The evolution of geohazard risk management in North Vancouver

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ABSTRACT
The District of North Vancouver (DNV) provides an excellent example of the evolving trends in urban geohazard risk management. Following a fatal landslide in 2005, DNV commissioned one of Canada's first quantitative landslide risk assessments and formally established a DNV wide natural hazards program to identify and manage risks associated with landslides, retaining structures, debris flows, floods, earthquakes and wildfire.

RÉSUMÉ
Le DNV de North Vancouver (DNV) fournit un excellent exemple de l'évolution des tendances en matière de gestion des géorisques urbains. Suite à un glissement mortel en 2005, DNV a commandé une des premières Canadiennes à des évaluations quantitatives des risques de glissements de terrain et officiellement mis en place un programme de l'échelle du DNV des risques naturels afin d'identifier et gérer les risques associés aux glissements de terrain, les ouvrages de retenue, des coulées de débris, les inondations, les tremblements de terre et le feu sauvage.

1 INTRODUCTION

Numerous techniques are available to manage the risks from urban geohazards once hazards have been identified and their level of safety estimated. These techniques are well documented in the Association of Professional Engineers and Geoscientists of British Columbia landslide guidelines (APEGBC 2010) and other technical publications. In British Columbia, what is missing at a provincial level is systematic mapping of potentially hazardous areas and acceptance criteria against which estimated levels of geohazard safety can be compared. Hazard mapping helps to ensure that geohazard assessments are conducted where required for proposed development or ongoing review of critical infrastructure. Acceptance criteria aid in determining if and how a site can safely be developed based on the results of a geohazard assessment, or whether the level of safety for existing development is adequate. These gaps are currently being filled by local governments, the most progressive of which are carrying out these activities in a transparent manner and with input from technical experts and the public.

The Corporation of the District of North Vancouver (DNV) provides an excellent example of the evolving trends in urban geohazard risk management. Following a fatal landslide in 2005, DNV commissioned one of Canada's first quantitative landslide risk assessments. A public task force was established to review the suitability of risk tolerance criteria which were formally adopted by DNV in 2009. Landslide and debris flow screening studies and detailed assessments were completed throughout the municipality and the risk tolerance criteria were applied to these studies where appropriate. Furthermore, databases, web tools, and training seminars are being developed to help convey geohazard information to planners, building inspectors and the public. Official Community Plans are being updated to incorporate current knowledge of geohazard susceptibility, and multi-disciplined collaborative studies are underway to better understand and reduce the vulnerability of municipal infrastructure.

2 BACKGROUND

DNV is located at the foot of the North Shore Mountains north of the City of Vancouver, and is home to about 85,000 residents (Figure 1). The municipality is currently managed by a mayor, six councillors, an executive team and municipal staff. It has an annual budget of approximately $130 million. In-house resources include engineering and planning departments, a GIS group, and an emergency management office that is operated jointly with neighbouring municipalities.

DNV covers an area of approximately 17,000 ha, approximately 20% of which is developed. Topography generally slopes from north to south with elevations ranging from sea level up to 1,450 m. Mountain streams including Capilano River, Mosquito Creek, Lynn Creek, and Seymour River have incised through glacial and interglacial fluvial, marine and till deposits forming a series of steep escarpments (Figure 1). The Pleistocene deposits are typically overlain by colluvium and / or fill.

DNV receives, on average, approximately 2,400 mm of rainfall annually at lower elevations, with most of this falling during the period from November to February. During this period the region is subject to 'pineapple express' storms with tropical or subtropical origin that can produce more than 100 mm of rainfall with intensities exceeding 15 mm/hr. They are also associated with very high freezing levels (often above 2,500 m) and associated snowmelt. These storms often trigger landslides throughout southwest British Columbia. For example, Eisbacher and Clague (1981) identified 27 landslide triggering storms affecting the Vancouver area in the period 1900 to 1979.

