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**GEOLOGICAL SURVEY OF CANADA
OPEN FILE 7816 (revised)**

**Risk Map Atlas:
Maps from the Earthquake Risk Study for the
District of North Vancouver**

C.L. Wagner, J.M. Journeay, N.L. Hastings, and J.A. Prieto

2015



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Abstract

Natural Resources Canada, as part of its Public Safety Geoscience program, worked in cooperation with the District of North Vancouver (DNV) and other partners to develop and test methodologies that are appropriate for assessing earthquake risk at a municipal scale in Canada. The earthquake loss estimation software, Hazus-MH, was used to analyze the losses to buildings, infrastructure, and people in the District and to estimate the damage and injuries resulting from earthquakes. The initial analysis was repeated to show possible changes in outcome if buildings in the community were assumed to be retrofitted to modern building codes. This Risk Map Atlas provides a selection of maps and notes showing the inventory of buildings and infrastructure, hazard parameters, and results from the study. The Atlas is intended to help similar Canadian communities in the development of an earthquake risk assessment.

Scientific Disclaimer

Natural Resources Canada (NRCan) has developed the capacity to model consequences of hypothetical earthquakes for Canada. Results demonstrating this capability have been modelled with Hazus-MH loss estimation software in consultation with other seismic risk assessment experts. Mapped impacts and losses are based on reasonable assumptions and simplifications. Analyses of potential impacts of topography, basin structure, aftershocks, tsunamis, and fire following, as well as scientific uncertainty and interdependency, have NOT been included in this study. **The Data on these maps are intended to convey regional trends and should be used as a guide only. The results shown do not replace site specific geotechnical investigations for design, construction, or engineering purposes.**

Introduction

The threat to public safety and the damage costs due to natural hazard events in Canada is large. The goal of the Public Safety Geoscience Program of Natural Resources Canada is to provide practical geoscientific information that helps Canadians reduce future losses from natural hazards. The purpose of the Quantitative Risk Assessment Project, one of the activities under the program, is to adapt, test, and validate best practice methods and tools to support the assessment of natural hazard risks in Canada. Until now, no national methodology has been available in Canada for assessing earthquake risk.

The Earthquake Risk Study for the District of North Vancouver was the pilot study to explore earthquake risk and potential loss reduction at a municipal scale. As a growing community situated on the Pacific Ocean and in the seismically active region of the Coast Mountains, the District of North Vancouver is challenged to understand and assess its risks from potentially damaging earthquakes.

This study used the US Federal Emergency Management Agency's (FEMA) Hazus-MH loss estimation modelling software which was adapted for use in Canada by the Public Safety Geoscience Program of Natural Resources Canada. The modelling program was used to estimate what might happen to the District of North Vancouver after an earthquake and the associated risks, such as triggered landslides. The estimates include: the type of damage that can be anticipated in buildings, the number and severity of injuries, the location of vulnerable buildings and populations, and the disruption to important services such as roads, water, sewers, and electricity.

This Risk Map Atlas presents a folio of maps and accompanying notes that document the inventory, analytic methodologies, and results of earthquake risk analyses on the buildings and facilities in the District of North Vancouver. This document mirrors the

case study report (Journeay et al., 2015) with a focus on Hazus-MH indicators that have a potential application in support of emergency management, land use planning, infrastructure development, public safety, and financial and/or socio-economic security.

Project Partners

The **District of North Vancouver** (DNV) is the lead municipal partner for this case study and responsible for overall context and focus for the project. Primary roles include the sharing of detailed technical information about the community and critical assets, and the identification of policy goals and target criteria that have guided all aspects of the risk assessment process. Staff members from the Engineering department (Fiona Dercole, Michelle Weston and colleagues) have worked with research partners at each step of the process and have provided important new insights on the needs and operational requirements for earthquake risk reduction and disaster resilience planning at a municipal scale in Canada. They have worked with community members of the Natural Hazards Task Force to review study results and to help transform the scientific and technical knowledge about the risk environment into a form that will support both day-to-day and longer-term strategic planning activities in the community. Staff members from the Geographic Information Systems, Asset Management, Engineering, and Land Use Planning departments have provided data and assistance for this project.

The **North Shore Emergency Management Office** (NSEMO) coordinates cross-jurisdictional planning, preparedness, and the development of core operational capacities that are required to support emergency response and recovery efforts on behalf of the District of North Vancouver, the City of North Vancouver, and the District of West Vancouver. As a member of the Integrated Partnership for Regional Emergency Management (IPREM) in Metro Vancouver area, NSEMO also acts as a liaison between local and regional governments in the development of emergency plans and the coordination of disaster response and recovery efforts. Staff members at NSEMO (Dorit Mason and colleagues) have provided technical information on essential facilities and emergency service capacities in the region, and have contributed to the development of strategies for promoting the use of earthquake risk information by local governments, the business community, and members of the general public.

The **UBC Department of Civil Engineering** is a leader in fundamental and applied research on seismic hazards and structural engineering in Canada. Researchers at the Earthquake Engineering Research Facility (EERF; Carlos Ventura and Liam Finn) worked with members of the NRCan team to assess local-scale seismic hazards using a combination of deterministic and probabilistic ground motion models, and contributed vital information on building assets to support a site-specific analysis of earthquake risks for the District of North Vancouver. In addition, they have provided important insights and recommendations on seismic retrofit strategies that may be effective in reducing the vulnerabilities of older buildings that are susceptible to severe earthquake hazards in the District.

Natural Resources Canada (NRCan: Public Safety Geoscience Program) is the lead researcher for the project and one of several federal departments with a mandate to carry out fundamental research to help reduce the economic, social, and environmental impacts from natural hazards in Canada. NRCan contributes to the mandate of increasing public safety and reducing future losses through the generation of knowledge about geohazards (earthquakes, volcanoes, landslides, etc.) and through the development of analytic methods for risk assessment that are needed to inform the design and operation of buildings and engineered structures and the regulation of land use decisions, natural resource development, and emergency management operations at local, regional and national scales. Researchers with the Public Safety Geoscience Program have taken a lead role in the analysis and evaluation of earthquake risks for the District of North Vancouver through collaborative partnerships with case study partners, and with academic colleagues at the University of British Columbia and Simon Fraser University.

Defence Research and Development Canada (DRDC) provided financial support to the project through the Canadian Safety and Security Program (CSSP) (CSSP project number, Risk 09/10-0001SCP Quantitative Risk Assessment Project). This program is led

by Defence Research and Development Canada's Centre for Security Science, in partnership with Public Safety Canada. The CSSP is a federally-funded program to strengthen Canada's ability to anticipate, prevent/mitigate, prepare for, respond to, and recover from natural disasters, serious accidents, crime and terrorism through the convergence of science and technology with policy, operations, and intelligence. Funding was provided for the adaptation, testing, and validation of best practice methods and tools to support the assessment of natural hazard risks in Canada. Outputs of this study contribute to broader efforts led by DRDC and Public Safety Canada to develop an all-hazards risk assessment framework to support policy goals and operational requirements for a National Disaster Mitigation Program.

Project Overview

A risk assessment process involves a series of elements: knowledge, analysis, evaluation, and action. Knowledge encompasses the understanding of risk, identifying hazards that could affect a community, and having a community profile of who and what are vulnerable to the hazards. Analysis involves building scenario models for hazards based on available scientific and technical information, and using the scenarios in a loss estimation methodology to assess the impacts and consequences of a hazard with respect to building performance, public safety, lifeline resilience, and economic security. The evaluation element involves looking at how much risk is tolerable to a community and developing "what-if" situations that model mitigation alternatives. The action element is the implementation of mitigation steps to build community resilience to impacts from hazards.

Earthquake Risk: A natural hazard is an event or situation whose occurrence can cause damage or threaten lives. It is the likelihood of a potentially destructive natural phenomenon, such as ground shaking induced by an earthquake. Exposure is the measure of the amount of a structure or life that could be impacted by a potential hazard. These include the people, buildings, and infrastructure that are important to communities. Vulnerability is the likelihood that the exposure assets will be damaged or destroyed when exposed to a hazard event. Risk is the probability of a consequence, where the consequence is the composite of the hazard, exposure, and vulnerability. Consequence is measured by factors such as amount of damage, injuries, and anticipated socio-economic losses. Figure 1 illustrates the components of risk.

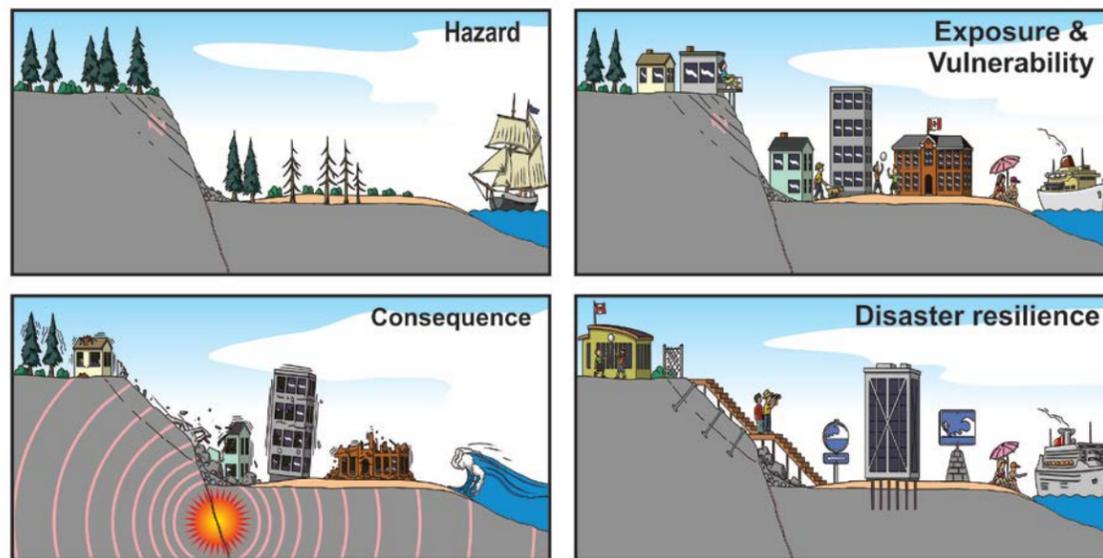


Figure 1. Illustrations that define each term used in the explanation of risk.

Earthquake risk assessment models need to incorporate all three aspects of risk. The location and characteristics of people and buildings in a community is the Exposure aspect of the risk assessment. The Vulnerability of these assets is provided in the database parameters about the people and buildings. Factors such as the construction material of the building and the building's seismic design code are measures of how vulnerable or resilient a building is to earthquake shaking. The Hazard is the earthquake scenario that is used in the risk model and applied to the inventory. Hazard maps or shaking parameters are used to model the ground shaking and also to determine whether that shaking will induce earth movement due to liquefaction and/or landslides. The output of the risk assessment model is the measure of the likely impacts and consequences of that hazard event on the inventory.

This process of risk assessment and management follows a modified version of the standardized process adopted by the International Standards Organization and the Canadian Standards Association (CSA, 2009). Those modifications, which emphasize use in risk-based land-use decisions, are covered by Struik et al. (2015).

Risk Assessment Model: The Multi-hazard Loss Estimation Methodology (Hazus-MH), developed by the US Federal Emergency Management Agency (FEMA), was chosen as a best practise method. Under NRCan's Quantitative Risk Assessment Project, the Hazus-MH software was adapted for use in Canada. The software, associated databases, and a manual (for the earthquake module) for Canadian users is published as Chow et al. (2014) and can be downloaded from www.hazuscanada.ca

The Hazus-MH model uses data contained in a database for each province and territory. The structure of the database includes:

- Population demographics per census area
- Building inventory (the count, square footage, replacement cost, and content cost) for 33 classes of occupancy, aggregated to census areas
 - Residential – 11 classes
 - Commercial – 10 classes
 - Industrial – 6 classes
 - Government – 2 classes
 - Education – 2 classes
 - Religion
 - Agricultural
- Essential facilities (schools, fire stations, hospitals, police stations, and emergency operations centres)
- Transportation networks and facilities,
- Utility networks and facilities, and
- High potential loss facilities (dams, levees, hazardous materials buildings, military facilities, and nuclear facilities).

With the US version of Hazus-MH a full suite of inventory data is provided for each state, with information available for all of the above listed items. For the Hazus-MH Canada model, a basic set of information is provided for users. The demographics inventory and the residential occupancy building inventory were generated for census areas using data from Statistics Canada. The buildings for commercial and industrial occupancies were generated from data purchased from Dun and Bradstreet and aggregated per census area. Aggregated data for the other occupancies are currently not available with the Hazus-MH Canada release. Also, data for essential facilities, transportation, utilities, and high potential loss facilities are not available for use with Hazus-MH Canada.

The provincial/territorial aggregated inventory is provided for Canadian users as a starting point and it is strongly recommended that users obtain local building inventories to update the aggregated values so that the risk assessment analysis may be more

current and apply to the local building characteristics. Users may also add local inventory features to the non-aggregated data file in the provincial database. Data manipulation local information is required to conform to the Hazus database format.

The Hazus-MH model contains fragility curves and corresponding damage functions for each combination of building occupancy, building type (construction material), and building seismic design level. These functions are used to analyze potential impacts of an earthquake on collections of buildings (aggregate analysis) and on the specific infrastructure facilities. In addition, Hazus-MH provides the capability to predict the extent and likelihood of damage to individual structures using more specific engineering parameters in the Advanced Engineering Building Module (AEBM). At this most detailed level of analysis, Hazus-MH can be used to evaluate the effectiveness of risk reduction strategies by altering building fragility curves to simulate the effects of mitigation measures. The user can then make a comparison of the results with and without such measures in place.

District of North Vancouver: The District of North Vancouver was selected as an ideal candidate in which to test and validate the methodology for assessment of earthquake risk and loss reduction. The District is one of 23 local governments represented in the broader Metro Vancouver region. With a total population of approximately 2.3 million (2011 Canada Census) Metro Vancouver is situated in the seismically active southwest corner of the British Columbia mainland. Bounded by the Georgia Strait, Burrard Inlet, and the Coast Mountains, the District is a mid-sized urban community of approximately 83,000 people, exposed to many natural hazards – earthquakes, landslides, liquefaction, flooding, debris flows, and wildfires.

The District is recognized as a leader for its work in establishing risk tolerance criteria to guide planning and policy development in areas exposed to natural hazards. In 2011, the District received the United Nations Sasakawa Award for Disaster Risk Reduction and it has been recognized as a “Role Model City” for the United Nations Program for Disaster Resilient Cities. Risk management policies are currently focused on protecting people and critical assets from the impacts of debris flow, flood and interface fire hazards. The District intends to use the knowledge from this study to strengthen the community’s resilience capacity with respect to mitigation, preparedness, response, and recovery from earthquakes by identifying the people, buildings and infrastructure that are most vulnerable.

Risk Assessment Exposure Data: To ensure the analysis is applicable to the characteristics of the municipality, the aggregated inventory used by Hazus-MH was updated using the building inventory obtained from the District and building construction information provided by EERF (Earthquake Engineering Research Facility at UBC). The information on individual buildings was used to generate the parameters required for the Hazus database, such as building occupancy (residential, commercial, industrial, etc.), building square footage, and building seismic design level. Building replacement costs and content costs were calculated using square footage values along with the suggested cost per square foot values based on building occupancy, as published in Hazus-MH manual (FEMA, 2012a). The generated list of buildings and parameters was aggregated for each census area and transferred to the provincial database used by Hazus-MH. The location and parameters for schools and fire stations, road and rail networks and bridges, and utility pipelines and facilities were also obtained from the District and added to the database. (The hospital, emergency operations centre, and police station serving the District are located in a neighbouring community.) Replacement costs for these facilities were calculated based on information provided by the District or by using the suggested values in the Hazus-MH manual.

The list of individual buildings for the District was also prepared for use in the AEBM model. Specific AEBM parameters were generated for each building based on its occupancy, building construction material, and seismic design level.

Earthquakes: For this study, analysis was performed using two earthquake assessments: the Georgia Strait, M7.3 event and a 1 in 2475 year Probabilistic Seismic Hazard Assessment (PSHA). The regional ground shaking intensities for each scenario and potential damage are illustrated in Figure 2.

The Georgia Strait event represents a scientifically plausible major earthquake with a potential to generate losses that are consistent with national guidelines for disaster mitigation and risk reduction planning. This event is accepted within the

earthquake scientific community as a suitable scenario for risk analysis and, as such, was chosen for this study. Section 3 provides more information on Georgia Strait event.

The 1 in 2475 year assessment represents the ground shaking that is likely to occur in any given year for a recurrence interval of 1 in 2475 years. By definition, probabilistic ground motion models represent the cumulative threat of all known earthquake hazards at a specific location over a given future time horizon. Section 6 provides more explanation of probabilistic hazard assessments and the 1 in 2475 year PSHA.

Further information on the measurement of ground shaking and the hazard maps associated with earthquake scenario is provide in Sections 3 and 6.

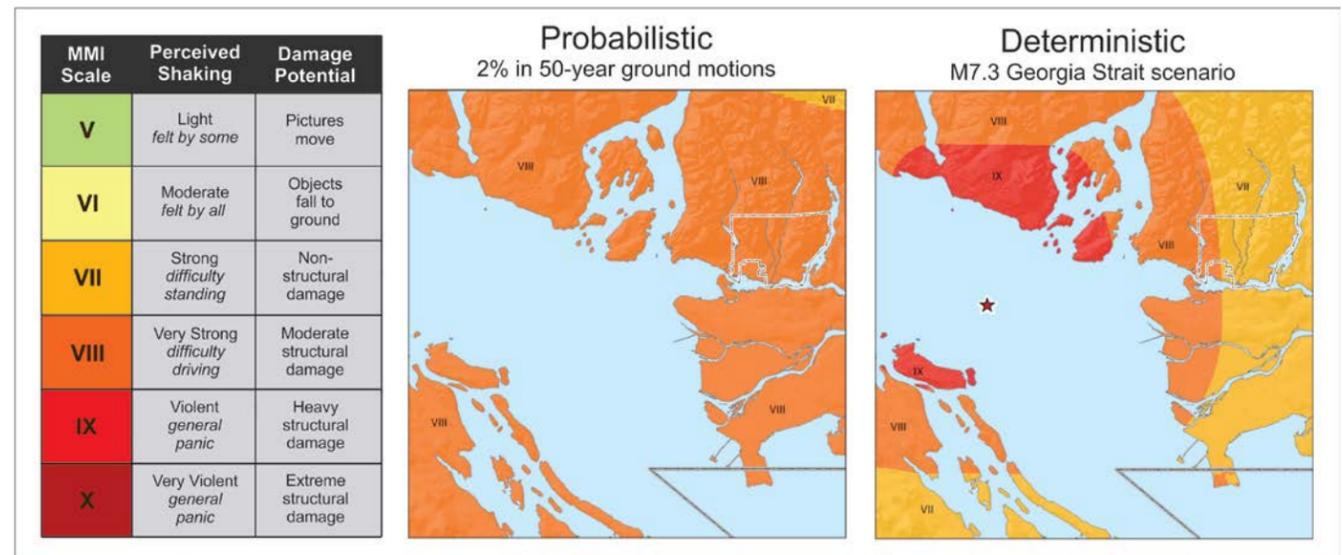


Figure 2. Probabilistic and deterministic ground motion models. These maps show the regional spatial distribution and expected intensities of ground shaking for the two earthquakes used in this study. Sources: Adapted from Petersen et al. (2008); USGS shakemaps.

Analysis: For each earthquake model, the damage and loss estimation analysis was run on the aggregated building inventory, the essential facilities, the transportation networks, and the utility networks and facilities. The AEBM analysis on the individual buildings was run twice; first with the current known seismic design level for each building; second with a modified seismic design level applied to some of the buildings to assume a retrofit to modern building code. This procedure represents a “what-if” situation and shows the possible changes in outcome if mitigation actions were applied.

The following factors are NOT considered in our analysis for the District of North Vancouver:

- Model and system interdependencies
- Uncertainty
- Aftershocks
- Basin and topographic effects
- Fire-following
- Tsunami.

Results: The risk assessment analysis for each earthquake assessment for this study resulted in three sets of information.

The results for the population and building data aggregated to census area include the estimated:

- Number of injuries and fatalities
- Social impacts such as population requiring shelter
- Level of building damages per census area based on Occupancy or Building (construction) Type
- Value of dollar loss due to the building damage
- Amount of building debris due to the building damage.

The above listed results are not shown in this atlas.

The results for the facilities inventory include the estimated:

- Level of damages and dollar loss to individual schools and fire stations
- Level of damages and loss of functionality to transportation systems and road bridges
- Level of damages and loss of functionality to utility facilities and pipelines

The results for the individual buildings using the AEBM analysis include the estimated:

- Level of damages to individual buildings using current seismic codes
- Level of damages to individual buildings using hypothetical mitigated seismic codes
- Value of dollar loss due to building damage
- Number of injuries or fatalities to population in individual buildings
- Recovery and repair time for individual buildings

Atlas Maps: This Risk Map Atlas provides a selection of the results from the study. Brief descriptive notes are shown on each map and more detailed notes are provided in the following sections. A thorough report of the study and the results can be found in the District of North Vancouver case study report (Journey et al., 2015), from which some descriptive notes in this atlas have been extracted.

The maps in this atlas have been divided into eight sections based on the information each map is displaying. The Community Exposure maps show the location and characteristics of the buildings in the District. The Hazard Potential maps show the characteristics of the land which present hazards that will influence any earthquake scenario. The Hazard Maps show the shaking parameters for the specific earthquake scenario. The Consequence/Damage maps show the type and amount of damage or injuries for the specific earthquake scenario as estimated by the Hazus-MH model. The Resilience/Mitigation maps show the type and amount of damage or injuries for the specific earthquake with hypothetical mitigation parameters applied to some buildings.

On the maps in this publication, the building characteristics (occupancy, building type/material, building seismic code) are shown for individual buildings. The analysis results for schools, fire stations, bridges, and utility facilities are also shown for individual structures. The results from the AEBM analyses performed on all of the individual buildings are not displayed for the individual buildings in this document. Instead the results indicators have been grouped to indicate regions of similar values.

Acknowledgements

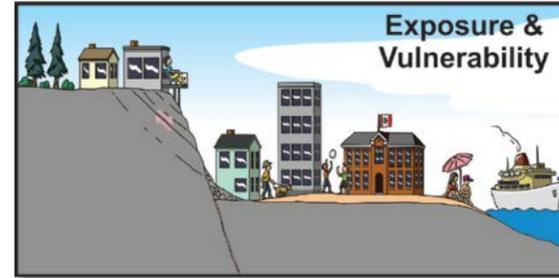
Alison Bird, Geological Survey of Canada, reviewed this document and provided excellent feedback. Heather Crow, Geological Survey of Canada, provided support to the project through the engagement of geotechnical consulting companies and

local/regional governments who provided borehole data. This data, along with guidance from Ms. Crow, was used to develop the NEHRP (National Earthquake Hazard Reduction Program) soil map for the District of North Vancouver. Borehole data was shared by Metro Vancouver, the City of North Vancouver, the District of West Vancouver, Greater Vancouver Water District, British Columbia Ministry of Transportation, BC Hydro, and by BGC Engineering, Stantec Consulting Ltd, and Thurber Engineering Ltd. in consultation with their clients. Heather Crow also provided an initial review of the atlas. The authors wish to thank their current and former colleagues at the Geological Survey of Canada who have assisted with the planning, technical, and presentation aspects of this study: William Chow, Bert Struik, Malaika Ulmi, Maggie Wojtarowicz, Robert White, Rowan Arundel, and Jessica Shoubridge. Adrienne Jones and Carmel Lowe provided project support within the Public Safety Geoscience Program.

Section 1: Community Exposure Maps

Introduction

Building location, occupancy, and infrastructure data and characteristics were provided by the District of North Vancouver GIS department in 2010. Road and utility replacement costs were provided by the Asset Management department the same year. Additional information on schools, fire stations, and road bridges were provided by DNV personnel in 2012.



Map 1A. District of North Vancouver, Community Overview

The District of North Vancouver is one of three municipalities who coordinate emergency management services through the North Shore Emergency Management Office. The District covers more than 160 square kilometres, spreading from the sea level shorelines of Burrard Inlet and Indian Arm to the heights of Grouse Mountain (1231 metres) and Mount Seymour (1449 metres). The current population of approximately 85,000 people lives primarily at the lower elevations in an urban area covering approximately 45 square kilometres. The rest of the area (78%) is designated as natural green space with forest and parkland managed by Provincial, Metro Vancouver, or District agencies. The District also encompasses two First Nation communities. There are four town/village centres in the Official Community Plan (OCP) where the District is proposing further development of commercial and residential buildings.

Map 1B. District of North Vancouver, Building Occupancy

There are approximately 23,000 buildings in the District of North Vancouver. Residential development began in the late 1800s and proceeded rapidly through the 1950s to 1970s. Many of the older neighbourhoods and town centres are situated along the waterfront and valley escarpments – areas that have been significantly modified over the years with anthropogenic fill to accommodate increasing demands for growth and development in the community. Map 1B shows the distribution of use (or occupancy class) of the buildings. The occupancy classes are defined by those required by the Hazus-MH loss estimation software used in this study (FEMA, 2012a, Table 3.2). Using the categories of Building Type and Subtype from the information supplied by the District, the Hazus occupancy classes were assigned to buildings.

Single family homes make up over 89% of the buildings in the District while multi-family buildings account for 4%. The residential buildings spread from the waterfront to the slopes. The commercial buildings (2.6% of the building) are concentrated in the established town centres and along the waterfront. Industrial buildings (2.5% of the buildings) are situated mainly along the waterfront. In the Hazus-MH earthquake loss estimation software, the extent of economic loss and social disruption that is expected is based on building use (occupancy class) and the level of physical damage sustained as a result of the earthquake scenario.

Map 1C. District of North Vancouver, Building Construction Material

Thirty-six building types are used in the Hazus-MH model to classify specific characteristics of construction within the general categories of wood, steel, concrete, masonry, and mobile homes (FEMA, 2012a, Table 3.1). Building type, along with the seismic design level, is used in Hazus-MH to predict the extent of physical damage to a building, which in turn is used to determine the potential for injury and loss of functionality for any given level of ground shaking.

The construction material information for the buildings within the District was provided by the researchers at the Earthquake Engineering Research Facility in the Department of Civil Engineering at the University of British Columbia. The majority (89%) of buildings in the District of North Vancouver are wood frame single-family homes. Although generally resistant to ground

shaking, most residential structures in the District are not engineered to withstand ground deformation hazards caused by liquefaction and/or earthquake triggered landslides. The multi-family condominium, apartment, and townhouse complexes in the District are constructed of wood, with a few of them built of concrete or masonry. Most of the commercial and industrial buildings are made of concrete, wood, or unreinforced masonry that predate modern seismic design codes. Many of these buildings are located in areas exposed to both ground shaking and ground deformation hazards.

Map 1D. District of North Vancouver, Building Seismic Design Level

A seismic design level was assigned to each building in the District of North Vancouver inventory used for this study. The seismic code was determined based on available information regarding the age and type of construction material, and whether the building has been seismically retrofitted since the time of construction.

Performance-based guidelines were introduced into the National Building Code of Canada in the early 1970s to reduce levels of damage and to ensure minimum thresholds of safety for people in areas exposed to earthquake hazards. However, enforcement of these guidelines only applies to new construction and/or buildings undergoing significant renovation as part of the development approval process. Seismic design codes were introduced in the District of North Vancouver in 1973. The number of older buildings in the District that pre-date or were designed to lower design thresholds far exceeds the number of buildings that conform to modern building codes. Nearly 67% of all buildings were constructed prior to the adoption of modern seismic design codes. The majority of these structures (93%) are single and multi-family residential structures of wood-frame construction.

The guidelines used to determine the current seismic design code for the buildings in the District are:

- Pre-Code: Built before 1973 or year built is unknown
- Low Code Special: Built between 1973 and 1990 and Building Type is Wood, Steel, or Concrete
- Low Code: Built between 1973 and 1990 and Building Type is Masonry, Mobile, or other
- Moderate Code Special: Built from 1990 to 2005 and Building Type is Wood, Steel, or Concrete
- Moderate Code: Built from 1990 to 2005 and Building Type is Masonry, Mobile, or other
- High Code Special: Built 2005 or later and Building Type is Wood, Steel, or Concrete
- High Code: Built 2005 or later and Building Type is Masonry, Mobile, or other

Seismic design code, along with the building type, is used by Hazus-MH to predict the extent of physical damage to a building, which in turn is used to determine the potential for injury and loss of functionality for any given level of ground shaking. For each combination of building type and seismic design code there is a fragility curve and corresponding damage function that is used in the Hazus-MH model to analyze potential impacts of an earthquake.

Map 1D shows the distribution of seismic design levels for the District building, based on current conditions.

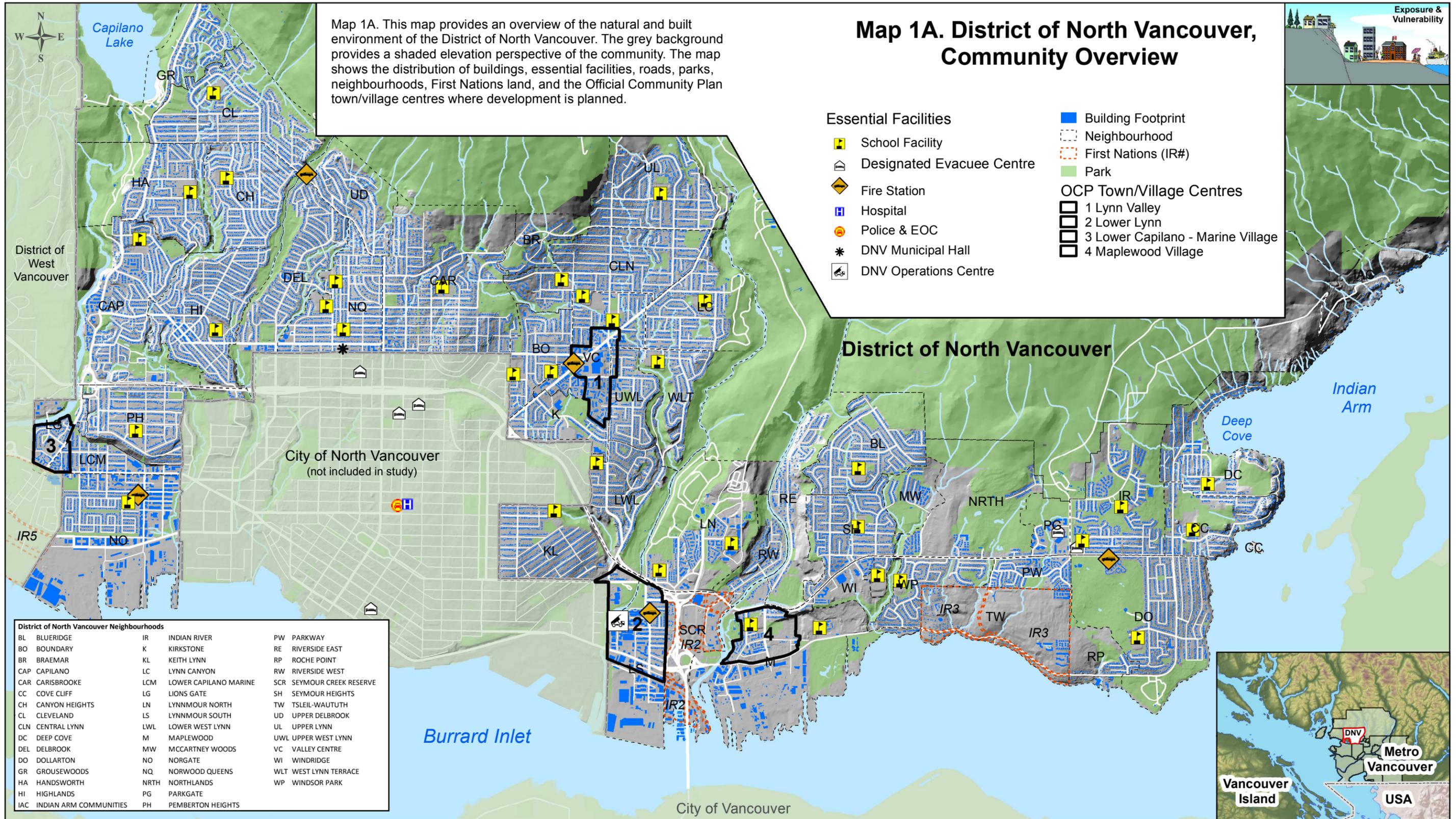
Map 1E. District of North Vancouver, Social Vulnerability

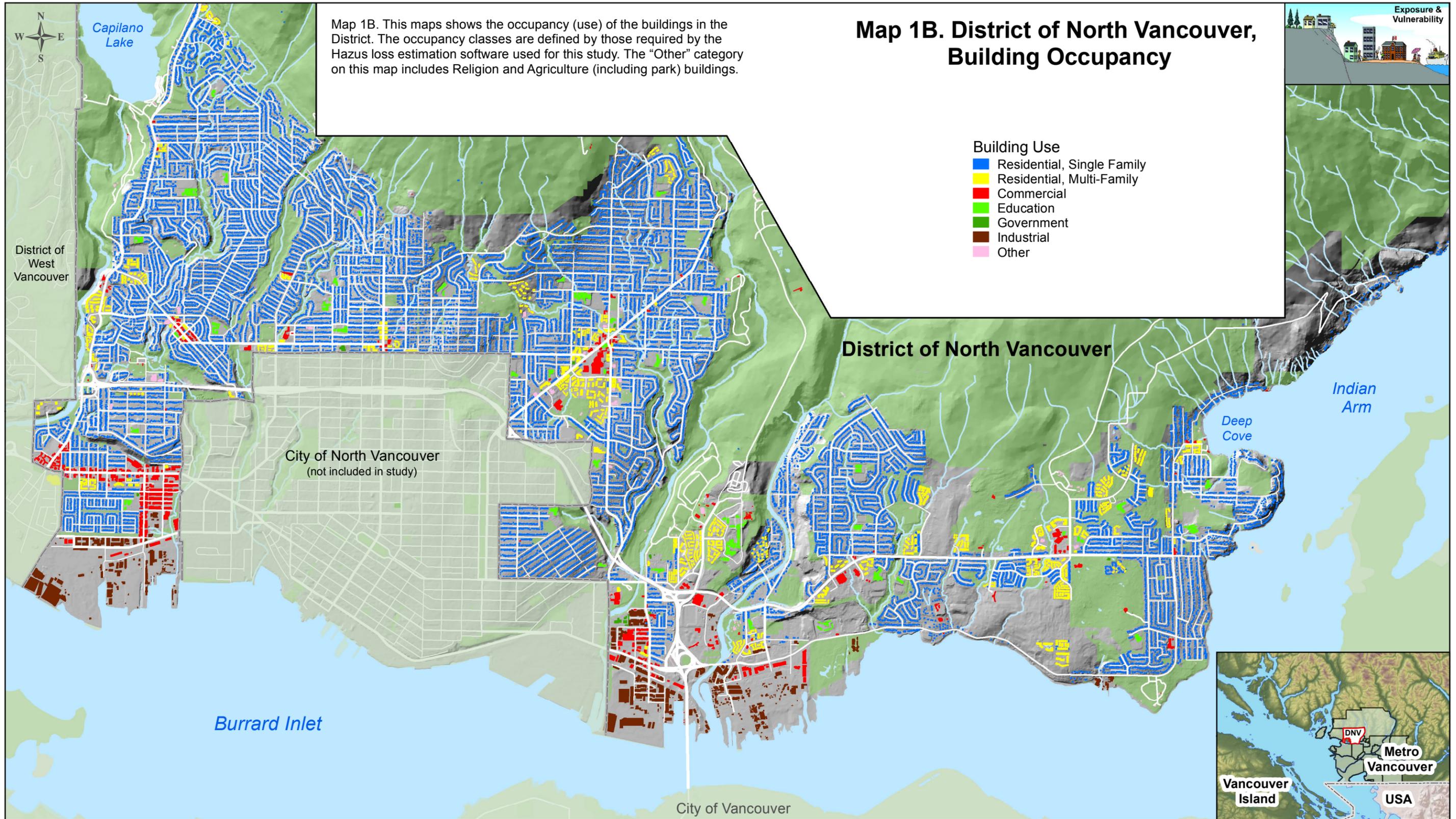
Social vulnerability looks at characteristics of a community that have the potential to amplify the negative impacts and consequences of a disaster event. The analysis is based on the well-known 'hazards of place' model and is described further in Journeay et al. (2015). Key characteristics for social vulnerability include:

- the extent to which people are susceptible to the physical impacts of a major earthquake;
- the social and economic variables that enable some to take actions that minimize the impacts of a hazard event while forcing others to succumb; and
- the demographic variables that influence capabilities to cope with and recover from the impacts of a disaster event.

