GEOLOGICAL SURVEY OF CANADA
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District of North Vancouver, British Columbia, Earthquake Hazard Assessment, Case Study: Risk Assessment Project

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1.0 INTRODUCTION

Natural Resources Canada (NRCan), is working with the District of North Vancouver (DNV), in British Columbia, and the Earthquake Engineering Research Facility (EERF) of the University of British Columbia (UBC), to analyze the risks to the community from earthquake related events. This activity is framed within the Public Safety Geoscience Program objective of compiling seismic hazard assessment information for the North Vancouver case study.

2.0 PROJECT SCOPE

This project deals with the generation of seismic hazard information to be used in the risk assessment software HAZUS-Canada to estimate social and economic losses from various earthquake scenarios. The contribution here is to provide ground motions based on a DNV high resolution grid.

Use of the HAZUS software requires that the Canadian hazard database be harmonized with the HAZUS built-in database. The USGS seismic hazard database provides Peak Ground Acceleration (PGA), Peak Ground Velocity (PGV), and spectral values of acceleration at periods of 0.3 and 1 seconds for events with a return period of 100, 250, 475, 750, 1000, 1500, 2000 and 2475 years. The Canadian seismic database provides PGA and Spectral acceleration values at 0.2, 0.5, 1.0 and 2.0 seconds for only four return periods. The results of this research fill the gap in the Canadian data base by computing the remaining parameters required by HAZUS and provides a detailed grid of parameters across the study area.

The method and models used for obtaining probabilistic ground motion values are those used to develop the design ground motions incorporated in NBCC 2005 and NBCC 2010.

3.0 OBJECTIVES AND DESCRIPTION OF WORK

The work was divided in three main stages:

- Stage 1:

  Develop probabilistic seismic mean hazard values for PGA, PGV, SA(0.3) and SA(1), for the DNV and for the following return periods, Tr: 100, 250, 475, 750, 1000, 1500, 2000 and 2,475 years.

- Stage 2:

  Produce seismic scenarios for drafting shaking maps. The scenarios were defined by NRCan and UBC.

- Final Stage:

Generate report and files for the shake maps.

4.0 STAGE 1, METHOD

Sources

The seismicity sources used in the study correspond to those given by the **H, R** and **F** models described below. These models have been used for the development of the 2005 and 2010 version of the National Building Code of Canada (NBCC). A deterministic scenario for the Subduction zone is also considered. For this study the maximum hazard of the seismic models was adopted to represent the site hazard, that is, the highest value resulting from the analyses of the different models for each location (robust model) is selected as the representative spectral value for that location. This methodology follows the procedures used in the 2005 and 2010 building code models (Adams and Halchuk, 2003).

Return Periods

The return periods considered are: 100, 250, 475, 750, 1000, 1500, 2000, and 2475 years.

Computational aspects

The commercial software EZFRISK version 7.37 from Risk Engineering was used to estimate the probabilistic seismic hazard. Sources within 500 km of the site were taken into consideration. A grid was constructed within the boundaries of the DNV (Figure 1) to generate the points of hazard calculation. For the generation of the national seismic hazard maps a 10-km grid was utilized, but for this study, an approximate 250-meter grid with equidistant points rather than equal increments of latitude/longitude) was used.

Figure 1. District of North Vancouver boundary map.

5.0 SEISMICITY PARAMETERS

Earthquake Catalogue

Seismicity parameters have been obtained for Western Canada using a seismic catalogue up to 1991 (Adams and Halchuk, 2003). According to the Adams and Halchuk document, it appears that reprocessing the source zones and re-computing their magnitude-frequency relations to include more recent earthquakes would not change the hazard results significantly. The catalogue was a mixture of magnitudes, predominantly, local magnitude, Ml, which was considered equivalent to moment magnitude, Mw.

Earthquake Source Zones

The **H** and **R** models for Western Canada were constructed by Horner and Rogers (Adams and Halchuk, 2003). Figures 2 and 3 show the maps of these models.

The sources for the **H Model**:

- Brooks Peninsula
- Cascade Mountains
- Central Coast Mountains

- Juan de Fuca Bending
- Northern Juan de Fuca Bending
- Northern Juan de Fuca Ridge
- Nootka Fault
- Northern Rocky Mountain Trench
- Queen Charlotte Sound
- Revere-Dellwood Sovanco
- Southern Coast Mountains
- Southeastern British Columbia
- Georgia Strait
- Puget Sound

The **R Model** is characterized by the following sources:

- Juan de Fuca Plate Bending, onshore
- Brooks Peninsula
- Cascade Mountains
- Coastal
- Explorer Plate Bending
- Juan de Fuca Plate Bending, offshore
- Northern BC
- Nootka Fault
- Offshore
- Rocky Mountains F&T belt
- Southern BC
- Georgia Strait/Puget Sound

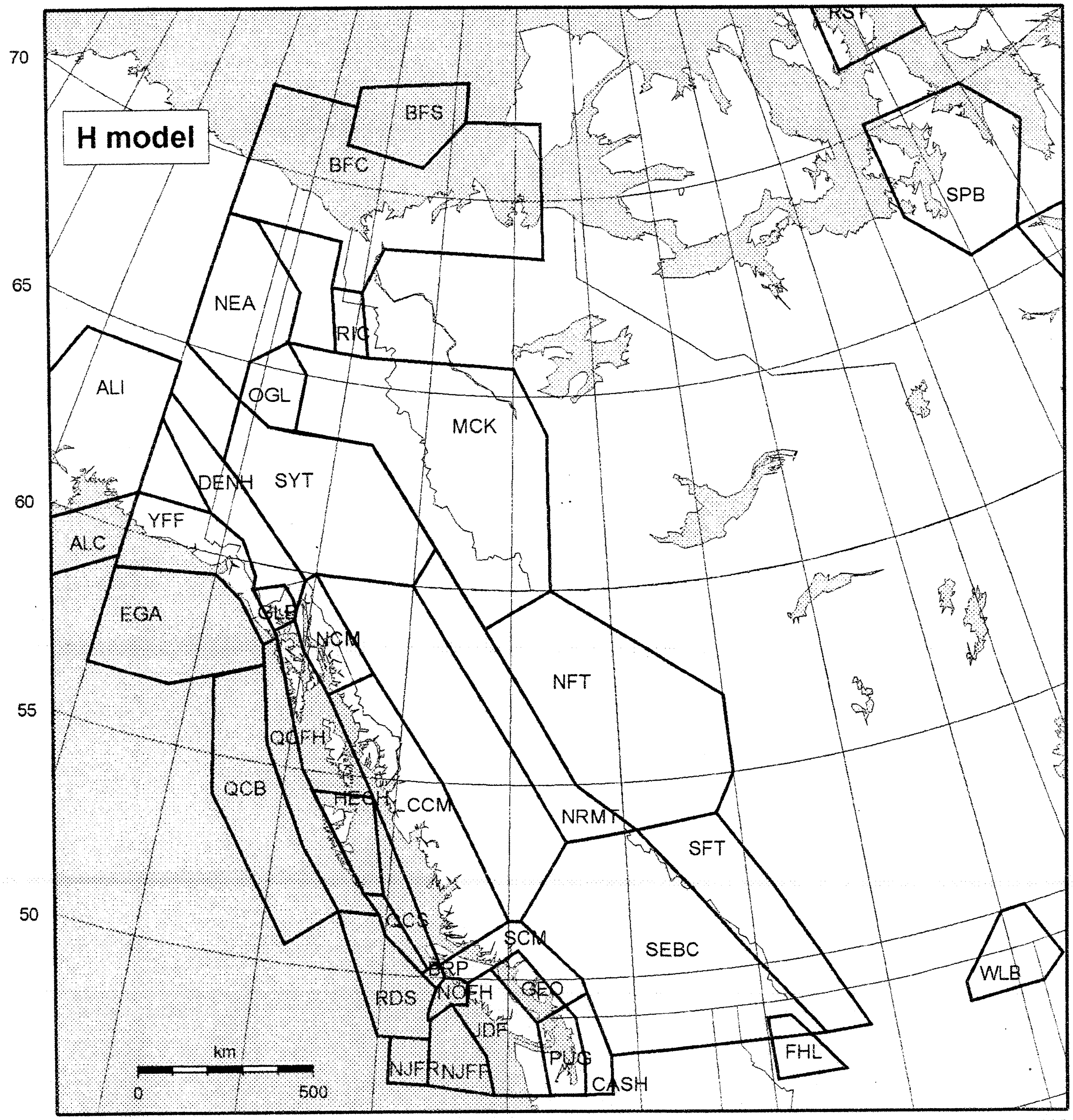

Figure 2. **H** model. From Adams and Halchuk, 2003.

