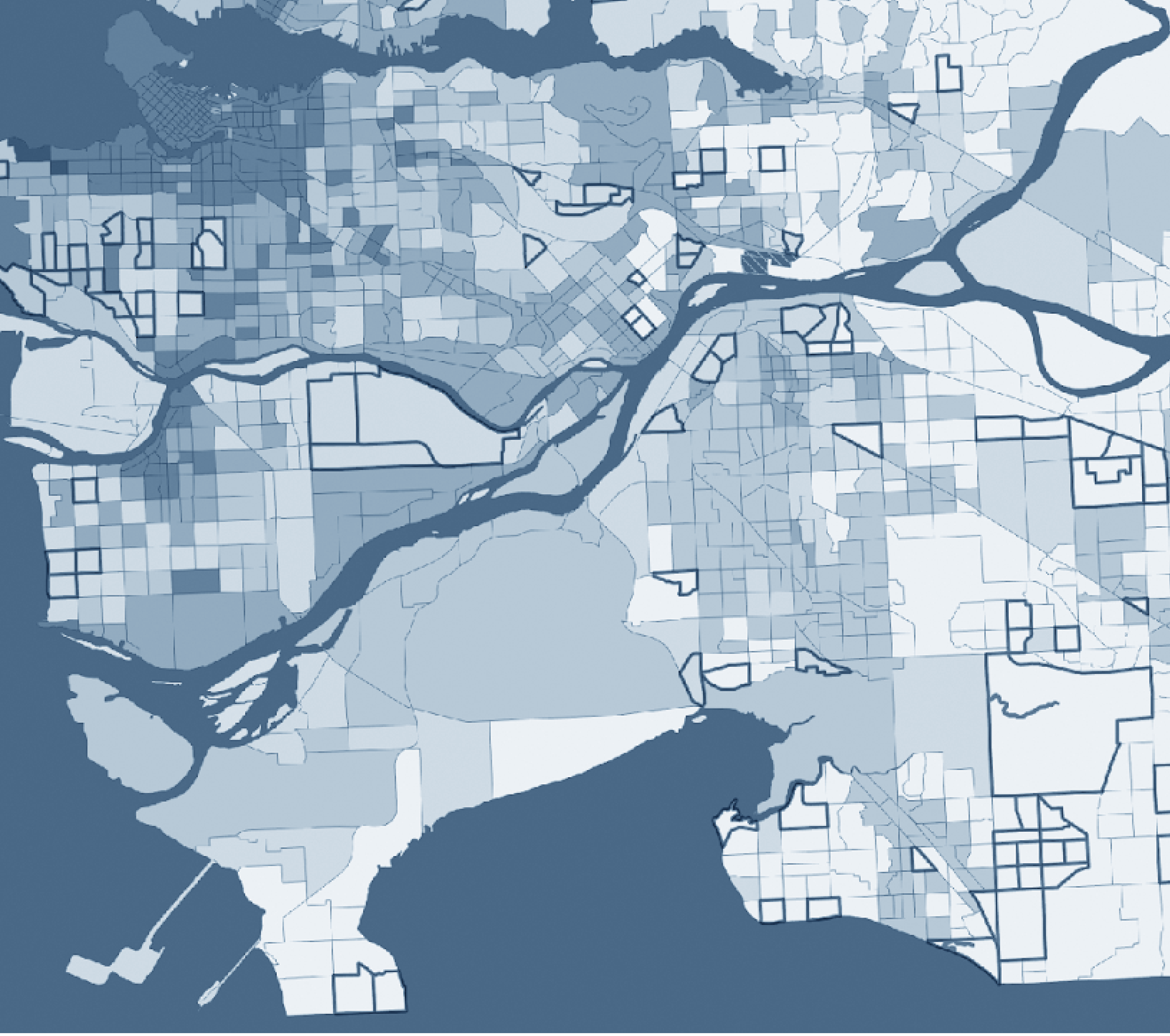

4.1 RISK DYNAMICS MODELLING IN METRO VANCOUVER

June 2022

DRRPathways.ca

RESILIENCE PATHWAYS

CO-CREATING NEW KNOWLEDGE FOR UNDERSTANDING RISK AND RESILIENCE IN BC

This article is part of the Resilience Pathways Report. The report has the following objectives: a) to share knowledge about existing practices and recent advances in understanding and managing disaster and climate risk in BC, including some information on relevant federal programs, and b) to provide insights on gaps and recommendations that will help build pathways to resilience in BC.

This article belongs to *Chapter 4 Climate and Disaster Risk Management: Research*. To read all articles in the report, see DRRPathways.ca.

The Resilience Pathways Report is a project of Natural Resources Canada.

4.1 RISK DYNAMICS MODELLING IN METRO VANCOUVER

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MODELLING NEIGHBOURHOOD EARTHQUAKE RISK DYNAMICS

Risk dynamics pertain to how the potential for disaster losses in urban areas may change over decadal timeframes. Disaster risk will transform over time in relation to factors such as population growth, land-use change, new construction, building code improvements, and changing social vulnerabilities. As time passes, the overall risk may increase or decrease, some types of losses may become more prominent, and the location of risk "hot spots" may shift. Efforts to anticipate future risk must consider not only shifts in numerous individual factors but also their layered interactions.

