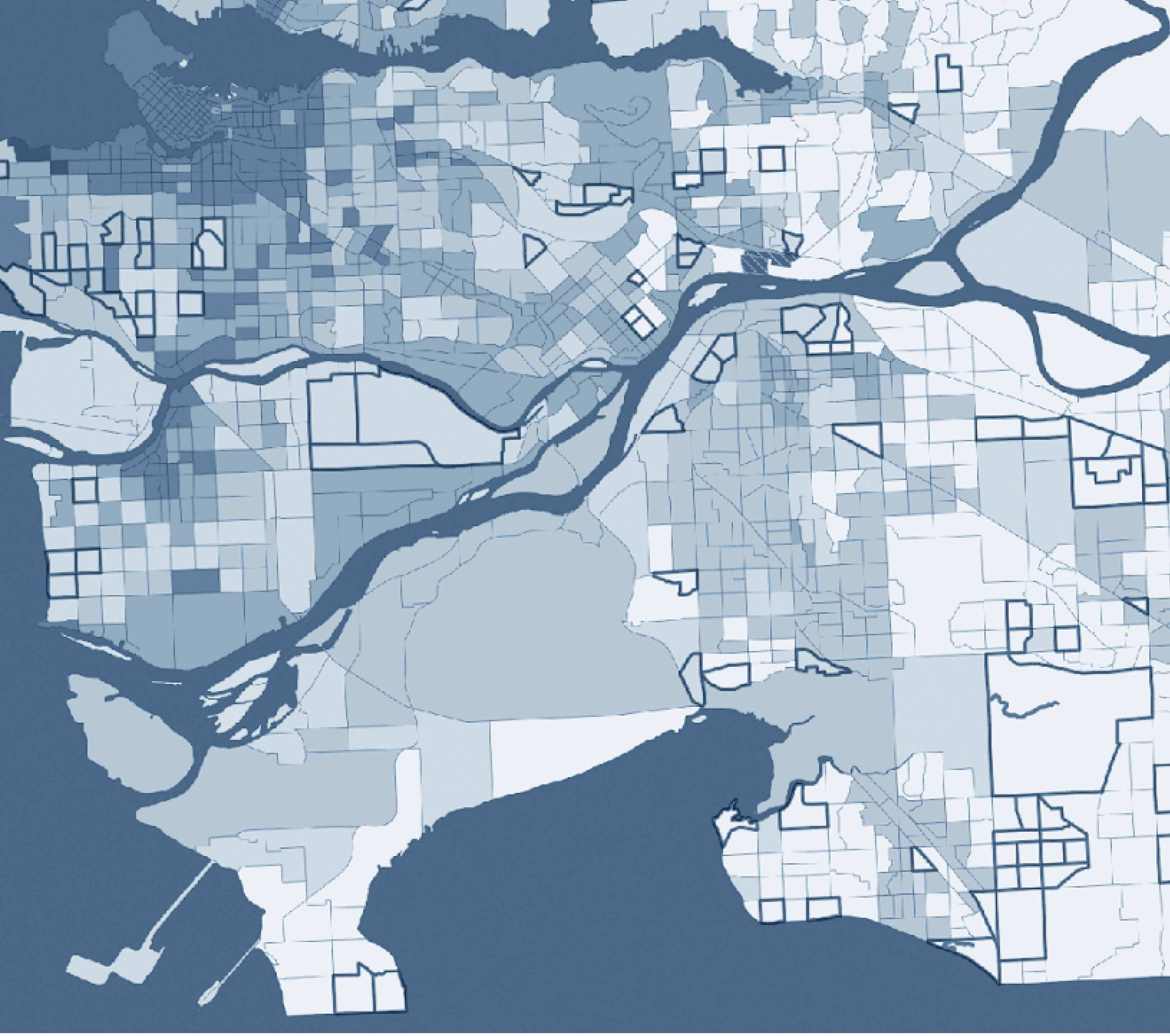

4.1 RISK DYNAMICS MODELLING IN METRO VANCOUVER

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.

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.

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)

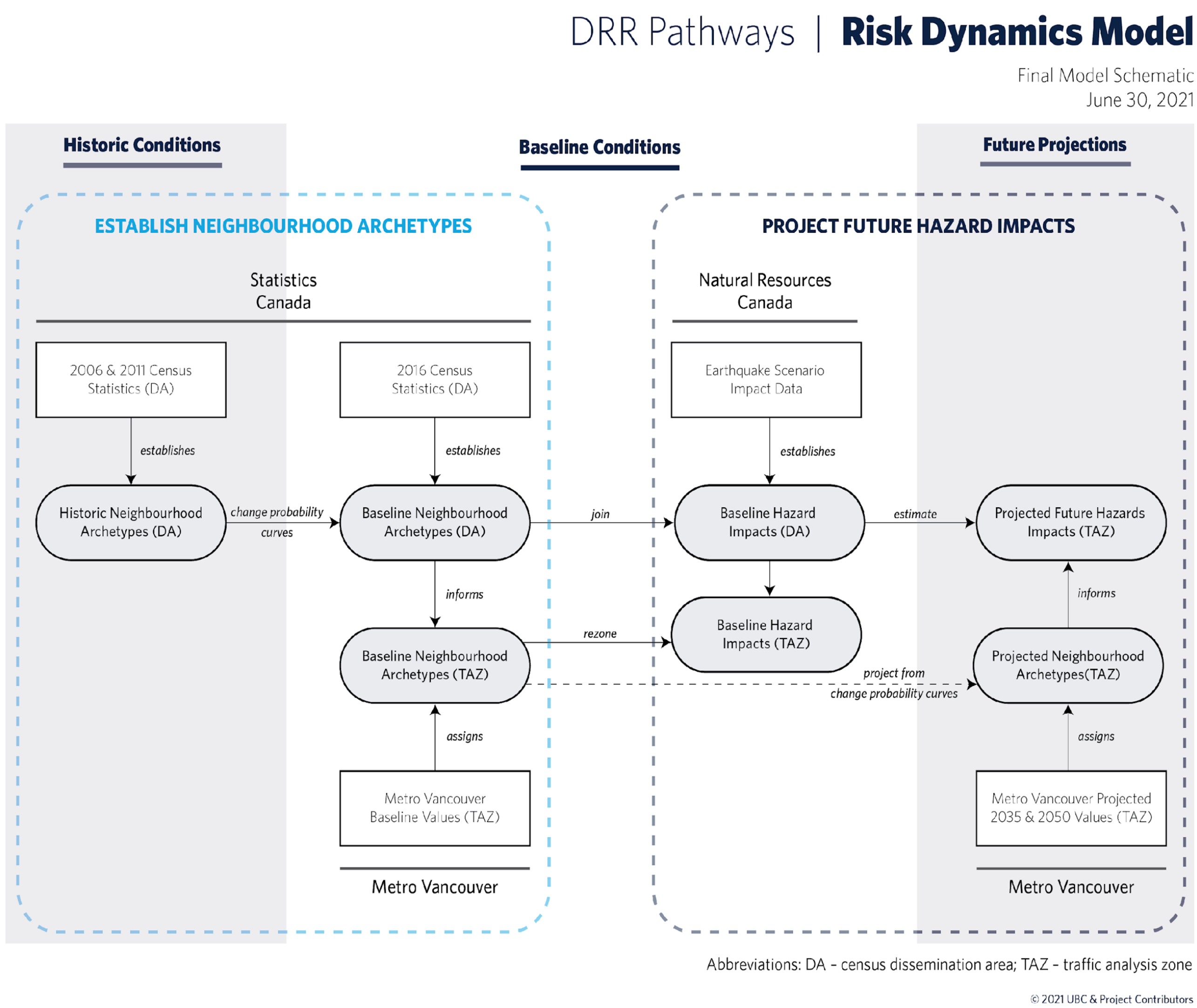

Figure 1: The Risk Dynamics Model for Metro Vancouver Future Hazards Impact Projections.

