Geological Survey Branch

Geoscience Map 2000-1

Sheet 1 of 2

(see Notes to Accompany Geoscience Map 2000-1)

British Columbia
Ministry of Energy and Mines

RELATIVE EARTHQUAKE HAZARD MAP OF GREATER VICTORIA, SHOWING AREAS SUSCEPTIBLE TO AMPLIFICATION OF GROUND MOTION, LIQUEFACTION AND EARTHQUAKE-INDUCED SLOPE INSTABILITY

TRIM SHEETS (92B.043, 044, 053 & 054)

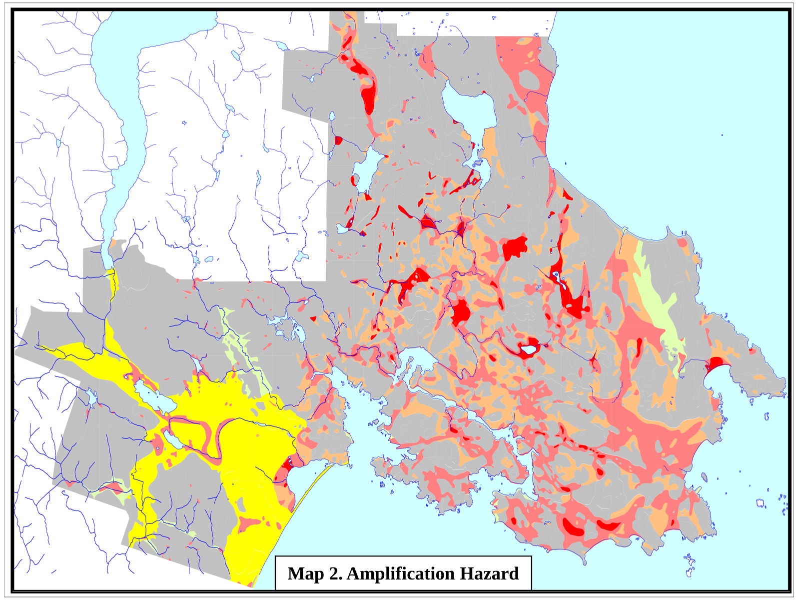
Patrick A. Monahan[1],P.Geo. and Victor M. Levson[2], P.Geo.,
Eric J. McQuarrie[3], P. Eng., Stephen M. Bean[3], P. Eng., Paul Henderson[4],P. Eng., and Alex Sy[4], P.Eng.

Scale 1:25,000 (approximate)

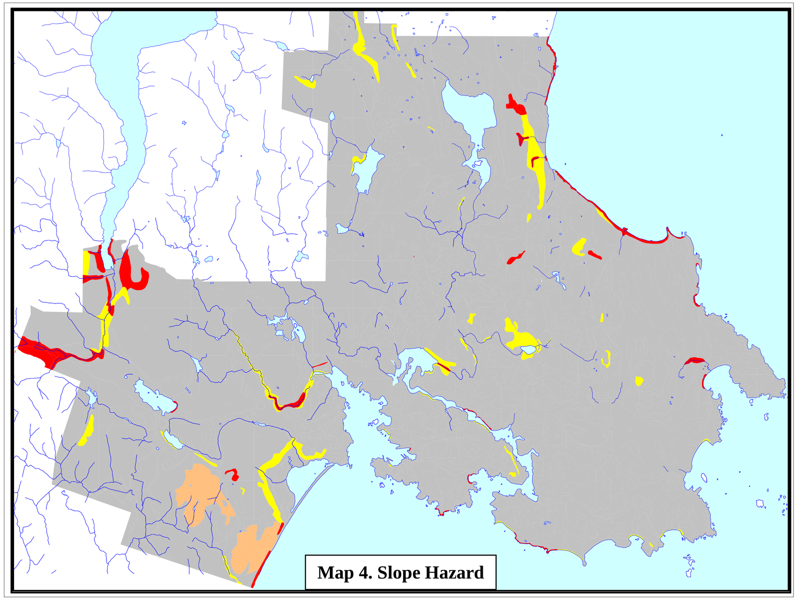
0.5 0.5 1.5 km

[1]Monahan Petroleum Consulting
[2] British Columbia Geological Survey
[3] Thurber Engineering Ltd.
[4] Klohn-Crippen Consultants Ltd.

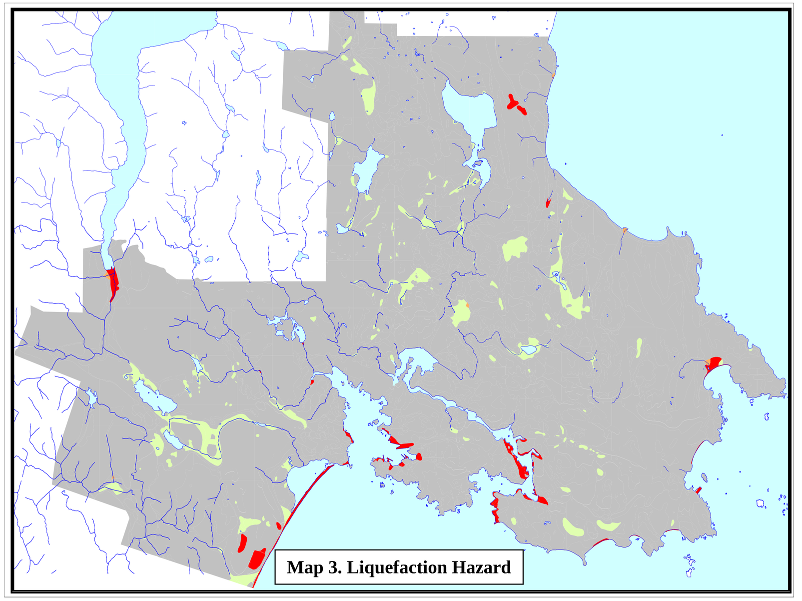
Maps 2 to 4 are simplified versions of the amplification of ground motion, liquefaction and earthquake-induced slope instability maps. These maps have been simplified from Geoscience Maps 2000-3a, 3b, and 3c by combining the very low and low ratings and the high and very high ratings to produce a three-class rating system – low, moderate and high.