Similar natural hazard events can cause different degrees and patterns of loss depending on the moment they strike within a community's history.[1,2] Loss model results for today's conditions may present an inaccurate and even misleading portrayal of potential losses in future years. If disaster mitigation policies and plans are made without accounting for future risk increases, they may be unduly conservative and skewed in the direction of current-day conditions.

Understanding how neighbourhoods change over time, and the implications related to earthquake impacts, can help land use planners identify areas of high concentration of potential future risk that could be mitigated through planning and policy changes. As well, understanding the increased population displacement and the trends across the region in the event of a future earthquake can allow emergency preparedness planners at different levels of government to better plan for significant large-scale responses in different parts of the country.

ALIGNMENT WITH THE SENDAI FRAMEWORK

At the Third United Nations World Conference on Disaster Risk Reduction in 2015, delegates adopted the Sendai Framework for Disaster Risk Reduction 2015–2030. This framework identifies four priorities and seven key targets for policy actions to reduce disaster losses and the costs associated with disasters. Our project addresses two of the four action priorities identified under the framework: *understanding disaster risk* and *investing in disaster risk reduction for resilience*. This work also addresses several targets of the Sendai Framework, including *reducing the number of people potentially affected by hazard risk*, *reducing direct economic and service losses*, and *helping to create local risk reduction and recovery strategies*.

ESTIMATING FUTURE RISK IN METRO VANCOUVER

Our team partnered with colleagues from Metro Vancouver and the Geological Survey of Canada at Natural Resources Canada (NRCan) to better understand how seismic risk may change across the Metro Vancouver region over the coming decades, focusing on the effects of anticipated changes in population and the built environment. We drew on Metro Vancouver's long-range population and housing forecasts and NRCan's seismic hazard impact assessment results for different earthquake scenarios to develop a simplified Risk Dynamics Model for the region.

Metro Vancouver is a rapidly growing and changing region, encompassing 21 municipalities, one Electoral Area, and one Treaty First Nation. The region is active from a natural hazard perspective, vulnerable to a broad spectrum of seismic, flood, and weather events. The regional population of Metro Vancouver is expected to grow from 2.2 million in 2006 to 3.4 million by 2041, an increase of approximately 55%. *Metro Vancouver 2040*, the region's regional growth strategy adopted in 2011, identifies numerous priority issues, including responding to climate change impacts and natural hazard risks, especially earthquakes, floods, and slope instability.[3] Metro Vancouver's regional growth projections were updated in 2019, providing a better understanding of how and where growth is expected to occur in the coming decades.

Past studies[4,5,6,7] have explored how similar disaster events occurring within the region could have very different impacts on society depending on when the event occurs in the region's development as structures are replaced, building codes change, and the population continues to rise. It is further noted that the development strategies (e.g., compact, status quo, or sprawled development) employed to accommodate that growth can affect how hazard impacts manifest. Recently updated earthquake scenarios developed by Geological Survey of Canada[8] allow us new insights into how earthquake shaking and its associated impacts may be distributed across the Metro Vancouver region.

To determine how the built environment in Metro Vancouver has changed historically, and how it is likely to change in the future, we first needed to establish a baseline set of neighbourhood archetypes. With this, we could explore how neighbourhoods in the region have changed over the past decade and estimate how they are likely to change in the decades to come. Using regional growth projections, we were then able to explore how a specific earthquake scenario may affect the region today and in the future. This process is summarized in Figure 1 and described in more detail in the following sections.

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STEP 1: UNDERSTANDING HOW NEIGHBOURHOODS CHANGE OVER TIME

To understand how the Metro Vancouver region's seismic risk is likely to change, we must first understand how neighbourhoods in the region have changed historically. This required establishing neighbourhood archetypes and examining how these archetypes have changed in the region over time. Census dissemination areas (DAs)

