NORTH VANCOUVER
DISTRICT

WHEN THE GROUND SHAKES

Earthquake risk in the District of North Vancouver and what we can do about it

Opportunities for increasing community resilience

WHAT IS A SHAKEOUT SCENARIO?

Shakeout scenarios explain in a general way what could happen if a major earthquake were to occur. They are based on estimation models that provide insight on expected physical impacts and associated socioeconomic consequences for an earthquake.

Shakeout scenarios provide a common framework of understanding to promote collaboration between scientists, planners, decision makers, and the general public. They also establish the necessary context to explore risk reduction strategies in all stages of pre-event emergency planning, longer-term land use decision making, and urban development choices.

When the Ground Shakes is a shakeout scenario describing a seismic hazard assessment for a magnitude 7.3 (M7.3) earthquake in the Georgia Strait. This scenario was selected because it represents a scientifically plausible scenario with the potential to generate losses that are relevant to the needs of emergency planning in the District of North Vancouver (DNV) and consistent with national guidelines for disaster mitigation and risk reduction planning.

The following is an account of what might be expected in the DNV if a M7.3 earthquake were triggered in the Georgia Strait in the near future. Numbers (dollar values, number of buildings, number of casualties, etc.) are drawn from the study *A Profile of Earthquake Risk for the District of North Vancouver*, which is the companion to *When the Ground Shakes*.

Though plausible, the scenario is not a prediction of what will happen. Rather, it represents a "what-if" scenario to assist emergency managers, municipal engineers and planners, residents, and businesses in identifying actions that can be taken in advance of a major earthquake to reduce risk and increase disaster resilience in the community.

Cover photo: DNV

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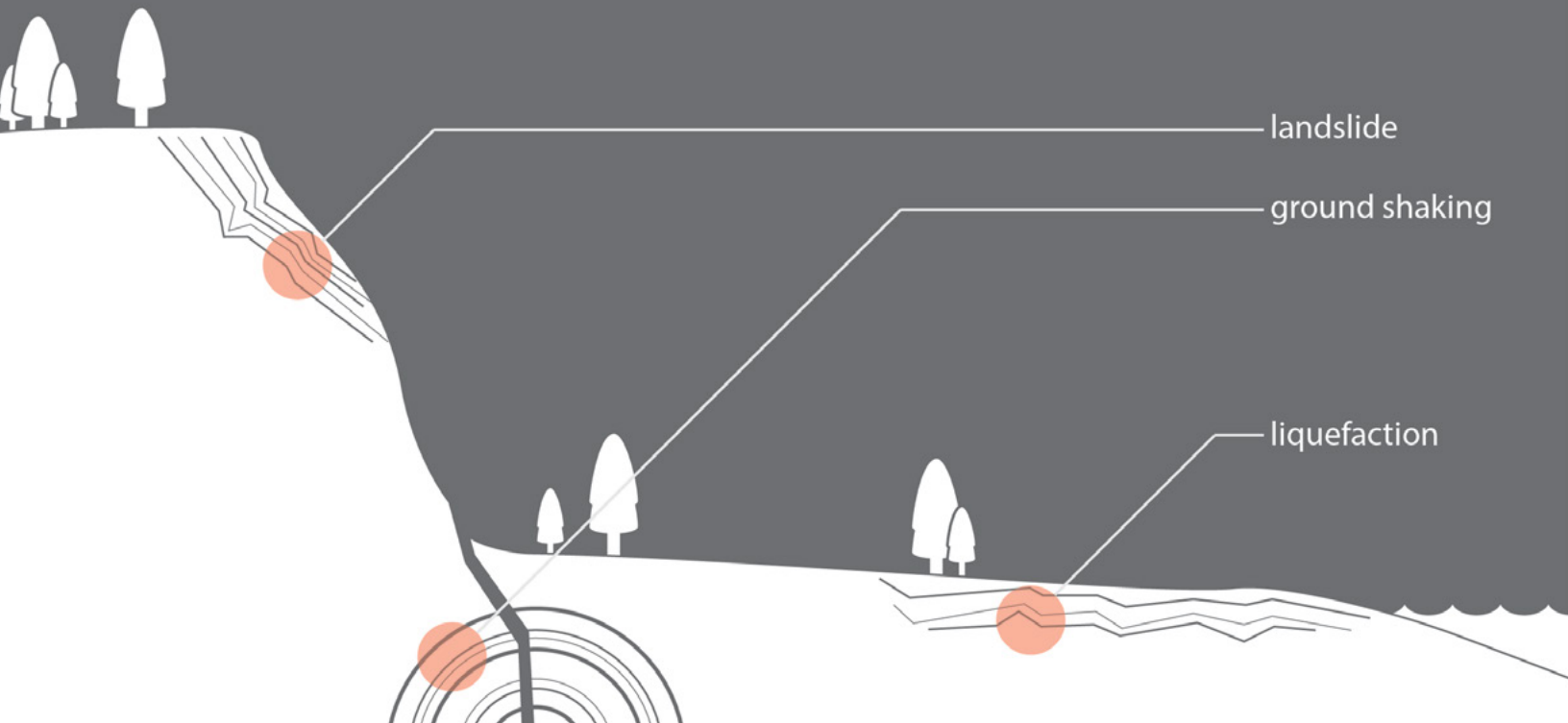


APRIL 19, AN EARTHQUAKE HITS...

Marjorie Jacobs
Resident, Retired, Age 86

8:41 AM
Marjorie Jacobs sits at her kitchen table, in the garden-level suite in her daughter's house in Westlynn Terrace, enjoying her breakfast tea. She saw her son-in-law Henry leave with her granddaughter 30 minutes ago. Henry takes Emma to daycare every morning, which is on a commercial block in Lower Lynn, not too far from his shop near the waterfront. Henry owns an electrical service and supply business and spends most of the day in his company van and at his customers' homes and businesses. Earlier, before she waved goodbye to Henry and Emma, Marjorie heard her daughter, Heather, leave the house to catch the bus to get to work.

8:44 AM
Marjorie puts her tea down and stands to reach for a book in the bookcase when everything around her starts to shake…

Amy Song
Resident and Business Owner, Age 44

8:41 AM
Amy Song has been at her computer working since early this morning. Her company has a major movie contract doing animation and special effects, and the deadline is coming up soon. One of her designers, Jaf, has just arrived with coffee for her and Ameena, who should be here any minute. Ameena commutes from downtown Vancouver, and several others of her small staff team travel from across the Lower Mainland to the North Shore to work with Amy. Her company has been here for eight years now, in an older brick building near the waterfront.

Amy hopes that she'll have time for a quick trip home at lunchtime to walk her dog, Coda. She only had time for a quick walk this morning, she was in such a rush to get to work, and Coda doesn't like being shut up all day in the condo.

8:44 AM
Amy and Jaf are talking to each other across the room about the day's work plan when their desks start shaking, hard. Overhead, the ceiling fan swings wildly, and around them computer monitors and office equipment crash to the floor. There's a loud, ripping crack behind them…

Graham Olsen
Resident and Municipal Project Engineer at District of North Vancouver, Age 39

8:41 AM
Graham Olsen is getting ready to meet with his boss about water and electrical pipelines for a new development project in the District of North Vancouver. He grabs the set of specification drawings and laptop from his desk and heads down the hall to the meeting room. He's running a few minutes late this morning after meeting with a contractor at his house in Lower Lynn. He and his partner, Nadia, recently bought an old house and have had seismic mitigation work done in the basement.

8:44 AM
Graham opens the DNV's mapping files from his laptop and starts to spread the drawings out over the table when the room starts vibrating, then shaking, and the meeting room's white board crashes to the floor...

EARTHQUAKE SCENARIO

THE GEORGIA STRAIT EARTHQUAKE

To assess the potential impacts of an earthquake in our region, researchers have selected an earthquake scenario on which to model physical damages and related socioeconomic consequences.

The selected earthquake is a sudden rupture along a 40 km segment of interlocking faults in the Georgia Strait that sends waves of seismic energy out in all directions. The amount of energy released generates a M7.3 earthquake that is felt throughout the Pacific Northwest.

The waves of seismic energy resonate through solid bedrock and reverberate off the edges of basin depressions that extend beneath Vancouver and the Fraser Valley. As the seismic waves reach the surface they are locally amplified by thick accumulations of sediment filling coastal deltas and buried valley channels that cut into the North Shore mountains. The intensity of ground shaking is violent and lasts more than 20 seconds.

The intensity and duration of ground shaking triggers liquefaction in water-saturated soils along valley bottoms and a series of landslides along valley walls at higher elevations. In some places the amount of vertical settlement and lateral spreading caused by liquefaction is enough to break buried pipes and cause tilting and toppling of buildings and other structures that are not adequately anchored at the surface.

Along river valleys and higher elevations the intensity of ground shaking will likely trigger a series of small landslides and debris flows. The location and magnitude of these slides will be determined by overall slope stability and how wet the soils are at the time of the earthquake.

It is likely that aftershocks will continue for weeks and months after the initial event.

EARTHQUAKES IN THE REGION

On June 24, 1997, a M4.6 earthquake was triggered by displacement along a shallow crustal fault in the Georgia Strait, midway between Nanaimo and Metro Vancouver. The earthquake rumbled across a broad region encompassing southern Vancouver Island, the Sunshine Coast, and Metro Vancouver. It was felt as far east as Abbotsford and as far south as Seattle. Reports of minor damage included broken glass in Vancouver and a broken water pipe in North Vancouver. The earthquake was preceded by a M3.4 foreshock event on June 13, and by numerous small aftershocks. There have been six other significant earthquakes in this same area over the past 40 years. The largest of these was a M4.9 earthquake in 1975 that was accompanied by strong aftershocks.

The M7.3 Georgia Strait earthquake used in this scenario is representative of a class of shallow, destructive earthquakes that have occurred in the region over the last 500 years.

The 2011 earthquake in Christchurch, New Zealand, caused the ground to liquify. Liquefaction may result in dramatic and irregular settlement, causing structural damage.

EARTHQUAKE HAZARDS

GROUND SHAKING

Ground shaking is the result of seismic energy triggered by the earthquake event itself, and the amplification of seismic waves at the earth's surface as they move through rock and soil.

The pattern and intensity of ground shaking will vary by distance from the earthquake source and the movement of seismic energy through the earth's crust (regional basin amplification). Neighbourhoods throughout the DNV will experience different amounts of ground shaking due to the modification of seismic energy by localized geological factors such as soil conditions and bedrock density (local site amplification).

PERMANENT GROUND DEFORMATION

Ground deformation is the permanent displacement of the earth's surface caused by any combination of fault rupture, landslides along steep unstable slopes, and soil liquefaction. Liquefaction occurs when water-saturated soils lose their stiffness and strength and behave like a liquid, spreading laterally and settling vertically.

The pattern of permanent ground deformation is controlled by local factors such as bedrock geology, soil conditions, slope gradient, and groundwater hydrology.

OTHER HAZARDS

In addition to the primary seismic hazards of ground shaking and ground deformation, earthquakes can cause second-order hazards such as fire, floods, tsunamis, and hazardous material spills, all of which have the potential to increase the level of damage and loss following the initial earthquake event. The most common and potentially devastating of these are tsunamis and any fires generated in dense urban settings.

The risk assessment that follows does not include impacts from aftershocks, regional basin amplification, tsunamis, floods, fires, or hazardous material spills.

Photo: Richard Munt

OUR COMMUNITY

LOCATION

The District of North Vancouver (DNV) is located north of the City of Vancouver, across Burrard Inlet. It borders the City of North Vancouver, District of West Vancouver, Squamish Nation, and Tsleil-Waututh Nation, and with these communities makes up the North Shore of Metro Vancouver. DNV is 160 square kilometres, with natural green space accounting for 78% of this area.

The North Shore mountains form an impressive backdrop to the skyline of Metro Vancouver, rising more than 1,400 meters above sea level and forming the northeast margin of the Georgia Basin—a crustal depression that has accumulated sedimentary deposits shed from mountainous highlands over the past 85 million years of geologic history. Mountain rivers have formed a series of steep escarpments that spread out into broad deltaic fans along the waterfront, the industrial heart of the community.

Photo: Nicky Hastings

BUILT ENVIRONMENT

BUILDINGS

Residential development began in the late 1800s and proceeded especially rapidly from the 1950s to 1970s. Many of the older neighbourhoods and town centres are located along the waterfront and valley escarpments—areas that have been significantly modified from their natural state to accommodate increasing demands for growth and development in the community. More than 60% of homes and businesses in the DNV were built before 1975, prior to the introduction of modern building code guidelines for seismic safety.

There are 23,000 buildings spread across 45 neighbourhoods and commercial-industrial areas in the DNV. The vast majority of people (95%) live in single-family wood frame homes in well-established neighbourhoods. The remaining 5% live in multi-family condominium, apartment, and townhouse complexes made of wood, steel, concrete, and masonry.

There are 1,200 commercial and industrial buildings in the DNV. Most commercial and industrial buildings are concentrated in established town centres and in business precincts along the waterfront. Nearly 45% of all DNV buildings containing five or more businesses are unreinforced masonry structures (53 of 119 structures). Commercial and industrial hubs are located along the waterfront in close proximity to rail lines and waterfront port facilities. Areas of highest business concentration (where five or more businesses share one building) along the waterfront are exposed to some of the highest levels of ground shaking and liquefaction.

INFRASTRUCTURE

Homes, businesses, and public facilities rely on an extensive network of utility and transportation infrastructure for basic lifeline services such as water, electricity, and communication. Potable water is supplied from two major watersheds in the North Shore mountains through a 450 km network of underground pipes, distribution lines, pumping facilities, and regional treatment plants. Wastewater is managed through a 770 km network of pipes and centralized treatment plants that are managed through service partnerships with Metro Vancouver. BC Hydro supplies electrical power through an extensive network of transmission lines and substations that are distributed across the North Shore.

Transportation systems include 510 km of highway and secondary roads, 36 bridges, and 60 km of rail lines that are managed by the DNV and other authorities. With continued development in the municipality, these infrastructure systems are becoming increasingly complex, interconnected, and in need of upgrades.

FUTURE GROWTH

The direction provided by DNV's 2011 Official Community Plan (OCP) is to manage about 75% of expected population growth through infill and development of higher-density communities within established town and village centres.

The major town centres of Lynn Valley and Lower Lynn have been designated for high-density residential and mixed-use commercial development. The village centres of Lower Capilano-Marine and Maplewood are designated for mixed-use residential and commercial development. Together, town and village centres have the potential to accommodate approximately 7,500 new homes and businesses in the coming decades.

Current and proposed patterns of development in the OCP have important implications for seismic safety and longer-term disaster resilience of the community. New development and redevelopment in town centres will meet the seismic safety guidelines of the building code.

PEOPLE

POPULATION

DNV is a vibrant and diverse community of 85,000 people. More than 60,000 people make their way to work and school on any given day. Nearly half of those commuting from DNV are travelling by car, bus, and SeaBus to jobs in downtown Vancouver and across the greater Metro Vancouver region. The remaining daytime population is at home or at jobs and activities within the community.