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

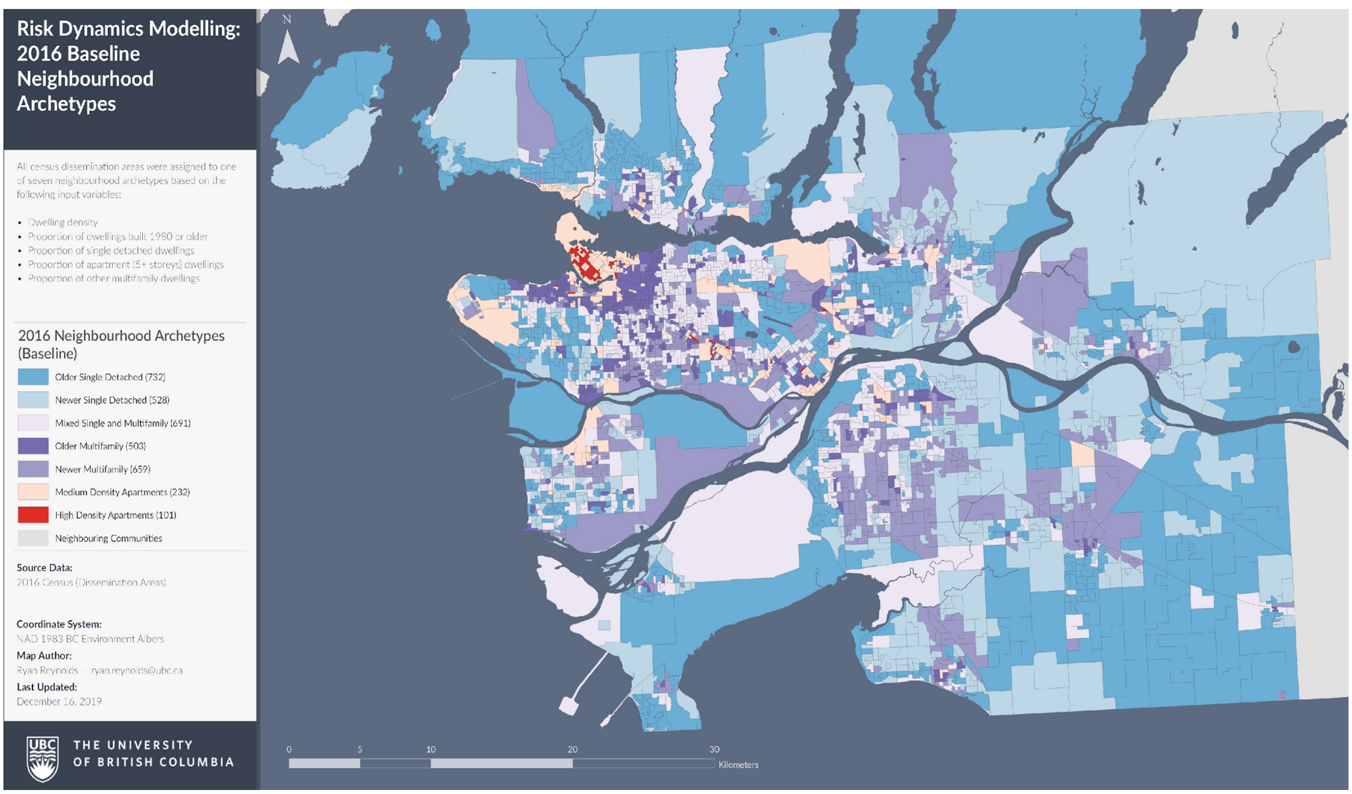

Figure 2: Map showing the distribution of the seven neighbourhood archetypes across Metro Vancouver[i].

[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).

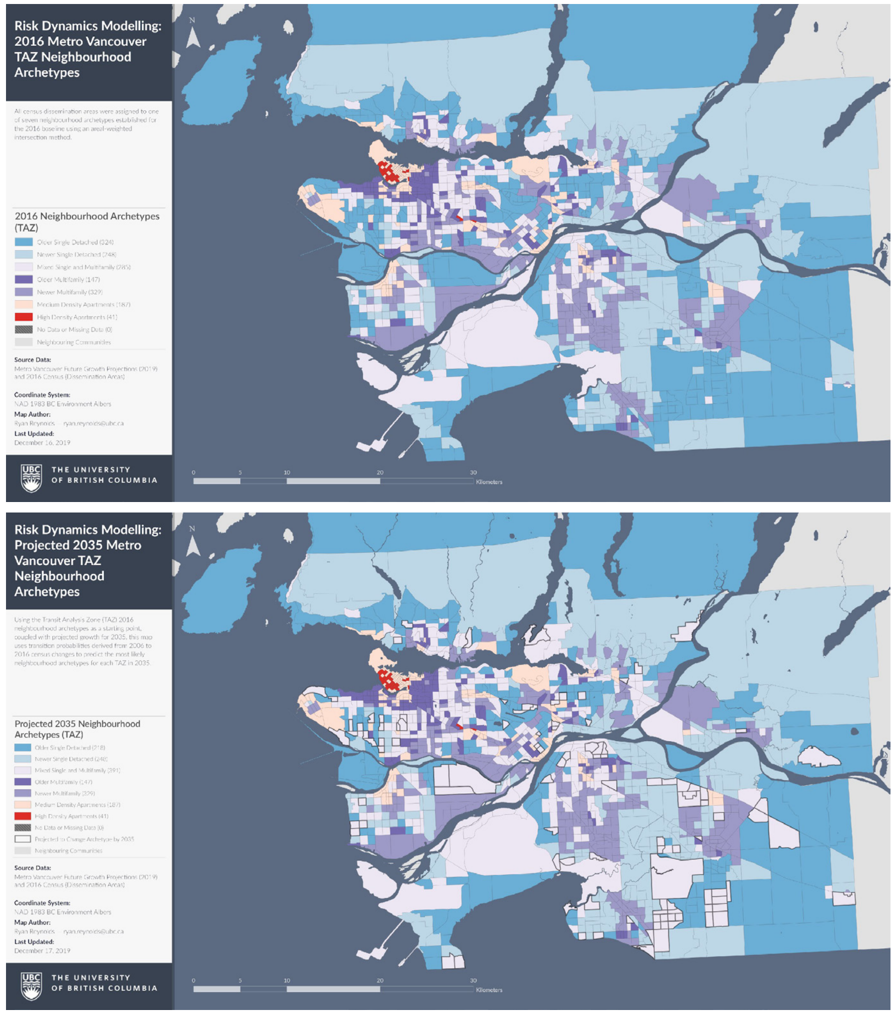

Figure 3: 2016 baseline neighbourhood archetypes and 2035 projected neighbourhood archetypes at the scale of traffic analysis zones.

