BC Natural Disaster Technical Briefing

Wednesday, December 15, 2021

Landslides, Floods and Infrastructure Impacts

BC Natural Disaster Technical Briefing

Dr. Jonathan Fannin, P.Eng.

Dr. Amy Kim, P.Eng.

Dr. Scott McDougall, P.Eng.

Dr. Steven Weijs

Dr. Dharma Wijewickreme, P.Eng.

Agenda

Technical presentations (8:30 a.m.)

- Storm impacts
- Rainfall and river flows
- Debris flow risk management
- Geohazards mitigation
- Pipeline impacts
- Erosion and dike failures
- Flood risk management
- Pipeline integrity
- Transportation network planning

Dr. Amy Kim, P.Eng.

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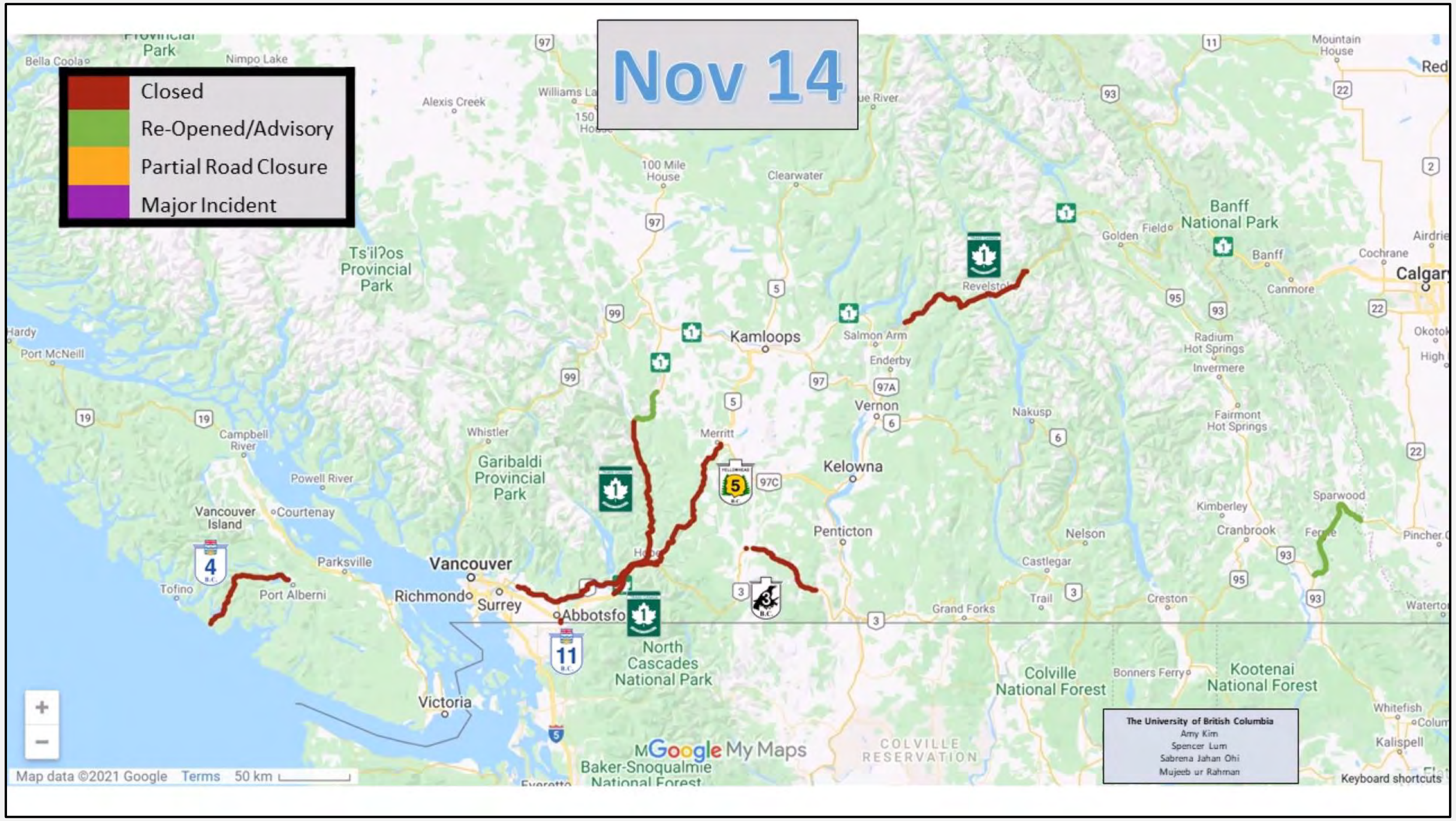
Costliest natural disaster in Canadian history

Photo credits: Right: Highway 1 - Tank Hill Underpass by BC Ministry of Transportation and Infrastructure, licensed under CC BY-NC-ND 2.0; Other photos: J. Fannin and S. Weijs.

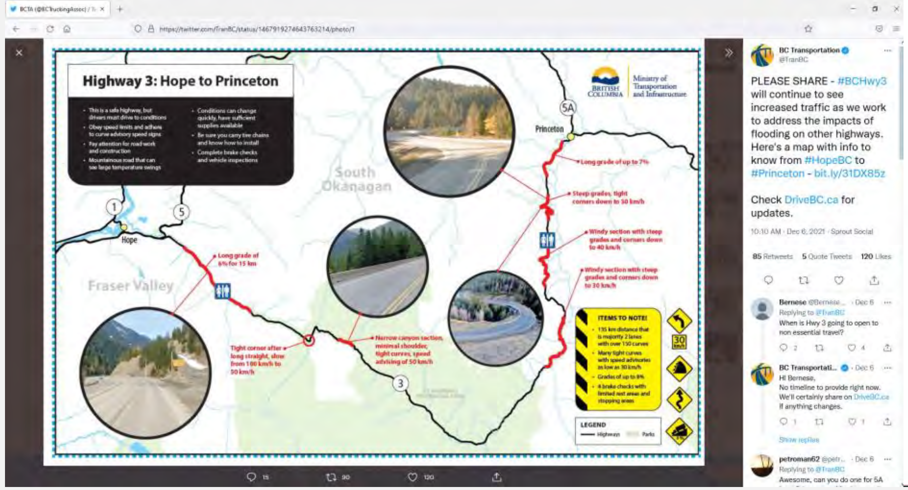
Major road closures and advisories in southern BC November 14 – December 2, 2021

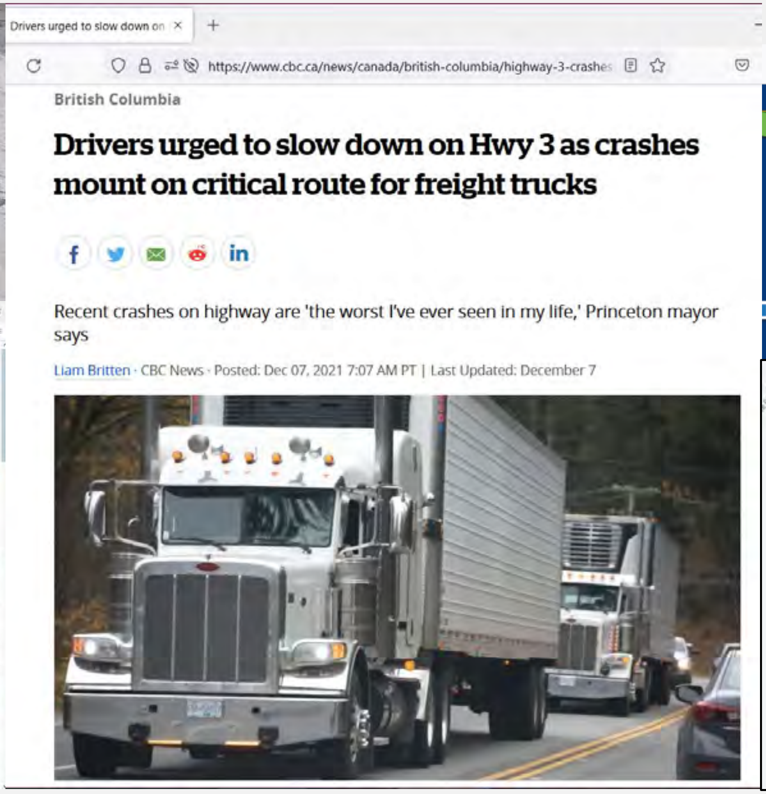


Recovery and repair, December 2021

Photo credit: Right: BC Highway 5 - Bottletop Bridge repairs by BC Ministry of Transportation and Infrastructure, licensed under CC BY-NC-ND 2.0.