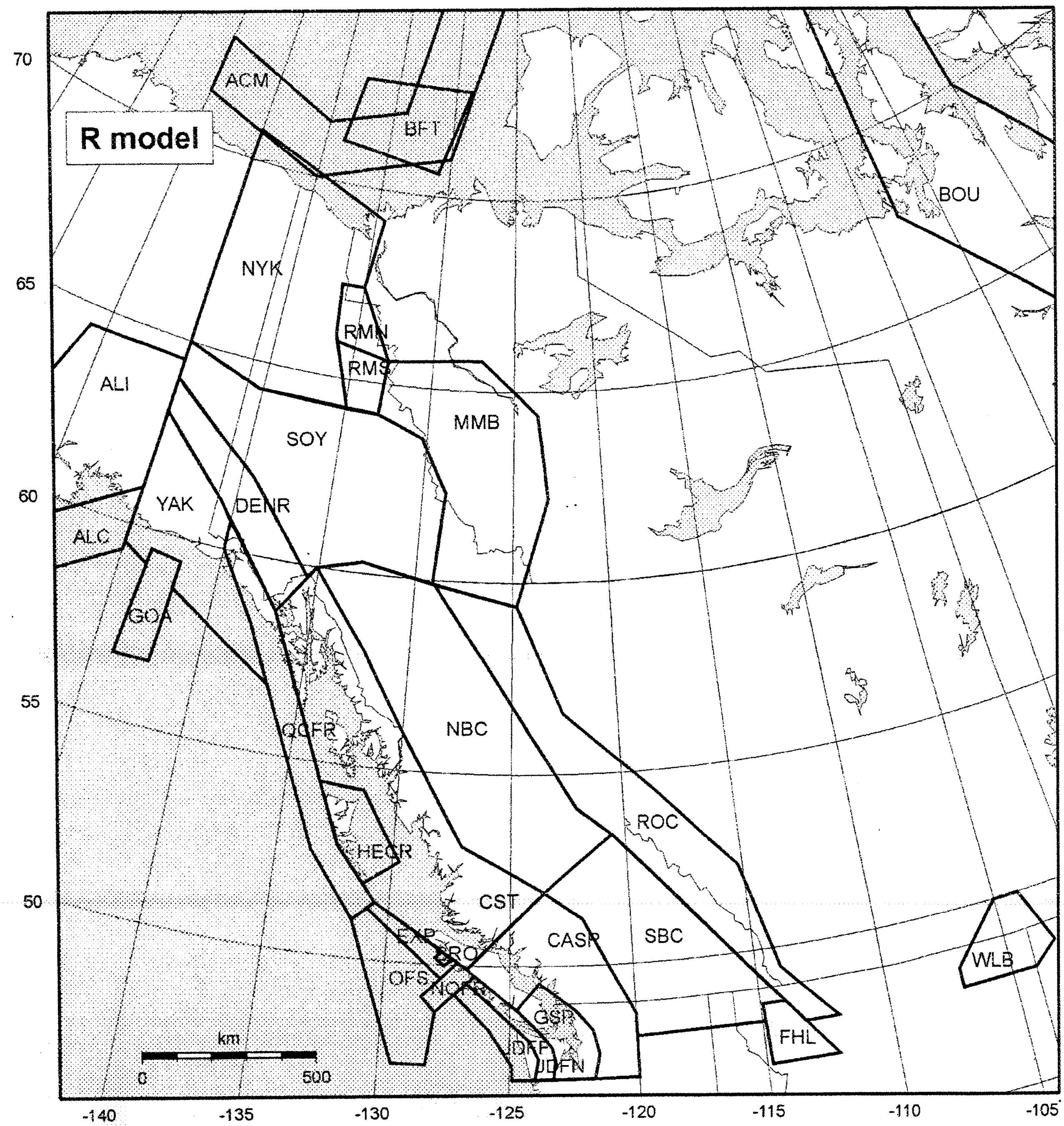

Figure 3. **R** model. From Adams and Halchuk (2003)

Magnitude Recurrence Parameters

The parameters for the estimation of hazard are given in Adams and Halchuk (2003). A lower magnitude cut-off of Mw = 4.75 was used. This is considered the smallest magnitude of engineering interest.

Deterministic Model for Cascadia, C.

The Cascadia subduction zone has generated great prehistoric earthquakes off Vancouver Island. From the geological record, the mean recurrence interval is assessed at about 600 years, and the last occurrence was in 1700 A.D. Present evidence suggests that the next great Cascadia subduction earthquake may have a moment magnitude as large as 9 (Satake *et. al.* 1996), with a rupture length of up to 900 km. In regards to hazard estimation, at any site of interest, only part of the rupture will be close enough to contribute significant damaging ground motions. Thus, the hazard approximates that of a smaller (still great) earthquake near to the site. Moreover, at the time of the Adams and Halchuk (2003) report, because of data limitations, the maximum magnitude that could be used in ground motion estimation equations for subduction events was near to 8.2. Therefore, for the purpose of the Cascadia subduction earthquake scenario in this report, we have adopted a magnitude of 8.2. For onshore sites we have modelled the Cascadia event as an offshore line source or locus set one third of the way into the transition zone below the locked zone. The locus is taken to represent the closest point of energy release for onshore sites, and is used for computing distances to the various sites.

6.0 STRONG GROUND MOTION RELATIONS

For the probabilistic analyses and for the western Canadian shallow source zones, including the subcrustal transition zones west of Vancouver Island, as well as, the Queen Charlotte Fault, the modified ground motion relations by Boore et al. (1993, 1994 - hereafter termed 'BJF') that were used in developing seismic hazard for NBCC 2005 and 2010 were adopted.

For deep subcrustal source zones under the Puget Sound and for the Cascadia subduction zone the Youngs et al. (1997) relationship, adjusted to "firm soil," was used. A representative depth of 50 km was assigned to the normal-mechanism events within the subducting slab, and 25 km for the depth of energy release for the Cascadia megathrust earthquake. For the Cascadia subduction zone hazard calculation, the Youngs et al. (1997) ground motion relation was used with a magnitude of 8.2 and a representative depth of 25 km. This was also done to maintain consistency with the NBCC 2005 and 2010.

For the shallow, surficial events for deterministic scenarios the median values of the New Generation Attenuation Equations, NGA, from Boore and Atkinson (2008), Campbell and Bozorgnia (2008) and Chiou and Youngs (2008) were used with equal weights. The shear wave velocity used in the deterministic scenarios equations was 760 m/s (soils type B/C). The use of median values in the attenuation relations is consistent with the United States Geological Survey, USGS practice, Frankel (2012).

