BRITISH COLUMBIA Emergency ManagementBC

Institute for Catastrophic Loss Reduction

Seismic Landslide Hazard Mapping for Greater Vancouver

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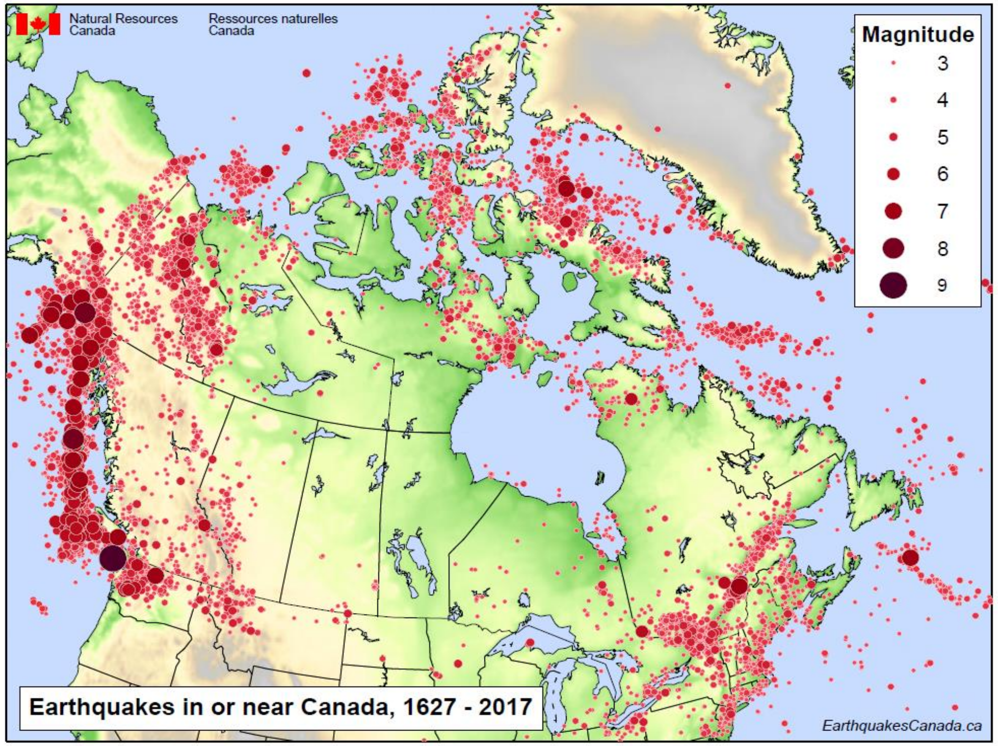
Today’s Agenda

- **Background and Motivation**
- Region of Study and Required Information
- Methodology
- Example solution
- Conclusion and Future Works

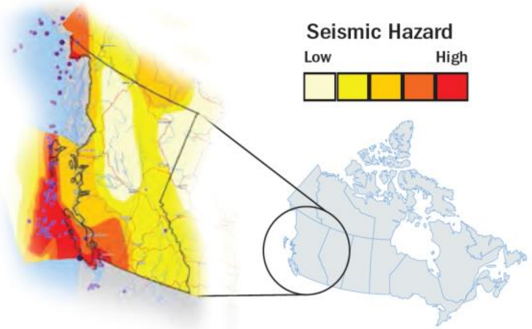
Background and Motivation: Seismicity of Canada



Source: Earthquakes Canada

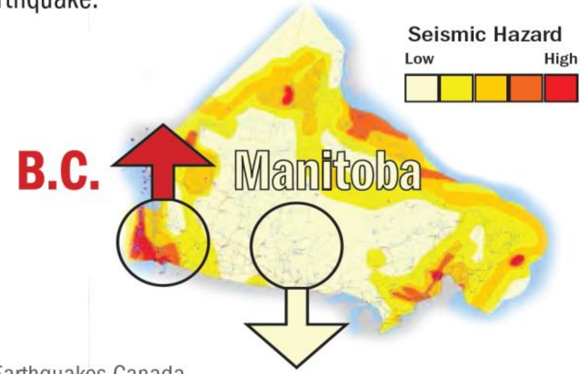
Why Vancouver?

90% of **earthquakes** occur along active plate boundaries.
60% of Canada's earthquakes occur along BC's coast.

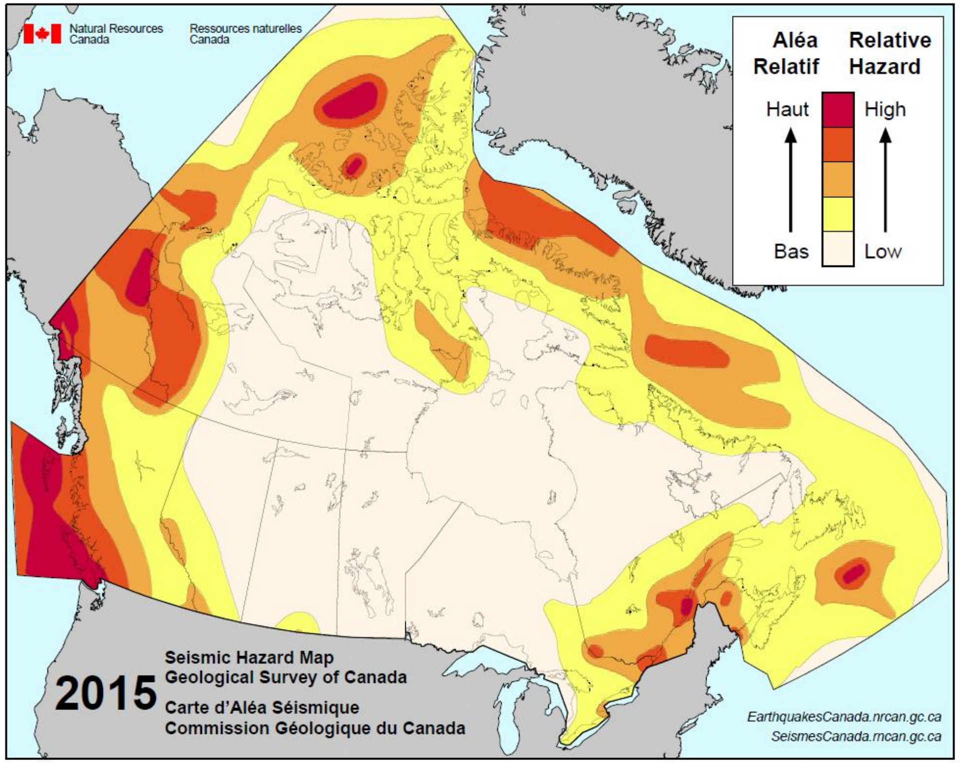


Source: Earthquakes Canada

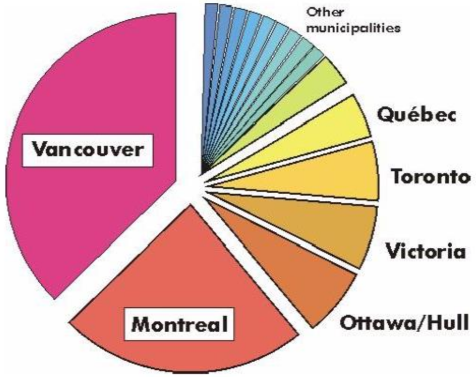
BC is the province **most likely** to experience an earthquake, and **Manitoba** is the province **least likely** to experience an earthquake.