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

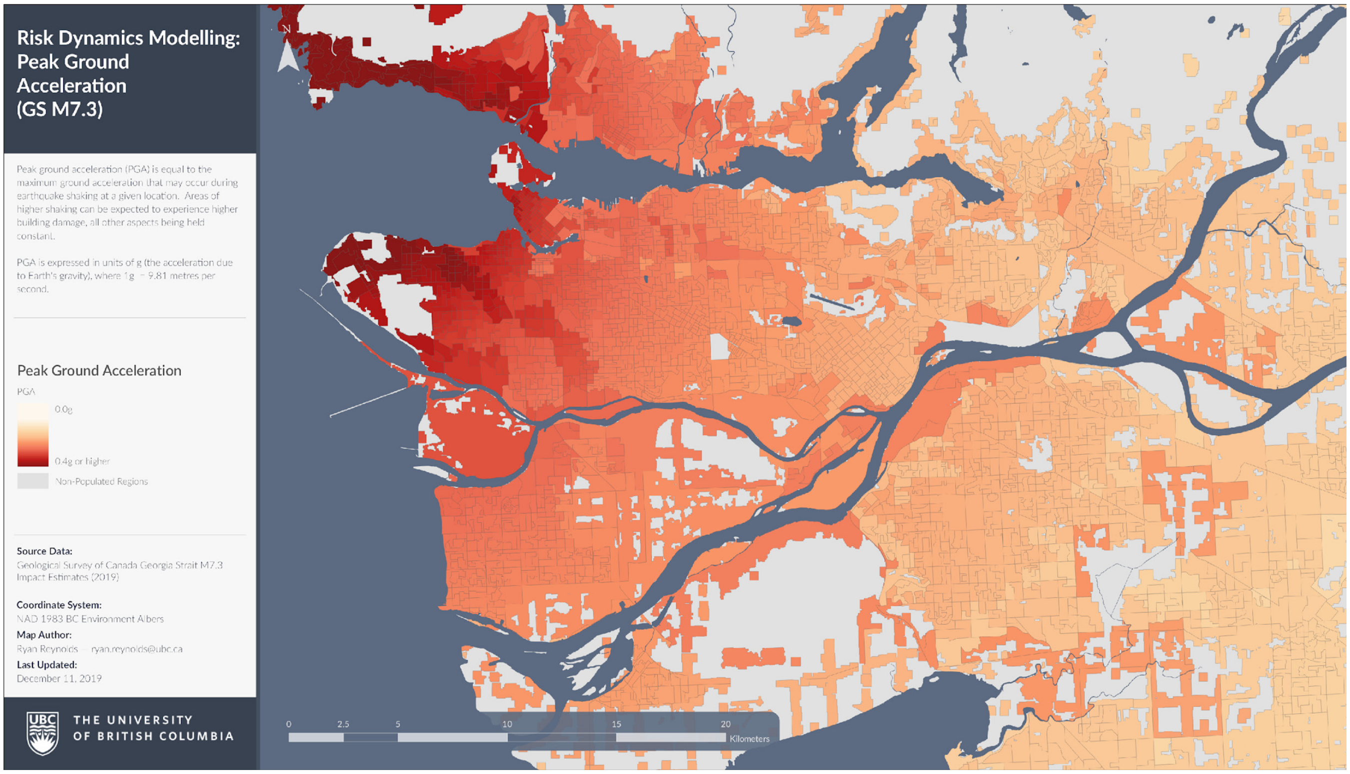

Figure 4: Map of peak ground acceleration in Metro Vancouver region for Georgia Strait M7.3 Scenario (Source Data: Geological Survey of Canada).

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.

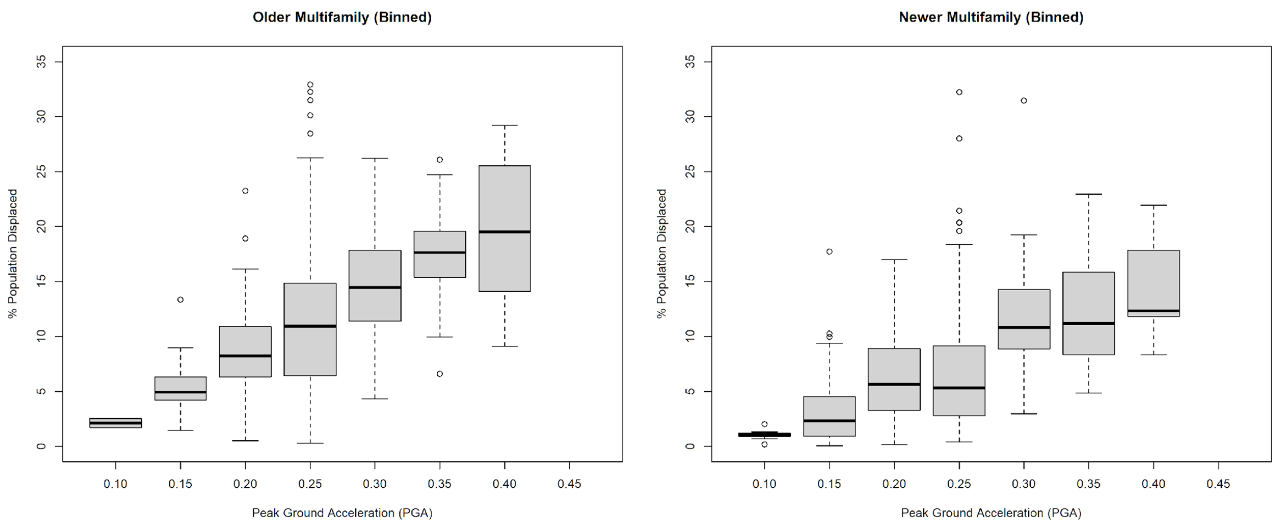

Figure 5: Peak ground acceleration (PGA) and population displacement percentage for "older multifamily" and "newer multifamily" neighbourhood archetypes.

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]

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.

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

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.