It is possible to obtain Peak Ground Velocity, PGV, using the NGA (2008) equations. However, as several of the previous attenuation relations do not include PGV, and also to be consistent with a recent GSC report (Halchuk, 2011) that proposes values for HAZUS for the whole Canada (although in a different scale/resolution than this study), we calculated PGV values from Spectral Acceleration at 1 second. This was done using the following the formula suggested by the HAZUS methodology, which was originally proposed by Newmark and Hall (1982):

$$PGV(cm/s)=[Sa(1.0)s \times 9.81/2\pi]/1.65*100$$

Ground Motion Parameters

Values for PGA, SA(0.2), SA(0.3), SA(0.5) and SA(1) for 5% damping, and Peak Ground Velocity, PGV are provided.

Units

PGA and Sa values are in units of gravity, g, and the velocities in centimetres per second, cm/s.

7.0 REFERENCE SOIL CONDITION

The initial reference soil used is Type C from the NBCC (2005), i.e., a shear wave velocity between 360 and 760 m/s, for the probabilistic scenarios. This was modified to match the boundary between soil types B and C (Vs=760 m/s), as it is described in the next section. In the case of deterministic scenarios we used directly a Vs=760 m/s as representative of soil types B/C.

8.0 RESULTS, STAGE 1

The results are included as an electronic file. Values are provided for each point of the grid characterised by its latitude and longitude (3284 grid points). PGA values correspond to a 0.01 seconds period column in the electronic file.

The values obtained from this study will be incorporated into HAZUS. Therefore, values originally provided by the software were modified to allow for the fact that USGS (HAZUS) values are mean rather than median ones. The USGS uses mean values that include the effects of epistemic uncertainties in their probabilistic hazard estimations. HAZUS values are also representative of the boundary between soils type B and C, rather than mean type C values. In order to accommodate these differences, we used a factor of 1.27 (which is the product of a factor of 1.50 to convert median to mean values and a factor 0.85 to include the effect of soil type boundary B/C) to modify values originally provided by Adams(2010). A couple of issues are worth noting here: First, the version of the EZFRISK software used does not allow for the automatic inclusion of uncertainties in the input parameters (to directly estimate the epistemic uncertainty) meaning that only median values are the direct output from this program. Second, the mean/median ratio of the hazard can vary depending on location, governing model, parameter and return period used. A comparison done for opposite sites within the DNV suggested that the mean/median ratio can have values in the range from 1.20 to 1.50, although they did not change significantly within the geographic region. We preferred to use a single, slightly conservative, mean/median ratio of 1.50 for the whole DNV region. In the case of deterministic scenarios, median values of the attenuation equations were used.

Figures 4 to 9 show PGA, SA(1s) and PGV for return periods of 475 and 2475 years. It is worth noting from the Figures that the contour lines showing ground motion values are in different directions depending on natural period and return periods, e. g. short period-amplitudes can be controlled by near sources, while intermediate and long period spectral values could be governed for more distant events. Figures and values calculated also show that there is a low gradient of hazard across the study region, particularly for long periods and PGV values. We think that only 2 significant digits should be considered in any of the hazard values that we provide.

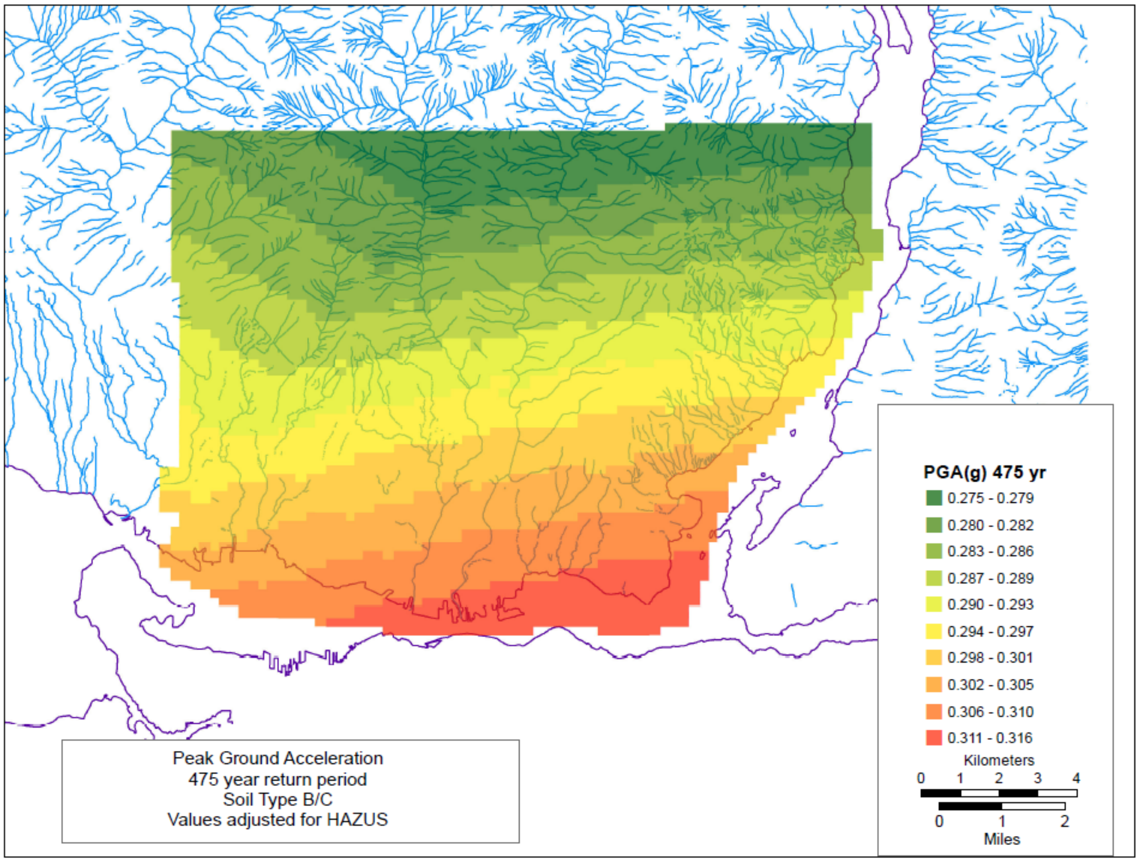

Figure 4. PGA, return period, Tr=475 y.