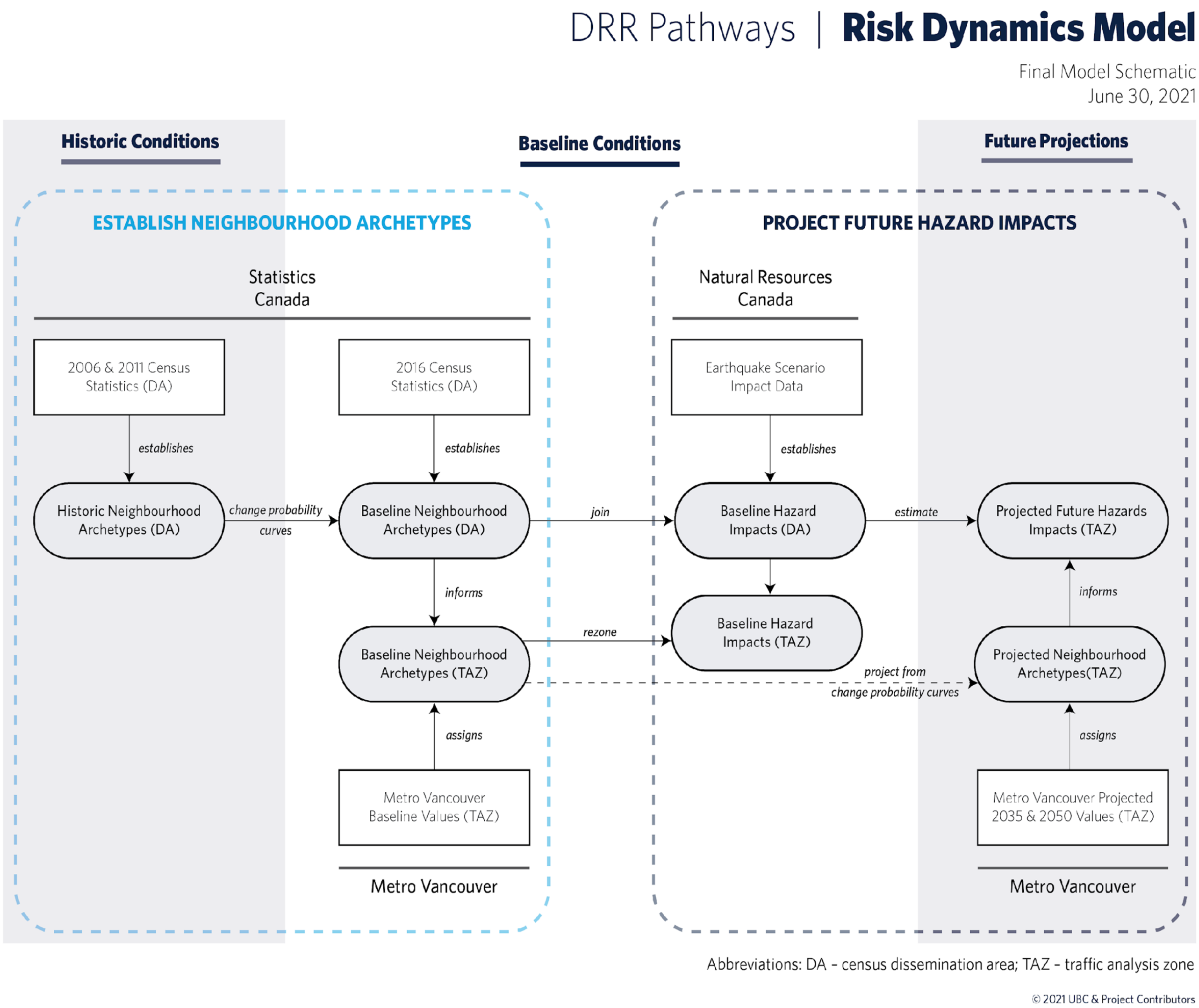

Figure 1: The Risk Dynamics Model for Metro Vancouver Future Hazards Impact Projections.

created by Statistics Canada were used as our unit of analysis and act as a proxy for neighbourhoods. DAs are small, relatively stable geographic units with an average population between 400 and 700 persons. In high-density urban areas, DAs tend to cover an area of a couple of city blocks, while in suburban and rural areas, DAs can cover much larger areas.[9] There are 1,562 dissemination areas in the Metro Vancouver region.

Neighbourhood archetypes were established using a series of cluster analyses to classify each DA by dwelling density, building type, and building age using data from Statistics Canada's *2016 Census of Population*. After careful review, we established a set of seven archetypes (Table 1) that we felt best matched with the types of neighbourhoods we see throughout Metro Vancouver, based on their most prominent characteristics. Figure 2 shows the distribution of these archetypes for the western portion of the Metro Vancouver region.

To determine how archetypes change over time in the region, we applied these same archetypes to the 2006 and 2011 censuses and established the probabilities that given archetypes would change over time and which archetypes they were most likely to become. With this understanding, it became possible to estimate how neighbourhoods are likely to change over the next few decades.

Table 1: The seven archetypes used to describe neighbourhoods in the Metro Vancouver region

Archetype	Description	Number of DAs
Older Single Detached	Neighbourhoods of predominantly single-detached dwellings, built largely prior to 1980.	732
Newer Single Detached	Neighbourhoods of predominantly single-detached dwellings, built largely after 1980.	528
Mixed Single and Multifamily	Neighbourhoods with a balanced mix of single-detached and multifamily dwellings.	691
Older Multifamily	Neighbourhoods of predominantly multifamily dwellings, built largely prior to 1980.	503
Newer Multifamily	Neighbourhoods of predominantly multifamily dwellings, built largely after 1980.	659
Medium Density Apartments	Neighbourhoods of predominantly medium-density apartments of at least five storeys.	232
High Density Apartments	Neighbourhoods of predominantly high-density apartments of at least five storeys.	101