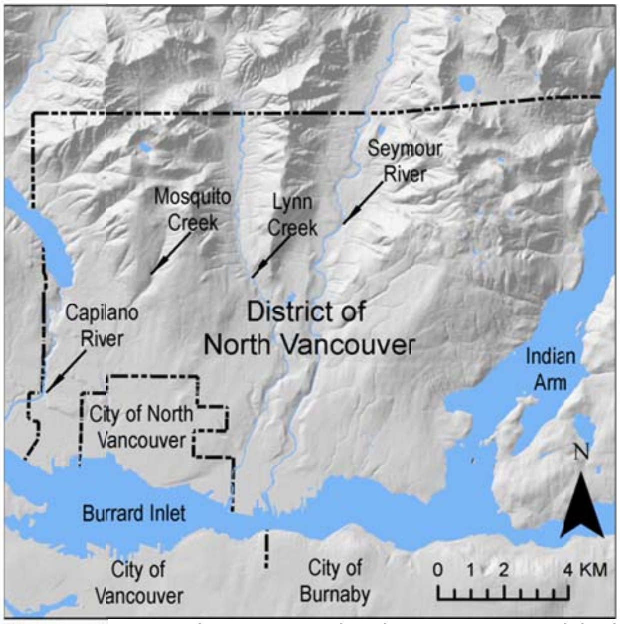

Figure 1. Location Map showing DNV municipal boundaries

Residential development began in the late 1800's and proceeded rapidly through the 1950's to 1970's. Often residential lots on escarpment crests were levelled by pushing or end dumping local and imported materials over the edge of the escarpments. Tree stumps and organic materials were often incorporated in the fill. Consequently, several of the escarpment slopes are prone to rapid to extremely rapid flow slides when colluvium and loose fill becomes saturated.

In recent decades, permanently and seasonally occupied dwellings were constructed on alluvial and debris-flow fans located along the eastern margin of the municipality. Several of these properties are prone to debris flows and debris floods. As well, two major DNV watersheds supply drinking water for the Metro Vancouver Region, and water quality can be affected by landslide and debris-flow activity within these watersheds.

The lower mainland of British Columbia is located near the junction of the converging Juan de Fuca Plate and North American Plates and is vulnerable to subduction earthquakes. Earthquakes can produce strong ground motion that can damage structures or trigger natural hazards such as liquefaction and landslides. Ocean floor ground displacement associated with earthquakes can sometimes also trigger tsunami. The National Building Code of Canada (NBCC, 2005) specifies a design peak ground acceleration on rock with an annual 1:2,475 frequency of exceedance that is approximately 0.43 to 0.44g for the North Shore.

3 BERKLEY 2005 LANDSLIDE

Prior to 2005, risks associated with natural hazards were predominantly managed through DNV's subdivision and building permit application process. Studies were underway to inventory and characterize existing debris flow hazards and risks.

In the early morning of January 19, 2005, heavy rainfall triggered a fill-slope failure at the crest of the DNV Berkley Escarpment (Figure 2). The landslide destroyed two homes at the base of the slope, seriously injuring one person and killing another. A review of previous engineering reports, published literature, and aerial photographs revealed that five other fill-slope failures had occurred along the escarpment since 1972, one which had also damaged homes at the base of the slope in 1979.

Concerns over the potential impact of future landslides prompted DNV Municipal Council to commission a landslide risk assessment and mitigation program. The landslide, risk assessment, and mitigation program are described in Porter et al. (2007) as well as in several engineering reports that are available on-line through DNV's websites (e.g. BGC 2006a, b). Key details are highlighted below.