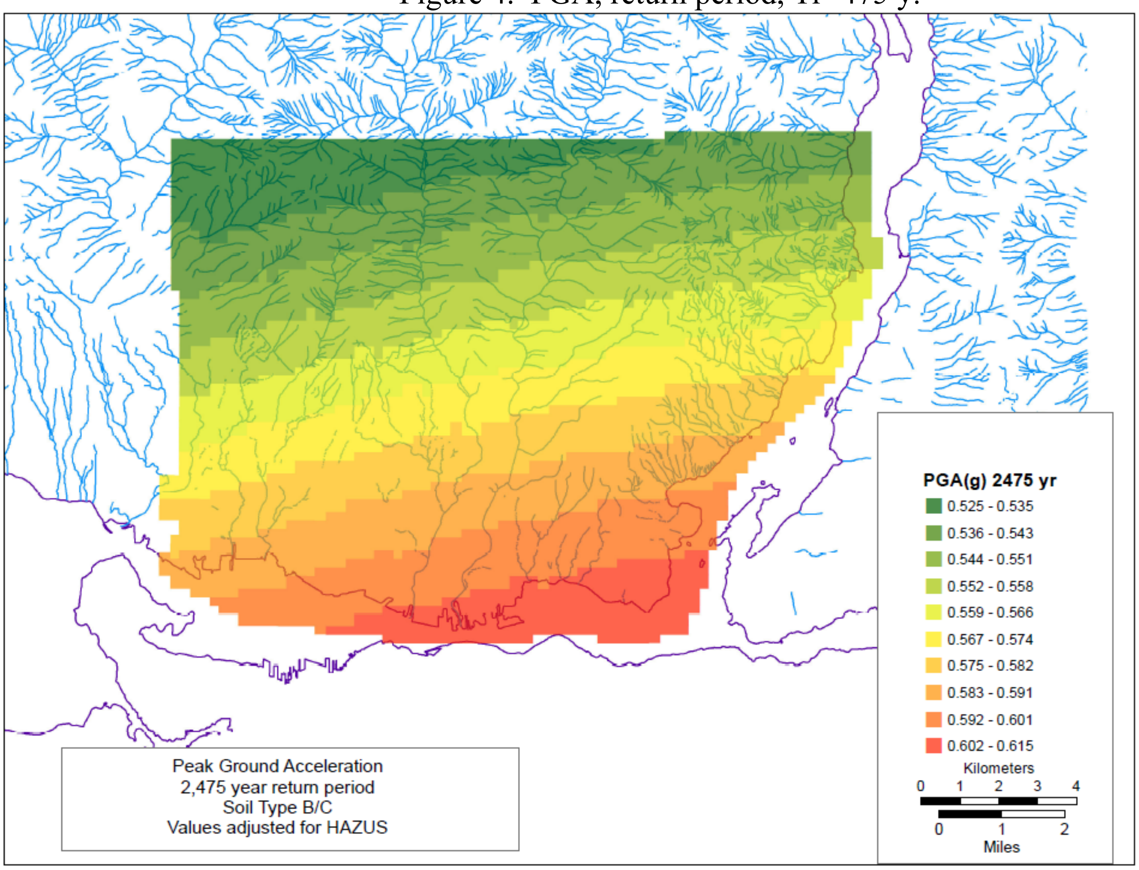

Figure 5. PGA, Tr=2,475 y.

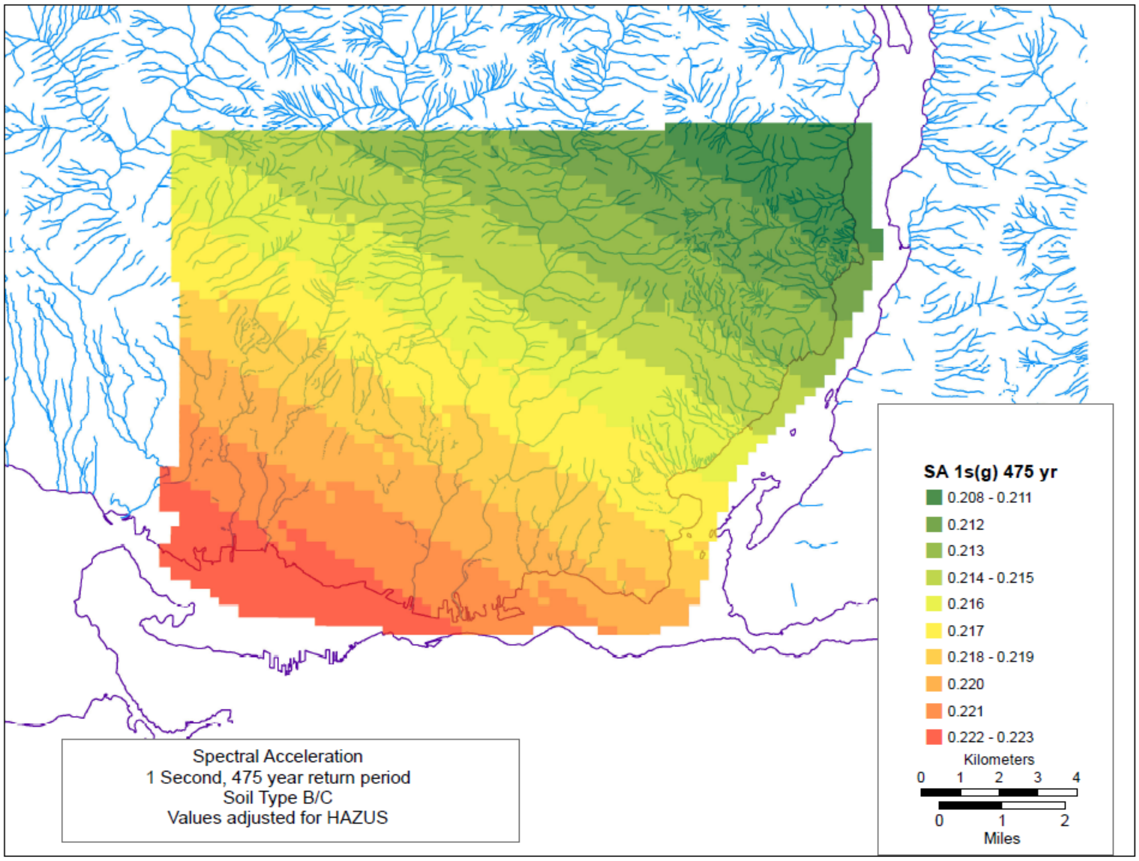

Figure 6. SA(1s), 5% damping, Tr=475 y.

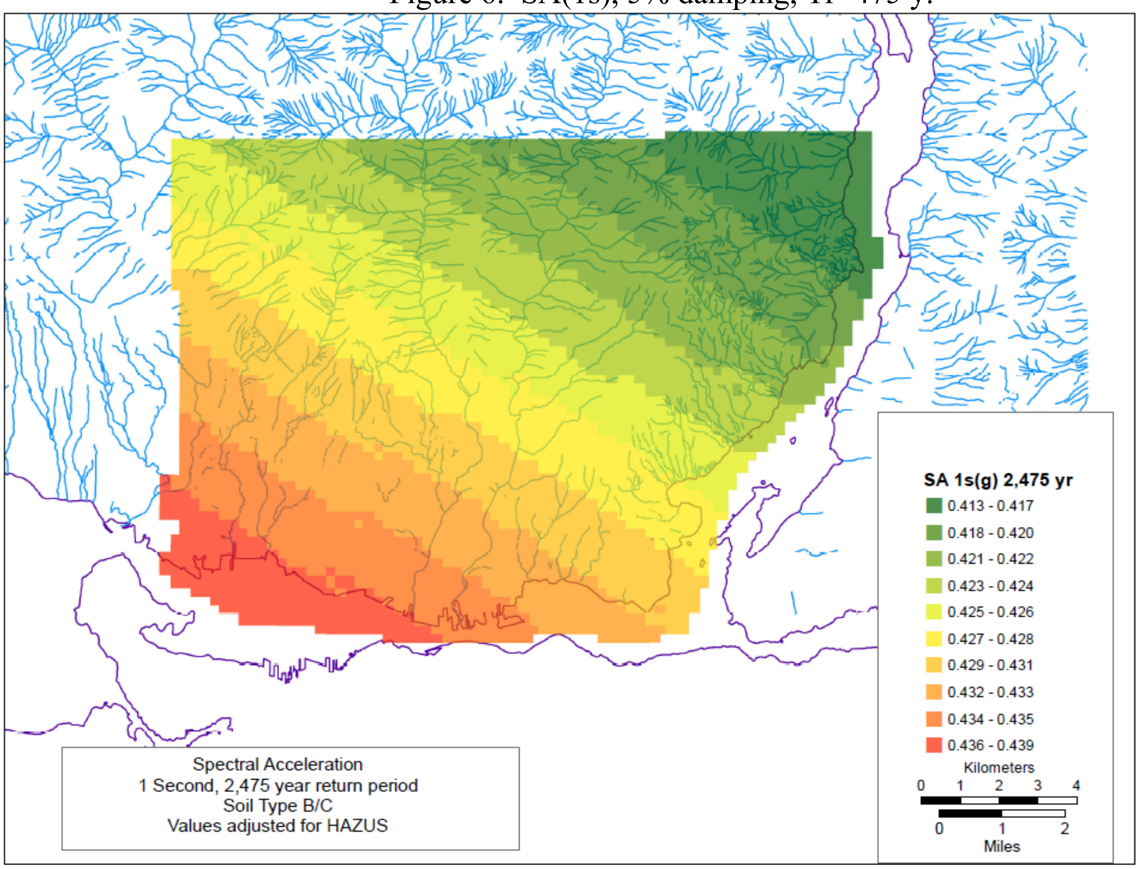

Figure 7. SA(1s), 5% damping, Tr=2,475y.