Variables used to measure these social characteristics include age, income, physical ability, housing characteristics, access to emergency social services, the degree of connectedness in a community, plus other variables. Knowing who is most vulnerable, and the underlying socio-economic drivers, provides insights on the types of emergency services that are likely to be needed in areas during response and recovery operation.

Map 1E shows the distribution of social vulnerable population in the District, based on the many factors analyzed as part of a regional assessment undertaken to identify trends for Metro Vancouver.





Map 1B. This maps shows the occupancy (use) of the buildings in the District. The occupancy classes are defined by those required by the Hazus loss estimation software used for this study. The "Other" category on this map includes Religion and Agriculture (including park) buildings.

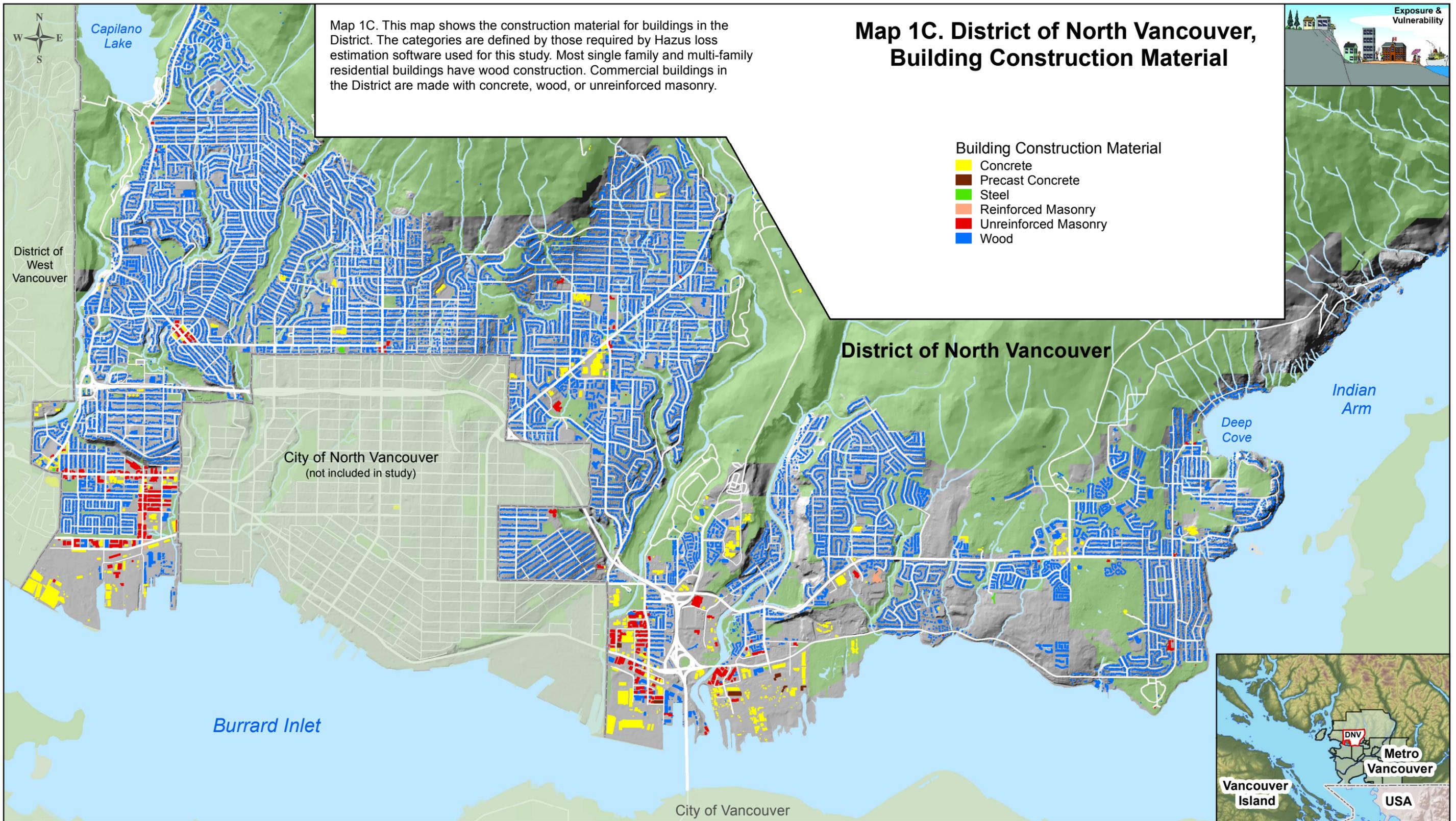
Map 1B. District of North Vancouver, Building Occupancy

- Building Use**
- Blue Residential, Single Family
 - Yellow Residential, Multi-Family
 - Red Commercial
 - Green Education
 - Light Green Government
 - Brown Industrial
 - Pink Other

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Credits: Building location, occupancy, and infrastructure provided by the District of North Vancouver. Building details provided by the Earthquake Engineering Research Facility, Department of Civil Engineering, University of British Columbia. All results were generated by Natural Resources Canada in consultation with other seismic risk assessment experts, using best available data, current scientific and engineering knowledge, and reasonable assumptions. Earthquake impacts were modelled with Hazus loss estimation software. Estimates were generated for a specific earthquake scenario using limited hazard information.



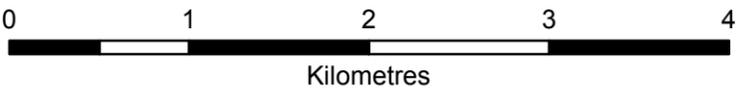
Map 1C. This map shows the construction material for buildings in the District. The categories are defined by those required by Hazus loss estimation software used for this study. Most single family and multi-family residential buildings have wood construction. Commercial buildings in the District are made with concrete, wood, or unreinforced masonry.

Map 1C. District of North Vancouver, Building Construction Material

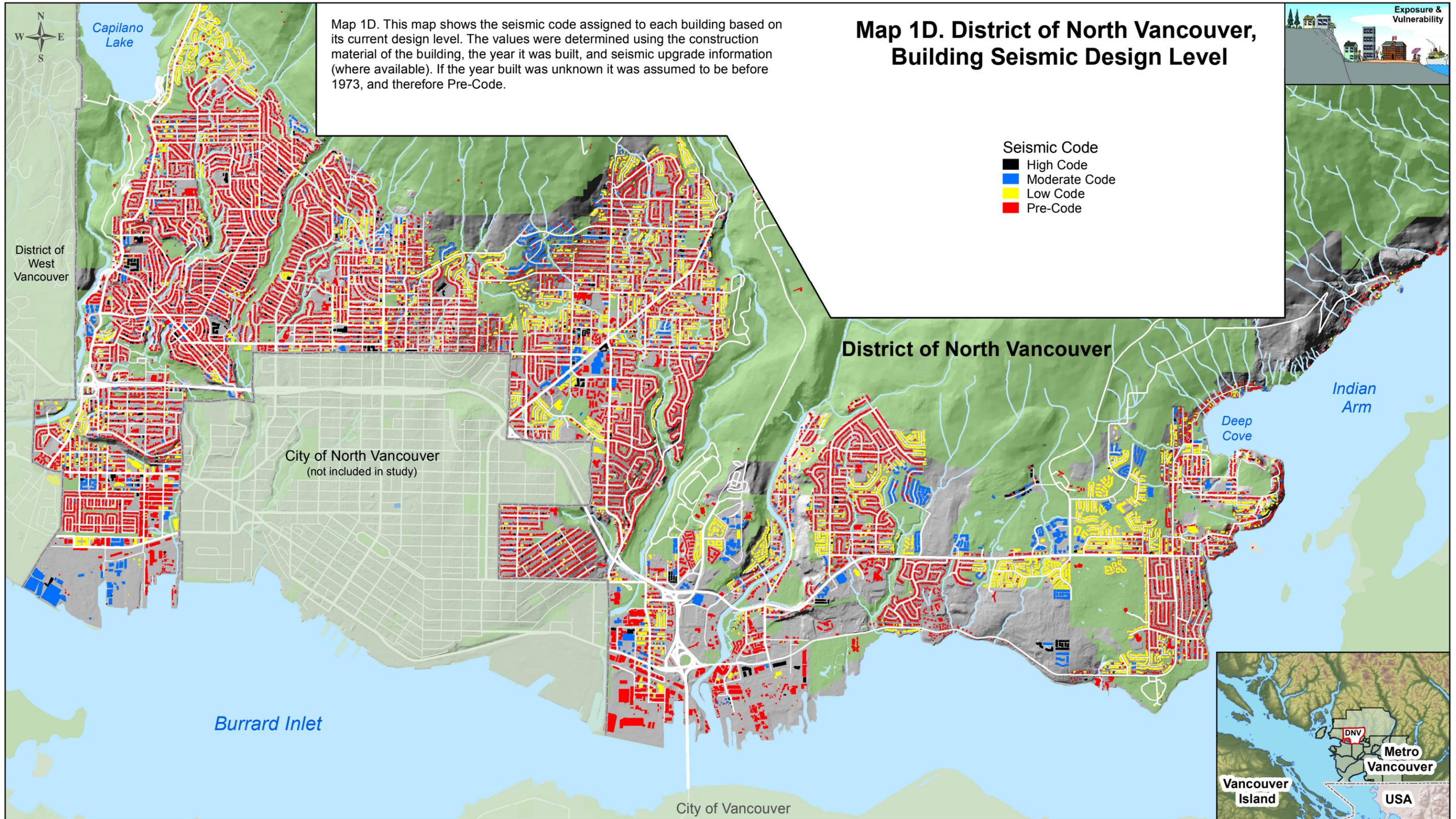
- Building Construction Material**
- Concrete
 - Precast Concrete
 - Steel
 - Reinforced Masonry
 - Unreinforced Masonry
 - Wood



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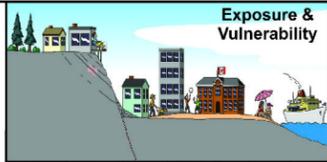
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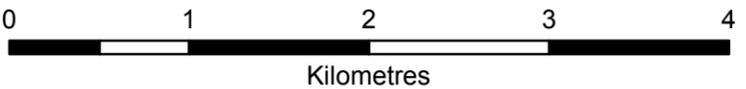
Map 1D. This map shows the seismic code assigned to each building based on its current design level. The values were determined using the construction material of the building, the year it was built, and seismic upgrade information (where available). If the year built was unknown it was assumed to be before 1973, and therefore Pre-Code.

Map 1D. District of North Vancouver, Building Seismic Design Level

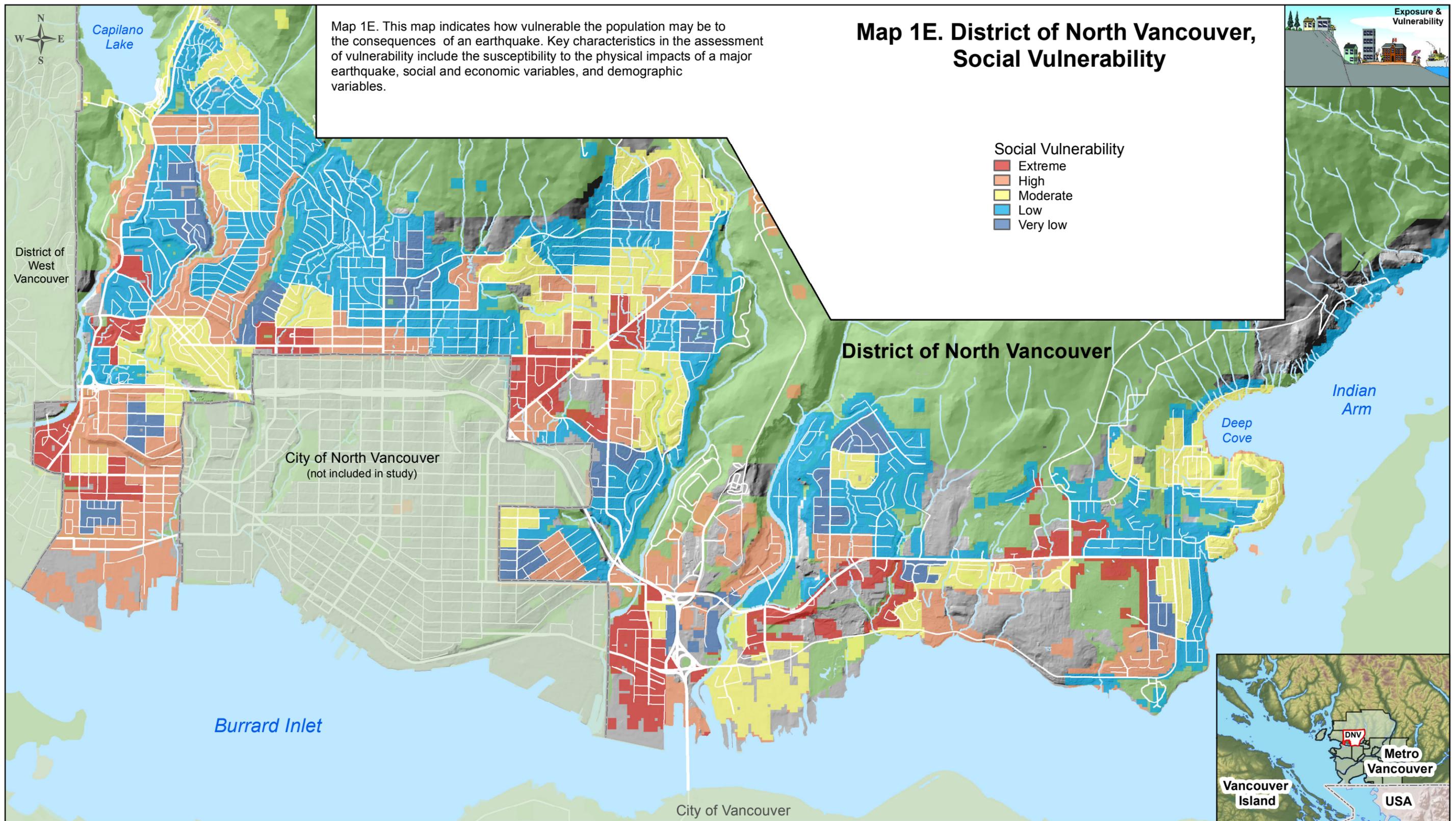
- Seismic Code**
- High Code
 - Moderate Code
 - Low Code
 - Pre-Code



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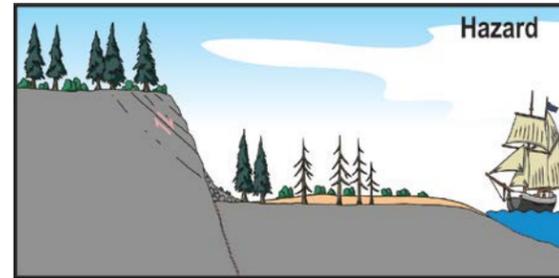
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Section 2: Hazard Potential Maps

Introduction

Shaking from earthquakes can generate ground forces that have the potential to cause permanent deformation of the earth's surface. Ground deformation can include displacement due to earthquake-triggered fault ruptures, liquefaction of water-saturated soil, and/or landslide activity along steep, unstable slopes. The maps in this section show the susceptibility of the soils in the District of North Vancouver to liquefaction and landslides. These factors are relevant to all earthquakes.



Map 2A. Liquefaction Susceptibility

Liquefaction susceptibility is the potential for soil to liquefy. Liquefaction describes the behavior of water-saturated soils that lose strength and internal cohesion as a result of excess pore pressures generated by intense ground shaking. Prior to an earthquake, the weight of buried soils rests on a framework of sand grains that are saturated with groundwater under static conditions. Ground shaking disrupts the sand grain framework so that the overlying weight is no longer supported along grain boundaries, thereby increasing pore water pressure causing the entrainment and flow of soil particles and loss of internal cohesion. Liquefaction causes the sandy, saturated soils to behave temporarily like quick-sand which reduces the support for overlying buildings, roadways and other infrastructure. The likelihood of liquefaction at any given location is governed by a number of factors that include the frequency and duration of ground shaking, the degree of groundwater saturation, grain size distribution, and thickness of surficial materials.

The liquefaction susceptibility map was generated for this study using geological information from the surficial geology map of the District of North Vancouver (Bednarski, 2014). Based on the geological characteristics of age, depositional environment, and material type, a liquefaction rating was assigned to each soil type. The classification system for this rating assignment is that presented by Youd and Perkins (1978), summarized in Table 4.10 of FEMA, 2012a, and shown in Table 1.

For analysis in the Hazus-MH model, liquefaction susceptibility is divided into five classes, from Very Low to Very High. Map 2A shows that, in the District of North Vancouver, the areas with high susceptibility to liquefaction are located along parts of the waterfront and at the mouths of the creeks. These areas contain soft soil and sediment deposited where the creeks enter Burrard Inlet. See Map 2C for the soil class map.

Map 2B. Landslide Susceptibility

Earthquake-triggered landslides are particularly common in mountainous terrain and in regions along the coast where rock and soil slopes are weakened through saturation from snowmelt and heavy rains, and have been undercut by glaciers, rivers and/or ocean waves. Landslides include a variety of rock falls and deep-seated slumps of rock and/or surficial materials. They occur primarily on steep slopes where intense ground shaking can cause shear stresses due to ground shaking intensities exceed the frictional resistance within rock masses and soil horizons

Landslide susceptibility maps show areas with the potential for material to slide downslope. The landslide susceptibility map for this study was generated using the relationship proposed by Wilson and Keefer (1985) and recommended in the Hazus-MH Earthquake Technical Manual (FEMA, 2012a). The susceptibility is based on the type of geology and soil, the ground water level, and the slope angle (Table 2). Depth to ground water was interpolated on the basis of water well control points and hydrogeologic units.

Type of Deposit	General Distribution of Cohesionless Sediment in Deposits	Likelihood that Cohesionless Sediments when saturated would be Susceptible to Liquefaction (by Age of Deposit)			
		< 500 yr Modern	Holocene < 11 ka	Pleistocene 11 ka – 2 Ma	Pre-Pleistocene > 2 Ma
(a) Continental Deposits					
River Channel	Locally variable	Very High	High	Low	Very Low
Flood Plain	Locally variable	High	Moderate	Low	Very Low
Alluvial fan and plain	Widespread	Moderate	Low	Low	Very Low
Marine terraces and plains	Widespread		Low	Very Low	Very Low
Delta and fan-delta	Widespread	High	Moderate	Low	Very Low
Lacustrine and playa	Variable	High	Moderate	Low	Very Low
Colluvium	Variable	High	Moderate	Low	Very Low
Talus	Widespread	Low	Low	Very Low	Very Low
Dunes	Widespread	High	Moderate	Low	Very Low
Loess	Variable	High	High	High	Unknown
Glacial till	Variable	Low	Low	Very Low	Very Low
Tuff	Rare	Low	Low	Very Low	Very Low
Tephra	Widespread	High	High	?	?
Residual soils	Rare	Low	Low	Very Low	Very Low
Sebka	Locally variable	High	Moderate	Low	Very Low
(b) Coastal Zone					
Delta	Widespread	Very High		Low	Very Low
Esturine	Locally variable	High	Moderate	Low	Very Low
Beach					
High Wave Energy	Widespread	Very High	Low	Very Low	Very Low
Low Wave Energy	Widespread	High	Moderate	Low	Very Low
Lagoonal	Locally variable	High	Moderate	Low	Very Low
Fore Shore	Locally variable	High	Moderate	Low	Very Low
(c) Artificial					
Uncompacted Fill	Variable	Very High	---	---	---
Compacted Fill	Variable	Low	---	---	---

Table 1. Liquefaction susceptibility of sedimentary deposits. (FEMA, 2012a)

Landslide deformation is measured in terms of critical acceleration of the landslide mass and the magnitude of lateral displacement down the slope. For the Hazus-MH model, landslide susceptibility is measured on a scale of 1 to 10 (I to X), with 10 being the most susceptible. Results calculated for this study are consistent with those calculated using the method adopted by the Association of Professional Engineers and Geoscientists of British Columbia guidelines for legislated landslide assessment for proposed residential developments (APEGBC, 2010).

In the District of North Vancouver, the landslide susceptibility is moderate to high at locations along the Seymour River valley, along the Lynn Creek valley, around Capilano Lake, and on the southern slope of the Pemberton Heights neighbourhood.

Map 2C. National Earthquake Hazard Reduction Program (NEHRP) Soil Class

The US National Earthquake Hazard Reduction Program (NEHRP) has defined five seismic site categories (A – E) based on their average travel time-weighted shear wave velocity down to a depth of 30 metres (see Table 3), although classes C, D, and E can also be defined through standard penetration resistance or undrained shear strength. A sixth category, F, is defined for special

case soils (e.g. liquefiable soils, quick and highly sensitive clays, peat, etc.) and site specific geotechnical investigations are required to assess seismic amplification. In general, the amplification factors given by the 2010 National Building Code of Canada indicate that the expected level of ground shaking increases up to four times between classes A to E due to decreasing soil stiffness.

Map 2C shows the NEHRP seismic site classes for the District of North Vancouver. These site classes are based on detailed mapping of surficial deposits within the District (Bednarski, 2014). Standard Penetration Test (SPT) measurements from eighty boreholes were used to validate and refine Vs30 estimates for both surface and subsurface materials (Prieto and Ventura, 2013). An additional ninety in situ micro-tremor measurements (UBC Earthquake Engineering Research Facility unpublished data) and direct observation of site period characteristics at 3 sites were used to further improve our interpretation of Vs30 and seismic response characteristics (Molnar, 2012). Category F is not used in the Hazus-MH model.

Geologic Group		Slope Angle, degrees					
		0-10	10-15	15-20	20-30	30-40	>40
(a) DRY (groundwater below level of sliding)							
A	Strongly Cemented Rocks (crystalline rocks and well-cemented sandstone, $c' = 300$ psf, $\Phi' = 35^\circ$)	None	None	I	II	IV	VI
B	Weakly Cemented Rocks and Soils (sandy soils and poorly cemented sandstone, $c' = 0$, $\Phi' = 35^\circ$)	None	III	IV	V	VI	VII
C	Argillaceous Rocks (shales, clayey soil, existing landslides, poorly compacted fills, $c' = 0$, $\Phi' = 20^\circ$)	V	VI	VII	IX	IX	IX
(b) WET (groundwater level at ground surface)							
A	Strongly Cemented Rocks (crystalline rocks and well-cemented sandstone, $c' = 300$ psf, $\Phi' = 35^\circ$)	None	III	VI	VII	VIII	VIII
B	Weakly Cemented Rocks and Soils (sandy soils and poorly cemented sandstone, $c' = 0$, $\Phi' = 35^\circ$)	V	VIII	IX	IX	IX	X
C	Argillaceous Rocks (shales, clayey soil, existing landslides, poorly compacted fills, $c' = 0$, $\Phi' = 20^\circ$)	VII	IX	X	X	X	X

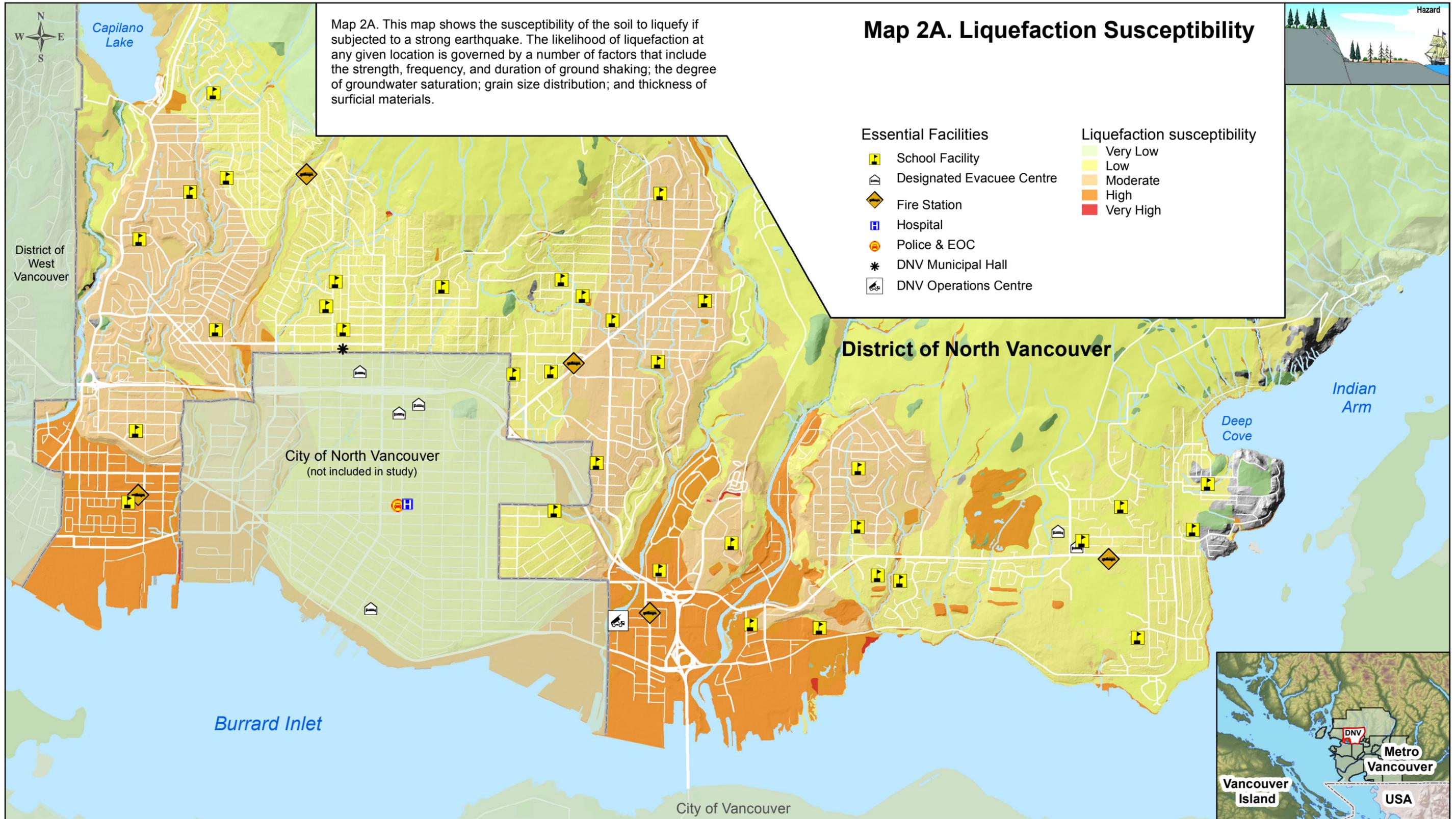
Table 2. Landslide susceptibility of geologic groups. Susceptibility is categorized in values I to X. (FEMA, 2012a)

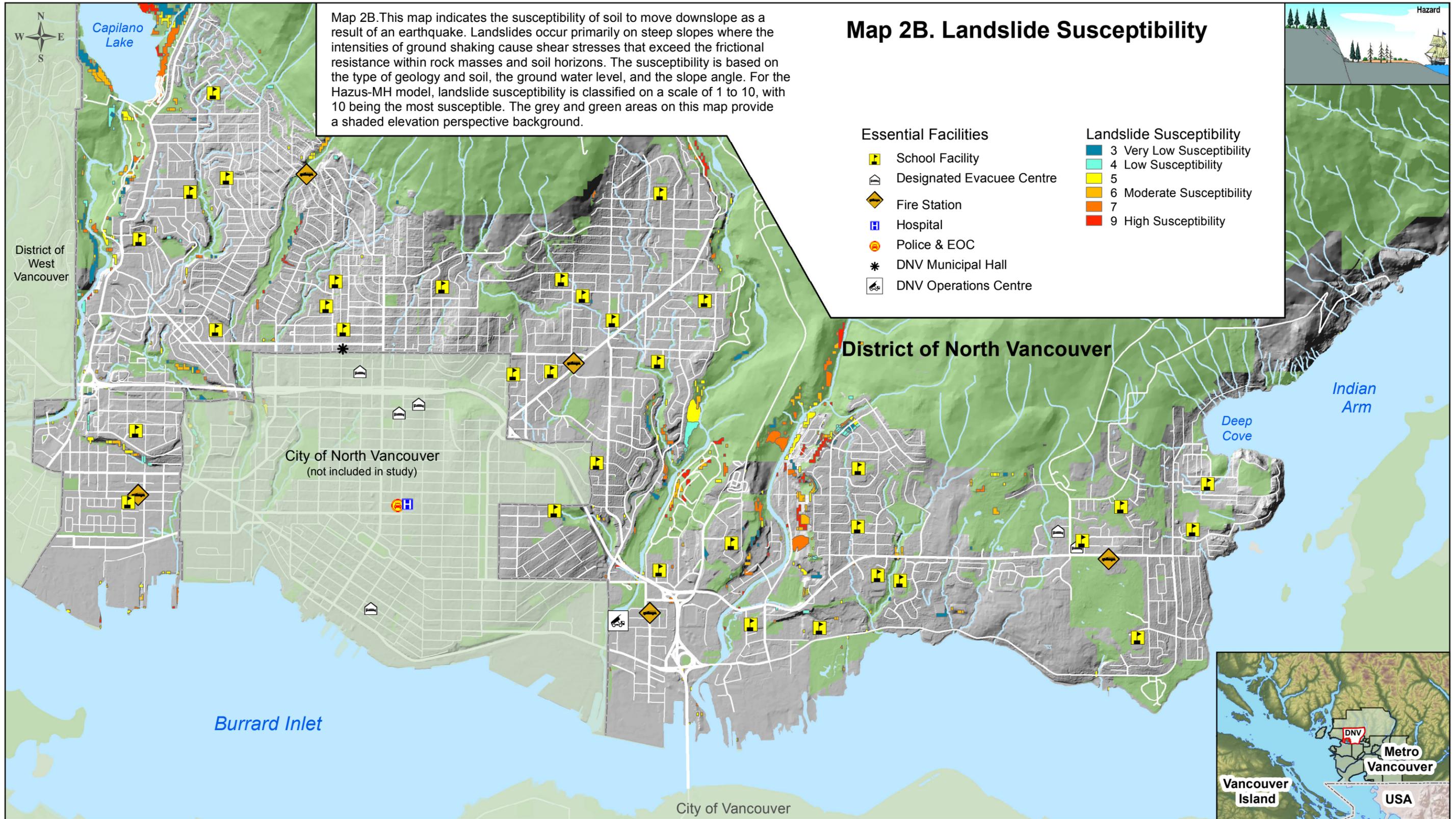
Site Class	Ground Profile Name	Average Properties in Top 30 m, as per Appendix A		
		Average Shear Wave Velocity, \bar{V}_s (m/s)	Average Standard Penetration Resistance, \bar{N}_{60}	Soil Undrained Shear Strength, s_u
A	Hard rock	$\bar{V}_s > 1500$	n/a	n/a
B	Rock	$760 < \bar{V}_s \leq 1500$	n/a	n/a
C	Very dense soil and soft rock	$360 < \bar{V}_s < 760$	$\bar{N}_{60} > 50$	$s_u > 100$ kPa
D	Stiff soil	$180 < \bar{V}_s < 360$	$15 \leq \bar{N}_{60} \leq 50$	$50 \text{ kPa} < s_u \leq 100 \text{ kPa}$
E	Soft soil	$\bar{V}_s < 180$	$\bar{N}_{60} < 15$	Any profile with more than 3 m of soil with the following characteristics: <ul style="list-style-type: none"> • Plasticity index: $PI > 20$ • Moisture content: $w \leq 40\%$, and • Undrained shear strength: $s_u < 25$ kPa
F	Other soil ⁽¹⁾	Site-specific evaluation required		

⁽¹⁾ Other soils include:

- a. Liquefiable soils, quick and highly sensitive clays, collapsible weakly cemented soils, and other soils susceptible to failure or collapse under seismic loading
- b. Peat and/or highly organic clays greater than 3 m in thickness
- c. Highly plastic clays ($PI > 75$) more than 8 m thick, and
- d. Soft to medium stiff clays more than 30 m thick.