AGE AND FAMILY STRUCTURE

DNV has an aging population with one in four residents over the age of 55. The total number of seniors (age 65+) has increased nearly fourfold over the past 30 years. The proportion of young children (less than 14 years) is higher than regional and provincial norms, but the total number has been in steady decline over the past 10 years. Based on population projections for the next 10 years, it is expected that dependency rates for the elderly will increase from 22% to nearly 29%, and for young children will decrease from 28% to 25%.

Nearly 17% of the total population is composed of unattached individuals living alone or with non-relatives. About 64% of census families have children living at home. In lone-parent families, more than 80% are led by women.

ETHNICITY

Roughly 30% of residents have emigrated from outside of Canada, and nearly 14% of all immigrants living in the DNV arrived in Canada sometime after 2006. The most common countries of origin are the United Kingdom (18%) and Iran (17%). Visible minorities account for 22% of the total population and the largest visible minority groups are Chinese and West Asian. Two out of three immigrants speak English and/or French in the home, with the most common non-official languages being Persian (Farsi), Korean, and Cantonese.

Slightly more than 1% of the total DNV population is of Aboriginal identity. There are two First Nations with reserves located in the DNV—Tsleil-Waututh Nation and Squamish Nation.

HOME OWNERSHIP AND INCOMES

The rate of home ownership is about 80%. The average monthly shelter cost for homeowners is $1,630 with nearly one in four spending 30% or more of their total income on shelter. With an effective vacancy rate of 0% and a dwindling supply of rental housing stock available, there are few options for renters. The average monthly shelter cost for renters is $1,271, well above the provincial average of $989. The proportion of renters spending 30% or more of available total income on shelter is 42%.

The median employment income level for individuals in the labour force is $62,000. Median earnings for those working in the most common occupations of business, finance, professional services, and specialized management positions range from $73,000 to $92,000. The median after-tax income for families and couples in 2010 was $89,000 and $96,000, respectively. For lone-parent families this amount was $54,000, and for those living with non-relatives it was $32,000.

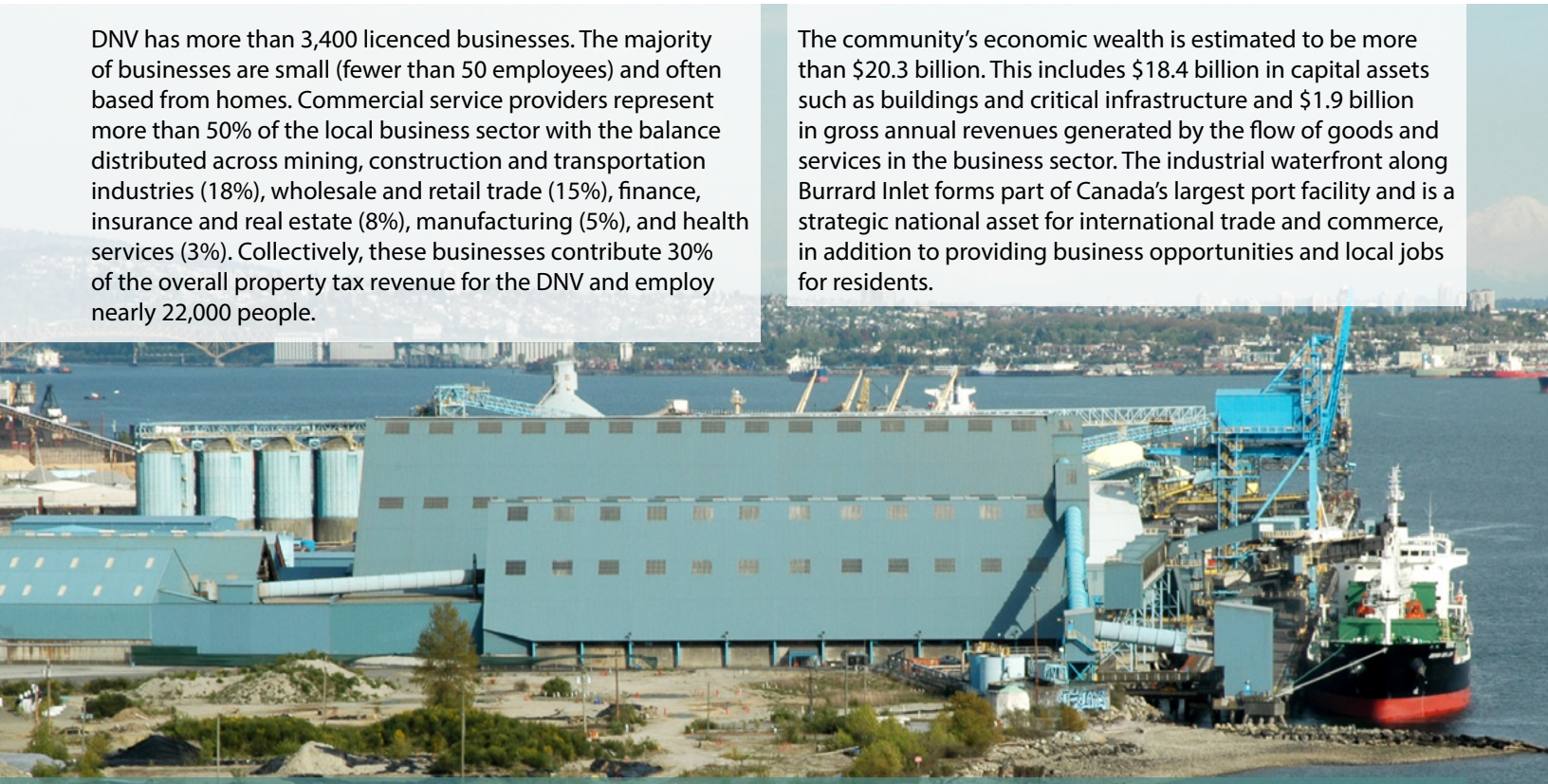
ECONOMY

BUSINESS AND LABOUR

DNV has more than 3,400 licenced businesses. The majority of businesses are small (fewer than 50 employees) and often based from homes. Commercial service providers represent more than 50% of the local business sector with the balance distributed across mining, construction and transportation industries (18%), wholesale and retail trade (15%), finance, insurance and real estate (8%), manufacturing (5%), and health services (3%). Collectively, these businesses contribute 30% of the overall property tax revenue for the DNV and employ nearly 22,000 people.

COMMUNITY WEALTH

The community's economic wealth is estimated to be more than $20.3 billion. This includes $18.4 billion in capital assets such as buildings and critical infrastructure and $1.9 billion in gross annual revenues generated by the flow of goods and services in the business sector. The industrial waterfront along Burrard Inlet forms part of Canada's largest port facility and is a strategic national asset for international trade and commerce, in addition to providing business opportunities and local jobs for residents.



CAPITAL ASSETS

Capital assets include homes, businesses, public facilities, and critical infrastructure. Approximately 84% of the DNV's total building assets are single- and multi-family residential buildings. An additional 11% are commercial and industrial buildings, and the remaining 5% are public facilities (government operations, schools, and churches). The majority of buildings (86%) are wood frame and generally resistant to earthquake shaking. However, older concrete and unreinforced masonry buildings are valued at $3.7 billion, and these are likely to sustain significant structural losses from earthquake damage.

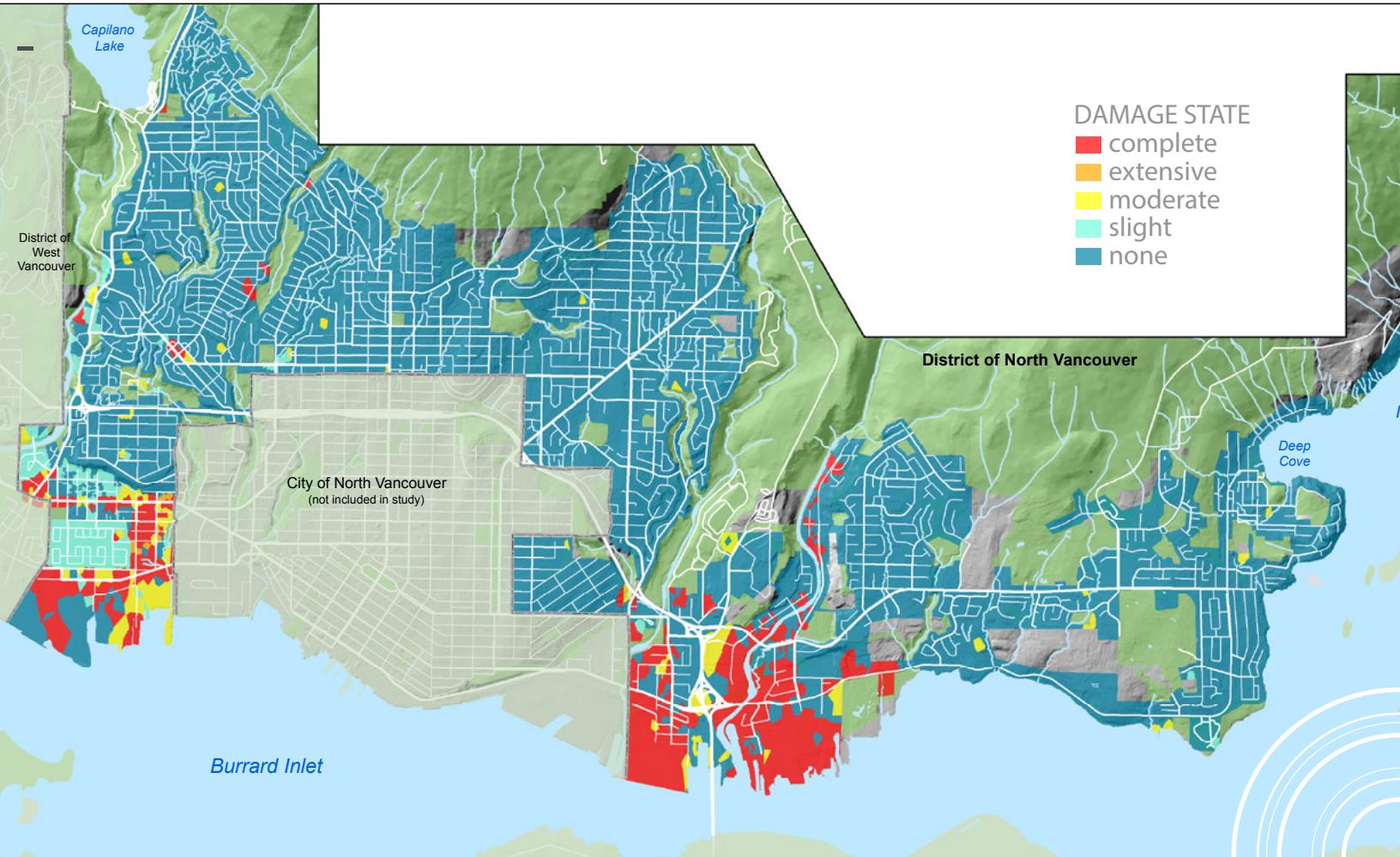
Utility and transportation infrastructure assets are estimated at close to $1.6 billion and include water pipelines, roads, rail lines, bridges, and related facilities. Water utilities represent about 55% of total infrastructure assets with $290 million in potable water and $575 million in wastewater utilities. (Metro Vancouver owns additional water and wastewater systems, and electrical infrastructure is owned by BC Hydro.) Roads and bridges account for almost 40% of infrastructure assets ($600 million), and the remaining 5% represents rail line systems that serve port and industrial facilities along the waterfront.

Photo: Nicky Hastings

WHAT CAN WE EXPECT TO HAPPEN?

WHERE WILL DAMAGE OCCUR?

BUILDING DAMAGE EXPECTED UNDER CURRENT CONDITIONS

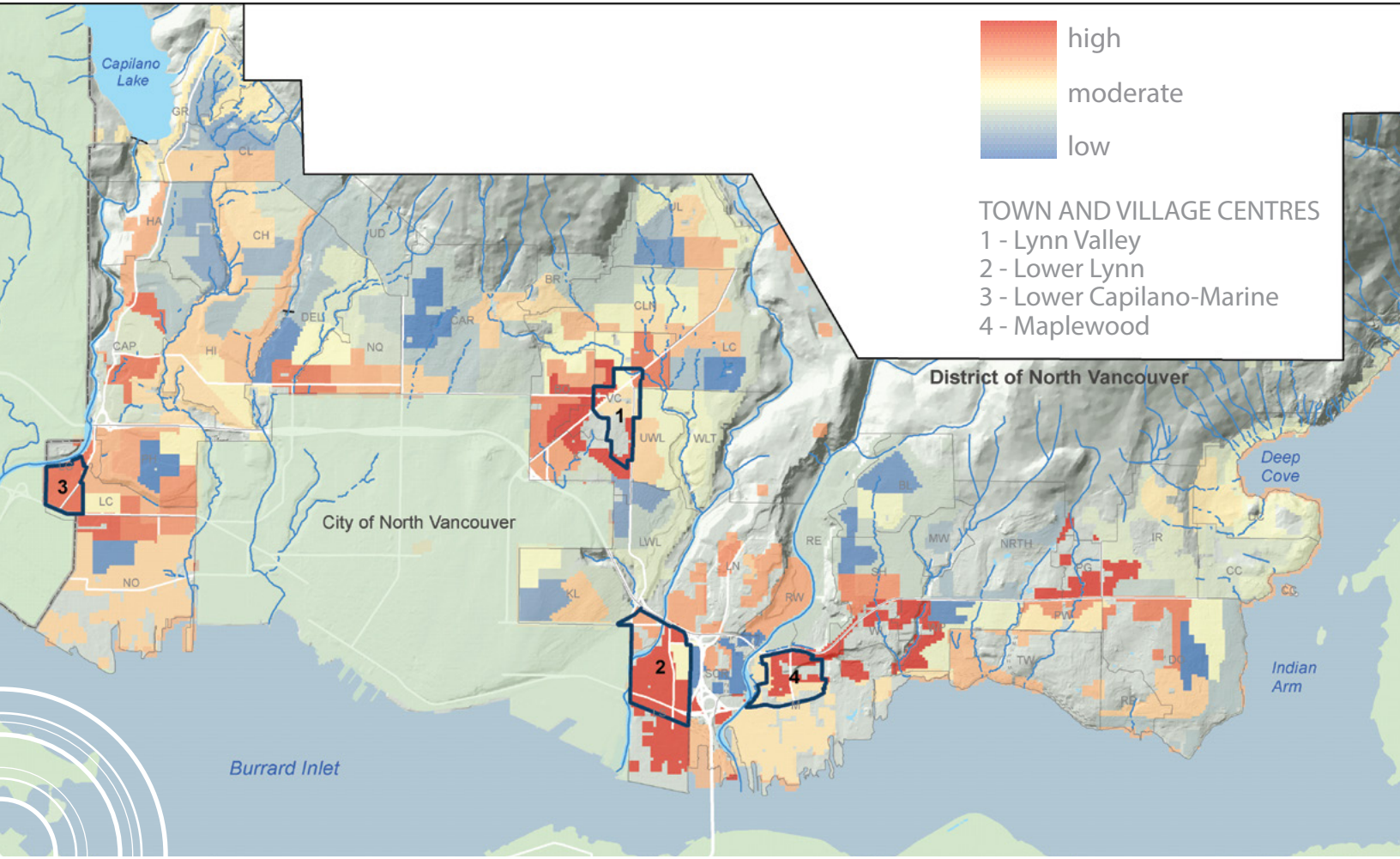


This map shows the expected damage to buildings from a M7.3 earthquake based on building age, location, and construction type. Complete and extensive damage to a building means that the building will need to be replaced. Moderate and slight damage can usually be repaired.