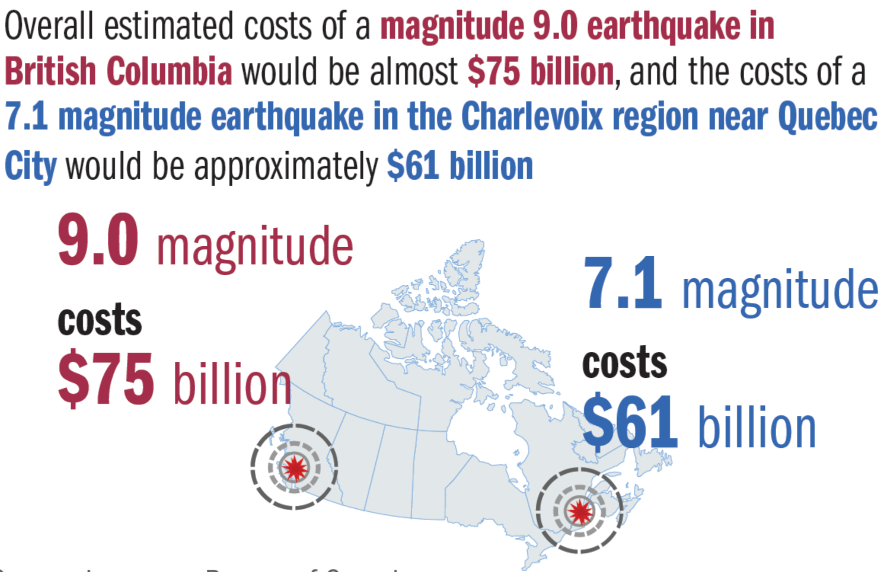
Source: Earthquakes Canada



Why Vancouver?



Relative distribution urban seismic risk in Canada. More than three quarters of the vulnerability is concentrated in six of Canada's largest urban areas. (Adams et al. 2002)



Source: Insurance Bureau of Canada

Effects of Large Earthquakes:

- Shaking
- Liquefaction
- Tsunami
- <u>Landslides</u>

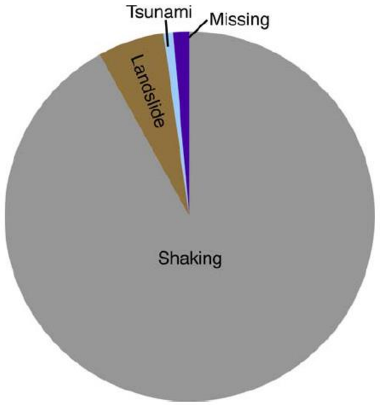
The Las Colinas debris flow at Santa Tecla (a suburb of the capital San Salvador) triggered by the January 2001 El Salvador earthquake. Over 500 people died in the area affected by this slide. [from: http://landslides.usgs.gov]

The 1946 Vancouver Island earthquake (M 7.3) triggered more than 300 landslides over an area of about 20,000 km2 (Mathews, 1979), providing some indication as to what might happen during a future earthquake of this magnitude

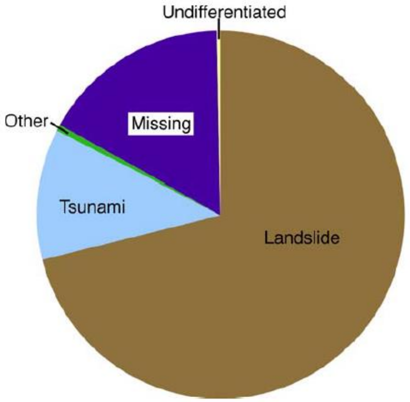
Why landslides?

Global earthquake casualties:

- 1,442,342 documented fatalities for the period of 40 years.
- Shaking (i.e., partial or total building collapse) stays the main reason of fatalities.
- We observe that landslides are responsible for 71.1% of the non-shaking deaths, followed by tsunami at 11.5%.



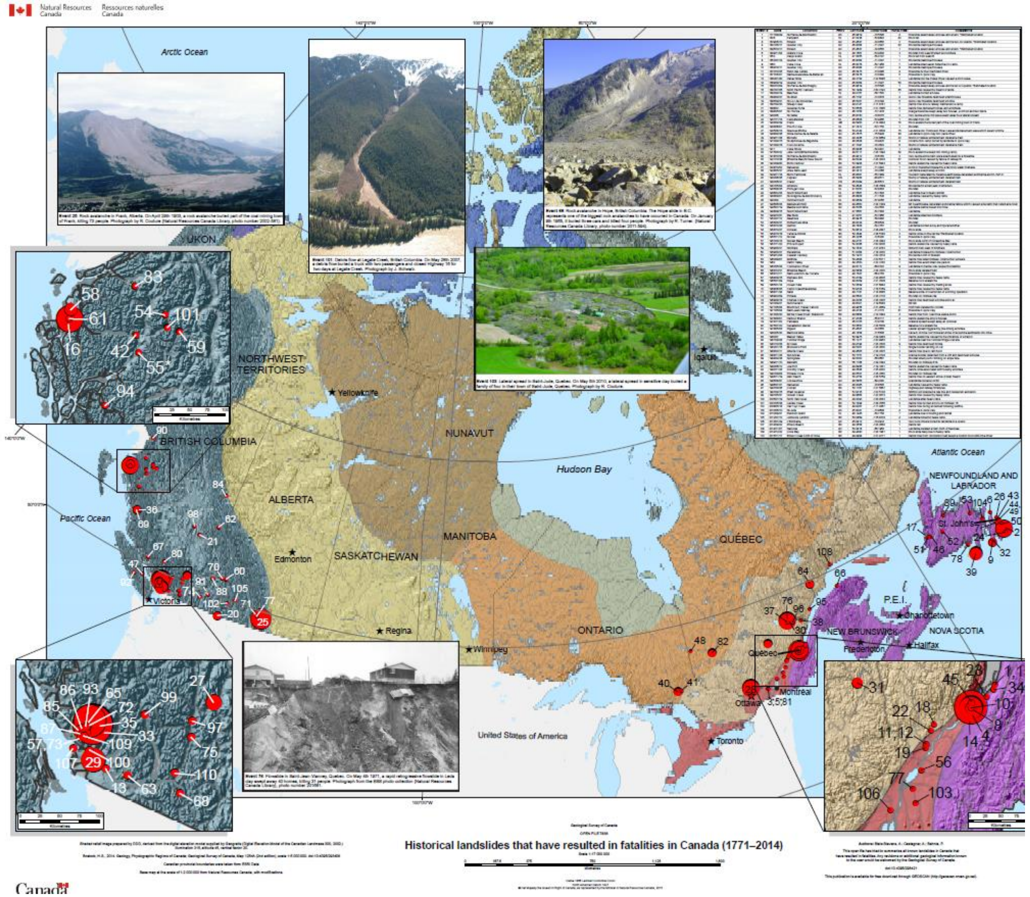
Fatality causes for all deadly earthquakes between September 1968 and June 2008, with deaths from the 2004 Sumatra event removed (Marano et al, 2010)



Non-shaking earthquake fatalities for all deadly earthquakes between September 1968 and June 2008, with deaths from the 2004 Sumatra event removed (Marano et al, 2010)

Historical landsides that have resulted in fatalities in Canada (1771-2014)

- More than 700 fatalities in 110 events across Canada.
- More than 50 % of landslides with fatalities have occurred in BC.