Table 3. National Earthquake Hazard Reduction Program (NEHRP) seismic site classes. (NBC, 2010)

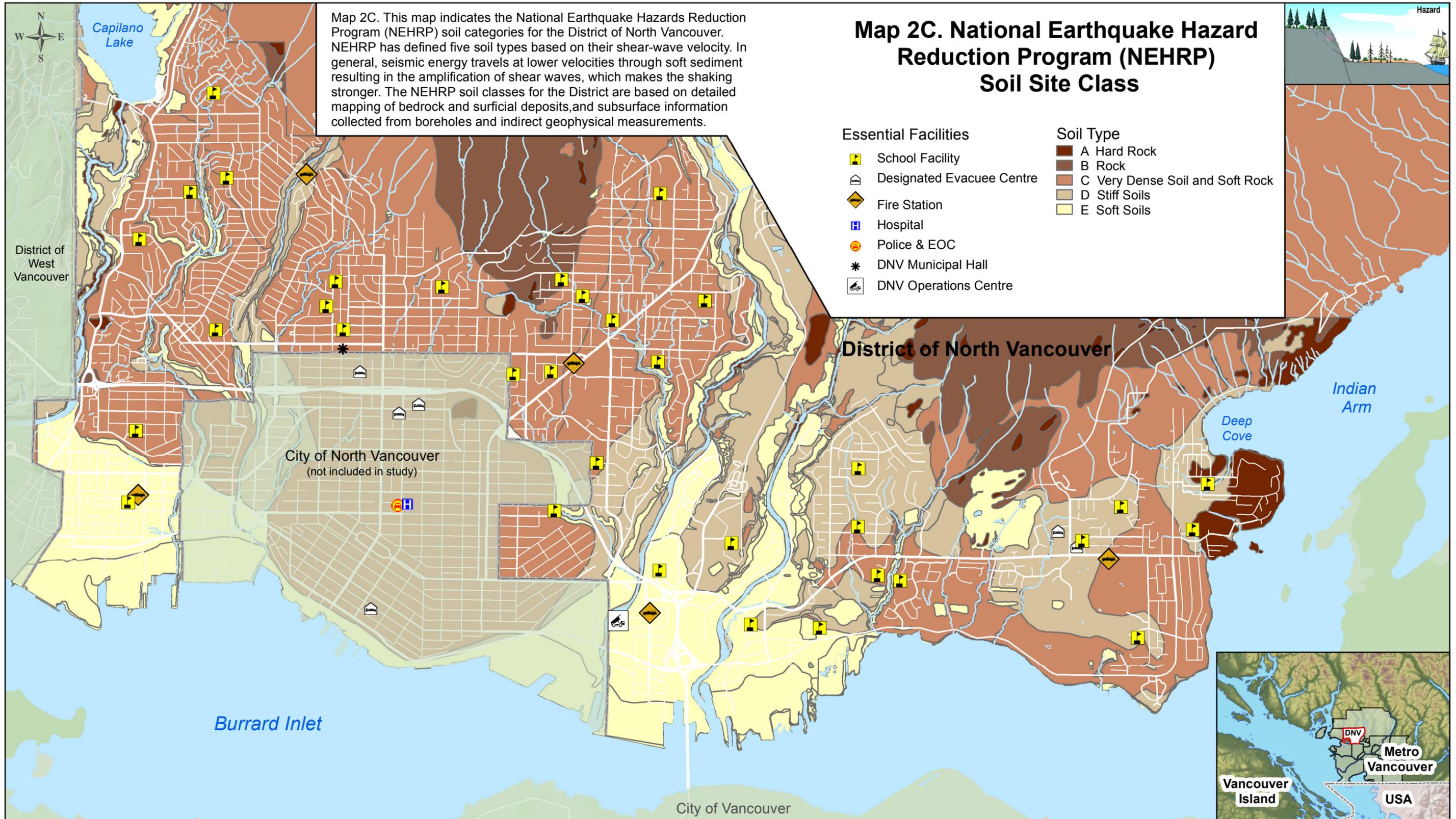




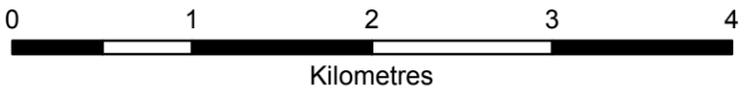
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Section 3: Hazard Maps, Georgia Strait Event

Earthquake Event Hazard Maps

The pattern and intensity of ground shaking due to an earthquake will vary as a function of the distance from the earthquake source, the attenuation of seismic energy as it moves through the earth's crust, and the modification of seismic energy by localized geological factors such as soil conditions and bedrock density (local site amplification).

The combined effects of shaking and amplification are commonly represented as a ground motion model that shows both the spatial distribution and intensity of ground motion parameters at any given location. The model includes data for

- Peak Ground Velocity (PGV): the maximum change in displacement over time, measured in cm/sec
- Peak Ground Acceleration (PGA): the maximum increase in velocity over time, measured in %g
- Spectral Acceleration at 0.3 second: maximum acceleration of an object at reference period 0.3 sec, measured in g
- Spectral Acceleration at 1.0 second: maximum acceleration of an object at reference period 1.0 sec, measured in g

Spectral acceleration is measured at different time periods. The values provide a measure of what a building is likely to experience for short and long periods of vibration. Short period spectral accelerations at 0.3 second are used to predict expected patterns of structural damage for low-rise buildings (1-3 stories). Longer period spectral accelerations at 1.0 second are used to predict expected patterns of damage for taller buildings and linear engineered structures that have a natural period of oscillation at these longer time periods.

Hazus-MH loss estimation software uses the data from ground motion models for its 'User-supplied' hazard type analysis.

Amplification factors based on the NEHRP soil classes and the 2010 National Building Code of Canada have been developed for Canada (Table 4). These factors are applied to the ground motion values to assess the distribution and intensities of ground shaking over a range of frequencies. The factors have been applied to the ground shaking values developed for the two earthquake scenarios chosen for this study.

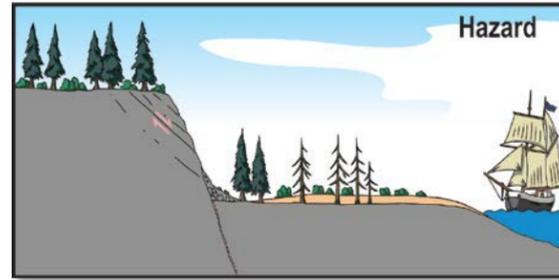
Permanent deformation of the earth's surface can result from the ground forces generated by earthquake shaking. Permanent Ground Deformation (PGD) maps are necessary for the evaluation of potential damage to roads and pipelines in Hazus. The maps include:

- Liquefaction Probability
- Permanent Ground Deformation as a result of Lateral Spreading due to Liquefaction
- Permanent Ground Deformation as a result of Settlement due to Liquefaction
- Landslide Probability
- Permanent Ground Deformation due to Landslide

NRCan project members generated the suite of hazard maps for each of the two earthquake assessments used in this study. Maps showing the PGD displacement as a result of Lateral Spreading due to Liquefaction and the PGD due to Landslide are included in Sections 3 and 6. Local factors are incorporated into the hazard maps for this project.

Measuring Earthquakes

The relative severity of a seismic event can be measured in terms of earthquake magnitude and/or intensity. As an example, the magnitude of an earthquake is analogous to the power output of a radio signal at its source (energy), whereas intensity and ground motion is analogous to the signal strength at a receiver location some distance away from the source (vibration). The



Site Class	$S_{0.2}$				
	≤ 0.25	0.50	0.75	1.00	≥ 1.25
A	0.7	0.7	0.8	0.8	0.8
B	0.8	0.8	0.9	1.0	1.0
C	1.0	1.0	1.0	1.0	1.0
D	1.3	1.2	1.1	1.1	1.0
E	2.1	1.4	1.1	0.9	0.9
F	-- ^a				

Site Class	$S_{1.0}$				
	≤ 0.25	0.50	0.75	1.00	≥ 1.25
A	0.5	0.5	0.5	0.6	0.6
B	1.6	0.7	0.7	0.8	0.8
C	1.0	1.0	1.0	1.0	1.0
D	1.4	1.3	1.2	1.1	1.1
E	2.1	2.0	1.9	1.7	1.7
F	-- ^a				

Note: Use straight-line interpolation for intermediate values of $S_{0.2}$

^a Site-specific geotechnical investigations and dynamic site response analysis should be performed.

Table 2. Amplification factors for Canada (Prieto and Ventura, 2013)

overall magnitude of an earthquake is assessed indirectly using a combination of instruments that measure the type, frequency, period, and duration of seismic waves as they arrive at the Earth's surface. The intensity of ground shaking is measured in terms of the extent to which people experience the effects of horizontal and vertical ground motions under their feet, and the severity of damage to structures and natural features.

The magnitude scale measures earthquake magnitude in terms the relative amplitude of a seismic wave with respect to a reference standard. It is suitable for reporting small and medium-sized earthquakes (<M6), but has been superseded in most countries by the Moment Magnitude scale, which provides a more robust and internally consistent measure of magnitude for earthquakes of larger sizes. Moment magnitude measures the total amount of energy released during an earthquake event. It is a function of the overall mass of rock that has shifted within the Earth's crust, the amount of displacement along the fault surface and the size of the rupture zone.

The intensity of an earthquake is often measured using the Modified Mercalli Intensity (MMI), a graduated scale that describes the effects of an earthquake. Each of the MMI scale intervals represents what people have felt or are likely to experience on the ground, and expected levels of damage to buildings, engineered structures, and natural features (See inset figure in Maps 3A to 3D and 6A to 6D). The intensity of an earthquake is a function of overall magnitude, distance away from the epicenter, site conditions, and the type of structures in which people are situated. Earthquakes of equivalent magnitude in two separate locations with different patterns of human settlement will generate very distinct MMI intensity patterns with different levels of corresponding damage and loss

The Georgia Strait Event

The Georgia Strait event represents a M7.3 shallow crustal earthquake in the Strait of Georgia (Figure 3), between Vancouver Island and the BC mainland. It is a scientifically plausible major earthquake with a potential to generate losses that are consistent with national guidelines for disaster mitigation and risk reduction planning. Although credible, the event is not a prediction of what is most likely to happen, nor is it a worst-case scenario. It does provide information on what might be expected if a near-source catastrophic earthquake were to occur at some point in the future. The use of a deterministic event in a scenario-based risk assessment method will quantify the likely impacts and consequences of a plausible earthquake on the assets of a community.

Because the earthquake epicentre for the Georgia Strait is located close to the Earth's surface, shaking would be felt widely throughout the BC lower mainland and Vancouver Island, with very strong shaking in the Metro Vancouver area. The ground

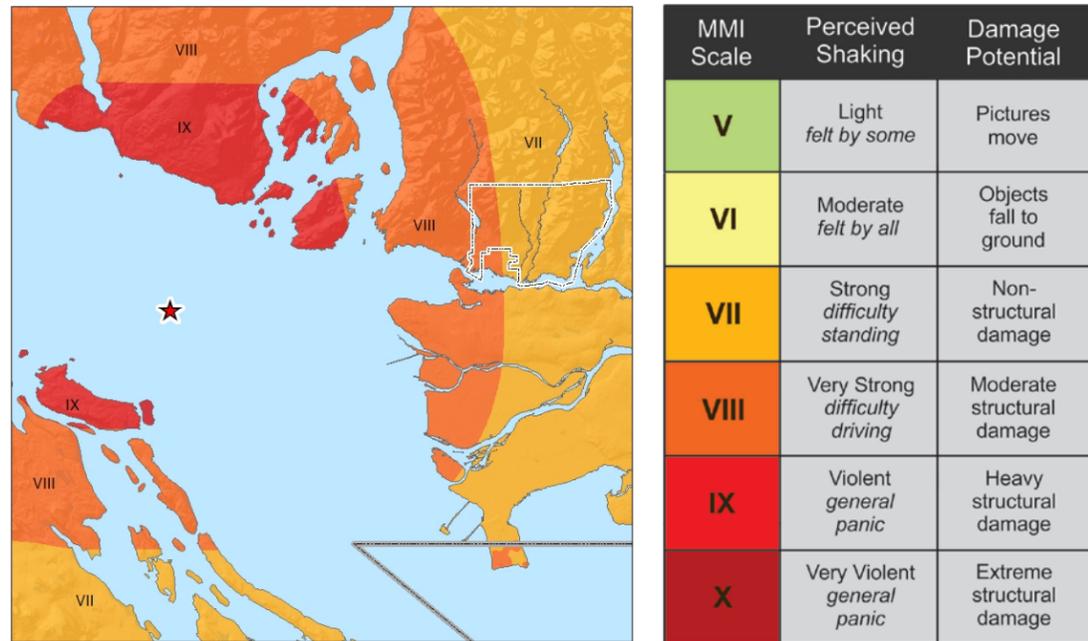


Figure 3. Georgia Strait earthquake event epicentre and regional ground shaking intensity values. Source: USGS shakemap.

shaking maps for the District of North Vancouver were generated specifically for this project. Methods used to generate the maps are discussed in Prieto et al, 2013. Amplification factors based on the NEHRP soil classes and the 2010 National Building Code of Canada have been applied to the ground shaking values for Georgia Strait.

Map 3A. Peak Ground Velocity, Georgia Strait Event

Peak ground velocity (PGV) is a measure of the maximum change in displacement over time that a particle is likely to experience during an earthquake. It has been shown to be a reliable indicator of general building damage patterns. Values for PGV are measured in cm/sec. Map 3A shows the PGV values for a Georgia Strait event.

Map 3B. Peak Ground Acceleration, Georgia Strait Event

Peak ground acceleration (PGA) is a measure of the maximum increase in velocity over time that a particle is likely to experience during an earthquake. Acceleration is measured as a force and expressed in units of %g. The PGA values are used primarily in assessing the potential for seismically induced ground deformation. Map 3B shows the PGA values for the Georgia Strait event.

Map 3C. Permanent Ground Deformation by Lateral Spreading due to Liquefaction, Georgia Strait Event

Permanent ground deformation hazards caused by liquefaction can include: 1) lateral spreading as soil horizons fail suddenly and are displaced horizontally in a viscous state, and/or 2) vertical settlement caused by changes in soil volume and settling during the shaking event. The amount and type of displacement will vary as a function of ground shaking intensity and localized geologic setting. Map 3C shows the estimated movement of ground material as a result of lateral spreading due liquefaction for a Georgia Strait event.

Map 3D. Permanent Ground Deformation due to Landslide, Georgia Strait Event

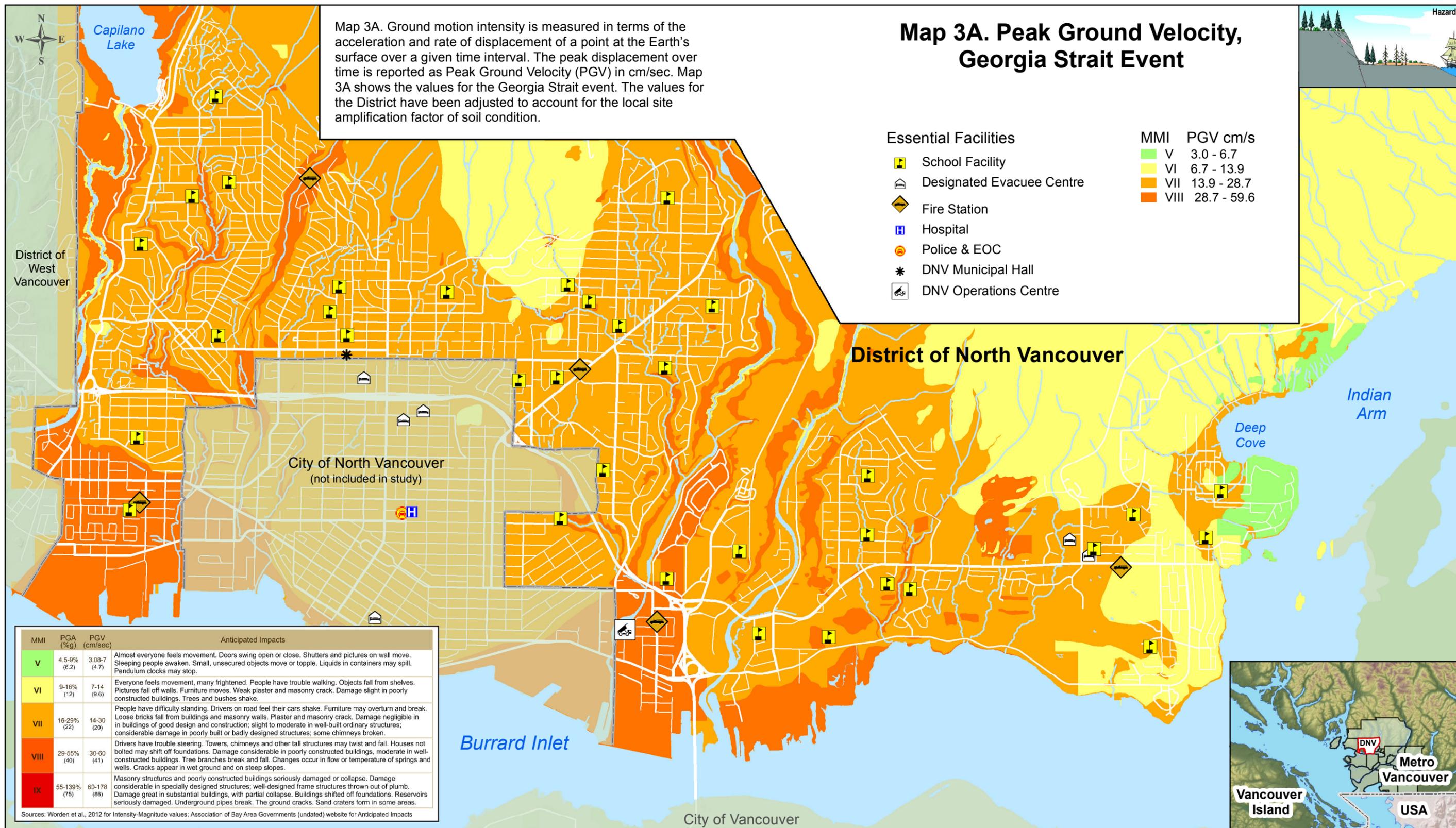
Permanent ground deformation caused by landslide movement represents the movement of ground material downslope due to shaking from an earthquake event. The spatial extent and pattern of permanent ground deformation is controlled by local factors such as bedrock geology, surficial geology, soil conditions, slope gradient, and groundwater hydrology. Map 3D shows the estimated movement of ground material as a result of landslides, for the Georgia Strait M7.3 event.

Map 3E. Spectral Acceleration at 0.3 second interval, Georgia Strait Event

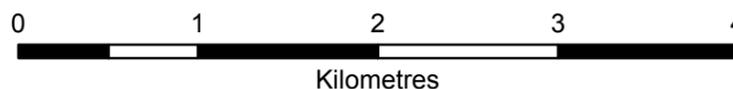
Spectral acceleration describes the maximum acceleration in an earthquake on an object at a specific time period and is measured in units of force (g). Map 3E shows the short period spectral acceleration at the 0.3 second interval for the Georgia Strait event.

Map 3F. Spectral Acceleration at 1.0 second interval, Georgia Strait Event

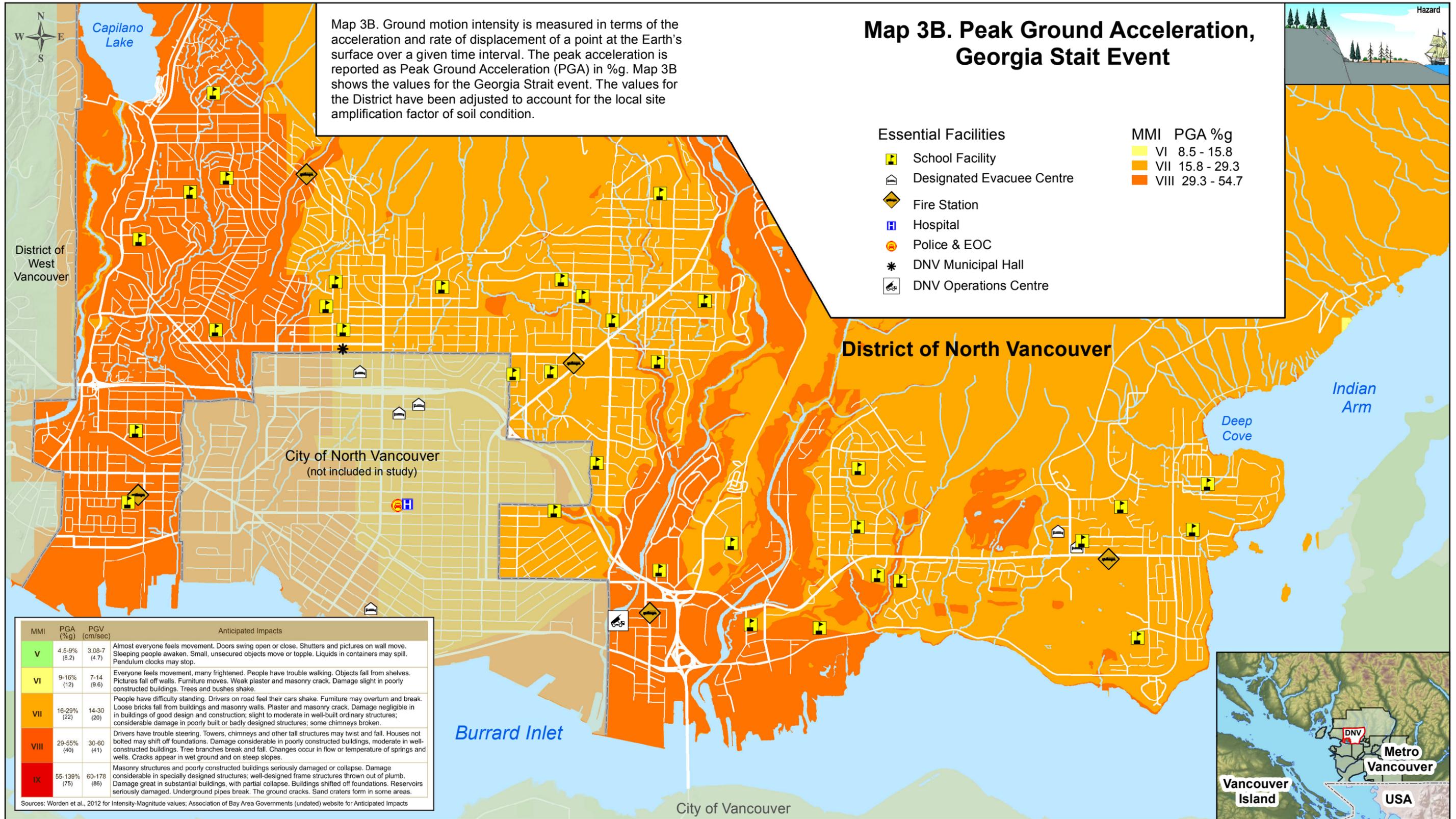
Spectral acceleration describes the maximum acceleration in an earthquake on an object at a specific time period and is measured in units of force (g). Map 3F shows the spectral acceleration at the 1.0 second interval for the Georgia Strait event.



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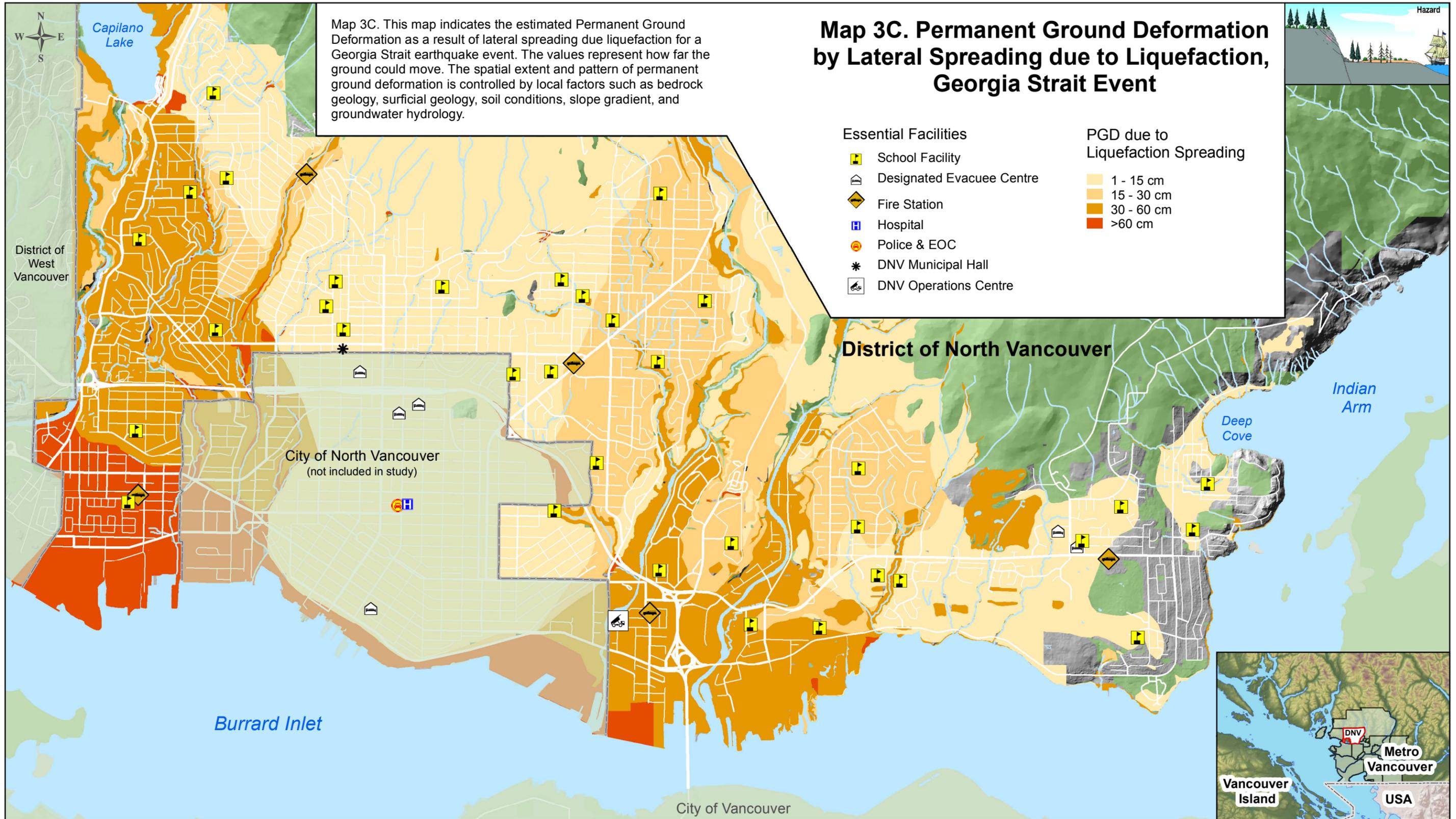
Credits: Building location, occupancy, and infrastructure provided by the District of North Vancouver. Building details provided by the Earthquake Engineering Research Facility, Department of Civil Engineering, University of British Columbia. All results were generated by Natural Resources Canada in consultation with other seismic risk assessment experts, using best available data, current scientific and engineering knowledge, and reasonable assumptions. Earthquake impacts were modelled with Hazus loss estimation software. Estimates were generated for a specific earthquake scenario using limited hazard information.



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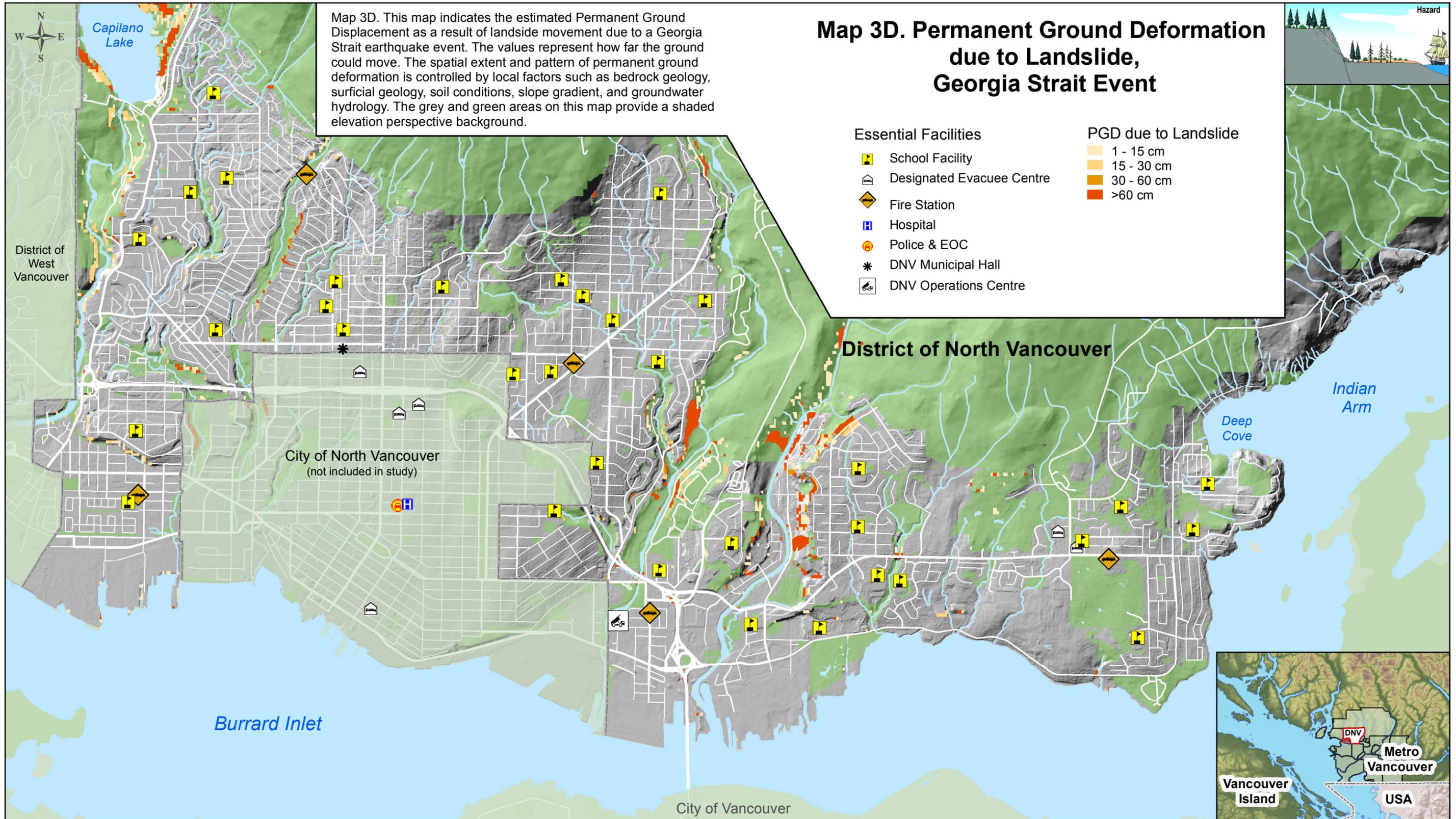
Credits: Building location, occupancy, and infrastructure provided by the District of North Vancouver. Building details provided by the Earthquake Engineering Research Facility, Department of Civil Engineering, University of British Columbia. All results were generated by Natural Resources Canada in consultation with other seismic risk assessment experts, using best available data, current scientific and engineering knowledge, and reasonable assumptions. Earthquake impacts were modelled with Hazus loss estimation software. Estimates were generated for a specific earthquake scenario using limited hazard information.



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Map 3D. This map indicates the estimated Permanent Ground Displacement as a result of landside movement due to a Georgia Strait earthquake event. The values represent how far the ground could move. The spatial extent and pattern of permanent ground deformation is controlled by local factors such as bedrock geology, surficial geology, soil conditions, slope gradient, and groundwater hydrology. The grey and green areas on this map provide a shaded elevation perspective background.

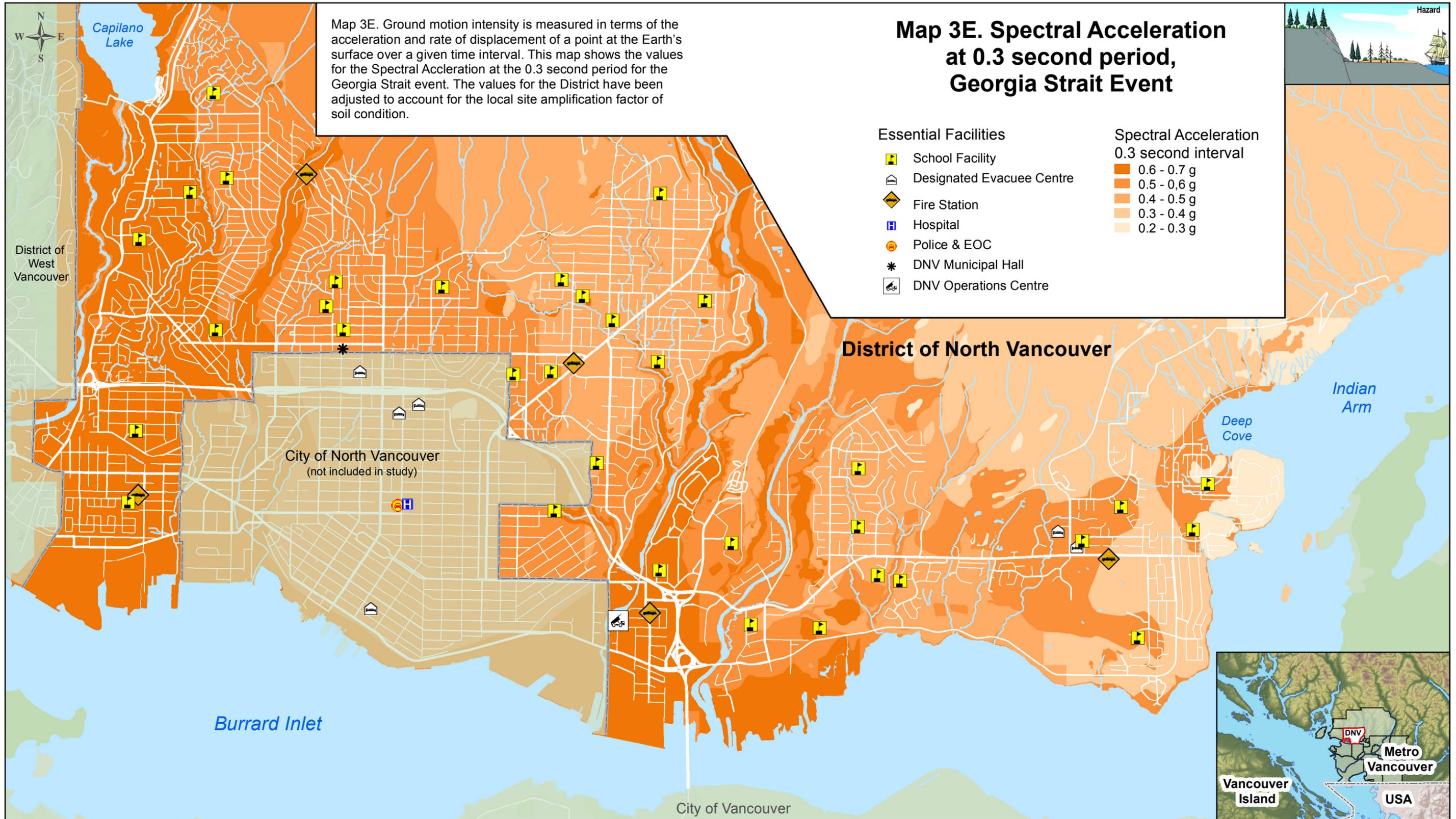
Map 3D. Permanent Ground Deformation due to Landslide, Georgia Strait Event

- | | |
|-----------------------------|-----------------------------|
| Essential Facilities | PGD due to Landslide |
| School Facility | 1 - 15 cm |
| Designated Evacuee Centre | 15 - 30 cm |
| Fire Station | 30 - 60 cm |
| Hospital | >60 cm |
| Police & EOC | |
| DNV Municipal Hall | |
| DNV Operations Centre | |

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Map 3E. Ground motion intensity is measured in terms of the acceleration and rate of displacement of a point at the Earth's surface over a given time interval. This map shows the values for the Spectral Acceleration at the 0.3 second period for the Georgia Strait event. The values for the District have been adjusted to account for the local site amplification factor of soil condition.