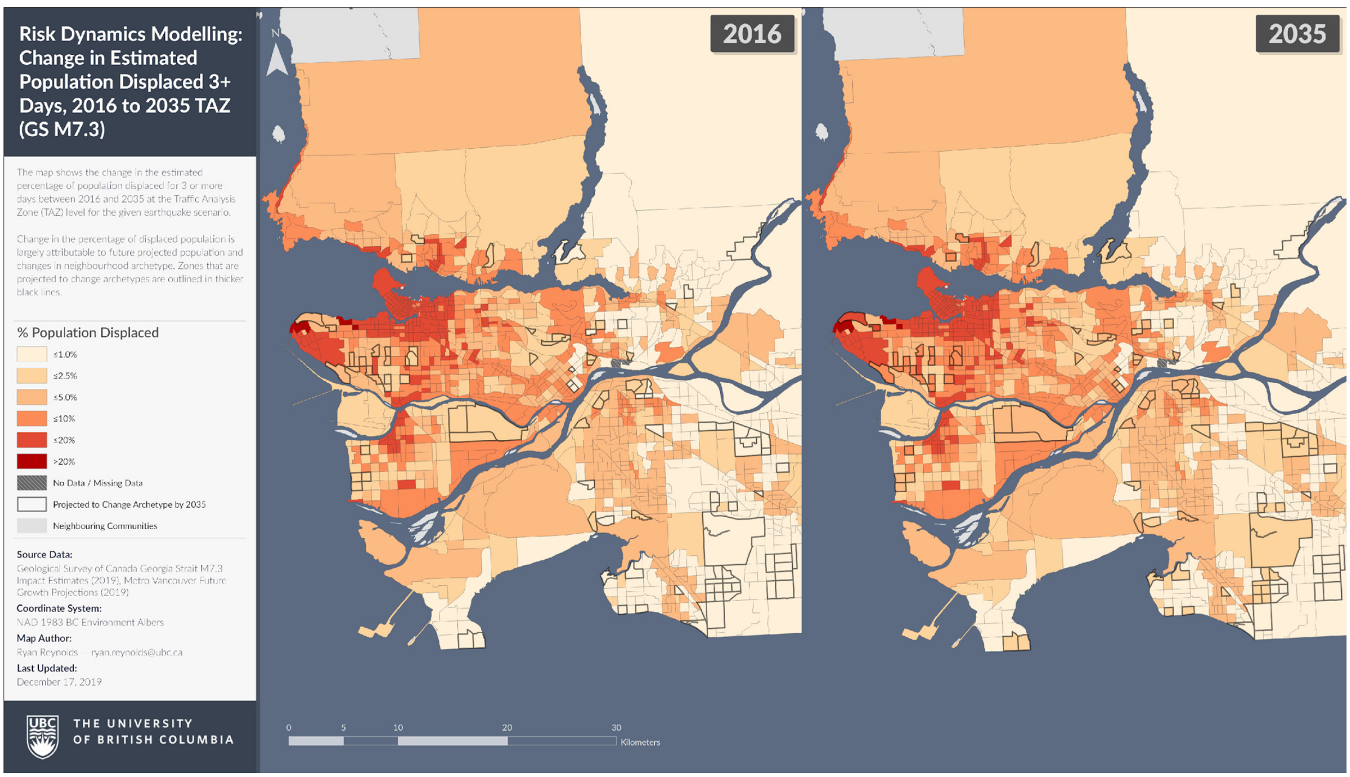

Figure 6: Map comparing estimated population displacements for M7.3 Georgia Strait scenario for 2016 and 2035 at the scale of traffic analysis zones.

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

Recommended citation
Chang, S.E., Reynolds, R.P., Kim, J., Risk Dynamics Modelling in Metro Vancouver, in Resilient Pathways Report: Co-creating new Knowledge for Understanding Risk and Resilience in BC; Safaie, S., Johnstone, S., Hastings, N.L., eds., Geological Survey of Canada, Open File 8910, 2022 p. 299-309, https://doi.org/10.4095/330542

4.2 NEIGHBOURHOOD SOCIAL VULNERABILITY IN VANCOUVER

June 2022

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4.2 NEIGHBOURHOOD SOCIAL VULNERABILITY IN VANCOUVER

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ABOUT NEIGHBOURHOOD SOCIAL VULNERABILITY

The physical damage and societal impacts of natural hazards are rarely distributed evenly across space, through time, or within affected populations.[1, 2] Experience from past disasters demonstrates that some portions of the population are inherently more susceptible to the impacts of disasters due to a mix of the physical, geographic, social, or economic traits intrinsic to these groups.[3] Socially vulnerable populations are often more profoundly impacted during disaster events and generally experience a slower post-disaster recovery process following significant disaster events than their less vulnerable neighbours.[4]

Similarly, many factors influence vulnerability to hazards at the neighbourhood level. Some are physical, such as the neighbourhood's location and exposure to the hazard, the potential environmental and structural impacts, and the likely disruption to critical infrastructure services. Other factors are social, relating to characteristics of residents such as income or housing tenure that may influence their propensity to suffer losses and experience difficulty recovering from disasters (Figure 1).

While a considerable body of research and practice has focused on the physical and built environment aspects of disasters, the *social aspects* of disasters have been less well established in Canada until recently. While there are generally agreed-upon measures of physical vulnerability for buildings, critical infrastructure, and access to services such as power, water, and wastewater, there are no such accepted measures for social vulnerability. However, the need for evidence-based and empirically derived information to support structural mitigation and response planning efforts related to social vulnerability has been generally agreed upon within research and practitioner communities.[5]

Socially vulnerable populations are often more profoundly impacted during disaster events and generally experience a slower post-disaster recovery process following significant disaster events than their less vulnerable neighbours.

Much of today's research into social vulnerability builds on the Hazards-of-Place model and

Figure 1: Many factors influence social vulnerability (Photo: Mike W./flickr).

methodologies established by Susan Cutter and colleagues as part of their Social Vulnerability Index.[6] These studies often include socioeconomic indicators to identify potentially vulnerable groups within a population. Such indicators are quantitative measures of a single characteristic of a population and are often derived from census statistics (e.g., percentage of renters, percentage aged 65+), but can also include travel times to key services (e.g., walking time to nearest primary school, travel time to nearest food market via public transit) or the number of facilities within a given distance or travel time (e.g., number of medical clinics within 2 km, number of community hubs within a 30-minute walk). Individual indicators are often combined into indices or "themes" that allow for targeted assessment of vulnerable groups sharing similar traits.

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 directly addresses the first priority for action, *understanding disaster risk*, and provides information for two other priorities: *investing in disaster risk reduction for resilience* and *enhancing disaster preparedness for effective response*. This work also addresses several targets of the Sendai Framework, including: *reduce the number of affected people globally*; *reduce direct economic loss in relation to GDP*; and *increase the number of countries with national and local disaster risk reduction strategies*.

SOCIAL VULNERABILITY FROM EARTHQUAKE IN VANCOUVER NEIGHBOURHOODS

Our team at UBC partnered with colleagues from the Geological Survey of Canada at Natural Resources Canada (NRCan), the City of Vancouver (the City), and Sage on Earth Consulting (Sage) with the shared goal of better understanding the spatial distribution of socially vulnerable populations within the City of Vancouver, as part of the City's seismic retrofit program. The project aimed to assist policymakers in identifying Vancouver neighbourhoods with populations most vulnerable to the physical impacts of a significant disaster event. We used physical disaster impact assessments completed as part of NRCan's recent earthquake scenario modelling efforts to estimate social impacts for three socially vulnerable groups. Our end goal is to provide information and insights for designing measures to reduce vulnerability and increase earthquake resilience within Vancouver neighbourhoods.

