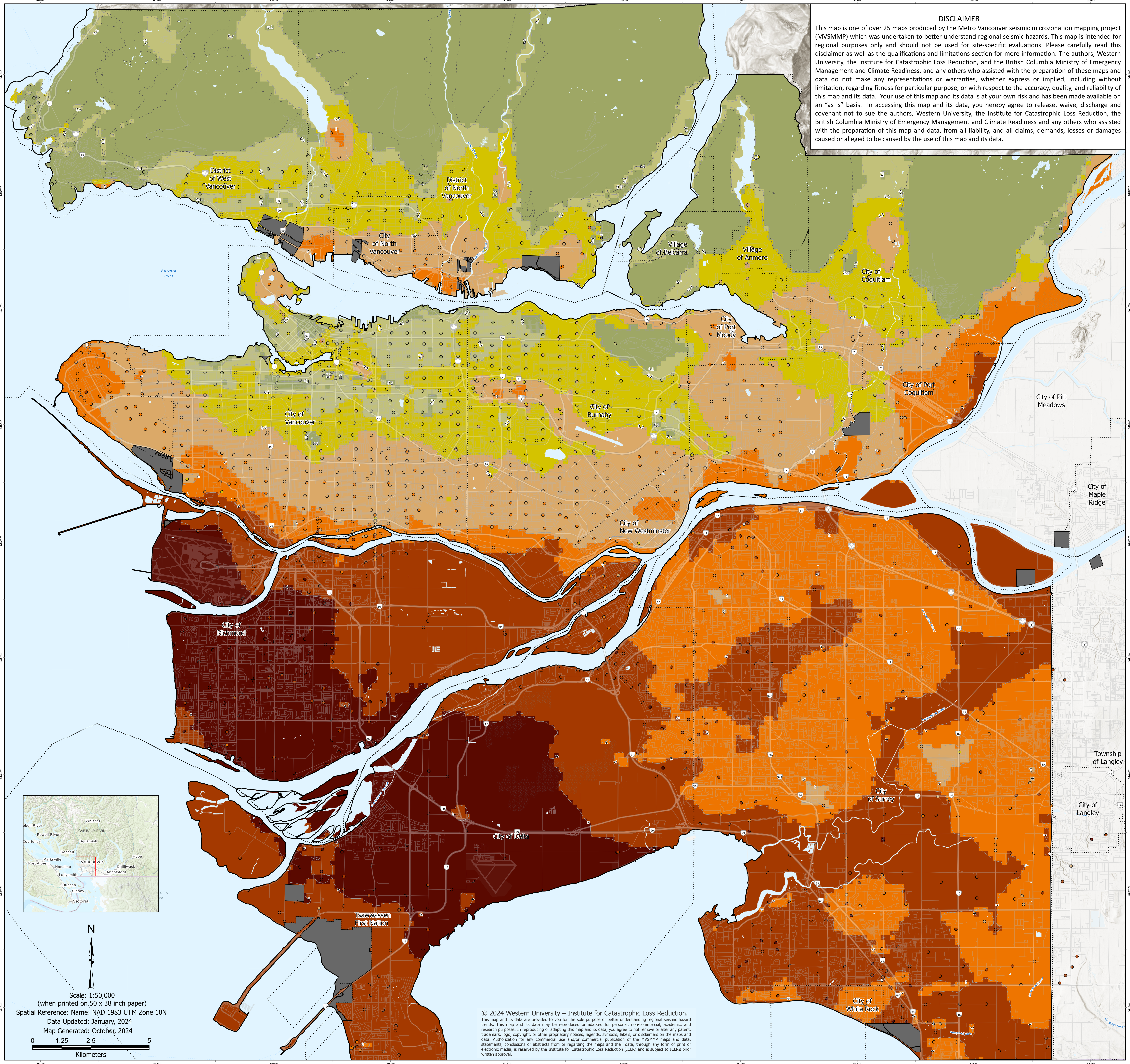
DISCLAIMER

This map is one of over 25 maps produced by the Metro Vancouver seismic microzonation mapping project (MVSMMP) which was undertaken to better understand regional seismic hazards. This map is intended for regional purposes only and should not be used for site-specific evaluations. Please carefully read this disclaimer as well as the qualifications and limitations section for more information. The authors, Western University, the Institute for Catastrophic Loss Reduction, and the British Columbia Ministry of Emergency Management and Climate Readiness, and any others who assisted with the preparation of these maps and data do not make any representations or warranties, whether express or implied, including without limitation, regarding fitness for particular purpose, or with respect to the accuracy, quality, and reliability of this map and its data. Your use of this map and its data is at your own risk and has been made available on an "as is" basis. In accessing this map and its data, you hereby agree to release, waive, discharge and covenant not to sue the authors, Western University, the Institute for Catastrophic Loss Reduction, the British Columbia Ministry of Emergency Management and Climate Readiness, and any others who assisted with the preparation of this map and data, from all liability, and all claims, demands, losses or damages caused or alleged to be caused by the use of this map and its data.