Recovery and Repair, December 2021





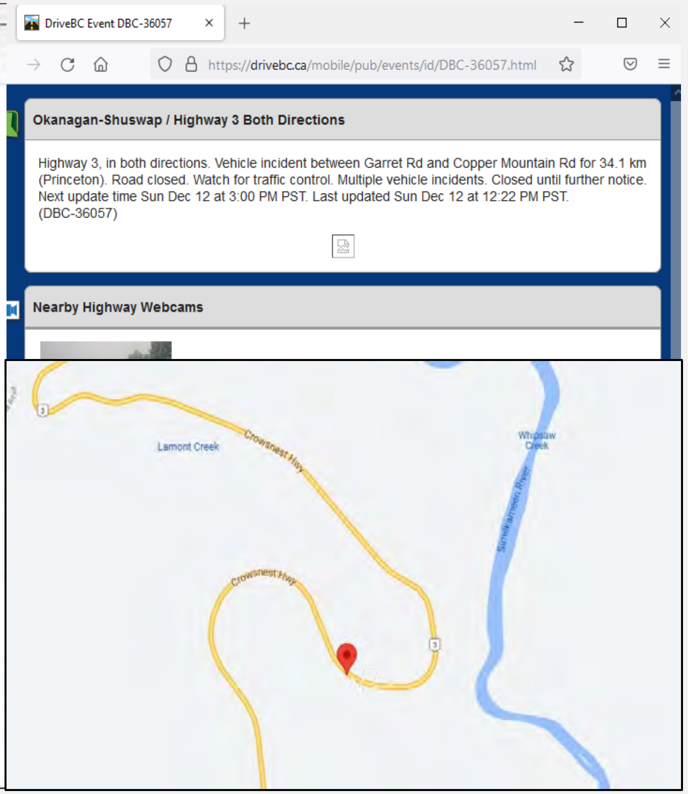


Photo credit: Top left: BC Ministry of Transportation and Infrastructure, licensed under CC BY-NC-ND 2.0.

Major road closures and advisories in southern BC

Dr. Steven Weijs

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Atmospheric river

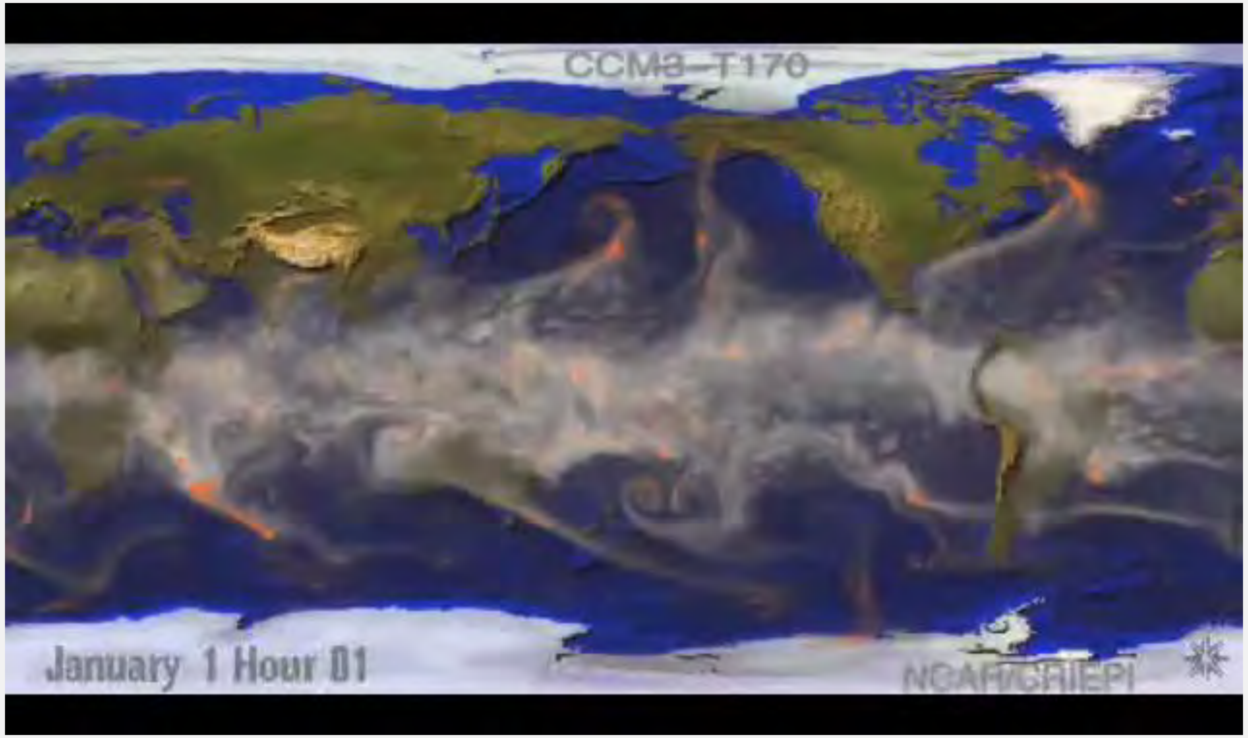


Image source: CCM3 T170 cloud and precipitation simulation , James Hack, Akira Kasahara, David Williamson, Steve Hammond, CRIEPI, Don Middleton, University Corporation for Atmospheric Research (UCAR).