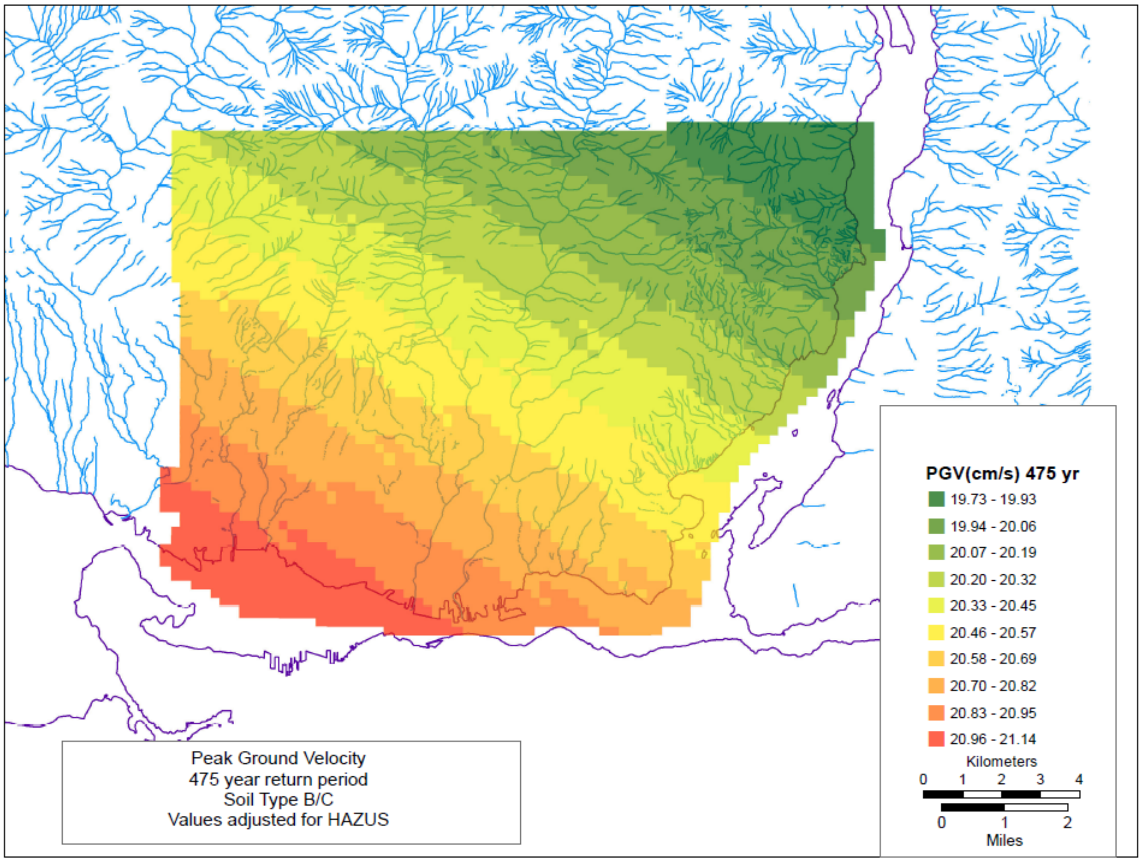

Figure 8. PGV, Tr=475 y.

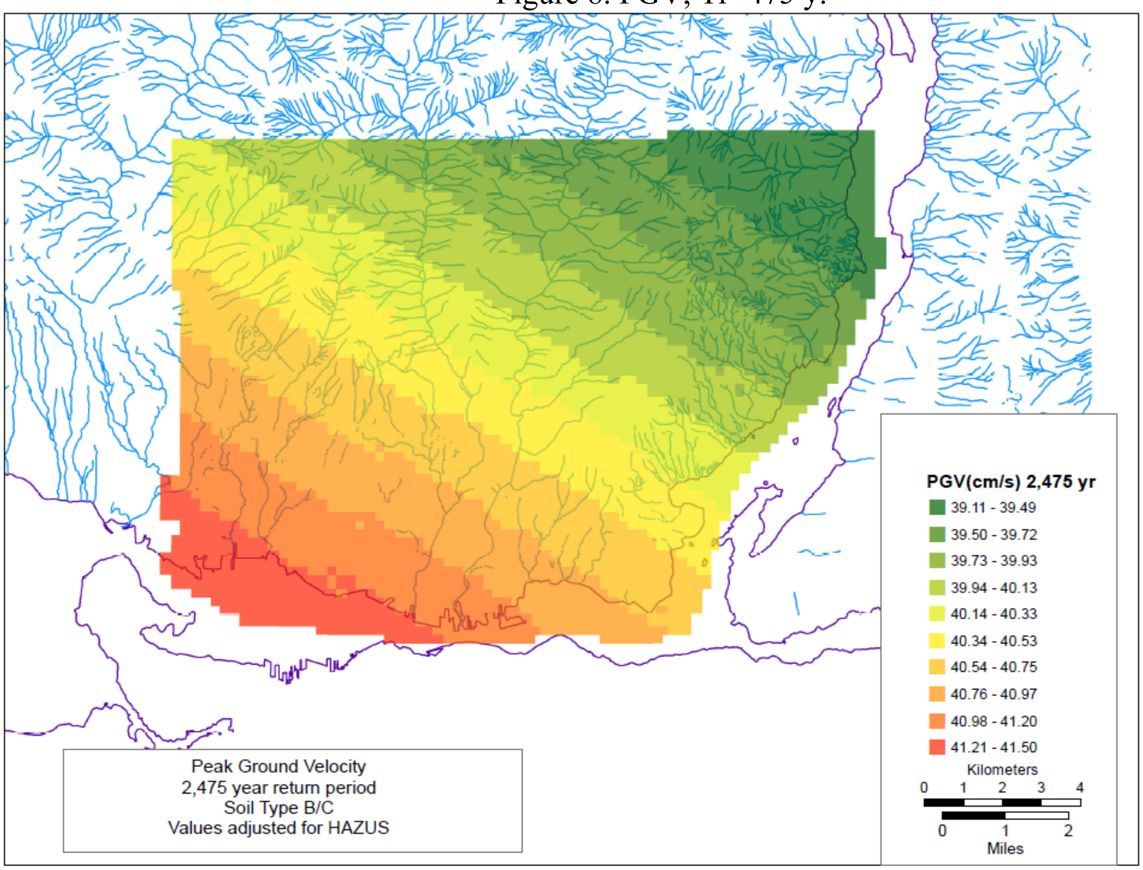

Figure 9. PGV, Tr=2,475 y.

9.0 SCENARIOS, STAGE 2

Figures 10 and 11 show the seismic hazard by source (deaggregation by source), SA(1s) values for models **H** and **R** at North Vancouver.