Map 2. Amplification Hazard



Map 4. Slope Hazard



Map 3. Liquefaction Hazard

Legend

Relative Hazard Ratings

High / Moderate / Low

Maps 2 - 4, and Amplification Hazard on Map 1.

Moderate to High Liquefaction Hazard	High Slope Hazard
Low to Moderate Liquefaction Hazard	Moderate Slope Hazard

Map 1 Only.

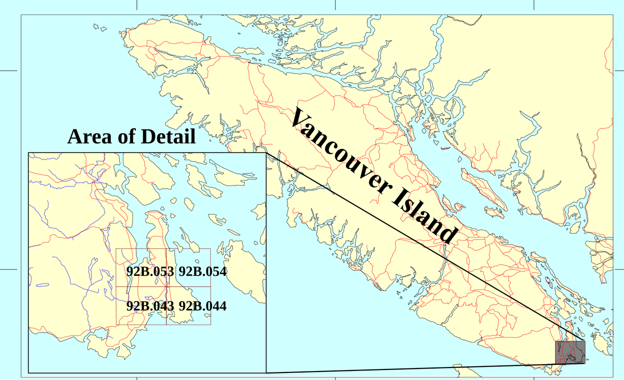
- Streams; potential for locally high to very high liquefaction hazard.
- : Bedrock in shallow (generally < 3 m) excavation
- ★ Small outcrop
- ● Borehole

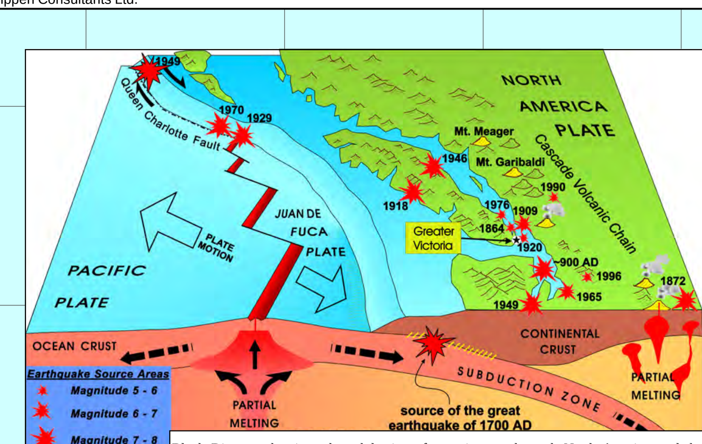
* Low to high hazard is applied to areas with insufficient data to assign a more specific hazard rating, but the average hazard rating can be considered moderate in these areas (see also comments on Map 1 referring to areas assigned low to high hazard rating on the slope hazard map).

The relative amplification hazard ratings shown on Maps 1 and 2 are generalized ratings and do not reflect the amplification hazard in all cases. **In particular, the amount of amplification due to soil conditions diminishes as the strength of ground shaking (i.e. acceleration) increases. Maps 5 to 8 show how *amplification factors* (not the actual amount of earthquake ground motion) can vary with different strengths and periods of ground motion. The variation in ground motions predicted using the amplification factors shown in Maps 5 to 8 does not exceed the seismic design criteria of the current building code (National Research Council of Canada, 1995), but could be significant for structures not governed by the seismic provisions of the code as well as older structures.**

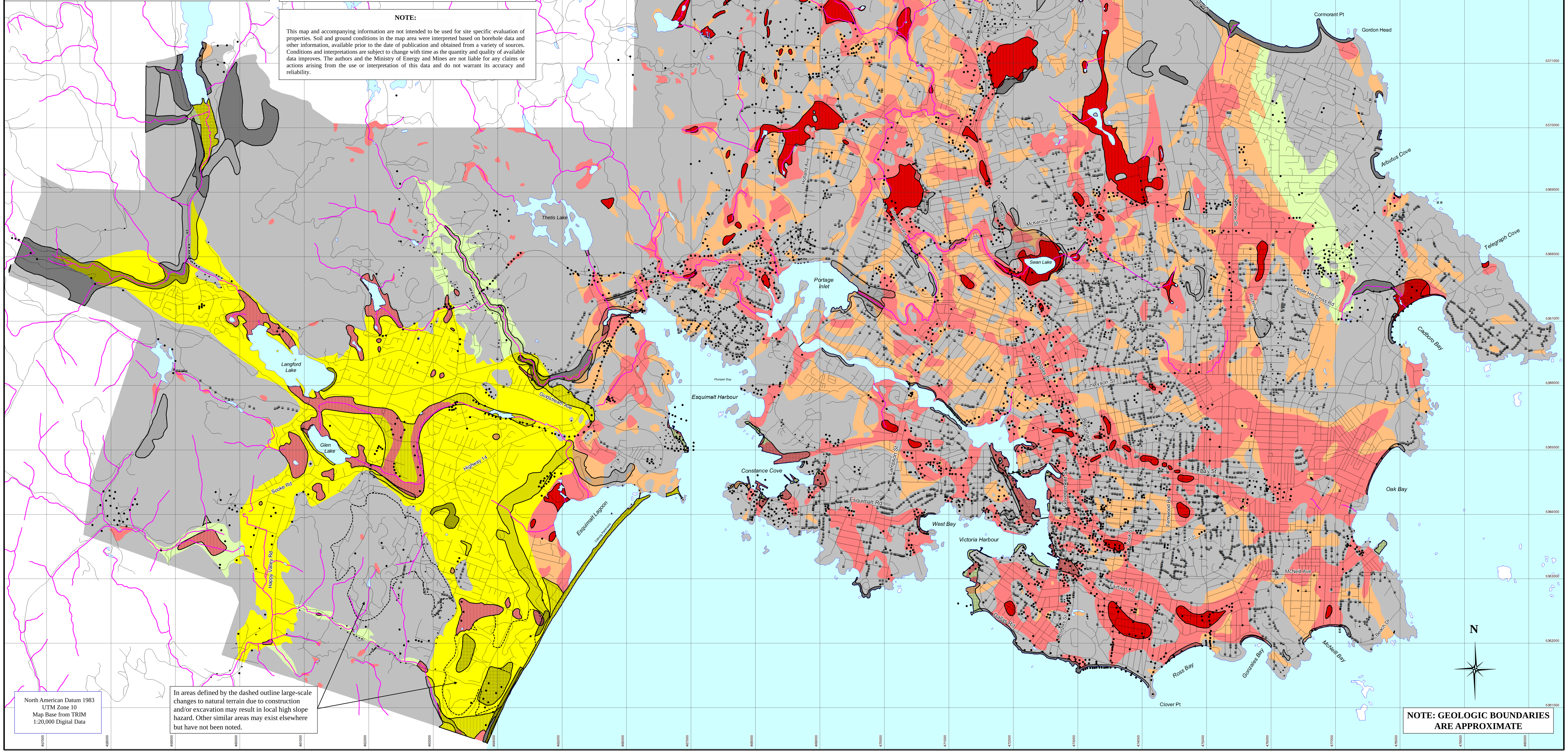
NOTE:

