Metro Vancouver Seismic Microzonation Hazard Mapping - Metro Vancouver Conference Day

UWO: **Dr. Sheri** Molnar, Associate Professor, Dept. Earth Sciences

ICLR: **Jessica** Shoubridge, MAP, Founder & Principal Thrive Consulting

EGBC: **Allison** Chen, P.Eng., P.E., Practice Advisor, Professional Practice, Standards & Development

June 7th, 2024

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Institute for Catastrophic Loss Reduction
Building resilient communities

British Columbia
Ministry of Emergency Management and Climate Readiness

We respectfully acknowledge that Metro Vancouver is located on the unceded, traditional territories of 10 local First Nations, including the xʷməθkʷəy̓əm (Musqueam) Sḵwx̱wú7mesh Úxwumixw (Squamish) and səl̓ilw̓ətaʔɬ (Tsleil-Waututh) Nations.

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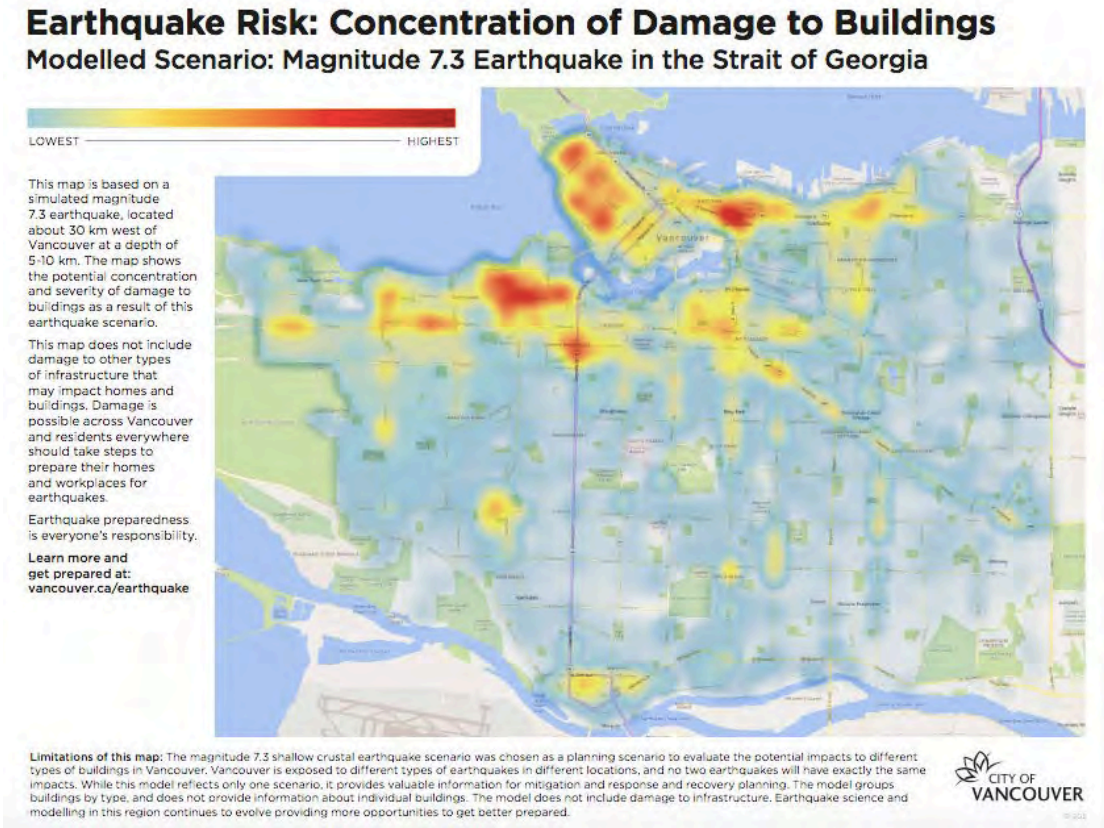
Agenda

11:00am	Welcome, High Level 'Why' Cat Risk, Intro's
11:15am	Overview of the MV Mapping Project (3 hazards, 29 maps)
11:25am	Q & A, Discussion
11:30am	End Use Cases & Applications for MV Microzonation Maps
11:40am	Q & A, Discussion & Close

The High Level 'Why'?

- Seismic risk in MV is catastrophic, but there is much we can & should do to reduce it/better manage it
- Seismic hazard still represents significant risk to life, unlike other 'major hazards of concern' in the region and recovery challenges unlike any other hazard (Christchurch example)
- $20 billion+ initial shaking (No AS), $10 billion FF. Every dollar we spend on mitigation/risk reduction/resilience pays off ~13:1 in response/recovery costs
- These maps represent ~a decade of advancement in seismic hazard knowledge for the region, a huge asset if well applied
- Basin effects can only be considered via this type of regional mapping/modelling, and will not be captured via site-specific analysis of any type



Intro's

- Please introduce yourself (name/affiliation) and mention **<u>one way</u>** you are/or would like to better integrate seismic hazard (or risk) info into your workflows/budgets/projects….

Metro Vancouver
Seismic Microzonation Mapping Project (MVSMMP)

A multi-year research project to generate a suite of **region-specific seismic hazard maps** that capture local earthquake site effects, specifically:

- Earthquake **shaking de/amplification** inclusive of 1D site and 3D sedimentary basin effects
- Seismic-induced **landslide** hazard potential
- Seismic-induced **liquefaction** hazard potential

The MVSMMP is led by the University of Western Ontario in collaboration with the Institute of Catastrophic Loss Reduction (ICLR) and with support from the British Columbia Ministry of Emergency Management and Climate Readiness (EMCR).

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Metro Vancouver Seismic Microzonation Mapping Project

Level 3 Seismic Microzonation Maps

- Supersede Existing Level 1 and 2 SMMs of Local Communities
- Comprehensive and Equitable Regional Geodata
- Consistent State-of-the-Art Seismic Hazard Analyses

Professional Practice

- Promote comprehension and use through professional practice standards

1. EGBC Technical Peer Review of project methodologies, analyses, and map outcomes
2. EGBC Professional Practice Guidelines *Development and Use of Seismic Microzonation Maps in British Columbia*

Communication and Engagement

- Promote comprehension and use through knowledge sharing

1. Include regular engagement opportunities **during** and after SMM project
2. Involve non-technical users in peer-review process

Published online at EGBC Guidelines & Advisories webpage

"Nothing in science has any value to society if it is not communicated"
(Anne Roe, 1953)

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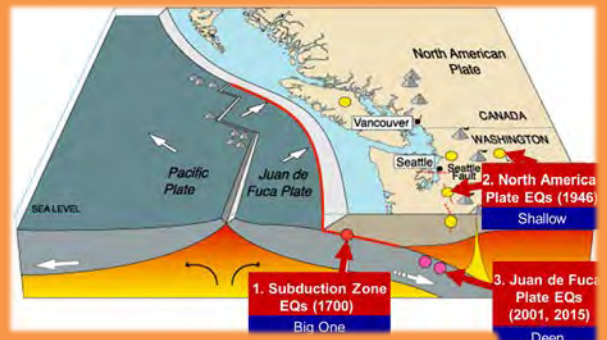
Why does Metro Vancouver need region-specific seismic hazard maps?

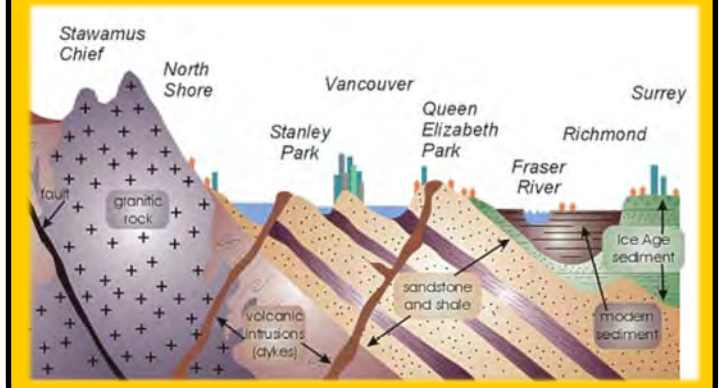
Metro Vancouver has the highest seismic risk in Canada

Complex regional seismic hazard



Paleo-liquefaction evidence but no strong earthquake recordings

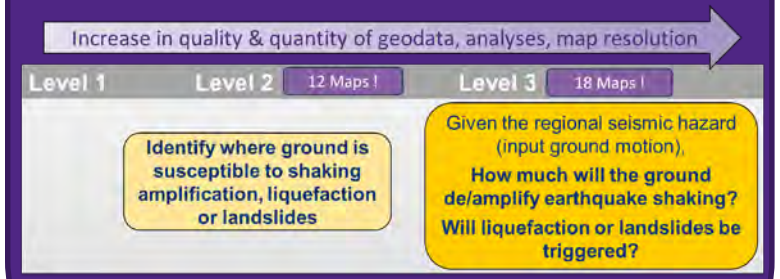
Highly variable seismic site conditions



- Basin within a Basin

Level 3 Seismic Microzonation Maps

- Supersede Existing Level 1 and 2 SMMs of Local Communities
- Comprehensive and Equitable Regional Geodata
- Consistent State-of-the-Art Seismic Hazard Analyses
- Standardized Approach to Seismic Microzonation Maps