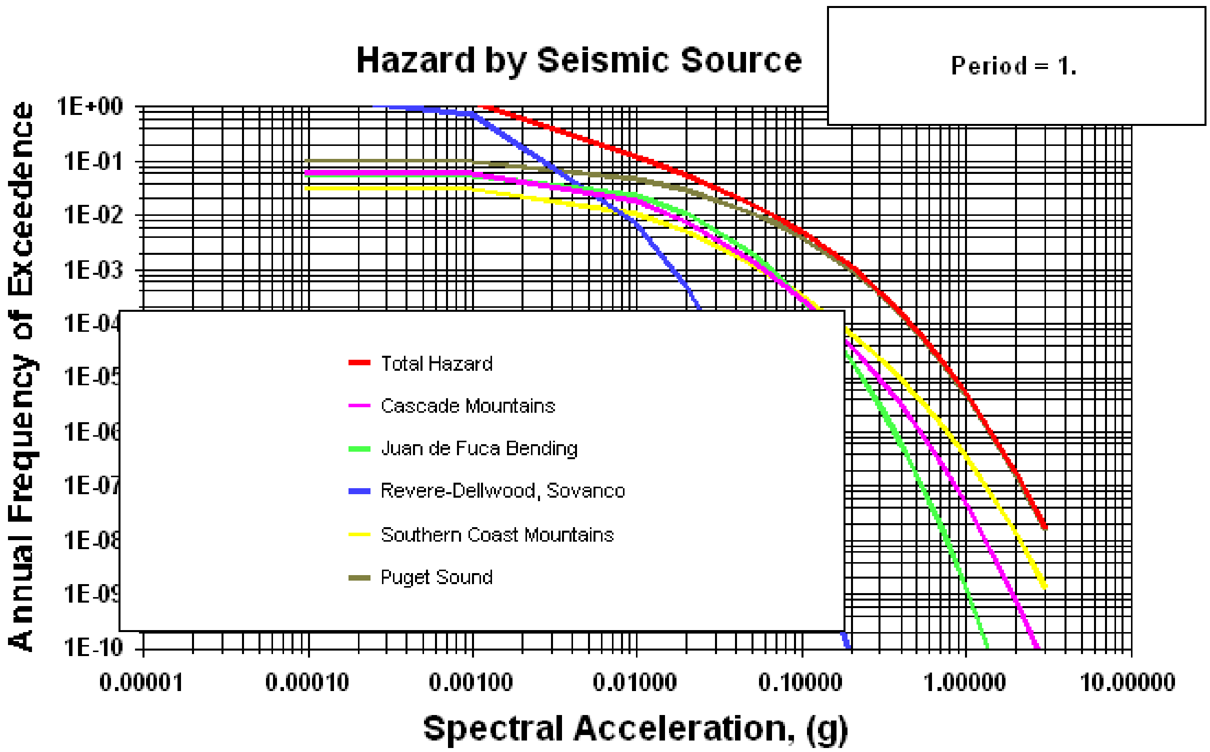

Figure 10. Seismic hazard by source, SA(1s), Model **H**. Only sources with the highest hazard levels are shown.

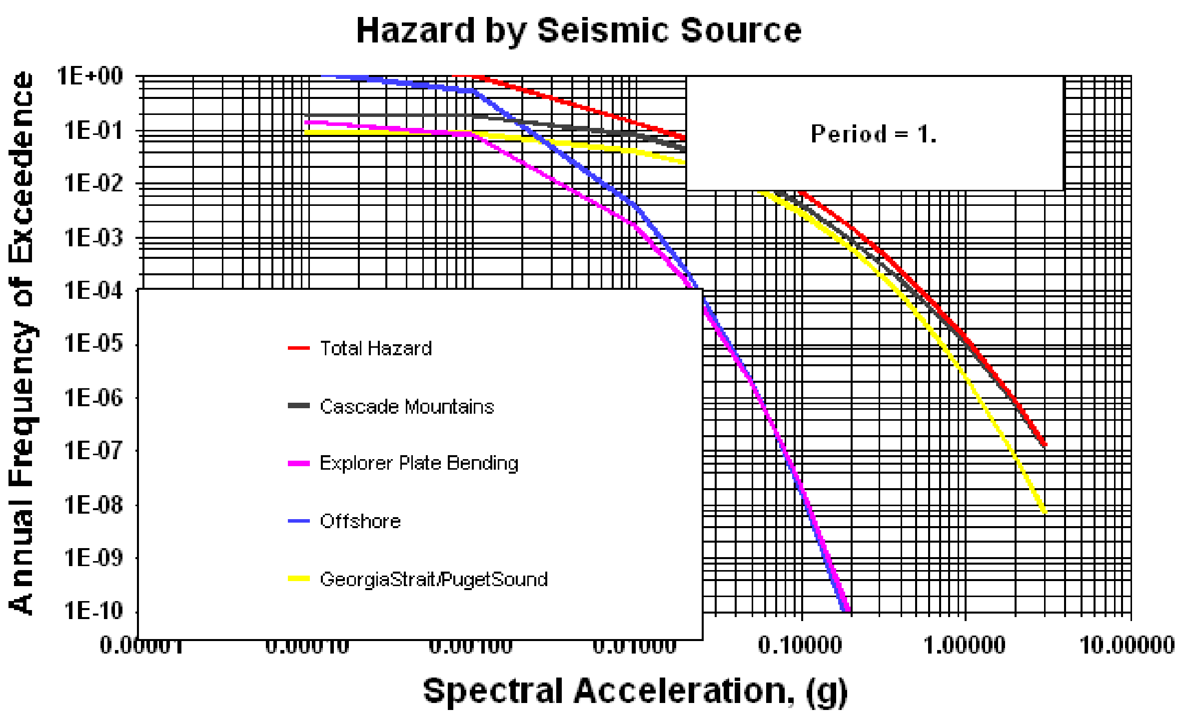

Figure 11. Seismic hazard by source, SA(1s), Model **R**. Only sources with the highest levels of hazard are shown.

It is clear from figures 10 and 11 that the hazard at DNV, at the 2,475 years return period appears to be controlled by:

- Puget Sound/Georgia Strait (Deep source)
- Southern Coast Mountains/Cascade Mountains (Shallow source)

A summary of deaggregation parameters is shown in Table 1.

Table1. Deaggregation parameters, Tr=2475 y.

	Model R, PGA	**Model R, SA(1s)**	**Model H, PGA**	**Model H, SA(1s)**
Mean distance (km)	58.4	50.4 (Modes at 8 and 60 km)	70.04	74.2
Mean magnitude	6.44	6.96	6.42	6.72
Mean epsilon	1.81	1.41	1.89	1.71

Note that distance deaggregation for Model **R** at SA(1s) and Tr=2475 is characterized by a bimodal distribution (Figure 12).