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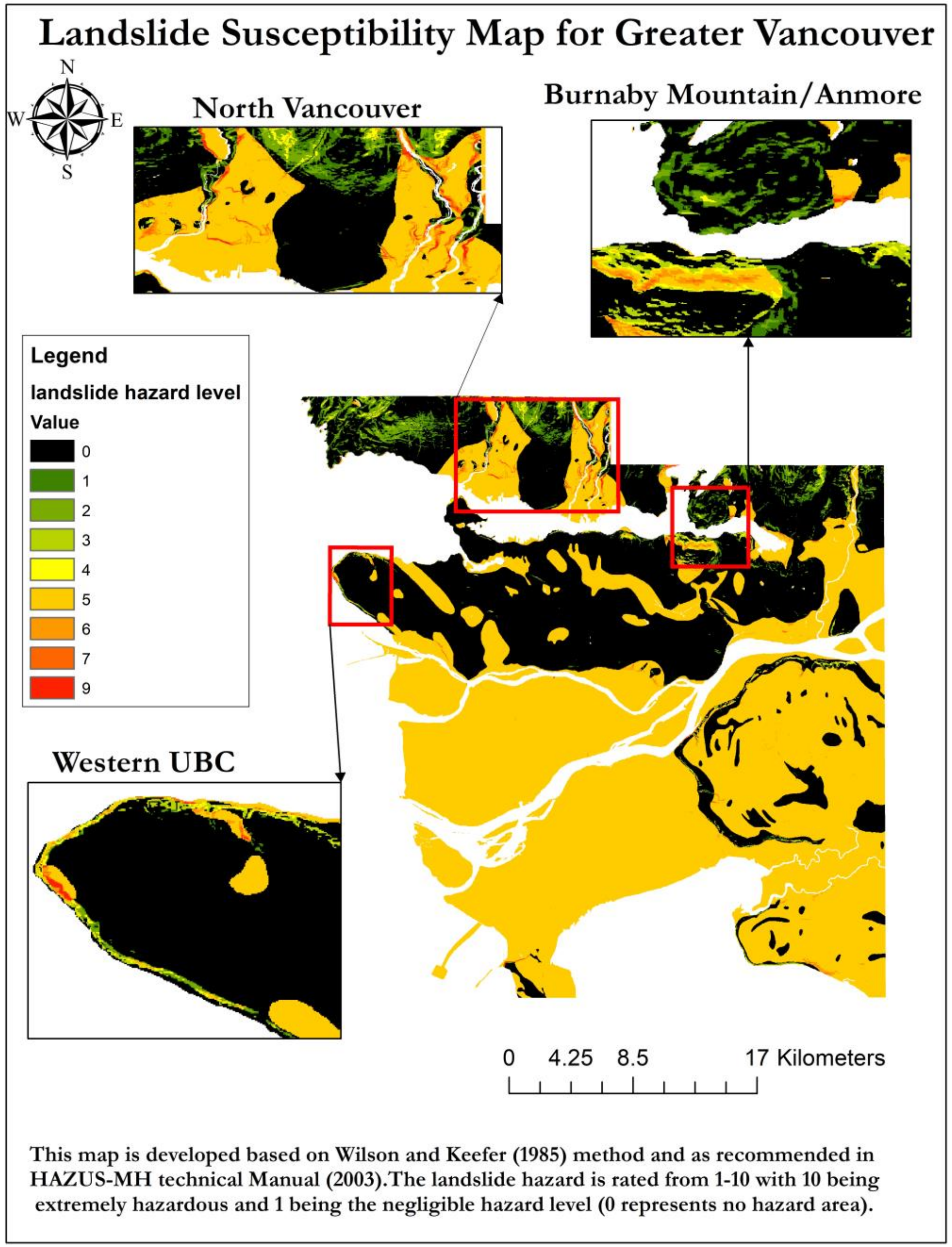
Region of Study:

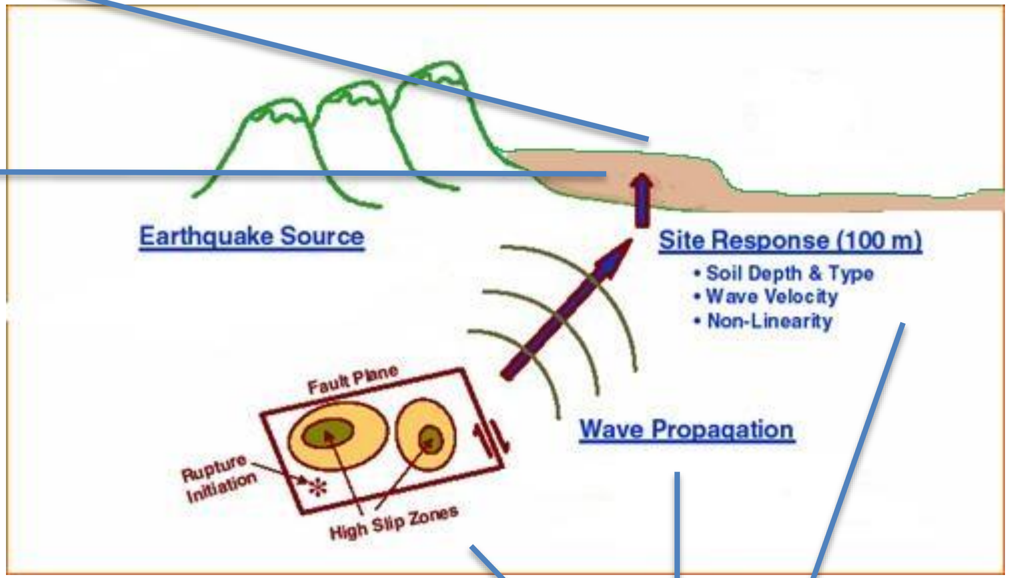
- The area under study covers most cities in Metro Vancouver.
- This map shows landslide susceptibility (i.e. relative likelihood of future landsliding based solely on the intrinsic properties of a locale or site) for the region of study.
- **Landslide hazard map** (including seismic parameters of the region and strength parameters of soil types) is under development.



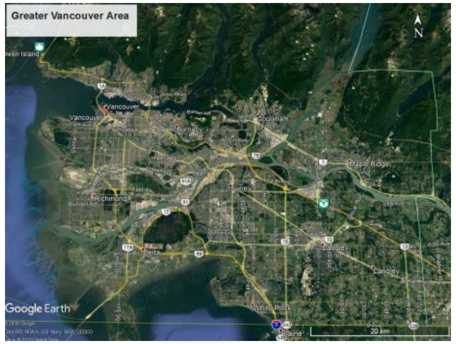
Required Data for Seismic Landslide Hazard Mapping:

3. Topographic Information

2. Subsurface Information



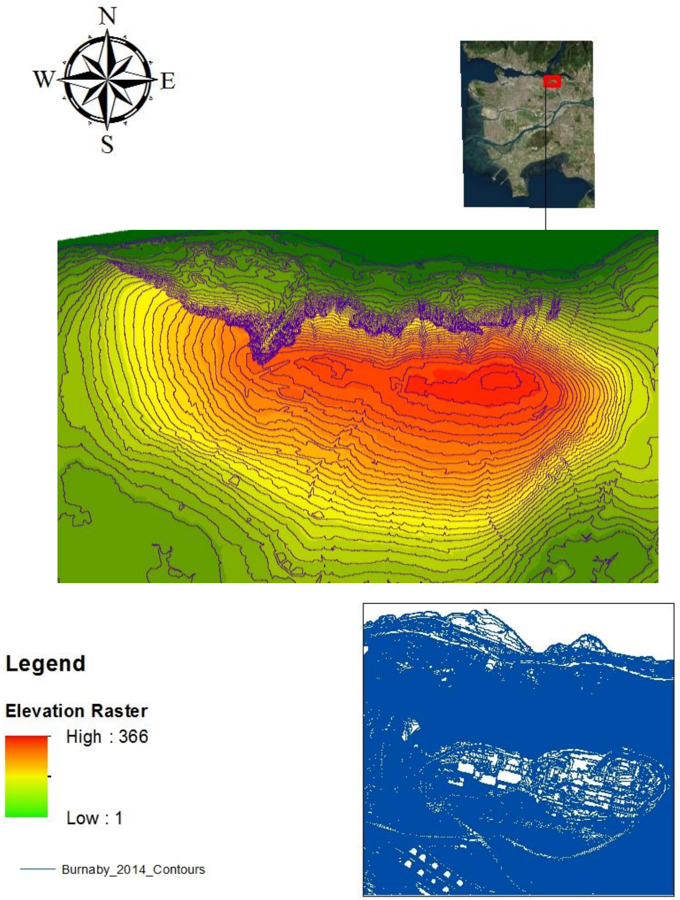
1. Seismic hazard information



Greater Vancouver area

1. Topographic Information

- the resultant high-resolution elevation contours from Light Detection And Ranging (LiDAR) data, provide detailed topographic information (1 by 1 m in steep slope areas) for the region1.