Atmospheric river: total precipitable water

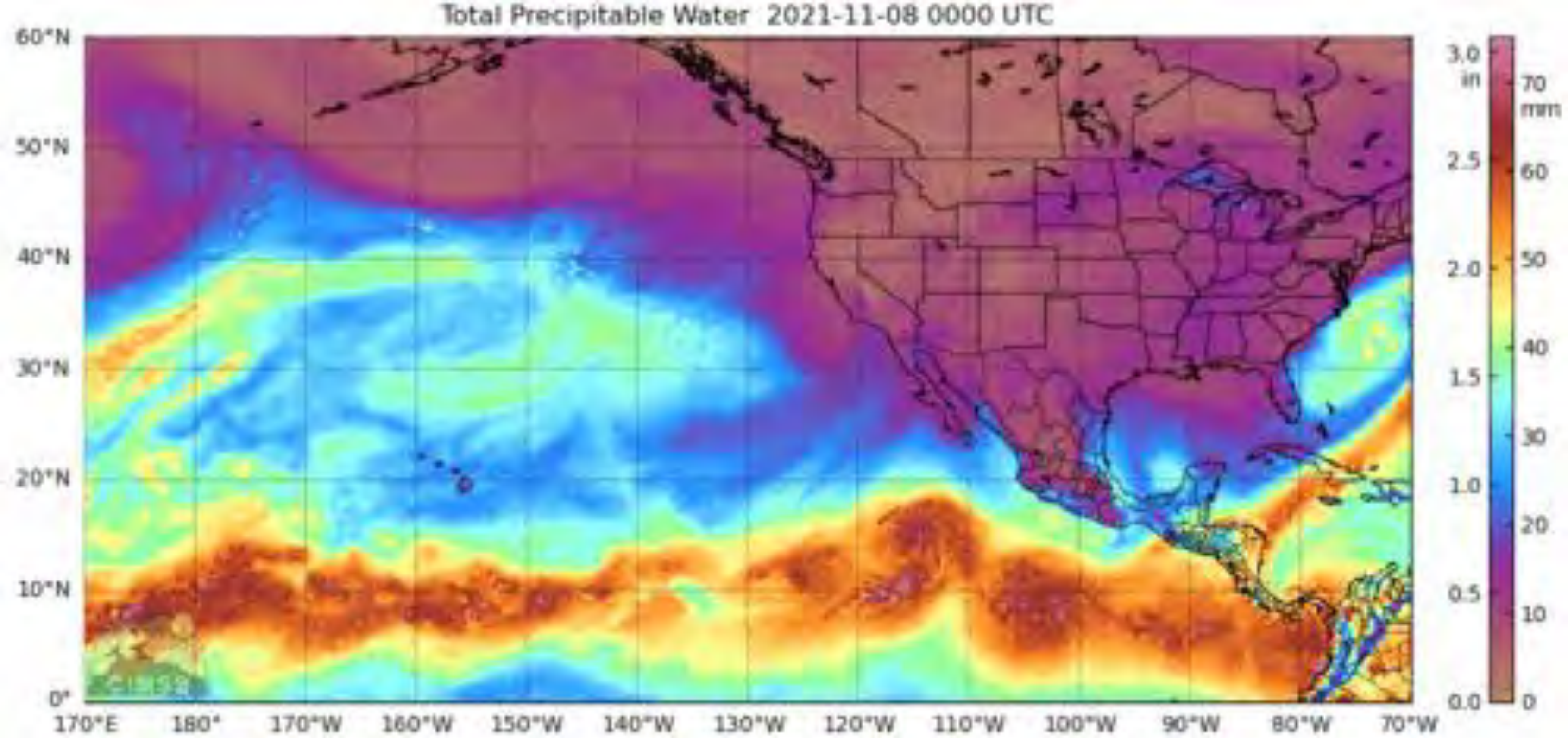
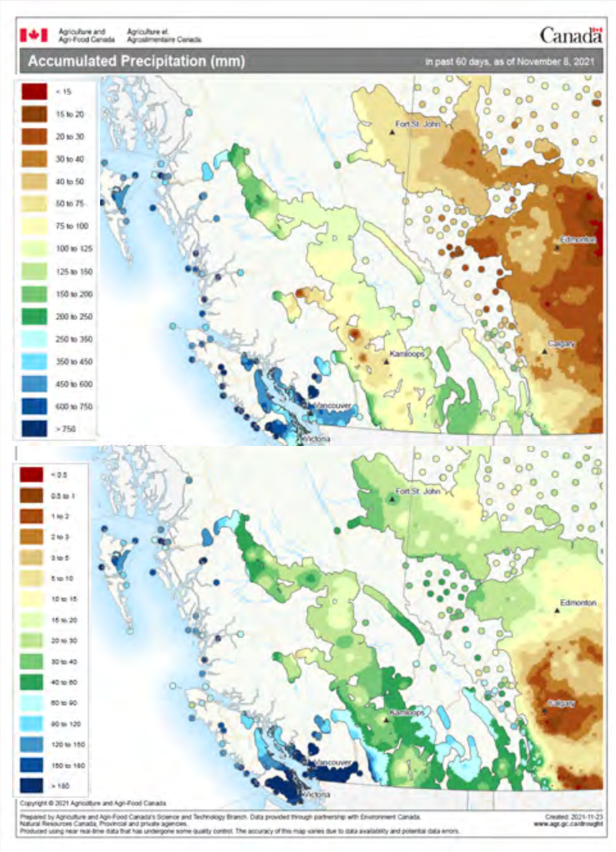


Image source: Total precipitable water, compiled from CIMSS MIMIC-TPW2 product: ftp://ftp.ssec.wisc.edu/pub/mtpw2.

Precipitation before and during the event



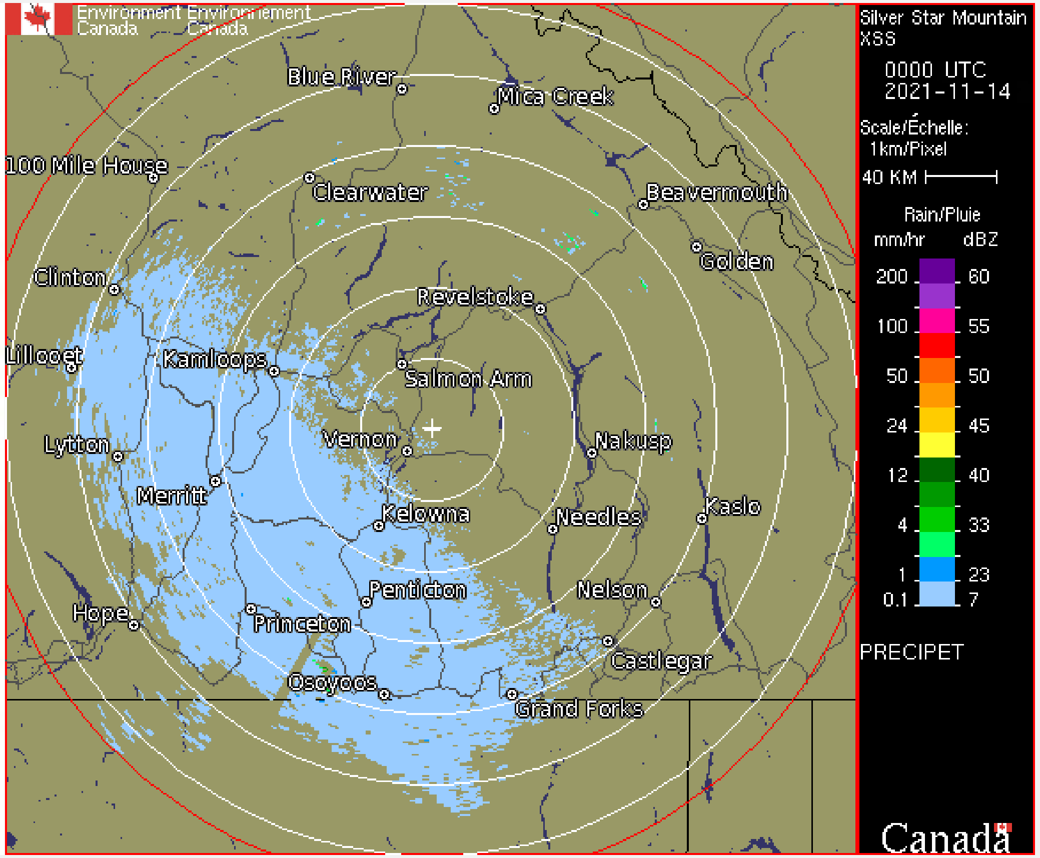
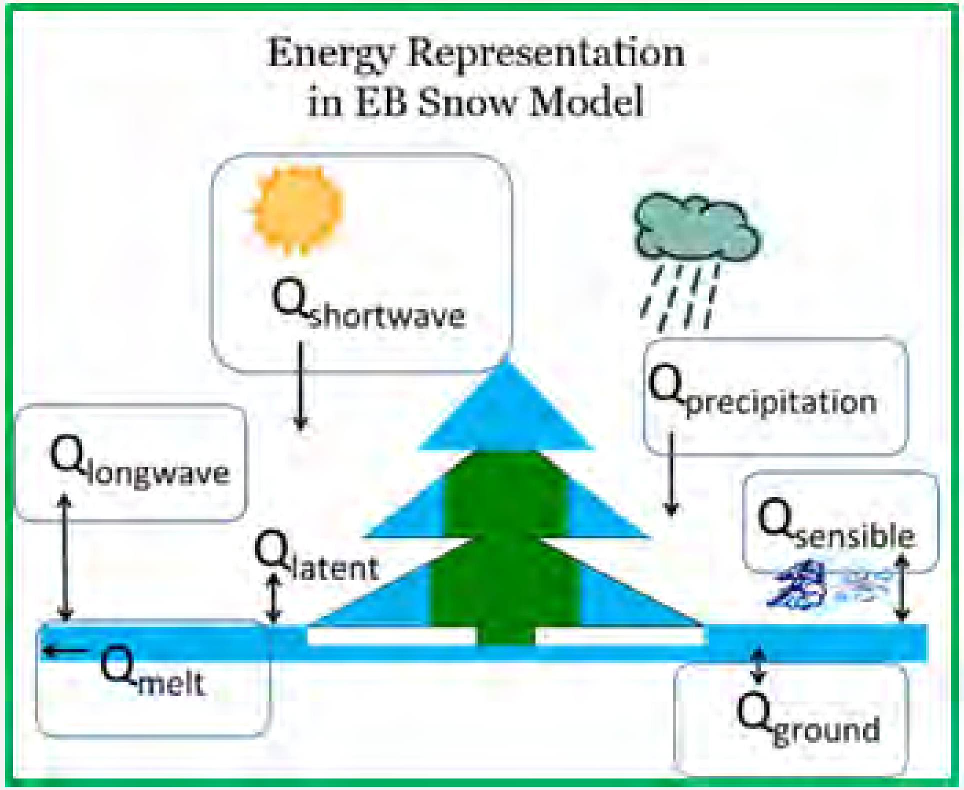


Image source: Left: agr.gc.ca/drought. Right: Environment Canada, Silver Star Mountain radar.