This map and accompanying information are not intended to be used for site specific evaluation of properties. Soil and ground conditions in the map area were interpreted based on borehole data and other information, available prior to the date of publication and obtained from a variety of sources. Conditions and interpretations are subject to change with time as the quantity and quality of available data improves. The authors and the Ministry of Energy and Mines are not liable for any claims or actions arising from the use or interpretation of this data and do not warrant its accuracy and reliability.





Block Diagram showing the subduction of oceanic crust beneath North America, and the distribution of significant historical earthquakes in the Victoria region and some of the larger earthquakes on the Queen Charlotte fault. Modified from the Geological Survey of Canada.



North American Datum 1983
UTM Zone 10
Map Base from TRIM
1:20,000 Digital Data

In areas defined by the dashed outline large-scale changes to natural terrain due to construction and/or excavation may result in local high slope hazard. Other similar areas may exist elsewhere but have not been noted.

NOTE: GEOLOGIC BOUNDARIES ARE APPROXIMATE

Victoria is in one of the most seismically active areas of Canada. Vancouver Island has experienced two large historic earthquakes, in 1918 (Magnitude=7.0) and 1946 (Magnitude=7.3; Rogers, 1998). The 1946 earthquake was the most damaging in western Canada and caused minor damage in the Victoria area, which was 200 km from the epicentre (Wuorinen, 1976). In addition, there is the potential for a very large (Magnitude ~9) earthquake on the Cascadia subduction zone west of Vancouver Island (Rogers, 1998; Hyndman, 1995). Clague (1996) has documented evidence for prehistoric earthquakes in southwest British Columbia. The tectonic setting of the region and distribution of significant historical earthquakes for the Victoria region are shown on the block diagram.

The effects of an earthquake are not only dependent upon the magnitude of the earthquake and the distance from the source, but vary considerably due to local geological conditions. The objective of this map is to show areas of Greater Victoria where the earthquake hazard is likely to be increased due to the presence of potentially unstable slopes, and soils susceptible to amplification of ground motion and/or liquefaction. Although the timing, location and magnitude of earthquakes cannot be predicted, areas in which the earthquake hazard is increased due to these factors can be mapped with varying degrees of completeness using existing geological and geotechnical data.

This map (Map 1) is a composite earthquake hazard map, and has been compiled from three other maps published as part of this investigation: a relative liquefaction hazard map (Geoscience Map 2000-3a; Monahan *et al.*, 2000a), a relative amplification of ground motion hazard map (Geoscience Map 2000-3b; Monahan *et al.*, 2000b) and an earthquake-induced slope instability hazard map (Geoscience Map 2000-3c; McQuarrie and Bean, 2000). The methodology of preparation of these source maps is summarized below and simplified versions are included here as inset maps (Maps 2 to 4). ***However, for details of the assessment of earthquake hazards in the Victoria area, and to determine the specific hazards that are likely to affect different areas, the user should refer to the source maps and accompanying report.***

USE OF THIS MAP

This map is intended for regional purposes only, such as land use and emergency response planning, and should not be used for site-specific evaluations. It should be used to help planners select areas for development, avoid geologically vulnerable areas and prioritize seismic upgrading programs. ***This map does not replace the need for site-specific geotechnical evaluations*** prior to new construction or upgrading of buildings and other facilities.

This map flags areas of high hazard for planning purposes. However, the user must refer to the more detailed liquefaction, amplification of ground motion amplification and slope instability hazard maps noted above for details of the hazards potentially present in an area.

A high hazard does not necessarily preclude land from a specific use. In these areas more detailed engineering studies may be required, depending on the use proposed and the specific hazards present, and higher costs may be incurred. A qualified professional engineer or geologist should be consulted when making decisions related to this map. The qualifications and limitations of this map are discussed in more detail below.

SUMMARY OF RELATIVE EARTHQUAKE HAZARD ASSESSMENT IN VICTORIA

GEOLOGICAL MAPPING

The initial step in evaluating earthquake hazards was preparation of a surficial geological map that shows the thickness and distribution of Quaternary stratigraphic units (Geoscience Map 2000-2; Monahan and Levson, 2000). The map is based on data from borehole logs, engineering drawings for municipal sewer and water lines, airphoto interpretation and large-scale topographic maps. In areas where borehole data are sparse, the subsurface conditions had to be inferred from topographic and geomorphic evidence. To assist the user in determining the accuracy of the subsurface geological mapping, sites where subsurface geological data were available are shown on this map. Limited field checking was conducted.