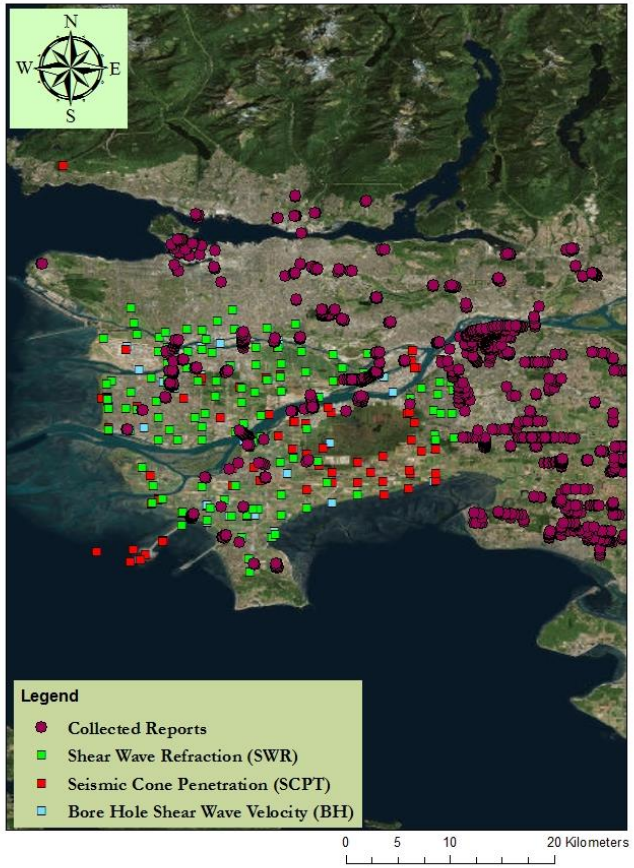


Field Observations:

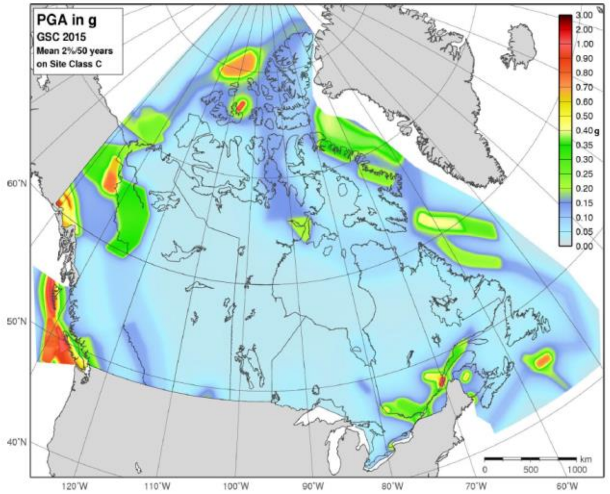
Sloping areas on very steep sides of Burnaby Mountains, some deformation signs were evident, July 7, 2018, Burnaby Mountains

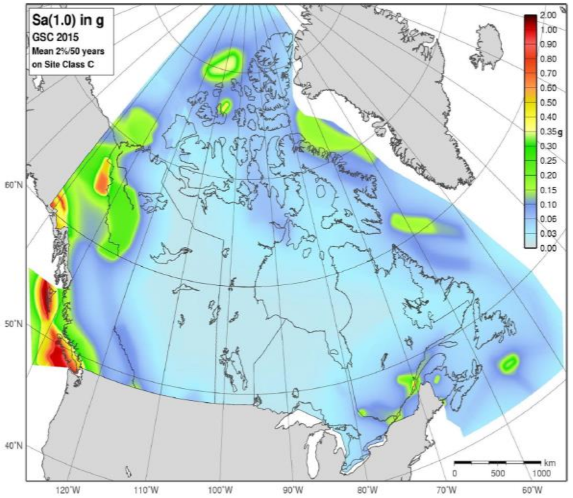
2. **Subsurface information**

A geodatabase of subsurface geodata (geology, geophysical, and geotechnical information) across the region is assembled from public and private sources to derive strength parameters for geologic units in the region.

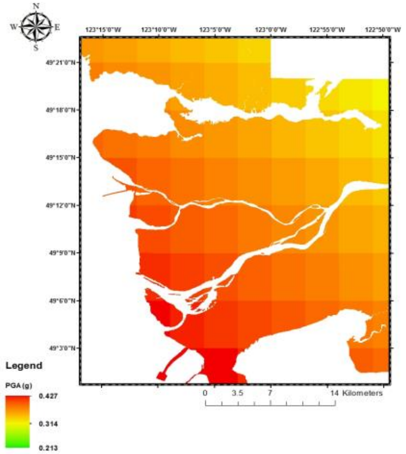


3. Seismic Information





Peak Acceleration and spectral acceleration at 1 (s) maps for Canada. Mean values of 5% damped peak acceleration for Site Class C and a probability of 2%/50 years, in g.



PGA (2% in 50 years exceedance) for Southwestern BC

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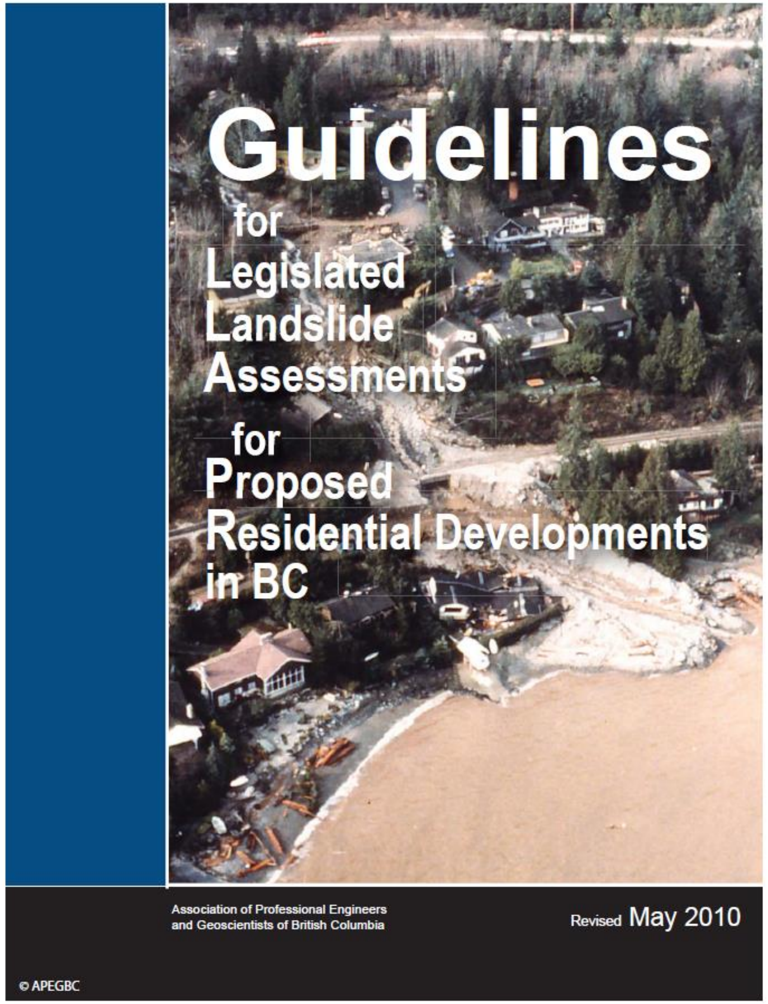
Available Guidelines for Landslide Assessments