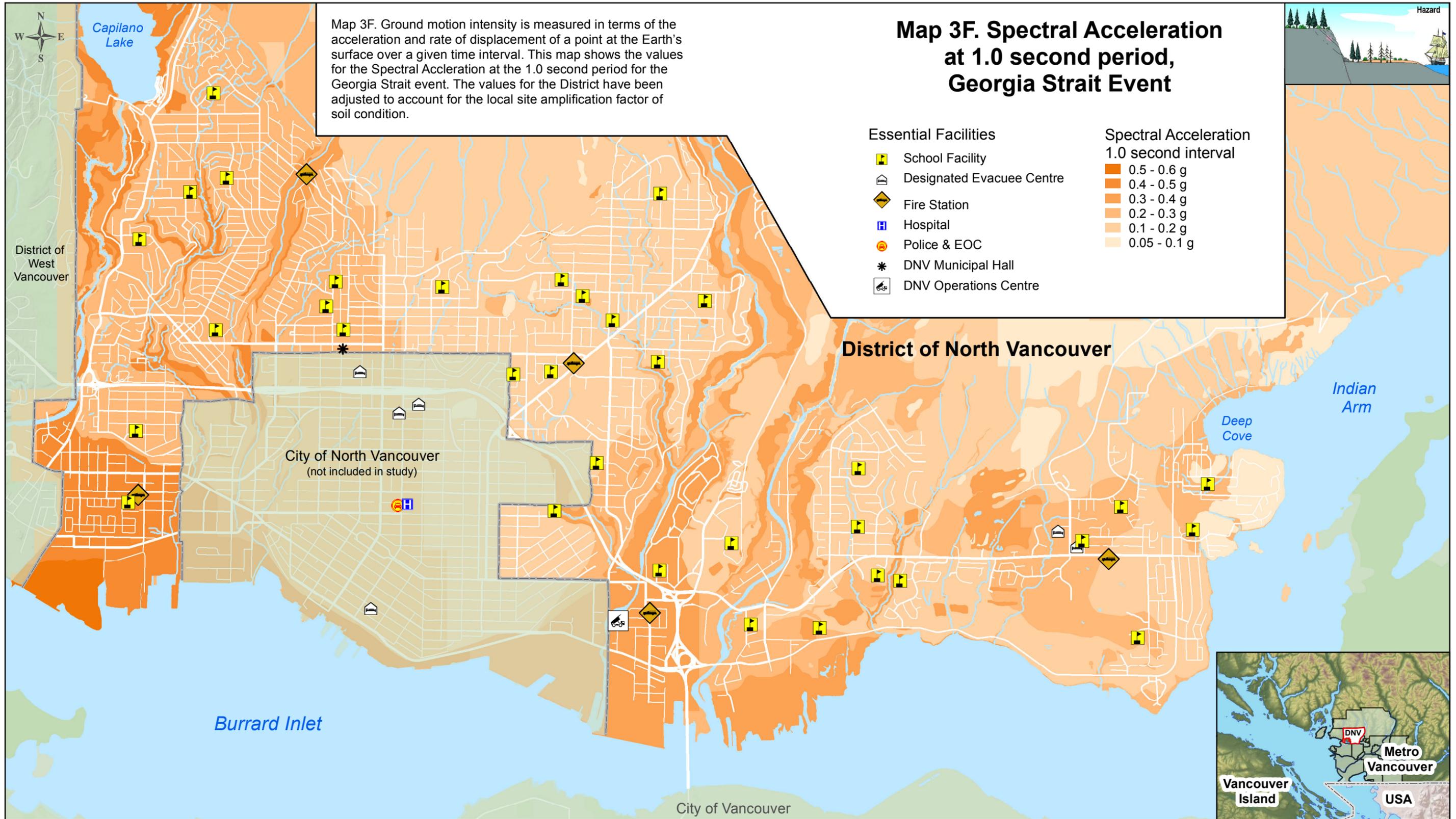
Map 3E. Spectral Acceleration at 0.3 second period, Georgia Strait Event

- Essential Facilities**
- School Facility
 - Designated Evacuee Centre
 - Fire Station
 - Hospital
 - Police & EOC
 - DNV Municipal Hall
 - DNV Operations Centre
- Spectral Acceleration 0.3 second interval**
- 0.6 - 0.7 g
 - 0.5 - 0.6 g
 - 0.4 - 0.5 g
 - 0.3 - 0.4 g
 - 0.2 - 0.3 g

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Map 3F. Ground motion intensity is measured in terms of the acceleration and rate of displacement of a point at the Earth's surface over a given time interval. This map shows the values for the Spectral Acceleration at the 1.0 second period for the Georgia Strait event. The values for the District have been adjusted to account for the local site amplification factor of soil condition.

Map 3F. Spectral Acceleration at 1.0 second period, Georgia Strait Event

- Essential Facilities**
- School Facility
 - Designated Evacuee Centre
 - Fire Station
 - Hospital
 - Police & EOC
 - DNV Municipal Hall
 - DNV Operations Centre
- Spectral Acceleration 1.0 second interval**
- 0.5 - 0.6 g
 - 0.4 - 0.5 g
 - 0.3 - 0.4 g
 - 0.2 - 0.3 g
 - 0.1 - 0.2 g
 - 0.05 - 0.1 g

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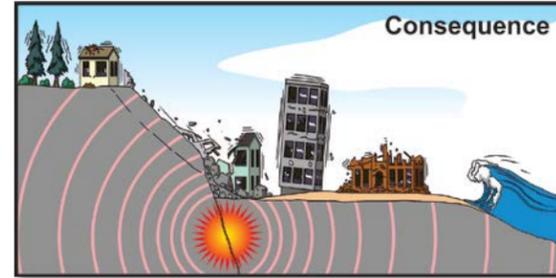


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Section 4: Consequence/Damage Maps, Georgia Strait Event

Introduction

Maps 4A to 4D show the results for the detailed level of analysis using the Advanced Engineering Building Module. Each building in the District of North Vancouver inventory was assigned a fragility curve based on its occupancy, building material, and seismic code. For illustration purposes for this publication, the results for the individual buildings have been grouped into polygons to illustrate regions of similar damage values. The Geographic Information System (GIS) process to create Thiessen polygons from points was used to create polygons around the individual buildings. The polygons were then dissolved based on analysis results to create regions of identical results. Note that the Thiessen analysis creates polygons to cover the entire area of analysis, and may create a large polygon where only one dot exists. Small polygons have been filtered out. As a result of this process, the results for individual buildings cannot be identified.



Maps 4E to 4H show the results for specific facilities and infrastructure assets in the District.

Map 4A. Building Damage State, Current Building Design Level, Georgia Strait Event

In the Hazus-MH model, damage state probabilities are analyzed for both structural and non-structural components of the building system, and are used to calculate various types of building-related losses. Structural damage encompasses cracks and/or failure of load-bearing elements of a building including walls, columns (posts & pillars), beams (girders & joists), braces, floor and roof components (sheathing, slabs, etc.) and underlying building foundations. Non-structural damages encompass failure and/or toppling of ceilings, windows, mechanical systems (water, power, heating, etc.), furnishings, and building inventory.

Hazus-MH calculates the probability of a building sustaining damage as one of five possible Damage States: None, Slight, Moderate, Extensive, and Complete. (Table 5)

To represent the building damage states resulting from a Georgia Strait event, Map 4A shows the damage state with the greatest value for each building. Note that the probability values for two or more damage states may be close but the damage state with the highest values was chosen for the map. For example, a building may have a 29% probability of experiencing Complete damage state and a 28% probability of experiencing Moderate damage state and would then be represented on the map as a building likely to experience a Complete damage state. The map is provided to show an overview of general regions of similar damage states.

Map 4B. Building Loss Ratio, Current Building Design Level, Georgia Strait Event

The loss ratio represents the relationship between the estimated loss value and the replacement value of the building and contents. For Map 4B the estimated total loss for the building (structural, non-structural, and content) is divided by the total pre-event value of the building (replacement cost and content value).

Loss ratio values are computed as a standard measure of losses. The ratio, as opposed to actual dollar values, provides a means of comparing losses across an area and with other events. The loss ratio provides a value that is independent of the value of the building.

Damage State		Description
	Slight	Small plaster cracks at corners of door and window openings and wall-ceiling intersections; small cracks in masonry chimneys and masonry veneers. Small cracks are assumed to be visible with a maximum width of less than 1/8 inch (cracks wider than 1/8 inch are referred to as "large" cracks).
	Moderate	Large plaster or gypsum-board cracks at corners of door and window openings; small diagonal cracks across shear wall panels exhibited by small cracks in stucco and gypsum wall panels; large cracks in brick chimneys; toppling of tall masonry chimneys.
	Extensive	Large diagonal cracks across shear wall panels or large cracks at plywood joints; permanent lateral movement of floors and roof; toppling of most brick chimneys; cracks in foundations; splitting of wood sill plates and/or slippage of structure over foundations.
	Complete	Structure may have large permanent lateral displacement or be in imminent danger of collapse due to cripple wall failure or failure of the lateral load resisting system; some structures may slip and fall off the foundation; large foundation cracks. Three percent of the total area of buildings with Complete damage is expected to be collapsed, on average.

Table 3. Description of Damage States. (FEMA, 2012b)

Map 4C. Daytime Casualty Rate, Current Building Design Level, Georgia Strait Event

Casualty estimates are calibrated on the basis of empirical data gathered from historic earthquake events and are limited to physical impacts caused by earthquake damage. Not considered in the analysis are the effects of secondary health issues (e.g. heart attack, psychological effects) or accidents that may occur during emergency response/recovery operations.

Hazus-MH divides the casualties into four categories. Level 1 injuries include severe cuts, first and second-degree burn, sprains, bruises and head injuries that do not result in loss of consciousness. These are injuries that would require basic medical aid that would be administered in the field by paramedics or those trained in emergency first aid. Hazus-MH does not estimate the number of Injuries that are less severe and that could be self-treated. Level 2 injuries include more severe burns, fractured bones, dehydration and head injuries that would result in loss of consciousness. These are injuries that would require a greater degree of medical care but are not expected to be life threatening. Level 3 injuries are more severe and may include uncontrolled bleeding, spinal injuries and damages to internal organs caused by physical crushing beneath heavy objects that have toppled or fallen during the earthquake. These are injuries that may pose an immediate life threatening condition if not treated expeditiously by trained medical professionals. Level 4 injures include mortal wounds caused by toppling and/or building collapse that result in death before emergency care can be administered.

Map 4C shows the estimated injury/casualty rate for a daytime event (occurring at 2 pm). The rate is calculated as the proportion of people in a building who are expected to sustain injuries that would require medical attention or that might result in loss of life. The values for all four injury levels were totaled then divided by the population of the building.

Map 4D. Building Recovery Time, Current Building Design Level, Georgia Strait Event

Hazus-MH estimates the Repair Time and Recovery Time for buildings to be returned to pre-event conditions. Repair (or construction) times are a function of damage state and building occupancy. Recovery time estimates include repair time, plus cleanup time, delays in decision making, financing, inspection, etc. The Recovery Time values represent "estimates of the median time for recovery of building functions." (FEMA, 2012a, page 15-19) Recovery Time is based on individual buildings and

there is no interdependency between the buildings. Hazus-MH estimates the results for Recovery Time in discrete values: 2, 5, 10, 20, 60, 90, 120, 135, 270, 360, 480, 720, and 960 days. Map 4D shows the estimated recovery time for buildings.

Map 4E. School Buildings and Fire Stations, Building Damage State, Georgia Strait Event

As described in Map 4A, Hazus-MH calculates the probability of a building sustaining damage due to an earthquake event as one of five possible Damage States. Map 4E shows the damages states with the greatest probability value, for each school and fire station building. Results shown are based on the AEBM analysis of the individual school buildings and fire station buildings.

Since 2001, the province of British Columbia has invested in a seismic mitigation program to upgrade or replace schools that do not meet current design guidelines for life safety (BC Ministry of Education, 2014a). The Ministry, in partnership with the Association of Professional Engineers and Geoscientist BC (APEGBC) and UBC's Earthquake Engineering Research Facility, have assessed and rated school structures built prior to 1992. As of September 2014, 143 schools have been upgraded, 10 schools are under construction, 7 schools are moving toward construction, and 53 schools are supported for future upgrades (BC Ministry of Education, 2014b).

In the District of North Vancouver, there are 25 public schools, 8 independent schools, and a major university that collectively encompass approximately 100 buildings and related facilities. Three elementary schools have been upgraded as part of the provincial seismic retrofit program and three secondary schools are supported or in the process of being retrofitted to comply with current design guidelines for life safety. Those school upgraded by 2012 were assigned a high seismic design code for this study. For the non-retrofit school buildings, the earthquake seismic design code was based on the construction material (if known), the year built, and the building use.

For the Georgia Strait event, it is estimated nearly 70% of the school facilities in the District (classrooms and auxiliary structures) are expected to sustain little or no damage in the scenario earthquake. It is estimated that approximately 25 school facilities are vulnerable to moderate levels of damage that would require extensive repairs during the recovery process. Most of these are older concrete buildings that support auxiliary functions (recreation, school operations, etc.) and temporary structures (portables) that are used as overflow classrooms. While most school facilities in the District are expected to perform well in an earthquake, at least 8 structures are likely to sustain extensive and complete levels of damage. Of these, three structures are main school facilities. Hotspots of concern include older concrete buildings and related facilities that have yet to be seismically upgraded in Norgate, Lynnmour South and Maplewood - areas that are known to be exposed to severe levels of ground shaking and liquefaction.

There are five fire stations within the District of North Vancouver. Three of these have high seismic design code. The damage state with the highest probability for each building following a Georgia Strait earthquake is shown on Map 4E. Note that the fire station shown as Complete, in the Lynnmour South neighbourhood, has a 29% probability of experiencing a Complete damage state, a 28% probability of experiencing a Moderate damage state, and a 27% probability of experiencing a Slight damage state. The fire station adjacent to Mosquito Creek, in the Upper Dellbrook neighbourhood, shown to experience Moderate damage state, has recently been seismically upgraded and was assigned a High seismic code in this study.

Map 4F. Roads and Bridges, Functionality at Day 1, Georgia Strait Event

There are more than 500 kilometres of highway, arterial, and secondary roadways in the District of North Vancouver. The Trans-Canada Highway (Highway 1), maintained by the province, is a primary transportation corridor that connects arterials and secondary roadways in the District with other regional transportation networks via the Lions Gate and Iron Workers Memorial bridges. Roads not owned by the District or the province are those within private neighbourhoods, within First Nations communities, or within federal parkland. Primary arterial and secondary roads of varying widths make up more than 85% of the network and are almost entirely of asphalt construction. Gravel, dirt, and mixed surface roadways make up the balance and

provide vital access to critical infrastructure, recreational facilities, and satellite communities in the highlands and along the shores of Burrard Inlet.

Damage to roads is calculated using fragility curves which are defined in terms of permanent ground displacement (PGD).

There are 32 roadway bridges within the District of North Vancouver. Nearly half of the bridges in the study area are owned and operated by the District of North Vancouver with remaining bridges administered by the regional transportation authority. While many of these bridges are in the process of being seismically upgraded, for this earthquake risk assessment only those assets owned and operated by the District were analyzed. The Lions Gate and Iron Workers Memorial bridges were not assessed in this study.

Fragility curves for bridges are defined in terms of Spectral Acceleration at 0.3 second and 1.0 second, and by permanent ground displacement (PGD). In Hazus, there are 28 classes for highway bridges based on seismic design, number of spans, structure type, pier type, abutment and bearing type, and span continuity. For the District of North Vancouver, a highway bridge class was assigned to each bridge (in 2012) by DNV staff with knowledge of the bridges.

Pedestrian bridges were not assessed in this study. Damage curves for pedestrian bridges are not available in the Hazus-MH model.

Restoration curves are used to calculate the expected functionality of the roadways and bridges at discrete time intervals following an earthquake (1, 3, 7, 14, 30, and 90 days). Interdependency between components is not considered for the restoration calculations.

Map 4F shows the expected functionality of the road segments and bridges at Day 1 after the earthquake.

Map 4G. Potable Water Pipelines and Facilities, Georgia Strait Event

There are over 400 kilometres of potable water pipelines in the District of North Vancouver. Map 4G shows some results for the potable water pipelines and potable water facilities after a Georgia Strait event.

Hazus-MH loss estimation software estimates the functionality of a building at discrete days following the event (1, 3, 7, 14, 30, and 90 days). The functionality is based on the damage and use of the building. The increase in functionality over time is based on an assumed repair rate. This map shows the functionality of each potable water facility at Day 1 after the event. The results indicate that 2 out of the 35 buildings will have less than 50% functionality and 5 buildings will have greater than 90% functionality.

The results for the pipelines indicate the estimated total repair rate. Damage to pipelines is based on the Ground Motion (PGV), Ground Failure (PGD), liquefaction, and type of pipe material. Generally the damage to a pipeline due to Ground Failure (PGD) is a break, while the damage to a pipeline due to seismic wave propagation (PGV) results in a leak. The program calculates the repair rate for breaks and leaks assuming that damage due to ground failure will consist of 20% leaks and 80% breaks, and the damage due to seismic waves will consist of 80% leaks and 20% breaks (FEMA, 2012a, page 8-9). The Hazus-MH program estimates the number of breaks and leaks per kilometre of pipeline and then generates a total repair rate per kilometre of pipeline. The total repair rate values for the Georgia Strait event are shown in Map 4G. The values range from less than 0.25 repairs per kilometre to more than 1.5 repairs per kilometre.

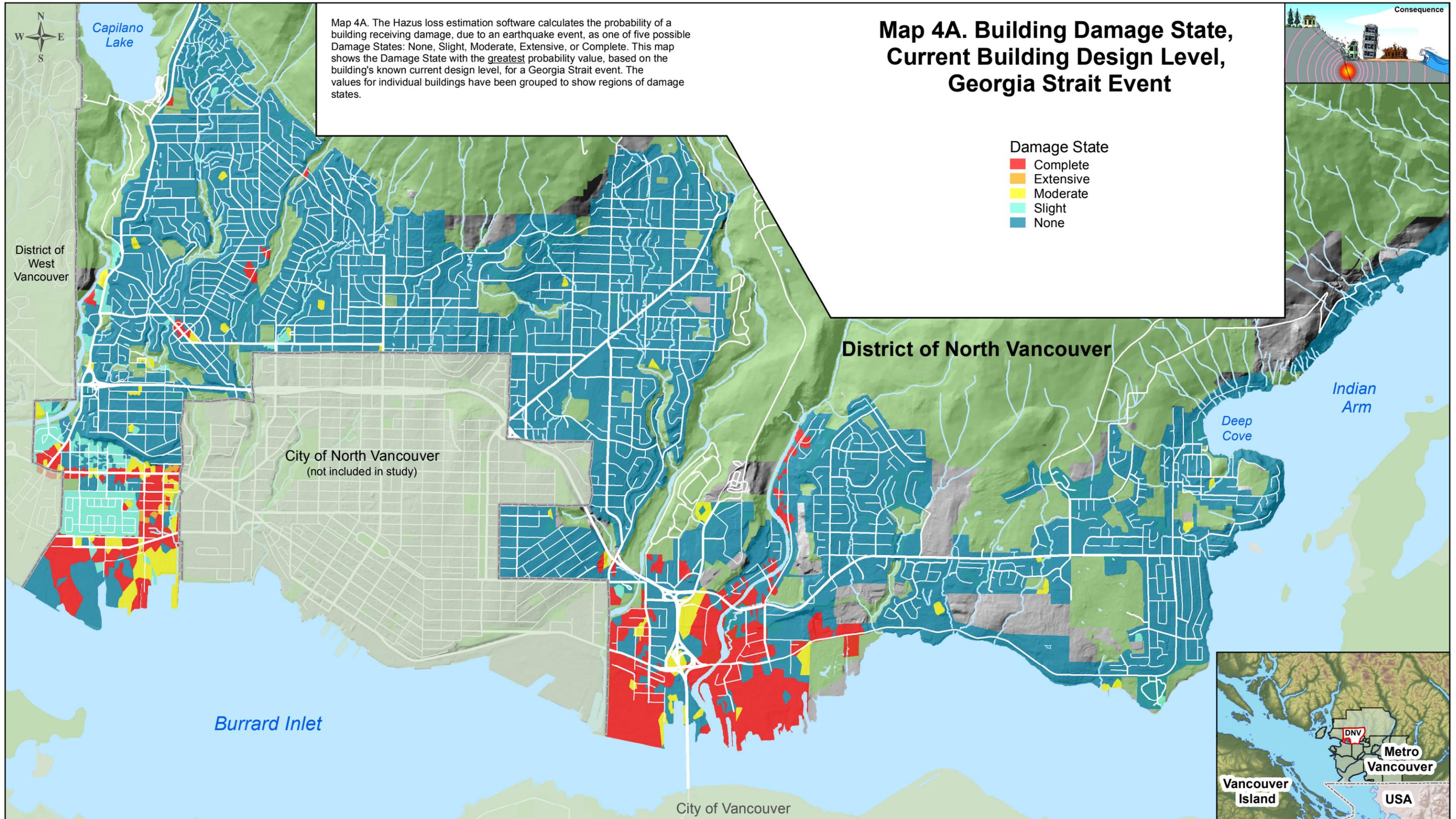
Although the words "Very Low" to "Very High" have been assigned to the classes on the map, these descriptions are based on the relative values in the results (0.01 being the lowest and 3.3 being the highest). These descriptions are not based on any technical knowledge as to whether the values for the number of repairs are considered high or low by technical experts.

Map 4H. Waste Water Pipelines, Georgia Strait Event

There are almost 900 kilometres of sanitary and storm pipelines in the District. Map 4H shows some results for the waste water pipelines after a Georgia Strait event.

The results for the pipelines indicate the estimated total repair rate. Damage to pipelines is based on the Ground Motion (PGV), Ground Failure (PGD), liquefaction, and type of pipe material. Generally the damage to a pipeline due to Ground Failure (PGD) is a break, while the damage to a pipeline due to seismic wave propagation (PGV) results in a leak. The program calculates the repair rate for breaks and leaks assuming that damage due to ground failure will consist of 20% leaks and 80% breaks, and the damage due to seismic waves will consist of 80% leaks and 20% breaks (FEMA, 2012a, page 8-9). The Hazus-MH program estimates the number of breaks and leaks per kilometre of pipeline and then generates a Total Repair Rate per kilometre of pipeline. For the Georgia Strait event, the Total Repair Rate values range from 0.001 repairs per kilometre to more than 1.8 repairs per kilometre.

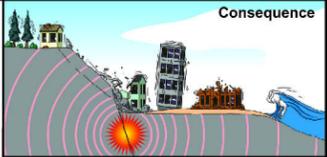
Although the words “Very Low” to “Very High” have been assigned to the classes on the map, these descriptions are based on the relative values in the results. These descriptions are not based on any technical knowledge as to whether the values for the number of repairs are considered high or low by technical experts.



Map 4A. The Hazus loss estimation software calculates the probability of a building receiving damage, due to an earthquake event, as one of five possible Damage States: None, Slight, Moderate, Extensive, or Complete. This map shows the Damage State with the greatest probability value, based on the building's known current design level, for a Georgia Strait event. The values for individual buildings have been grouped to show regions of damage states.

Map 4A. Building Damage State, Current Building Design Level, Georgia Strait Event

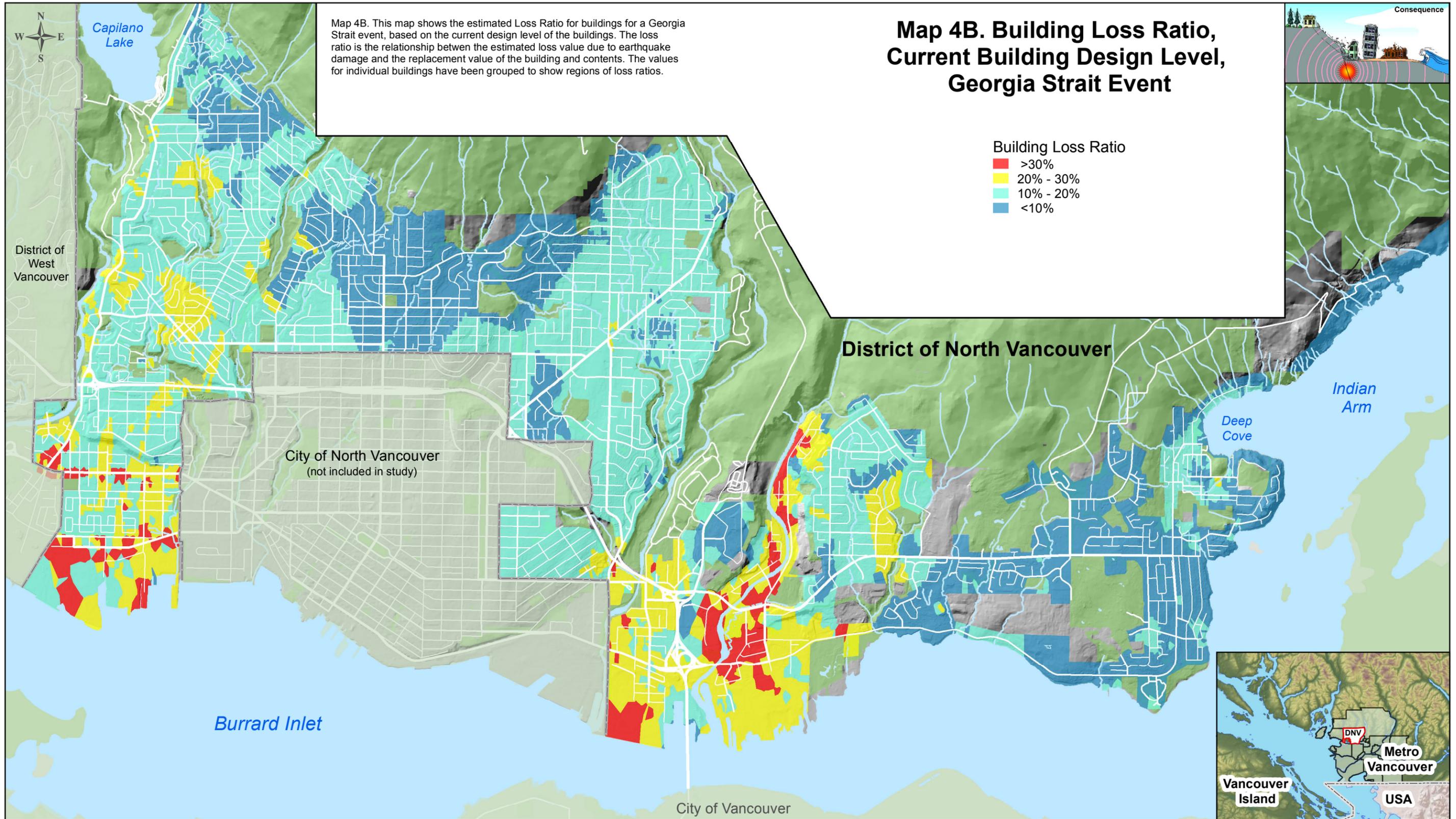
- Damage State
- Complete
 - Extensive
 - Moderate
 - Slight
 - None



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Map 4B. This map shows the estimated Loss Ratio for buildings for a Georgia Strait event, based on the current design level of the buildings. The loss ratio is the relationship between the estimated loss value due to earthquake damage and the replacement value of the building and contents. The values for individual buildings have been grouped to show regions of loss ratios.

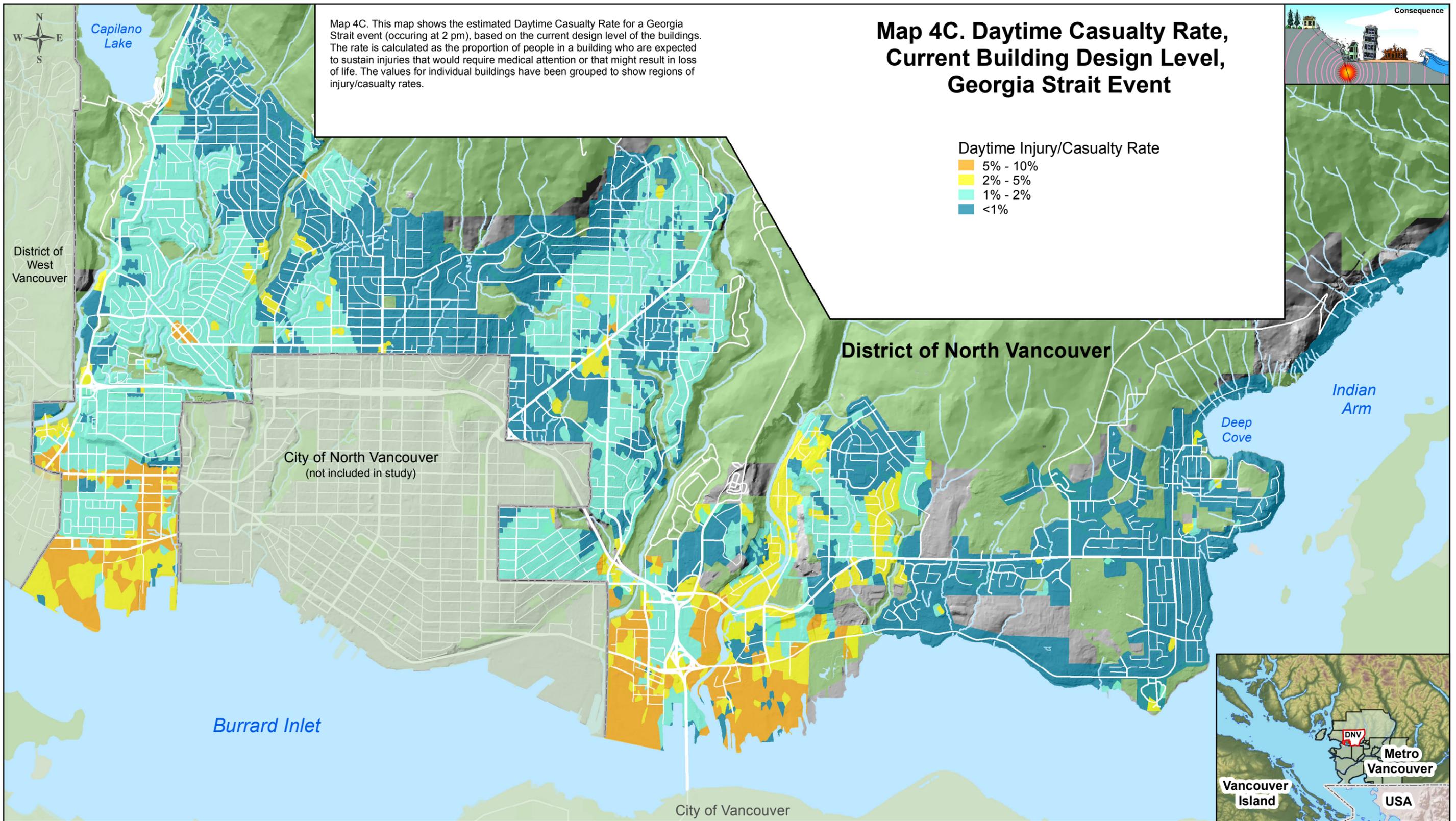
Map 4B. Building Loss Ratio, Current Building Design Level, Georgia Strait Event

Building Loss Ratio
 >30%
 20% - 30%
 10% - 20%
 <10%

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Map 4C. This map shows the estimated Daytime Casualty Rate for a Georgia Strait event (occurring at 2 pm), based on the current design level of the buildings. The rate is calculated as the proportion of people in a building who are expected to sustain injuries that would require medical attention or that might result in loss of life. The values for individual buildings have been grouped to show regions of injury/casualty rates.