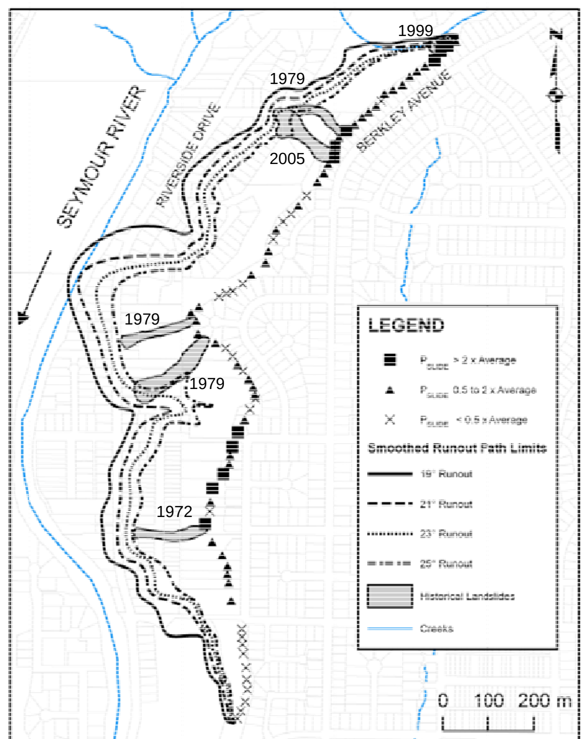

Figure 2. Location Map showing Berkley Escarpment, historical landslides, hypothetical source areas, and potential runout angles

3.1 Factors Contributing to the Landslides

Airphoto mapping, field reconnaissance and shallow subsurface investigations revealed a number of factors common to all the historical landslides along the Berkley Escarpment. These included the presence of over-steepened slopes (locally often >40^{o}), the presence of several metres of loose fill at the escarpment crest, and surface and subsurface drainage conditions that facilitated the development of a perched water table within the loose soils during periods of heavy rainfall. In many cases over-steepened fills were retained by stumps, woody debris, or retaining walls that were in disrepair. Also prior to the 2005 landslide, few of the homes along the escarpment were connected to the municipal storm sewer system, and roof and perimeter drainage was often directed over the edge of the escarpment.

3.2 Risk Assessment and Mitigation Plan

The consequences from past flow slides were numerous and included injury, fatality, property damage, loss of property value, and litigation costs. A decision was made to focus on the risk of fatality since this consequence was deemed the most appropriate factor against which to prioritise requirements for risk management.

Algorithms were developed to estimate future landslide risk from potential source areas along the escarpment crest. The risk model was calibrated so that the calculated total annual probability of a flow slide somewhere along the escarpment, and the associated risk of fatality, was in line with the historical average.

At the time of the risk assessment, local landslide risk tolerance criteria were not available. Consequently, estimates of individual and societal risk were compared against criteria used in Hong Kong and recommended by the Australian Geomechanics Society (AGS 2007).

Forty-three properties were identified where the estimated risk of fatality for home occupants most at risk exceeded 10^{-4} per annum (1:10,000), the recommended maximum tolerable risk for existing development. A mitigation strategy was developed to reduce the risks at these properties to less than 10^{-4} per annum. By the time the risk assessment was completed, a number of DNV capital projects related to risk control were already underway. These included the extension of the storm sewer system and connection of homes to it, the demolition of seven homes that were purchased with Provincial assistance, and the reshaping of the escarpment crest in the immediate vicinity to the 2005 landslide.

These activities left six properties at the crest of the escarpment that continued to pose unacceptable individual or societal risks to residents below. The remedial work at these sites involved removal of fill and deteriorating retaining walls, slope reshaping at approximately a 2H:1V ((27^o) grade, and design and installation of bioengineering measures to control surface erosion. Remedial works were completed over the 2006 summer period.

Ongoing remote monitoring of precipitation, as well as groundwater conditions in piezometers installed around the headscarp of the 2005 landslide is carried out, and visual inspections to look for evidence of slope deformation are conducted when antecedent and storm rainfall exceed pre-set thresholds.

3.3 Recommendations Stemming from the Berkley Landslide

The Berkley landslide led to a number of recommendations to further reduce landslide risk throughout the municipality and the province. At the municipal level, these included the establishment and long-term funding of a natural hazards management program, which is described in detail below.