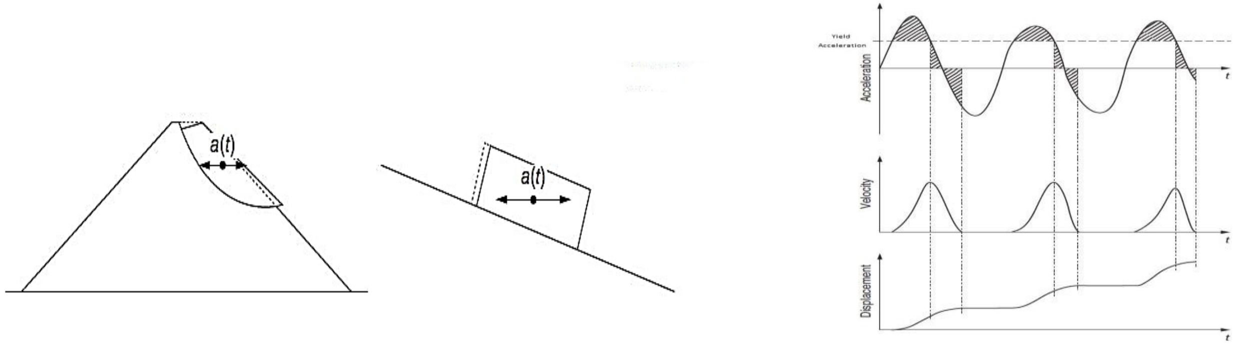
- Newmark displacement method and empirical equation of Bray and Travasarou (2007) is adopted for displacement calculations.
- In the guidelines, slope displacements of 15 cm or less are considered acceptable for a slip surface between a residential building and the slope face.

Landslide hazard	Sliding displacement (cm)
Very low	<5
Low	$5<D<15$
Moderate	$15<D<30$
High	$D>30$

Landslide hazard criteria used by California Geological Society (CGS) (From Saygili and Rathje (2009)



Newmark displacement method



Newmark's Sliding block model: (a) actual slope and sliding block representation of slope subjected to earthquake loading (adopted from Duncan et al.2014)

Topography info

Subsurface Data

Seismic Hazard Parameters

Empirical Equations

Yield acceleration (Ky)

Destabilizing forces

Stabilizing forces

Predicted Displacement map

Seismic Landslide hazard map

Flowchart of Newmark displacement analyses

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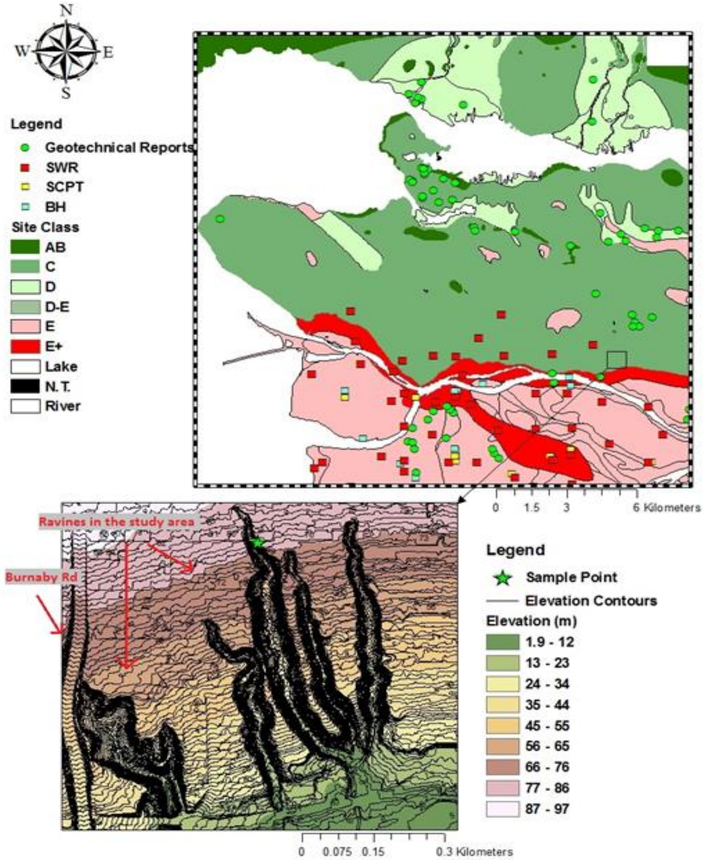
An example map for 1.5 $\mathbf{km^2}$ area in South Burnaby:

(a)



(b)

Greater Vancouver region and selected quadrangle in this study: (a) Sample point from field survey in July21, 2018(the green star in part b shows its location) (b) Site classes and available reports(collected geotechnical reports and Hunter et al (2016) data, SWR: Surface Shear Wave Refraction, BH: Borehole shear wave velocity logs, SCPT: Seismic Cone Penetrometer