Together, we identified a set of fourteen indicators of socioeconomic vulnerability, using census dissemination area (DA) polygons as our units of analysis and proxies for "neighbourhoods" for the City of Vancouver. We combined these indicators into three themes that addressed aspects of social vulnerability most relevant to the policy interests of the partnership (Table 1).

This work resulted in a set of indicator, cluster, and theme maps at the neighbourhood scale for the City of Vancouver. These maps highlight some of the many aspects of social vulnerability within the area of interest. We provided this information to the City of Vancouver to assist policy makers in updating the City's seismic retrofit policies. In addition to identifying areas of elevated social vulnerability related to financial, housing, and social service demand at the neighbourhood level, the information can also assist with creating targeted social programs to address the root causes of social vulnerability in highlighted neighbourhoods.

THE NEIGHBOURHOOD SOCIAL VULNERABILITY ASSESSMENT PROCESS

We established a six-step approach to measuring and summarizing information about social vulnerability and iterated upon this approach with our project partners. Our initial goal was to determine what the group's policy objectives were going to be, how best to address the questions related to those questions, and how best to identify the appropriate social vulnerability groups. This required identifying and reviewing potential indicator data, establishing vulnerability thresholds, and creating associated map products for review by our partners (Figure 2). We provide more detail on each step in the following sections.

In addition to identifying areas of elevated social vulnerability related to financial, housing, and social service demand at the neighbourhood level, the information can also assist with creating targeted social programs to address the root causes of social vulnerability in highlighted neighbourhoods.

Table 1: Three themes

Reduced Financial Capacity	Greater Social Service Dependency	Housing and Shelter Challenges
Neighbourhoods with above-average concentrations of residents that may have a lower financial capacity to respond following a disaster:	Neighbourhoods with above-average concentrations of residents that may have a greater dependence on social services:	Neighbourhoods with above-average concentrations of residents that may face difficulties acquiring emergency shelter or permanent housing:
Indicators: • Low-income workers • Government transfer recipients • Unemployed workers • Workers who work from home • Tenants in subsidized housing • Households that spend at least 30% of their income on shelter	Indicators: • Young children • Elderly adults • Low-income workers • Unemployed workers • Single-parent families • Not fluent in English	Indicators: • Renters • Recently moved into the community • Adults without a high school education • Tenants living in subsidized housing • Families living in non-suitable housing • Households that spend at least 30% of their income on shelter

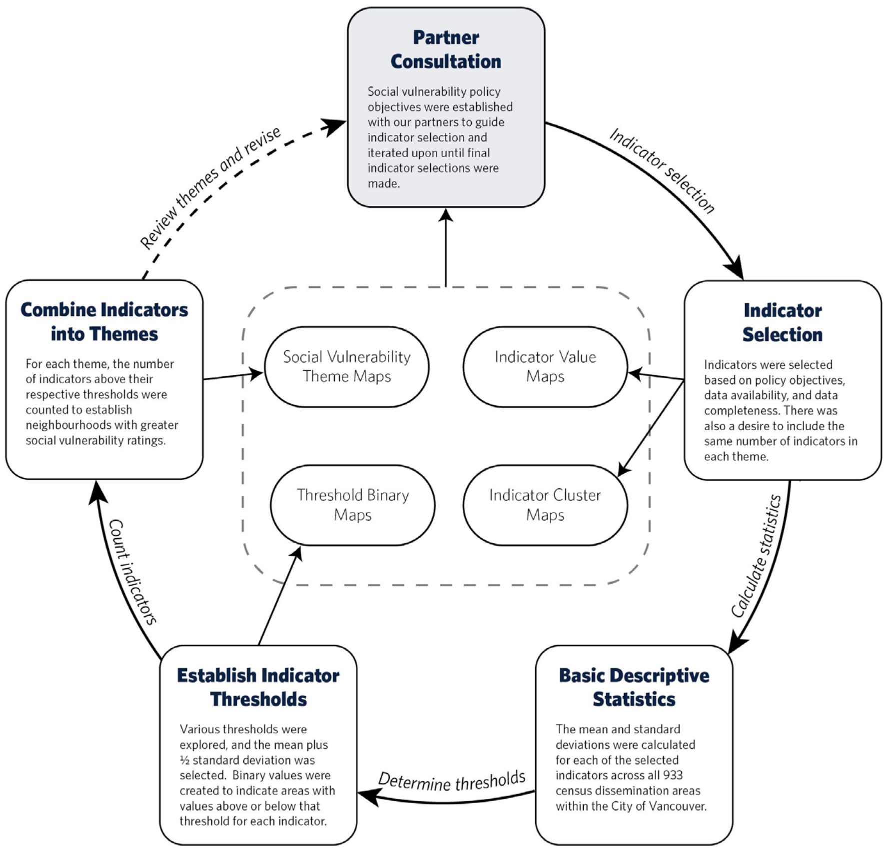

Figure 2: Social vulnerability assessment process (Graphic: UBC and Project Contributors).

STEP 1: ESTABLISH POLICY GOALS

We established an initial set of policy objectives to place this project into context, establish our scope, and guide model development. While the primary goal was to support policy-making processes related to the City's seismic retrofit program, it was also clear this information would be of interest to other groups within the City and to additional work being undertaken by our DRR Pathways partners.

STEP 2: SELECT INDICATORS

We conducted an initial review of academic and practitioner literatures to determine which indicators had been used in previous social vulnerability modelling in Canada, the US, and abroad. An initial set of 84 potential indicators were identified and reviewed to determine data availability and suitability at the neighbourhood scale within the City of Vancouver. From this list, a final set of 14 indicators were selected that met project objectives (Table 2).

A set of per-indicator maps were generated along with cluster maps highlighting hot and cold spots across the city. Figure 3 and Figure 4 show two such examples.

STEP 3: CALCULATE BASIC DESCRIPTIVE STATISTICS

With the final set of 14 socioeconomic indicators in place, we needed to establish which indicator thresholds we wanted to use. To this end, basic statistics were calculated for each indicator for all 933 DAs within the City of Vancouver, including mean, median, mode, standard deviation, minimum, and maximum values. Figure 5 shows an example of thresholds for one of the indicators.

STEP 4: ESTABLISH INDICATOR THRESHOLDS

Several different approaches to establishing indicator thresholds were explored and assessed for suitability. We determined that a cut-off equal to the indicator mean plus half a standard deviation $(\underline{x}+\sigma/2)$ best fit our needs. A binary variable was created for each indicator to represent areas that fell above or below that threshold, as shown in Figure 5.