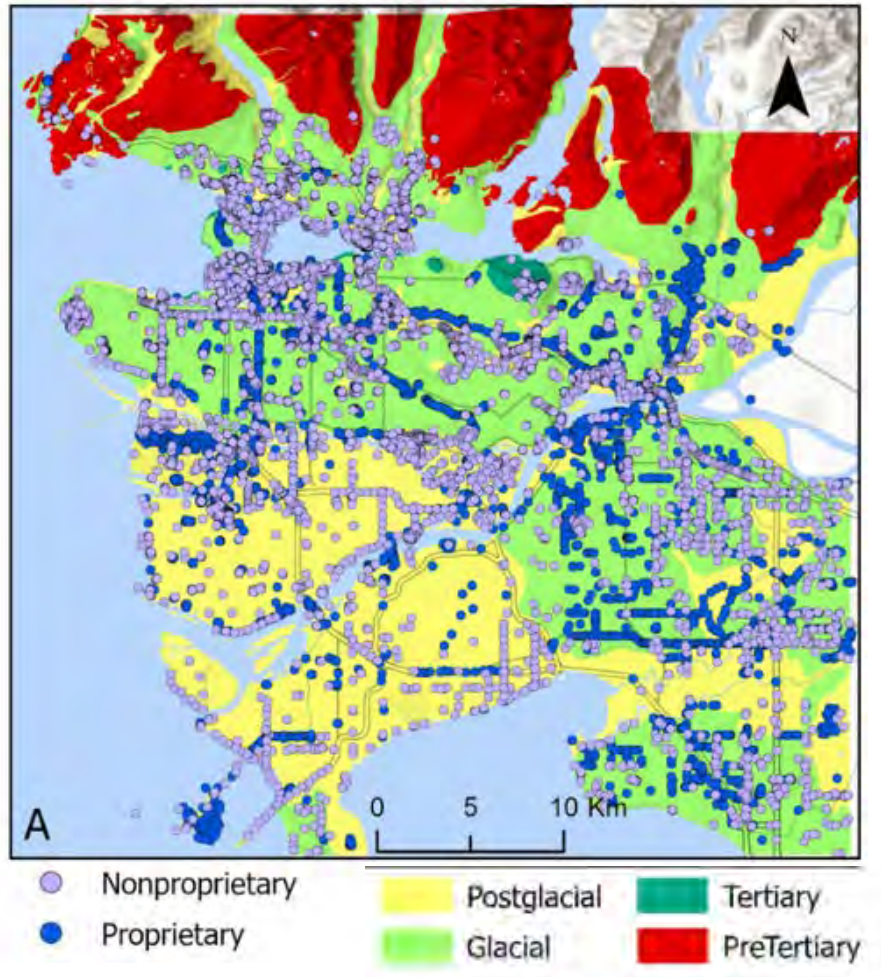
Comprehensive Regional Geodatabase

for Seismic Site Characterization, Development of Regional 3D Velocity Models, and Site-Specific Seismic Hazard Analyses

The MVSMM Project geodatabase consists of over 15,000 unique geodata locations

1. Non-Proprietary geodata was compiled from available online (open data) government sources
   - e.g., ~500 velocity depth profiles of the Geological Survey of Canada (Hunter et al. 1998, 2016)

2. Proprietary geodata compiled from 24 local governments, stakeholder groups, engineering firms, and geoconsultants via data sharing agreements when applicable
   - Primarily *in situ* invasive field testing data (S/CPT, downhole, SPT) and some geotechnical laboratory testing of samples



Molnar et al. 2020; Adhikari et al. 2021; Molnar et al. 2023; Adhikari, 2024

Comprehensive Regional Geodatabase

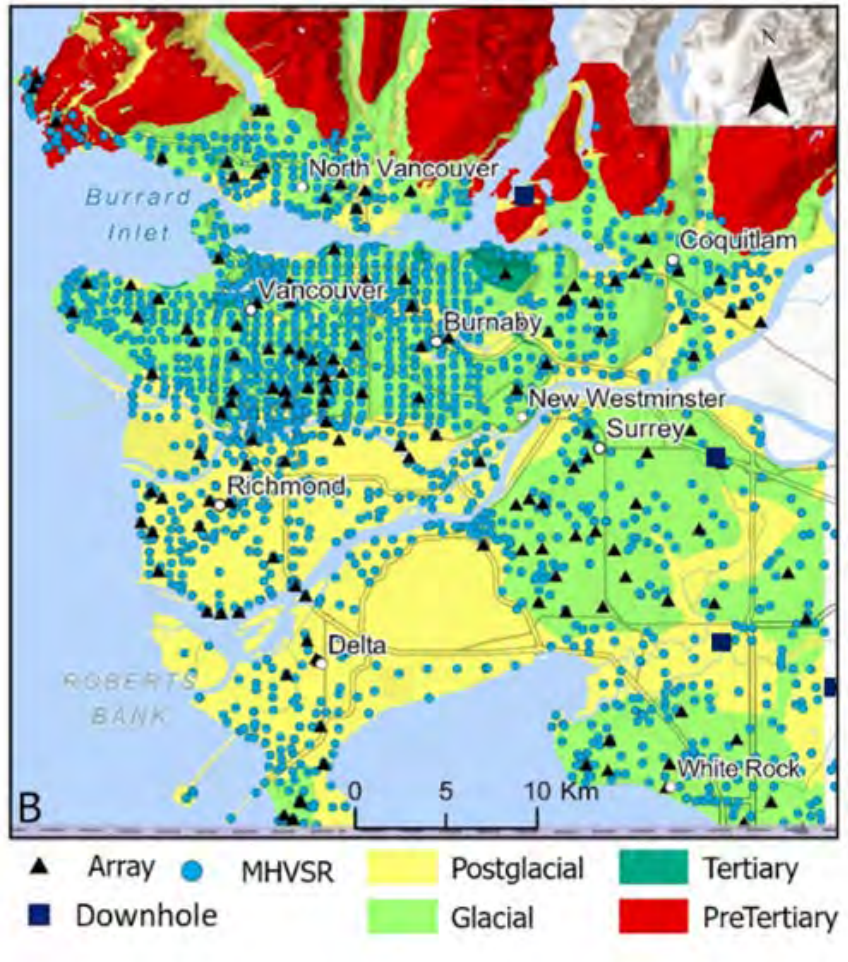
for Seismic Site Characterization, Development of Regional 3D Velocity Models, and Site-Specific Seismic Hazard Analyses

3. Multi-method *in situ* non-invasive seismic field testing approach over 5 field campaigns (2018-2022)

  - Single-station microtremor horizontal to vertical spectral ratio (**MHVSR**) testing **over 2,300 locations** at an average ~800 meter spacing
  - Combined active- and passive-source **surface wave array testing** (MASW and AVA) at **over 120 locations**
  - Joint inversion of site peak frequencies and combined Rayleigh wave dispersion curve to obtain Vs depth profile model

- Cost effective for achieving spatial coverage and improved geodata equity across the region

Multiple invasive and non-invasive geodatasets are needed to measure the great variety of seismic site conditions



Molnar et al. 2020; Adhikari et al. 2021; Molnar et al. 2023; Adhikari, 2024

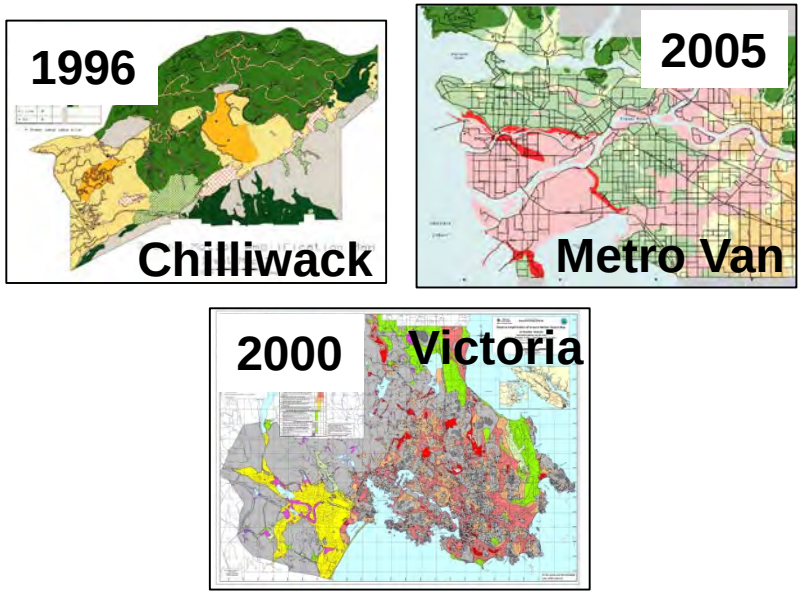
What are seismic microzonation maps?

Effects of earthquake shaking are not uniform due to variation in local site conditions

Seismic microzonation is the process of subdividing a seismically prone region into zones of similar {insert type of seismic hazard here}.

Seismic microzonation maps display predicted variation in earthquake hazards due to local site conditions.