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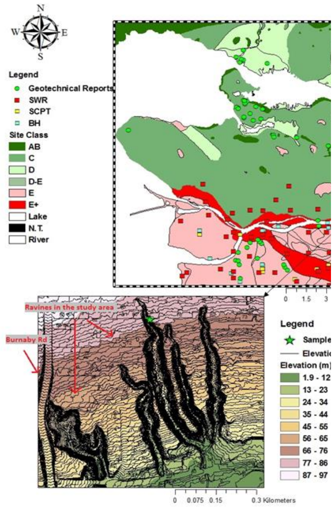
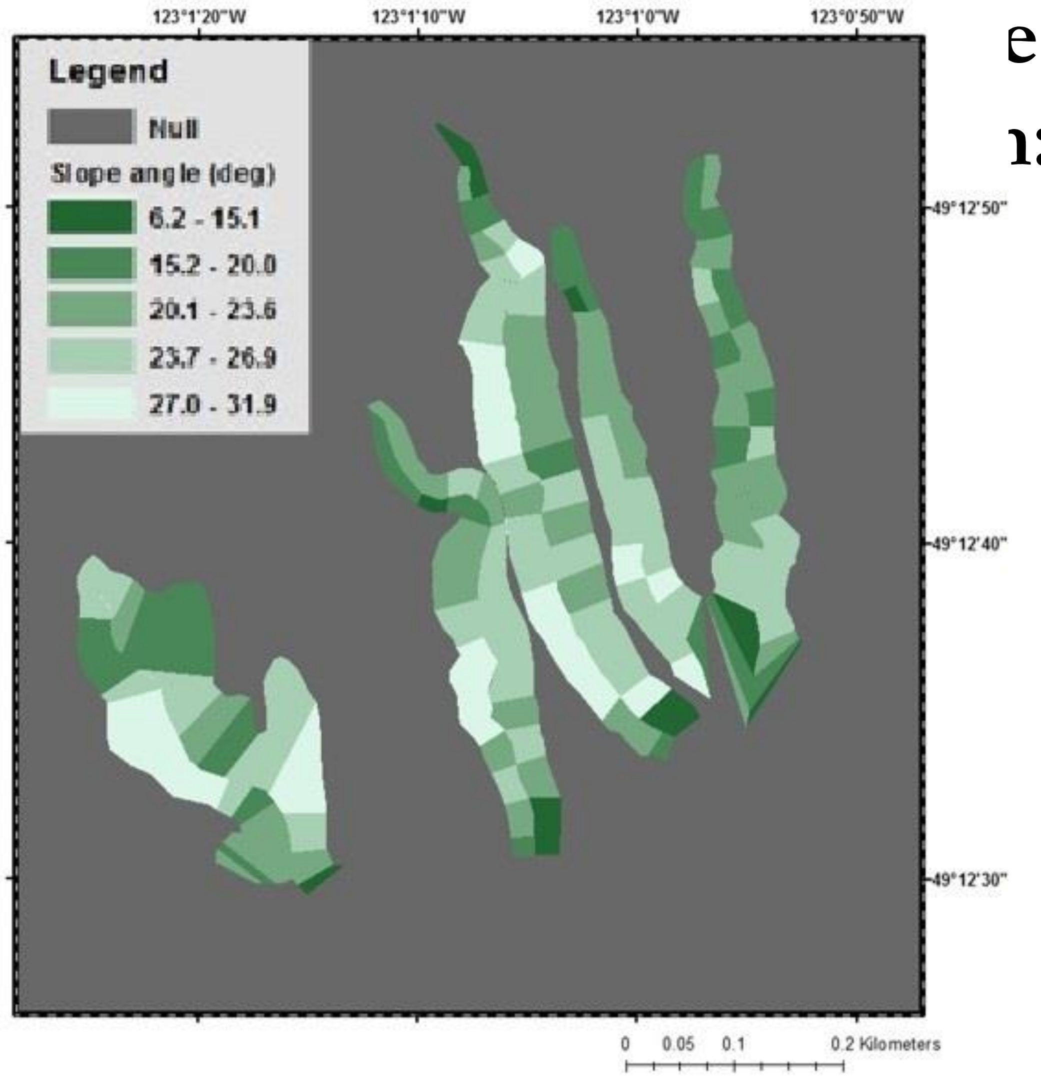
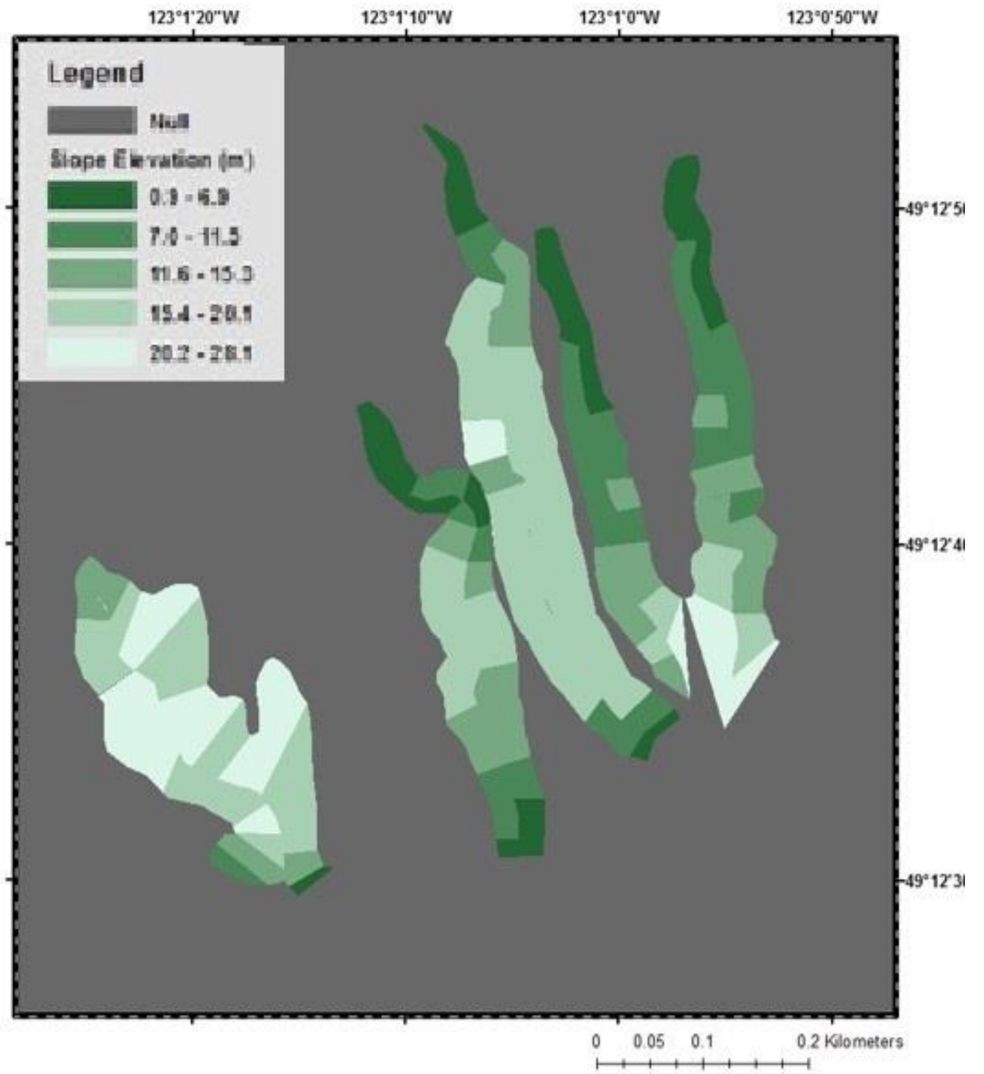
(a)





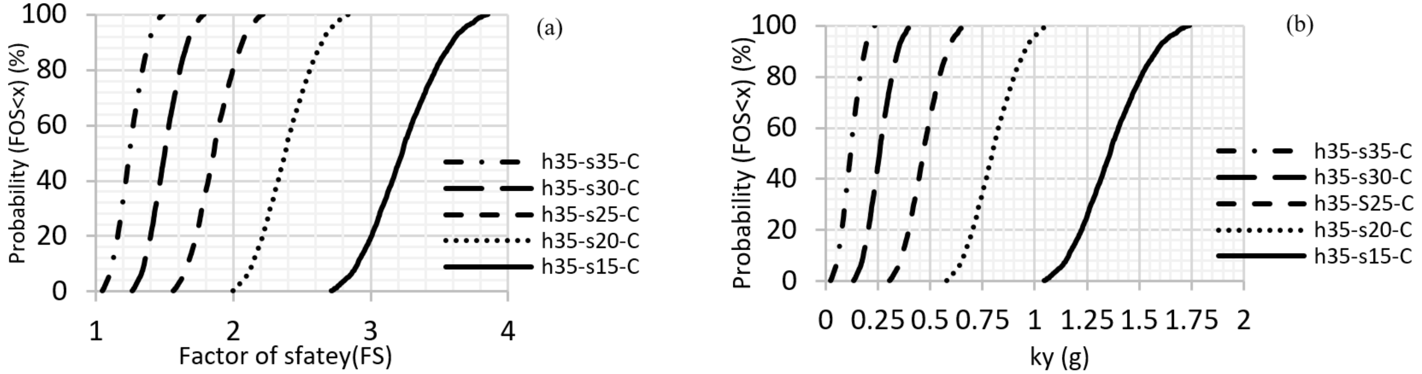


Based on topographic analyses and user defined grids for the region under study (a) slope angles (b) and elevation values (c) are captured

Yield acceleration(Ky) mapping based on probabilistic stability analyses :

- In the region of interest, there is sufficient and consistent information about the soil type and its relative density (D_r). Therefore, grain size, soil type, D_r and the confining pressure are utilized to derive the required strength parameters. (e.g. Lepz (1985) and later Bolton (1995) and Salgado et al. (2000))

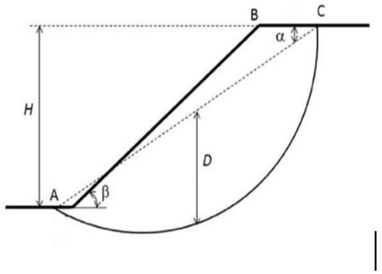
- Using the normally distributed soil parameters determined for the two soil-layer model as discussed above, Monte Carlo probabilistic analyses were performed for different 2D Burnaby slope sections with varying slope angle (15-35^0) and height (2-35 m).