Map 4C. Daytime Casualty Rate, Current Building Design Level, Georgia Strait Event

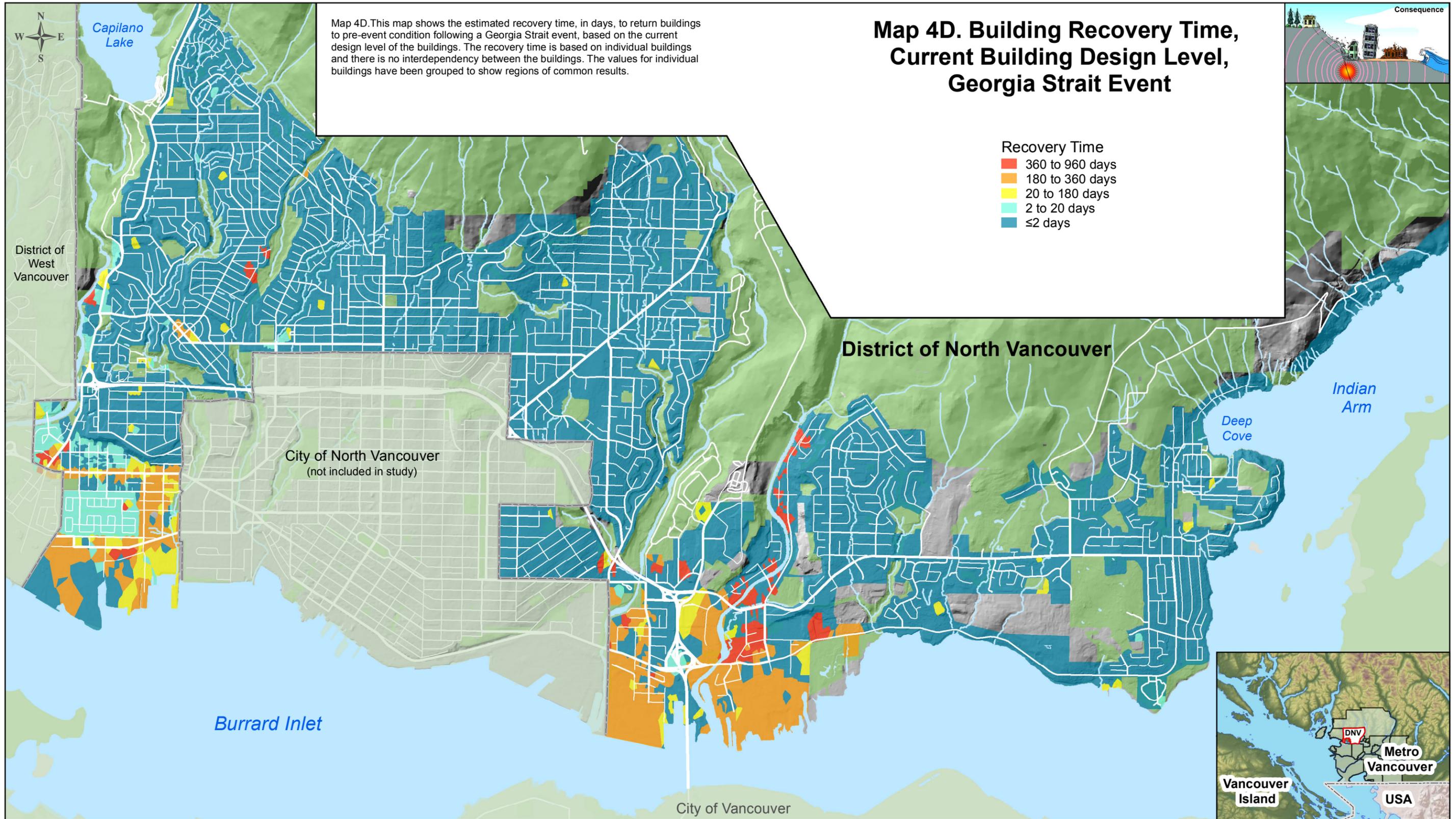
Daytime Injury/Casualty Rate

- 5% - 10%
- 2% - 5%
- 1% - 2%
- <1%

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Map 4D. This map shows the estimated recovery time, in days, to return buildings to pre-event condition following a Georgia Strait event, based on the current design level of the buildings. The recovery time is based on individual buildings and there is no interdependency between the buildings. The values for individual buildings have been grouped to show regions of common results.

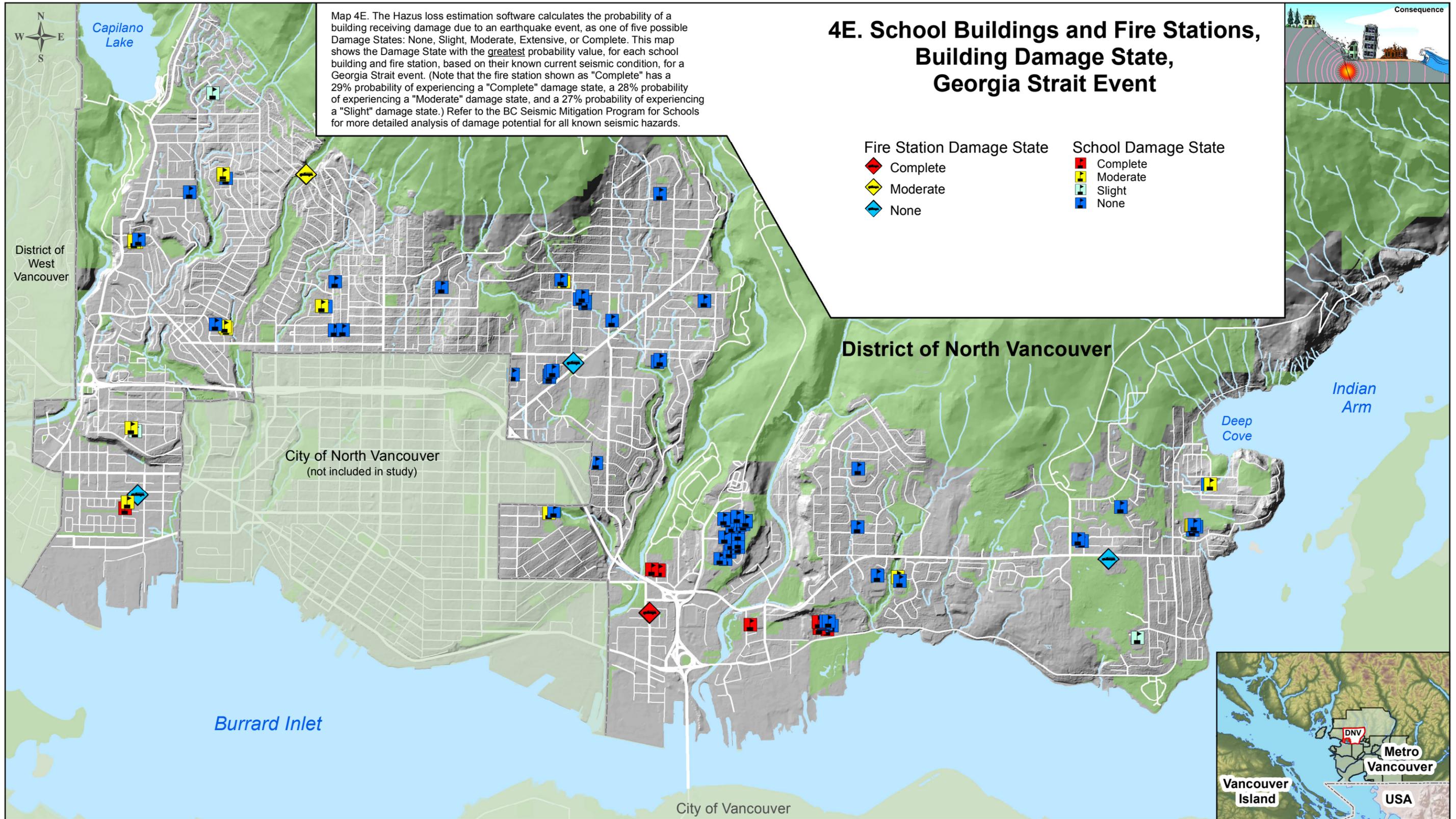
Map 4D. Building Recovery Time, Current Building Design Level, Georgia Strait Event

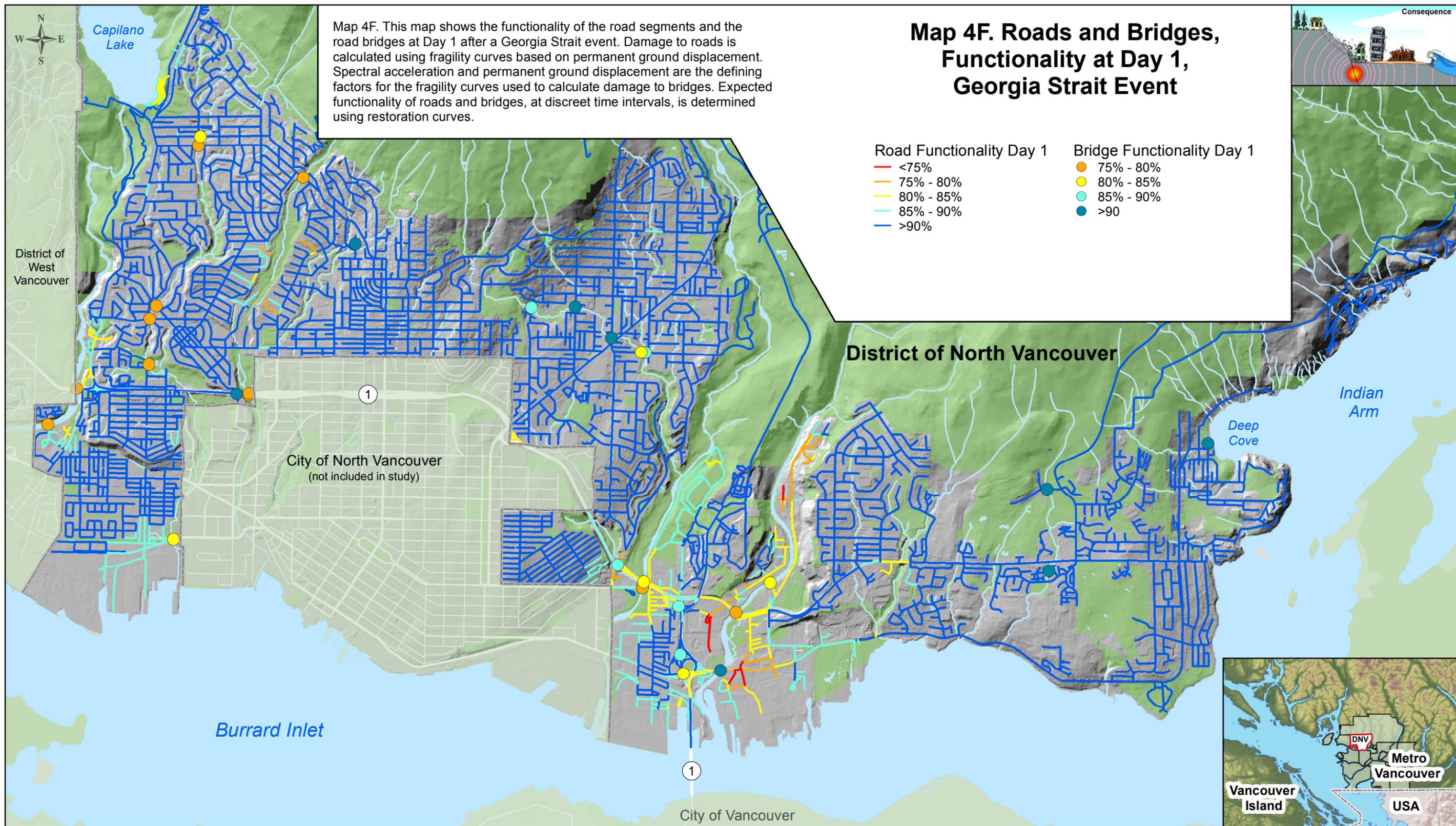
- Recovery Time
- 360 to 960 days
 - 180 to 360 days
 - 20 to 180 days
 - 2 to 20 days
 - ≤2 days

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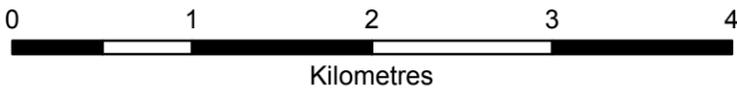


Map 4F. This map shows the functionality of the road segments and the road bridges at Day 1 after a Georgia Strait event. Damage to roads is calculated using fragility curves based on permanent ground displacement. Spectral acceleration and permanent ground displacement are the defining factors for the fragility curves used to calculate damage to bridges. Expected functionality of roads and bridges, at discrete time intervals, is determined using restoration curves.

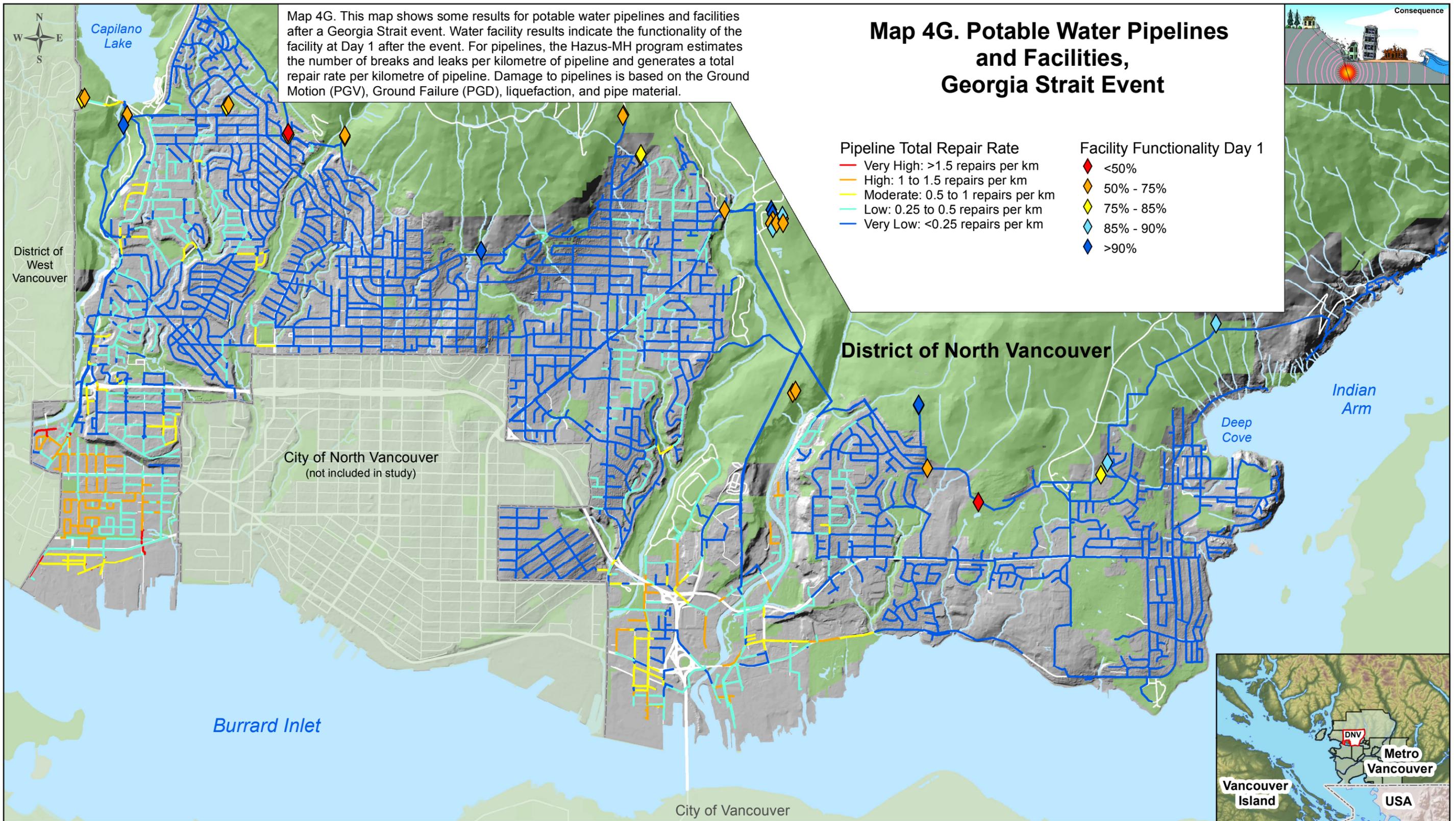
Map 4F. Roads and Bridges, Functionality at Day 1, Georgia Strait Event

- | | |
|---------------------------------|-----------------------------------|
| Road Functionality Day 1 | Bridge Functionality Day 1 |
| — <75% | ● 75% - 80% |
| — 75% - 80% | ● 80% - 85% |
| — 80% - 85% | ● 85% - 90% |
| — 85% - 90% | ● >90% |
| — >90% | |

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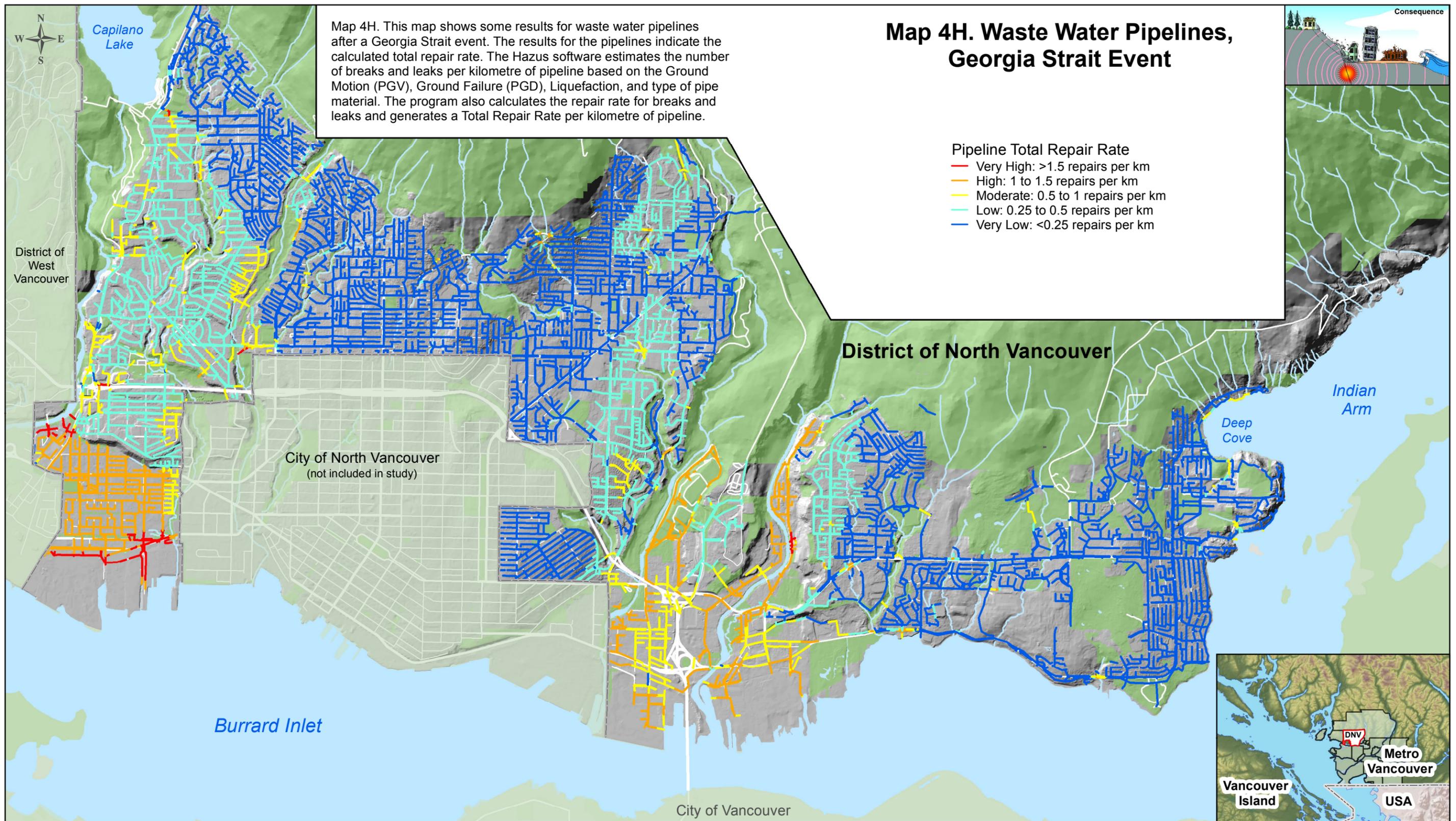


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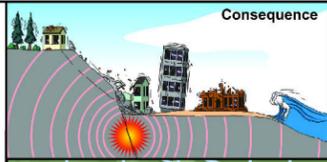
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Map 4H. This map shows some results for waste water pipelines after a Georgia Strait event. The results for the pipelines indicate the calculated total repair rate. The Hazus software estimates the number of breaks and leaks per kilometre of pipeline based on the Ground Motion (PGV), Ground Failure (PGD), Liquefaction, and type of pipe material. The program also calculates the repair rate for breaks and leaks and generates a Total Repair Rate per kilometre of pipeline.

Map 4H. Waste Water Pipelines, Georgia Strait Event

- Pipeline Total Repair Rate**
- Very High: >1.5 repairs per km
 - High: 1 to 1.5 repairs per km
 - Moderate: 0.5 to 1 repairs per km
 - Low: 0.25 to 0.5 repairs per km
 - Very Low: <0.25 repairs per km



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Section 5: Resilience/Mitigation Maps, Georgia Strait Event

Introduction

The results for the building damage for the Georgia Strait event using the current design level were examined. As can be seen in Map 4A, most of the buildings with Extensive or Complete damage states are located in the southern part of the community in areas of high liquefaction susceptibility. The individual buildings found to experience an Extensive or Complete damage state using their current design level were re-assigned a High Code design level. The AEBM Hazus-MH earthquake analysis was rerun using these modified codes.

This hypothetical retrofit analysis was performed as a “what-if” situation and demonstrates the change in damage/injury results if retrofit measures were done on buildings in the community.

Map 5A. Building Damage State, Retrofit Building Design Level, Georgia Strait Event

Hazus-MH calculates the probability of a building sustaining damage as one of five possible Damage States: None, Slight, Moderate, Extensive, and Complete. Map 5A shows the damage state results for a Georgia Strait event after a hypothetical retrofit is applied to some buildings. The damage state with the greatest value was chosen. The results for the individual buildings have been grouped into polygons to illustrate regions of similar damage values

Note that the probability values for two or more damage states may be close but the damage state with the highest values was chosen for the map. For example, a building may have a 29% probability of experiencing a Complete damage state and a 28% probability of experiencing a Moderate damage state.

The map is provided to show an overview of general regions of similar damage states. For information on results for individual buildings, analysis results for the individual buildings should be consulted.

Comparison of Map 5A with Map 4A shows a significant change in building damage states. Most of the buildings which had experienced a Complete damage state with current seismic conditions are estimated to experience a None damage state under retrofit conditions.

Map 5B. Building Loss Ratio, Retrofit Building Design Level, Georgia Strait Event

Map 5B shows the Building Loss Ratio results for a Georgia Strait event after a hypothetical retrofit is applied to some buildings. As described for Map 4B, the loss ratio represents the relationship between the estimated loss value and the replacement value of the building and contents. For this map the estimated total loss for the building (structural, non-structural, and content) is divided by the total value of the building (replacement cost and content value).

The reduction in Damage state values shown in Map 5A is reflected in the reduction of building loss ratio. Those areas where the hypothetical retrofit seismic codes were applied show a reduction in loss ratio.

Map 5C. Daytime Casualty Rate, Retrofit Building Design Level, Georgia Strait Event

Map 5C shows the estimated injury/casualty Rate for a Georgia Strait daytime event (occurring at 2 pm) for buildings after a hypothetical retrofit is applied to some buildings. The rate is calculated as the proportion of people in a building who are expected to sustain injuries that would require medical attention or that might result in loss of life. The values for all four injury levels were totaled then divided by the population of the building.

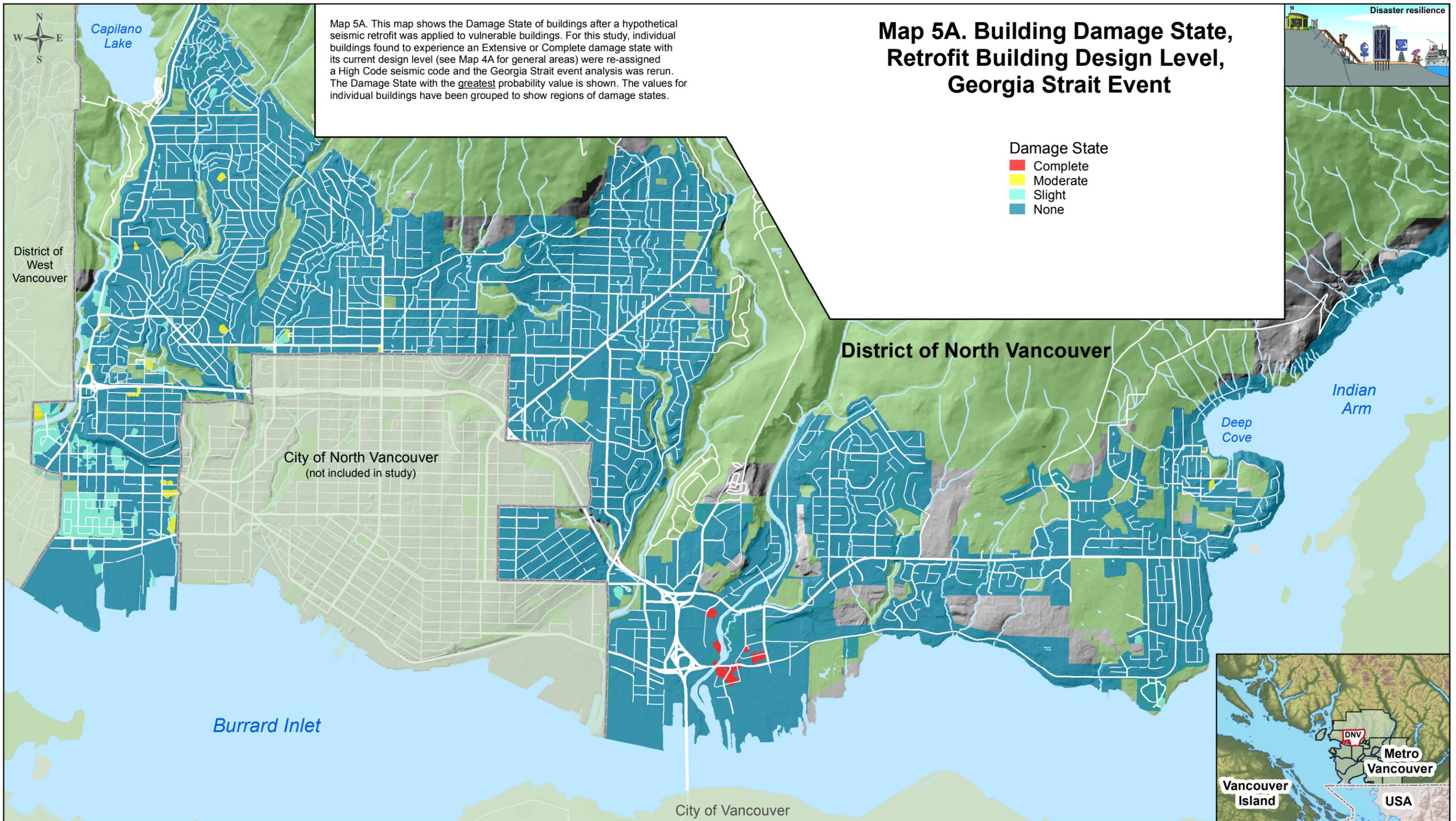


Comparison of Map 5C and Map 4C show a reduction in the Daytime Casualty rate due to the reduction of damage to the buildings.

Map 5D. Building Recovery Time, Retrofit Building Design Level, Georgia Strait event

In Hazus-MH there is a distinction between Repair Time and Recovery Time. Repair (construction) times are a function of damage state and the building occupancy. Recovery time estimates include repair time, plus cleanup time, delays in decision making, financing, inspection, etc. The Recovery Time values represent “estimates of the median time for recovery of building functions.” (FEMA, 2012a, page 15-19) Recovery Time is based on individual buildings and there is no interdependency between the buildings. Hazus-MH estimates the results for Recovery Time in discrete values: 2, 5, 10, 20, 60, 90, 120, 135, 270, 360, 480, 720, and 960 days. Map 5D shows the estimated recovery time for buildings for a Georgia Strait event after a hypothetical retrofit is applied to some buildings. Repair time values have not been mapped in this atlas.

Comparison of Map 5D and Map 4D shows a significant reduction in recovery time. The reduction in building damage states shown in Map 5A is reflected in the reduction of recovery time.



Map 5A. This map shows the Damage State of buildings after a hypothetical seismic retrofit was applied to vulnerable buildings. For this study, individual buildings found to experience an Extensive or Complete damage state with its current design level (see Map 4A for general areas) were re-assigned a High Code seismic code and the Georgia Strait event analysis was rerun. The Damage State with the greatest probability value is shown. The values for individual buildings have been grouped to show regions of damage states.

Map 5A. Building Damage State, Retrofit Building Design Level, Georgia Strait Event

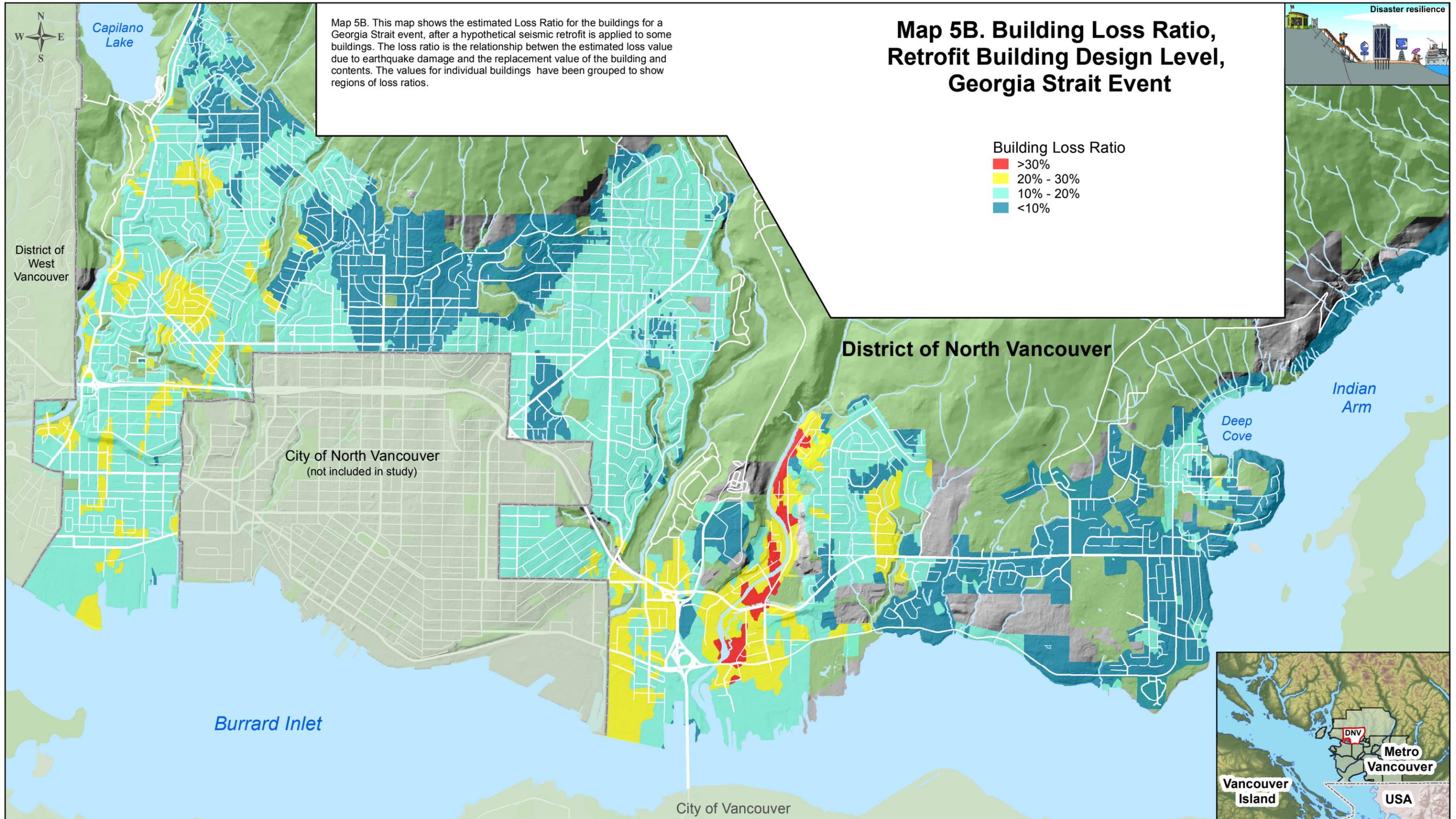
- Damage State
- Complete
 - Moderate
 - Slight
 - None



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Map 5B. This map shows the estimated Loss Ratio for the buildings for a Georgia Strait event, after a hypothetical seismic retrofit is applied to some buildings. The loss ratio is the relationship between the estimated loss value due to earthquake damage and the replacement value of the building and contents. The values for individual buildings have been grouped to show regions of loss ratios.

