >30 m of soft to medium stiff clays (Table 4.1.8.4.A in NRC, 2005). At a class F site, site-specific geotechnical evaluation is required to assess amplification of the firm-ground seismic hazard values.

The map of seismic site classes for the City of Ottawa presented here was compiled jointly by staff of the Geological Survey of Canada, and the Earth Sciences Department of Carleton University. The map depicts the spatial distribution of class A to E site conditions within the City of Ottawa municipal boundaries and demonstrates the application of geophysical techniques for compiling seismic classification maps. The site classes were defined exclusively by using the travel-time-averaged shear-wave velocity over the upper 30 m of the ground (Vs30). It should be noted that it is possible that class F site conditions may be found within the areas mapped as C through E, as Vs30 alone does not allow class F conditions to be indentified. Similarly, some areas mapped as classes A and B may instead be class C if more than 3 m of soil underlies the bottom of a spread footing or mat foundation (see Commentary J, item 100 in NRC, 2006).

The map was compiled using sub - surface geological data obtained from borehole records and measurements of shear - wave velocities using shallow geophysical techniques. The borehole data consist of ~ 21 000 water - well and engineering records that were compiled from the Urban Geology of Canada's National Capital area website, Geological Survey of Canada (http://gsc.nrcan.gc.ca/urbgeo/natcap/index_e.php; Belanger, 1998), and from the Ontario Ministry of Environment water-well database. Based on our interpretation of the borehole unit descriptors, the borehole records were classified into three generalized stratigraphic units which have distinct shear-wave velocity (Vs) characteristics. These three units (from surface downwards) are: (1) deglacial/post-glacial deposits (consisting of glaciomarine, deltaic, and fluvial deposits); (2) glacial deposits (till, diamicton and glaciofluvial deposits); and (3) bedrock. The interpretation of the borehole stratigraphy considered the surficial geology mapped nearby, the vertical ordering of the deposits, proximally-located boreholes and/or geophysical data, and knowledge of the general stratigraphy of the Ottawa area. The resulting borehole database provides the thicknesses of deglacial/post-glacial deposits and glacial units (units 1 and 2), and the depths to the two seismic impedance boundaries (top of glacial sediments and bedrock surface). Bedrock at a given location was classified into Paleozoic and Precambrian rock types and further subdivided into lithologies using local geology maps (Carson, 1982; Belanger, 1998).

The generalized stratigraphic units of the water well and engineering logs, from surface down to and including bedrock, were converted into unique time-averaged Vs profiles using average observed Vs refraction velocities for glacial deposits and bedrock types and functions that relate average Vs to depth for the deglacial/post-glacial deposits (Hunter et al., 2009, see also Hunter et al., 2007; Motazedian and Hunter, 2008; Benjumea et al., 2008). These velocity-depth functions and refraction velocities are based on direct measurements of shear-wave velocities at 685 surface reflection/refraction shear-wave survey locations, 25 line-km of landstreamer shear-wave reflection profiling (see Pugin et al., 2007), and nine downhole shear-wave velocity surveys. Each of these Vs profiles was then used to determine the travel-time-averaged Vs for the upper 30 m of the ground surface (Vs30) allowing an NBCC seismic site class to be associated with each borehole and geophysical site.

The ~22 000 determinations of Vs30 were contoured using a "natural neighbors" interpolation technique. The final mapped boundaries between site classes were edited to respect borehole and surface geophysics data points as well as known surficial geological boundaries. The boundaries between site classes are subject to uncertainty in position, especially where few data points occur. To reflect the uncertainty in the contouring, the variability in data density, and to show the complexity of local geology, data points are displayed on the map and keyed by a symbol for the data type and by the colour of the associated seismic site class. In some areas where data density is high, these seismic site classification boundaries are accurate to within a few hundred meters. In other areas, where data are sparse, the uncertainty in the mapped boundary might be 2 km or larger.

All five of the NBCC seismic site classes A to E are present within the City of Ottawa. In particular, the map reveals that class D and E areas are present beneath the urban and suburban parts of the city, mainly due to the presence of thick deposits of 'soft' glaciomarine sediments (or Leda clay). In some places Leda clay reaches thicknesses up to 100 m, infilling buried bedrock valleys. Locally, the transitions from classes A to E can occur over distances of less than 500 m (e.g. Motazedian and Hunter, 2008), reflecting the steeply-sloped margins of the buried valleys.

Relationship between Site Class and Amplification

The 2005 NBCC provides tables of amplification factors (Tables 4.1.8.4.B and 4.1.8.4.C, NRC, 2005) which modify the firm-ground spectrum (shaking with a 1:2475 year return period) to the design ground motion spectrum. The current factors indicate that the expected level of ground shaking increases four-fold from class A to E due to the decreasing soil stiffness, and suggest that soft soils (D and E) will experience greater shaking during an earthquake than stiffer soils or bedrock. The amplification factors, when used for building design, do take frequency content into account even though shaking frequency is not considered in the definition of site class.

It is recognized that the NBCC amplification factors have some limitations, may have considerable uncertainty (for details see Finn and Wightman, 2003), and may not take into account the complexity of local site effects (Boore, 2004; CFEM, 2006; Benjumea et al., 2008). For example, seismic shaking can be amplified or attenuated by factors that may act in combination with the geological materials immediately underlying a site. These include: shear-wave velocity and/or density contrasts between rock and overlying soil layers (impedance contrast amplification); internal reflection of seismic energy within a soil layer (resonance amplification); focusing or defocusing caused by topography or by subsurface geometry (buried bedrock topography effects); basin-edge effects (e.g. Cassidy and Rogers, 2004); and generation of Rayleigh and Love waves across the surface of a sediment-filled basin (basin effects).