Some areas of the DNV will be more damaged than others. Where these overlap with socially vulnerable areas, the demand for emergency support services is likely to be the greatest—both during and after a disaster.

WHO IS MOST VULNERABLE?

SOCIALLY VULNERABLE POPULATIONS UNDER CURRENT CONDITIONS



Some residents will be more vulnerable than others to the negative impacts of a major earthquake. This map is based on more than 50 demographic variables that are known to contribute to social vulnerability. People in areas with high social vulnerability generally have a lesser capacity to respond to and recover from the impacts of an earthquake. The following list includes social variables with the greatest degree of influence on overall patterns of social vulnerability in the DNV:

- low-income families and those living alone with limited resources
- non-English-speaking individuals from ethnic minorities who have recently immigrated
- children under the age of 5 and elderly over 65 who may not have the means to look after themselves
- single-parent families
- individuals and families who have recently moved to the DNV and have not made social connections in the community

RESIDENTS

April 19

8:44 EARTHQUAKE!

Marjorie puts her tea down and stands to reach for a book in the bookcase when everything around her starts to shake. The shaking intensifies quickly, and Marjorie tries to move back to the table for support. The shaking makes her unsteady and she falls to the floor, along with the cup of tea, which shatters. The bookcase isn't attached to wall and it topples onto Marjorie, hitting her head and pinning her to the ground.

Emma arrived at her daycare in Lower Lynn about 15 minutes ago and is still settling in with the other children when the room begins shaking. They are in a group in the middle of the room, under suspended overhead lights but away from the masonry walls, which have started to crack from the shaking. A slice of daylight appears between the roof and the south wall, and the roof begins to slide sideways.

Henry is driving to his first customer of the day when his van starts to bounce. He looks in the rear-view mirror for potholes in the road, but his attention quickly returns to the road ahead as the cars in front of him screech to a halt. They don't all stop in time and some are rear-ended, while a few others jump the sidewalk and another crosses the centre line into oncoming traffic. Henry watches as a powerline leans slowly into the street and the power cable suddenly snaps, spraying sparks.

Heather has arrived at work and is preparing for a staff meeting in the fourth floor conference room. When the shaking starts, Heather dives under the table and tries to hold on. She is only a few feet from the window when it shatters, sending glass fragments through the room and onto the street below.

8:49 AM (5 minutes after the quake)

Heather tries to call her mother at home. The call went through the first time but was not answered, and now the network is so busy that she can't make a call to anyone. She tries to text Henry.

Marjorie lost consciousness when the bookcase fell on her. The sound of the phone ringing brings her back to awareness, but she can't move to get it. She has a head wound and her arm may be broken.

Emma's daycare has partially collapsed and a few of the children and a care provider are trapped under the rubble of the south wall. When the shaking ended, the other care providers quickly moved the children outside and into a street full of debris. It's as far away from the building as they could get without getting too close to neighbouring buildings, some of which have collapsed completely or look like they are about to do so.

Henry's van is hemmed in on all sides with other vehicles. Up ahead, some drivers have left their cars to investigate the many collisions. He can see almost every driver and passenger with a cell phone in their hand, but few have made a connection. He's not sure if he should try to help or walk back to Emma's daycare. He remembers that he has a first aid kit in the van and starts to look for it.

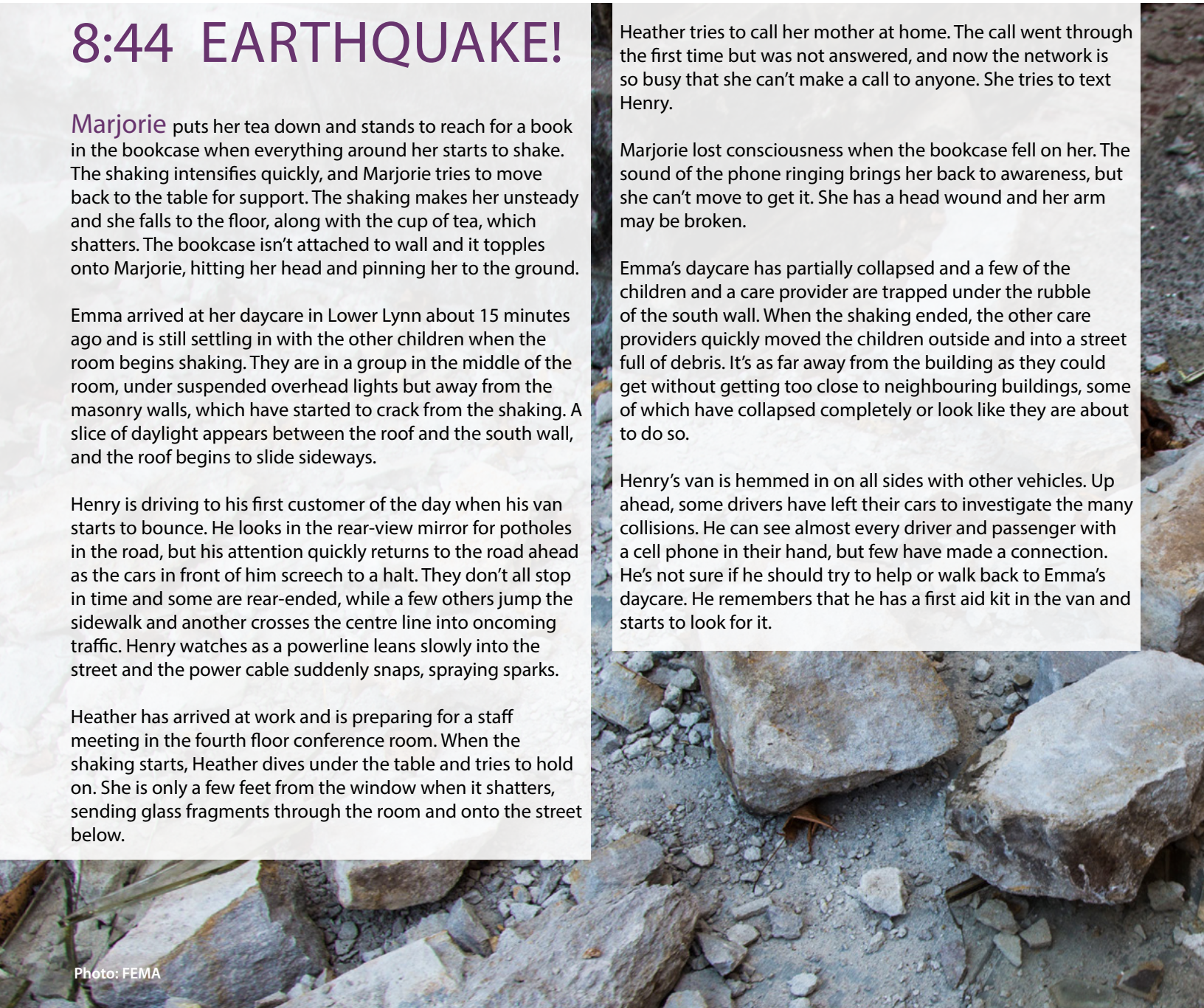


Photo: FEMA

9:54 AM (1 hour after the quake)

Henry can't find Emma. People from neighbouring businesses have gathered at the daycare building. Everyone is frantic, but working together to move large pieces of walls and the roof to get to those trapped beneath.

Heather and her coworkers are trading what information they know, but it isn't much. No one is sure if they should leave the building or not. There is broken glass everywhere and some furniture has fallen over, but otherwise not much damage that they can see. Heather wants to find her family but doesn't know where to go first—the daycare or home.

Marjorie still can't move. A neighbour's house a few doors down slid back from the road by about 20 feet when the side of the ravine gave way. The ravine runs along the backyards of all the houses for several blocks of their street. Marjorie heard the trees cracking and wood shrieking but doesn't know what has happened. She hears sirens in the distance.

April 20 (1 day after the quake)

After the second aftershock, some of Marjorie's backyard slid into the ravine. The house doesn't seem to be much damaged, but she needs someone to look after her and Henry and Heather can't be here right now. Marjorie is at a friend's house, a few blocks from home but away from the ravine. Her neighbour found her under the bookcase. She is hurt, but much less seriously than others.

Henry is with Heather at the hospital, waiting for news of Emma. Neither have slept and both have walked many kilometres over the last day, trying to find their family. Heather found Henry yesterday afternoon at the daycare, where emergency crews were recovering victims. Though now at the hospital, Emma hasn't received more than preliminary care. The hospital is overwhelmed with the number of people in need.

Most people in residential neighbourhoods are likely to shelter in place or be displaced for relatively short periods of time following the earthquake. However, there are isolated pockets of significant building damage that will result in longer-term displacement during the recovery process.

The most vulnerable populations are in areas likely to sustain the highest levels of earthquake damage, casualties, and social disruption.

BUILDING PERFORMANCE

RESIDENTIAL BUILDINGS

Concentrated pockets of extensive or complete damage to residential buildings of all types are expected in the older residential neighbourhoods of Norgate, Pemberton Heights, Highlands, Edgemont, Lower Lynn, and Riverside—areas that would be exposed to a combination of extreme shaking and ground failure during a major earthquake.

More than 215 residential buildings in these areas are likely to sustain permanent structural failure and would be in imminent danger of collapse. The majority pre-date modern building design guidelines for seismic safety. Hotspots of expected building damage include older neighbourhoods built on deposits of sand and clay along the waterfront and on unstable glacial and valley fill deposits (escarpments) along the Capilano, Lynn, and Seymour rivers.

CHILD AND ELDER CARE FACILITIES

The DNV has over 90 child and elder care facilities. They include a mix of public and private facilities in commercial and residential buildings that are exposed to a wide range of seismic hazards. More than 95% of these buildings are expected to sustain little or no significant damage in the earthquake. However, a few of these care facilities are located in older concrete and unreinforced masonry buildings located in low-lying neighbourhoods—areas that will experience severe ground shaking and liquefaction.

Photo: FEMA

PUBLIC SAFETY

DISPLACEMENT AND SHELTER NEEDS

Most people displaced by the earthquake will seek short-term shelter with family and friends while others will stay in motels or arrange rental accommodation in areas with little or no damage. Those whose homes are not habitable may be forced to relocate. Several hundred people will likely not have the means to provide for themselves and will seek public shelter and emergency services that could be provided by relief organizations.

It is anticipated that many hundreds of people will be seeking short-term shelter and social assistance in the weeks and months following the earthquake. The majority of people in the DNV are expected to stay in their homes, but approximately 4,250 people will need to seek shelter elsewhere. About 2,600 people are expected to return home within one month, and an additional 300 people are expected to return after six months. More than 1,350 people will be displaced for up to a year, possibly longer.

More than 600 homes are likely to sustain damages that would make them uninhabitable during the first 20 days of the recovery process. Most people who have been displaced will return to their homes within the first three months as potable water and electrical power services are restored.

Areas of more extensive damage and building collapse are likely to be cordoned off for up to a year during the recovery process. Hotspots of concern include neighbourhoods along the valley escarpments of Lynn Creek and Seymour River.

DAY vs. NIGHT

More casualties are expected during an earthquake that happens during the day when residents are at work or away from home. At night, most residents will be at home, and most live in wood frame houses resilient to major damage.

CASUALTIES

If the earthquake happens during the day, more than 2,000 people are likely to need immediate medical attention and several hundred people are likely to sustain life-threatening injuries resulting in hospitalization and possibly death. Most of the fatalities are expected to be caused by older buildings toppling or collapsing due to structural failure.

Areas of concern include the Lower Lynn-Maplewood area where more than 1,000 people are expected to sustain serious injuries that would require immediate medical care and the Norgate area where more than 650 people are expected to need paramedic services. The number of serious injuries across the DNV requiring advanced medical care is likely to overwhelm the capacity of existing hospital resources.

Photo: FEMA

LIFELINES

ROADS AND EMERGENCY ROUTES

Road networks are vulnerable to damage from severe ground shaking, liquefaction, and earthquake-triggered landslides. Second-order impacts resulting from road damage include vehicle accidents and hazardous material spills, both of which can cause injury and loss of life.

Disaster debris can block roads and restrict access to hardest hit areas by first responders for days and weeks following the earthquake. The amount of debris generated during an earthquake has the potential to limit access to road and rail networks that are vital during the response and recovery process.

Disaster response routes are a provincial and municipal government priority. Routes along the waterfront and major east-west transportation corridors that cross the Capilano, Lynn, and Seymour valleys are especially important to maintain. These routes, including their bridges, receive upgrades to keep them in good operating condition and resilient to earthquake damage.

Even with these upgrades, however, some damage can be expected, which may impede emergency response efforts and delay the repair of water and electrical lines by repair service trucks and equipment.

WATER AND ELECTRICAL SYSTEMS

It is estimated that nearly one third of the utility (water and electricity) infrastructure in the DNV will be affected by a major earthquake. Utility systems are expected to sustain damage and loss of functionality in low-lying areas along the waterfront, and in older residential neighbourhoods at higher elevations where more of the pipes are older and susceptible to damage in an earthquake. Of particular concern are water facilities adjacent to the Capilano Reservoir and pumping stations that service the Cleveland, Upper Lynn, and Northlands neighbourhoods.

Electrical and water systems are both expected to sustain a 50% drop in service capacity on the day of the earthquake. As many as 14,700 homes will be without power and 15,000 homes will be without access to potable water. Without these, residents will not have access to water for drinking or washing, or access to electricity to power lights, appliances, heaters, computers, and more.

It is expected that potable water services will be restored within the first month of the recovery process. However, pockets of service disruption are likely to persist for up to three months or longer, depending on the availability of utility repair crews.

DISASTER DEBRIS

Roughly 280,000 tons of disaster debris could be generated by the earthquake. This includes nearly 160,000 tons of steel and concrete and 120,000 tons of mixed wood, brick, glass, and general building debris (11,200 truckloads).

Areas with the most disaster debris will be found in higher-density town centres where there is a lot of building material in place, and in older neighbourhoods where a higher proportion of buildings are likely to sustain extensive or complete damage.

