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Landslide Hazards

• Between 2004 and 2010, *non-seismic* landslides killed over 32,000 people worldwide (Petley 2012)

• In the U.S., between 25 and 50 people are killed each year by landslides; annual capital losses typically range from $1 to $3 billion (USGS 2004)

• Over the past 30 years in the State of Washington, landslides have claimed the lives of 54 people, and resulted in direct losses of $300 million (DNR 2015)

**Climate Change**

Relationship between the frequency of landslide events and mean annual rainfall for localities throughout New Zealand (Hicks, 1995).

**Co-Seismic Landslides**

Co-seismic landslides initiated by the 2011 Tohoku, Japan Earthquake (Wartman et al. 2013)
Landslide Risk Assessment

Risk = Hazard \times Consequences

La Conchita Landslide

Co-Seismic Landslide Zones, Calif. Dept. of Geol.
• Document effects of geologic disasters to advance research and practice

• Collect and make freely available potentially perishable field data

• More information: www.geerassociation.org

GEER Oso Landslide Team Members

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Oso Landslide

- Occurred on Saturday, 22 March 2014, at 10:37 a.m. local time

- Preceded by 3 weeks of heavy rainfall

- 58 people were within the inundation zone when the landslide occurred; of those, 15 survived
Geologic Setting

- **North Fork Stillaguamish River Valley** of the Northern Cascade Range

- Soils consist of Quaternary deposits of glacial-fluvial outwash, till, and glacial-lacustrine soils

- Following glacial retreat 16k b.p., river incised into the glacial sediments
Recent Site History

• Multiple episodes of movement have been described in studies dating back to the 1950s

• “Travel across the slide surface is extremely treacherous because of hidden “pockets” of saturated material that will not support a man’s weight” (Thorsen, 1969)

• Clear pattern of headward advancement, with the mass laterally constrained
Mass Movement in 2006
Mass Movements in 2006 and 2014

Characteristics of Environmental Disasters (after Smith 2014)

- Do not occur as one-time events, but are repeated and are thus associated with a recurrence interval
- Origin of the event is clear and produces known threats
- Warning time is often short
- Human exposure is usually due to location of people in a hazardous area
Steelhead Heaven

- Steelhead Haven was established in the 1960s
- Portion of the valley directly below the slope contained 108 lots zoned for Single Family Residences
- Structures were located on 49 of the lots

Number of homes with time

Home value with time (after Zillow.com)
Land-Use Policy

- If a property is within a “Landslide Hazard Area”, then the following restrictions on land use apply:
  
  - Structures shall be setback from landslide hazard areas, such that:
    
    *The minimum setback at the top of the slope is the maximum of (i) the slope height divided by three and (ii) 50 feet*
    
    *The minimum setback at the toe of the slope is the maximum of (i) the slope height divided by two and (ii) 50 feet*
    
  - All of the structures affected by the March 2014 landslide were more than 300 feet away from the toe of the slope and therefore not subject to land-use restrictions due to landslide hazard.
The annual probabilities of multiple fatalities in the vicinity can be estimated based on historical performance:

- **Slope failures that translate the river channel and potentially impact people within hundreds of meters of the toe** (e.g. landslides of 1951, 1967 and 2006) occur between once per decades and once per centuries (i.e., ~30 to ~300 years).

- **Large slope failures that run-out across the valley and its inhabitants** ("Oso") occur between once per centuries and once per millennia (say ~300 to ~3,000 years).

- No national or state guidelines exist in the United States for levels of risk due to landslides that warrant action.
"Who would have thought that a landslide could have happened in that area?"
Risk Communication

• Multiple studies identified the potential for a “catastrophic” failure affecting human safety and property.

For example, A 2001 report, which made use of earlier geotechnical and geological studies by others expressed the status quo conditions as follows:

"Large, persistent, deep-seated landslides don’t just go away"

"Catastrophic failure potential places human lives and properties at risk.”

• We are not aware of any predictions that the debris from a landslide in this valley could run-out thousands of feet across the valley floor like it did in 2014
Reflections from Oso: Needs for Landslide Science

• How will the landslide be initiated?
• What are the warning signs?
• How large will it be?
• How far will it move?
• How fast will it move?