Snow Melt Contribution



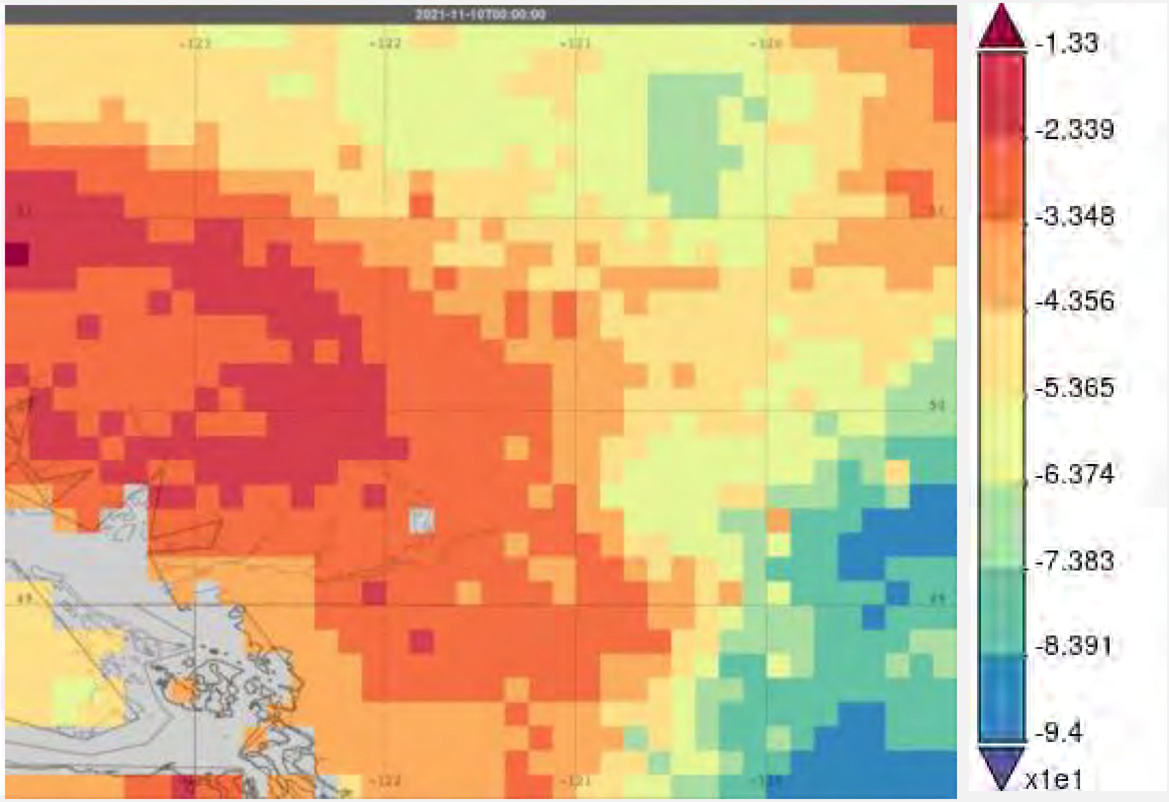
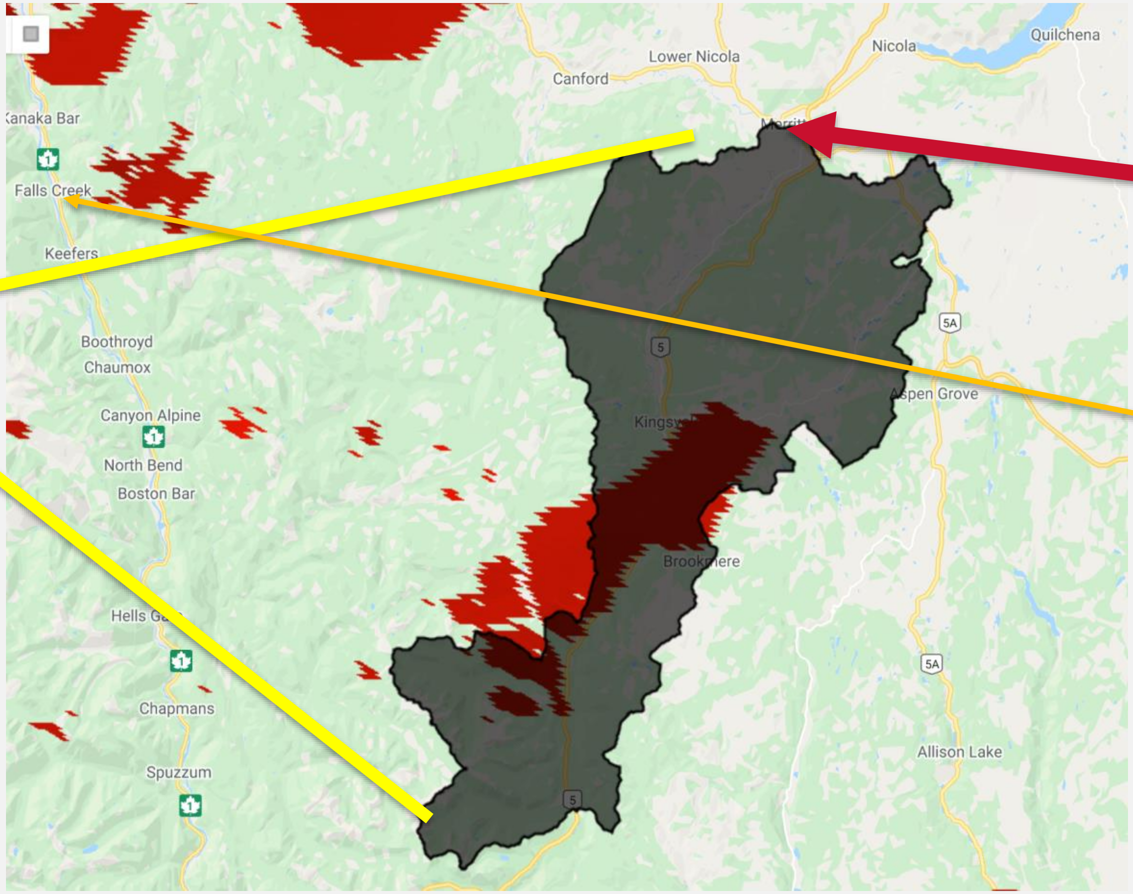
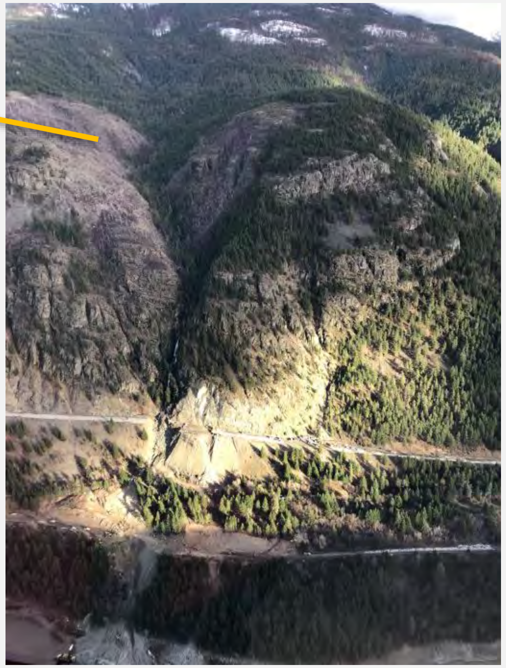


Image source: Left: HEC-HMS guide: https://www.hec.usace.army.mil/confluence/hmsdocs/hmsguides/modeling-snowmelt/modeling-rain-on-snow-events. Right: Net longwave radiation from NLDAS.