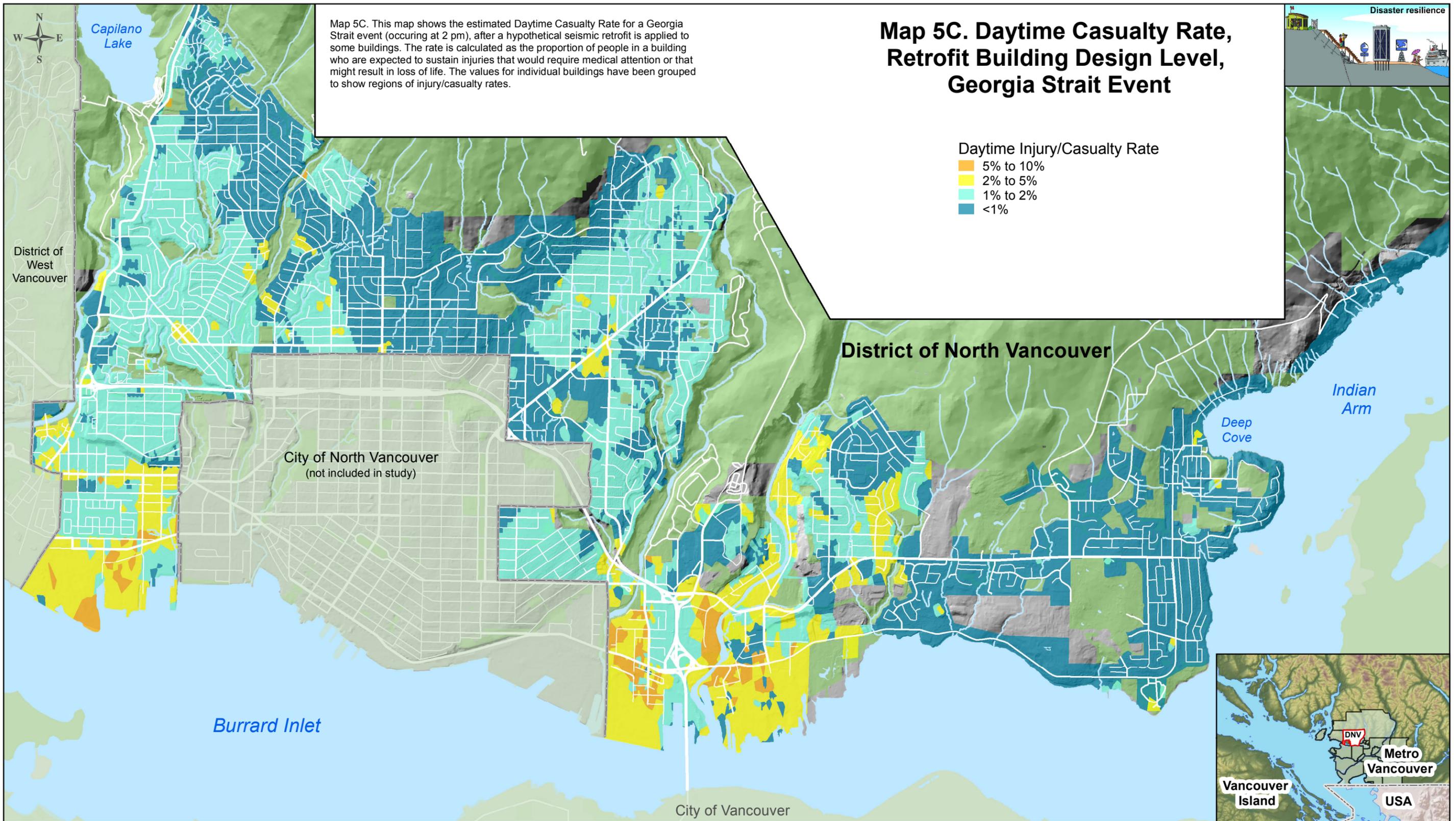
Map 5B. Building Loss Ratio, Retrofit Building Design Level, Georgia Strait Event

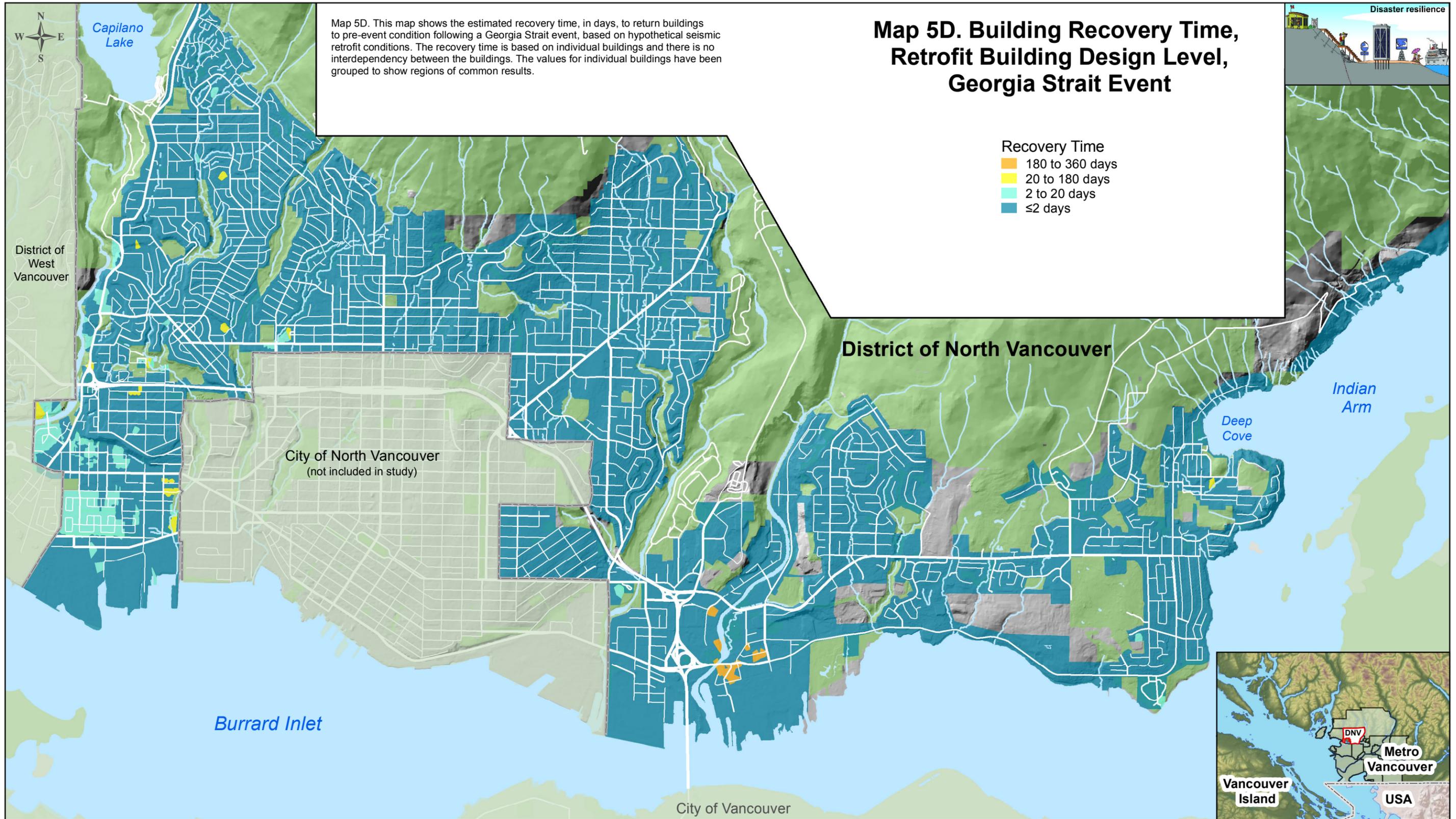
Building Loss Ratio
 >30%
 20% - 30%
 10% - 20%
 <10%

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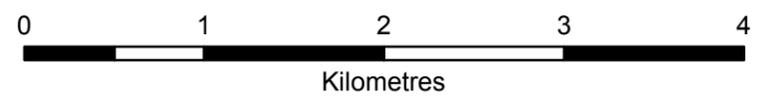


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Section 6: Hazard Maps, 1 in 2475 Year PSHA

The 1 in 2475 year earthquake

The 1 in 2475 ground motions represents the ground shaking that is likely to occur in any given year and at a specific site, for a recurrence interval of 1 in 2475 years. By definition, probabilistic ground motion models represent the cumulative threat of all known earthquake hazards at a specific location over a given future time horizon.

Methods of Probabilistic Seismic Hazard Assessment (PSHA) are based on a theoretical understanding of seismic source zone characteristics, associated ground motion relationships, and empirical records of known seismic activity that are used to establish relationships between earthquake magnitude and frequency. Probabilistic seismic hazard assessments are used in the National Building Code of Canada (NBCC, 2010) to quantify the likelihood of exceeding minimum thresholds of ground shaking from known earthquake hazards at a particular location over time horizons that are relevant for planning and policy development (Adams and Halchuk, 2003; Halchuk and Adams, 2008). Outputs of these probabilistic models are used to establish building performance guidelines that ensure a minimum threshold of seismic safety for occupants during an earthquake. The 1 in 2475 year probabilistic ground motions, which are the same as those used in the NBCC, have an equivalent to a probability of 0.000404 per annum. This means that over a 50-year period, there is a 2 percent chance of an earthquake causing ground motion greater than that of the given value.

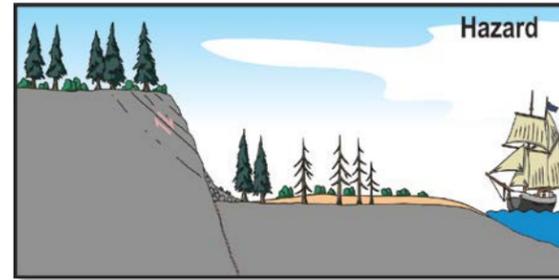


Figure 4 shows the regional ground shaking intensity for a 1 in 2475 year probabilistic ground motions.

It must be noted that probabilistic models are not suitable for analysis of aggregated exposure inventory. Because probabilistic ground motions indicate motion at a specific point location, the results of analyses of aggregated data covering an area are unrealistic. In this atlas, the results shown in Map7A to Map7D and Map8A to Map 8D are the results from the AEBM model analysis on the individual buildings. Results shown in Map 7E to Map 7H are from the analysis of specific buildings and infrastructure in the District's asset inventory.

The ground shaking maps for the 1 in 2475 year PSHA for the District were generated specifically for this project. Methods used to generate the maps are discussed in Prieto et al, 2013. Amplification factors based on the NEHRP soil classes and the 2010 National Building Code of Canada have been applied to the ground shaking values for the model.

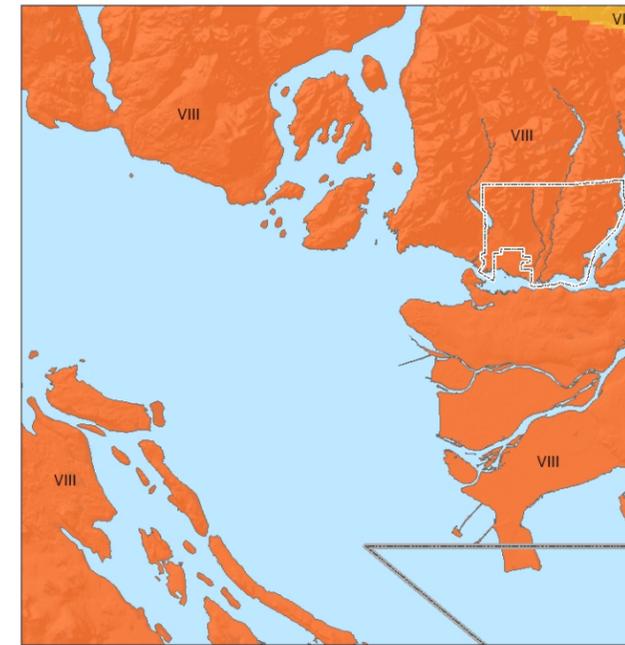
Section 3 provides more information on hazard maps.

Map 6A. Peak Ground Velocity, 1 in 2475 Year PSHA

Peak ground velocity (PGV) is a measure of the maximum change in displacement over time that a particle is likely to experience during an earthquake. It has been shown to be a reliable indicator of general building damage patterns. Values for PGV are measured in cm/sec. Map 6A shows the PGV values for a 1 in 2475 year PSHA.

Map 6B. Peak Ground Acceleration, 1 in 2475 Year PSHA

Peak ground acceleration (PGA) is a measure of the maximum increase in velocity over time that a particle is likely to experience during an earthquake. Acceleration is measured as a force and expressed in units of %g. The PGA values are used primarily in assessing the potential for seismically induced ground deformation. Map 6B shows the PGA values for a 1 in 2475 year PSHA.



MMI Scale	Perceived Shaking	Damage Potential
V	Light felt by some	Pictures move
VI	Moderate felt by all	Objects fall to ground
VII	Strong difficulty standing	Non-structural damage
VIII	Very Strong difficulty driving	Moderate structural damage
IX	Violent general panic	Heavy structural damage
X	Very Violent general panic	Extreme structural damage

Figure 4. Regional ground shaking intensity values for a 1 in 2475 year probabilistic earthquake. Source: Adapted from Petersen et al. (2008).

Map 6C. Permanent Ground Deformation by Lateral Spreading due to Liquefaction, 1 in 2475 Year PSHA

Permanent ground deformation hazards caused by liquefaction can include: 1) lateral spreading as soil horizons fail suddenly and are displaced horizontally in a viscous state, and/or 2) vertical settlement caused by changes in soil volume and settling during the shaking from an earthquake. The amount and type of displacement will vary as a function of ground shaking intensity and localized geologic setting. Map 6C shows the estimated movement of ground material as a result of lateral spreading due to liquefaction for a 1 in 2475 year PSHA.

Map 6D. Permanent Ground Deformation due to Landslide, 1 in 2475 Year PSHA

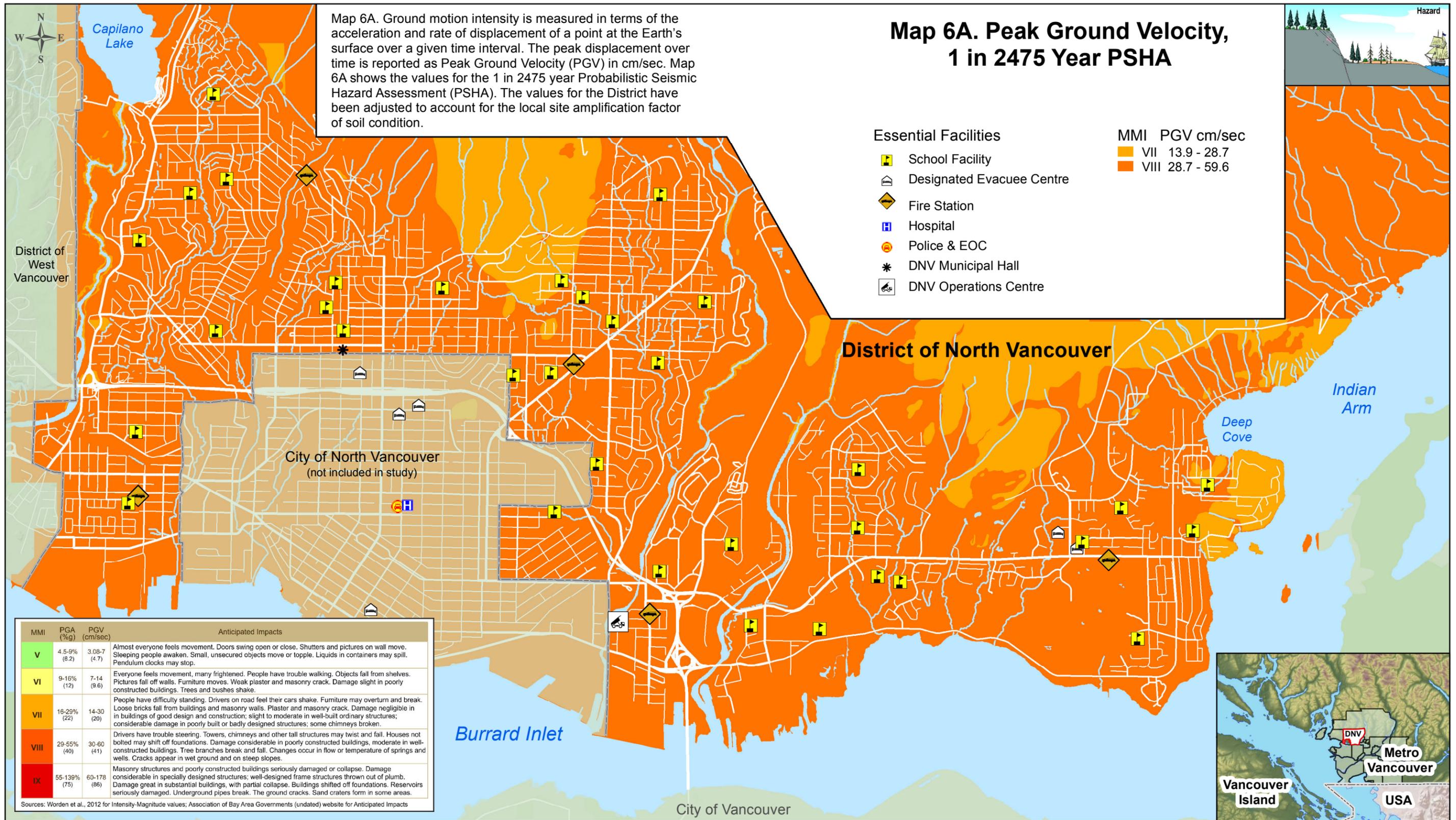
Permanent ground deformation caused by landslide movement represents the movement of ground material downslope due to shaking from an earthquake. The spatial extent and pattern of permanent ground deformation is controlled by local factors such as bedrock geology, surficial geology, soil conditions, slope gradient, and groundwater hydrology. Map 6D shows the estimated movement of ground material as a result of a landslide due to a 1 in 2475 year PSHA.

Map 6E. Spectral Acceleration at 0.3 second interval, 1 in 2475 Year PSHA

Spectral acceleration describes the maximum acceleration in an earthquake on an object at a specific time period and is measured in units of force (g). Map 6E shows the short period spectral acceleration at the 0.3 second interval for a 1 in 2475 year PSHA.

Map 6F. Spectral Acceleration at 1.0 second interval, 1 in 2475 Year PSHA

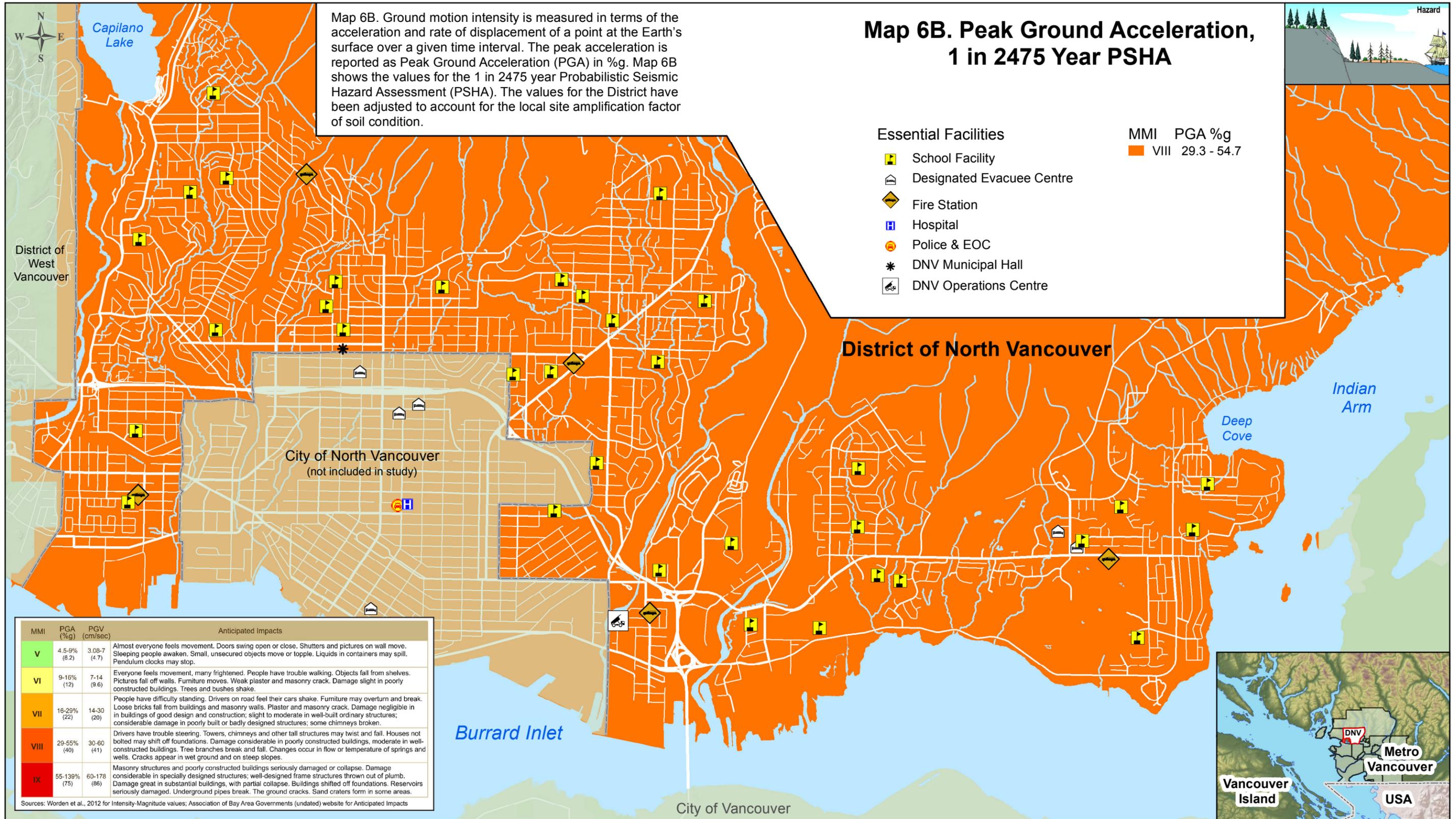
Spectral acceleration describes the maximum acceleration in an earthquake on an object at a specific time period and is measured in units of force (g). Map 6F shows the spectral acceleration at the 1.0 second interval for a 1 in 2475 year PSHA.



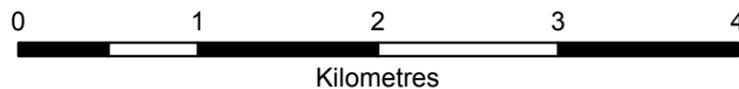
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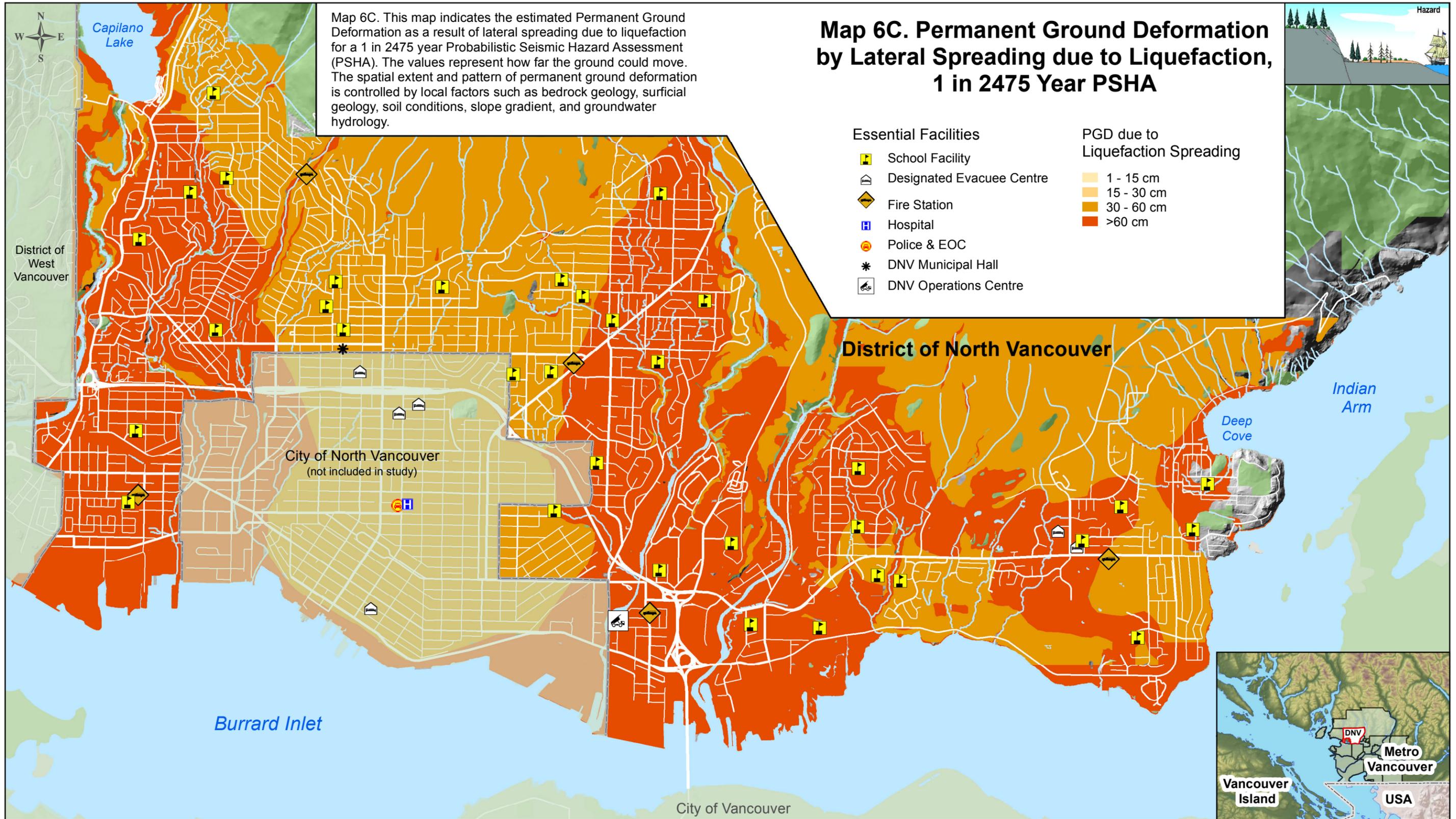
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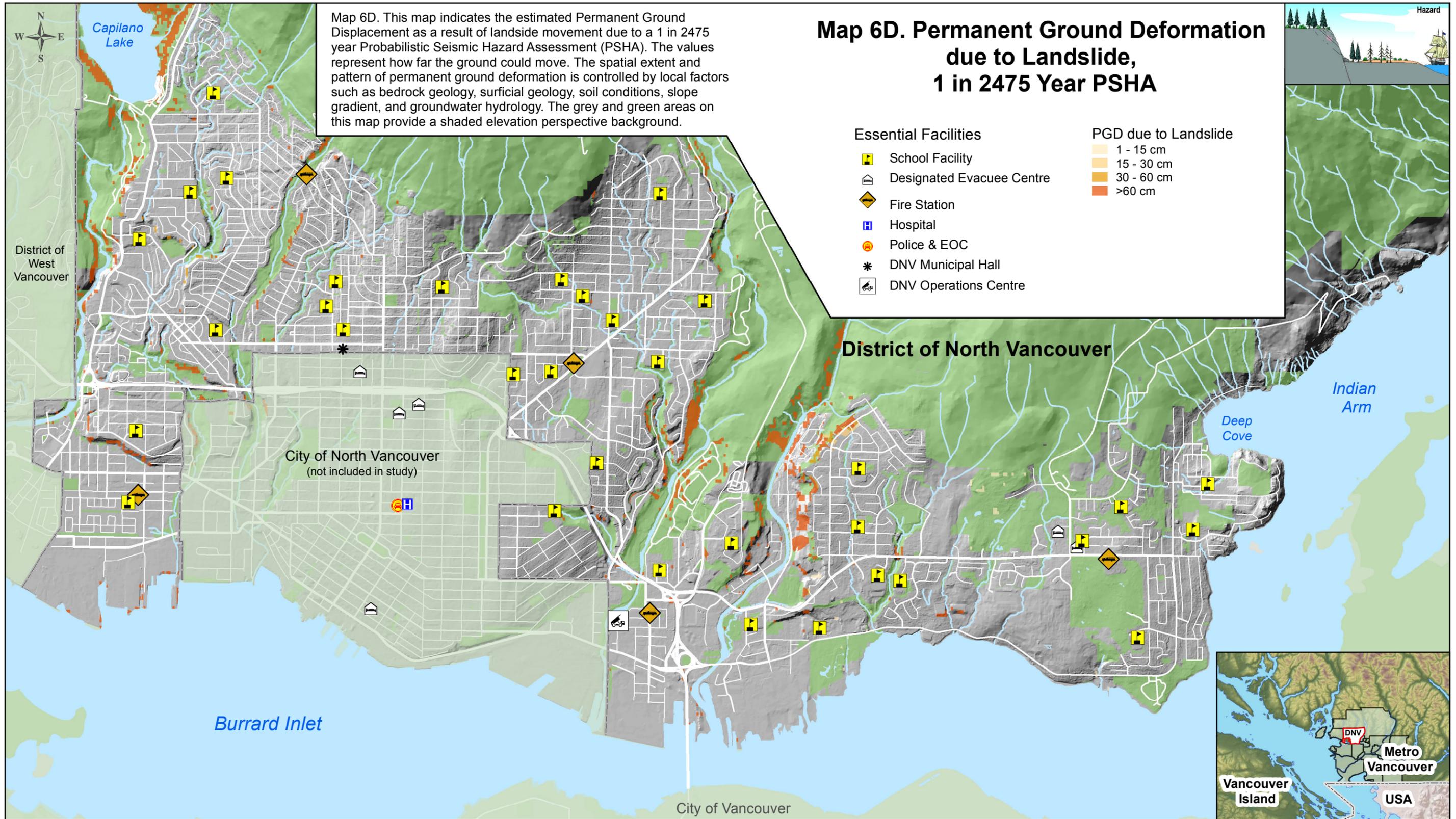


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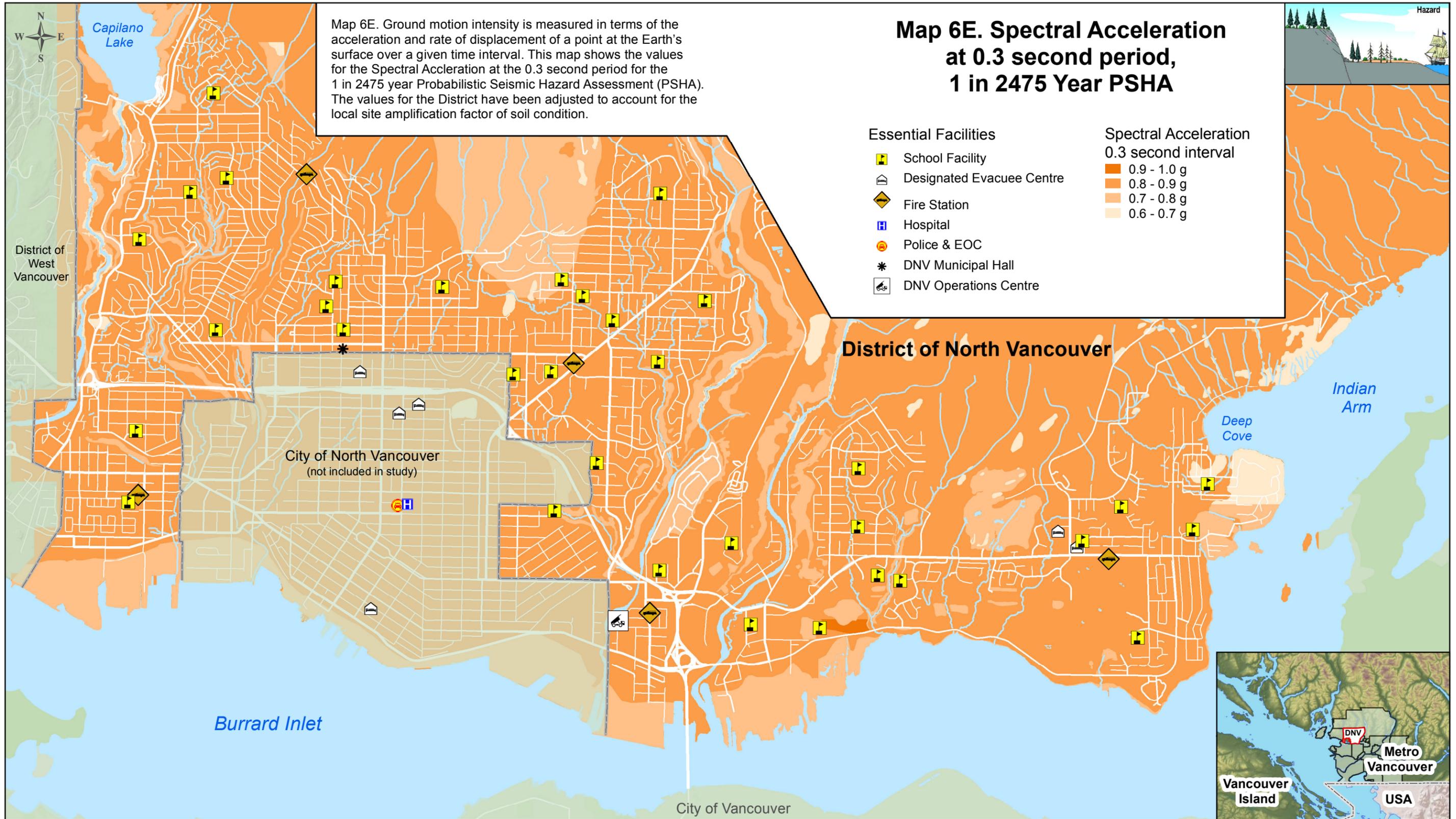
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Map 6E. Ground motion intensity is measured in terms of the acceleration and rate of displacement of a point at the Earth's surface over a given time interval. This map shows the values for the Spectral Acceleration at the 0.3 second period for the 1 in 2475 year Probabilistic Seismic Hazard Assessment (PSHA). The values for the District have been adjusted to account for the local site amplification factor of soil condition.

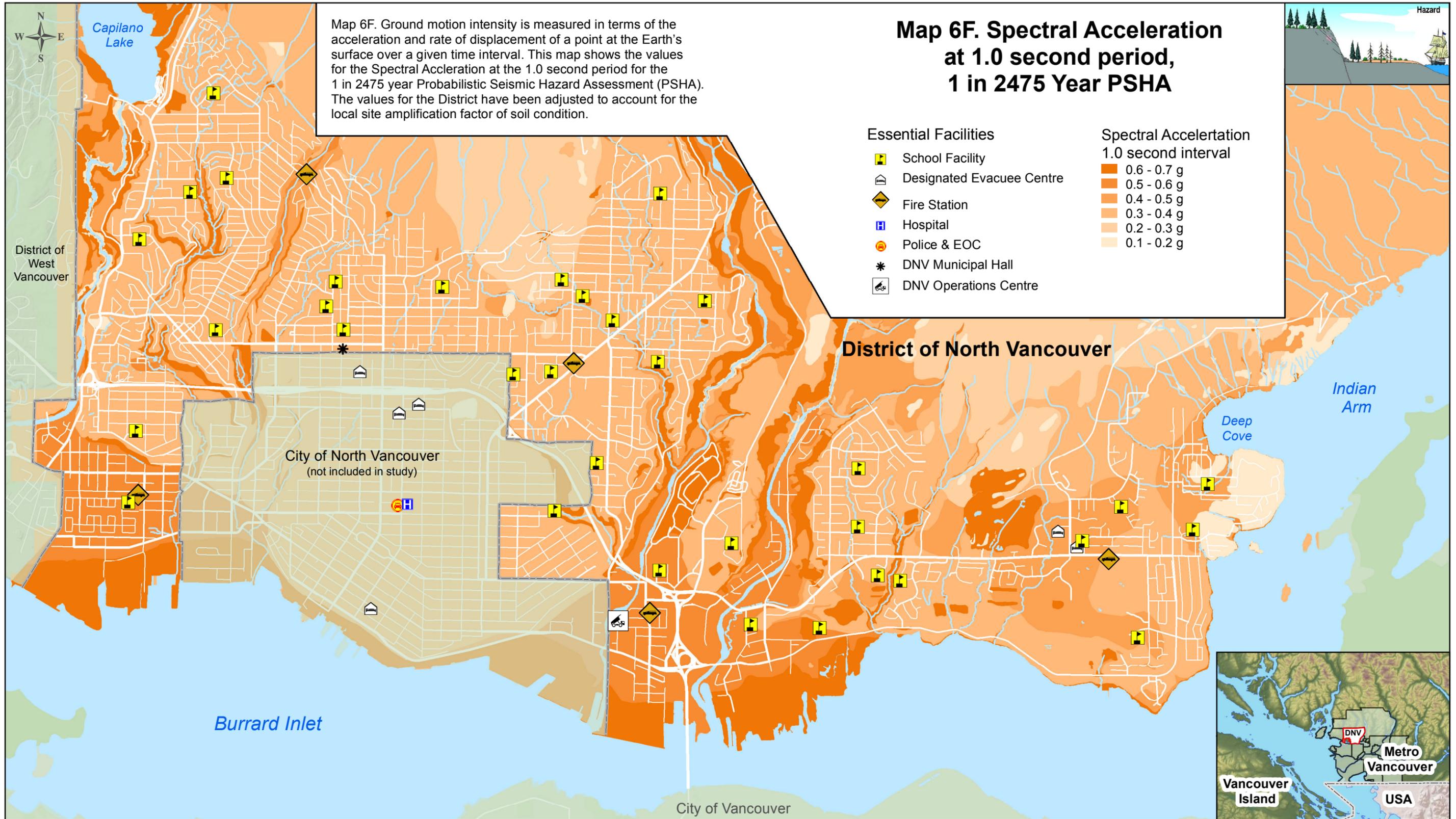
Map 6E. Spectral Acceleration at 0.3 second period, 1 in 2475 Year PSHA

- Essential Facilities**
- School Facility
 - Designated Evacuee Centre
 - Fire Station
 - Hospital
 - Police & EOC
 - DNV Municipal Hall
 - DNV Operations Centre
- Spectral Acceleration 0.3 second interval**
- 0.9 - 1.0 g
 - 0.8 - 0.9 g
 - 0.7 - 0.8 g
 - 0.6 - 0.7 g

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Map 6F. Ground motion intensity is measured in terms of the acceleration and rate of displacement of a point at the Earth's surface over a given time interval. This map shows the values for the Spectral Acceleration at the 1.0 second period for the 1 in 2475 year Probabilistic Seismic Hazard Assessment (PSHA). The values for the District have been adjusted to account for the local site amplification factor of soil condition.