Microzonation maps typically accomplished at urban or region scale

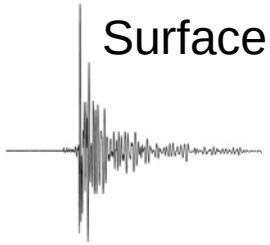


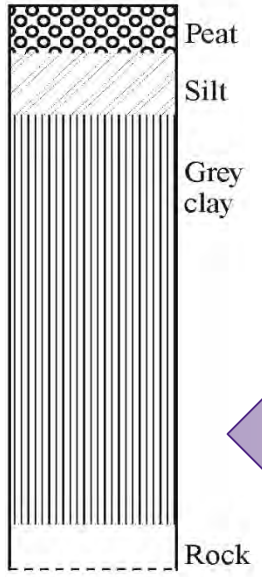
Previous SMM in southwest BC led by Vic Levson (BCGS) and Pat Monahan

Scales and accuracy of seismic hazard assessment

Site → Urban → Region → Country

Surface motion

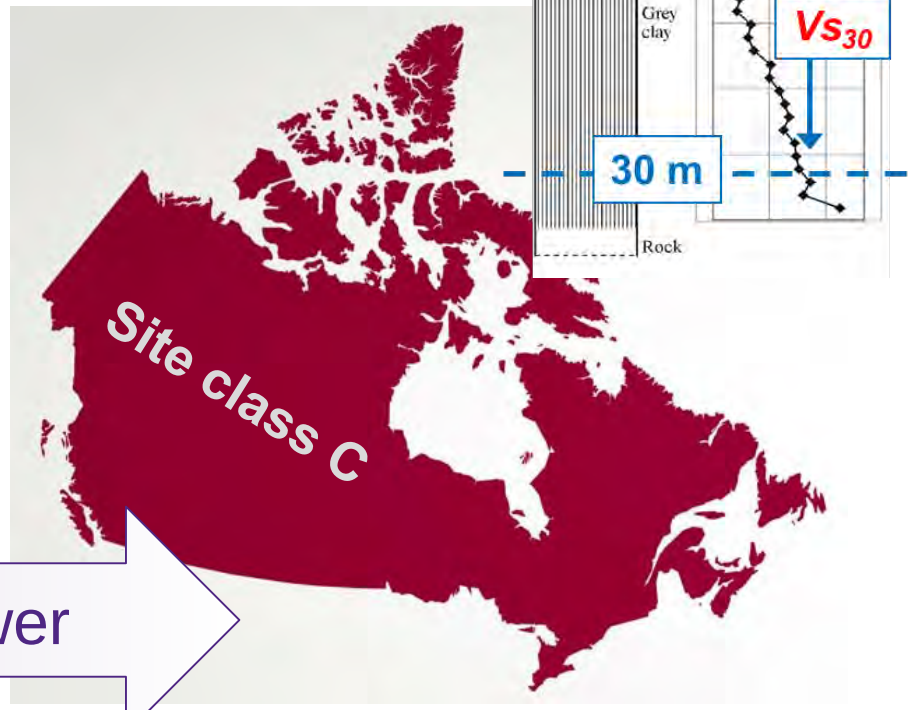




Input motion

[Microzonation mapping](#)

Site effects
Basin effects
Topographic effects

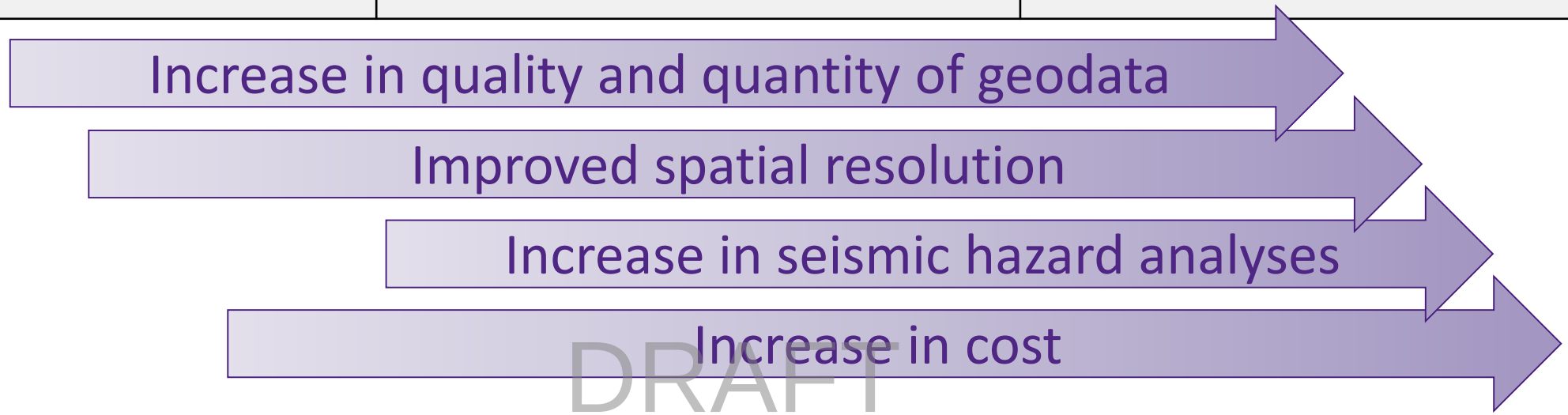


higher Accuracy lower

Ground motion = *f*(source) + *f*(path) + ***f*(site)** + uncertainty

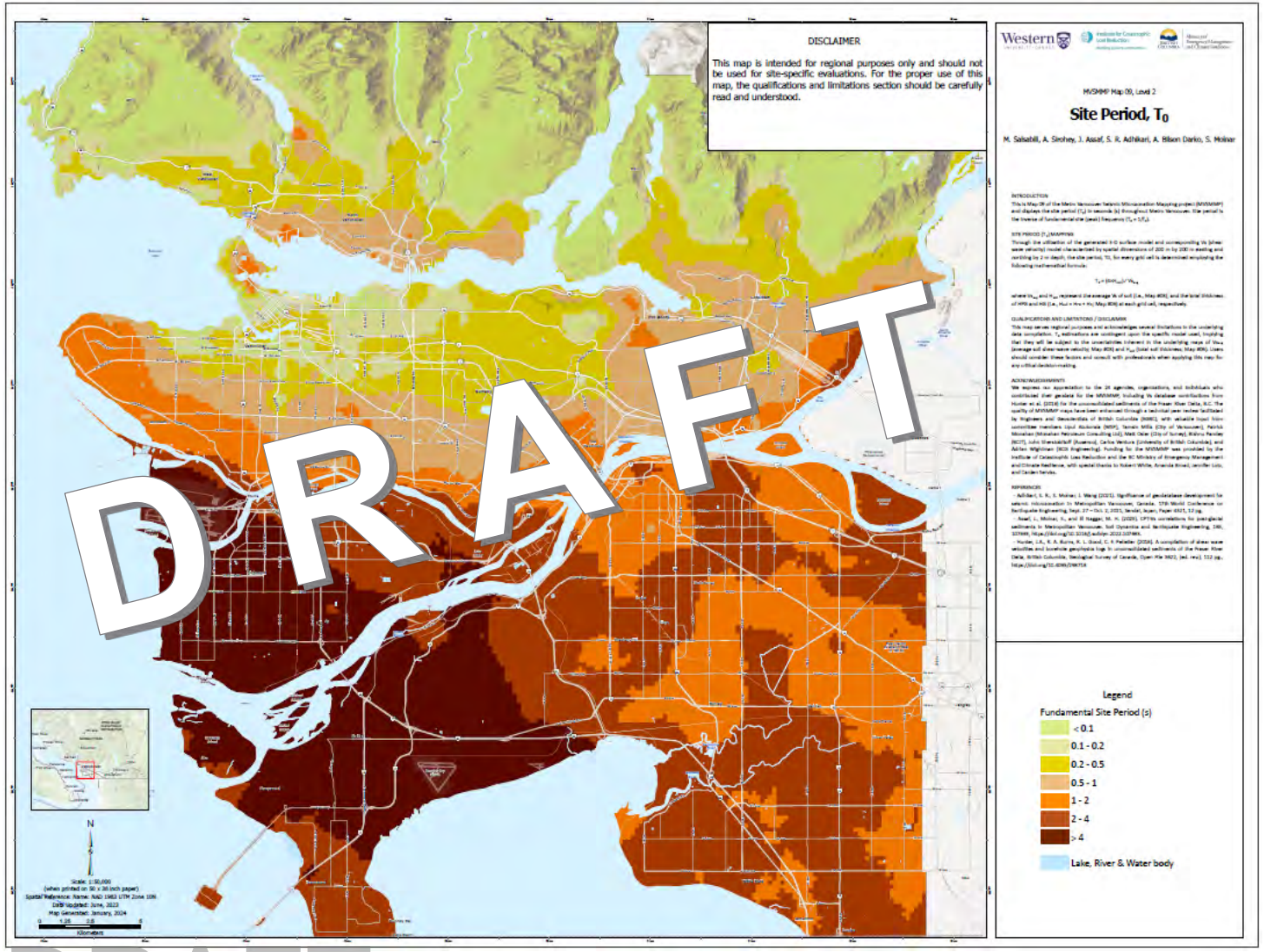
Levels of seismic microzonation mapping

Level 1	Level 2	Level 3
Susceptibility maps Surficial and remote sensing maps / spatial datasets. Remote sensing (topo) maps. Limited use of subsurface data.	**Susceptibility or Hazard Maps** Subsurface geological data and area-specific data on physical properties.	**Advanced analyses of Hazard** Extensive seismological and subsurface geological, geophysical and geotechnical data and simulations. Detailed subsurface maps and models.