• What will be the consequences of the landslide? (human and capital losses)

• How will information about landslide risk be conveyed to stakeholders (e.g. members of the public, and public officials)?
Christchurch, New Zealand Earthquake Sequence (2010-2011)

Image Sources: GNS Science, Wikipedia
Christchurch, New Zealand Earthquake Sequence (2010-2011)

Image Sources: GNS Science, Wikipedia
22 February 2011 Event occurs on a Tuesday at 12:51 pm
Re-Settling the Christchurch Region
Port Hills Landslide Risk Study

• Led by GNS Science (Dr. Chris Massey)

• Council sought "excellent science to support confident decision making"

• Focused on Risk of Loss of Life

• Pilot study followed by a large-scale implementation

\[
R_{(LOL)} = P_{(H)} \times P_{(S:H)} \times P_{(T:S)} \times V_{(D:T)}
\]  

[1]

where:

• \( R_{(LOL)} \) is the risk (annual probability of loss of life (death) of a person) from debris avalanches or cliff top recession;

• \( P_{(H)} \) is the annual probability of an initiating event;

• \( P_{(S:H)} \) is the probability of a person, if present, being in the path of avalanching debris at a given location, or the probability of a person at a given location falling over the edge of the cliff as the cliff recedes;

• \( P_{(T:S)} \) is the probability that a person is present at that location;

• \( V_{(D:T)} \) is the vulnerability, or probability of a person being killed if present and hit by debris or from falling over the edge of the cliff top as it recedes.
Port Hills Landslide Risk Study
Communication and Outreach Products

What is mass movement?

‘Mass movement’ is the process of rock and soil moving down-slope all at once (‘en masse’). Observable features can include deposits of displaced rock and soil, ground bulging (caused by compression), ground cracking (from extension), seepage and springs, as well as headsoarp features. Mass movements can be a hazard to life, and cause damage to dwellings and property (such as retaining walls), and infrastructure (e.g. underground pipes and culverts, roads and power substations).

Mass movement types on the Port Hills

The main types of mass movement on the Port Hills are debris avalanches, falls, slides, slumps and flows. The slides generally occur in rock and loose material (wind deposited silt). Some of the mass movements are combinations of slides, debris avalanche and rockfall. The slump features are predominantly silt material.

Why do some mass movements move differently to others?

Differences in the rate and nature of movement are caused by differences in the nature of the materials (rock or soil), steepness of the slope, and how much water is involved.

Some types of mass movement can move considerable distances and very quickly, while others move just enough to cause minor damage to the land.

A landslide may transition into a debris flow given the right conditions. Debris flows can travel very rapidly.

What triggers mass movements?

Some mass movements can be triggered by strong ground shaking (earthquakes), some by high intensity or long duration rainfall or snow melt, earthworks and/or drainage modifications, or there may be no apparent triggering event. The likelihood of mass movement occurring on the Port hills is greater now than before the 2010/11 Canterbury Earthquakes due to the likelihood of aftershocks and the disturbed state of the soil and rock masses.

Which areas are included in this report?

The Stage 1 Report covers the urban parts of the Port Hills where there are concentrations of cracks, bulges and other ground damage indicating instability.

How were the areas assessed?

Ground surface features, such as those shown on the example map on the following page, were mapped by GNS Science between October 2012 and January 2013. From these investigations and observations the extent of the mass movement features were defined, the nature of the rock and soil materials determined, and approximate volumes calculated. This information was then used to make a preliminary assessment of potential risk to people, property and infrastructure.
Communication and Outreach Products

To put these numbers in perspective, the odds of a Lotto Division 1 win (correctly picking 6 numbers out of 40) are:
- 1 in 3,838,380 or about $2.6 \times 10^7$ per ticket.

If someone bought one ticket every week for 75 years, their lifetime odds of such a win would be:
- 1 in 984 or about $1.0 \times 10^3$ per lifetime.

### Average Individual Fatality Risk, Selected Causes

NZ resident population in 2008 (source: NZ Ministry of Health mortality statistics)

![Graph showing average individual fatality risk for various causes over age bands](image-url)
Port Hills Land Damage case studies

We’ve made up some case studies to help you understand how areas have been classed in the Port Hills Land Damage Project and what the GNS Science Stage One Report findings might mean for residents.

Sharon and Mike living in a Class II area

Sharon and Mike’s old villa in the Port Hills was seriously damaged in the earthquakes. Their plans to rebuild are finally getting off the ground and they can’t wait to get started. This week they got a letter from the Council saying their property is in a preliminary Class II area. Now they’re wondering if this will cause more delays.

Living in a Class II area won’t stop Sharon and Mike from rebuilding. They are likely to need a site-specific geotechnical report for any work that needs a building or resource consent. There are a range of ways developments in these areas can be carried out to better protect Sharon and Mike’s land and that of their neighbours. In future, for example, earthworks that don’t currently need a resource consent may require one.

Sharon and Mike should also look out for Ministry of Business, Innovation and Employment (MBIE) guidance for engineers working on foundation solutions for some of the areas susceptible to slope instability.

“Can I rebuild and what do I need to do?”