Probabilistic stability analyses for 35 m high slope (h35) and varying slope angle (15 to 35 degrees) and resulting CDF of (a) FOS for different slope angles (h: slope height, s: slope angle, C: circular failure) and (b) K_y for different slope angles (h: slope height, s: slope angle, C: circular failure)

Yield acceleration derivation (seismic slope stability) from static FOS:

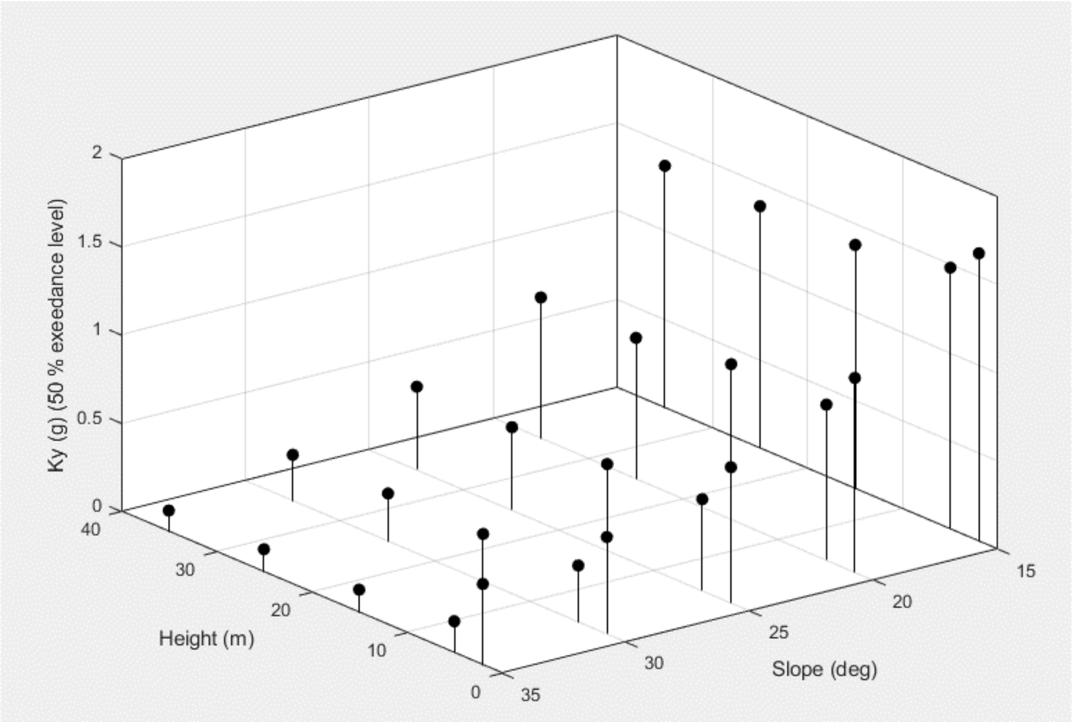
- Chien and Tsai (2017) method is employed to directly estimate Ky from available information. In this method having static FS for a slope, the yield acceleration is calculated as:
- $\mathbf{K_y = \frac{FS-1}{\frac{1}{tan\varphi}+tan\alpha}(DCF+1)}$
- $\mathbf{DCF} = \begin{cases} \boldsymbol{e^{(0.4+0.43\times tan\varphi)}\times\frac{D'}{H} - 1.5\times\left(\frac{D'}{H}\right)}, & \boldsymbol{(\beta-\alpha)\geq 5} \\ \mathbf{0}, & \boldsymbol{(\beta-\alpha)<5} \end{cases}$



Definition of parameters used for depth factor correction (DFC) in yield acceleration equation

Calculated Yield Acceleration (ky) for different slope geometries:

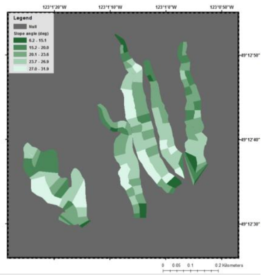
- This chart is driven from different 2D stability analyses for slopes with different angle and height values.
- For a height and angle of interest , mean value of Ky for slope can be estimated to be used in displacement calculations.



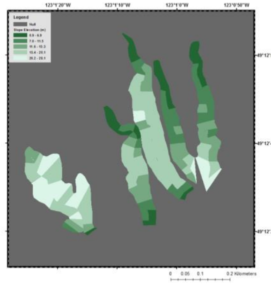
Mean Ky (50% of exceedance) for different slope and height values

Yield acceleration(Ky) mapping based on probabilistic stability analyses :

Topographic information

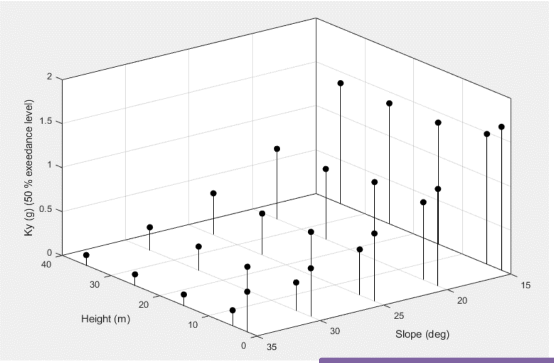


Map of slopes angle

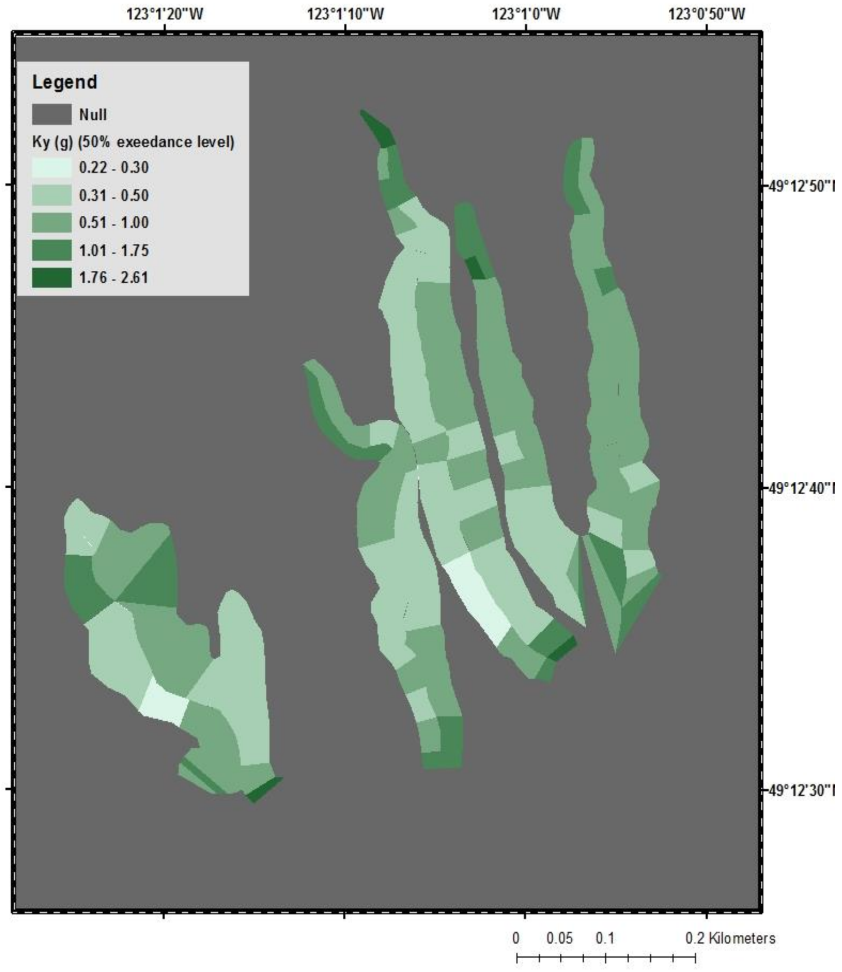


Map of slopes elevation

Subsurface information



Calculated Ky for different slope angle and height



Map of yield acceleration(Ky)

Empirical equation to predict the displacement:

- Rathje and Saygili (2008) model. In this model PGA (m/s^2) and earthquake magnitude (M) are used to calculate the displacement (D in cm) and standard deviation of the model.