1. Published Maps

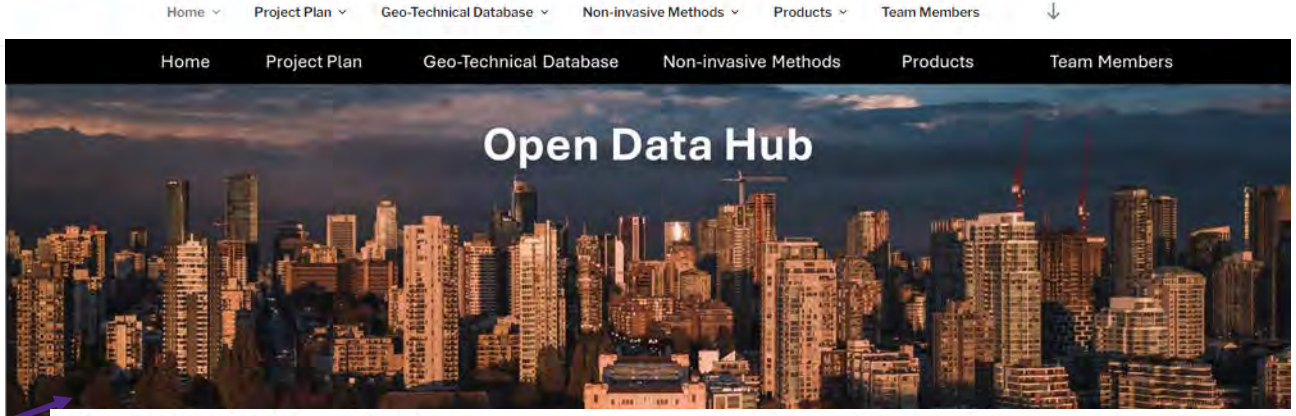
- Design of map sheets including:
  - (on left) The Map and Disclaimer (left)
  - (on right) Map Title, Authors, Explanation, Qualifications and limitations, Acknowledgements, References, and Recommended Citation. And Legend with sufficient text.
- Iterative improvements to this map sheet presentation from engagement consultations (2019, 2023) and technical peer review (2022-2024).
- PDF file format

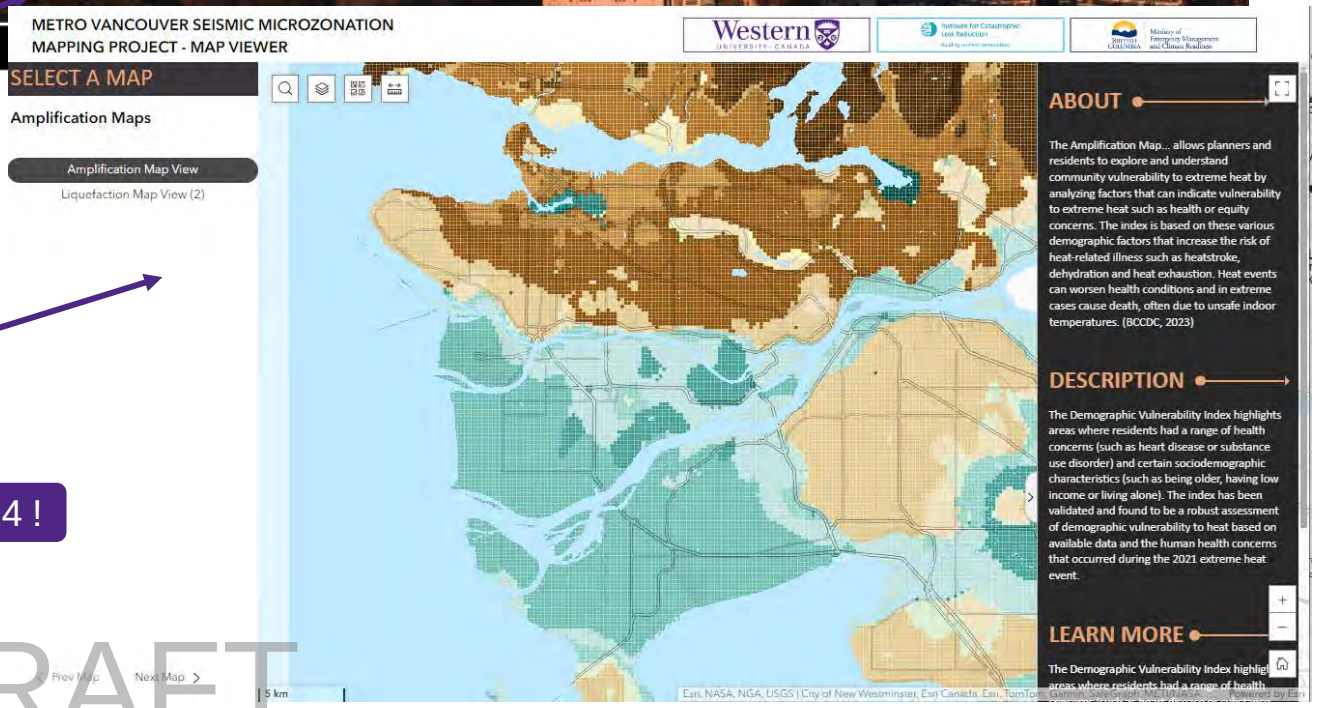


2. Open Access

- Project website
  - Products
    - Publications list and links
    - Presentations list and links
    - Engagement and Training Events list and links
  - Open Data webpage
    - With links to **Published Maps** (Map sheets, PDF format) Coming summer 2024 !
    - Access to online Map Viewer experience
      - Links to digital **ArcGIS Files** with embedded attribute tables (map **data** values) Coming summer 2024 !
    - With links to **Geodatabase** files

      Coming ~Fall 2024 !





The MVSMMP Research Team: over 30 individuals

Dr. Sheri Molnar (PI), Alex Bilson Darko and Natalia Gomez (Proj. Manager)
Research Associates: Dr. Mohammad Salsabili, Dr. Hadi Ghofrani, Dr. Adebayo Ojo
PhD students: Sujan Adhikari, Jamal Assaf, Ali Yeznabad, Alireza Javanbakht, Shuqi Bian, Benjamin Fordjour
MSc students: Chris Boucher, Meredith Fyfe, Natalia Gomez, Magdalena Kapron, Sameer Ladak, Aamna Sirohey
Field Support: Azhar Izman, Youssef Shaban, Christie Tsang, Rachel Choboter, Alex Vanderhoeff, Sanaz Darzipour, Charlotte Motuzas
BSc thesis students: Tess Leishman, Anthony Carelli; Admin. Assistant: Claire Mortera
Geodatabase Support: Ranjana Ghimire, Rozhan Raoufi, Andrew Beney, Jacob Edgett, Tyler Beattie

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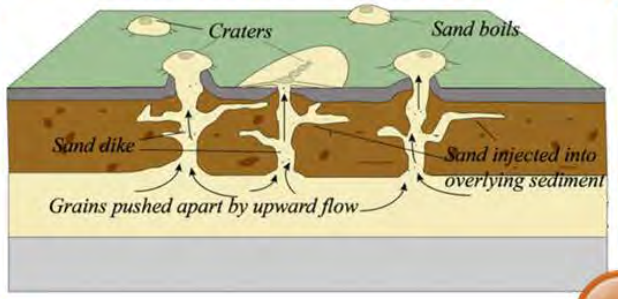
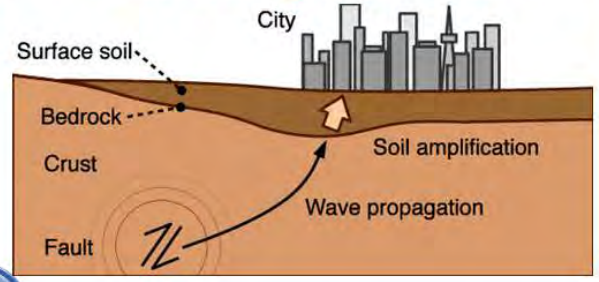
Liquefaction Hazard Potential



1D Soil Shaking Hazard



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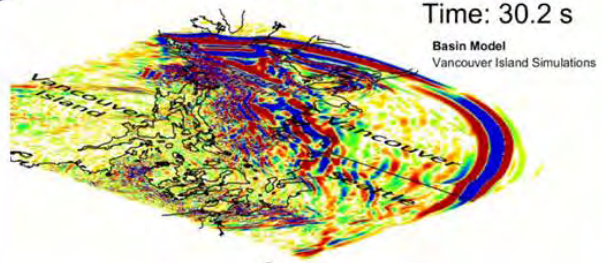
Landslide Hazard Potential

3D Basin Shaking Hazard



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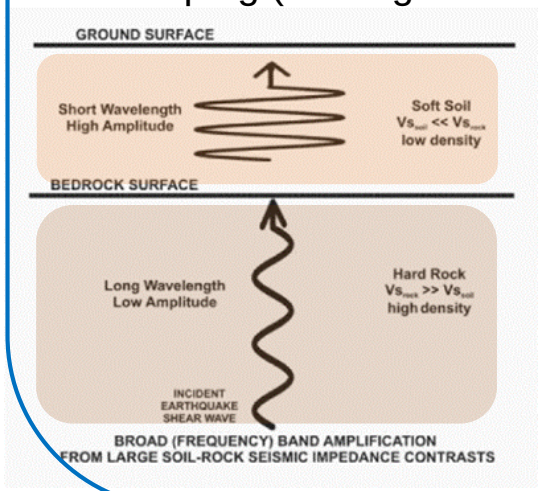
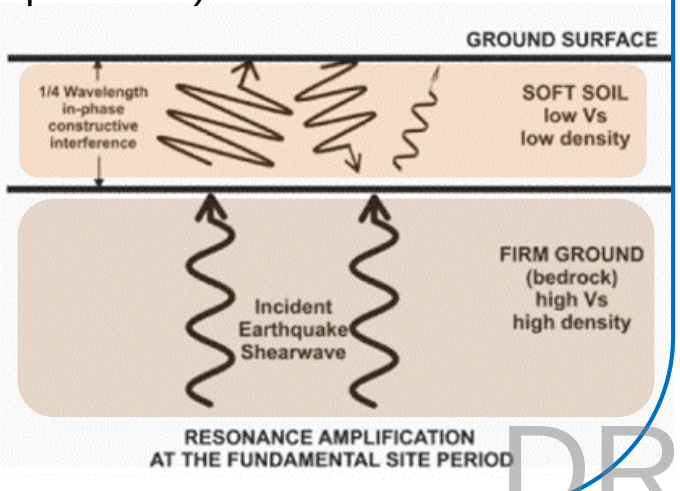
Seismic Hazard: Ground Motions or Shaking

1D site effects

- Shaking amplitudes increase as waves propagate upward (one-dimensional) from stiffer rock to softer sediments
- Waves can become trapped in soft sediment when very stiff ground below. Leads to resonance, shaking amplitudes increase at particular frequency or period; **T = *4h / Vs***
- At strong shaking, **nonlinear soil behavior** will reduce the shear stiffness (elongate site period) and increase soil damping (leading to deamplification)