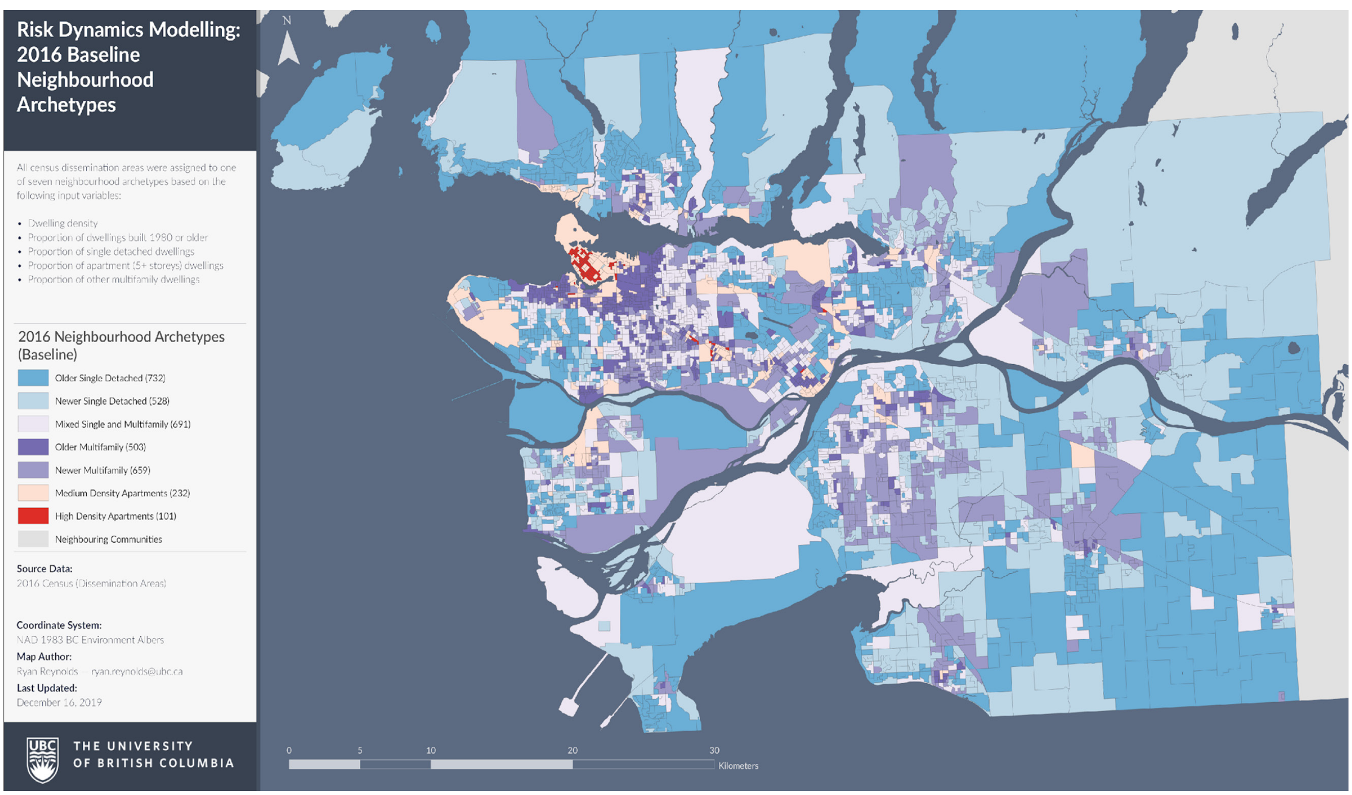

Figure 2: Map showing the distribution of the seven neighbourhood archetypes across Metro Vancouver[i].

[i] *Full-sized project maps are available for this project, Risk Dynamics Modelling, at DRRPathways.ca.*

STEP 2: ESTIMATING FUTURE NEIGHBOURHOOD CHANGES

Metro Vancouver has been working to understand how growth and development are likely to occur in the region over the next several decades. They have developed growth projections for 2035 and 2050 as part of their Metro 2050 strategy.[10] Baseline data for 2016 was also available as part of this work to allow for comparison with recent values. The projections provide information on future estimated population sizes, dwelling counts, and employment counts at the scale of traffic analysis zones (TAZs). As TAZ and DA boundaries do not align, we classified the TAZ data from 2016 using areal weighted interpolation from the neighbourhood archetypes for 2016 created earlier. This resulted in baseline archetypes for each of the 1,561 TAZs in the Metro Vancouver region.

Using the change probability curves established previously and our new baseline neighbourhood archetypes, we were able to estimate the most likely neighbourhood changes across the region for 2035. Figure 3 shows the baseline archetypes (2016) and projected future archetypes (2035) for side-by-side comparison. In total, 106 of the 1,561 TAZ units were estimated to change type between 2016 and 2035 (changing neighbourhood archetypes shown with black outlines).