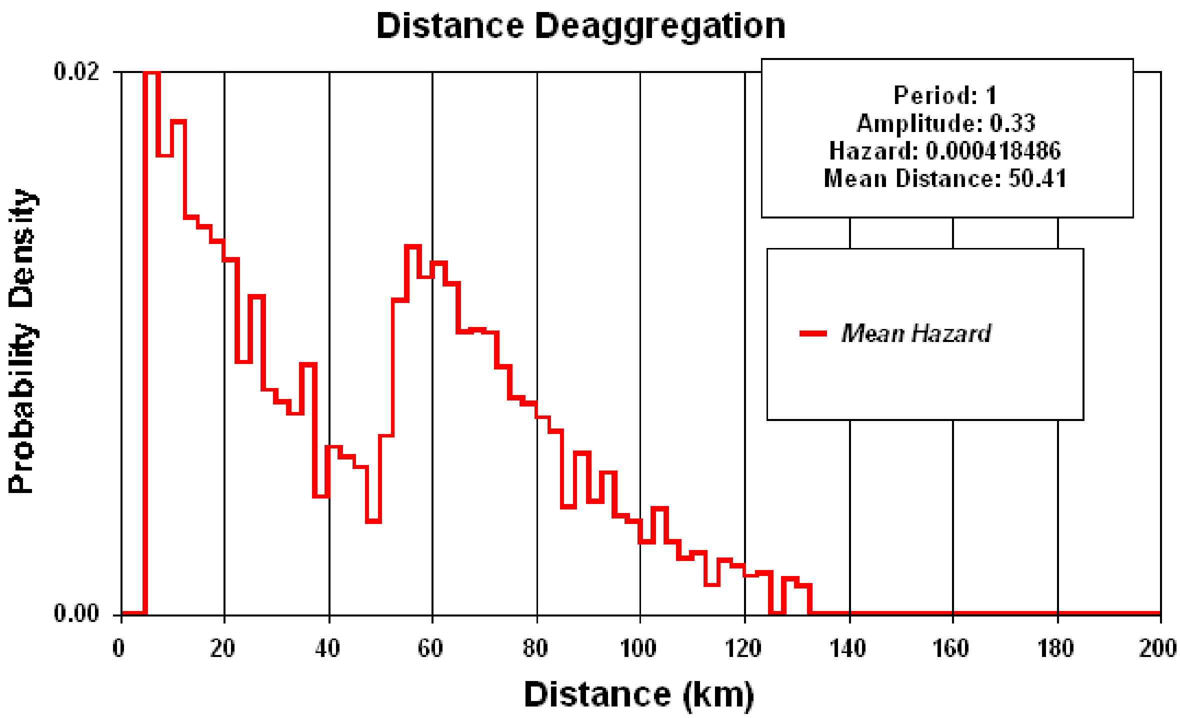

Figure 12. Deaggregation of distance, SA(1s), Tr=2,475, Model **R**.

The bimodal distribution of distance can be related to the fact that hazard for model **R** is dominated by a deep source (Puget Sound/Georgia Strait) with approximate depths of 50 to 60 km and also a shallow source (Cascade mountains) that could be responsible for the near distance peak (approximate 10 km).

The joint team, NRCan and UBC selected the following earthquake scenarios for the hazard study:

- Cascadia event: Distance, D=160 km, magnitude, Mw=8.2.

- Georgia Strait, shallow, surficial event: a fault modeled all along the marine corridor Nanaimo-Vancouver, fault length, L=54 km, Mw=7.3.

- Deep Puget Sound/Georgia Strait: An inslab (within the subducting plate) event, horizontal distance, D=28 km, h(depth)=50 km, Mw=6.8. This scenario is consistent with a Nisqually earthquake type event.

- Kendall fault, shallow, surficial event: a fault modeled starting at a distance, D=66 km south east the DNV and running in the USA, parallel to the international border, Mw=6.8.

Median values using the attenuation equations, already mentioned, were calculated. Results are included in the electronic files attached for PGA, 5% damping spectral acceleration values, SA, for periods of 0.05 s, 0.1 s, 0.2 s, 0.3 s, 0.4 s, 0.5 s, 0.75 s, 1 s, 2 s, 3 s, 4 s and PGV. Ground motion values corresponding to PGA for the Cascadia, Deep Puget inslab and Georgia strait scenarios are shown in Figures 13 to 15.

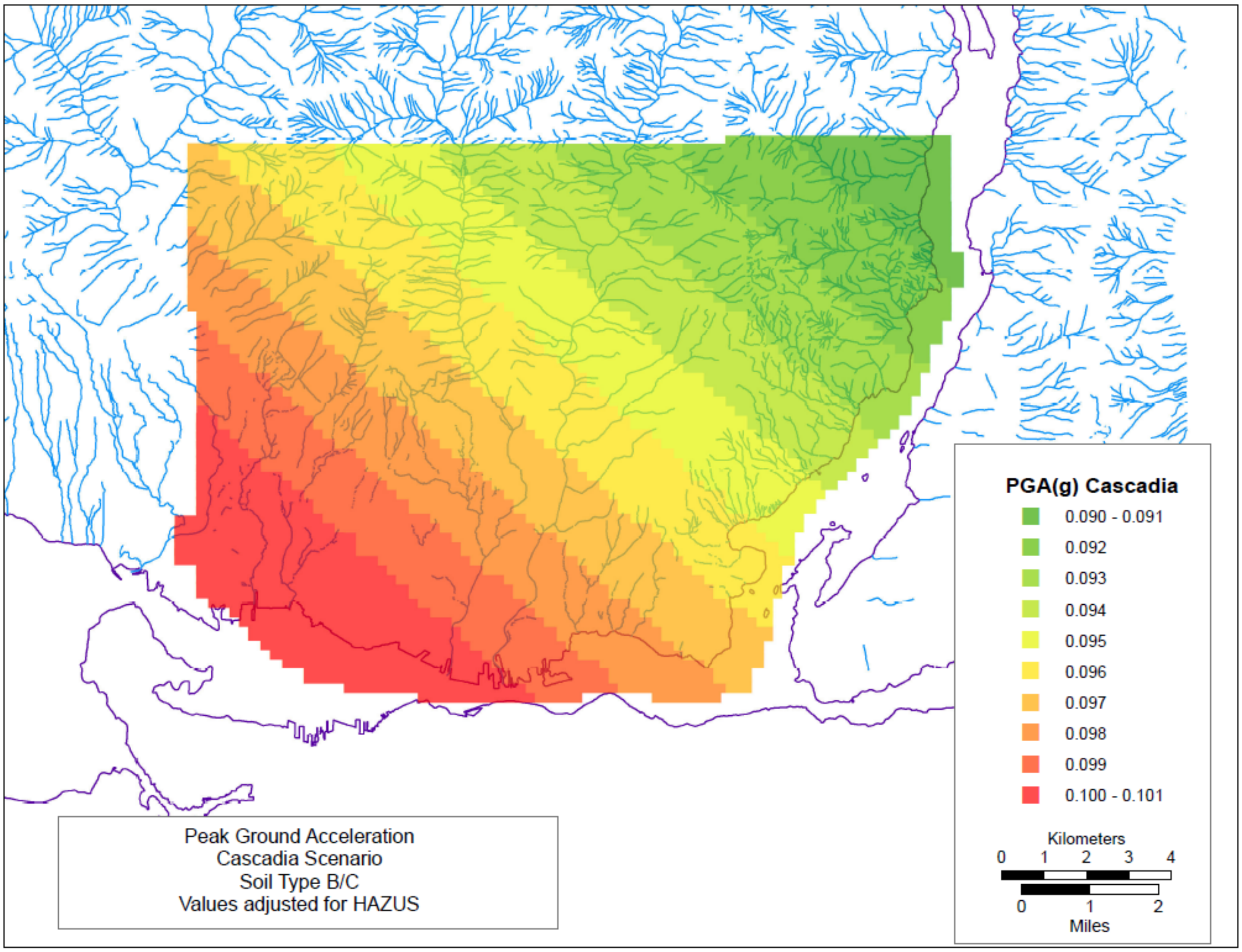

Figure 13. Cascadia event scenario. PGA.