The Council has contacted the insurance industry to let them know about the report, and that the Council is still processing consents in Class II areas. Insurers are likely to make decisions on a case-by-case basis, so Sharon and Mike should contact their insurance company directly to discuss their individual case.

“What about our insurance?”

If you need support, call the Canterbury Support Line on 0800 777 846, free and confidential services.

For more information, including the full copy of the GNS Science Report, and frequently asked questions on the project, and for each of the areas, visit [Link]
Communication and Outreach Products

Port Hills Land Damage

Here's a timeline showing steps the Council is taking to investigate areas in the Port Hills where land stability has changed since the 2010/2011 Canterbury Earthquakes.

1. Most of New Zealand's hill areas face land stability issues that may not be easy to spot. Possible hazards are rockfall, seasideroll, cliff collapse, debris inundation and landslides.

2. Cracks and other land damage were caused by the earthquakes. Some cracks suggest there has been mass movement, where rock and/or soil have moved down a slope.

3. The Council commissions GNS Science to investigate 16 areas in the Port Hills where there's been mass movement. The focus is on prioritise future study and identify the risk to lives, homes and infrastructure.

4. GNS Science Stage One Report
   - The first of a series of GNS Science reports is released and gives sub areas within the 16 wider areas a preliminary Class I, II or III category.

5. PRIORITY FOR FUTURE STUDY
   - This report identifies the priority for future investigations of mass movement areas:
     - Class I areas
     - Class II areas
     - Class III areas

6. Any further mass movement could cause lives lost. Homes and/or critical infrastructure may be severely damaged.
   - Any further mass movement could severely damage homes and affect critical infrastructure.
   - Any further mass movement could cause minor damage to homes and local infrastructure.

7. Class I areas have the highest priority for further study. These studies will help determine the risk to people, property and infrastructure from instability.
Guidance for building in toe slump areas of mass movement in the Port Hills (Class II and Class III)

Supplementary guidance to ‘Guidance on repairing and rebuilding houses affected by the Canterbury earthquakes’, December 2012.

Notes:

This guidance only applies to the GNS Science Class II and Class III areas of mass movement. It does not apply to Class I areas.

The principal users of this document will be professional geotechnical, structural engineers, designers and building control officials. The content of this document is therefore technical and written for a professional engineering and technical audience.

This guidance is issued under section 175 of the Building Act 2004.
Port Hills Landslide Risk Assessment: Reflections and Lessons Learned

Bold Leadership

"It is a council responsibility to determine acceptable life risk levels."

"I do feel for the people badly affected by rockfall, their dreams have been shattered. However, we have to make hard calls to send a message that we don't accept development in area where the level of risk is high."
Landslide Risk Assessment: Reflections and Lessons Learned

Bring the Community Along From Day One

• Multiple lines of communication: open meetings, one-on-one consultations, web presence

• Open discussion of the decision making process

• Strong support for the scientific team
Port Hills Landslide Risk Assessment: Reflections and Lessons Learned

Risk assessments should be conducted in *advance* of an event

- Significant time was required to conduct the risk assessment, leaving many in limbo as they awaited outcomes of mapping, and policy implementation
Landslide risk assessment does not capture all landslide-related risks
Port Hills Landslide Risk Assessment: Reflections and Lessons Learned

Uncertainty in Risk Assessment is Dominated by Consequence Evaluation

NSF Project: Investigation of the Effects of Rockfall Impacts on Structures During the Christchurch Earthquake Series
Final Thoughts

We do not have a thorough understanding of the landslide risks we face in the U.S.

• New technologies (e.g., remote sensing) now allow for more accurate and cost-effective mapping

• Support land use planning

• Allows risk mitigation to be prioritized

• There are no standards for mapping landslide hazards and risks

• Need a common vision of how to organize and coordinate to address landslide risk
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- New technologies (e.g., remote sensing) now allow for more accurate and cost-effective mapping
- Supports for land use zoning
- Allows risk mitigation to be prioritized
- There are no standards for mapping landslide hazards and risks
- Need a common vision of how to organize and coordinate to address landslide risk

"Inventories are a liability"

- Should serve as a transparent basis for decision making
Final Thoughts

Information on landslide risk should be fully disclosed and made understandable to all

• "All" includes the citizens as well as public officials

• Allows people to make informed decisions

• Enables land and housing markets to operate efficiently

• A better informed electorate makes government more responsive

• Unless people understand the risks we face, it is difficult to achieve risk management policies
"Future landslides are inevitable there" (USGS)
"Future landslides are inevitable there" (USGS)

"A decade after La Conchita's mudslide tragedy, the pull of community proves stronger than fear."

www.flickriver.com, Los Angeles Times