AMPLIFICATION OF GROUND MOTION HAZARD MAP (MAP 2; Monahan et al., 2000b)

Amplification of ground motion refers to the increase in the intensity of ground shaking that can occur due to local geological conditions, such as the presence of soft soils. The amplification hazard is estimated by assigning U.S. National Earthquake Hazard Reduction Program (NEHRP; Building Seismic Safety Council, 1994) site classes to each geological map unit defined above. The NEHRP site classes are defined primarily on the basis of the average shear-wave velocity in the upper 30 m of the underlying soil and rock. This hazard is greatest in areas underlain by thick deposits of soft clay, particularly where they are capped by peat and organic soils, and lowest where bedrock is exposed (Monahan and Levson, 1997; Monahan *et al.*, 1998, 2000). Consistent with these hazard ratings, damage in the City of Victoria from the 1946 Vancouver Island earthquake was concentrated in soft soil areas, and damage was the least where bedrock is at or near the surface (Wuorinen, 1976).

However, several important qualifiers must be added to these hazard ratings.

- *The intensity of amplification on soft soils diminishes as the strength of ground shaking (i.e. acceleration) on bedrock increases* (Building Seismic Safety Council, 1994). Consequently, amplification by soft soils may be minimal in the event of a large earthquake in close proximity to the city (i.e. *all* areas will be shaken strongly), but could be significant for a large earthquake tens of kilometres distant and generating moderate shaking on bedrock in the city. However, a moderate shaking event is *much more likely* to occur than a strong shaking event, so that areas assigned a high amplification hazard on Maps 1 and 2 will be subjected to potentially damaging ground motions *much more often* than areas with a very low hazard (see Maps 5 to 8 and adjoining text, and the relative amplification of ground motion hazard map (Monahan *et al.*, 2000b) for more details).

- *The map does not address amplification of ground motion due to resonance*. The specific periods of ground motion that match the natural periods of a site can be greatly amplified, and can be particularly destructive to structures whose natural periods match those of the site* (Reiter, 1990; Rial, 1992).

- *The map does not address amplification due to topography*, which can exceed amplification due to soil conditions in some cases. High amplification is commonly experienced on hills, ridges and the tops of cliffs (Finn, 1994; Somerville, 1998), which are generally underlain in the Victoria area by dense soils and bedrock. Consequently, the very low and low hazard ratings normally expected on bedrock may not apply on such topographic features.

- *The map does not address amplification due to three-dimensional effects*, such as the focussing of energy due to the structure of the earth's crust in the region, which can be as great as amplification due to soil conditions (Somerville, 1998).

The amplification of ground motion hazard map reflects variations in earthquake hazard due to soil conditions, which are applicable to most earthquakes that will affect the region. Topographic and three-dimensional effects are more dependent on the earthquake location and direction of seismic energy.

LIQUEFACTION HAZARD MAP (MAP 3; Monahan et al., 2000a)

Liquefaction is the transformation that occurs when earthquake shaking causes a sand to lose its strength and behave somewhat like a liquid. It commonly is one of the major causes of damage in an earthquake. The susceptibility of a site to liquefaction is dependent upon the depth to water table and the density, grain size and age of the underlying deposits (e.g. Youd and Perkins, 1978). In the Victoria area, the liquefaction hazard is greatest in geologically young beach sands and in artificial fills. The latter are common in port facilities and other shoreline areas (Monahan *et al.*, 1998, 2000). Many sandy shoreline deposits along the east coast of Vancouver Island liquefied during the 1946 Vancouver Island earthquake(Rogers,1980) and non-engineered fills perform poorly in earthquakes. However, the liquefaction hazard is generally not high in the Victoria area.

EARTHQUAKE-INDUCED SLOPE INSTABILITY HAZARD MAP (MAP 4; McQuarrie and Bean, 2000)

The slope instability hazard was assessed by estimating the intensity of seismic motions that would cause a given slope to fail, considering the slope angle and typical strengths of the geological units present. The slope instability hazard is greatest along sea cliffs where sediments are exposed and along valleys and gullies deeply incised into these deposits. Most rock slopes appear to be relatively stable, although the potential for boulder ravelling or very small rock falls exists, and some areas of less stable bedrock occur in the Mount Finlayson/Malahat/Goldstream River area (McQuarrie and Bean, 2000).

C0MPOSITE RELATIVE EARTHQUAKE HAZARD MAP (MAP 1)

Map 1 was prepared by combining the amplification of ground motion (most likely cases), liquefaction and earthquake-induced slope instability maps (Monahan *et al*., 2000a, b, and McQuarrie and Bean, 2000). The amplification of ground motion hazard is the most widespread in the Victoria area. Consequently, the colour coding on this map represents the amplification hazard. This map is simplified from the source amplification map (Monahan *et al*., 2000b) by combining the very low and low hazard ratings, and the high and very high hazard ratings to produce a three-class hazard rating system – low, moderate and high. Areas of moderate and high liquefaction and slope instability hazards are shown by cross hatched and shaded areas superimposed on the amplification map. As with the amplification hazard ratings, high and very high hazard ratings have been combined for the liquefaction and slope instability hazards. Similarly, the three inset maps for each hazard (Maps 2 to 4) have been simplified from the source maps by using a three-class rather than the five-class system used on the source maps.

The different hazards have been shown together in this way because the hazard rating scales are not directly comparable. The liquefaction and slope instability hazard ratings both reflect the probability of liquefaction or slope failure – the stronger the ground shaking required to cause failure, the lower the hazard rating. A moderate rating indicates that liquefaction or slope failure could occur at the level of ground shaking used for building design under the current building code. The amplification hazard reflects the frequency that an area could be subjected to damaging ground motions. However, the intensity of amplification on soft soils diminishes as the strength of ground shaking (i.e. acceleration) increases. Consequently, at the level of ground shaking used for building design under the current building code, amplification could be minimal, and all areas could be shaken equally strongly. Furthermore, the three hazards mapped are not cumulative in all cases. Although amplification may increase the probability of liquefaction, liquefaction inhibits amplification, so that in areas with high liquefaction and amplification hazards, ground motions will not be amplified if liquefaction is triggered.