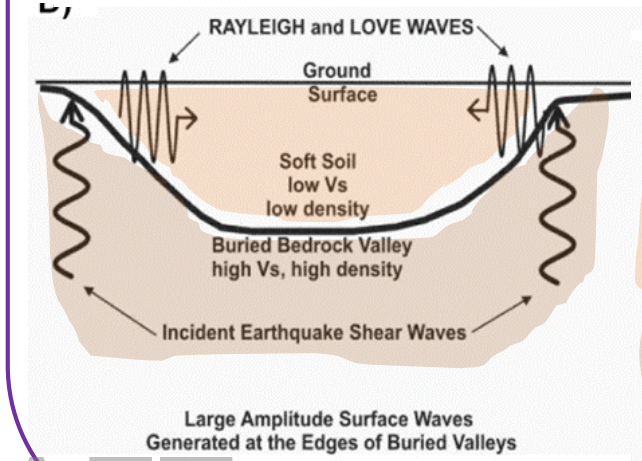


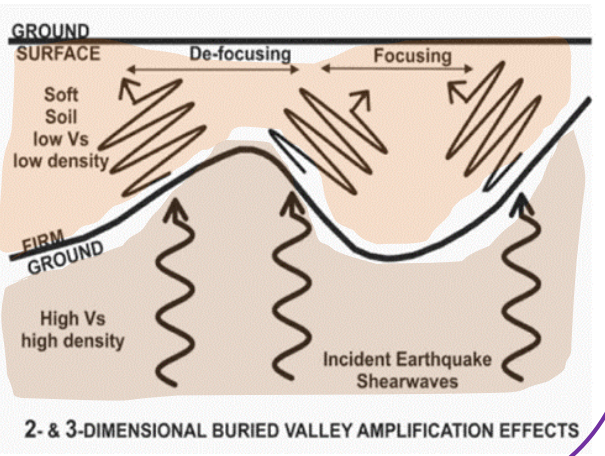


3D basin effects

3D basin structure increases the amplitude and duration of earthquake waves by:

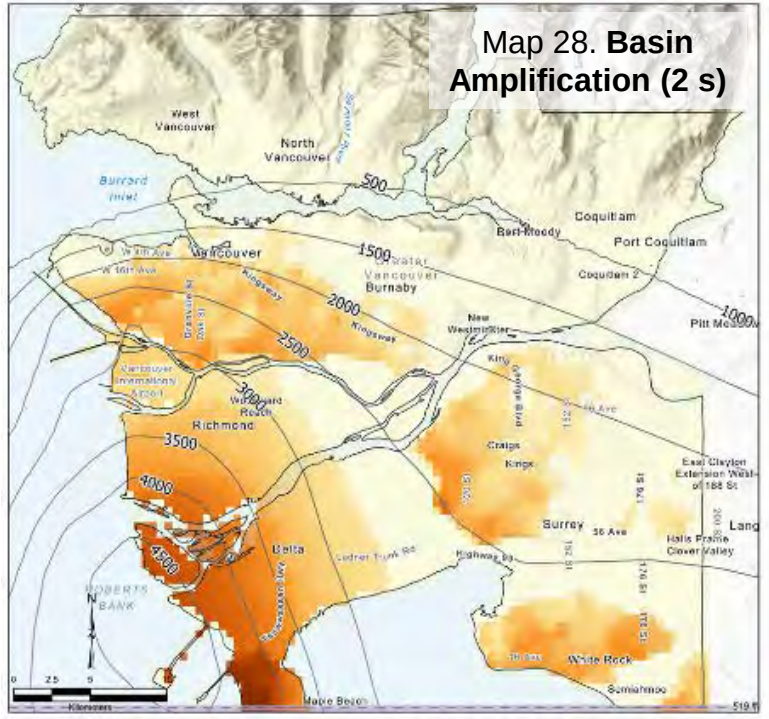
- **generation** of long-period **surface waves** from the conversion of incident shear waves at the basin edges,
- **reverberation** of surface waves within the basin,
- and **focusing** of shear waves at the basin edges.



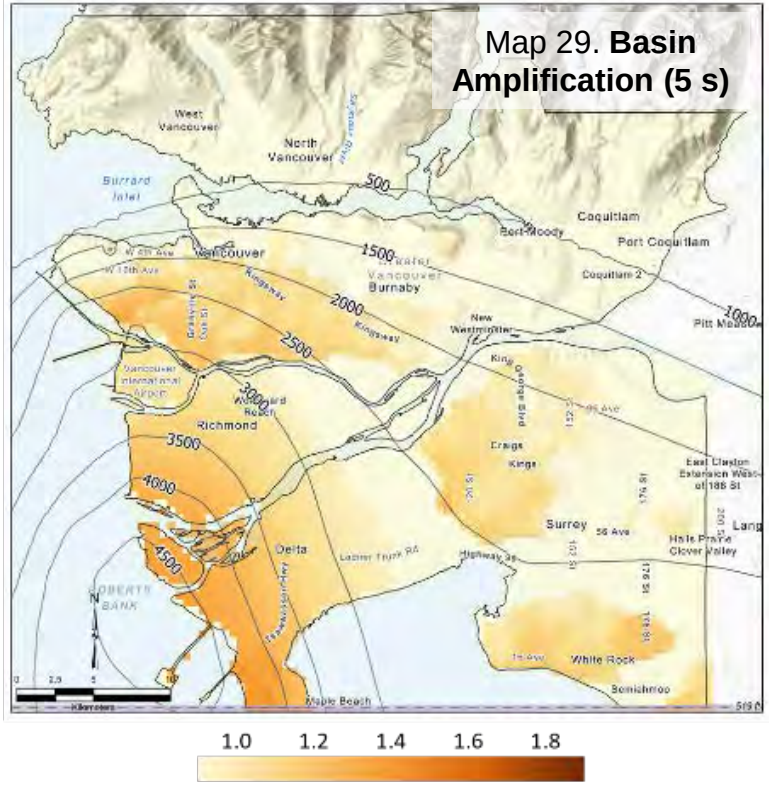


3D Sedimentary Basin Effects

3D Georgia Basin Shaking Hazard



Map 28. **Basin Amplification (2 s)**



Map 29. **Basin Amplification (5 s)**

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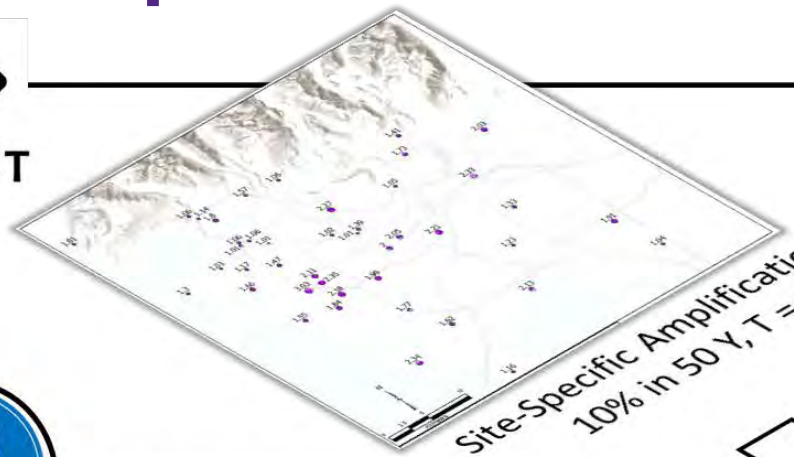
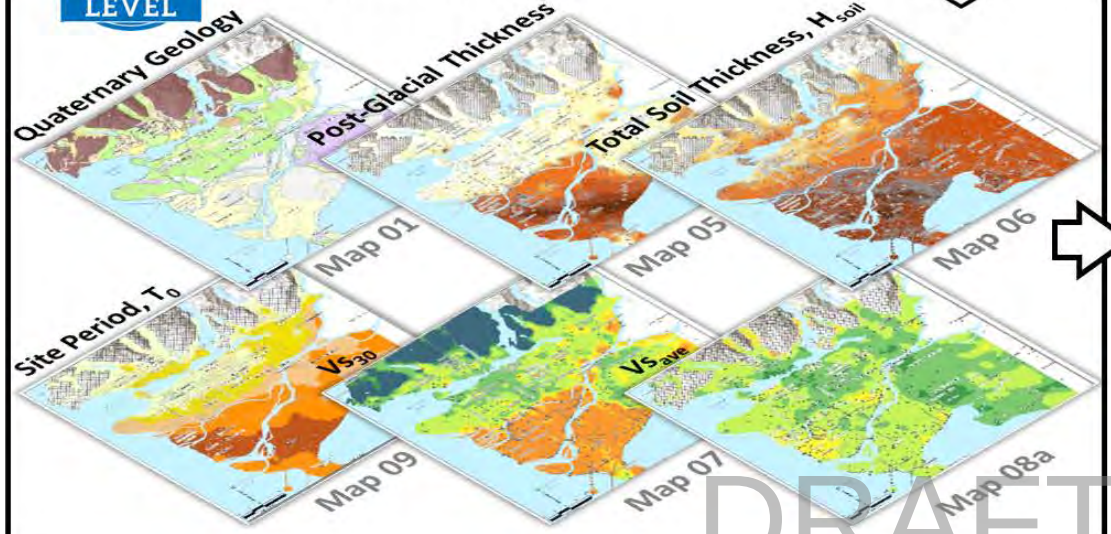
Shaking de/amplification Hazard Mapping

0.2 s = 2 storey building
0.5 s = 5 storey building
2.0 s = 20 storey building
5.0 s = 50 storey building