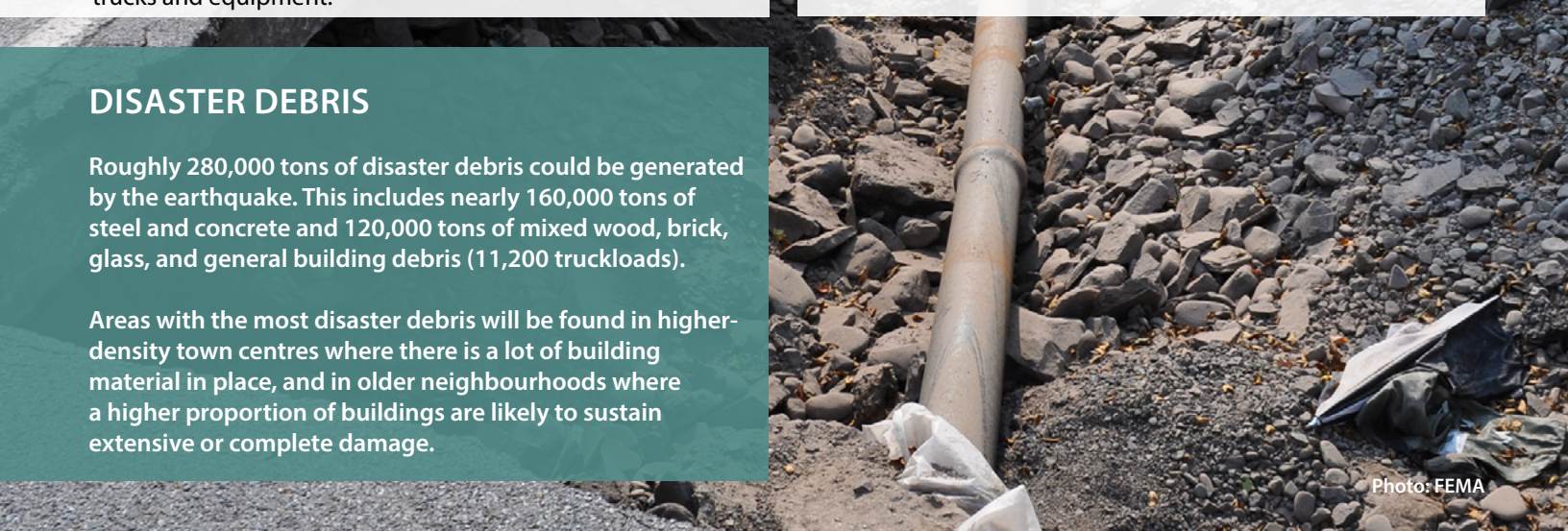


Photo: FEMA

ECONOMIC SECURITY

EMPLOYMENT

More than 18,000 employees are likely to be displaced as a result of business disruption caused by building damage and/or the loss of essential services such as water and electricity. More than one third of those displaced will return to work within the first week. However, more than 11,000 employees will be displaced for up to three months with as many as 8,500 still unable to return to their place of work up to one year after the earthquake.

Residents who are employed in the DNV will experience work disruption, leading to reduced income. This may threaten a household's ability to provide for itself and make repairs. The extent of business disruption is expected to have a significant and long-lasting impact on the community.

Residents who are employed outside of the DNV will also be affected since they may experience challenges travelling to work or be employed at a workplace suffering damage.

SERVICES

The goods and services residents rely on every day will be disrupted during an earthquake. Shops may be closed, or open but not able to restock their inventory. Residents will likely have to rely on the food and household supplies they have on hand—possibly for days or weeks. Community services like recreation centres and libraries will be closed until they can be assessed for damage and public safety.

INSURANCE

Residents who have earthquake insurance will be able to seek assistance from their insurance providers to address damages to their homes. However, deductibles are typically very large, and must be paid in full before insurance will step in to cover the remaining costs. Investing in seismic upgrades and non-structural mitigation will help to reduce damage.

Photo: FEMA

BUSINESSES

April 19

8:44 EARTHQUAKE!

Amy and Jaf are talking about the day's work plan when their desks start shaking, hard. Overhead, the ceiling fan swings wildly, and around them computer monitors and office equipment crash to the floor. There's a loud, ripping crack behind them, and they watch as a jagged fracture line shoots across the wall. They dive under their desks as the wall starts to lose large pieces of drywall, then chunks of concrete.

Ameera is huddled beside a mailbox. She is only a few blocks from work, and was walking from the bus stop when the ground began to shake. She lost her footing and fell on the side of the street. The buildings around her are falling apart, debris landing all around her.

8:49 AM (5 minutes after the quake)

Ameera is slowly walking down the street to the design studio. She is in shock and doesn't know what to do. Around her many buildings have become piles of rubble, and many others show damage to their facades—windows, signs, and awnings are on the ground. She doesn't know what kind of damage has happened inside. Ameera keeps moving in the direction of the studio, picking her way slowly around cars and debris.

Sections of the roof and side wall narrowly missed Amy when they came down. She's been cut and bruised by the debris that showered down on them. Amy thinks she's in an open pocket that was somehow created around her when the building collapsed. Everything is covered in dust. She can see Jaf trapped under his desk but can't tell how badly he's hurt. He isn't moving, and there's such a mess of furniture, concrete, wire, and glass around her that she can't get to him.

Photo: FEMA

9:54 AM (1 hour after the quake)

Emergency crews are trying to respond to areas they know are in crisis. They are only just beginning to get a sense of how much damage there is and how many people urgently need their help. Crews are trying to make their way to the older commercial and industrial buildings along the waterfront but are making very slow progress due to the amount of debris and vehicles on the road. The buildings are very badly damaged and the risk to the crews is high, but they know people are hurt and trapped in the rubble.

When Amy heard Ameera calling her name she called back, over and over again, until Ameera found her. Both women are now trying to get to Jaf, who hasn't responded to their calls. Another of Amy's team, Greg, has just joined them. Greg was about four kilometres away when the shaking started. He waited out the shaking in his car, and then managed to drive another two blocks before the street became too congested to go further. He ran the rest of the way to work.

April 20 (1 day after the quake)

Amy is at home in her condo in Lower Capilano-Marine. The condo was built within the last ten years and has experienced relatively minor damage. Her dog, Coda, is unhurt, and the building has water and power, but her possessions have shaken onto the floor and are strewn everywhere. Greg brought her home this morning, Ameera with her. They were up most of the night trying to get to Jaf, and only stopped this morning when they managed to alert the emergency crews who were canvassing streets near the waterfront looking for people hurt or trapped in the rubble.

The paramedic who assessed Amy's condition outside the studio didn't want to release her, but with so many more serious injuries throughout the community she will not be going to the hospital—there isn't room. Ameera will stay with her. In fact, Ameera needs a place to stay since transit isn't running and the bridges to downtown are closed. They don't know if Jaf is alive or not.

Amy's business has been devastated. She was leasing the building, so she didn't lose that asset when it collapsed, but she no longer has a work site. She has some of her files at home, though not all were backed up when the earthquake hit. Her business no longer has any equipment, and though Amy bought business contents insurance, she does not have earthquake coverage or business interruption insurance.

Damages to commercial and industrial businesses along the waterfront will result in disruption to jobs and wages, the impacts of which will ripple through the community. Hardest hit will be employees in small retail and large industrial businesses located in older buildings susceptible to higher levels of earthquake damage.

BUILDING PERFORMANCE

COMMERCIAL AND INDUSTRIAL

Larger businesses are concentrated in mixed-use neighbourhoods and commercial-industrial zones located in areas exposed to higher levels of ground shaking and liquefaction. Hotspots of concern include concentrations of older commercial buildings in Lower Capilano-Marine, Norgate, Edgemont, and Lower Lynn, and established industrial facilities along the waterfront in Norgate, Lower Lynn, and Maplewood. More than 250 buildings in these areas are likely to be damaged beyond repair as a result of severe ground shaking, liquefaction, and toppling of taller buildings. The majority of these are older concrete and unreinforced masonry structures built prior to the introduction of modern seismic design guidelines.

The extent and concentration of damage in these areas will be significant and will likely result in large parts of the business district being cordoned off during the recovery and rebuilding process.

HOME-BASED BUSINESSES

It is estimated that 1,300 buildings in the DNV are used as home-based businesses. The majority of these are wood frame structures that are expected to sustain little or no damage in the earthquake, but at least 30 buildings are likely to be damaged beyond repair. The most vulnerable of these are pre-code wood frame and unreinforced masonry buildings located in the Lower Capilano-Marine, Edgemont, Lower Lynn, and Riverside areas.

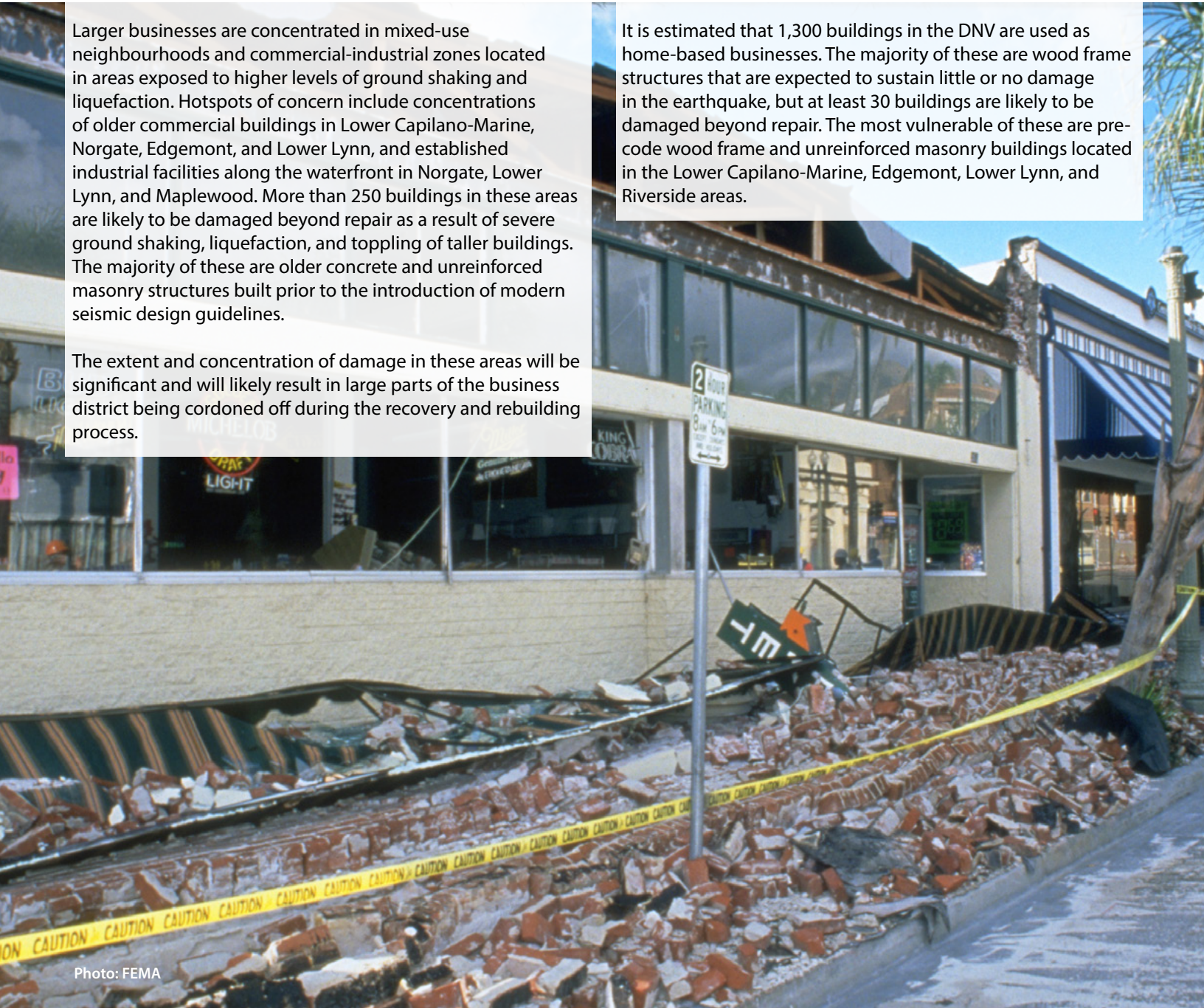


Photo: FEMA

LIFELINES

WATER AND ELECTRICAL SYSTEMS

Electrical power will be restored relatively quickly to nearly 90% of pre-earthquake levels one week after the earthquake, leaving about 3,250 homes and businesses without access to electrical services. Full recovery of electrical services is expected to take several months.

Returning potable water systems to pre-earthquake levels will happen more quickly and is highly dependent on the number of people available to repair leaks and breaks to water pipelines. It is estimated that nearly half of all homes and businesses in the DNV will still be without access to potable water one week after the earthquake. Full service capacity is expected to be restored within one month after the earthquake.

Damages to regional water mains, wastewater trunk lines, and related pumping facilities will have a significant impact on service capacities for other municipalities in the Metro Vancouver area. Shared infrastructure along the Capilano and Seymour valleys provides many municipalities with access to drinking water and wastewater management.

INTERDEPENDENCIES

Businesses rely on complex support networks to function. Infrastructure and utility lifelines play a vital role in that support network. Water and electricity are critical to daily operations, and transportation networks facilitate the movement of goods, employees, and customers.

Businesses also rely on supporting industries and supply chain partners for necessary goods and services to operate. The shutdown of an upstream supplier or transportation company that is essential for the flow of goods and services may cause a business to falter, even if there is no significant damage to the building in which the business operates. There are many such business interdependencies within the DNV and neighbouring municipalities, particularly among port-based industries along the waterfront.

TRANSPORTATION NETWORK

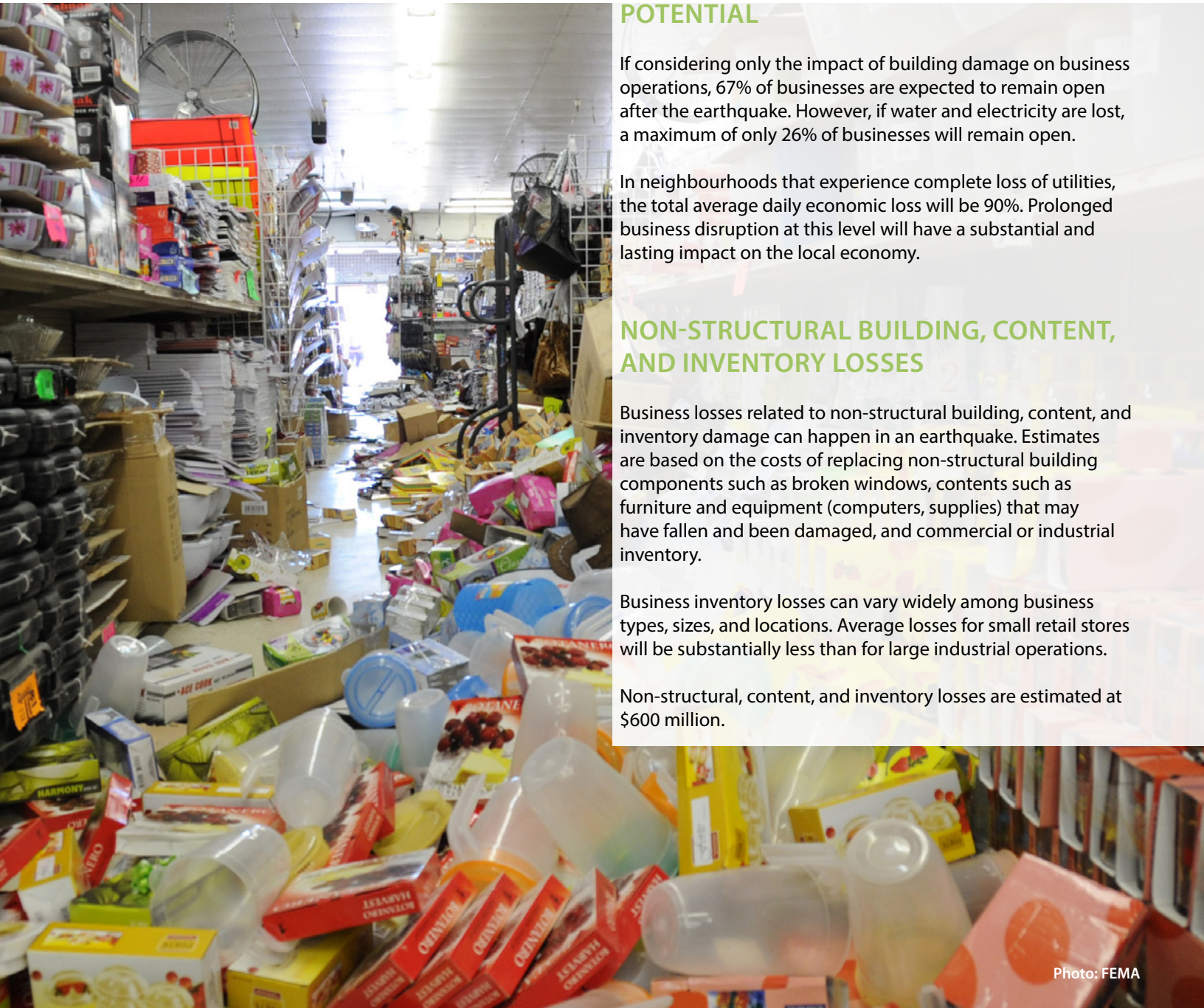
Significant interruptions are expected to the flow of goods and services that will be essential during the recovery process. Major east-west transportation corridors along the waterfront and that cross the Capilano, Lynn, and Seymour valleys will be disrupted, as will other important east-west connectors and neighbourhood streets.