QUALIFICATIONS AND LIMITATIONS

1. **This map is intended for regional purposes only, such as land use and emergency response planning, and cannot be used for site specific evaluations.**

2. Because of the techniques used to prepare the regional map, the uneven distribution of the data on which the map is based, and the commonly gradational nature of geological boundaries, all geologic map unit boundaries shown are *approximate*. The geological units often include smaller occurrences of other map units, and unit boundaries may change as more borehole data become available. Furthermore, the characteristics of geological materials are variable and, therefore, parts of a particular map unit may behave differently than the rest of the unit during an earthquake. **Consequently, the hazard *at a specific site* may be higher or lower than shown on the map.**

3. This map does not consider the effects of subaqueous failures that could occur along the coastline or along the shores of lakes and might affect the slope above the shoreline.

4. Except where noted, this map does not consider man-made alterations to ground conditions, whether the changes lower or increase the hazard at a site. For example, poor soil sites may have been improved during construction, which will change the hazard rating from that shown on the map. The assessment of slope instability hazard does not consider artificial cuts and fills or other man made changes to the natural terrain. Nor does it consider damage caused by construction procedures, settlements, failures of retaining walls or instabilities caused by water, storm or sewer lines that could rupture during an earthquake.

5. Neither the stability of dams under earthquake shaking, nor the hazards related to failure of dams or other man-made structures have been addressed.

6. Only the larger fills of which the authors were aware are shown on the map. Other areas of fill are present, and new areas of fill will be developed in the future. The properties of fills vary widely, from dense engineered fills with a very low liquefaction hazard to loose fills with a very high liquefaction hazard. Insufficient data were available to distinguish these, so to be conservative all fill units were assigned a high liquefaction hazard, to indicate that such a hazard could be present. Non-engineered fills historically perform very poorly in earthquakes.

7. The National Earthquake Hazard Reduction Program (NEHRP) site classes for susceptibility to amplification of ground motion (Building Seismic Safety Council, 1994), which are based on the average response of various types of soils, have been used to estimate the amplification of ground motion hazard. This approach has the following limitations:
   a) The map does not address amplification of ground motion due to resonance. If the periods of a specific earthquake match the natural periods of a site, ground motions can be greatly amplified, and this can be particularly destructive to structures whose natural periods match those of the site (Rial *et al.*, 1992).
   b) This map does not specifically address amplification of ground motion due to topography. For example, topographic amplification of ground motions can occur on hills, ridges and the tops of cliffs (Finn, 1994; Somerville, 1998).
   c) Amplification due to three-dimensional effects, such as the focusing of energy by buried bedrock structures is not considered (Somerville, 1998).

8. This map shows the areas where the earthquake hazard varies due to amplification of ground motion, liquefaction and earthquake-induced slope instability. ***However, a low hazard rating on this map does not mean that there are no earthquake hazards because all areas could be subjected to significant ground shaking in a strong earthquake.*** Furthermore, the degree of amplification on soft soils diminishes as the intensity of ground shaking on bedrock increases, so that in the case of a strong earthquake close to the city, little *variation* in ground shaking may occur due to local soil conditions at short period ground motions. However, the city will be affected more often by more distant earthquakes that generate moderate shaking on bedrock, so that areas with a high amplification hazard will be subjected to potentially damaging ground motions *more often* than sites with a low amplification hazard. This subject is discussed in more detail in the amplification hazard map (Monahan *et al*., 2000b).

9. Other earthquake hazards, such as tsunamis, land subsidence and ground rupture are not addressed on this or any companion maps published as part of this investigation.

10. For further information on the types of hazards that might affect specific areas, the user should refer to the companion earthquake hazard maps by Monahan *et al.* (2000) and McQuarrie and Bean (2000).

11. **This map cannot be used to *directly* predict the amount of damage that will occur at any one site because many other factors such as building design and construction details must be considered.** The map in no way shows how different types of buildings or other man-made structures will perform during earthquakes. This map shows the relative natural hazard due to geological factors alone.

Geological Survey Branch

Notes to Accompany Geoscience Map 2000-1

Sheet 2 of 2

RELATIVE EARTHQUAKE HAZARD MAP OF GREATER VICTORIA, SHOWING AREAS SUSCEPTIBLE TO AMPLIFICATION OF GROUND MOTION, LIQUEFACTION AND EARTHQUAKE-INDUCED SLOPE INSTABILITY

TRIM SHEETS (92B.043, 044, 053 & 054)

Patrick A. Monahan[1],P.Geo. and Victor M. Levson[2], P.Geo.,
Eric J. McQuarrie[3], P. Eng., Stephen M. Bean[3], P. Eng., Paul Henderson[4],P. Eng., and Alex Sy[4], P.Eng.

Scale 1:25,000 (approximate)

0.5 0 0.5 1 1.5 km

[1]Monahan Petroleum Consulting
[2] British Columbia Geological Survey
[3] Thurber Engineering Ltd.
[4] Klohn-Crippen Consultants Ltd.