Gauge nr. : 08LG010
Coldwater River at Merritt
Catchment Area: 914 km^2
Average elevation: 1160 m
Flow record: 1966-1995
Q10 (Obedkoff): 130 m^3/s

Image source: Top right: CTV News, www.ctvnews.ca/canada/images-and-video-of-flooding-mudslides-in-b-c-1.5667192.
Middle right: produced from MODIS/006/MCD64A1 data set of burnt area, using google earth engine.

Runoff event volume:

– 43 mm

Peak:

– 405 m^3/s

– 436 $L/s/km^2$

– 1.59 mm/hr

Estimated $T_{R:}$

– >2000 yrs

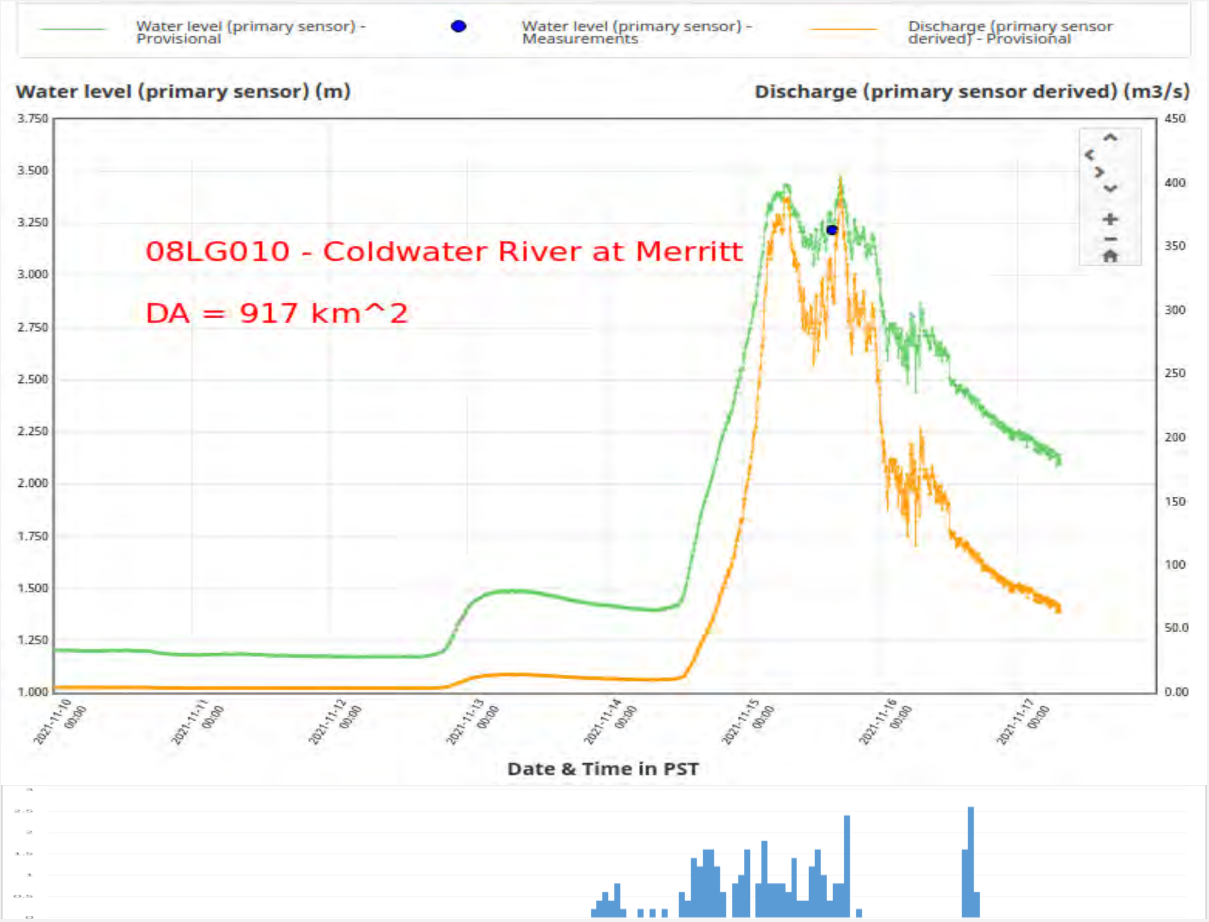


Image source: Real time streamflow data from Environment Canada
https://wateroffice.ec.gc.ca/report/real_time_e.html?stn=08LG010th engine.

Dr. Jonathan Fannin, P.Eng.

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Landslide risk management: debris flows

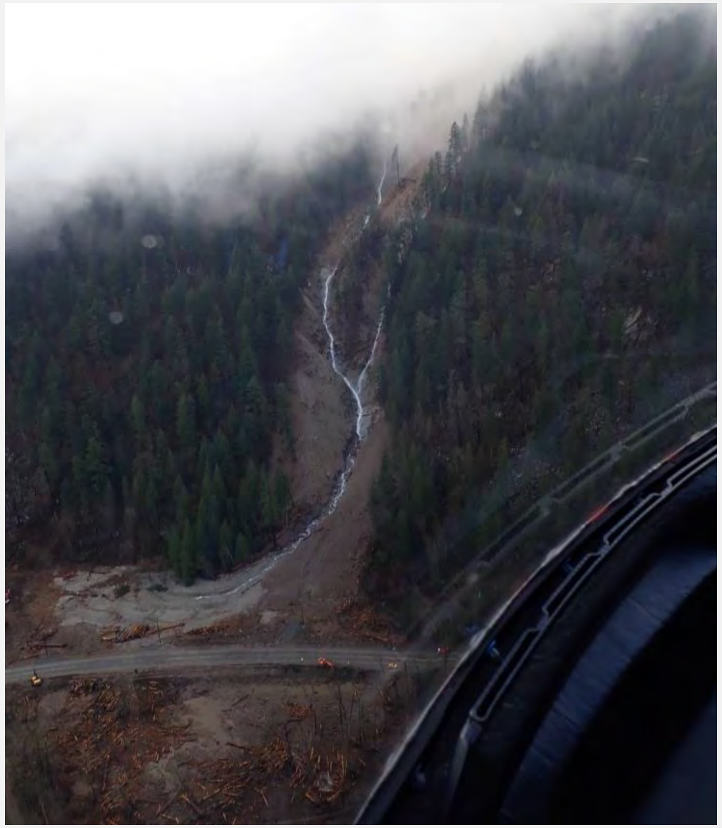

Image source: J.Fannin.

Debris flow risk management

P(H) - probability of occurrence

P(S:H) - probability of spatial impact

P(T:S) - probability of temporal effect

Image source: https://www.flickr.com/photos/tranbc/51684852986/in/album-72157720143417483.

Debris flows: probability of occurrence

Image source: S.Weijs & J.Fannin.

Debris flows: probability of spatial impact

Image source: Left: J.Fannin. Middle: https://www.flickr.com/photos/tranbc/51682693761/in/album--72157720143417483.
Right: https://www.flickr.com/photos/tranbc/51683583095/in/album-72157720143417483.

Debris flows: travel distance and event magnitude

Image source: Left: www.transmountain.com/news/2021/ensuring-safety-during-bc-and-wa-storm-impacts.
Right: https://www.flickr.com/photos/tranbc/51687939324/in/album-72157720143417483.

Debris flows: Seymour Watershed research site

Image source: Jamieson slide (November 1990) MetroVancouver.

Debris flows: probability of occurrence P(H)

Image source: Left: MetroVancouver, D.Dunkley. Right: J.Fannin.