Scale: 1:50,000
(when printed on 50 x 38 inch paper)
Spatial Reference: Name: NAD 1983 UTM Zone 10N
Data Updated: January, 2024
Map Generated: October, 2024

0 1.25 2.5 5
Kilometers

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MVSMMP Map 08, Level 2

Fundamental Site Period (T_0)

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INTRODUCTION

This is Map 08 of the Metro Vancouver Seismic Microzonation Mapping project (MVSMMP) and displays the spatial distribution of fundamental site period (T_0) in seconds (s) throughout Metro Vancouver. The fundamental site period represents the natural vibration period of a soil column and is the inverse of fundamental site (peak) frequency ($T_0 = 1/f_0$).

Earthquake ground motions are amplified around the natural modes of vibration of a site by shear wave resonance. Generally, earthquake shaking at longer periods (e.g., swaying) corresponds to softer and/or thicker sediments compared to shorter period earthquake shaking (e.g., rapid vibrations) that correspond to stiffer and/or thinner sediments. The natural vibrational modes of a site depend on soil thickness (h) and the average shear-wave velocity (Vs) of the soil (Vs_{ave}). For a single soil layer over bedrock, $T_0 = 4h/Vs_{ave}$. For T_0, h is equivalent to the total sediment thickness (H_{soil}; MVSMMP Map 06; Salsabili et al. 2024b).

T_0 is one of several other measures that summarize subsurface site conditions, including Quaternary geology (MVSMMP Map 01), sediment thicknesses (MVSMMP Maps 05 and 06), and the time-averaged shear-wave velocity of the top 30 metres, Vs_{30} (MVSMMP Map 07). Regional mapping of T_0 and these other measures of subsurface site conditions are beneficial to regional evaluation of seismic shaking amplification, i.e., seismic shaking susceptibility mapping. Although Vs_{30}, is the most utilized quantitative measure of subsurface site conditions in current seismic hazard analysis and regional seismic microzonation mapping worldwide, use of T_0 is growing. This Level 2 seismic microzonation map of T_0 is used in combination with other regional seismic susceptibility maps of H_{PG} and Vs_{30} to regionally map shaking amplification hazard of western Metro Vancouver (see MVSMMP Maps 16 to 27).

SITE PERIOD (T_0) MAPPING

Regional mapping of fundamental site period (T_0) across western Metro Vancouver is accomplished using a comprehensive Level 2 seismic microzonation mapping (SMM) approach calculating T_0 based on Level 2 SMM of the total sediment thickness (H_{SOIL}) in combination with prediction of the time-averaged shear-wave velocity of the total sediment column (Vs_{ave}) based on a three-dimensional (3D) velocity model of western Metro Vancouver. T_0 is calculated based on an equivalent single soil layer approach where $T_0 = 4 \times H_{soil} / Vs_{ave}$.

Development of a 3D velocity model is accomplished using 3D geostatistical estimation of the Seequent Leapfrog Geo modelling software. First, a 3D model of the post-glacial and glacial sediments spatial volumes is constructed from the developed Level 2 SMM H_{PG} and H_{soil} maps in combination with surface topography from a 50-m raster mesh of a LiDAR digital elevation model (LidarBC). Development of these Level 2 seismic microzonation maps and their geodatasets are described in MVSMMP Maps 05 and 06 (Salsabili et al. 2024a, b). Overall, the MVSMMP developed a comprehensive geodatabase for western Metro Vancouver over a period of 6 years from non- and proprietary data sources and including 5 field campaigns of multi-method seismic field testing (Molnar et al. 2023; Adhikari 2024). The MVSMMP geodatabase played a crucial role in ensuring a variety of both invasive and non-invasive geodata measurements were compiled. Since each field method has inherent advantages and disadvantages, access to geodata from a variety of field data methods ensures overall benefit of each method are captured in the regional geodatabase. The first-generation of 3D volume models developed of western Metro Vancouver utilizing the MVSMMP's geodatasets and Seequent Leapfrog Geo software are described in Adhikari and Molnar (2024).

The next step is generating the 3D Vs model by determining the spatial distribution of Vs with depth within the post-glacial and glacial volumes. The 3D volume model is partitioned into blocks with dimensions of 200 m lateral and 2 m vertical extent. Vs is predicted for each block using conventional ordinary kriging within each 3D volume. Vs is therefore determined spatially every 200 m and at each 2 m depth interval using 3D geostatistical estimation of the Vs data within each 3D volume. This 3D modelling process captures lateral and vertical (depth) trends present in the Vs data; such trends are present amongst post-glacial or glacial sediments but are not expected between them.