INPUT



2 LEVEL Shaking Susceptibility



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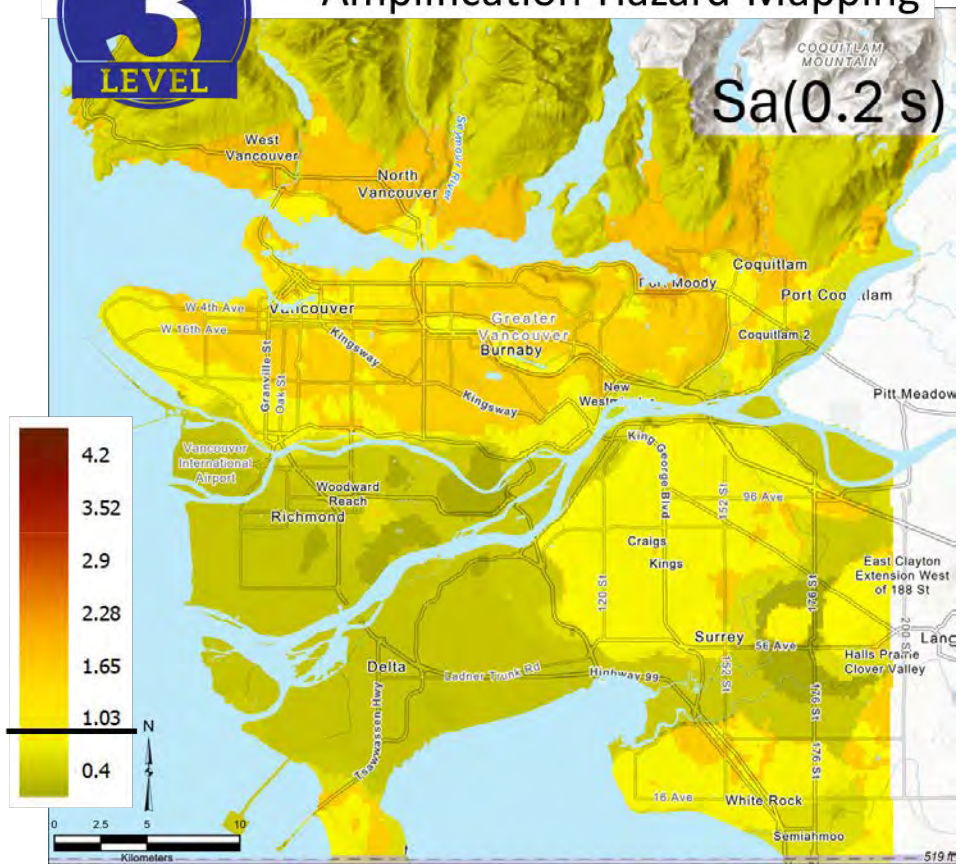
3 LEVEL Amplification Hazard Mapping



Geostatistical Interpolation

MVSMMP **Maps 19, 21, 23, and 27**

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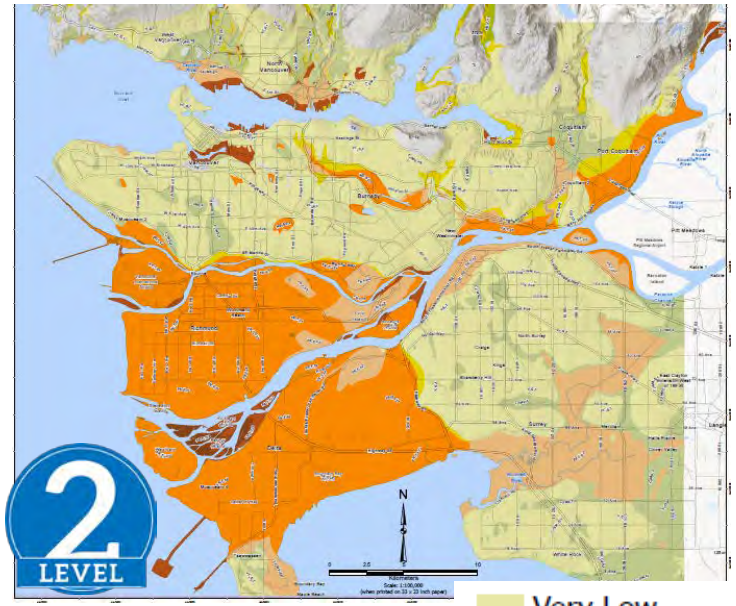
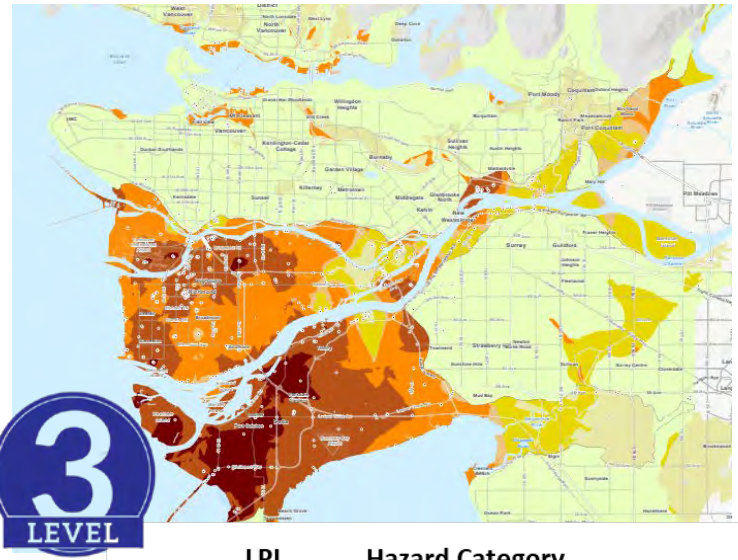
Liquefaction Hazard Mapping

Map 03: Liquefaction Susceptibility

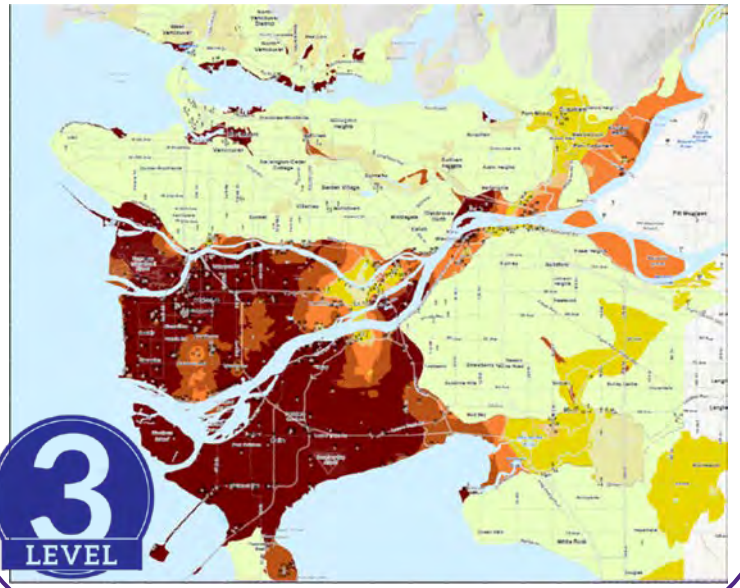


Map 13: Liquefaction Hazard Potential (475 year return period)



LPI	Hazard Category
0	Very low hazard
1-5	Low hazard
5-10	High hazard – sand boils and ground cracking may develop
10-15	

Map 14: Liquefaction Hazard Potential (2,475 year return period)



LPI	Hazard Category
15-25	Very high hazard – sand boils and ground cracking are likely. Lateral spreading may develop.
25-35	
> 35	

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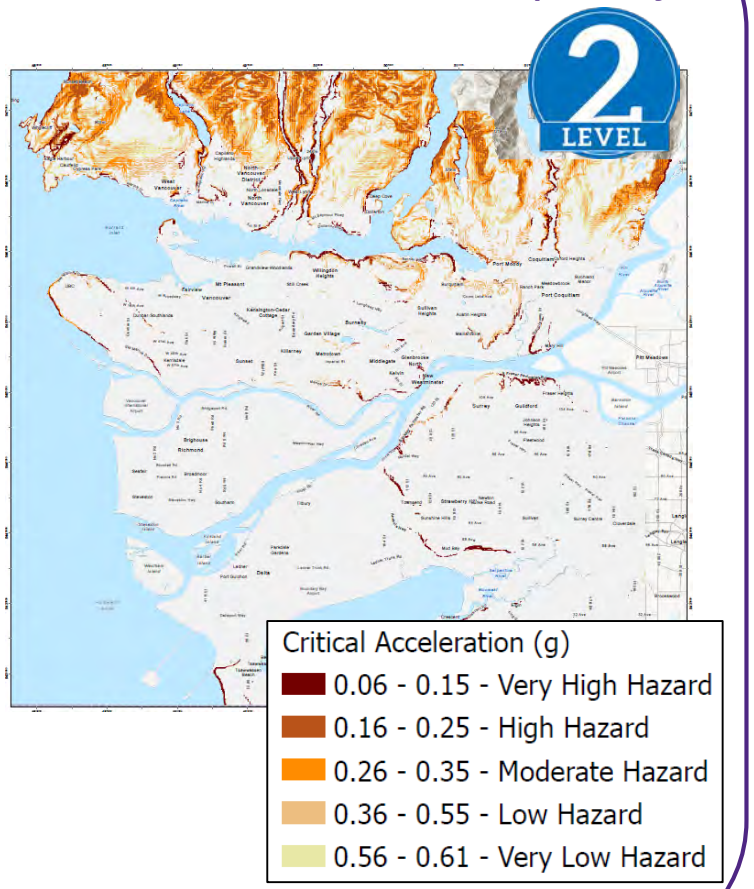
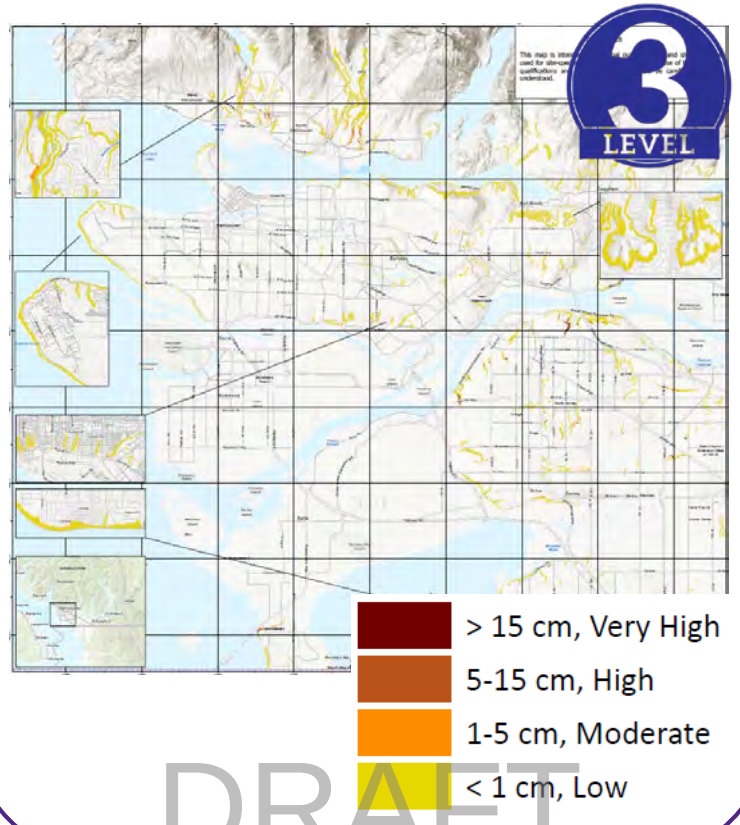
Landslide Hazard Mapping