Debris flows: probability of spatial impact P(S:H)

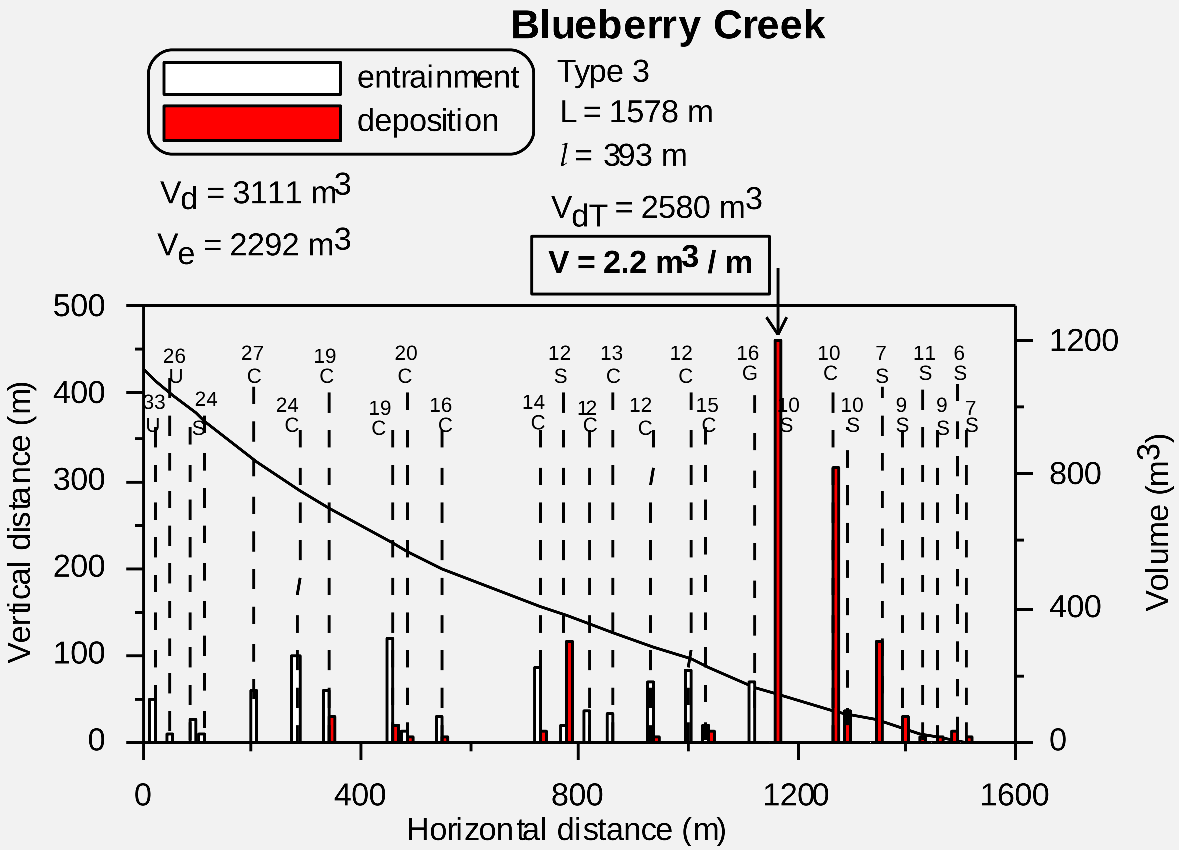

Image source: https://www.for.gov.bc.ca/hfd/pubs/docs/Lmh/Lmh18.pdf. Photos: J.Fannin.

Debris flows: risk management

Image source: Left: J.Fannin. Right: https://www.flickr.com/photos/tranbc/51683296670/in/album-72157720143417483.

Dr. Scott McDougall, P.Eng.

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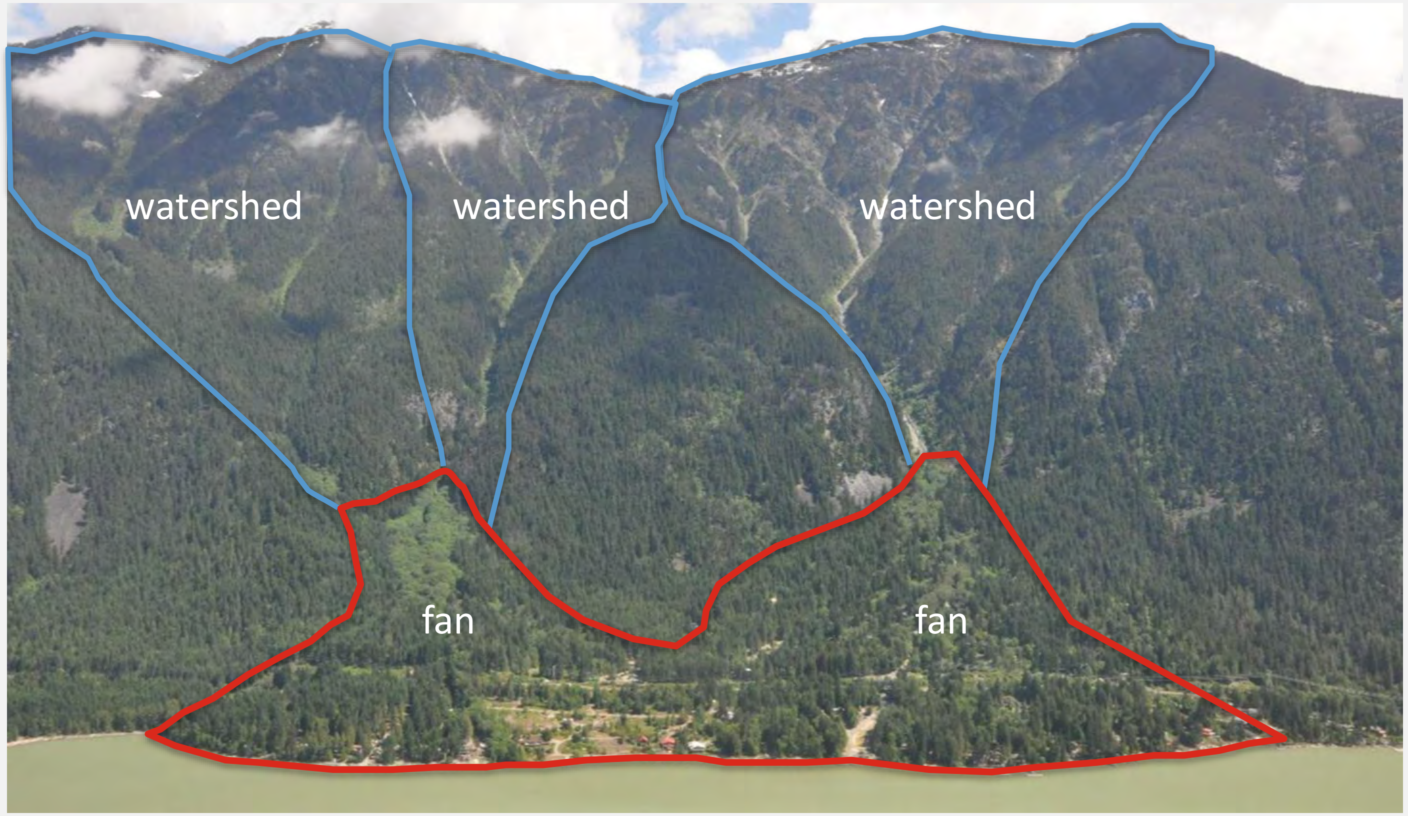
A number of landslides impacted highways and other linear infrastructure during the November events

Photos from one of my students, who was stuck between the landslides on Hwy 7 near Agassiz.
Image source: Amin Ahmed.