Vs_{ave} is then calculated at each 200-m spaced location (column of vertical blocks) of the 3D Vs model employing the following equation:

$$Vs_{ave} = H_{soil} / \textstyle\sum_1^n h / Vs_i$$

where, n is the number of vertical blocks, h is the 2-m height of each vertical block, and Vs_i is the shear-wave velocity of each ith vertical block. This step effectively results in spatial mapping of Vs_{ave} at a 200-m resolution.

T_0 is then calculated for each 200-m uniform grid location based on a single soil layer (H_{soil}) and its corresponding Vs_{ave}. For locations of outcropping rock based on the Quaternary geology map of western Metro Vancouver (MVSMMP Map 01; Adhikari et al. 2024), $T_0 < 0.1$ s is assigned and consistent with measured $f_{0HV} > 10$ Hz (Sirohey 2022). This equivalent single soil layer approach to T_0 calculation leads to 20% overestimation at long periods (Dobry, 1976). A region-specific correction is developed based on the simplified Rayleigh approach to T_0 calculation (Urza et al. 2017) to account for the influence of the Vs gradient with depth within the equivalent single layer: $T_{0,CORR} = 0.77 \times (T_0) + 0.052$. Corrected T_0 values are utilized to produce this fundamental site period map of western Metro Vancouver (map unit is seconds).

QUALIFICATIONS AND LIMITATIONS

This map is one of over 25 maps produced as part of the Metro Vancouver seismic microzonation mapping project (MVSMMP) by Associate Professor Sheri Molnar's seismic hazard research group at Western University in accordance with generally accepted seismic microzonation mapping practices.

This map may be used to better understand regional seismic hazards and thereby to inform decision making and planning related to regional seismic hazards. This map and its data are only intended to convey regional seismic hazard trends. Each MVSMMP map is designated exclusively for regional use and should not be used for site-specific evaluations or purposes. Use of this map should not replace the sound judgment of seismic hazard experts and earthquake engineering professionals, nor substitute for the standard of care required of such professionals in interpreting and applying the results of the seismic data provided by this map. This map and its data should not used as a replacement for site-specific geotechnical investigations for specific design, construction, and/or engineering purposes or as may be recommended by the 2020 National Building Code of Canada or the 2024 British Columbia Building Code.

Determination of map values is dependent on the quality, quantity, and locations of input geodata from a variety of site-investigation methods and data sources. The MVSMMP developed a comprehensive geodatabase for the map region over a period of 6 years from non- and proprietary data sources and including 5 field campaigns of multi-method seismic field testing. Site modal period estimations are contingent upon values and uncertainties inherent in the underlying mapping of average shear-wave velocity and sediment thickness.

All hazard zonation boundaries are *approximate*. Boundaries may change as more subsurface geodata become available. Part of a hazard zone may behave differently than another; consequently, the hazard at a specific site may be higher or lower than shown on the map.

This map is generated considering natural **non-engineered ground conditions** everywhere, except geologically mapped anthropogenic fill deposits that are most commonly present at shorelines. Human-based engineering alterations to ground conditions (e.g., soil improvements, engineered dykes, roadway fills) are not included, but would be generally expected to reduce the hazard ratings shown on the map. The assessment of slope instability hazard does not consider artificial cuts and fills or other human alterations to the natural terrain.

Seismic hazard analyses of the natural ground conditions are considered, including one-dimensional site effects, two-dimensional slope instability (landslide hazard potential mapping only), and three-dimensional basin structure effects (shaking de/amplification hazard mapping only). Potential impacts of topography, aftershocks, tsunamis, and fire following, as well as scientific uncertainty and interdependency, have NOT been included.

Users should consider these limitations and consult with a qualified seismic hazard expert or earthquake engineering professional when making decisions related to this map. In higher hazard areas, more detailed engineering studies may be required, depending on the use proposed and the specific hazards present, and higher costs may be incurred.

As a condition of use of the MVSMMP maps and data, you agree to indemnify and hold harmless the authors, Western University, the Institute for Catastrophic Loss Reduction, the British Columbia Ministry of Emergency Management and Climate Readiness, and any others who assisted with the preparation of these maps and data from and against any and all claims, demands, damages, losses, expenses, or loss of profits arising or resulting from your use or interpretation of the MVSMMP maps and data.