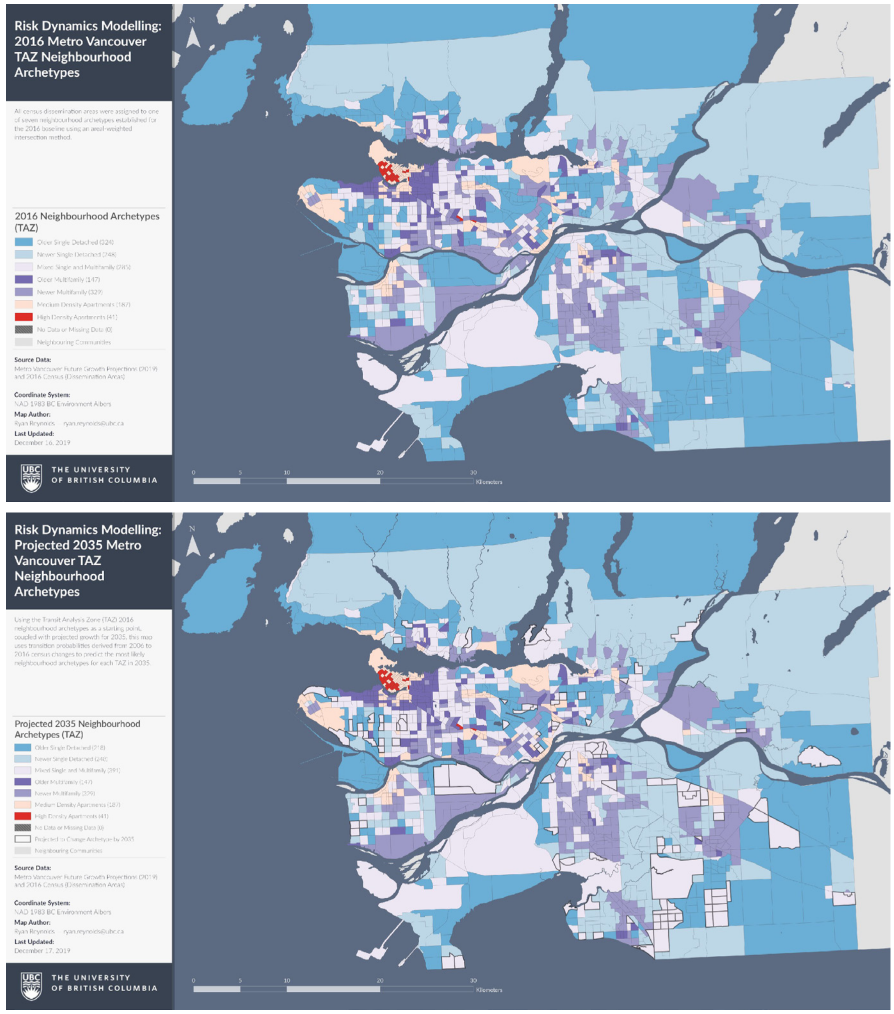

Figure 3: 2016 baseline neighbourhood archetypes and 2035 projected neighbourhood archetypes at the scale of traffic analysis zones.

STEP 3: ESTIMATING SEISMIC RISK

Our colleagues at NRCan have recently developed several updated earthquake scenarios with associated risk assessments for the Metro Vancouver region. For this study, we opted to use a simulated magnitude 7.3 event centred on the Georgia Strait between Vancouver Island and the BC Lower Mainland. The highest peak ground acceleration (PGA) for this scenario is concentrated along the northwest corner of the region and decreases south and east (Figure 4).

Baseline hazard impacts were provided by NRCan for this scenario at the level of settlement areas (SAs), which are the occupied built-up areas located within DAs. NRCan's assessments include several physical and social impact metrics for each SA unit. For the purposes of this study, we opted to use the percentage of the population displaced for three or more days as our impact metric. Nighttime