Displacement

Yield acceleration

Seismic Parameters

- $$\ln D = a_1 + a_2\left(\frac{k_y}{PGA}\right) + a_3\left(\frac{k_y}{PGA}\right)^2 + a_4\left(\frac{k_y}{PGA}\right)^3 + a_5\left(\frac{k_y}{PGA}\right)^4 + a_6 \ln(PGA) + a_7(M-6)$$

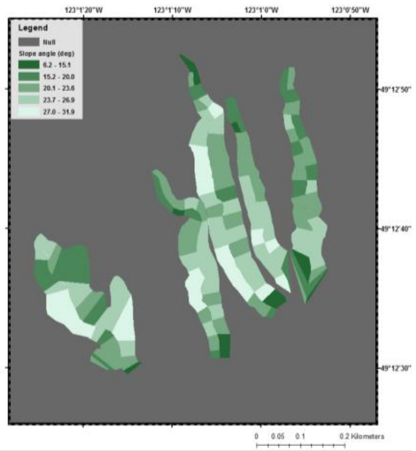
(Standard deviation is $\sigma_{lnD} = 0.732 + 0.789\left(\frac{k_y}{PGA}\right) - 0.539\left(\frac{k_y}{PGA}\right)^2$ and with $a_1 = 4.89, a_2 = -4.85, a_3 = -19.64, a_4 = 42.49, a_5 = -29.06, a_6 = 0.72, a_7 = 0.89.$)

- This empirical model was developed using the rigid sliding block approach and is only appropriate for shallow sliding surfaces which makes it a useful option for expected shallow failures in the region under study.

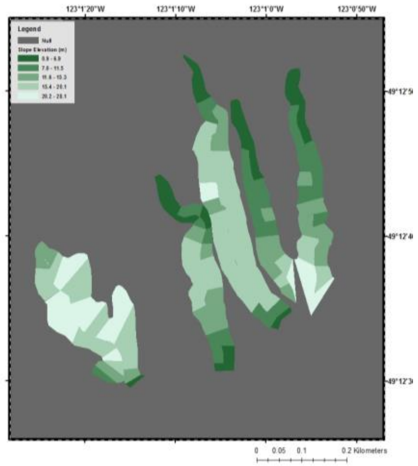
Developing the final map

- based on topographic analyses and user defined grids **slope angles** and **elevations** are captured for the region (Figure a & b) and then the **corresponding yield acceleration** (mean value) is assigned to the grids (Figure c). the **final displacements** under earthquake loading is calculated for the grids (Figure d).

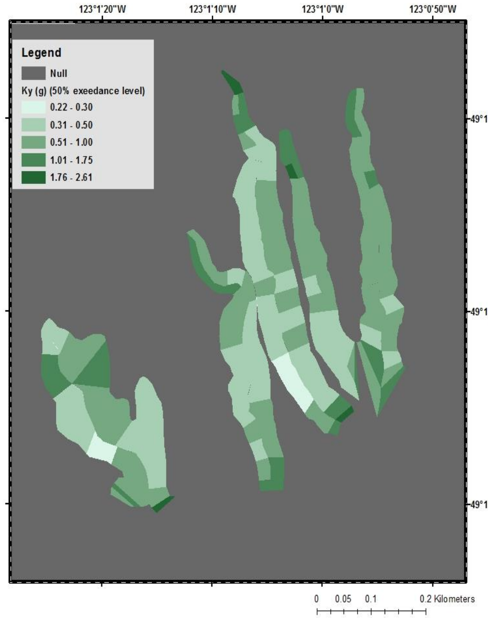
(a)



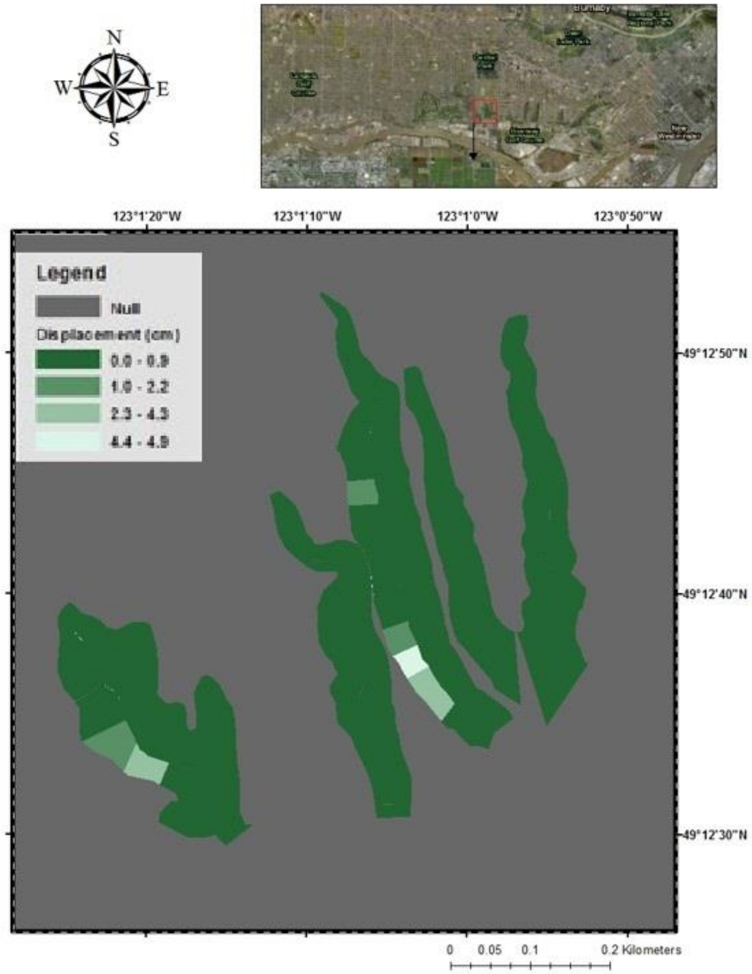
(b)



(c)



(d)



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Conclusions and Future Works:

- The seismic landslide hazard map predicts very low hazard level (displacement<5 cm) for the region which is in agreement with the observations in our field survey in July 2018 where no signs of deformation were recorded (e.g. cracks, settlements, previous landslides, scarps).
- Full probabilistic displacement calculation (based on regions probabilistic seismic hazard analyses) will enable us to capture more accurate values of displacement for slopes.
- Geotechnical database acquired from private and public agencies will be assessed to capture the appropriate geotechnical parameters for soil in different regions.
- The GIS based topographic work to capture slopes in all of the region. The final seismic landslide hazard map will be developed for all of Greater Vancouver region.

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- Thank You!
- Questions?

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