EGBC PEER REVIEW

The maps of the MVSMMP underwent a peer review process facilitated by Engineers and Geoscientists of British Columbia (EGBC) by professional geoscientists (Patrick Monahan, Monahan Petroleum Consulting), geotechnical earthquake engineers (Upul Atukorala, WSP; Adrian Wightman, BGC Engineering), municipal civil engineers (Matt Osler, City of Surrey), planners and sustainability specialists (Tamsin Mills, Pinna Sustainability), and structural earthquake engineers (Bishnu Pandey, BCIT; John Sherstobitoff, Ausenco; Carlos Ventura, Univ. British Columbia). Review comments on fieldwork, data analysis, and interpretations were considered by the MVSMMP project team and addressed in the maps, as appropriate.

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REQUIRED CITATION

Salsabili, M., S. R. Adhikari, A. Sirohey, J. Assaf, A. Bilson Darko, S. Molnar (2024). Fundamental Site Period (T0), Metro Vancouver seismic microzonation mapping project (MVSMMP), Map 08, SMM Level 2, Scale 1:50,000, 1 Map Sheet with accompanying Data Layers, Using ArcGIS Pro, version 3.3 (ESRI Inc., Redlands, California), University of Western Ontario, Dept. Earth Sciences, London, ON. Borealis, https://doi.org/10.5683/SP3/RNVWIN.

REFERENCES

Adhikari, S. R. (2024). Development of a regional geodatabase and 3D models of Metro Vancouver and their use and impact to regional seismic hazard mapping, University Western Ontario, PhD Thesis, https://ir.lib.uwo.ca/etd/9949.

Adhikari, S. R., and S. Molnar (2024). Development and comparison of 3D seismic geology and shear-wave velocity models of Metro Vancouver, Seismica, 3, 2, 1-16.

Adhikari, S. R., P. Monahan, M. Salsabili, A. Bilson Darko, S. Molnar (2024). Quaternary Geology, Metro Vancouver seismic microzonation mapping project (MVSMMP), Map 01, SMM Level 1-2, Scale 1:50,000, 1 Map Sheet with accompanying Data Layers, Using ArcGIS Pro, version 3.3 (ESRI Inc., Redlands, California), University of Western Ontario, Dept. Earth Sciences, London, ON. Borealis, https://doi.org/10.5683/SP3/BOIPW4.

Dobry, R., Oweis, I., & Urzua, A. (1976). Simplified procedures for estimating the fundamental period of a soil profile. Bulletin of the Seismological Society of America, 66(4), 1293-1321.

LidarBC. British Columbia Lidar Data. https://lidar.gov.bc.ca/pages/download-discovery (last accessed: 2023/11).

Molnar, S, A Bilson Darko, H Ghofrani, S Adhikari, M Salsabili (2023). The Metro Vancouver Seismic Microzonation Mapping Project: Overview and multi-method approach to regional geodatabase development, Joint Canadian and Pacific Conference on Earthquake Engineering, Vancouver, BC, Paper 258, 8 p.

Salsabili, M., S. R. Adhikari, A. Sirohey, J. Assaf, A. Bilson Darko, S. Molnar (2024a). Post-Glacial Sediment Thickness (Hpg), Metro Vancouver seismic microzonation mapping project (MVSMMP), Map 05, SMM Level 2, Scale 1:50,000, 1 Map Sheet with accompanying Data Layers, Using ArcGIS Pro, version 3.3 (ESRI Inc., Redlands, California), University of Western Ontario, Dept. Earth Sciences, London, ON. Borealis, https://doi.org/10.5683/SP3/T4UQM6.

Salsabili, M., S. R. Adhikari, A. Sirohey, J. Assaf, A. Bilson Darko, S. Molnar (2024b). Post-Glacial and Glacial Sediment Thickness (Hsoil), Metro Vancouver seismic microzonation mapping project (MVSMMP), Map 06, SMM Level 2, Scale 1:50,000, 1 Map Sheet with accompanying Data Layers, Using ArcGIS Pro, version 3.3 (ESRI Inc., Redlands, California), University of Western Ontario, Dept. Earth Sciences, London, ON. Borealis, https://doi.org/10.5683/SP3/8Y8N8D.

Sirohey, A. (2022). Soil amplification and peak frequencies from thousands of passive seismic measurements across Metro Vancouver, British Columbia, Canada. University of Western Ontario, MSc (Geophysics) Thesis, https://ir.lib.uwo.ca/etd/8810.

Urzúa, Alfredo, Ricardo Dobry, and John T. Christian (2017). Is harmonic averaging of shear wave velocity or the simplified Rayleigh method appropriate to estimate the period of a soil profile?. Earthquake Spectra, 33, 3 895-915.

Legend

Fundamental-mode site period, T_0 (s)

- < 0.1
- 0.1 - 0.2
- 0.2 - 0.5
- 0.5 - 1
- 1 - 2
- 2 - 4
- > 4

T_0, f_{0HV} measurements

T_0 contours (s)

Administrative Boundaries

MVSMMP Study Area

First Nation Communities

Rock Outcrops

Lake, River & Water body