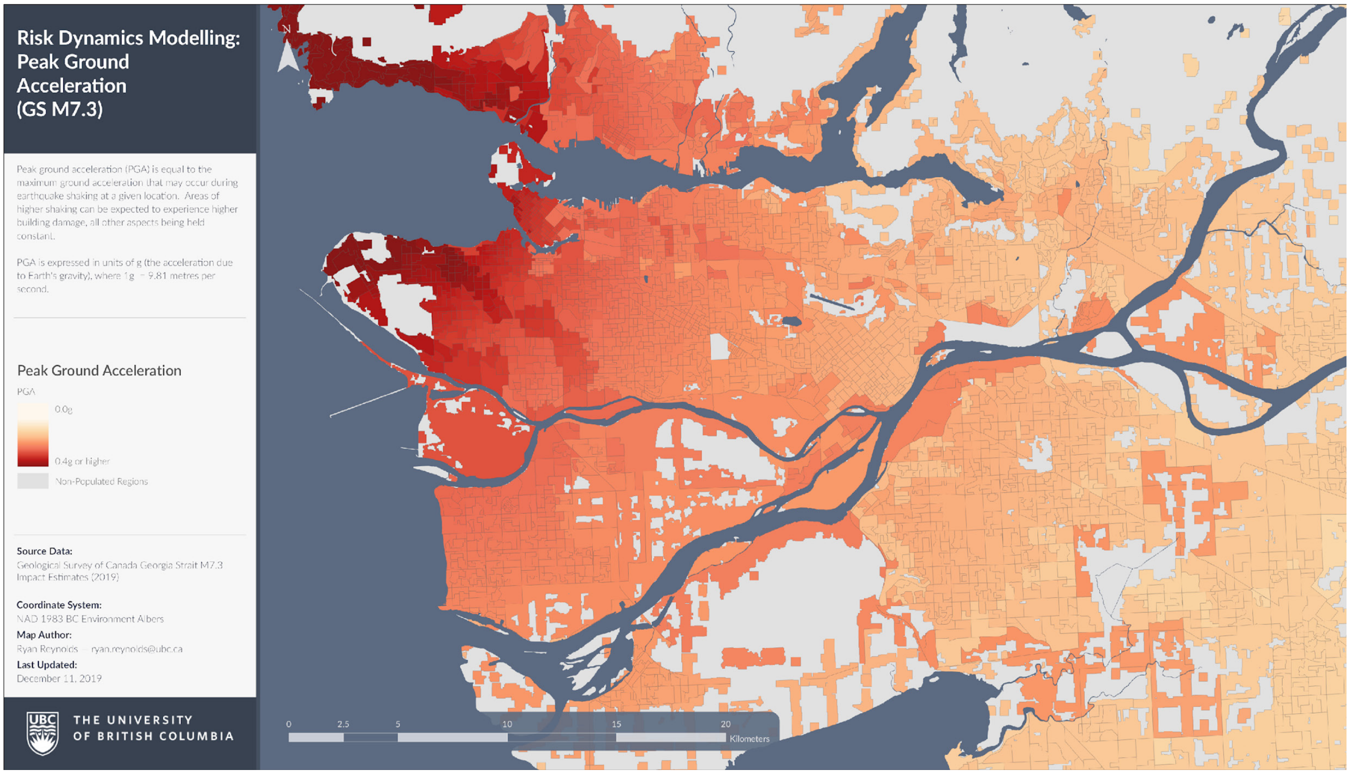

Figure 4: Map of peak ground acceleration in Metro Vancouver region for Georgia Strait M7.3 Scenario (Source Data: Geological Survey of Canada).

population estimates were used when calculating displaced populations.

At this point we needed to convert hazard impact values from the original SA level to the final TAZ level of our neighbourhoods. This was accomplished by establishing a set of neighbourhood fragility curves to establish a probabilistic relationship between PGA and population displacement. Fragility curves were developed empirically for each of the seven neighbourhood archetypes using NRCan's original source data. Examples for the "older multifamily" and "newer multifamily" neighbourhood archetypes are compared in Figure 5.

STEP 4: ESTIMATING FUTURE RISK FOR TRAFFIC ANALYSIS ZONES

Finally, we estimated the risk for a hypothetical M7.3 earthquake occurring in 2035 using NRCan's Georgia Strait scenario. Displaced population results were obtained by applying the neighbourhood fragility curves to the urban development projections for 2035 from Metro Vancouver's growth projection data. Table 2 compares the estimated displaced populations for the 2016 baseline and 2035 projected populations for the same scenario. Displaced population is expected to grow by 43,000 people to 176,000. Figure 6 shows the expected distribution of displaced populations throughout the western portion of the Metro Vancouver region.

ADAPTING THIS APPROACH BEYOND METRO VANCOUVER

The approach developed as part of this project should be transferable to locations outside of the Metro Vancouver region; it should be possible for researchers and practitioners exploring risk dynamics elsewhere in Canada to undertake such a project where appropriate data is available. However, there are several issues that may make this process difficult, discussed in the Challenges section, below.

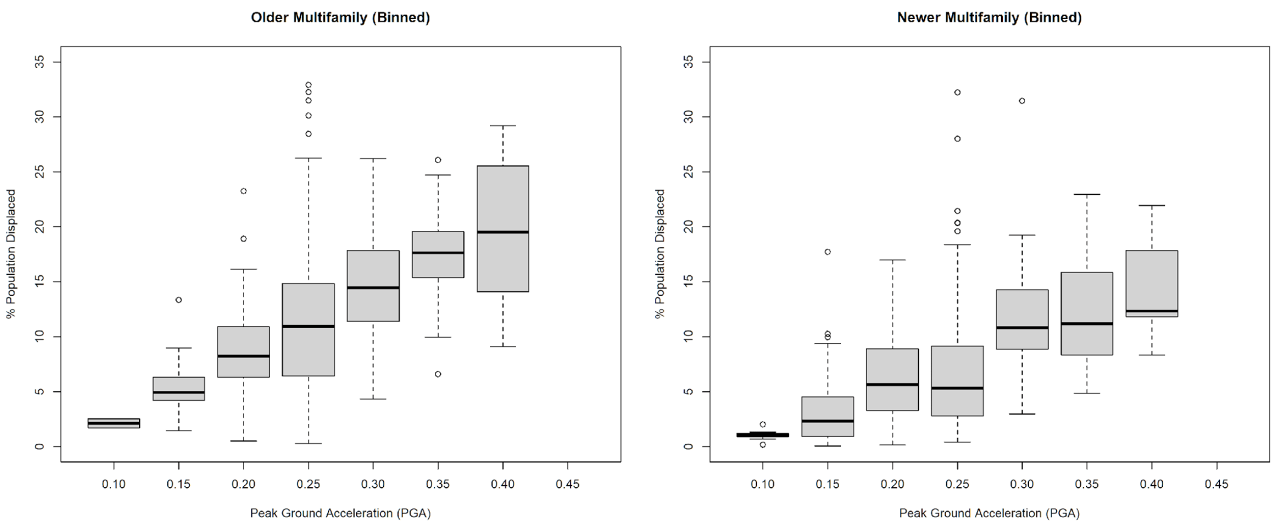

Figure 5: Peak ground acceleration (PGA) and population displacement percentage for "older multifamily" and "newer multifamily" neighbourhood archetypes.