Map 6F. Spectral Acceleration at 1.0 second period, 1 in 2475 Year PSHA

- | | |
|-----------------------------|--|
| Essential Facilities | Spectral Acceleration 1.0 second interval |
| School Facility | 0.6 - 0.7 g |
| Designated Evacuee Centre | 0.5 - 0.6 g |
| Fire Station | 0.4 - 0.5 g |
| Hospital | 0.3 - 0.4 g |
| Police & EOC | 0.2 - 0.3 g |
| DNV Municipal Hall | 0.1 - 0.2 g |
| DNV Operations Centre | |

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Section 7: Consequence/Damage Maps, 1 in 2475 Year PSHA

See Section 4 for notes regarding how the results for individual buildings were grouped to show regional trends. Section 4 also provides more detailed descriptive notes for the individual maps.

Map 7A. Building Damage State, Current Building Design Level, 1 in 2475 Year PSHA

To illustrate damage states in Map 7A, the damage state (see Map 4A for definitions) with the greatest value was chosen for each building. Note that the probability values for two or more damage states may be close but the damage state with the highest values was chosen for the map. For example, a building may have a 29% probability of experiencing Complete damage state and a 28% probability of experiencing Moderate damage state and would then be represented on the map as a building likely to experience a Complete damage state. The map is provided to show an overview of general regions of similar damage states. For those concerned with individual buildings, analysis results for the individual buildings should be consulted.

Map 7B. Building Loss Ratio, Current Building Design Level, 1 in 2475 Year PSHA

The loss ratio represents the relationship between the estimated loss value and the replacement value of the building and contents. For this map the estimated total loss for the building (structural, non-structural, and content) is divided by the total value of the building (replacement cost and content value).

Map 7C. Daytime Casualty Rate, Current Building Design Level, 1 in 2475 Year PSHA

Map 7C shows the estimated injury/casualty rate for a daytime occurrence (at 2 pm) for a 1 in 2475 year PSHA. The rate is calculated as the proportion of people in a building who are expected to sustain injuries that would require medical attention or that might result in loss of life. The values for all four injury levels were totaled then divided by the population of the building.

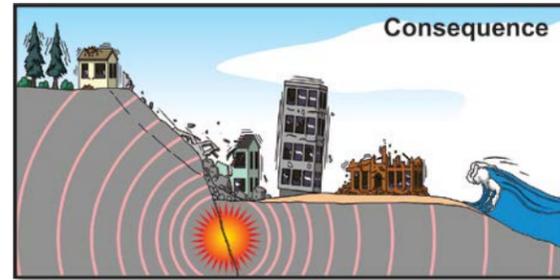
Map 7D. Building Recovery Time, Current Building Design Level, 1 in 2475 Year PSHA

In Hazus-MH there is a distinction between Repair Time and Recovery Time. Repair times depend on damage state and the building occupancy. Recovery time estimates include repair or construction time, plus cleanup time, delays in decision making, financing, inspection, etc. The Recovery Time values represent “estimates of the median time for recovery of building functions.” (FEMA, 2012a, page 15-19) Recovery Time is based on individual buildings and there is no interdependency between the buildings. Hazus-MH estimates the results for Recovery Time in discrete values: 2, 5, 10, 20, 60, 90, 120, 135, 270, 360, 480, 720, and 960 days. Repair time values have not been mapped in this atlas.

Map 7E. School Buildings and Fire Stations, Building Damage State, 1 in 2475 Year PSHA

As described in Map 4A, Hazus-MH calculates the probability of a building sustaining damage due to an earthquake as one of five possible Damage States: None, Slight, Moderate, Extensive, and Complete. This map shows the damage states with the highest probability value for each school and fire station building. The schools and fire stations, along with other emergency facilities, are included in the Essential Facilities database for Hazus. Results shown in Map 7E are based on the AEBM analysis of the individual school buildings and fire station buildings.

For the 1 in 2475 year PSHA, it is expected that 35% of the school facilities are likely to sustain little or no damage and 36% of the school facilities are likely to sustain extensive or complete levels of damage. Of these, four structures are main school facilities.



There are five fire stations within the District of North Vancouver. The damage state with the highest probability for each building following a 1 in 2475 year earthquake is shown on Map 7E. Note that the fire station shown as Complete, in the Lynnmour South neighbourhood, has a 34% probability of experiencing a Complete damage state, a 32% probability of experiencing a Moderate damage state, and a 27% probability of experiencing an Extensive damage state. The fire station adjacent to Mosquito Creek, in the Upper Dellbrook neighbourhood, shown to experience moderate damage state, has recently been seismically upgraded and was assigned a High seismic code in this study.

Map 7F. Roads and Bridges, Functionality at Day 1, 1 in 2475 Year PSHA

Map 7F shows the functionality of the road segments and bridges at Day 1 following the 1 in 2475 year PSHA.

Map 7G. Potable Water Pipelines and Facilities, 1 in 2475 Year PSHA

This map shows some results for the potable water pipelines and potable water facilities after a 1 in 2475 year PSHA.

Hazus-MH loss estimation software estimates the functionality of a building at discrete days following the earthquake (1, 3, 7, 14, 30, and 90 days). The functionality is based on the damage and use of the building. The increase in functionality over time is based on an assumed repair rate. This map shows the functionality of each potable water facility at Day 1 after the event. The results indicate that 25 out of the 35 buildings will have less than 50% functionality and 1 building will have greater than 85% functionality.

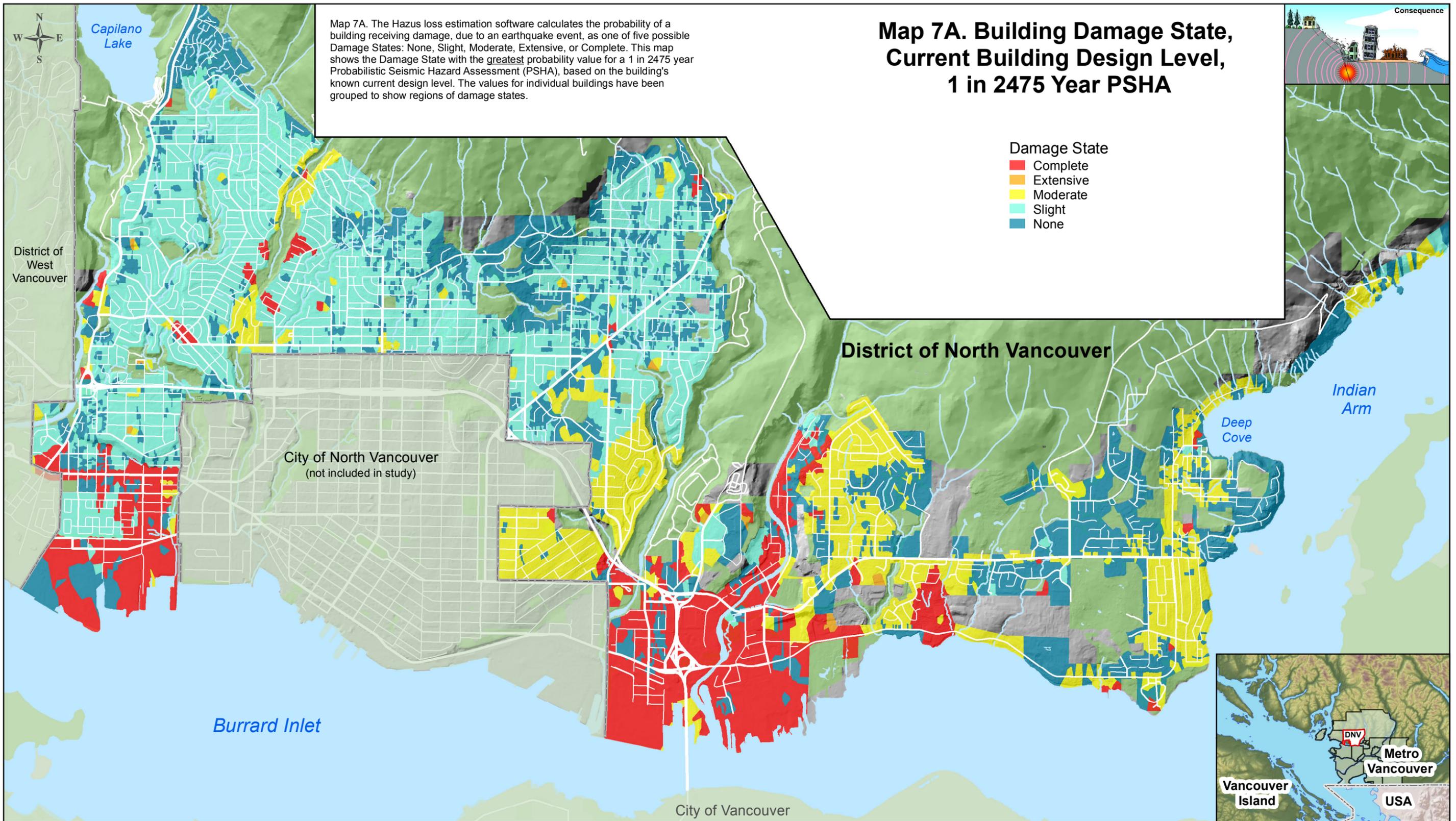
The results for the pipelines indicate the calculated total repair rate. Damage to pipelines is based on the Ground Motion (PGV), Ground Failure (PGD), liquefaction, and type of pipe material. Generally the damage to a pipeline due to Ground Failure (PGD) is a break, while the damage to a pipeline due to seismic wave propagation (PGV) results in a leak. The program calculates the repair rate for breaks and leaks assuming that damage due to ground failure will consist of 20% leaks and 80% breaks, and the damage due to seismic waves will consist of 80% leaks and 20% breaks (FEMA, 2012a, page 8-9). The Hazus-MH program estimates the number of breaks and leaks per kilometre of pipeline and then generates a Total Repair Rate per kilometre of pipeline. The Total Repair Rate values for the 1 in 2475 year PSHA range from less than 0.25 repairs per kilometre to more than 1.5 repairs per kilometre.

Although the words “Very Low” to “Very High” have been assigned to the classes on the map, these descriptions are based on the relative values in the results (0.01 being the lowest and 3.3 being the highest). These descriptions are not based on any technical knowledge as to whether the values for the number of repairs are considered high or low by technical experts.

Map 7H. Waste Water Pipelines, 1 in 2475 Year PSHA

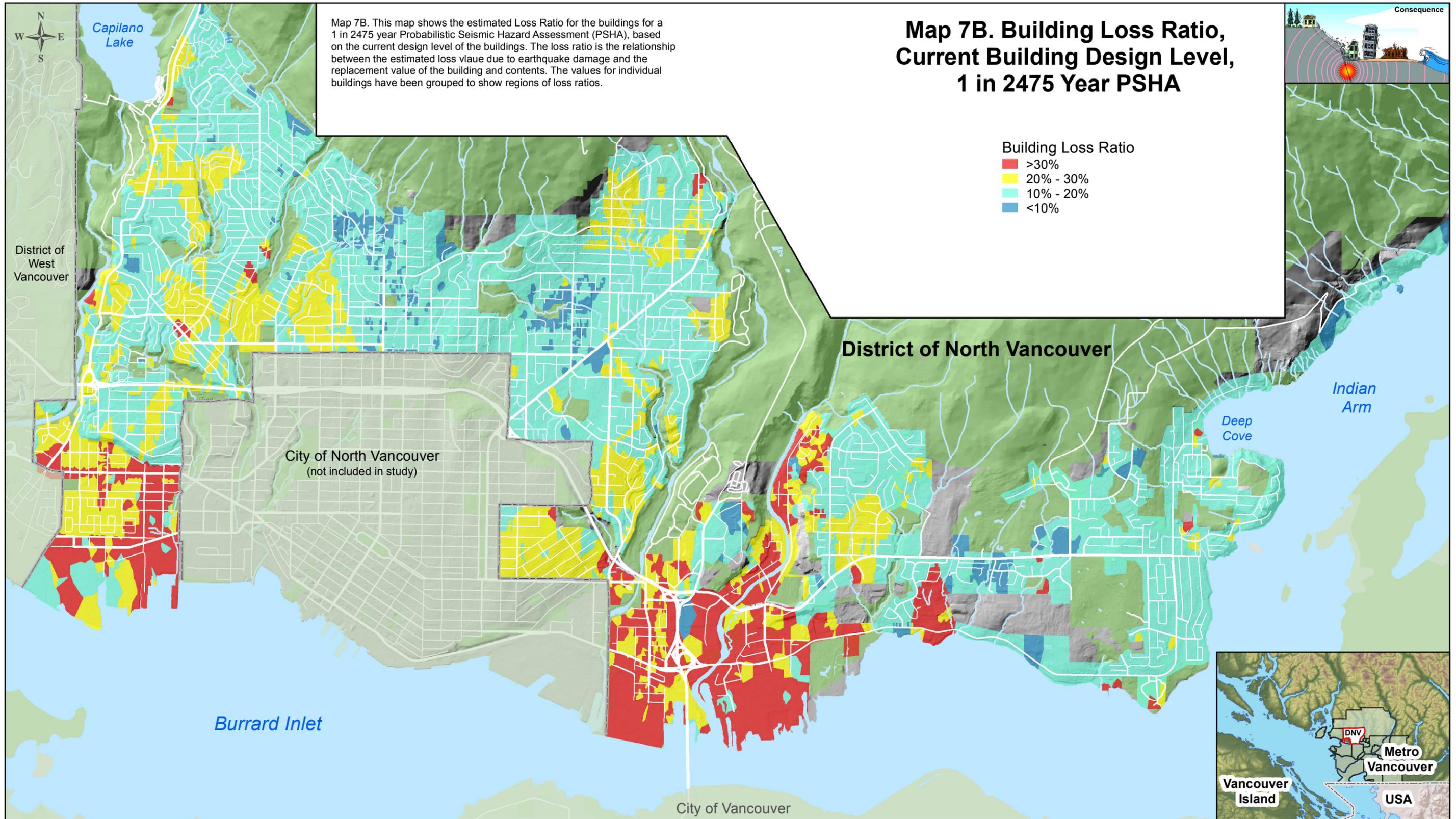
The results for the pipelines indicate the calculated total repair rate. Damage to pipelines is based on the Ground Motion (PGV), Ground Failure (PGD), liquefaction, and type of pipe material. Generally the damage to a pipeline due to Ground Failure (PGD) is a break, while the damage to a pipeline due to seismic wave propagation (PGV) results in a leak. The program calculates the repair rate for breaks and leaks assuming that damage due to ground failure will consist of 20% leaks and 80% breaks, and the damage due to seismic waves will consist of 80% leaks and 20% breaks (FEMA, 2012a, page 8-9). The Hazus-MH program estimates the number of breaks and leaks per kilometre of pipeline and then generates a Total Repair Rate per kilometre of pipeline. For the 1 in 2475 year PSHA, the Total Repair Rate values range from 0.018 repairs per kilometre to more than 3.3 repairs per kilometre.

Although the words “Very Low” to “Very High” have been assigned to the classes on the map, these descriptions are based on the relative values in the results. These descriptions are not based on any technical knowledge as to whether the values for the number of repairs are considered high or low by technical experts.



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Map 7B. This map shows the estimated Loss Ratio for the buildings for a 1 in 2475 year Probabilistic Seismic Hazard Assessment (PSHA), based on the current design level of the buildings. The loss ratio is the relationship between the estimated loss viaue due to earthquake damage and the replacement value of the building and contents. The values for individual buildings have been grouped to show regions of loss ratios.

Map 7B. Building Loss Ratio, Current Building Design Level, 1 in 2475 Year PSHA

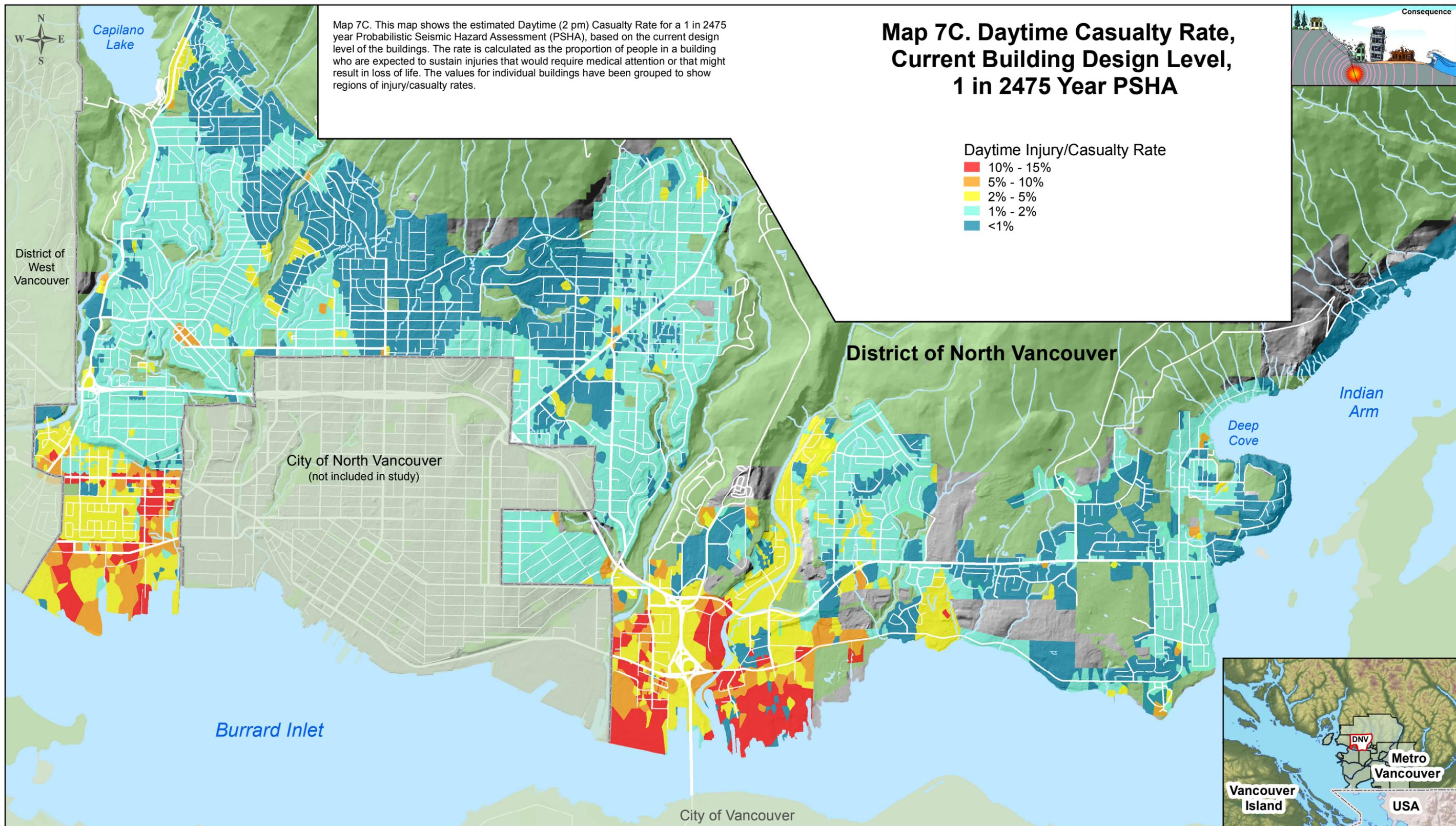
Building Loss Ratio

- >30%
- 20% - 30%
- 10% - 20%
- <10%

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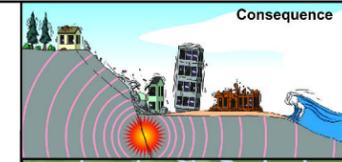


Map 7C. This map shows the estimated Daytime (2 pm) Casualty Rate for a 1 in 2475 year Probabilistic Seismic Hazard Assessment (PSHA), based on the current design level of the buildings. The rate is calculated as the proportion of people in a building who are expected to sustain injuries that would require medical attention or that might result in loss of life. The values for individual buildings have been grouped to show regions of injury/casualty rates.

Map 7C. Daytime Casualty Rate, Current Building Design Level, 1 in 2475 Year PSHA

Daytime Injury/Casualty Rate

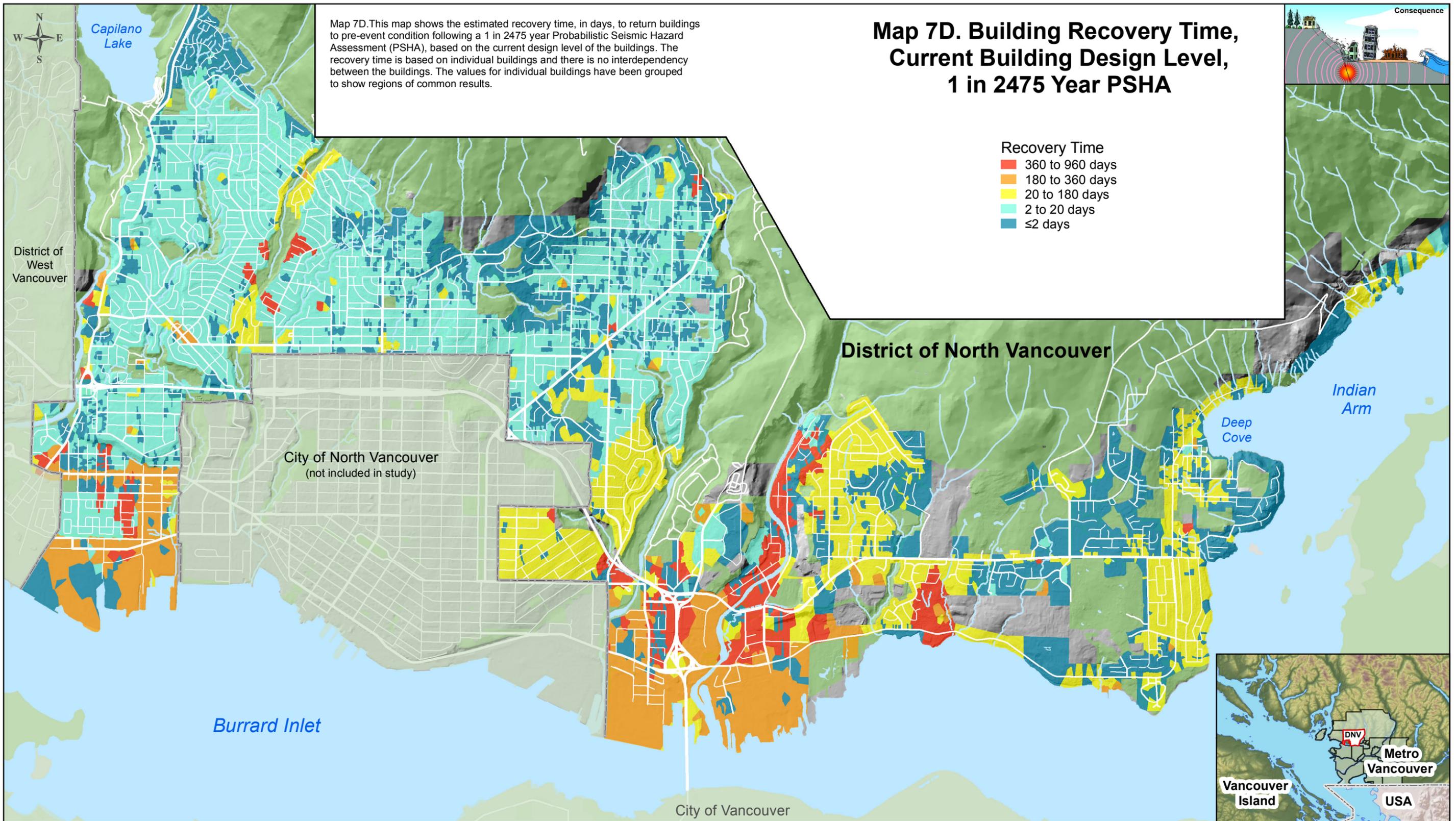
- 10% - 15%
- 5% - 10%
- 2% - 5%
- 1% - 2%
- <1%



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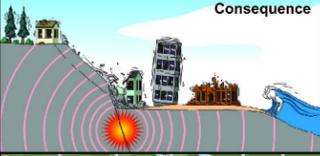
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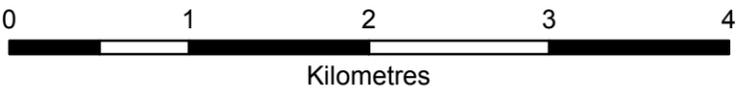
Map 7D. This map shows the estimated recovery time, in days, to return buildings to pre-event condition following a 1 in 2475 year Probabilistic Seismic Hazard Assessment (PSHA), based on the current design level of the buildings. The recovery time is based on individual buildings and there is no interdependency between the buildings. The values for individual buildings have been grouped to show regions of common results.

Map 7D. Building Recovery Time, Current Building Design Level, 1 in 2475 Year PSHA

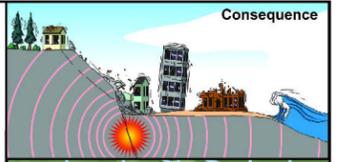
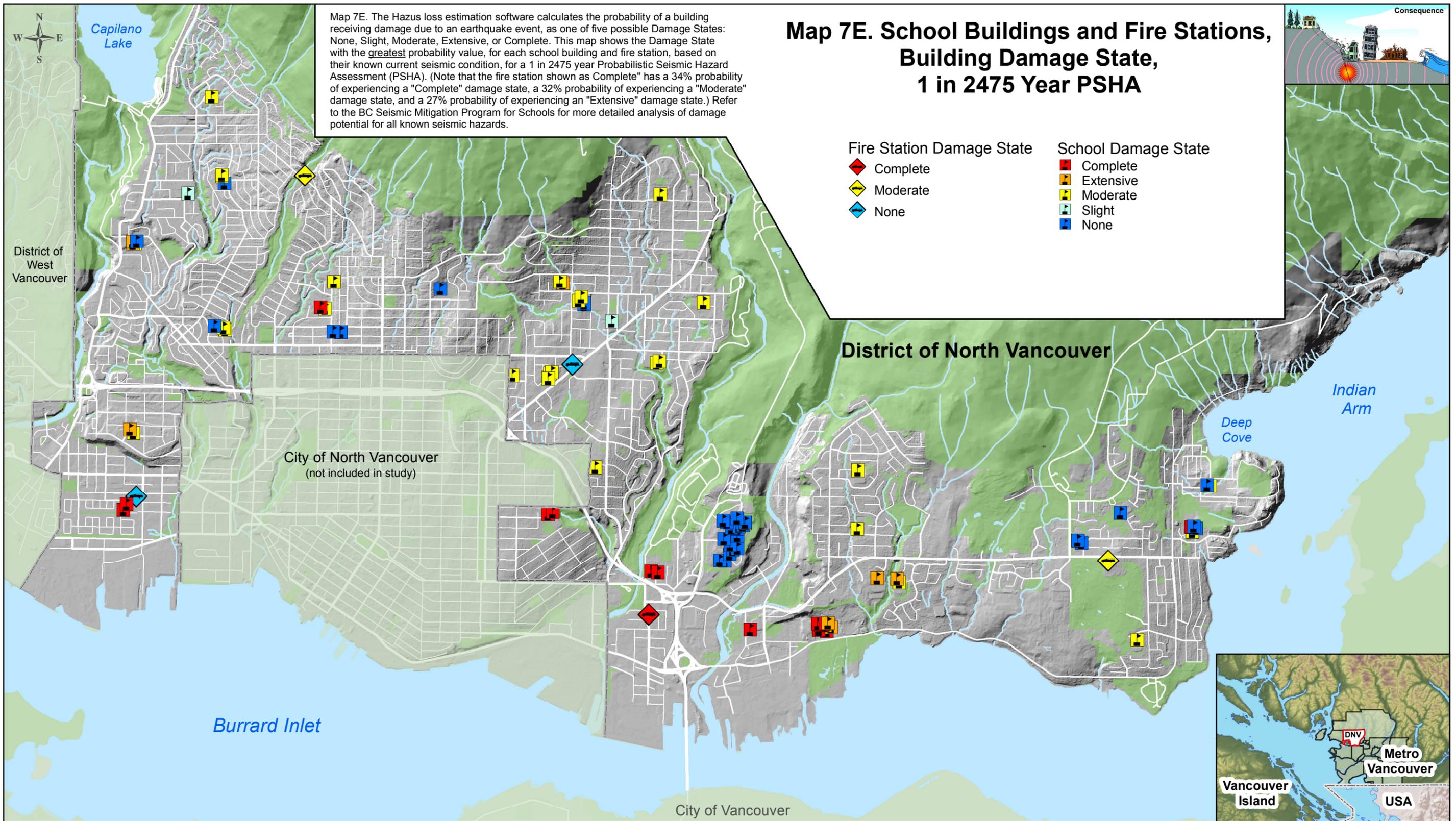
- Recovery Time
- 360 to 960 days
 - 180 to 360 days
 - 20 to 180 days
 - 2 to 20 days
 - ≤2 days



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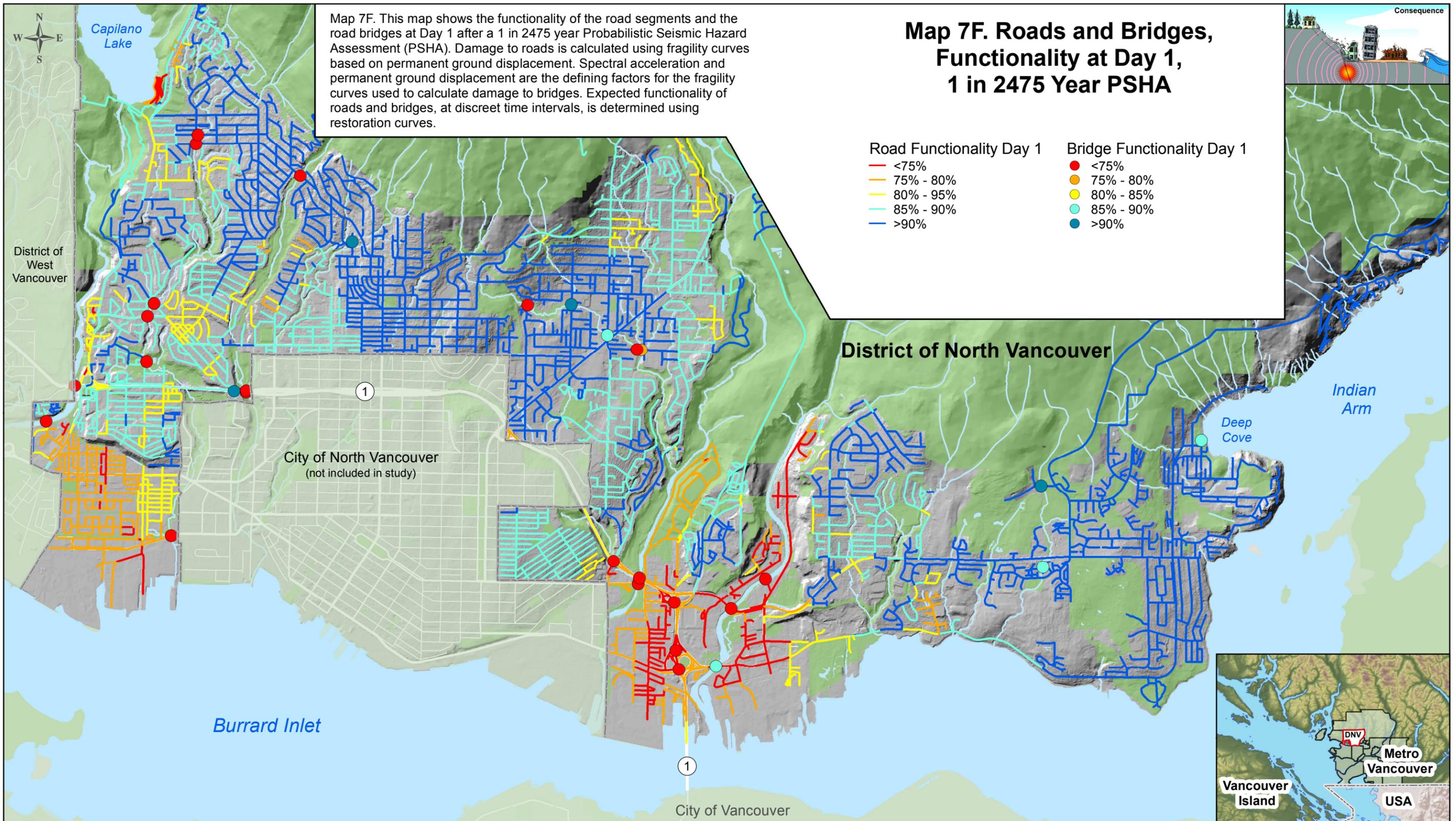
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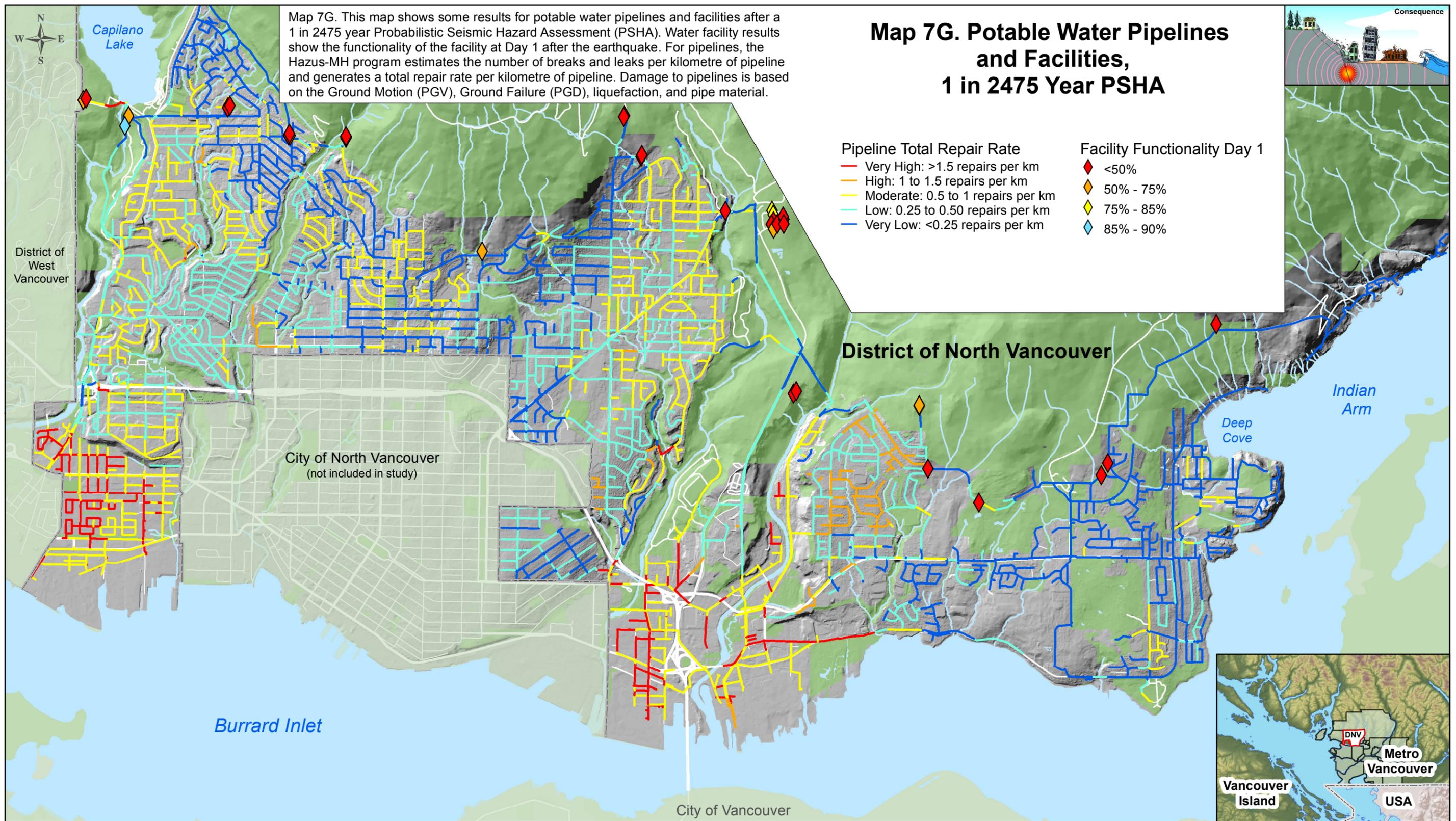


Map 7F. This map shows the functionality of the road segments and the road bridges at Day 1 after a 1 in 2475 year Probabilistic Seismic Hazard Assessment (PSHA). Damage to roads is calculated using fragility curves based on permanent ground displacement. Spectral acceleration and permanent ground displacement are the defining factors for the fragility curves used to calculate damage to bridges. Expected functionality of roads and bridges, at discreet time intervals, is determined using restoration curves.