STEP 5: COMBINE INDICATORS INTO THEMES

We selected six indicators to contribute to each of the three social vulnerability themes identified in Step 1. Having the same number of indicators in each theme helps make comparisons between theme maps easier for map readers. Indicators were selected based on how they contributed to specific themes, and some indicators were used in more than one theme.

For each theme, we summed the number of indicators that were above the threshold values established in Step 4 for each of the 933 DAs within the City of Vancouver. In cases where data were not available for a specific DA, it was treated as being below threshold for the purpose of these counts. This resulted in above-threshold counts ranging between zero (very low vulnerability) and six (very high vulnerability).

A final set of maps was generated for indicator counts for each of the three social vulnerability themes, highlighting areas where four or more indicators were above the established threshold values. An example of a final theme map is shown in Figure 6.

STEP 6: REVIEW AND ITERATE

Once theme maps were generated for all themes, we reviewed them to ensure that the themes were addressing the previously established policy objectives and appropriately identifying groups that should be included within each theme. With updated guidance from our partners, the process was repeated to refine the indicators selected, establish more idealized thresholds, and adjust the theme maps to better address project goals (Figure 2). The final set of maps was completed on September 18, 2019.

Table 2: The 14 Social Vulnerability Indicators Selected for this Project

Indicator	Reason for Inclusion
1. Children, Aged 0–9	Children are generally dependent upon their parents or guardians, are often less mobile, require additional care when not in school, and may require greater assistance to evacuate during an emergency.
2. Older Adults, Aged 75+	Seniors often tend to have limited or fixed income, are often less mobile, are more likely to be government transfer recipients, may be more reluctant to evacuate, and may require additional assistance post-disaster.
3. Low-Income Adults, Aged 18–64	Low-income adults are more likely to be subject to “renovictions” if renting, while low-income homeowners may face greater limitations on their ability to rebuild or repair damages to their homes.
4. Government Transfer Recipients	Reliance upon government transfers for a large part of a household’s income can increase a household’s social vulnerability immediately following an emergency and throughout the recovery process. Transfers can include benefits and other forms of income or compensation from federal, provincial, or municipal governments.
5. Unemployed Workers	Unemployed workers and their families may be without income and health benefits resulting in decreased disaster response capacity and slower post-disaster recovery.
6. Workers Working from Home	Those who work from home can face issues not experienced by their peers who work in designated workplaces. Home-based workers can experience issues related to social isolation due to reduced social interactions through work. As their homes are their workplaces, any damage to their homes can directly impact their ability to earn income until necessary repairs are completed.
7. Home Tenure: Renters	Renters often lack control over their dwelling and are subject to contracts with landlords, impacting their overall housing stability. Insurance for renters can also be more restrictive than for homeowners.

Indicator	Reason for Inclusion
8. Households with High Shelter Costs	Households that spend 30% or more of household income on shelter costs often have little available capacity to cover additional costs associated with evacuation, repairs, replacement of goods, and other post-disaster recovery costs.
9. Households in Non-suitable Housing	Households where there are insufficient bedrooms for the size and composition of the household are already experiencing sub-standard living conditions, which are likely to be exacerbated by disaster impacts. Large families are especially likely to fall into this category.
10. Tenants in Subsidized Housing	Housing subsidies assist households by reducing their total shelter costs. Tenants in subsidized housing may face significant difficulties finding temporary or permanent shelter following a disaster as subsidized housing is often quite limited and may not be in a suitable location for their needs.
11. New to the Community in the Past Year	Those who have moved into a community in the past year are likely to be unfamiliar with local evacuation procedures, shelter locations, relief sources, and recovery information. Recent movers are also less likely to have developed deep or broad social networks they can turn to for assistance following a disaster.
12. Adults with No High School	Adults with fewer than 12 years of formal education are often less able to respond to disaster events, are more often dependent upon government support, and often have less overall adaptive capacity than those with higher levels of education.
13. Not Fluent in English	A lack of fluency in the official language(s) used by a community may indicate reduced integration into the broader community and shallower social networks, resulting in increased vulnerability. Language proficiency is also important in understanding emergency instructions and gaining access to assistance or relief.
14. Lone-Parent Families	Lone-parent households often face increased financial and support constraints, may have additional childcare responsibilities, and are more likely to live on post-disaster economic margins than two-parent families.

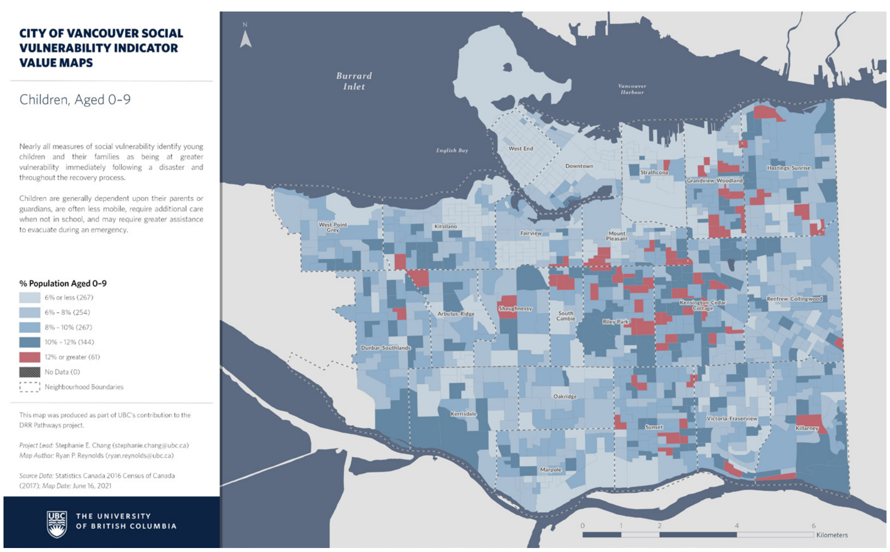

Figure 3: Indicator value map for children aged 0–9 (areas in dark blue and red show areas of elevated vulnerability).

ADAPTING THIS APPROACH BEYOND THE CITY OF VANCOUVER

While this project focused on specific vulnerabilities relevant to the seismic retrofit program at the City of Vancouver, our approach should be accessible to researchers and practitioners exploring social vulnerability anywhere in Canada where neighbourhood-scale data is available, or through adaptation at other scales where appropriate data exists. Statistics Canada makes DA data available for many larger communities across the country, and many municipalities collect their own data that could be adapted for use in social vulnerability assessments.

There are issues related to statistical correlation and suitability of purpose that should be fully considered before including specific indicator data into a social vulnerability index. Randomized rounding of census-style data can impact results when working at finer scales and must also be considered. Finally, some expertise in geographic information systems (GIS) and spatial analysis is required to properly generate—and possibly interpret—social vulnerability index maps. The sources included at the end of this report and in our endnotes may be of interest to anyone seeking to adapt this approach outside the City of Vancouver.