In 2008 the Provincial Coroner issued a report on the 2005 landslide fatality. The report contained a number of recommendations to the Province, the Union of BC Municipalities, and the Association of Professional Engineers and Geoscientists of BC (APEGBC). Amongst recommendations to the province was a call to establish a legislated provincial standard for how landslide assessments should be conducted and coordination of the development of provincial landslide safety levels. The Coroner also recommended that a database of landslide hazard and risk information be created and made accessible to all stakeholders to facilitate informed decision-making.

4 DNV NATURAL HAZARDS MANAGEMENT PROGRAM

DNV's Natural Hazards Management Program was formally initiated in 2007 when it became apparent that there were a number of natural hazards affecting the municipality requiring long term management strategies.

With limited funding available, it was recognized that a risk-based approach would best meet the need to understand the extent of the hazards, the vulnerabilities of the people and assets exposed to the hazards, and provide evidence to make defensible decisions about mitigation. Program objectives are to:

a. Understand hazards and risks using a proactive approach.
b. Reduce risk to life, infrastructure and environment by establishing policies to set priorities for mitigation based on risk.
c. Educate stakeholders by developing tools to communicate knowledge of hazards and risks and encouraging dialogue about responsibility for management of hazards and risks.
d. Maintain a hazard database of easily retrievable geotechnical and hydrotechnical information.
e. Liaise with the scientific, academic and government communities to create and follow best practices in natural hazard management.

The program is a component of the Engineering, Parks and Environment Division and is closely linked with emergency management and community planning.

The annual operating budget for the program is approximately $300,000. The operating budget includes one full time staff member to manage the program and a consulting account to retain geotechnical expertise as required. Capital expenditures vary from year to year depending on DNV-wide financial priorities. Government grant opportunities, such as the Flood Protection Program or Union of BC Municipalities' (UBCM) Strategic Wildfire Prevention Program, are accessed whenever possible.

Geotechnical and hydrotechnical reports and inspection notes are collated in the DNV's Hazard Database. The database is accessed using a web-based, GIS format. Establishing the database required up-front investment and considerable effort to search for, scan and enter historical reports. Ongoing maintenance is minimal.

4.1 Risk Management Framework

The overall framework for the natural hazards management program was designed to be compatible with Canadian guidelines (CAN/CSA Q850-97) which were tailored to meet DNV's requirements (Figure 3).

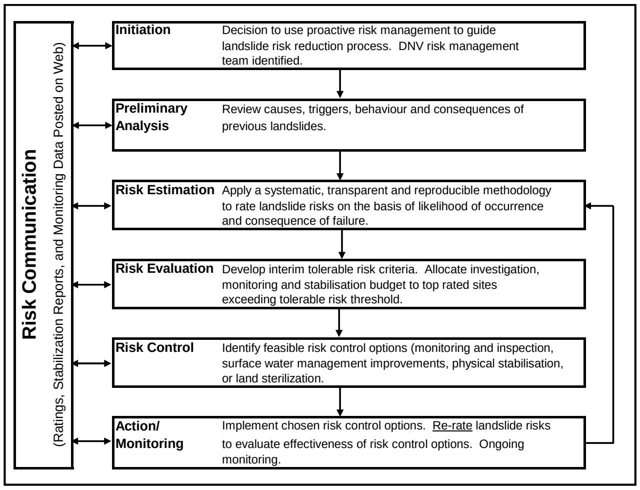

Figure 3. Risk management framework (after CAN/CSA Q850-97

4.2 Natural Hazards Task Force

DNV's Natural Hazards Task Force was assembled in October 2007 to provide a forum to gather input from an informed, broad-based community perspective regarding tolerable or acceptable risk for landslides and other natural hazards. Prior to this DNV had been using the Hong Kong criteria, on an interim basis, to manage landslide risks but DNV Council and staff recognized the importance of establishing risk tolerance criteria based on community consultation, taking into consideration social values and risk perception. The mandate of the natural hazards task force was to:

a. Review risk tolerance criteria established by other jurisdictions.
b. Develop an understanding of the risks faced by Canadians and local residents in everyday life.
c. Host community consultations.
d. Prepare and present recommendations for establishing DNV natural hazards risk tolerance criteria.