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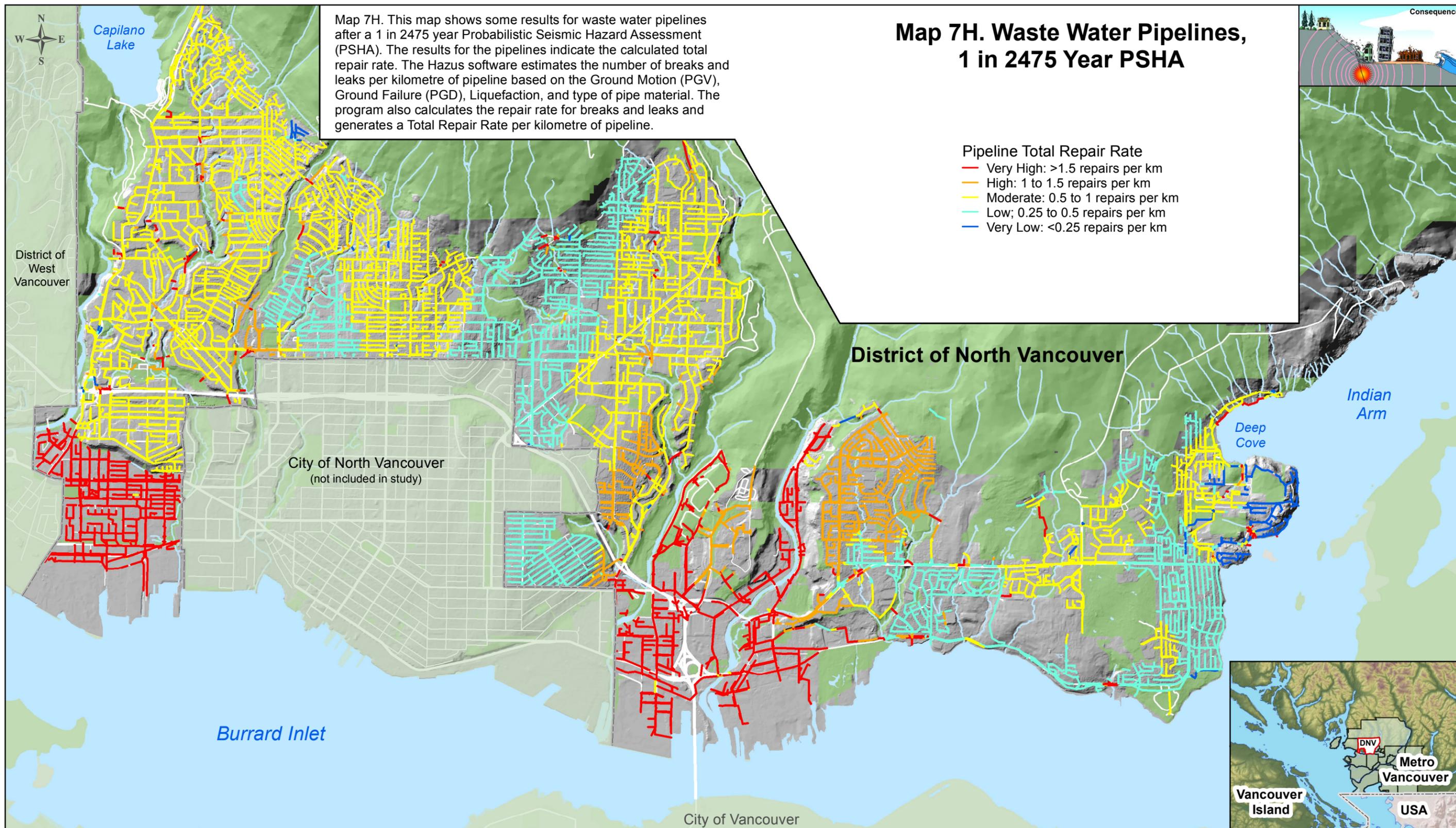
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Map 7H. This map shows some results for waste water pipelines after a 1 in 2475 year Probabilistic Seismic Hazard Assessment (PSHA). The results for the pipelines indicate the calculated total repair rate. The Hazus software estimates the number of breaks and leaks per kilometre of pipeline based on the Ground Motion (PGV), Ground Failure (PGD), Liquefaction, and type of pipe material. The program also calculates the repair rate for breaks and leaks and generates a Total Repair Rate per kilometre of pipeline.

Map 7H. Waste Water Pipelines, 1 in 2475 Year PSHA

- Pipeline Total Repair Rate**
- Very High: >1.5 repairs per km
 - High: 1 to 1.5 repairs per km
 - Moderate: 0.5 to 1 repairs per km
 - Low: 0.25 to 0.5 repairs per km
 - Very Low: <0.25 repairs per km

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Section 8: Resilience/Mitigation Maps, 1 in 2475 Year PSHA

Introduction

The results for the building damage for the 1 in 2475 year PSHA using the current design level were examined. As can be seen in Map 7A, most of the buildings with Extensive or Complete damage states are located in the southern part of the community in areas of high liquefaction susceptibility. The individual buildings found to experience an Extensive or Complete damage state using their current design level were re-assigned a High Code design level. The AEBM Hazus-MH earthquake analysis was rerun using these modified codes.



This hypothetical retrofit analysis was performed as a “what-if” situation and demonstrates the change in damage/injury results if retrofit measures were done on buildings in the community.

The results for the individual buildings have been grouped into polygons to illustrate regions of similar damage values.

Map 8A. Building Damage State, Retrofit Building Design Level, 1 in 2475 Year PSHA

Map 8A shows the damage states for a 1 in 2475 year PSHA after a hypothetical retrofit is applied to some buildings. The map is provided to show an overview of general regions of similar damage states. For information on results for individual buildings, analysis results for the individual buildings should be consulted.

Comparison of Map 71 and 8a shows a reduction in the number of buildings experiencing a Complete damage state. There are still areas showing Complete damage state even after the hypothetical retrofit codes are applied. These results indicate “hot spot” areas where further investigation could be performed.

Map 8B. Building Loss Ratio, Retrofit Building Design Level, 1 in 2475 Year PSHA

Map 8B shows the building loss ratio results for a 1 in 2475 year PSHA after a hypothetical retrofit is applied to some buildings. The loss ratio represents the relationship between the estimated loss value and the replacement value of the building and contents. For this map the estimated total loss for the building (structural, non-structural, and content) is divided by the total value of the building (replacement cost and content value).

The reduced values of building loss ratio reflect the reduced number of buildings experiencing Complete damage state.

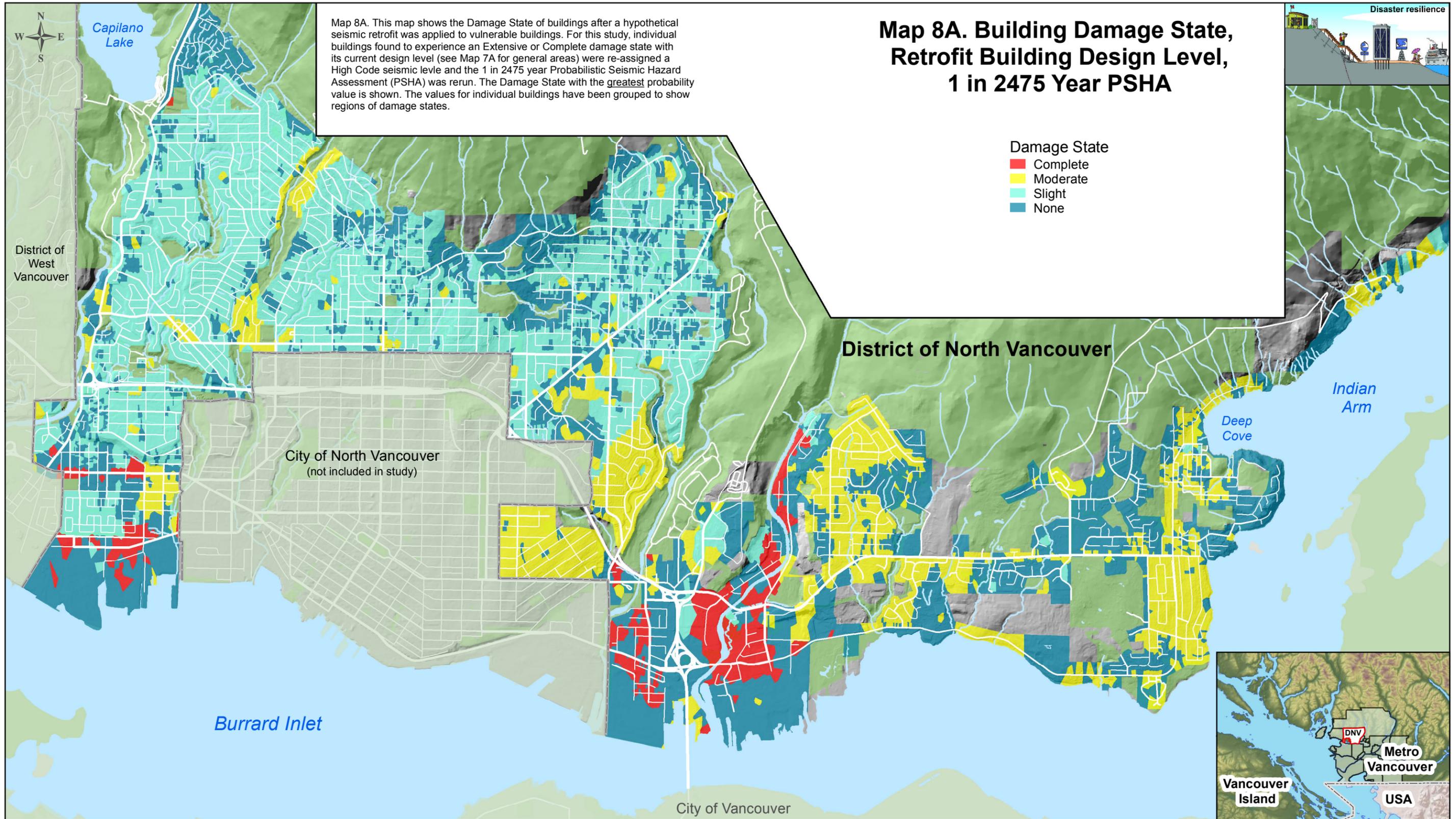
Map 8C. Daytime Casualty Rate, Retrofit Building Design Level, 1 in 2475 Year PSHA

Map 8C shows the estimated injury/casualty rate for a 1 in 2475 year PSHA daytime occurrence (at 2 pm) for buildings after a hypothetical retrofit is applied to some buildings. The rate is calculated as the proportion of people in a building who are expected to sustain injuries that would require medical attention or that might result in loss of life. The values for all four injury levels were totaled then divided by the population of the building.

Comparison of Map 7C and Map 8C shows that retrofit conditions could greatly reduce the casualty/injury rate.

Map 8D. Building Recovery Time, Retrofit Building Design Level, 1 in 2475 Year PSHA

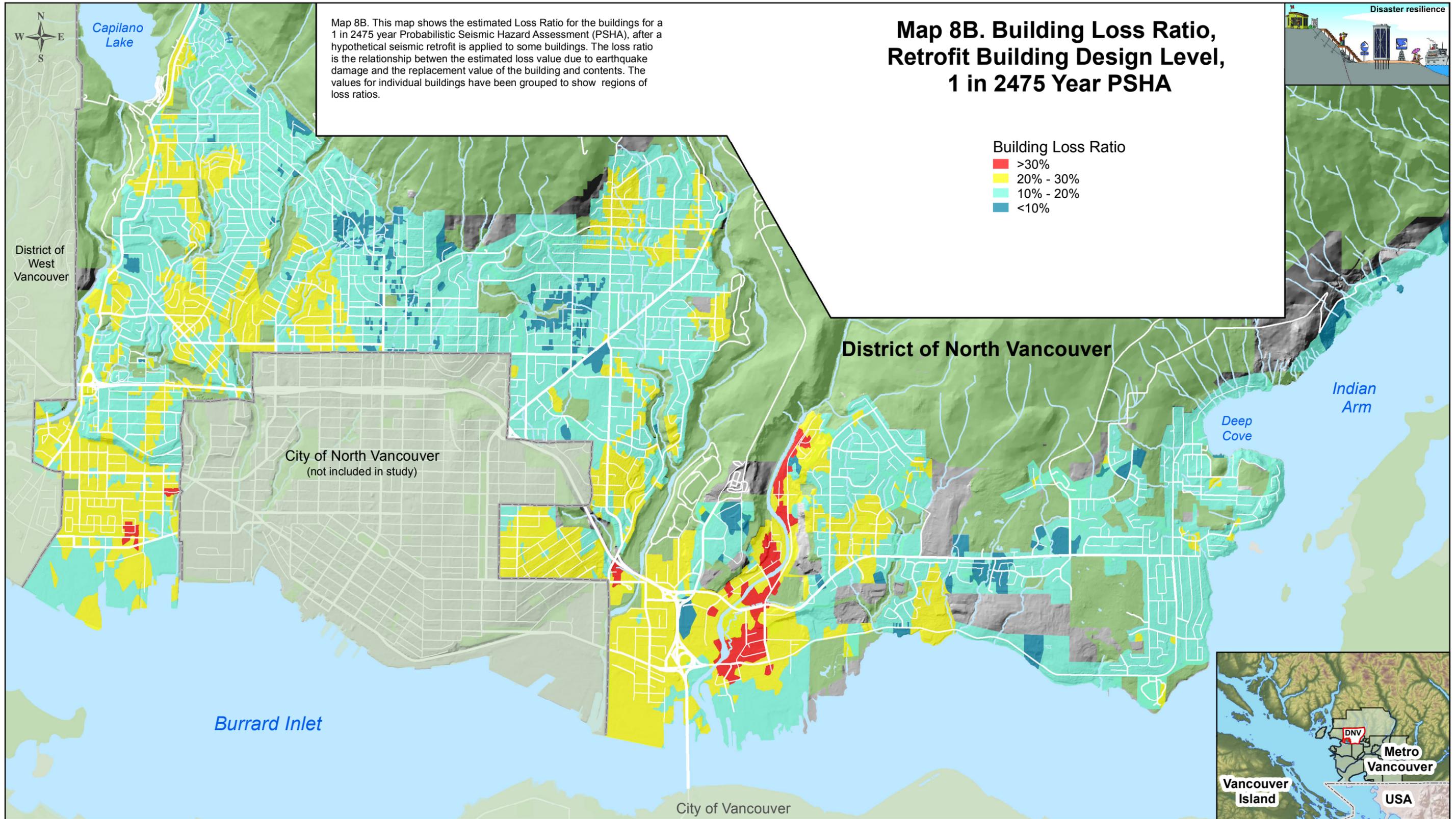
Map 8D shows the estimated recovery time for buildings for a 1 in 2475 year PSHA after a hypothetical retrofit is applied to some buildings. The reduction in recovery time values reflects the reduction in Damage State values.



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Map 8B. This map shows the estimated Loss Ratio for the buildings for a 1 in 2475 year Probabilistic Seismic Hazard Assessment (PSHA), after a hypothetical seismic retrofit is applied to some buildings. The loss ratio is the relationship between the estimated loss value due to earthquake damage and the replacement value of the building and contents. The values for individual buildings have been grouped to show regions of loss ratios.

Map 8B. Building Loss Ratio, Retrofit Building Design Level, 1 in 2475 Year PSHA

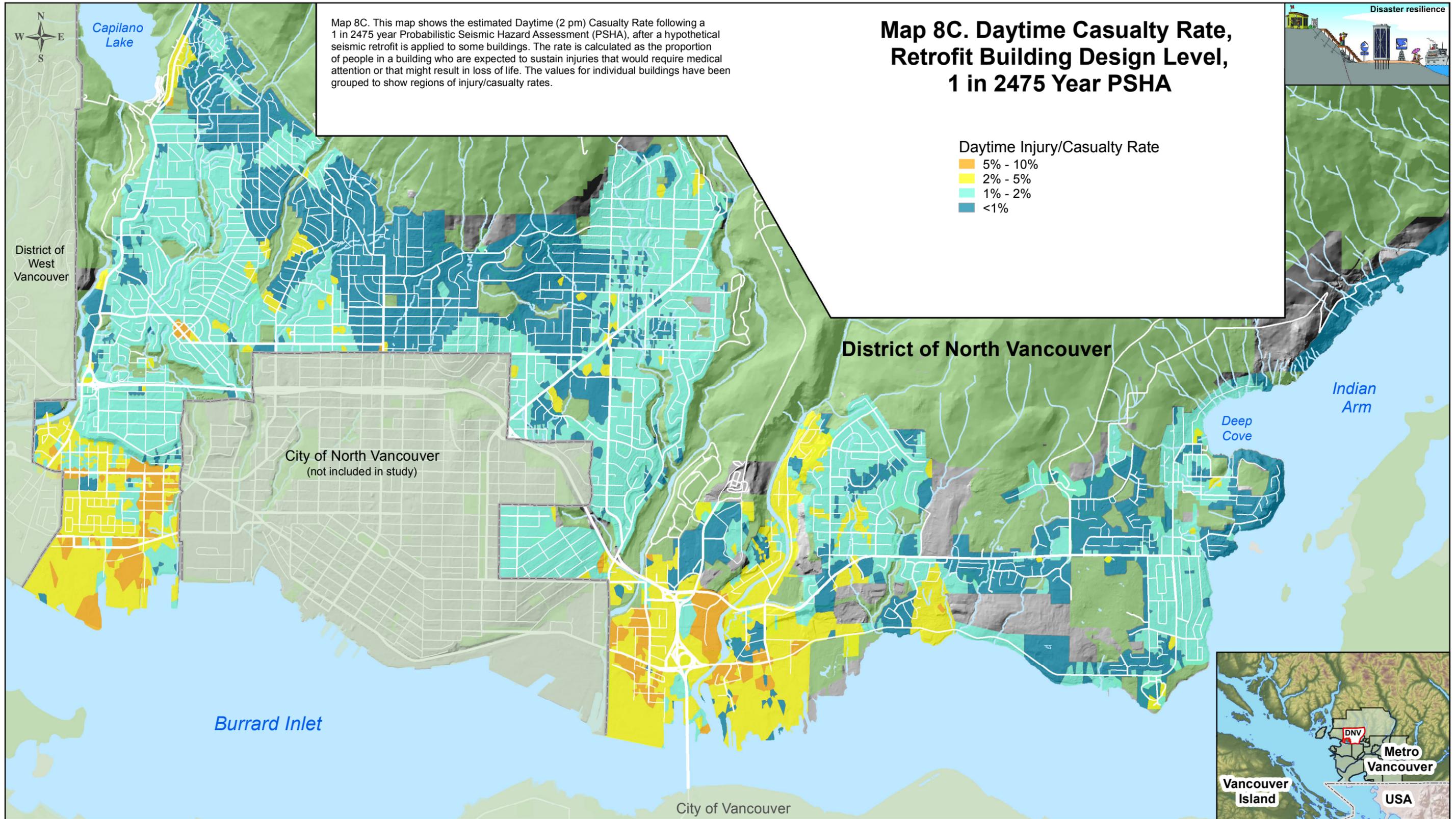
- Building Loss Ratio**
- >30%
 - 20% - 30%
 - 10% - 20%
 - <10%



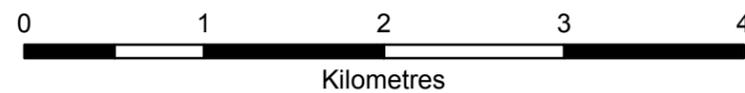
Disclaimer: Her Majesty the Queen in right of Canada, as represented by the Minister of Natural Resources ("Canada"), does not warrant or guarantee the accuracy or completeness of the information ("Data") on this map and does not assume any responsibility or liability with respect to any damage or loss arising from the use or interpretation of the Data. **The Data on this map are intended to convey regional trends and should be used as a guide only. Results do not replace the need for site specific geotechnical investigations for specific design, construction, and/or engineering purposes.**



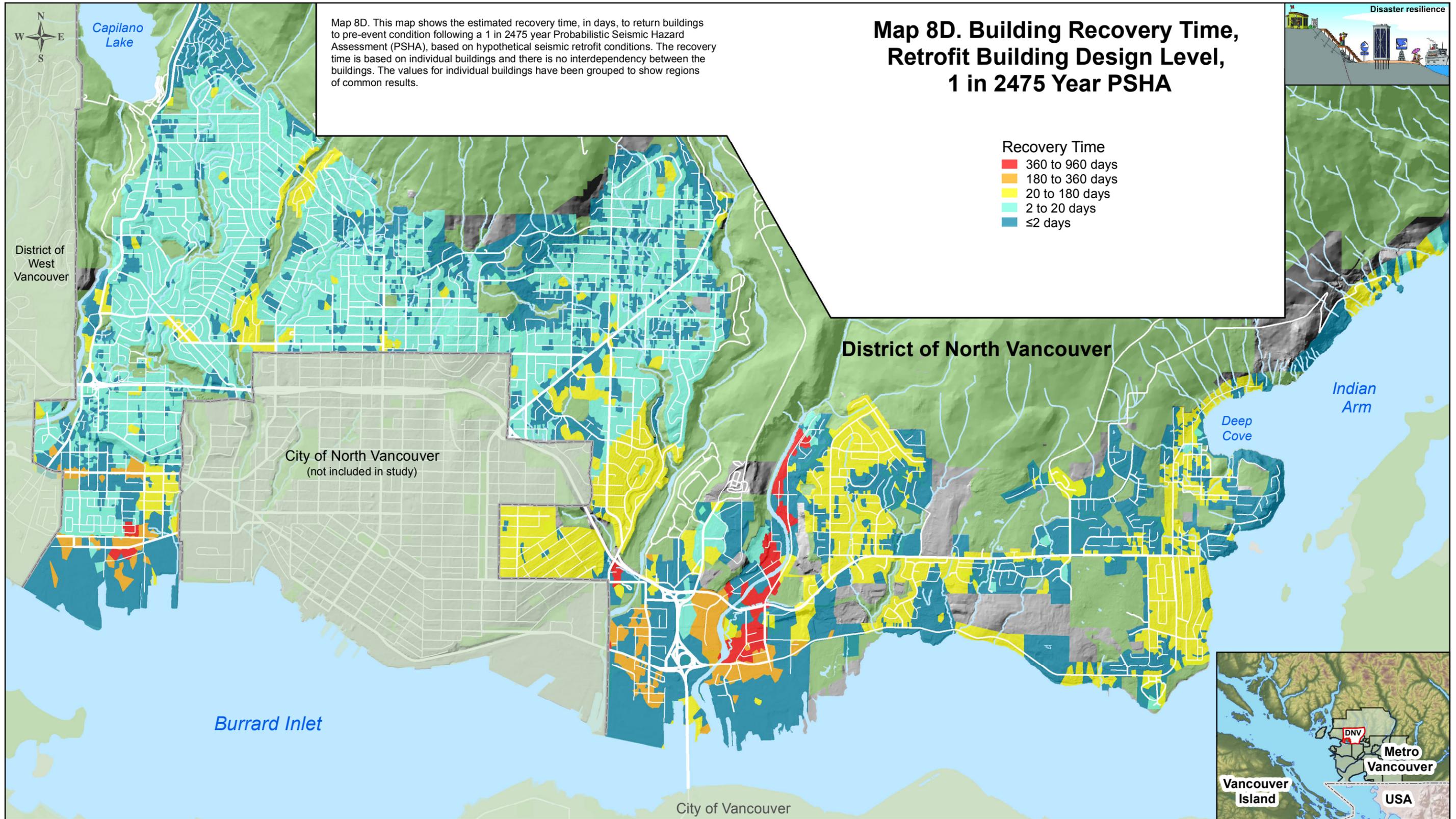
Credits: Building location, occupancy, and infrastructure provided by the District of North Vancouver. Building details provided by the Earthquake Engineering Research Facility, Department of Civil Engineering, University of British Columbia. All results were generated by Natural Resources Canada in consultation with other seismic risk assessment experts, using best available data, current scientific and engineering knowledge, and reasonable assumptions. Earthquake impacts were modelled with Hazus loss estimation software. Estimates were generated for a specific earthquake scenario using limited hazard information.



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Map 8D. This map shows the estimated recovery time, in days, to return buildings to pre-event condition following a 1 in 2475 year Probabilistic Seismic Hazard Assessment (PSHA), based on hypothetical seismic retrofit conditions. The recovery time is based on individual buildings and there is no interdependency between the buildings. The values for individual buildings have been grouped to show regions of common results.

Map 8D. Building Recovery Time, Retrofit Building Design Level, 1 in 2475 Year PSHA

- Recovery Time
- 360 to 960 days
 - 180 to 360 days
 - 20 to 180 days
 - 2 to 20 days
 - ≤2 days

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Conclusions

The Hazus-MH Canada model was used to analyze the risk to buildings, infrastructure, and people in the District of North Vancouver and estimate the damages and injuries resulting from earthquakes. The analysis indicates significant damage and loss would be experienced from both a Georgia Strait event and a 1 in 2475 year probabilistic seismic hazard assessment. The initial analysis was repeated to show possible changes in outcome if some buildings in the community were assumed to be retrofitted to modern building codes. The second analysis indicates that damage and costs could be reduced if mitigation efforts were applied to the buildings.

This study provides a credible, science-based analysis of the infrastructure and demographics that are most vulnerable to earthquakes. A modelling scenario such as the one demonstrated in this study enables a community to reduce risk by highlighting poorly built structures and focusing on risk reduction policies that can significantly strengthen a community's capability to be more disaster resilient.

Using preliminary results from this study, the District of North Vancouver has prepared an earthquake ready action plan which includes:

- mitigation of risks to municipal facilities and infrastructure
- seismic design guidelines for liquefaction hazard areas
- incorporation of disaster resilience measures into development plans
- seismic retrofits for high risk areas
- development of a culture of preparedness in the workplace and in the community
- business continuity plans
- coordinated response strategies for emergency responders and the transportation and engineering departments.

The experience gained will be shared with other Canadian communities in order to help them better assess, plan, and prioritize for an earthquake. Methods employed in the study will also help shape a national seismic risk assessment for Canada.

References

Adams, J. and Halchuk, S., 2003. Fourth generation seismic hazard maps of Canada: Values for over 650 Canadian localities intended for the 2005 National Building Code of Canada; Geological Survey of Canada, Open File 4459, 155 p.

Association of Bay Area Governments, Resilience Program, undated, Modified Mercalli Intensity Scale (MMI) <http://resilience.abag.ca.gov/shaking/mmi/> [accessed December 2, 2014].

APEGBC (2010). Guidelines for legislated landslide assessments for proposed residential developments in BC; Association of Professional Engineers and Geoscientists of British Columbia, May 2010.

Bednarski, J.M., 2014, Surficial geology, District of North Vancouver, British Columbia; Geological Survey of Canada, Canadian Geoscience Map 203, 1 sheet. doi:10.4095/295128

BC Ministry of Education, 2014a. Seismic Mitigation Program for Schools: a progress report; Web Resource: <http://www.bced.gov.bc.ca/capitalplanning/seismic/10>

BC Ministry of Education, 2014b. Award-winning seismic mitigation program keeps students safe in schools; Web Resource: <http://www.newsroom.gov.bc.ca/2014/10/award-winning-seismic-mitigation-program-keeps-students-safe-in-schools.html>

CSA, 2009. ISO 31000:2009 Risk Management – Principles and guidelines, Canadian Standards Association and International Standards Organization. 24 p.

Chow, W., Hastings, N.L., Journeay, J.M., Prieto, J., Halchuk, S., Arundel, R., Wagner, C.L., Ulmi, M., Wojtarowicz, M., Bancroft, J.L., Rivard, J.R., Struik, L.C., Nastev, M., 2014. Hazus-MH 2.1 Canada application, databases and manual: earthquake module; Geological Survey of Canada, Open File 7458; 248 p. doi:10.4095/293799

FEMA, Federal Emergency Management Agency, 2012a. Hazus MH-2.1 Earthquake Model Technical Manual: http://www.fema.gov/media-library-data/20130726-1820-25045-6286/hzmmh2_1_eq_tm.pdf [accessed November 2014].

FEMA, Federal Emergency Management Agency, 2012b. Hazus-MH 2.1 Advanced Engineering Building Module (AEBM) Technical and User's Manual http://www.fema.gov/media-library-data/20130726-1820-25045-1705/hzmmh2_1_aebm_um.pdf [accessed November 2014].

Halchuk, S. and Adams, J., 2008. Fourth generation seismic hazard maps of Canada: maps and grid values to be used with the 2005 National Building Code of Canada; Geological Survey of Canada; Open File Report 5813, 32 p.

Journeay, J.M., Dercole, F., Mason, D., Weston, M., Prieto, J.A., Wagner, C.L., Hastings, N.L., Chang, S.E., Lotze, A., and Ventura, C., 2015. A profile of earthquake risk for the District of North Vancouver, British Columbia; Geological Survey of Canada, Open File 7677, 223 p. doi:10.4095/296256

Molnar, S., 2012. Assessment of shear-wave velocity at three selected sites in North Vancouver; University of British Columbia Earthquake Engineering Research Facility, Internal Report 12.

National Research Council Canada (NRC), 2010. National Building Code of Canada 2010, Volume 2, Division B, Part 4.

Petersen, M.D., Frankel, A.D., Harmsen, S.C., Mueller, C.S., Haller, K.M., Wheeler, R.L., Wesson, R.L., Zeng, Y., Boyd, O.S., Perkins, D.M., Luco, N., Field, E.H., Wills, C.J. and Rukstales, K.S., 2008. Documentation for the 2008 update of the United States National Seismic Hazard Maps; U.S. Geological Survey Open-File Report 2008–1128, 61 p.

Prieto, J.A. and Ventura, C.E., 2013. A NEHRP Soils map for the District of North Vancouver; Geological Survey of Canada, Internal Report 6.

Prieto, J.A., Ventura, C.E., and Finn, W.D.L., 2013. District of North Vancouver, British Columbia, Earthquake hazard assessment, case study: Risk assessment project; Geological Survey of Canada, Open File 7314. doi:10.4095/292540

Struik, L.C., Pearce, L.D., Dercole, F., Shoubridge, J., van Zijll de Jong, S., Allan, J.D., Hastings, N.L., and Clague, J.J., 2015. Risk-based land-use guide: Safe use of land, based on hazard risk assessment, Geological Survey of Canada, Open File 7772, 76 p. doi:10.495/295981

Wilson, R. C., and Keefer D. K., 1985. Predicting Areal Limits of Earthquake Induced Landsliding, Evaluating Earthquake Hazards in the Los Angeles Region; U.S. Geological Survey Professional Paper, Ziony, J.I., Editor, p. 317-493.

Worden, C.B., Gerstenberger, M.C., Rhoades, D.A., and Wald, D.J., 2012. Probabilistic relations between ground-motion parameters and modified Mercalli intensity in California; Bulletin of the Seismological Society of America, v. 102, no 1, p. 204-221. doi:10.1785/0120110156

Youd, T.L. and Perkins, D.M., 1978. Mapping of liquefaction induced ground failure potential; Journal of Geotechnical Engineering Division, American Society of Civil Engineers, v. 104, no. 4, p. 433-446.