Rail lines along the industrial waterfront are expected to remain operational in Maplewood and Lower Lynn, but are likely to sustain damages that would require repair in Norgate and Lower Capilano.

Though vital to the transportation network, major road and rail bridges that cross Burrard Inlet and connect the DNV to other parts of the Metro Vancouver region were not assessed.

Photo: FEMA

ECONOMIC SECURITY



BUSINESS DISRUPTION AND LOSS POTENTIAL

If considering only the impact of building damage on business operations, 67% of businesses are expected to remain open after the earthquake. However, if water and electricity are lost, a maximum of only 26% of businesses will remain open.

In neighbourhoods that experience complete loss of utilities, the total average daily economic loss will be 90%. Prolonged business disruption at this level will have a substantial and lasting impact on the local economy.

NON-STRUCTURAL BUILDING, CONTENT, AND INVENTORY LOSSES

Business losses related to non-structural building, content, and inventory damage can happen in an earthquake. Estimates are based on the costs of replacing non-structural building components such as broken windows, contents such as furniture and equipment (computers, supplies) that may have fallen and been damaged, and commercial or industrial inventory.

Business inventory losses can vary widely among business types, sizes, and locations. Average losses for small retail stores will be substantially less than for large industrial operations.

Non-structural, content, and inventory losses are estimated at $600 million.

Photo: FEMA

MUNICIPALITY

April 19

8:44 EARTHQUAKE!

Graham opens the DNV's mapping files from his laptop and starts to spread the drawings out over the table when the room starts vibrating, then shaking, and the meeting room's white board crashes to the floor. Graham drops down to take cover under the table and holds on. The shaking lasts for about 20 seconds, though it seems longer. When it's over, some of the chairs have toppled but he doesn't see any significant damage.

8:49 AM (5 minutes after the quake)

An engineer from Graham's department is needed at the North Shore Emergency Management Office (NSEMO) where an Emergency Operations Centre (EOC) is being set up. Graham was asked to go, so he is heading there now, on his bike. As he rides, he sees damage everywhere. Traffic is almost at a standstill.

9:54 AM (1 hour after the quake)

Graham got to the EOC about 40 minutes ago. Staff from all three North Shore municipalities were already here when he arrived, and many more have joined them since. He is representing the Engineering departments within the larger Operations team, working closely with Police, Fire, Health, and Emergency Support Services representatives. Other teams in the office are tasked with Planning, Logistics, Communications, Finance, and more.

Everyone has contributed information about the earthquake's impact in the community from what they saw on their way to the office. These "windshield" reports are being gathered together on a map and as a timeline of events for the EOC team to respond to. Graham reported a fire hydrant that was knocked over by a car and flooding the street, and facade damage to the recreation centre that he passed by en route to NSEMO. Others have added to the list, which is getting longer by the minute.

With telecommunication lines down it has been difficult to start the response effort. Graham has been trying to contact the road repair and utility repair crews, but can only use radio, and the people on the crews may be having emergencies of their own. He hasn't been able to reach his partner, Nadia.

April 20 (1 day after the quake)

Still at the EOC, Graham is working his third shift after an intense day and night. Over the last 24 hours he has been coordinating work crews to respond to buildings, roads, and utility infrastructure. Crews have inspected recreation centres and other facilities so that they could become temporary shelter sites or "reception centres" for people who can't get home or whose homes have been severely damaged. Crews have also inspected bridges and potable water and wastewater facilities, cleared roads of debris, redirected traffic, started repairs to pipelines, and more.

Graham is currently trying to coordinate response and repair activities with the regional and provincial agencies that share responsibility for infrastructure networks. Every available crew member and every private engineering consultant that the North Shore municipalities have access to is out in the field. They are running at full tilt, and still the damage reports are coming in.

Coordination with other North Shore municipalities at a joint Emergency Operations Centre will happen immediately after an earthquake hits.

BUILDING PERFORMANCE

MUNICIPAL BUILDINGS AND ESSENTIAL FACILITIES

The majority of municipal buildings (120) are expected to sustain little or no damage in the scenario earthquake. However, at least 30 municipal buildings are expected to sustain significant levels of damage, and 20 of these are likely to be damaged beyond repair. Buildings of concern include the DNV's Operations Centre and related structures in Lower Lynn, and a variety of historic buildings and recreational facilities in Norgate, Edgemont, Delbrook, Maplewood, and Dollarton.

Police services and the North Shore Emergency Management Office were intentionally co-located in a newer building adjacent to the Lions Gate Hospital in the City of North Vancouver. All of these facilities are on firm ground and are expected to perform well in a major earthquake.

Emergency fire and paramedic services within the DNV are likely to be affected. Fire Hall #2 and nearby emergency supply storage and training facilities in Lower Lynn are susceptible to damages caused by severe ground shaking and liquefaction and are expected to be operating at less than 25% capacity in the days following a major earthquake. Fire Hall #3 has recently been redeveloped to a higher seismic code and is expected to stay operational after an earthquake.

SCHOOLS

There are 35 schools and a major university in the DNV that collectively encompass 115 structures (buildings and related facilities). The structures of four elementary and secondary schools have been upgraded as part of the provincial seismic retrofit program and three more schools are in the process of being retrofitted to comply with current design guidelines for life safety. As a result of these mitigation efforts, approximately 80 of the 115 structures (70%) are expected to sustain little or no damage from the earthquake.

It is estimated that 25 structures (22%) are vulnerable to moderate levels of damage that will 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.

At least 10 structures (8%) are likely to sustain extensive and complete levels of damage. Hotspots of concern include older concrete buildings and related facilities that have yet to be seismically upgraded in Norgate, Lower Lynn, and Maplewood—areas that will experience severe levels of ground shaking and liquefaction.

EMERGENCY OPERATIONS

Lions Gate Hospital is the fourth busiest in the Metro Vancouver area, providing a full range of general and specialized acute care services and a bed capacity of 270. Though the hospital is expected to sustain only minor damage, the number of injuries in the DNV requiring specialized acute medical care would exceed current service by twice its capacity.

Emergency response facilities in areas hardest hit by the earthquake are expected to sustain structural and non-structural damages that would significantly reduce functional capacities in the early stages of emergency response operations.

LIFELINES

WATER AND ELECTRICAL SYSTEMS

Utility and related lifeline services are particularly vulnerable to earthquake damage and loss of functionality in areas of severe ground shaking, and in older neighbourhoods where pipelines are constructed of older brittle materials that are less resistant to damage. It is estimated that nearly one third of the utility infrastructure in the DNV would be affected by a major earthquake.

Expected damage to potable and wastewater pipelines is measured in terms of the number of leaks and breaks that are likely to occur within the network. For potable water pipelines in the DNV, there are likely to be 40 leaks at pipe joints and 60 breaks resulting in localized pipeline failure. For wastewater pipelines, the estimate is 100 leaks and 160 breaks. Though the majority of potable water facilities in the network are likely to sustain little or only moderate damage in this earthquake, at least two facilities are expected to have reduced functionality in the days following the earthquake.

Areas of concern are concentrated in two corridors. One corridor holds potable water facilities and pipeline infrastructure that runs roughly northwest to southeast through the neighbourhoods of Handsworth, Capilano, Pemberton Heights, Lions Gate, and Norgate. At least one pumping station at the Capilano Reservoir and both water main and distribution pipelines are expected to sustain damage and loss of functionality. Wastewater infrastructure here includes primary trunk lines, secondary pipes, and storm sewers.

The other main corridor runs north to south and includes pumping stations, water lines, and wastewater infrastructure along the Lynn and Seymour valley escarpments and within the neighbourhoods of Lower Lynn and Maplewood. Damages and corresponding loss of functionality are expected for portions of the water main and secondary distribution lines in Lower Lynn and Maplewood and pumping stations in Upper Lynn and Northlands.

Electrical substations near the Capilano Reservoir and adjacent to the Capilano River, as well as those in the Seymour Creek Reserve, are expected to sustain damage and loss of functionality.

TRANSPORTATION NETWORK

Seismic upgrades to bridge facilities in the past few years have improved overall resilience of the transportation network. Anticipated roadway damage includes slumping, caving, and lateral displacement of retaining walls and reinforced earth structures causing local rupture of highway segments.

Areas of particular concern include designated disaster response routes along the waterfront and major east-west transportation corridors that cross the Capilano, Lynn, and Seymour valleys. Portions of the disaster response route that are expected to sustain damage and loss of functionality during the earthquake include a short segment of Highway 1 north of the Ironworkers Memorial Bridge and associated off ramps, a 1-km section of highway crossing the Seymour and Lynn valleys, and a shorter section of highway near the Lynn Valley exit.

Other important connectors that are likely to be affected include east-west sections of the Dollarton Highway and Seymour Parkway where they cross the Seymour Valley and short sections of Mountain Highway and Capilano Road where they cross Highway 1. Secondary boulevards and avenues are likely to be damaged and in need of repair in the neighbourhoods of Maplewood, Lower Lynn, Seymour Creek Reserve, and Riverside. Rail lines along the industrial waterfront are likely to sustain damage in Norgate and Lower Capilano.

Though areas of damage to roads, rails, and bridges are relatively small, it is expected that loss of functionality in key areas of the transportation network will likely result in significant social disruption to the region overall.

ECONOMIC SECURITY

CRITICAL INFRASTRUCTURE LOSSES

Total capital losses for lifeline systems damaged in the scenario earthquake are estimated to be over $25 million. About 78% of these losses are the costs of repairing roads damaged by ground failure.

Capital losses to water utility systems are estimated at $5 million. Losses specific to potable water systems are $2 million, with more than half of these losses caused by damage to treatment and pumping facilities and the balance shared between pipelines and water distribution lines. Losses specific to wastewater systems are $3 million and are evenly allocated between pipelines and distribution lines. Losses related to major electrical facilities and natural gas pipelines have not been determined.

Direct losses to road and rail networks are estimated at $20 million. Close to $17 million will be needed to repair highways and secondary roads. Also included is $3 million to repair rail lines, $1 million of which is for rail infrastructure that serves port facilities along the waterfront. Bridge repair costs are relatively small ($210,000), though this assessment only accounts for municipal infrastructure.

Not included in this analysis are direct economic losses to bus, ferry, and port facilities in the DNV. Capital losses to port facilities are expected to be substantial as they are likely to sustain significant damage caused by severe shaking and liquefaction along the waterfront. Prolonged disruption of port operations will likely interrupt international trade and have a profound impact on both regional and national economies.

LOSSES OVERALL

The combined losses to homeowners, businesses, and government operations will have a profound and lasting impact on the economic security and resiliency of the community. Direct economic losses—those resulting directly from the earthquake—are estimated at $3 billion. Anticipated capital losses make up $2.3 billion of the total, and an additional $645 million in lost revenue will be caused by service disruption in the weeks and months following the earthquake.

Photo: Denise Relke

WHAT CAN WE DO TO PREPARE AND RECOVER?

COMMUNITY

Our actions can change the story's outcome. What would happen if we were more prepared? *Let's start again...*

April 19

8:44 EARTHQUAKE!

In Westlynn Terrace, Marjorie puts her tea down and stands to reach for a book in the bookcase when everything around her starts to shake. The shaking makes her unsteady and she falls to the floor, along with the cup of tea, which shatters. Books fall from the case, landing on and around her, but the bookcase is attached to the wall and doesn't move.

Marjorie's granddaughter, Emma, arrived at her daycare in Lower Lynn about 15 minutes ago and is still settling in with the other children when the room begins shaking. They are in a group in the middle of the room, under suspended overhead lights. The building is new. The old, pre-code masonry building that used to house the daycare was demolished last year and a new building was built on the site.

Emma's dad, Henry, is driving to his first customer of the day when his van starts to bounce. The cars in front of him screech to a halt. They don't all stop in time and some are rear-ended, while a few others jump the sidewalk and another crosses the centre line into oncoming traffic. Henry watches as a powerline leans slowly into the street and the power cable suddenly snaps, spraying sparks.

Henry's partner, Heather, has arrived at work and is preparing for a staff meeting in the fourth floor conference room. When the shaking starts, Heather dives under the table and tries to hold on. She is only a few feet from the window when it shatters, sending glass fragments through the room and onto the street below.