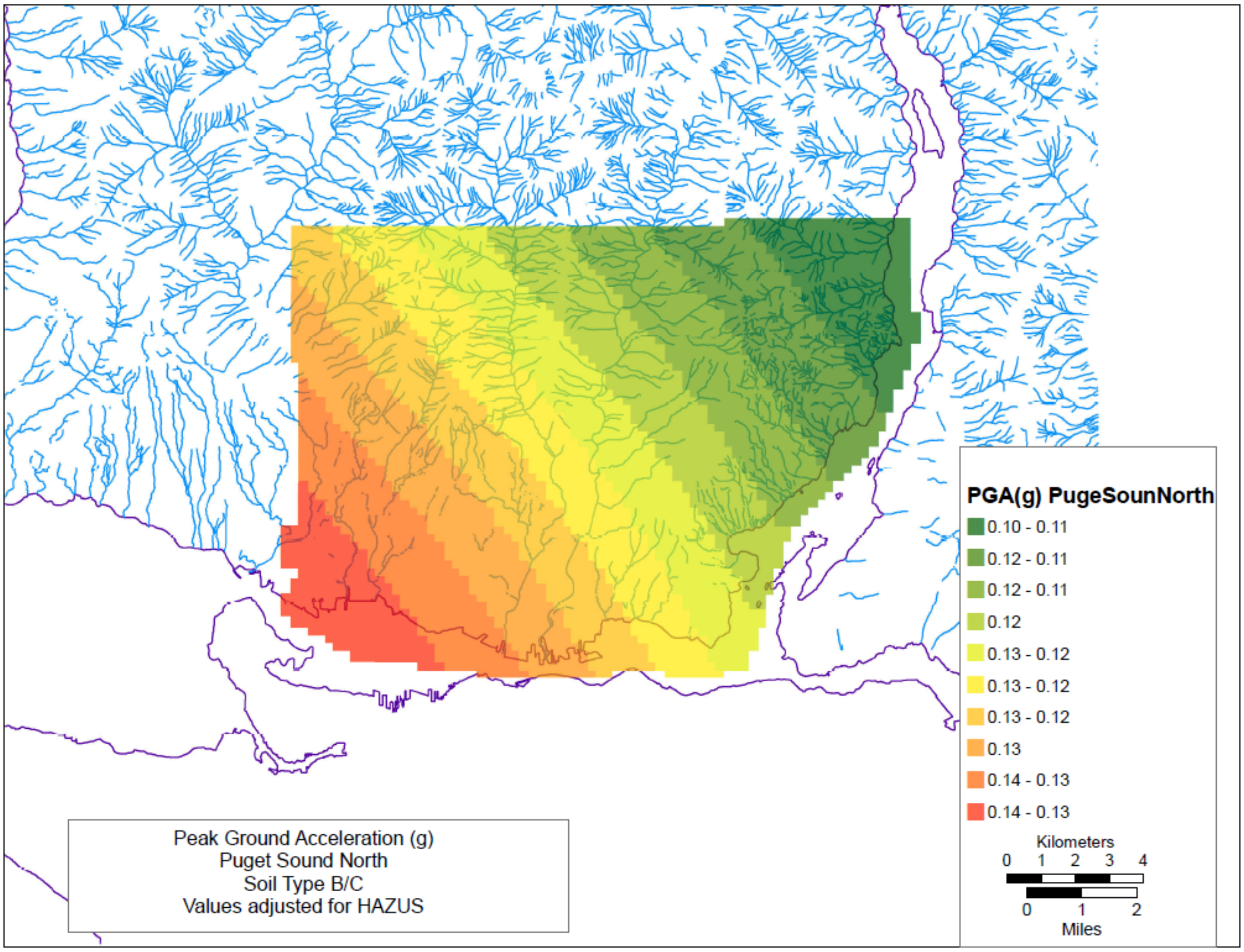

Figure 14. Deep Puget Sound inslab scenario. PGA.

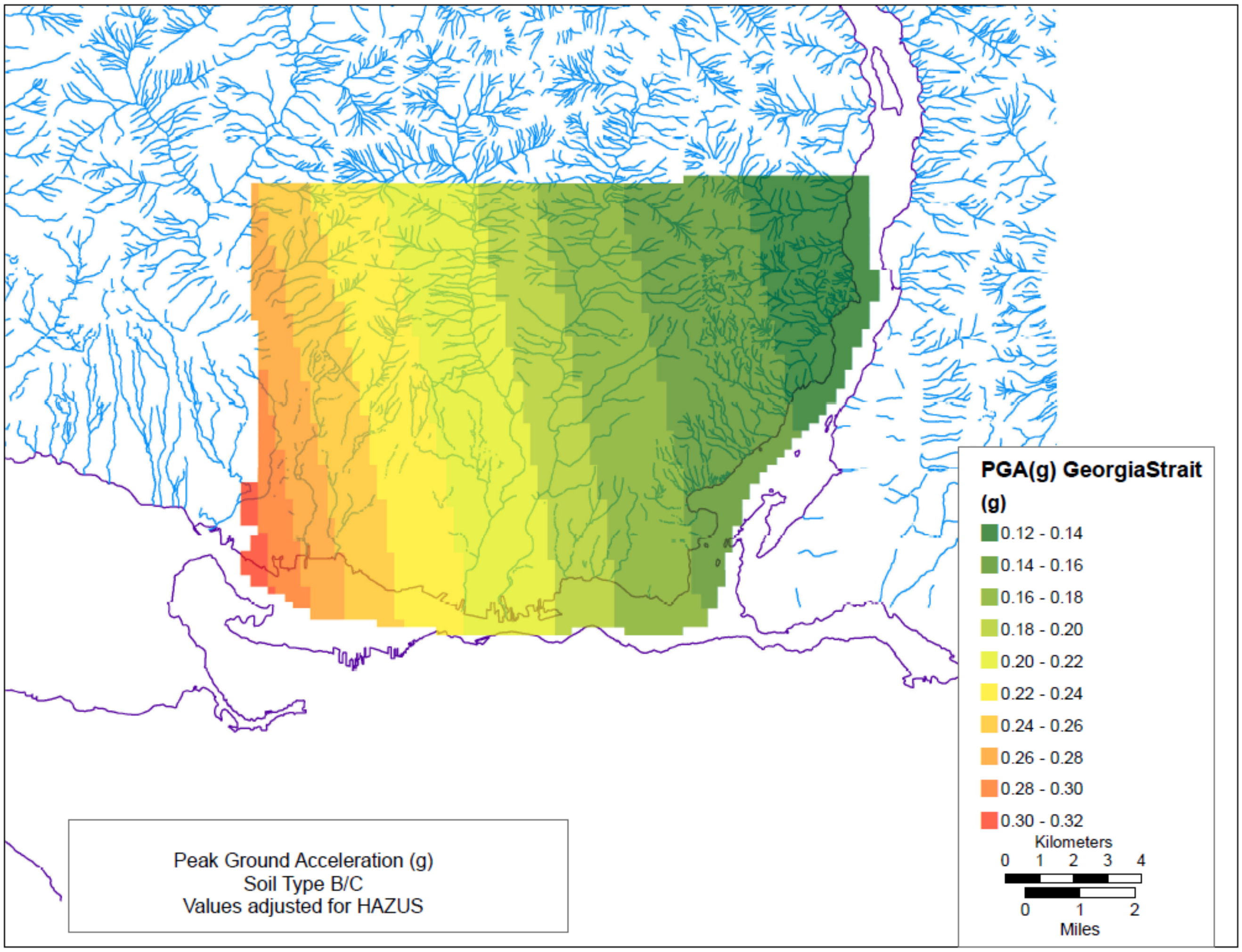

Figure 15. Georgia Strait scenario. PGA.

10.0 RECOMMENDATIONS FOR FUTURE WORK

We would like to recommend following further work:

- Permanent ground displacements (PGD) and site amplifications/de-amplifications are essential for analyses of losses to buildings and also to several infrastructure systems, e.g. water supply systems, pipelines, etc. HAZUS provides default methods to assess PGD and site effects. In addition, we would like to suggest that studies including more updated methods for estimation of site specific response analyses, liquefaction, lateral spreading, landsliding and fault surface rupture would be included for the development of ground motions for the region.

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