Table 2: Projected population displacements for M7.3 Georgia Strait earthquake scenario

	2016	2035	Change
Population[ii]	2,580,000	3,370,000	787,000
Displaced Population	133,000	176,000	43,000
	5.15%	5.22%	

OPPORTUNITY

RECOMMENDATIONS

Cities are continually changing. Similar natural hazard events can cause different degrees and patterns of loss if they strike at different moments in a community's history. A community's hazard risk landscape—whether from earthquakes, floods, wildfires, or any other natural hazard—changes over time as the community changes and grows.

Building this understanding into community development planning can help identify and better characterize the effectiveness of different risk reduction strategies and help select development strategies that take changing risk into account. The approach we have described is just one of many and we have identified several areas for improvement to our approach, which can be found in our technical report on the DRR Pathways website.[11]

[ii] *Population values represent 25 of 35 Metro Vancouver municipalities.*

CHALLENGES

There are three main challenges facing anyone developing a risk dynamics model:

1. **Data Availability:** This project was only possible because the underlying seismic risk, hazard impact assessment, and growth projection data were recently updated by our project partners. Similar hazard and growth data would be required for any other location seeking to develop a local risk dynamics model.

2. **Expertise:** Our approach requires an understanding of several statistical and geospatial analysis processes, including cluster analysis, probability curves, and areal weighted interpolation. While this skill set should be available within most medium and large municipalities, smaller municipalities and Indigenous communities may need to use consultants.

3. **Geographical Scale:** We opted to use census dissemination area (DA) and traffic analysis zone (TAZ) units to act as our proxy for neighbourhoods. These units were most appropriate to the questions we were seeking to answer; however, dissemination areas can vary significantly in size, from a few blocks to entire communities. In communities made up by a single DA, it would be necessary to find alternate data.

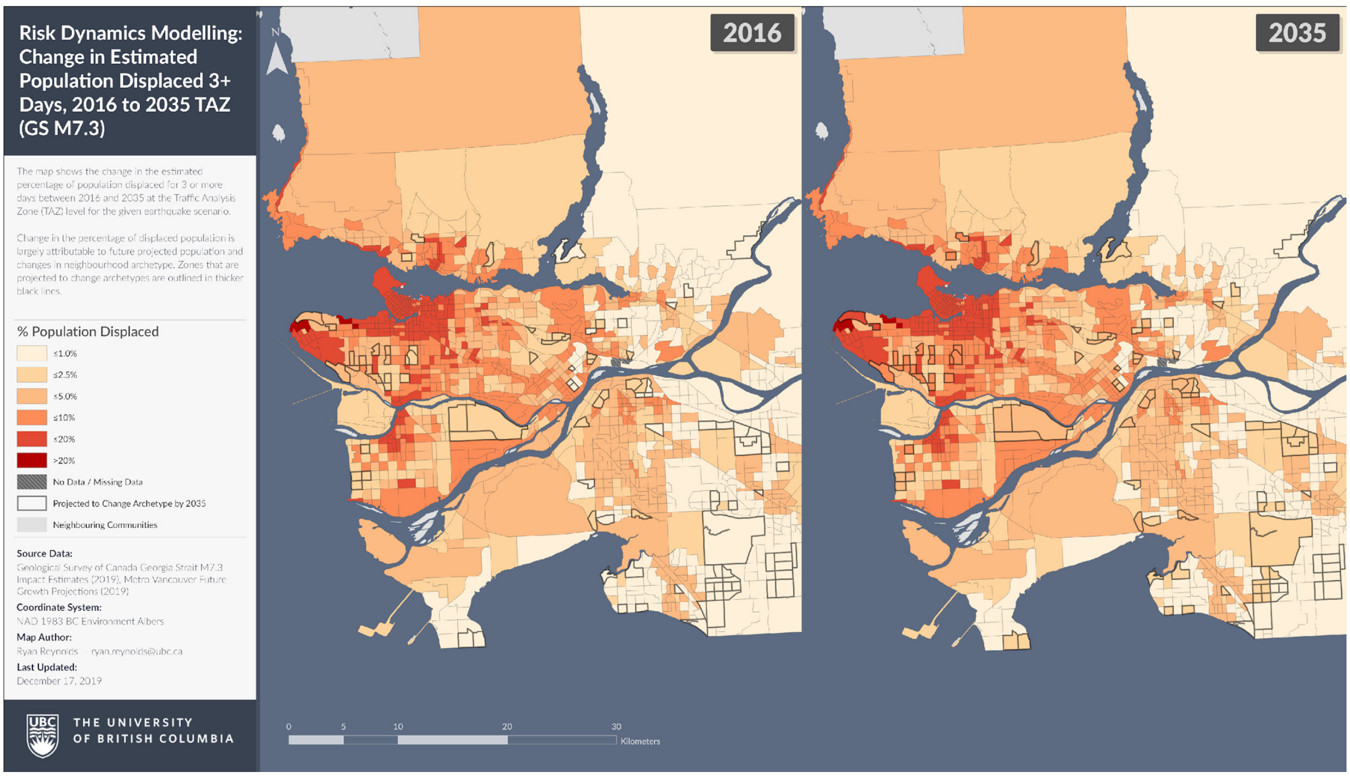

Figure 6: Map comparing estimated population displacements for M7.3 Georgia Strait scenario for 2016 and 2035 at the scale of traffic analysis zones.