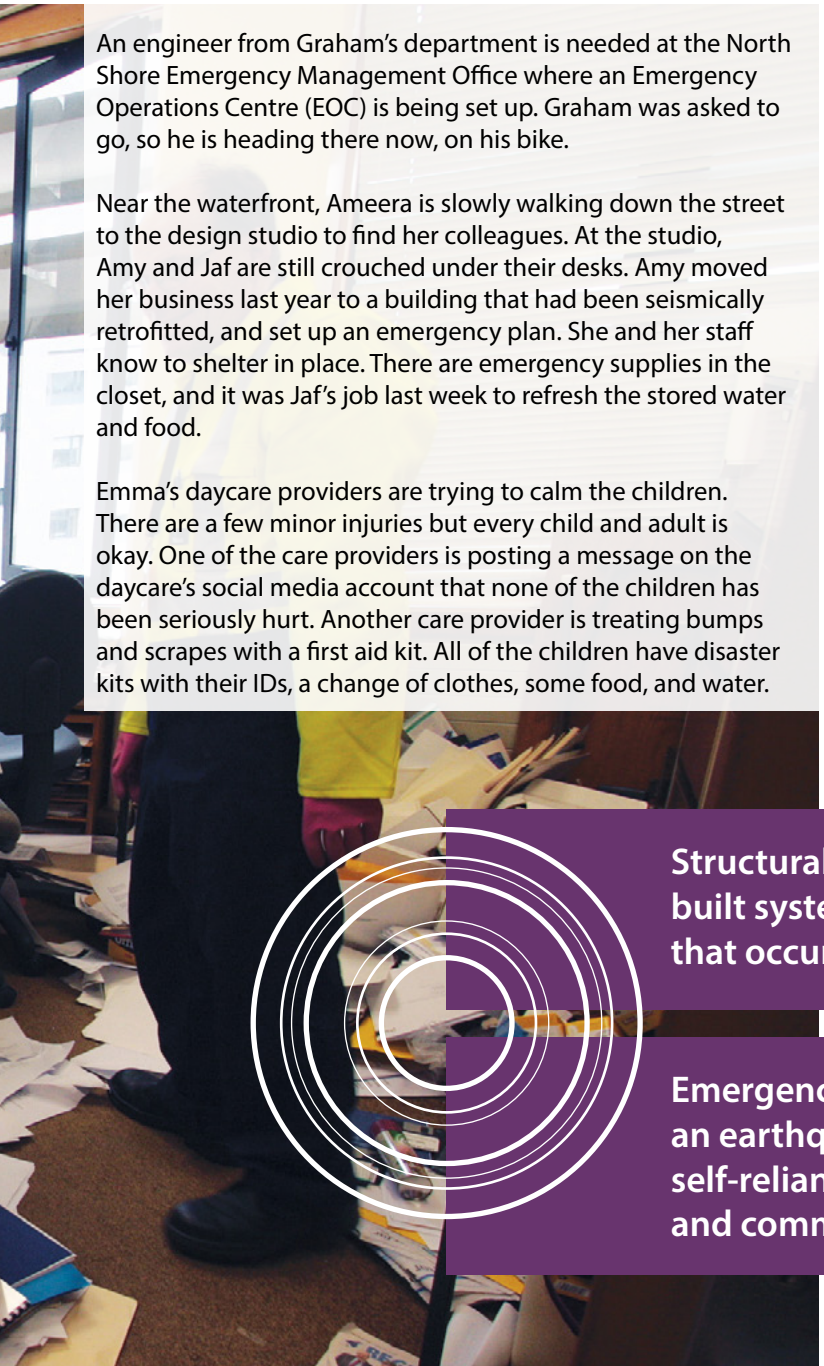
At Amy's design studio near the waterfront, she and Jaf are talking about the day's work plan when their desks start shaking, hard. Overhead, the ceiling fan swings wildly, and around them loose items like pens and phones fly off the desks. The larger equipment is restrained, attached to desks and walls. They dive under their desks to wait out the shaking, holding on.

Amy's colleague Ameera is outside huddled beside a mailbox. She is only a few blocks from work, and was walking from the bus stop when the ground began to shake. She lost her footing and fell on the side of the street. There is some debris falling around her from nearby buildings, but most of the buildings have had their structures upgraded in recent years.

At his office in the DNV's Engineering Department, Graham is starting work when the room starts vibrating, then shaking. Graham drops down to take cover under the table and holds on. The shaking lasts for about 20 seconds, though it seems longer. When it's over, some of the chairs have toppled but he doesn't see any significant damage.

Photo: Ann (Helen) Devereux (FlickrCC/annzstream)

8:49 AM (5 minutes after the quake)



An engineer from Graham's department is needed at the North Shore Emergency Management Office where an Emergency Operations Centre (EOC) is being set up. Graham was asked to go, so he is heading there now, on his bike.

Near the waterfront, Ameera is slowly walking down the street to the design studio to find her colleagues. At the studio, Amy and Jaf are still crouched under their desks. Amy moved her business last year to a building that had been seismically retrofitted, and set up an emergency plan. She and her staff know to shelter in place. There are emergency supplies in the closet, and it was Jaf's job last week to refresh the stored water and food.

Emma's daycare providers are trying to calm the children. There are a few minor injuries but every child and adult is okay. One of the care providers is posting a message on the daycare's social media account that none of the children has been seriously hurt. Another care provider is treating bumps and scrapes with a first aid kit. All of the children have disaster kits with their IDs, a change of clothes, some food, and water.

At her office, Heather tries to call her mother, Marjorie, at home, but the network is busy. With her cell phone she texts Henry. Is he okay? Is he still with Emma? She remembers the social media account the daycare set up—just last month—and sees the message that Emma is safe. Then she sends a message to the social media page that the residents of her block set up for emergencies, asking if someone can check in on her mother.

Marjorie is at the neighbourhood meeting spot on the corner with a gathering group of residents. She has her grab-and-go kit with basic supplies. One of her neighbours standing with her saw Heather's post and is writing back that Marjorie is unhurt and with her neighbours.

Henry's van is hemmed in on all sides with other vehicles. He can't get a network connection on his phone, but he knows he needs to get to the daycare. Their family's emergency plan requires that they meet at home if it is after work hours, but if an earthquake happens during the work day when Emma is in care, they've decided that Henry will go to the daycare. He sets off on foot, trying for a network connection as he goes.

Structural mitigation of vulnerable buildings and built systems will reduce the amount of damage that occurs.

Emergency management activities prepared before an earthquake happens will increase the awareness, self-reliance, and response capabilities of individuals and communities following the disaster.

9:54 AM (1 hour after the quake)

Heather and her coworkers are sheltering in the office. Her employer's emergency plan identifies this as the safest option for employees, and has a store of emergency supplies, a generator, radio, food, and water. There is broken glass everywhere and some furniture has fallen over, but otherwise not much damage that they can see. Heather received a text from Henry that he is with Emma and Marjorie and all are unhurt.

Marjorie, Henry, and Emma have reunited outside of their house. A neighbour's house a few doors down slid back from the road by about 20 feet when the side of the ravine gave way. The ravine runs along the backyards of all the houses for several blocks of their street. They decide to not enter their house until they can be sure of their safety.

At Amy's design studio, Ameera has joined them and so has Greg. Greg was about four kilometres away when the shaking started. He waited out the shaking in his car, and then managed to drive another two blocks before the street became too congested to go further. He ran the rest of the way to work.

Graham got to the EOC about 40 minutes ago. Staff from all three North Shore municipalities were already working when he arrived, and many more have joined them since. Reports are being gathered together on a map and also as a timeline of events for the EOC team to respond to, but with telecommunication lines down it has been difficult to start the response effort. Graham has been trying to contact the road repair and utility repair crews, but can only use radio, and the people on the crews may be having emergencies of their own.

Emergency crews are trying to respond to areas they know are in crisis. They are only just beginning to get a sense of how much damage there is and how many people urgently need their help. Crews know where to respond first and are able to take action because the municipalities have conducted risk assessments that identify the most vulnerable areas. This has allowed them to pre-position medical and utility repair supplies in key locations.

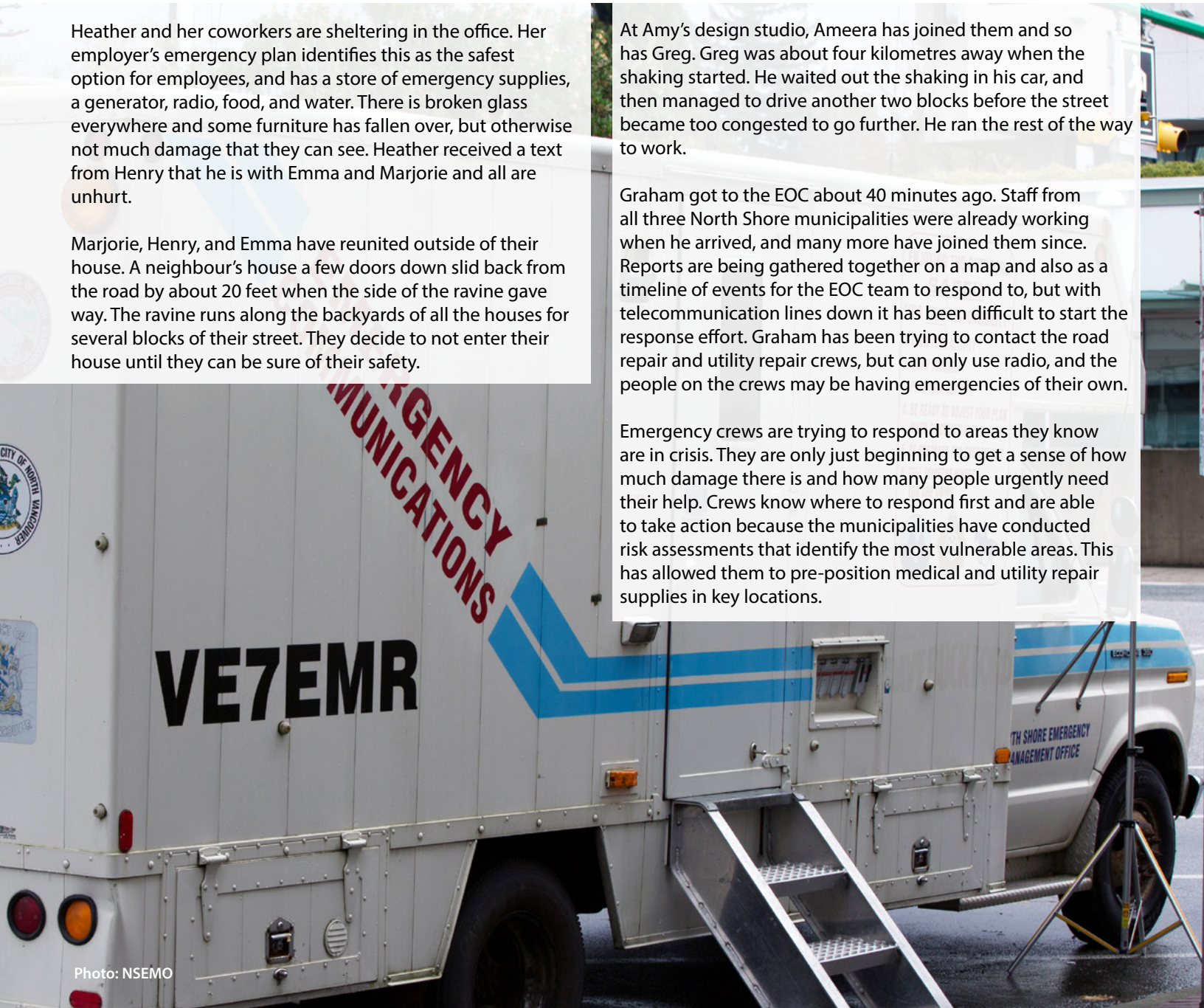


Photo: NSEMO

April 20 (1 day after the quake)

Still at the EOC, Graham is working his third shift after an intense day and night. Over the last 24 hours he has been coordinating work crews. They have opened reception centres, inspected bridges and potable water and wastewater facilities, cleared roads of debris, redirected traffic, started repairs to pipelines, and more.

Graham is currently trying to coordinate response and repair activities with the regional and provincial agencies that share responsibility for infrastructure networks. Every available crew member and every private engineering consultant that the North Shore municipalities have access to is out in the field. They are running at full tilt, and still the damage reports are coming in. The Province has declared a provincial state of emergency and additional help is on its way from across Canada and the US.

Photo: DNV

Graham was finally able to talk to his partner, Nadia. Their older house was severely shaken, but was still standing. The basement renovation to bolt sill plates to the foundation and brace the walls has helped the house withstand the shaking.

After the second aftershock, some of Marjorie's backyard slid into the ravine. The house doesn't seem to be much damaged, but hasn't been assessed yet. Heather has joined her family and they are staying with neighbours for the next few days as they wait for the seismic activity to lessen. Aftershocks can go on for months.

Amy is at home in her condo in Lower Capilano-Marine. The condo was built within the last ten years and has experienced relatively minor damage. Her dog, Coda, is unhurt, and the building has water and power, but her possessions have shaken onto the floor and are strewn everywhere. Ameera is with her. She needs a place to stay since transit isn't running and the bridges are closed for 24 hours for assessment.

Amy has heard from most of her staff that they are safe. She has closed the office for at least a week as everyone attends to their personal lives. Her condo will be her office for a while, and those of her staff who can will work from home until they get the all-clear to go back to the studio. Amy is contacting her insurance agent to start the process of getting her business up and running at full capacity again.

The impacts of a major earthquake will have long-lasting consequences in the community. In the weeks, months, and years that follow, how well we recover depends on the actions we take now—together.

WE CAN TAKE ACTION

BECOMING DISASTER RESILIENT

The focus of this chapter is to report the impact that structural mitigation measures will have on the community. Results comparing what we could expect today without seismic mitigation (the current scenario) against what we could expect today if seismic upgrades for buildings were already in place (the mitigation scenario) are described for building performance, public safety, and economic security; lifelines (water and electrical systems and transportation networks) are described only qualitatively.

This chapter also includes examples of adaptation measures that residents, businesses, and the municipality can do to increase community resilience.

"What makes a city resilient to natural and human-induced hazards can be seen as a combination of resilience accumulated through the process of urbanisation and planning, on one hand, and the result of specific actions to reduce disaster risk on the other."

United Nations, Making Cities Resilient Report 2012, p10

Photo: DNV

MITIGATION ACTIONS: STRUCTURAL AND NON-STRUCTURAL

Earthquake mitigation encompasses those actions that can be taken before a disaster to reduce vulnerabilities and the potential for future losses. Mitigation investments can be made in structural and non-structural measures.

Structural mitigation involves retrofitting core elements of a building or other engineered structure to increase physical resistance to severe shaking and ground deformation. These seismic retrofits are focused on load-bearing elements such as foundations, walls, beams, columns, floor and roof systems, and the connections between these building components that support a building.

Non-structural mitigation includes measures that minimize the exposure of people and physical assets to known earthquake hazards. Such measures include land use policies and development restrictions, early warning systems, and the physical retrofitting of non-structural building elements (facades, internal partitions, contents, machinery, and utility systems). Of these, land use and development restrictions are by far the most effective means of reducing vulnerabilities and increasing disaster resilience, and work well in areas undergoing growth or redevelopment. Early warning systems and retrofitting of non-structural building components are also effective in protecting people and critical assets during an earthquake, and have the potential to increase resilience during the recovery process.

ADAPTATION ACTIONS: PREPAREDNESS, RESPONSE, RECOVERY

Adaptation encompasses a wide range of measures that are planned for in advance, but implemented after a disaster. They increase the capacity of people, buildings and engineered systems to respond to and recover from the impacts and consequences of a major earthquake.

Adaptation measures include traditional emergency management—planning and preparedness activities that are designed to increase awareness, self-reliance, and response capabilities of individuals and communities following a disaster. They are effective in reducing the time required to restore current levels of functionality during the recovery process, but also have the potential to reduce underlying social and physical vulnerabilities in ways that fundamentally change the risk profile for a community during later phases of rebuilding.

The window of opportunity for implementing adaptation measures following a disaster is often very small and quickly crowded with diverse and often competing public policy issues. The key is to identify those actions with the greatest potential to effect change during the recovery process, and to marshal the resources and capabilities that will be required to implement these measures when the time comes.