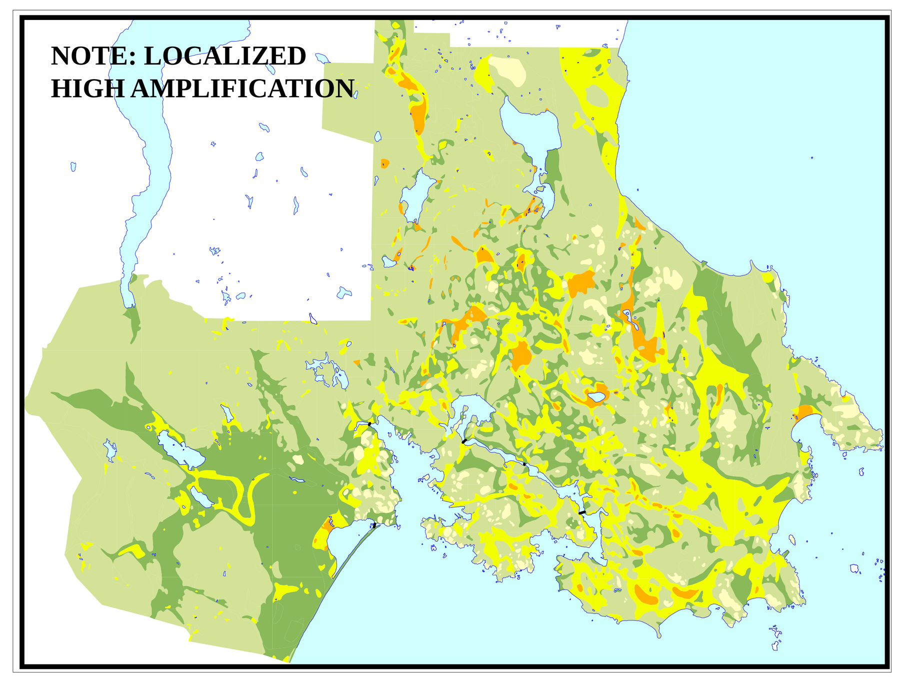
APPROXIMATE AMPLIFICATION FACTORS FOR DIFFERENT GROUND MOTIONS

***The relative amplification hazard ratings shown on Maps 1 and 2 are generalized ratings and do not reflect the amplification hazard in all cases.* In particular, the amount of amplification due to soil conditions diminishes as the strength of ground shaking (i.e. acceleration) increases. Maps 5 to 8 show how *amplification factors* (not the actual amount of earthquake ground motion) can vary with different strengths and periods of ground motion. See text below and amplification of ground motion hazard map (Monahan *et al.*, 2000b) for more details.**

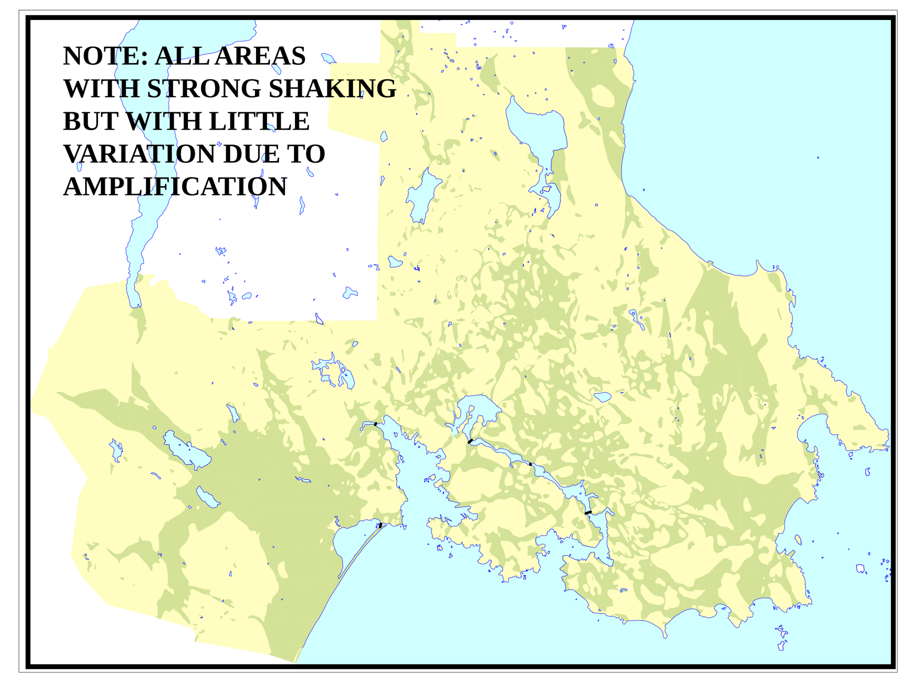
MODERATE EARTHQUAKE SHAKING
(0.1 g on bedrock - approximate onset of damage in buildings not designed to be earthquake resistant)

STRONG EARTHQUAKE SHAKING
(0.4 g on bedrock - current building code design acceleration for Victoria.)

SHORT PERIOD GROUND MOTIONS
(typically affecting short buildings*)



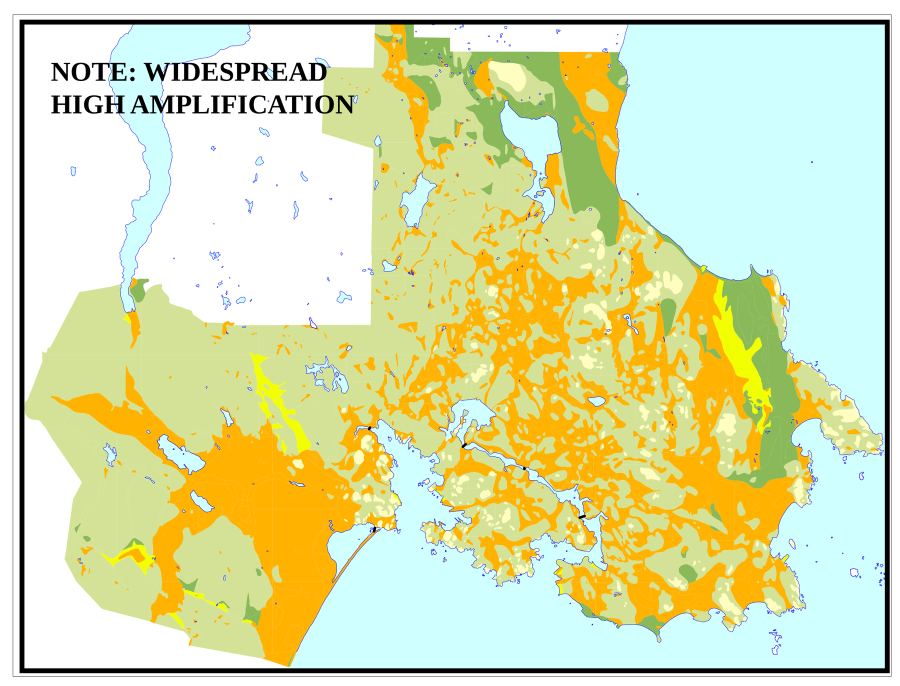
Map 5. amplification factors for short period ground motions at a moderate level of shaking on bedrock. Note that short period ground motions may be amplified 2.5 times (i.e. to 0.25 g) on soft soils. Note also that the high amplification hazard areas shown on Maps 1 and 2 also have high amplification on this map.