Eight volunteer members of the community were selected for the task force, representing a wide range of professional and personal interests and spanning the geographic region of the DNV. Over several months, the task force received presentations and education sessions from subject-matter experts in the topics of natural hazards, risk assessment, mitigation methods, local government financial models and legal considerations. After much discussion and deliberation, the task force reached out to the broader community through a public open house, an online survey and a public meeting. Survey participants were asked about their perceptions of which hazards caused the greatest concern, level of personal/family preparedness, allocation of municipal budget to hazards management, responsibility for management, and tolerable risk. A range of common risks such as driving and flying were expressed quantitatively, using Statistics Canada mortality rates, and compared to natural hazard mortality estimates. Survey participants were asked to state their risk tolerance for natural hazards in North Vancouver when compared to more common risks. Seventy-eight percent of survey respondents placed tolerable risk from natural hazards between 1;10,000 and 1:100,000 per year.

The task force compiled their findings and prepared a report and presentation to DNV Council outlining their recommendations for natural hazards risk tolerance criteria for DNV.

The task force continues to meet from time to time and provide DNV with feedback on new and proposed initiatives relating to natural hazards.

4.3 Landslide Safety (Risk Tolerance) Criteria

Two scenarios commonly encountered in DNV are the presence of existing or proposed residential developments at the base of steep slopes or debris-flow fans (most amenable to a risk-based approach) and residential development and associated retaining structures located on or at the crest of slopes (most amenable to a factor of safety approach).

Landslide safety (or risk tolerance) criteria were proposed by DNV staff based on discussion and review with its consultants and the Natural Hazards Task Force, and were formally adopted by DNV Council in 2009.

The criteria were designed to help evaluate the landslide risks associated with both existing and proposed residential developments and for the two common development scenarios described above. They were also designed to be compatible with recommended approaches to landslide safety assessments outlined in APEGBC (2010) including the landslide assurance statement and the guidelines for seismic slope stability assessment contained within that document. The criteria are outlined in Table 1.

Risk tolerance criteria are applied at the development and building permit phases of development. Additional discussion on concepts related to landslide risk acceptance and risk tolerance can be found in Porter et al. (2009).

Table 1. DNV Landslide Risk Tolerance Criteria

Risks reduced to As Low as Reasonably Practicable (ALARP) and not to exceed the criteria outlined below					
Application Type	**Risk $<10^{-4}$**	**Risk $<10^{-5}$**		**FS>1.3 (static) 1:475 (seismic)**	**FS>1.5 (static) 1:2,475 (seismic)**
Small renovation	X		or	X	
Repair or replace retaining structure		X			X
New development		X			X

1. Risk = annual probability of fatality for individual most at risk
2. FS = limit equilibrium factor of safety for global failure
3. Seismic slope stability criteria based on specified ground motion chance of exceedance and either FS>1.0 or ground deformation <0.15 m in non-liquefiable soils, as per APEGBC (2010)
4. Reducing risks to As Low as Reasonably Practicable (ALARP) means that the cost of further risk reduction would be grossly disproportionate to any risk reduction benefits gained.

4.4 Landslide and Debris Flow Screening Studies

Between 2006 and 2009 DNV undertook a series of flow slide, rock fall, and debris flow screening studies with the objective of obtaining a full inventory of residential developments within the DNV where landslides could potentially cause loss of life. The process was designed to lead to one of three conclusions for each identified property:

a. Risks are likely broadly acceptable and do not warrant further review;
b. Risks are likely tolerable to broadly acceptable – they should be kept under review and reduced further where practical as per the ALARP principle; or
c. Risks may be unacceptable, warranting more detailed site investigation and risk assessment, potentially leading to the identification of a need for risk control.