ACTION PLAN

DNV's *Earthquake Ready Action Plan* strengthens our capacity to become more resilient to earthquakes in four key areas—mitigation, preparedness, response, and recovery. It focuses on the people, buildings, infrastructure, and systems that are most vulnerable, as identified in this risk assessment. View the *Earthquake Ready Action Plan* at dnv.org/earthquake

STORY MAP

The Story Map helps users to explore some of the concepts of the risk assessment using an interactive map-based tool. Story Map users can zoom into areas of interest on the maps and view layers concurrently, such as building damage along with lifeline disruption, presenting a clear picture of potential impacts at a local level. View the Story Map at dnv.org/earthquake

BUILDING PERFORMANCE

LESS DAMAGE WITH STRUCTURAL MITIGATION

With seismic retrofit measures in place in buildings along the waterfront and valley escarpments, the number of buildings in the DNV likely to sustain damage in the scenario earthquake would be lowered in all damage categories, reducing levels of damage by 80-97%.

While there are no specific legislative guidelines for seismic retrofitting of vulnerable buildings in a community, the Local Government Act does require structures undergoing major renovation or redevelopment to be upgraded in compliance with national standards for building safety.

The general requirements of the National Building Code of Canada are applied through the BC Building Code, which includes elements specific to BC. It applies to all building construction and renovation in BC, and conformance with the code is required by the District of North Vancouver Building Regulation Bylaw. All new development in the DNV will be built to seismic standards.

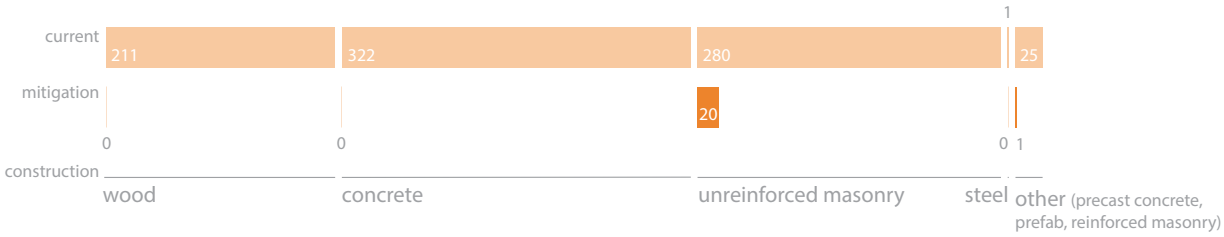
UPGRADING SCHOOLS

The Seismic Mitigation Program is seismically upgrading BC schools to achieve a life-safety standard, minimizing the probability of structural collapse in an earthquake. Since 2001 the BC Government has seismically upgraded or replaced 213 of BC's 339 high-risk schools. Seven schools in the DNV have benefitted from this program.

BUILDING PERFORMANCE INDICATORS

The indicators below consider all buildings in the DNV. The number of buildings damaged beyond repair—buildings with complete or extensive damage—is compared for the current scenario (today, without additional structural mitigation) and the mitigation scenario (today, with additional structural mitigation). Also compared are the current and mitigation scenarios for the amount of time needed to repair and restore damaged buildings.

BUILDINGS DAMAGED BEYOND REPAIR



WEEKS TO RESTORATION

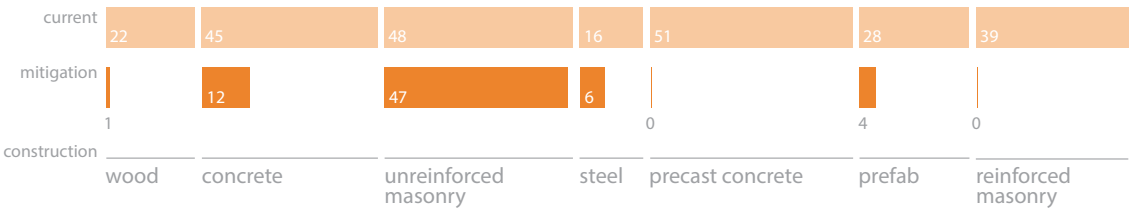


Photo: School District 44

MITIGATION ACTIONS AT HOME

See the US Federal Emergency Management Agency's "How-To Series" on protecting your property from earthquake damage. More at fema.gov

Inside Your Home

- Anchor large equipment properly
- Anchor tall bookcases and file cabinets
- Install latches on drawers and cabinet doors
- Mount framed pictures and mirrors securely
- Restrain desktop computers and appliances

Building Walls, Foundation, and Utilities

- Brace cripple walls
- Bolt sill plates to foundation
- Use flexible connections on gas and water lines
- Anchor and brace propane tanks and gas cylinders


Photo: Nicky Hastings

STEPS TO DISASTER RECOVERY

After any emergency or disaster, there may be an overwhelming anxiety on the many steps involved with the recovery process. See NSEMO's One Step at a Time: A Guide to Disaster Recovery for information on the 10 steps toward recovery that you can expect to take after a disaster. More at nsemo.org

10 Steps Toward Disaster Recovery

1: Take care of yourself and your family
2: Things to do first
3: Re-entering your home
4: Food, medicine, water, and sewage
5: Cleaning up - general
6: Cleaning up - after a flood
7: Cleaning up - after a fire
8: Replacing documents and money
9: Insurance matters
10: Repairing your home

PUBLIC SAFETY

FEWER CASUALTIES, FEWER DISPLACEMENTS

Investing in seismic retrofits that reduce the vulnerability of buildings along the waterfront and valley escarpments would prevent more than 50 critical injuries and fatalities and 100 injuries requiring hospitalization.

Seismic retrofits and construction of new buildings that meet modern safety codes have the potential to reduce social disruption and significantly increase resiliency in the community. The number of people displaced would be reduced by nearly half, while recovery times are likely to be reduced by six months or more with only a few small areas cordoned off for reconstruction.

Investment in such mitigation measures together with emergency planning measures would be effective in reducing underlying social vulnerabilities and increasing capacities of the community to withstand and respond to future disaster events of all types.

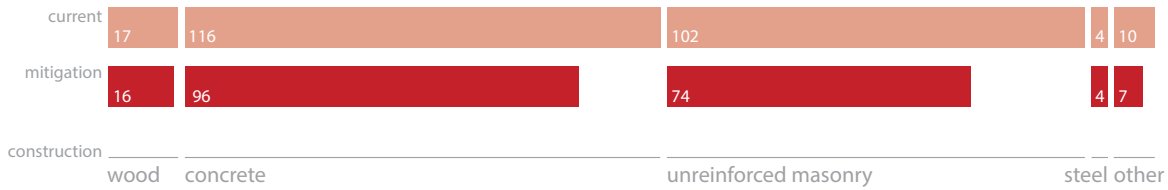
RECEPTION CENTRES

The North Shore has 30 facilities that may be used to support evacuated residents by providing food, clothing, and lodging vouchers. Four major community centres are identified as primary Reception Centres, and three of these can be used as Group Lodging Centres to host approximately 140 displaced people.

PUBLIC SAFETY INDICATORS

The indicators below consider all buildings in the DNV, and injuries are the result of building damage. The number of people who will be critically injured if the earthquake hit during the day is compared for the current scenario (today, without additional structural mitigation) and the mitigation scenario (today, with additional structural mitigation). Also compared are the current and mitigation scenarios for the number of people displaced from damaged buildings for longer than three months.

PEOPLE SUSTAINING CRITICAL INJURIES



PEOPLE DISPLACED FOR GREATER THAN 3 MONTHS

Photo: Gavin Newsom (FlickrCC/mayorgavinnewsom)

HOUSEHOLD EMERGENCY PLAN

A household emergency plan prepares your family to find each other, be safe, and be on your own for at least 72 hours. Your plan should include these actions:

- Know and practice all possible safe exits from home and alternate routes out of the neighbourhood.
- Create emergency kits and grab-and-go bags. These should have copies of personal identification, health information, insurance coverage, and other important information.
- Create meeting places to reunite with family and loved ones. Identify two places to meet: one right outside your home and another somewhere in your community, such as at a library, community centre, or place of worship. Make sure everyone knows the address and phone number of your second meeting place.
- Identify a friend to pick up your child if you are not available.
- Create out-of-area contact cards for each family member. In an emergency the local phone lines will be overloaded and this out-of-area contact number may be easier to call.
- Social media sites will be a great way to get information out to family members during and after an emergency.
- Practice your plan with all household members. Make sure each member has a copy of the household plan.
- Familiarize yourself with emergency plans for your workplace, school, child's school or daycare, and other places you frequently visit.
- Have a plan in place for your pets.

See information on household emergency plans at nsemo.org

LIFELINES

SHARED RESPONSIBILITY

DNV relies on an extensive system of reservoirs, dams, pipes, pumps, roads, rails, bridges, and related built systems to supply a variety of essential lifeline services to the community. The system is jointly owned and operated across several levels of government and by private sector utility and transportation companies. Maintenance and replacement of aging infrastructure is administered by the municipality's Asset Management Steering Committee, which is responsible for municipal roads, bridges, recreation centres, libraries, waterworks, and sewers.

Management of municipal drinking water, storm, and sanitary sewer systems is prioritized through a structured decision-making process that ranks and evaluates current infrastructure assets in terms of lifecycle costs and the risk of failure due to natural and human-made causes.

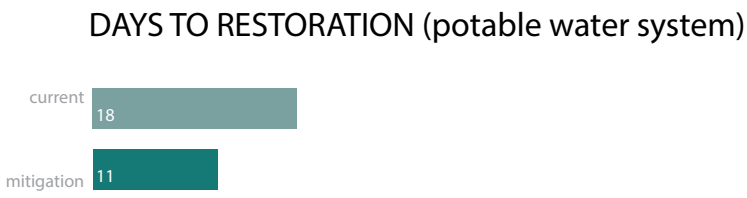
BC Hydro owns and operates a regional network of power generation and transmission facilities that provide electrical power services to the North Shore, and is recognized as an industry leader in risk management practices.

The transportation network includes the highway, major roads, and local roads. Highway 1, from the Ironworkers Memorial Bridge to West Vancouver, serves regional and provincial traffic and is the responsibility of the BC Ministry of Transportation and Infrastructure. It is also a disaster response route.

DNV shares responsibility for the major road network with TransLink, which contributes toward maintenance and upgrades. The local road network, consisting of roads, bicycle facilities, and sidewalks, is DNV's responsibility.

LIFELINE INDICATORS

The indicators below consider all buildings in the DNV. The time it would take to restore water and power is compared for the current scenario (today, without additional structural mitigation) and the mitigation scenario (today, with additional structural mitigation).



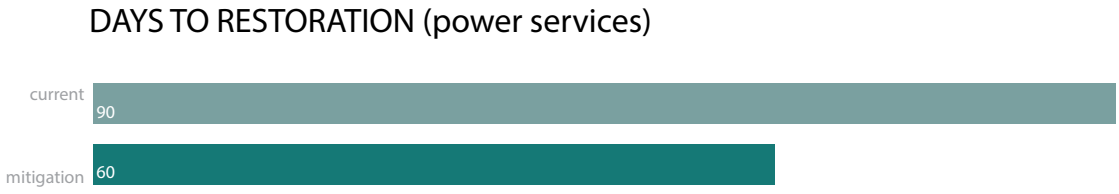


Photo: DNV

LIFELINE PREPAREDNESS AND RESPONSE

Water Reservoirs and Treatment
Reservoirs on the North Shore have recently been seismically upgraded. Metro Vancouver's water filtration plant is a new facility built to a high seismic standard.

Pipelines
Drinking water and wastewater cement pipelines are being replaced with steel, plastic, and ductile iron, and restrained joints are being added, all of which make pipes better able to withstand an earthquake.

Traffic Signals
DNV has an uninterrupted power supply to traffic lights, allowing them to operate and keep traffic flowing safely during general power outages.

Bridge Inspection
DNV staff are trained by bridge engineers to do Level 1 safety inspections of bridges following an earthquake. This allows for quick, local response to potential bridge safety issues. Most bridges have had seismic upgrades and replacement plans consider seismic risk.

Disaster Response Routes
Disaster Response Routes (DRRs) are a component of provincial and regional strategies for the post-disaster movement of responders and resources. Preferred DRRs have been pre-designated based on anticipated resiliency. Local staging areas have been identified to receive and transfer personnel, resources, and relief supplies using air, road, rail, and marine transportation.

Communications
The North Shore is serviced by a linked commercial radio system with repeaters at Simon Fraser University and Bowen Island. This system will allow agencies to communicate with each other during major emergency events. All NSEMO staff are certified radio operators.

ECONOMIC SECURITY

COMMUNITY LOSSES AVOIDED

Maximum credible losses if the Georgia Strait M7.3 earthquake scenario were to occur in 2014 are estimated at $3 billion, but if mitigation measures were in place to reduce the most vulnerable buildings the loss would be approximately $2.2 billion.

With losses avoided at nearly $800 million, the average benefits of mitigation outweigh costs by nearly 4 to 1. One of the most significant returns on investment could be for older concrete and unreinforced masonry buildings in commercial-industrial centres along the waterfront. Individual buildings along the waterfront could see benefits outweighing costs up to 11 to 1.

Other economic benefits of structural mitigation include a reduction in the extent and duration of disruption and a reduction in loss of business revenue during the recovery period.

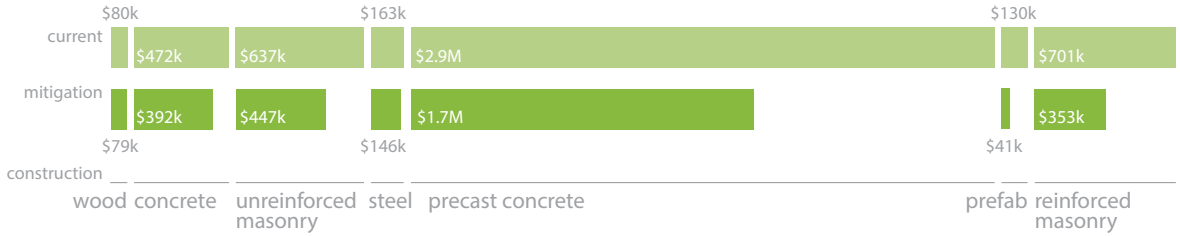
CONTINUITY PLANS

Businesses that do not have actionable continuity plans in place are susceptible to longer closures and may not be solvent after the earthquake. Closure of these businesses for periods of more than six months would likely result in loss of employment income for a significant number of people in the community.

ECONOMIC SECURITY INDICATORS

The indicators below consider all buildings in the DNV. The mean (average) capital loss per building is compared for the current scenario (today, without additional structural mitigation) and the mitigation scenario (today, with additional structural mitigation). The results can be viewed by construction type or by occupancy class.

MEAN CAPITAL LOSS PER BUILDING (construction type)



MEAN CAPITAL LOSS PER BUILDING (occupancy class)

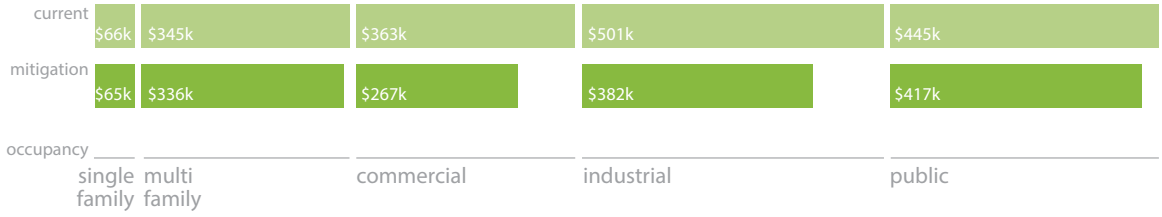


Photo: FEMA

BUSINESS AND EMPLOYER EMERGENCY PREPAREDNESS

See NSEMO's BEEP Guide for more information on the following topics. More at nsemo.org

Risk Assessment
Risk assessment can range from self-assessment to extensive engineering studies. The specific industry, size, and scope of your individual company will determine its needs.