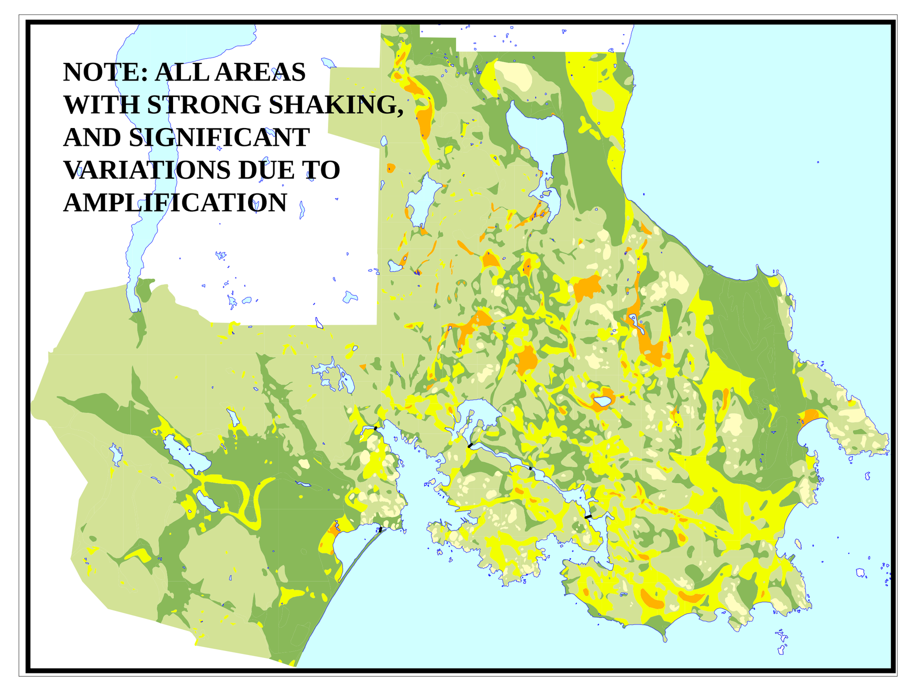
Map 7. amplification factors for short period ground motions at a strong level of shaking on bedrock. Note that in this case, there is little difference in amplification due to soil conditions across the area, and all areas will be shaken strongly but more or less equally (i.e.~0.4 g).

SHORT PERIOD GROUND MOTIONS

LONG PERIOD GROUND MOTIONS
(typically affecting tall buildings*)



Map 6. amplification factors for long period ground motions at a moderate level of shaking on bedrock. Note that long period ground motions may be amplified greater than 2.5 times or more on soft soils. Note also that the high amplification hazard areas shown on Maps 1 and 2 also have high amplification on this map.



Map 8. amplification factors for long period ground motions at a strong level of shaking on bedrock. Note that long period ground motions may be amplified 2.5 times on soft soils. Note also that the high amplification hazard areas shown on Maps 1 and 2 also have high amplification on this map.

LONG PERIOD GROUND MOTIONS

MODERATE EARTHQUAKE SHAKING | **STRONG EARTHQUAKE SHAKING**

Legend for Maps 5 to 8
Approximate Amplification Factors Relative to Rock, NEHRP Site class B)

Low	~1
Moderate	~1.5
High	
	>~2.5

Maps 5, 6, 7 and 8 show the approximate *amplification factors* for moderate and strong shaking (accelerations on bedrock of 0.1 g and 0.4 g, respectively), and for short and long period ground motions (typically affecting short and tall buildings, respectively*). The *amplification factor* is the amount by which ground motion on bedrock is multiplied due to soil conditions. Acceleration of 0.1 g represents the approximate onset of damage in buildings not designed to be earthquake resistant, and 0.4 g is the current building code design acceleration for Victoria (National Research Council of Canada, 1995). Both short and long period ground motions occur during an earthquake, but usually one type dominates depending on earthquake magnitude and distance from the source. These maps were prepared using the estimated average NEHRP site class for each geological map unit and the corresponding NEHRP amplification factors for short and long period structures (see relative amplification hazard map and accompanying report for more details; Monahan *et al*., 2000b).

Amplification factors decrease as the acceleration on bedrock increases, and this decrease is more pronounced for short period than long period ground motions. Short period ground motions can be amplified 2.5 times or more on soft soils during moderate shaking (Map 5; i.e. to 0.25 g, where acceleration on bedrock is 0.1 g). Conversely, relative amplification of short period ground motions due to the presence of soft soils during strong shaking is minimal, and all areas will be shaken strongly but more or less equally (Map 7; in this case ~0.4 g). Although little amplification of short period ground motions will occur during strong shaking (Map 7), *moderate shaking is much more likely to occur*, so that areas shown as having a high amplification hazard on Maps 1 and 2 will be subjected to potentially damaging short period ground motion *much more often* than low hazard areas. For example in the Victoria area, shaking of 0.1 g on bedrock is more than ten times as likely to occur as shaking of 0.4 g on bedrock. Although amplification of long period ground motions also diminishes as the intensity of ground shaking increases, it is still significant at 0.4 g (Maps 6 and 8). **Thus, in most cases (e.g. Maps 5, 6 and 8) and most often, the amplification hazard ratings shown on Maps 1 and 2 will reflect the intensity of amplification due to soil conditions (see relative amplification hazard map and accompanying report for more details; Monahan *et al*., 2000b)**

The variation in ground motions predicted using the amplification factors shown here does not exceed the seismic design criteria of the current building code (National Research Council of Canada, 1995), but could be significant for structures not governed by the seismic provisions of the code as well as older structures.