Limits of the flow slide and rock fall screening studies were based on a GIS exercise to identify homes in proximity to slopes higher than 10 m and steeper than 25^{o}, combined with a review of engineering records documenting historical landslide events. Subjective, but systematic estimates of partial risk (the likelihood of a hazard occurring and impacting a habitable structure) were made using simple criteria derived from site observations. These included factors such as measured slope angles, distance between habitable structures and the escarpment, and observations of prior landslides or slope deformation. More detailed risk site investigation and risk assessment was carried out for properties assigned a ‘High’ or ‘Very High’ partial risk. Owners of properties assigned a ‘Moderate’ partial risk were advised of the potential for landslides and of actions that could be taken to reduce their landslide risk. Records were created for each of these properties to help facilitate follow-up inspections.

Debris flow fans were identified for preliminary estimation of risk of loss of life based on the results an inventory and hazard assessment program that had been completed prior to 2005. Preliminary estimates of risk of loss of life were completed for occupied debris flow fans utilizing judgment-based spatial probability and occupant vulnerability values based on modeled debris flow runout path, velocity and flow depth. More detailed modeling and risk assessment has been carried out at select higher-risk fans using refined debris flow magnitude-frequency estimates. Owners of properties with estimated risk levels exceeding 10^{-5} per annum were notified of the results of the debris flow risk assessments and provided with information on ways to reduce their debris flow risk.

4.5 Debris Flow Warning System

Option identification and securing of funding for debris flow mitigation measures is underway, and debris basins and catch nets have been constructed or are planned for some of the highest-risk creeks. However, depending on funding priorities, it could take several decades to fully implement the debris flow mitigation program at all known risk areas. A debris flow warning system was developed to help manage risk, both as an interim measure at locations where risk exceeds DNV’s tolerance criteria, and as a means of satisfying the ALARP principle.

The system is based on a statistical analysis of rainstorms that have triggered debris flows and rainstorms that have not. The statistical analysis is combined with a high-resolution weather forecast supplied by the University of BC's Geophysical Disaster Computational Fluid Dynamic Centre.

The system provides a regional debris flow warning via hourly forecasts of when it is unlikely, possible or likely that debris flows could be triggered somewhere in the North Shore Mountains. It cannot predict when debris flows will occur on individual creeks.

The warning system does not advise residents which actions to take, but it provides information that residents can use to make more informed decisions that could reduce their temporal probability of being impacted by a debris flow. The forecast is also used to alert DNV’s emergency response team. The public can access to the warning system through DNV’s website (www.dnv.org.) or by phone and listening to an automated message. In the event of a severe warning, radio and television statements may also be issued.

4.6 Public Awareness

As each hazard or risk assessment study is completed, property owners are notified of the findings and invited to attend a public meeting to discuss the results and recommendations. These meetings have been well-attended providing opportunities for dialogue between property owners, DNV staff and geotechnical professionals.

Reports are posted on the DNV website and hard copies are distributed to public libraries. The natural hazards section of the DNV website contains educational information about natural hazards and links to further information such as Council meeting minutes, presentations, drainage maps, etc. It also contains background information about risk tolerance criteria and natural hazards management.

The DNV GIS department provides hazard maps that outline both potential hazard areas and field study report areas. A user can search a property address or area and visually see the potential natural hazards affecting that property, learn more about those hazards, and also download pertinent hazard and risk assessment reports directly from GIS pertaining to a particular area or address.

Educational brochures have been developed for landslide and debris flow hazards: *Guide to living near steep slopes* and, *Understanding debris flows* are displayed at District Hall at the front desk and at the permits counter. The brochures are also mailed to property owners in hazard areas and available at public meetings.