Insurance
Know exactly what you are covered for, as well as the limits of that coverage. Consider how you will pay creditors and employees, and provide for your own income if your business is interrupted.

Off-Site File Backups
Keep copies of important records and other priority documents in a water and fire resistant portable container off-site.

Utility Disruption
Plan ahead for extended disruptions of electricity, gas, telecommunications, sewer, and water utilities. Identify back-up options.

Crisis Communication Plan
Know how you will communicate with employees, customers, business partners, and service providers during an emergency. Plan how you will use your business website, social media, email, and telephone.

Emergency Plans
Create emergency plans for each work site, including evacuation plans or plans to shelter in place. Well-trained, confident, and prepared employees will be better able to respond.

COSTS AND BENEFITS

DIRECT COSTS OF STRUCTURAL MITIGATION AND LOSSES AVOIDED

For the most part, a cost-benefit analysis is limited to capital investments in buildings and critical infrastructure for which monetary values can be assigned. It does not include the broader range of socioeconomic variables and interdependencies that will ultimately determine a community's overall resilience.

The strength of this approach is that it provides an internally consistent and legally defensible metric against which policy alternatives can be compared and evaluated in absolute terms. However, the decision criteria used and the scope of mitigation choices considered are often limited by performance measures (indicators) that can be assigned a market value or its equivalent.

The cost-benefit analysis explores the effectiveness of strategically investing in seismic upgrades for those buildings across the DNV that are the most vulnerable to earthquake damage based on their location and construction type. It compares expected losses for current conditions to those of a mitigation scenario in which vulnerable buildings have been seismically retrofitted to current seismic design standards as part of the ongoing community development process. The costs of mitigation are estimated to be 2-3% of the total replacement value.

Losses avoided as a result of investments in structural mitigation are estimated at $800 million. The economic benefits are greatest for older concrete buildings, unreinforced masonry buildings, and other classes of vulnerable buildings (precast concrete, reinforced masonry, and prefab) that do not conform to modern design guidelines for seismic safety.

SOCIAL BENEFITS FOR COMMUNITY RESILIENCE

In addition to economic losses avoided, other benefits resulting from seismic upgrades to buildings include a reduction in the number of casualties (injuries and fatalities), reduction in the extent and duration of social disruption (repair and recovery time), and increased business productivity (revenue) during the recovery period. The overall result of these benefits is a reduction in vulnerability and a higher level of disaster resilience in the community.

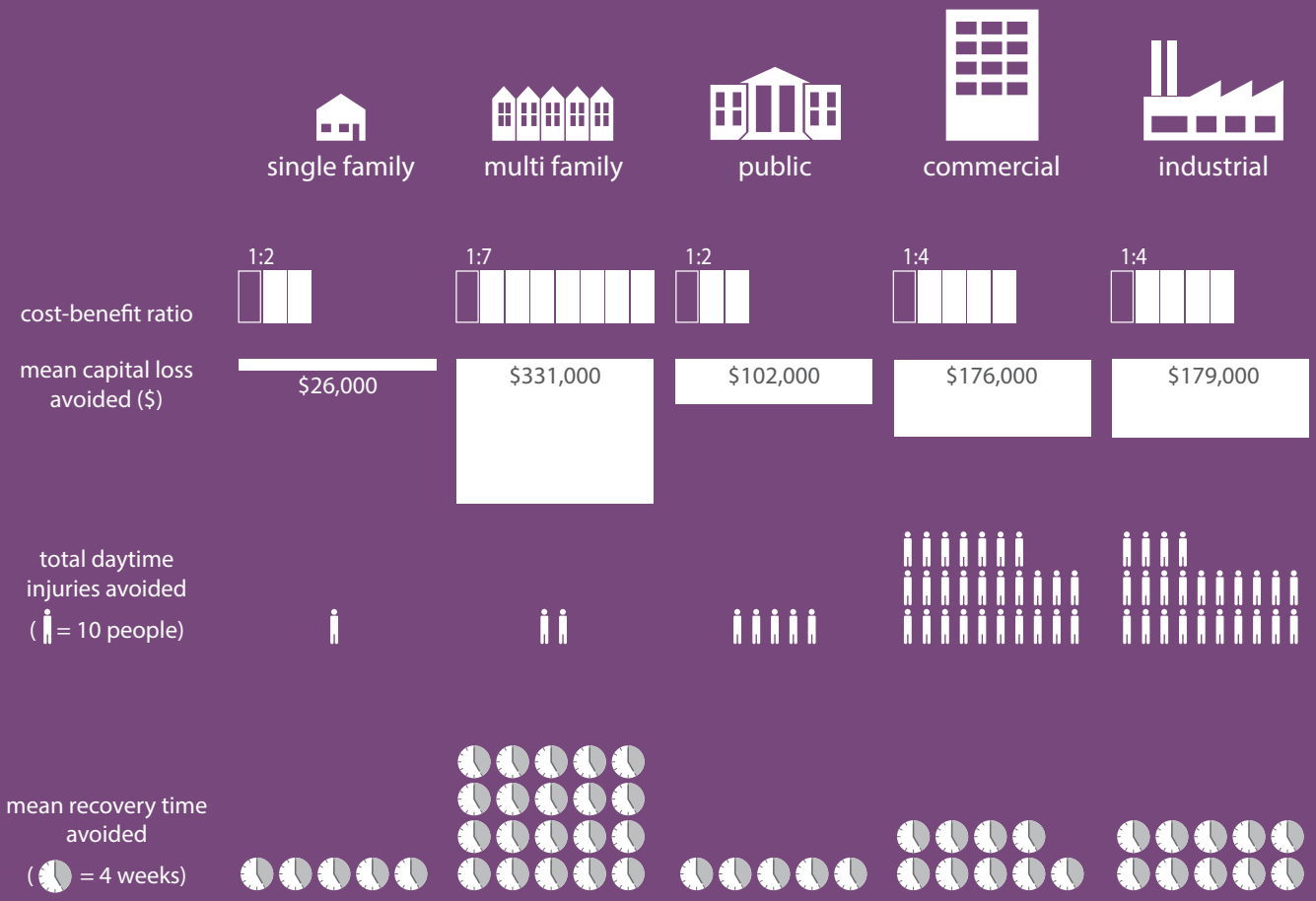
The overall result of these benefits is a reduction in vulnerability and a higher level of disaster resilience in the community.

Photo: DNV

COMPARING THE BENEFITS OF STRUCTURAL MITIGATION

Comparing economic benefits with the social benefits of structural mitigation—injuries avoided and less time needed to recover—between various types of buildings helps us to evaluate possible actions.

Buildings expected to sustain extensive or total damage and therefore in need of mitigation have been compared. According to modelled estimates for an earthquake that hits during the day, the highest gains appear to be in multi-family, commercial, and industrial buildings.



BUILDING RESILIENT COMMUNITIES

HOW DO WE INCREASE OUR RESILIENCY?

How does a community become resilient to the effects of an earthquake? Buildings, infrastructure, and the economy are important areas to focus on, but people are most important of all. Our communities are where people build their lives.

Social relationships between community members are critical in preparing for and recovering from a disaster. Residents, business owners, and local organizations like schools have tremendous ability to reduce levels of social disruption in their neighbourhoods.

There is much that the municipal government can do to prepare for and recover from a disaster, but it cannot build social relationships between community members. Community members must do this for themselves.

KNOW YOUR NEIGHBOUR

Do you know who lives next door? What about the other neighbours in your block? Would you notice if they were missing or hurt?

Neighbours who know each other can act as a safety net for individuals who live alone or for families who need extra help when an earthquake hits. Neighbours can keep current contact information for residents of their block or building, share food and emergency or repair equipment, and provide shelter to a neighbour whose home is damaged or destroyed.

The North Vancouver RCMP's Block Watch program offers a model for neighbours to get to know each other and organize around a common concern. Another possible way to begin getting to know your neighbours is to meet other residents at the local school, community centre, library, coffee shop, or recreation hotspot and look for others who are interested in strengthening their social networks and resilience to a disaster.

"All who make a city function, from municipal service providers to urban planners to the private sector and residents themselves, must be committed to building safer cities to secure resilience."

United Nations, Making Cities Resilient Report 2012, p4

Photo: Transition US (FlickrCC/transitionus)

BUSINESSES THRIVE TOGETHER, NOT ALONE

Many business owners are used to focusing on what happens inside their own four walls, paying close attention to inventory levels, the services they offer, their employees, and their bottom line. But all of these things are part of larger networks—transportation systems that ship goods and move people; buildings that hold inventory, equipment, and people at work; other businesses in the supply chain; and customers near and far.

When a disaster causes damage or devastation to a business, other businesses that are part of the supply chain are affected, as are other businesses nearby—especially when secondary hazards such as fires, floods, or spills threaten nearby buildings. Where retail and service businesses are clustered together, the closure of a neighbouring business can lessen the customer traffic to others.

Businesses can choose to work together to reduce the impacts of a disaster. Business owners can share and coordinate evacuation procedures and other emergency plans with neighbouring businesses, and organize to share emergency supplies and operational equipment—such as generators, refrigeration units, water, and internet access. Businesses that share a building can coordinate to make sure that all have appropriate insurance to repair building damage and keep businesses running.

INTERMUNICIPAL COOPERATION AND LEARNING

The District of North Vancouver coordinates emergency planning with neighbouring municipalities—the District of West Vancouver and City of North Vancouver. More broadly, DNV is a member of the Regional Emergency Planning Committee and also participates in or leads working groups focused on rapid damage assessment, disaster debris management, and the development of a risk-based land use guide. Recent collaboration with APEGBC and UBC is advancing the concept of performance-based design guidelines.

A United Nations role model city for disaster resilience, DNV presents at many conferences and workshops related to natural hazard management to share our experience and expertise in this field. Sharing what we learn about planning for and managing disasters in the DNV with municipalities across the province, country, and globe is a way that we can help others find a path to resilience, and we increase our own resilience by learning from their experiences.

It is our hope that this publication and the study on which it is based become best-practice examples for understanding and communicating earthquake risk and resiliency in municipalities.

A UNITED NATIONS ROLE MODEL CITY

The local government of the District of North Vancouver is a participant in the United Nations *Making Cities Resilient: "My City is Getting Ready!"* campaign. Launched in 2010, the campaign advocates for "widespread commitment by local governments to build resilience to disasters and increased support by national governments to cities for the purpose of strengthening local capacities." DNV was invited by the United Nations Office for Disaster Risk Reduction and its partners to join the campaign as a local government role model. We are committed to increasing community disaster resilience and sharing what we learn with other local governments. DNV received the UN Sasakawa Award for Excellence in Disaster Risk Reduction in 2011. For more information about the campaign, visit unisdr.org

STUDY: A PROFILE OF EARTHQUAKE RISK

THE STUDY

The study *A Profile of Earthquake Risk for the District of North Vancouver* is the basis for this shakeout scenario, *When the Ground Shakes*. The study is the result of a three-year research and development effort led by the Earth Sciences Sector of Natural Resources Canada together with case study partner the District of North Vancouver. It explores the realm of earthquake risk reduction at a municipal scale through collaborative partnerships with practitioners responsible for managing growth and development in areas exposed to earthquake hazards, and with academic researchers responsible for the development of methods and tools to support earthquake risk reduction and disaster resilience planning in Canada.

Study findings describe the probable impacts of a significant earthquake with greater clarity and detail than ever before, and document a system of target criteria and performance measures (indicators) that offer a comprehensive profile of earthquake risk in the community. The framework of indicators provides the capability to assess current conditions of earthquake risk and the effectiveness of mitigation strategies through the lens of public safety, building performance, lifeline resilience, and economic security.

The framework is implemented using a Canadian adaptation of the United States Federal Emergency Management Agency's Hazus loss estimation methodology. It is intended to help guide future risk reduction and disaster resilience planning activities in the community. Methodologies and insights gained in this study are transferrable to other communities that may face similar challenges of managing growth and development in areas exposed to earthquake hazards. The study contributes to broader efforts led by the Canadian Safety and Security Program to develop an all-hazard risk assessment framework to support disaster resilience planning at a national scale.

NORTH VANCOUVER DISTRICT

North Shore Emergency Management Office

Natural Resources Canada | Ressources naturelles Canada

UBC

DEFENCE RDDC DÉFENSE

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CASE STUDY PARTNERS

The District of North Vancouver (DNV) was the lead municipal case study partner and was responsible for the overall context and focus of the study. DNV shared detailed technical information about the community and critical assets, and identified policy goals and target criteria that have guided all aspects of the risk assessment process. DNV also worked with community members of the Natural Hazards Task Force to review study results to help translate scientific and technical knowledge about the risk environment into information and actions supporting day-to-day and longer-term strategic planning activities.

North Shore Emergency Management Office (NSEMO) supports 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 in the greater 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. NSEMO provided technical information on essential facilities and emergency service capacities in the region.

STUDY SPONSOR

Defence Research and Development Canada (DRDC) is the lead federal agency responsible for science and technology in support of public safety and socioeconomic security in Canada. Operational funding was provided to NRCan for the adaptation, testing, and validation of best practice methods and tools to support the assessment of natural hazard risks in Canada.

RESEARCH PARTNERS

Natural Resources Canada (NRCan: Earth Sciences Sector, Public Safety Geoscience Program) was the lead researcher for the study. NRCan contributes to increasing public safety and reducing future losses through the generation of knowledge about geohazards and the development of analytic methods for risk assessment, which are used to inform the design and operation of buildings and engineered structures, the regulation of natural resource development, land use decisions, and emergency management operations at local, regional, and national scales. Researchers with the Public Safety Geoscience Program held the lead role in the analysis and evaluation of earthquake risks for the DNV. *All photos by Nicky Hastings reproduced with the permission of Natural Resources Canada, 2015*.

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 helped 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-level analysis of earthquake risks for the DNV. They provided recommendations on seismic retrofit strategies that may be effective in reducing the vulnerabilities of older buildings.

The UBC School of Community and Regional Planning (SCARP) is one of only a few research facilities in Canada that focuses on disaster management and urban sustainability at local and regional scales. Researchers at SCARP contributed to the analysis of business disruption and related income losses that are likely to be sustained in the DNV as a result of earthquake damages to buildings and critical infrastructure systems that provide essential lifeline services to the community. They provided key insights on earthquake risks within the business sector, and strategies to increase disaster resilience of the community through strategic investments in both mitigation and adaptation.

NORTH VANCOUVER
DISTRICT

When the Ground Shakes is the companion to *A Profile of Earthquake Risk for the District of North Vancouver* by Natural Resources Canada.

Writing, editing, and design by Uncover Editorial + Design.