There is a strong need to measure seismic shaking on soils in the Ottawa area in order to assess the amplification factors of the NBCC and to better understand ground motion response. To date, only limited such measurements have been conducted, as reported by Al-Khoubbi and Adams (2004), Adams (2007), and Hunter et al., (2009).

This seismic site classification map is presented as one element of a regional framework for further assessment of seismic hazards in the Ottawa area, and as a guide for the local geotechnical engineering community as to the general distribution of seismic site conditions across Ottawa. The data on the map, however, show regional trends and are neither suitable, nor are intended, for building design. This map does not replace the need for site-specific geotechnical studies, as required by the 2005 NBCC and Ontario's 2006 Building Code.

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The map is available from:
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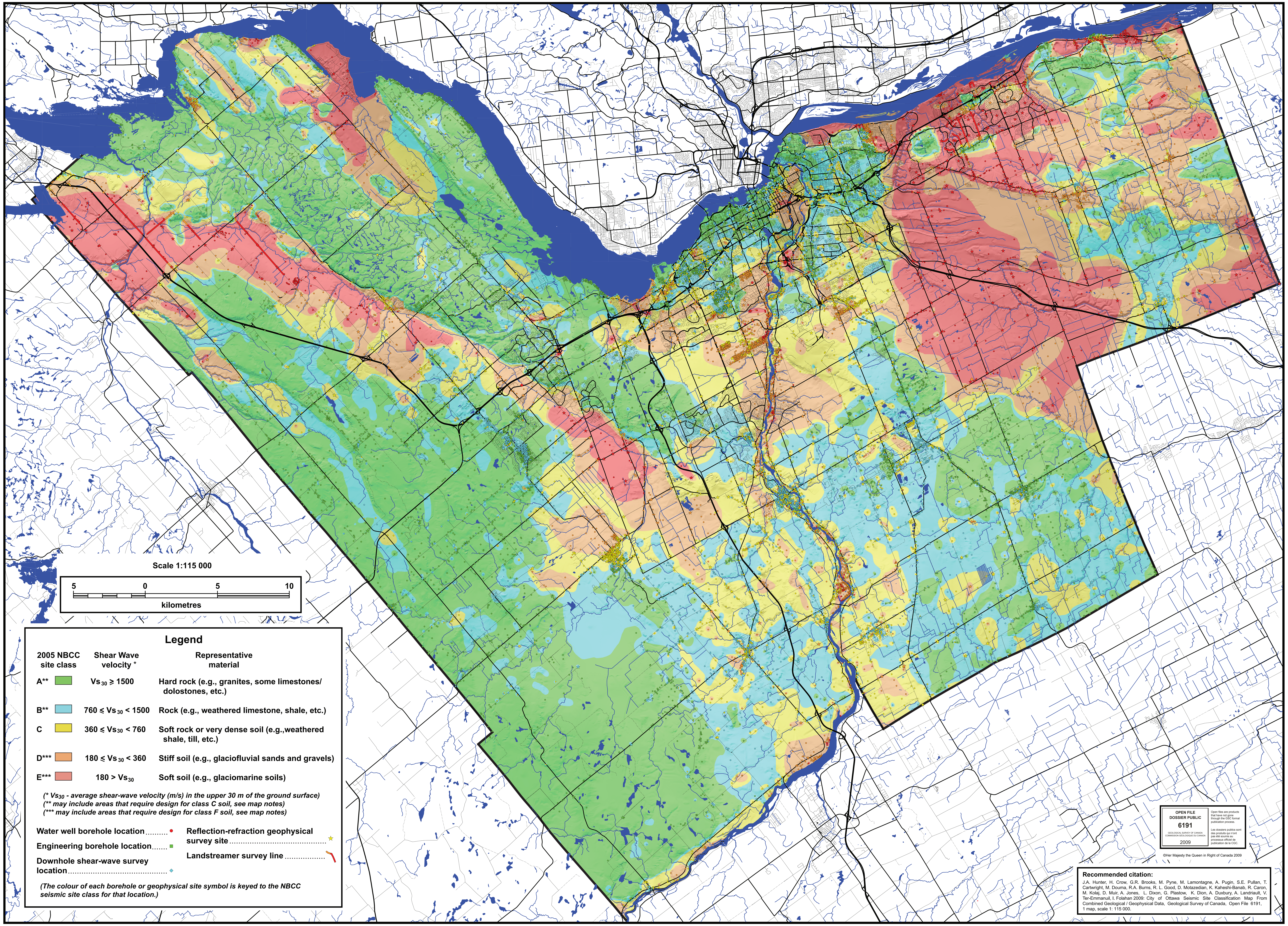

Scale 1:115 000

5 0 5 10
kilometres

Legend

2005 NBCC site class	Shear Wave velocity *	Representative material
A**	$Vs_{30} \geq 1500$	Hard rock (e.g., granites, some limestones/ dolostones, etc.)
B**	$760 \leq Vs_{30} < 1500$	Rock (e.g., weathered limestone, shale, etc.)
C	$360 \leq Vs_{30} < 760$	Soft rock or very dense soil (e.g.,weathered shale, till, etc.)
D***	$180 \leq Vs_{30} < 360$	Stiff soil (e.g., glaciofluvial sands and gravels)
E***	$180 > Vs_{30}$	Soft soil (e.g., glaciomarine soils)

(Vs_{30} - average shear-wave velocity (m/s) in the upper 30 m of the ground surface)*
*(** may include areas that require design for class C soil, see map notes)*
*(*** may include areas that require design for class F soil, see map notes)*

Water well borehole location ....

Engineering borehole location ....

Downhole shear-wave survey location ....

Reflection-refraction geophysical survey site ....

Landstreamer survey line ....

(The colour of each borehole or geophysical site symbol is keyed to the NBCC seismic site class for that location.)

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