Educating the Real Estate community has been an effective means to raise awareness about natural hazards and risks. Presentations have been made to local real estate businesses and real estate agents often contact the DNV before buying or selling properties near slopes and creeks, providing another opportunity for education. Initially, following the Berkley landslide, some real estate agents were hesitant to represent clients with homes located in landslide hazard areas. Through ongoing education and dialogue, a more balanced understanding has been achieved, and the agents are helping to ensure that knowledge of hazards and risks is passed on to new owners over time.

4.7 Geotech on Demand

As a component of the annual operating budget, funds are available to consult with geotechnical professionals as required. Throughout the fall and winter rainy season, field inspections are conducted in known hazard areas, photographs taken and records added to the hazard database.

When landslide risk assessments are completed and released to the public, some property owners contact the DNV to request further explanation. A DNV staff member and a geotechnical professional visit the property owner at their property to explain the findings of the assessment and show the property owner what areas of their property they should monitor. This service builds relationships between property owners, geotechnical professionals and DNV, opens lines of communication and educates property owners about the hazards and risks in their area. The follow up site visits are documented in the hazard database.

4.8 Community Planning Procedures

APEGBC (2010) provides guidelines for assessing landslide safety for proposed residential developments and provides a sample assurance statement to be completed by the Qualified Professional who is retained by the owner or developer to assess landslide safety. DNV has implemented a series of planning tools and procedures to help ensure that the APEGBC landslide guidelines are applied appropriately at all proposed development sites potentially subject to landslide hazards.

DNV's new Official Community Plan is anticipated to be released in mid 2011. The new OCP will include three new Natural Hazard Development Permit Areas (DPAs) – for slope, creek and wildfire hazards. The DPAs use GIS mapping to indicate potential hazard areas, identified by geotechnical, hydrotechnical and forestry professionals. The DPAs outline the requirements that need to be met by the applicant for each type of hazard, including risk assessment, mitigation if required, and ongoing maintenance.

Staff from multiple departments review new development and building permit applications in hazard areas. These departments include Community Planning, Environment, Engineering, Public Safety, Parks and others. As DNV-wide screening studies and risk assessments are completed, information sessions for staff are held to ensure that all departments are aware of the findings and where to access the reports.

4.9 Water and Stormwater Infrastructure

Stormwater management is a key component of DNV's natural hazards management program.

Through the course of detailed review of historical flow slide failures along the Berkley Escarpment, it was determined that poor surface drainage practices (i.e. conveying roof and perimeter drainage over the edge of the escarpment) was one of the most significant factors contributing to the spatial distribution of these landslides. Consequently, considerable emphasis was placed on connecting homes along the crest of the Berkley Escarpment and other landslide-prone slopes to the stormwater system as a means of reducing landslide risk.

The stormwater system comprises laterals connecting individual properties' roof and perimeter drains to over 370 km of storm mains, as well as stormwater outfalls. Much of the infrastructure was built in the 1960's and 70's, with service currently available to nearly 70% of properties within DNV. Stormwater mains continue to be extended and upgraded, with priority given to areas identified as having elevated landslide hazard and risk. Before 1980, it was a common engineering practice to allow stormwater to drain over the bank instead of pumping up to the municipal stormwater main in the street. When these properties are redeveloped or apply for building permits for renovations, it is a condition of the permit that they are connected to the municipal system or an alternate system approved by the Municipal Engineer. Covenants are registered on title to ensure long term maintenance of drainage systems is the responsibility of the property owner. For existing developments, a storm drainage connection incentive program encourages property owners to connect to the municipal system where not previously connected. The DNV funds the cost of the laterals for homes that are located on the crest of slopes identified as having landslide potential.

DNV conducted a program of geotechnical inspection of stormwater main outfalls to inventory potential landslide and erosion risks. This has facilitated a prioritization of ongoing inspection efforts, as well as outfall upgrades at some locations.

The water distribution system comprises nearly 365 km of water mains, constructed primarily from ductile iron, asbestos cement, steel and cast iron. Over 80 km of water main were constructed during the 1950's with ongoing installation and renewal rates of approximately 4 - 6 km per year. Ruptured water mains near the crest of escarpment slopes have triggered several landslides within the DNV over the past decade. The watermain replacement program is staged, and priorities are based on pipe material, previous breaks, and the number of people potentially affected. Several additional factors will be included in a new matrix implemented in 2011, including proximity to slopes with residential development below and geologic/soil conditions.