**** The critical period of ground motion for a specific building or building type should be determined by a qualified structural engineer.***

ACKNOWLEDGMENTS

This project received funding from the Capital Regional District, the Geological Survey of Canada, the British Columbia Resources Inventory Committee, Corporate Resources Inventory Initiative, and the Joint Emergency Preparedness Program. The authors also acknowledge the wealth of geological and geotechnical data and other assistance provided by the numerous agencies and individuals listed by Monahan *et al.* (2000). In particular, the authors acknowledge the assistance of G.C. Rogers, J. Cassidy, R. Lloyd, M. Williams, R. Gibbs, B. Harding, B. Kerr and J. Valeriote. Cartography by C. Spicer and G. Letham at AXYS Environmental Consulting Ltd.

OTHER SOURCES OF INFORMATION

For information on earthquake activity in British Columbia contact the Pacific Geoscience Centre of the Geological Survey of Canada at P.O. Box 6000, Sidney, B.C., V8L 4B2. For more information on earthquake hazards in Western Canada see the references listed below or visit the following web sites: http://www.em.gov.bc.ca/geology (and click on surficial mapping) or http://pgc.nrcan.gc.ca. For information on earthquake preparedness contact the B.C. Provincial Emergency Program at P.O. Box 9201, Stn Prov Govt, Victoria, B.C., V8W 9J1 [phone (250) 952-4913 or 1-800-663-3456] website http://www.pep.bc.ca or Emergency Preparedness Canada at P.O. Box 10000, Victoria, B.C., V8W 3A5 [phone (250) 363-3621].

REFERENCES

Building Seismic Safety Council (1994): NEHRP recommended provisions for seismic regulations for new buildings Part I - Provisions; *Federal Emergency Management Agency*, Washington, D.C., 290 pages.
Clague, J.J. (1996): Paleoseismology and Seismic Hazards, Southwestern British Columbia; *Geological Survey of Canada*, Bulletin 494, 88 pages.
Finn, W.D.L. (1994): Geotechnical Aspects of the Estimation and Mitigation of Earthquake Risk; *in* Issues in Urban Earthquake Risks, Tucker, B.E., Erdik, M. and Wang, C.H., Editors, *Kluwer Academic Publishers*, pages 35-77.
Hyndman, R.D. (1995): Giant Earthquakes of the Pacific Northwest, *Scientific American*, Volume 273, Number 6, pages 50-57.
McQuarrie, E.J. and Bean, S.M. (2000): Seismic Slope Hazard Map for Greater Victoria; *British Columbia, Ministry of Energy and Mines*, Geoscience Map 2000-3c.
Monahan, P.A. and Levson, V.M. (1997): Earthquake Hazard Assessment in Greater Victoria, British Columbia: Development of a Shear-Wave Velocity Model for the Quaternary Sediments; *in* Geological Fieldwork 1996, Lefebure, D.V., McMillan, W.J. and McArthur, J.G., Editors, *British Columbia Geological Survey, Ministry of Employment and Investment*, Paper 1997-1, pages 467-479.
Monahan, P.A., and Levson, V.M. (2000): Quaternary Geological Map of Greater Victoria; *British Columbia Ministry of Energy and Mines*, Geoscience Map 2000-2.
Monahan, P.A., Levson, V.M., McQuarrie, E.J., Bean, S.M., Henderson, P., and Sy, A. (1998): Seismic microzonation mapping in Greater Victoria, British Columbia, Canada; *in* Geotechnical Earthquake Engineering and Soil Dynamics III, P. Dakoulas, M. Yegian, and R.D. Holtz, Editors, *American Society of Civil Engineers*, Geotechnical Special Publication No. 75, pages 128-140.
Monahan, P.A., Levson, V.M., Henderson, P., and Sy, A. (2000a): Relative Liquefaction Hazard Map of Greater Victoria; *British Columbia Geological Survey, Ministry of Energy and Mines*, Geoscience Map 2000-3a.
Monahan, P.A., Levson, V.M., McQuarrie, E.J., Bean, S.M., Henderson, P., and Sy, A. (2000b): Relative Amplification of Ground Motion Hazard Map of Greater Victoria, *British Columbia Geological Survey, Ministry of Energy and Mines*, Geoscience Map 2000-3b.
Reiter, L. (1990): Earthquake hazard analysis, issues and insights; *Columbia University Press*, New York, 253 pages.
Rial, J.A., Saltzman, N.G. and Ling, H. (1992): Earthquake-induced resonance in sedimentary basins; *American Scientist*, Volume 80, pages 566-578.
Rogers, G.C. (1980): A documentation of soil failure during the British Columbia earthquake of 23 June, 1946; *Canadian Geotechnical Journal*, Volume 17, pages 122-127.
Rogers, G.C. (1998): Earthquakes and earthquake hazard in the Vancouver Area; *in* Geology and Natural Hazards of the Fraser River Delta, British Columbia, J.J. Clague, J.L. Luternauer, and D.C. Mosher, Editors, *Geological Survey of Canada,* Bulletin 525, pages 17-25.
Somerville, P. (1998): Emerging art: earthquake ground motion; *in* Geotechnical Earthquake engineering and Soil Dynamics III, P. Dakoulas, M Yegian, and R.D. Holtz, Editors, *American Society of Civil Engineers*, Geotechnical Special Publication No. 75, pages 1-38.
Wuorinen, V. (1976): Chapter 5; Seismic microzonation of Victoria: A social response to risk; *in* Victoria: physical environment and development, Foster, H.D., Editor, *Western Geographical Series*, Volume 12, pages 185-219.
Youd, T.L. and Perkins, D.M. (1978): Mapping liquefaction-induced ground failure potential. *Journal of Geotechnical Engineering*, Volume 104, pages 433-446.