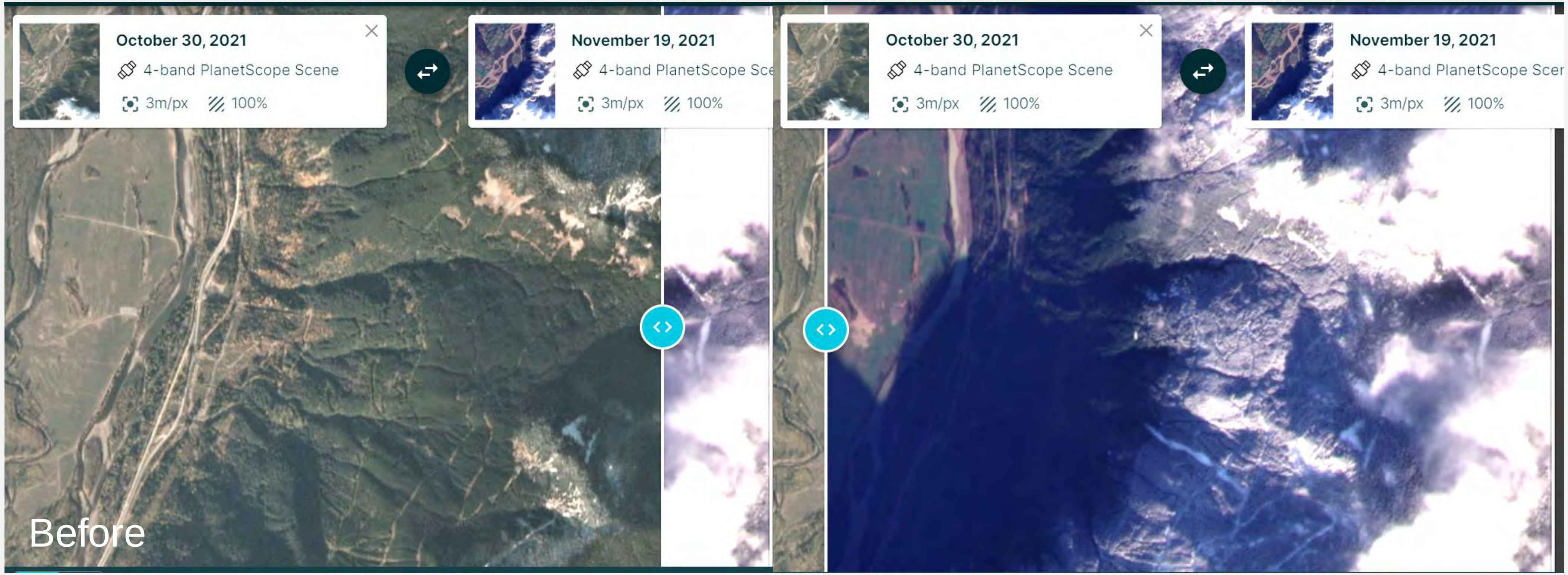
Debris flows are a channelized type of landslide



They recur on established paths, at least up to a point.

Image source: Lillooet Lake Estates.

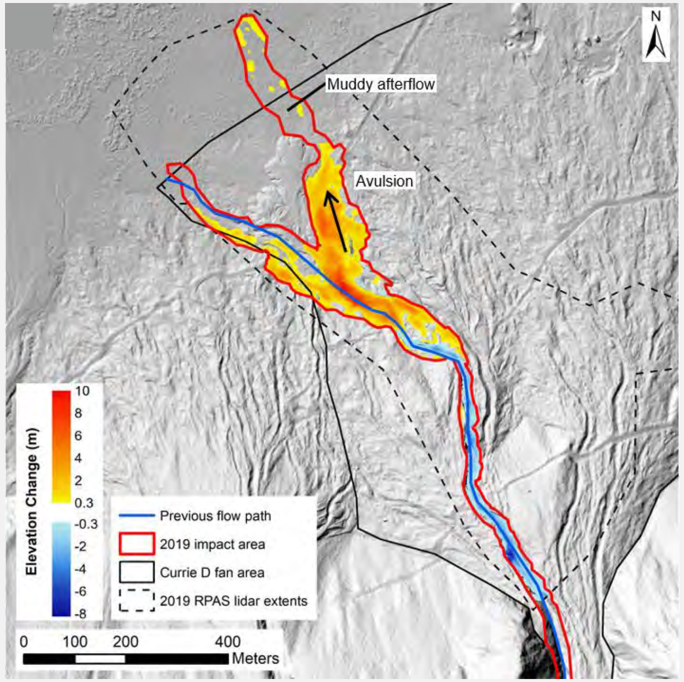
Changes evident in pre- and post-event airphotos and satellite images help us identify landslide source locations and outline impact areas



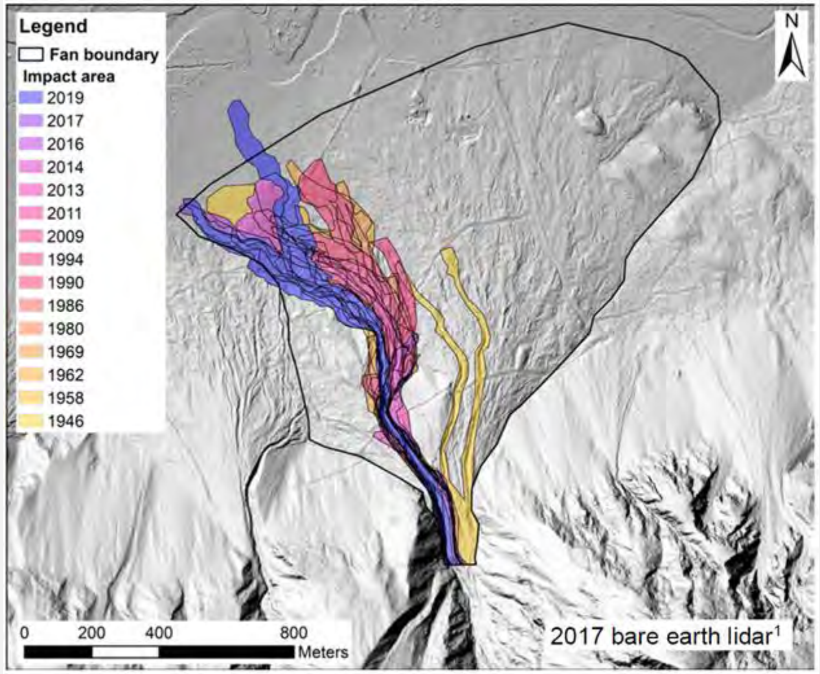
High quality images can be challenging to acquire at this time of year.

Image source: Planet & Andrew Mitchell.

Field mapping methods, including drone surveys, help us estimate landslide volumes and identify patterns



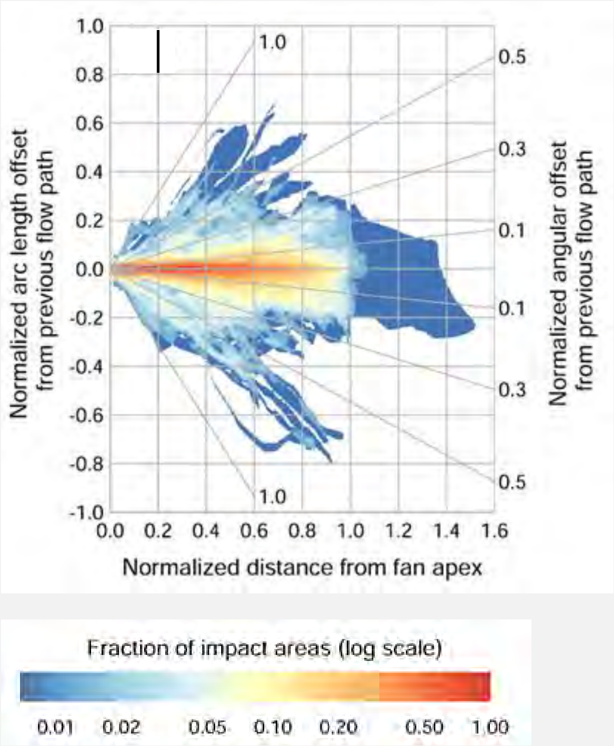
Detailed analysis of a single debris flow that occurred in 2019.