4.10 Partnerships with Science-based Organizations

In 2009, DNV partnered with Natural Resources Canada (NRCan) to test and refine a proposed national framework for risk-based planning associated with natural hazard threats in Canada. *Pathways-DM* is standards-based and aligned with national policy goals for disaster mitigation. There are three components of the *Pathways-DM* framework:

a. Process for risk-based planning.
b. Model for integrated risk assessment of natural hazards.
c. Planning support system for disaster mitigation.

This 4 year project is currently at the Analysis phase. DNV assets such as building stock, utility infrastructure, transportation networks and population centres have been compiled in a GIS database and are currently being analyzed using HAZUS-MH to estimate damage and losses from a variety of hazard scenarios. As the project progresses, outputs will include tools to assist DNV in visualizing, exploring and evaluating the consequences of land-use planning decisions. DNV staff from Engineering, Community Planning, Finance, Environment and Emergency Management have been involved in the project to-date. This project is funded by CRTI (a research and technology arm of the Federal government) and the results will be shared across Canada.

Concurrently, University of British Columbia Earthquake Engineering (UBC Civil Engineering) is leading a project to better estimate damages from earthquake events. UBC has compiled detailed building stock information on a block-by-block granularity level and installed strong-motion sensors across North Vancouver. Data compiled from the UBC project will directly feed into HAZUS-MH. An updated 1;20,000 surficial geology map will be produced by NRCan in 2011 and will assist with understanding the potential for local site amplification and attenuation of earthquake ground motion.

In late 2010, NRCan, the Justice Institute of BC (JIBC), DNV and Laurie Pearce designed and hosted a land-use planning tabletop exercise at the JIBC Simulation Centre in New Westminster, BC. Municipal staff from across the lower mainland and Vancouver Island of BC participated, using a case study of Mosquito Creek to make building permit and land use decisions in a debris flood hazard area. The exercise findings were shared with participants of a Land-Use Decision Support workshop, held later in the week, organized by Simon Fraser University's (SFU's) Centre for Natural Hazards Research, Public Safety Canada, NRCan, JIBC, Pearces2 Consulting, and the Integrated partnership for Emergency Management. The group continues its goal to produce a land-use planning decision support guide for local governments across Canada (CNHR 2010).

5 CONCLUSIONS

Aside from provincial and federal guidance on structural and foundation design for earthquakes, much of the responsibility for urban geohazard risk management in British Columbia lies with local municipal governments. This can present a significant challenge for municipalities situated in areas with high geohazard exposure and / or where smaller municipalities lack critical resources such as planning, engineering and GIS departments.

This paper has illustrated how the District of North Vancouver is addressing three broad challenges that are likely faced by many local governments in British Columbia:

a. The development of an understanding of the range of geohazard types that are present, their spatial distribution, and the risks that they pose to existing and future infrastructure and residential development through desk study, screening studies, and quantitative risk assessment.
b. The prioritization of risk mitigation and risk communication efforts through public consultation and the development and application of risk tolerance criteria.
c. Geohazard risk reduction through the establishment of a formal natural hazards management program, modification of land development planning and permitting procedures, incorporating geohazard considerations in the planning for water and stormwater infrastructure upgrades and maintenance, ongoing geotechnical inspection and monitoring programs, public education efforts, and construction of stabilization or protection measures at select locations where unacceptable geohazard risks have been identified.

Future challenges in North Vancouver and elsewhere around the province will arise from urban expansion into more hazardous areas, requirements for adaptation to climate change, and changes in our society's tolerance for risk. Provincial and Federal support for these initiatives would help improve consistency in how urban geohazards are identified, and how the risks are evaluated, communicated and managed across the country.

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