Map 04: Landslide Susceptibility



Map 15: Landslide Hazard Potential (475 year return period)



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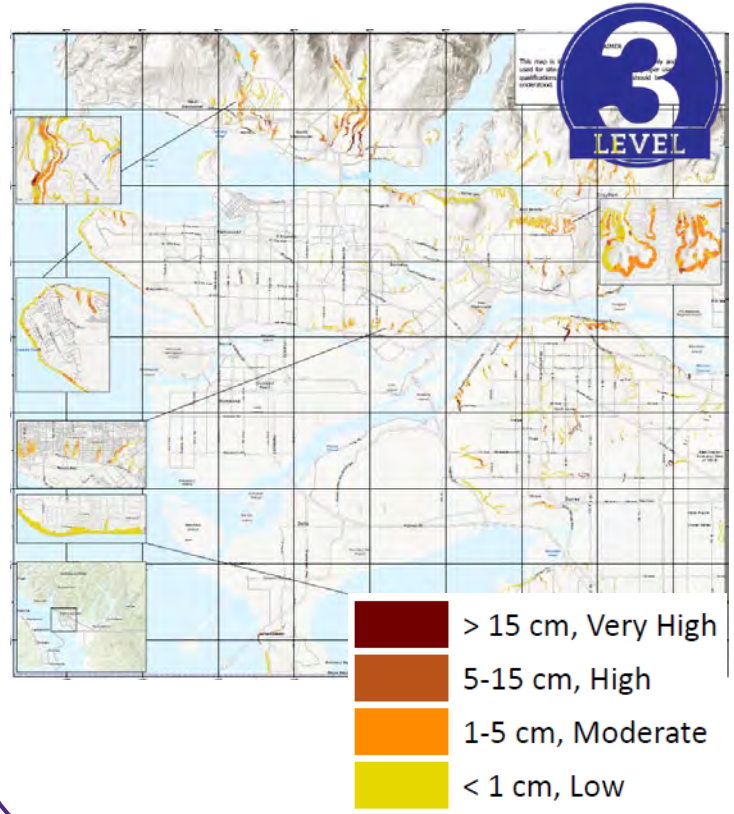
Map 16: Landslide Hazard Potential (2,475 year return period)



The Best Information Available

Key Facts

1. There is no Canadian standard for SMMs Now EGBC guidelines for BC!
2. No existing SMMs in Canada are accessible in digital (GIS layer) form until now
3. Very few regional SMMs in Canada are Level 3 until now

Key Deliverables

- EGBC Professional Practice Guidelines for Development and Use of SMM in BC (April 2024)
  - EGBC Webinar coming
- Regional Geodatabase(s)
- Regional Velocity Model(s)
- Suite of Region-Specific Seismic Hazard Maps (approx. 30 maps)

  12 Seismic Susceptibility (Level 2)

  18 Seismic Hazard (Level 3; mean return period of 475 and 2,475 years)

Q/A, Discussion

USE OF SEISMIC MICROZONATION MAPS

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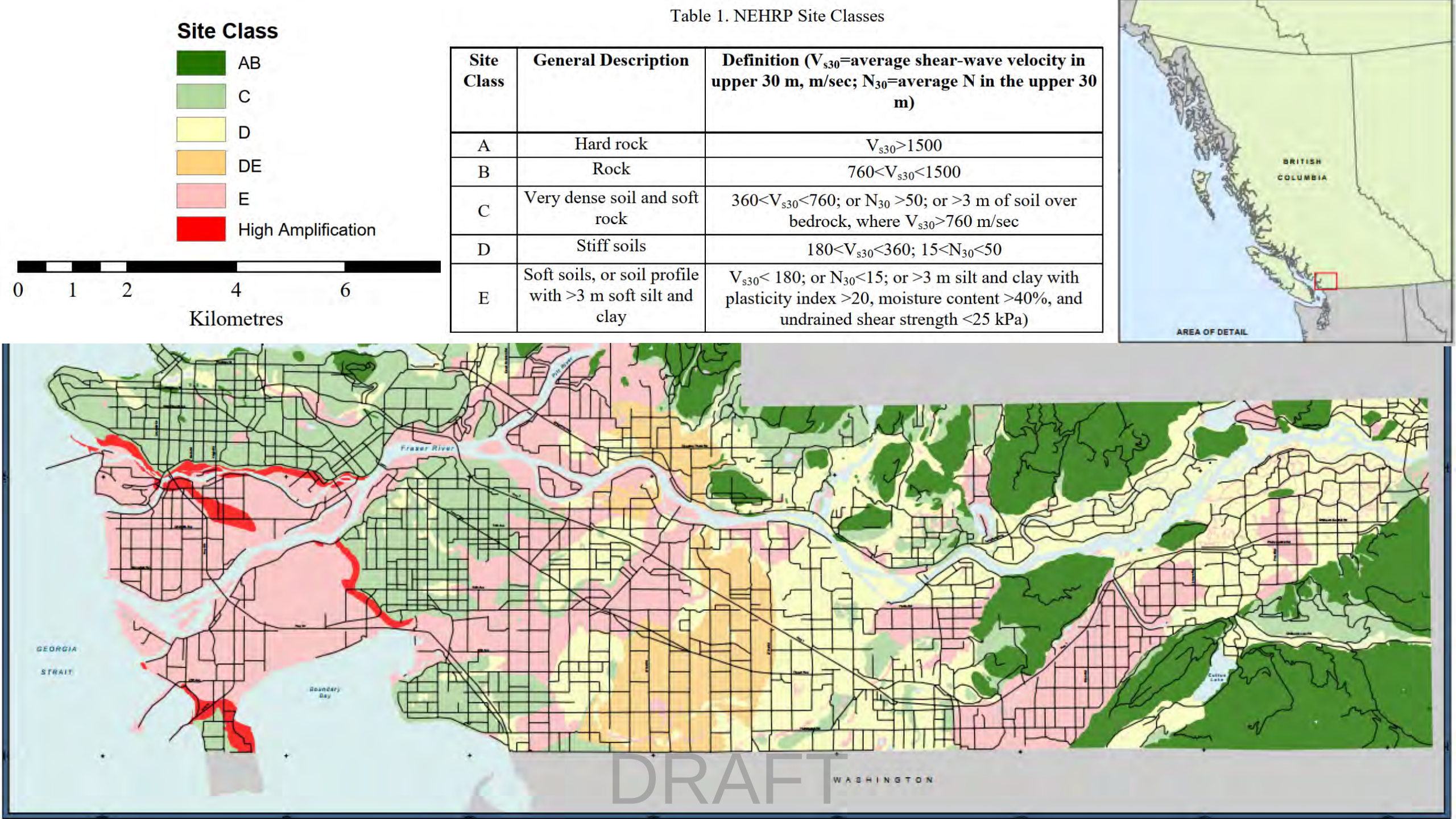
Professional Practice Guidelines

- Complement the MVSMMP
- Provide a common approach for using the MVSMMP and other seismic microzonation maps in BC
- Provide a common approach for carrying out seismic microzonation mapping projects in BC.
- Organized in three sections:
  - Introduction to Seismic Hazards and Seismic Microzonation Mapping
  - Use of Seismic Microzonation Maps
  - Development of Seismic Microzonation Maps

Table 1. NEHRP Site Classes

Site Class	General Description	Definition (V_{s30}=average shear-wave velocity in upper 30 m, m/sec; N_{30}=average N in the upper 30 m)
A	Hard rock	$V_{s30}>1500$
B	Rock	$760<V_{s30}<1500$
C	Very dense soil and soft rock	$360<V_{s30}<760$; or $N_{30}>50$; or >3 m of soil over bedrock, where $V_{s30}>760$ m/sec
D	Stiff soils	$180<V_{s30}<360$; $15<N_{30}<50$
E	Soft soils, or soil profile with >3 m soft silt and clay	$V_{s30}<180$; or $N_{30}<15$; or >3 m silt and clay with plasticity index >20, moisture content >40%, and undrained shear strength <25 kPa)



Geology

- Topographic
- Surficial
- Quaternary
- Depth to Bedrock
- Subsurface Data Point