RESOURCES

BC AND CANADA

1. Study exploring whether natural hazard risks for urban areas are growing over time, comparing 1971 to 2006.

Chang, S. E., M. Gregorian, K. Pathman, L. Yumagulova, and W. Tse. "Urban growth and long-term change in natural hazard risk." *Environment and Planning A* 44, no. 4 (2012): 989–1008.

2. Study exploring the effects of three different urban development patterns on future earthquake and coastal flooding risk in the City of Vancouver in 2041:

Chang, S. E., J. Z. K. Yip, and W. Tse. "Effects of urban development on future multi-hazards risk: The case of Vancouver, Canada." *Natural Resources* 98, no. 1 (2019): 251–265. https://doi.org/0.1177/0309132519895305

INTERNATIONAL

3. Report exploring the drivers of disaster risk, vulnerability, and how effective policy decisions can lead to a more resilient future:

Global Facility for Disaster Reduction and Recovery (CFDRR). "The making of a riskier future: How our decisions are shaping future disaster risk." Global Facility for Disaster Reduction and Recovery, (2016). Accessed December 10, 2021. https://www.gfdrr.org/sites/default/files/publication/Riskier%20Future.pdf

4. Study exploring ways to identify and project the risk dynamics of built-up areas in three Asian megacities:

Sarica, G. M., Zhu, T., and Pan, T. C. "Spatio-temporal dynamics in seismic exposure of Asian megacities: past, present and future." *Environmental Research Letters* 15, no. 9 (2020): 094092. https://iopscience.iop.org/article/10.1088/1748-9326/ababc7/meta

5. Study from North Carolina exploring how hurricane risk changes with time due to changes in the types and conditions of buildings:

Jain, V. K., and Davidson, R. A. "Forecasting changes in the hurricane wind vulnerability of a regional inventory of wood-frame houses." *Journal of Infrastructure Systems* 13, no. 1 (2007): 31-42. https://www.cs.rice.edu/~devika/evac/papers/Regional%20risk%20forecasting.pdf

ENDNOTES

[1] Stephanie E. Chang, Martin Gregorian, Karthick Pathman, Lilia Yumagulova, and Wendy Tse, "Urban growth and long-term change in natural hazard risk," *Environment and Planning A* 44, no. 4 (2012): 989–1008.

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[3] Metro Vancouver, "Metro Vancouver 2040: Shaping our future," *Regional growth strategy adopted by the Greater Vancouver Regional District Board on July 29, 2011; updated to February 28, 2020* (2020), pp. 80.

[4] Chang, Gregorian, Pathman, Yumaulova, and Tse, "Urban Growth."

[5] Stephanie E. Chang, Jackie Z. K. Yip, and Wendy Tse, "Effects of urban development on future multi-hazards risk: The case of Vancouver, Canada," *Natural Resources* 98, no. 1 (2019): 251–265, https://doi.org/0.1177/0309132519895305

[6] Gizem M. Sarica, Tinger Zhu, and Tso-Chien Pan, "Spatio-temporal dynamics in seismic exposure of Asian megacities: Past, present, and future," *Environmental Research Letters* 15, no. 9 (2020): 094092, https://doi.org/10.1088/1748-9326/ababc7

[7] Vineet K. Jain and Rachel A. Davidson, "Forecasting changes in the hurricane wind vulnerability of a regional inventory of wood-frame houses," *Journal of Infrastructure Systems* 13, no. 1 (2007): 3–24.

[8] Geological Survey of Canada, "Earthquake Scenarios," *Government of Canada OpenDRR portal on GitHub* (October 21, 2021), accessed April 14, 2022, https://opendrr.github.io/earthquake-scenarios/en/

[9] Statistics Canada, "Dissemination Block," *Illustrated Glossary (of the Census)* (November 15, 2017), https://www150.statcan.gc.ca/n1/pub/92-195-x/2016001/geo/db-id/db-id-eng.htm

[10] Metro Vancouver, "Drafting Metro 2050," *Metro Vancouver* (n.d.), accessed November 30, 2021, http://www.metrovancouver.org/metro2050

[11] Stephanie E. Chang, Ryan P. Reynolds, and Juri Kim, "Risk dynamics modelling: Exploring how seismic risk may change over time due to urban growth and development," *Disaster Risk Reduction Pathways* (June 30, 2021), https://www.drrpathways.ca/_files/ugd/c54559_7ae1a81222004ba1ab1dd127edf1cbb8.pdf

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