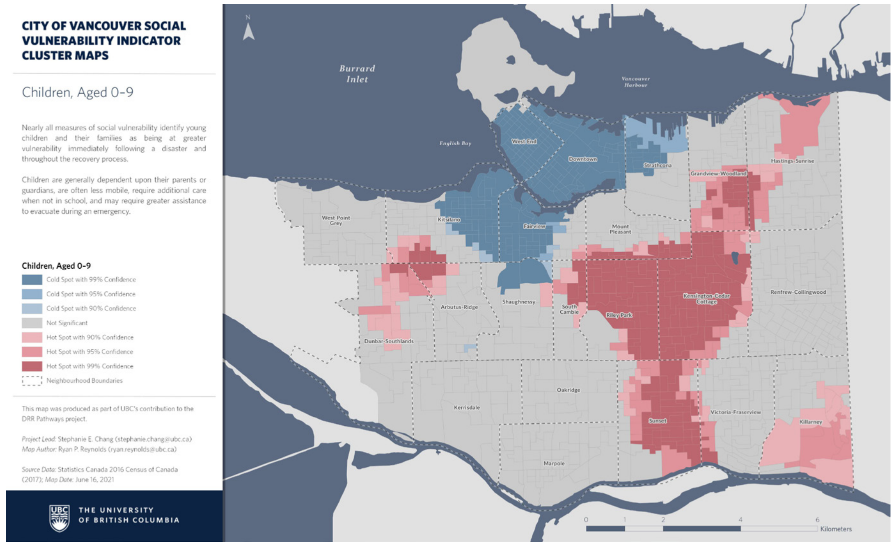

Figure 4: Cluster analysis map for children aged 0–9 (areas in red show high vulnerability hotspots, while areas in blue are cold spots).

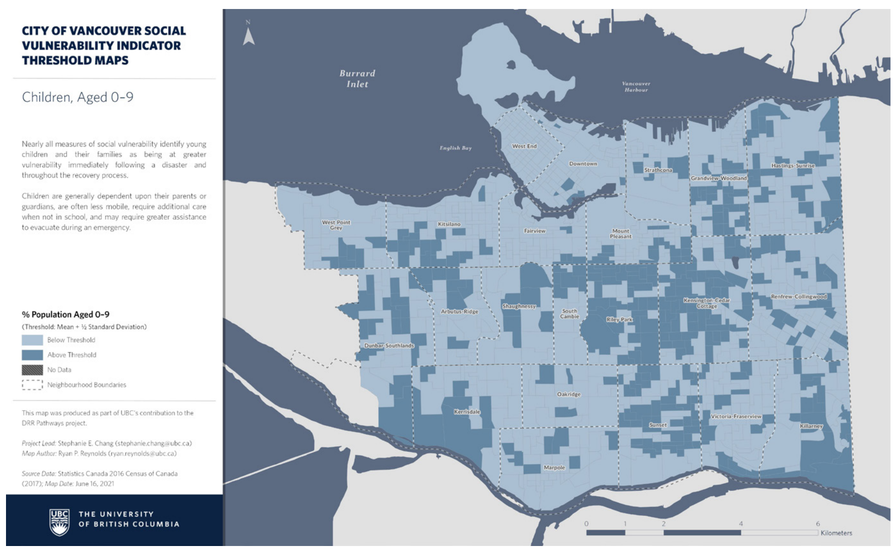

Figure 5: Threshold map for children aged 0–9 (areas in dark blue are above the indicator threshold, while light blue areas are below the threshold).

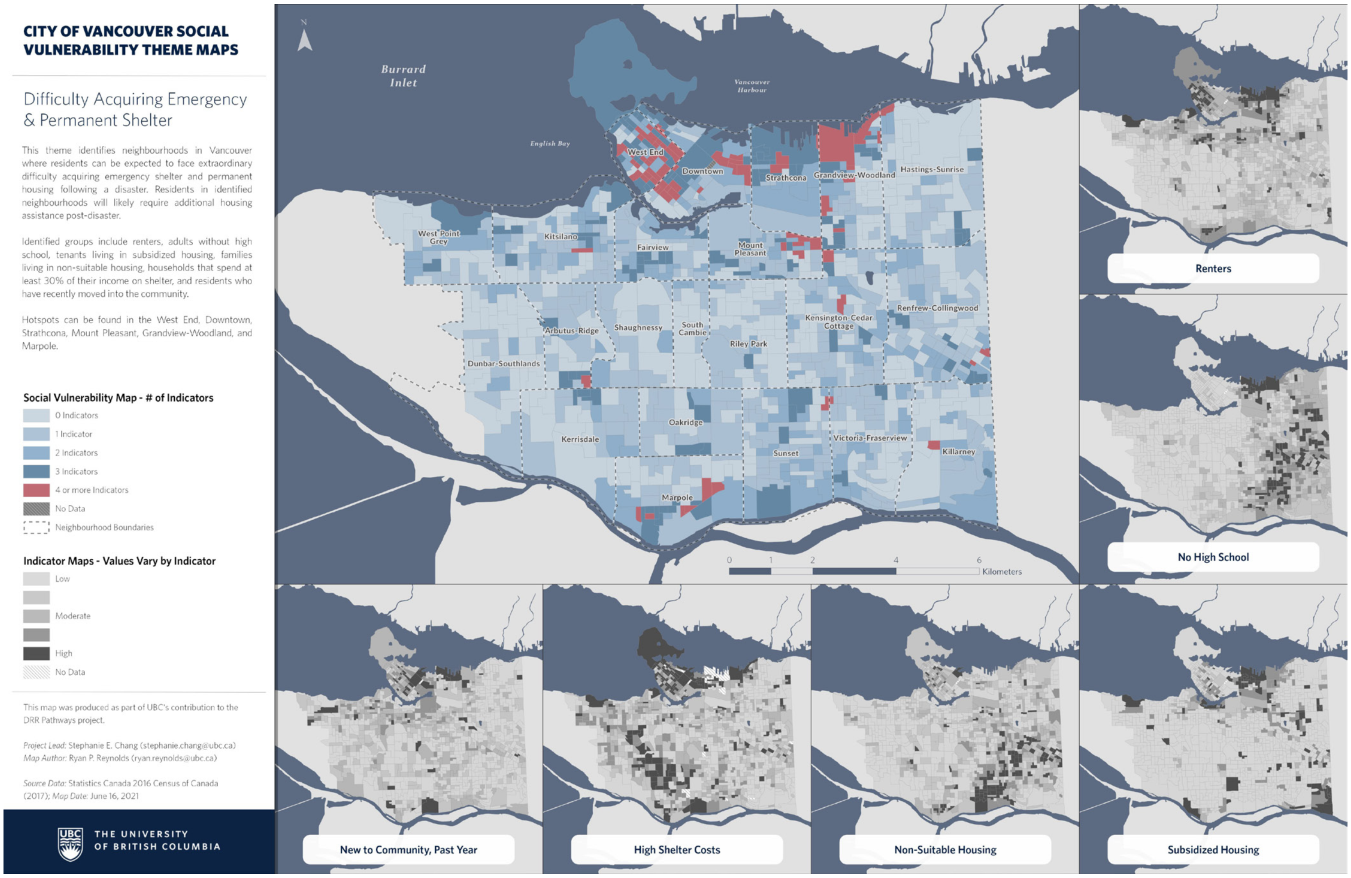

Figure 6: Social vulnerability theme map for residents facing difficulty acquiring emergency and permanent shelter.