Ground Shaking

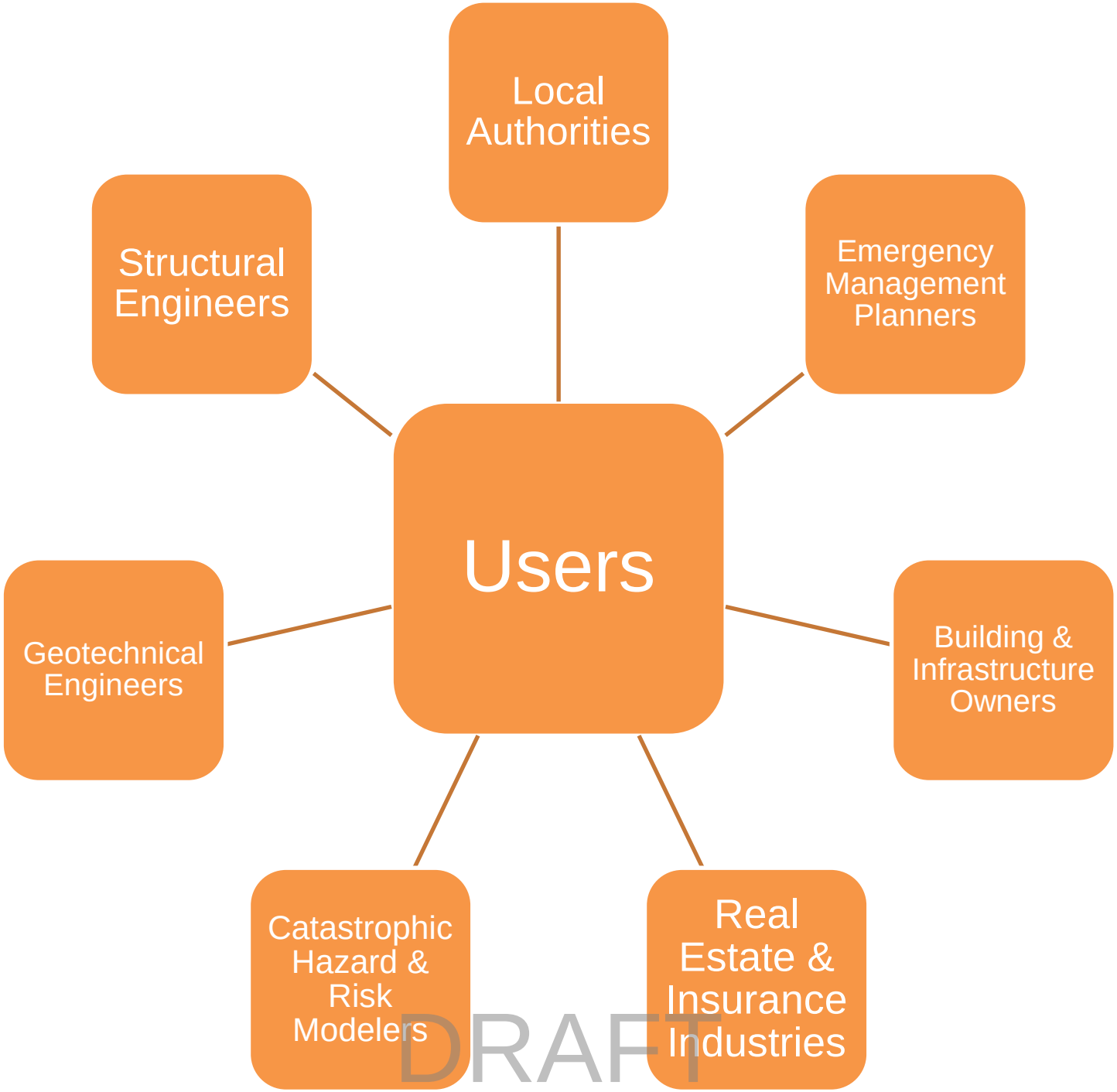
- V_{s30}, $V_{s,ave}$
- Site Period (T_0)
- Depth to V_s = 1.5 km/s
- Amplification Hazard Maps (various site and return periods)
- Basin Amplification Hazard Maps (various site periods and EQ sources)

Liquefaction

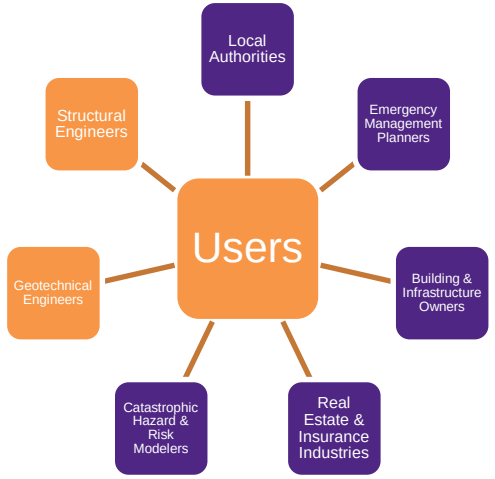
- Groundwater Table
- Liquefaction Susceptibility
- Thickness of Liquefiable Deposits
- Vertical or Lateral Displacement
- Seismic-Induced Liquefaction Hazard (475- and 2475-year return periods)

Landslide

- Topographic Slope
- Landslide Susceptibility
- Landslide Displacement
- Landslide Inventory
- Seismic-Induced Landslide Hazard Maps (1/475 and 1/2475 annual exceedance probabilities)



ENGINEERS & GEOSCIENTISTS
BRITISH COLUMBIA



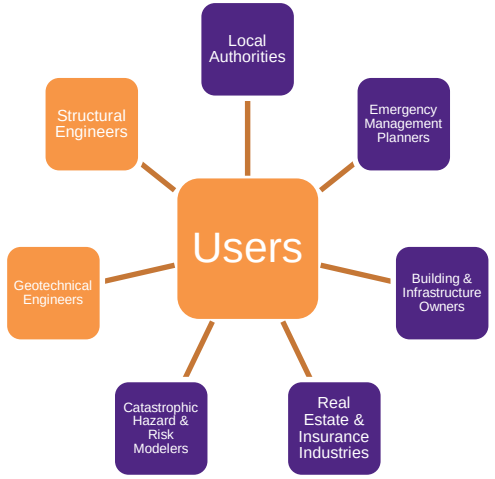
Use – Local Authorities + Emergency Planners

Regional planning, land use, and asset management

- Avoid new risk, reduce existing risk
- Avoid locating new critical infrastructure in particularly high-hazard areas
- Assess and prioritize retrofit of existing critical infrastructure

ENGINEERS & GEOSCIENTISTS BRITISH COLUMBIA

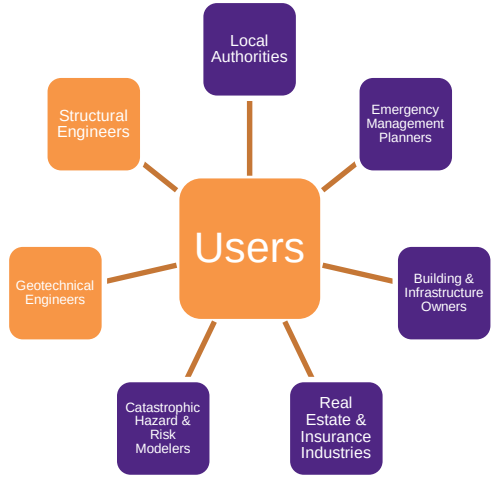
Use – Local Authorities + Emergency Planners cont'd



Risk assessments and emergency management

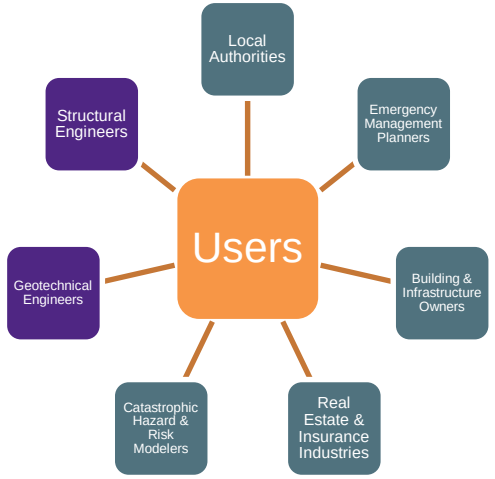
- Planning – doing as much as possible before the event
- Mitigation – prioritizing retrofits
- Response – estimating debris removal, supply, and post disaster building assessment requirements/priorities
- Recovery – determining what and where to rebuild

Use – Local Authorities + Emergency Planners cont’d



Policies

- Expectations for use and reference to maps
- Anticipating geotechnical and structural measures
- Prescriptive design requirements or alternate paths (linear infrastructure)



Use – Geotechnical + Structural Engineers

- Do not replace the need for site-specific seismic or geotechnical field investigations
- Can be utilized for preliminary assessments, feasibility studies, conceptual designs, and project planning/scoping
- For geotechnical engineers – do not drastically change the typical workflow, but can simplify the investigation and design process by providing more detailed data at an earlier stage
- For structural engineers – can depict amplification and basin effects to provide good estimates of parameters for the development of design response spectrum (for preliminary design)

Q/A, Discussion

For More Info & Upcoming Sessions

- EGBC Professional Practice Guidelines for Development and Use of SMM in BC (Guidelines are now live, EGBC Webinar coming soon).
- EERI BC Session- July 16th; no-cost for EERI-BC members, low-cost for general public.
- Complimentary videos online: ICLR Friday forum, URBC 2023 Panel Discussion, SC Chapter planner session.

Metro Vancouver Seismic Microzonation Mapping Project (2017 - 2026)

Release of Seismic Hazard Maps for western Metro Vancouver: **summer 2024**

Seismic Microzonation Mapping of eastern Metro Vancouver: **2024 to 2026**

Release of Seismic Hazard Maps for eastern Metro Vancouver: **Late 2026**

https://metrovanmicromap.ca

- Open data portal (geodata, maps) under development
- Online map viewer experience under development

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