OPPORTUNITY

RECOMMENDATIONS

Completing a neighbourhood-level social vulnerability assessment is important to understand how social impacts of disasters may be distributed throughout a community. Small changes made to community preparedness, emergency response, and disaster recovery plans and policies can significantly reduce potential impacts on vulnerable populations immediately following a disaster and help them recover from such events more quickly.

Knowing which communities are most vulnerable allows policy makers and emergency managers to prepare better to assist these populations should a disaster occur. Materials, equipment, and human resources can be pre-positioned to locations where the need is likely to be greatest. When combined with physical risk modelling, social vulnerability assessments allow decision makers to dispatch resources to the locations most likely to be in need following a disaster.

There is significant interest around measuring social vulnerability in BC, both as part of the DRR Pathways project and by the BC disaster risk reduction community at large. The approach we've described is just one of many[7,8] and we have also identified several potential future enhancements to our approach, which can be found in our technical report on the DRR Pathways website.[9]

CHALLENGES

There are three main challenges facing anyone working in neighbourhood social vulnerability assessments:

1. **Identifying policy objectives:** It is critical that there be clear policy objectives in place to

provide the necessary context and scope needed to guide social vulnerability model development for a community. It should be clear how the information provided by the social vulnerability assessments will be used to inform and adjust local policies, with the understanding that these needs may change or be clarified throughout the process.

2. **Identifying appropriate vulnerability indicators:** Indicators should be selected to meet policy objectives, based on data availability and completeness. The specific policy objectives should guide this process. Census data is often a good starting point, but other regional and local data sources should also be considered. Geospatial measures of proximity or density may also be appropriate.

3. **No silver bullet:** There is no single approach or set of indicators that is ready "out of the box." This process will take time and should benefit from the many voices that will be involved in and affected by policy and planning objectives. Social vulnerability assessments should be undertaken as part of a broader social policy movement within a community to be most effective.

RESOURCES OR SIMILAR PROJECTS

BC AND CANADA

1. Study describing unequal vulnerability to flood hazards:

Oulahen, G., L. Mortsch, K. Tang, and D. Harford. "Unequal vulnerability to flood hazards: 'Ground truthing' a social vulnerability index of five municipalities in Metro Vancouver, Canada." *Annals of the Association of American Geographers* 105, no. 3 (2015): 473–495.

2. Measuring social vulnerability to flood hazards in the context of environmental justice, across Canada:

Chakraborty, Liton, Horatiu Rus, Daniel Henstra, Jason Thistlethwaite, and Daniel Scott. "A place-based socioeconomic status index: Measuring social vulnerability to flood hazards in the context of environmental justice." *International Journal of Disaster Risk Reduction* 43 (2020): 101394.

3. Social vulnerability in national seismic risk model:

Natural Resources Canada is working on a national seismic risk model, which incorporates work on social vulnerability in addition to excellent modelling work around physical exposure and disaster impacts. This work is ongoing, but we hope to have more details about the social vulnerability impact in the near future.

INTERNATIONAL

4. Social vulnerability to environmental hazards; the Social Vulnerability Index (SoVI) tool:

Cutter, Susan L., Bryan J. Boruff, and W. Lynn Shirley. "Social vulnerability to environmental hazards." *Social Science Quarterly* 84, no. 2 (2003): 242–261. Accessed March 17, 2022. http://research-legacy.arch.tamu.edu/epsru/Course_Readings/Ldev671MARS689/LDEV671_Readings/Cutter_socialvuln_hazards_ssq.pdf

5. A review of social vulnerability methodologies:

Willis, I., and J. Fitton. "A review of multivariable social vulnerability methodologies: A case study of the River Parrett catchment, UK." *Natural Hazards and Earth System Sciences* 16, no. 6 (2016): 1387–1399.

6. A review of social vulnerability literature:

Cutter, S. L., Christopher T. Emrich, Jennifer J Webb, and Daniel Morath. "Social vulnerability to climate variability hazards: A review of the literature." *Final Report to Oxfam America*, 5 (June 17, 2009): 1–44.

ENDNOTES

[1] Susan L. Cutter, Bryan J. Boruff, and W. Lynn Shirley, "Social vulnerability to environmental hazards," *Social Science Quarterly* 84, no. 2 (2003): 242–261.

[2] UN/ISDR (United National International Strategy for Disaster Rediction), *UNISDR Terminology on Diaster Risk Reduction*, Geneva: United Nations, 2009.

[3] Liton Chakraborty, Horatiu Rus, Daniel Henstra, Jason Thistlethwaite, and Daniel Scott, "A place-based socioeconomic status index: Measuring social vulnerability to flood hazards in the context of environmental justice," *International Journal of Disaster Risk Reduction* 43 (2020): 101394.

[4] Chester W. Hartman and Gregory D. Squires, eds, *There is no such thing as a natural disaster: Race, class, and Hurricane Katrina*, Taylor & Francis, 2006.

[5] Susan L. Cutter, Christopher T. Emrich, Jennifer J Webb, and Daniel Morath, "Social vulnerability to climate variability hazards: A review of the literature," *Final Report to Oxfam America*, 5 (June 17, 2009): 1–44.

[6] Susan L. Cutter et al, "Social Vulnerability to Environmental Hazards."

[7] Jean Andrey and Brenda Jones, "The dynamic nature of social disadvantage: Implications for hazard exposure and vulnerability in Greater Vancouver," *The Canadian Geographer* 52, no. 2 (2008): 146–168.

[8] Greg Oulahen, Linda Mortsch, Kathy Tang, and Deborah Harford, "Unequal vulnerability to flood hazards: 'Ground truthing' a social vulnerability index of five municipalities in Metro Vancouver, Canada," *Annals of the Association of American Geographers* 105, no. 3 (2015): 473–495.

[9] Stephanie E. Chang, Ryan P. Reynolds, Juri Kim, and Jackie Z. K. Yip, "DRR Pathways technical report: Neighbourhood social vulnerability in the City of Vancouver," *Disaster Risk Reduction Pathways* (June 30, 2021), accessed March 17, 2022, https://241dccaf-92ec-466d-b658-ecf55b884b23.filesusr.com/ugd/c54559_f5ad16cdf58f46d29c5faafc255a8f29.pdf

Recommended citation
Reynolds, R.P., Chang, S.E., Kim, J., Yip, J.Z.K., Neighbourhood Social Vulnerability in Vancouver, in Resilient Pathways Report: Co-creating new Knowledge for Understanding Risk and Resilience in BC; Safaie, S., Johnstone, S., Hastings, N.L., eds., Geological Survey of Canada, Open File 8910, 2022 p. 310-320, https://doi.org/10.4095/330543