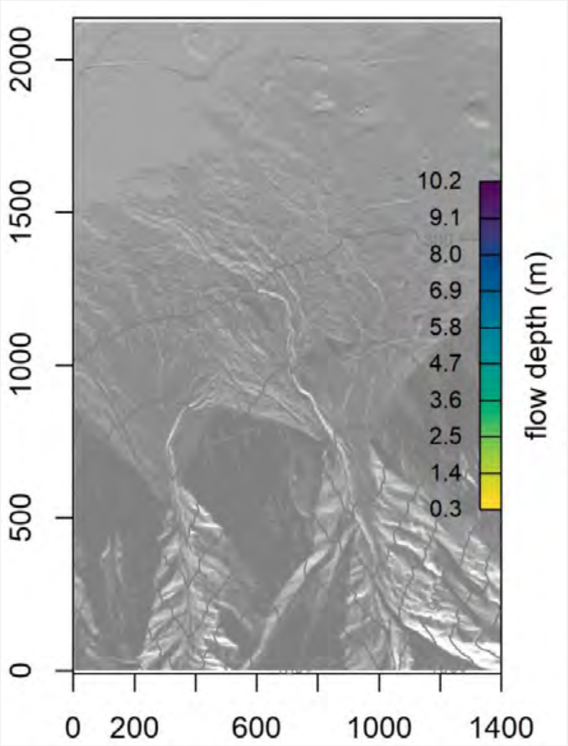
Composite of multiple debris flow impact areas dating back to 1946.

Image sources: Left and Middle: Andrew Mitchell. Right: Sophia Zubrycky.

The patterns we identify help us develop predictive models that can be used for site-specific risk assessment and mitigation design



Heat map based on 146 debris flow impact areas mapped on 30 different fans in southwestern BC.



Computer simulation of a debris flow.

Image sources: Left: Sophia Zubrycky. Right: Andrew Mitchell.

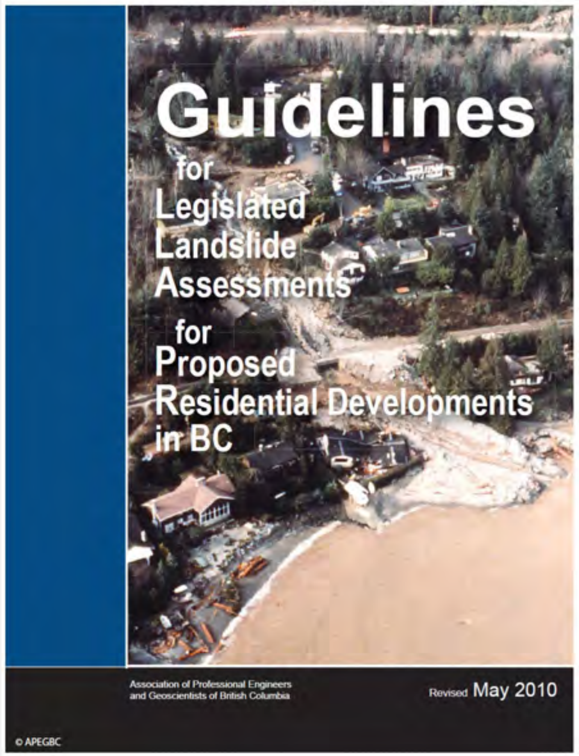
Mitigation can take different forms, ranging from avoidance to structural protection

Charles Creek near Lions Bay.

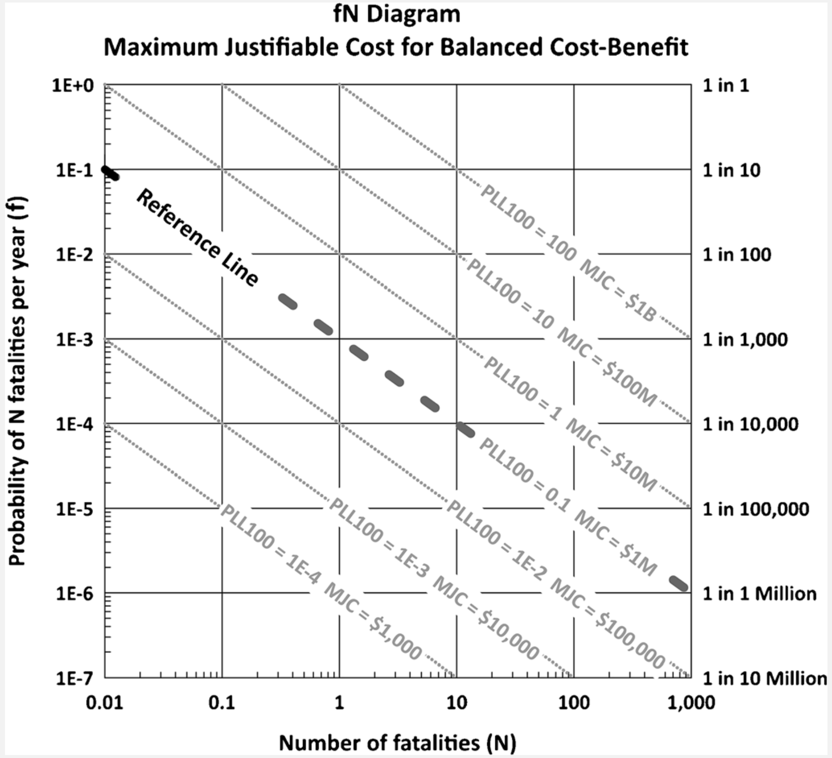
Large structures have been used locally (e.g. Sea-to-Sky) and internationally (e.g. Hong Kong, Japan, Europe) to mitigate debris flows, but they tend to be expensive.

Image sources: Left & Middle: Oldrich Hungr. Right: Emily Mark and Alex Strouth.

Landslide risk evaluation practice is evolving in BC, but broadly applicable guidance on tolerable levels of safety does not exist yet



An update to the EGBC professional practice guidelines is expected in 2022.



Research is underway to develop new tools that can be used for cost-benefit analysis.

Image sources: Left: EGBC. Right: Alex Strouth.

Linear infrastructure may cross several different hazard zones, so prioritization is a key challenge

Photos of recent debris flows on the south side of the Fraser River near Mount Cheam, showing impacts to multiple stakeholders in the same corridor.

Image source: Joshua Nicholas.

Dr. Dharma Wijewickreme, P.Eng.

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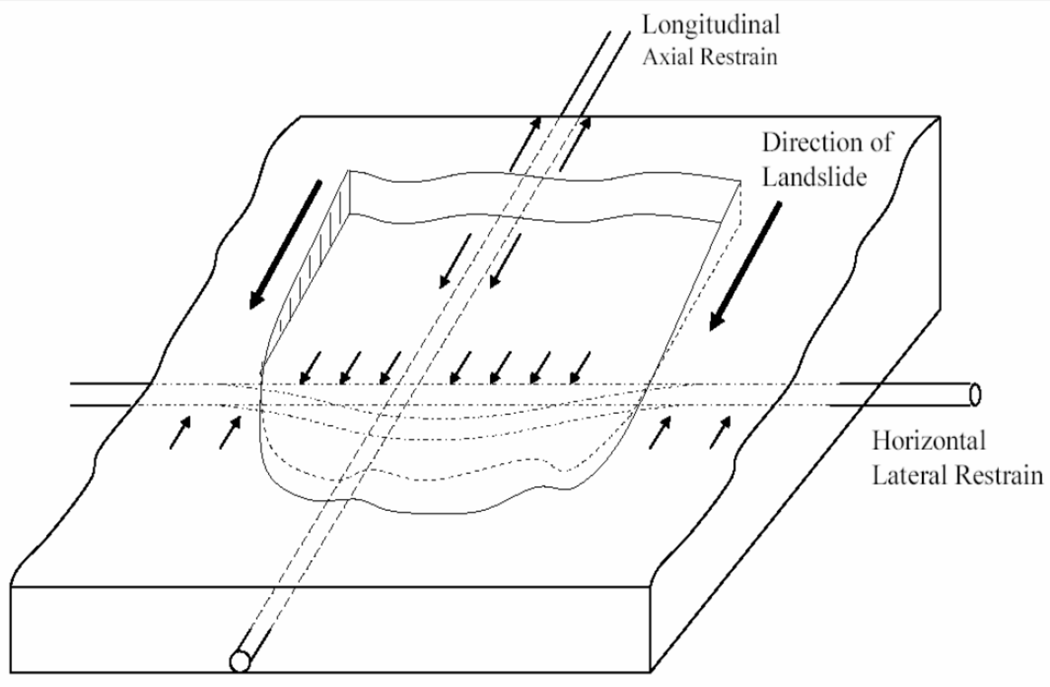
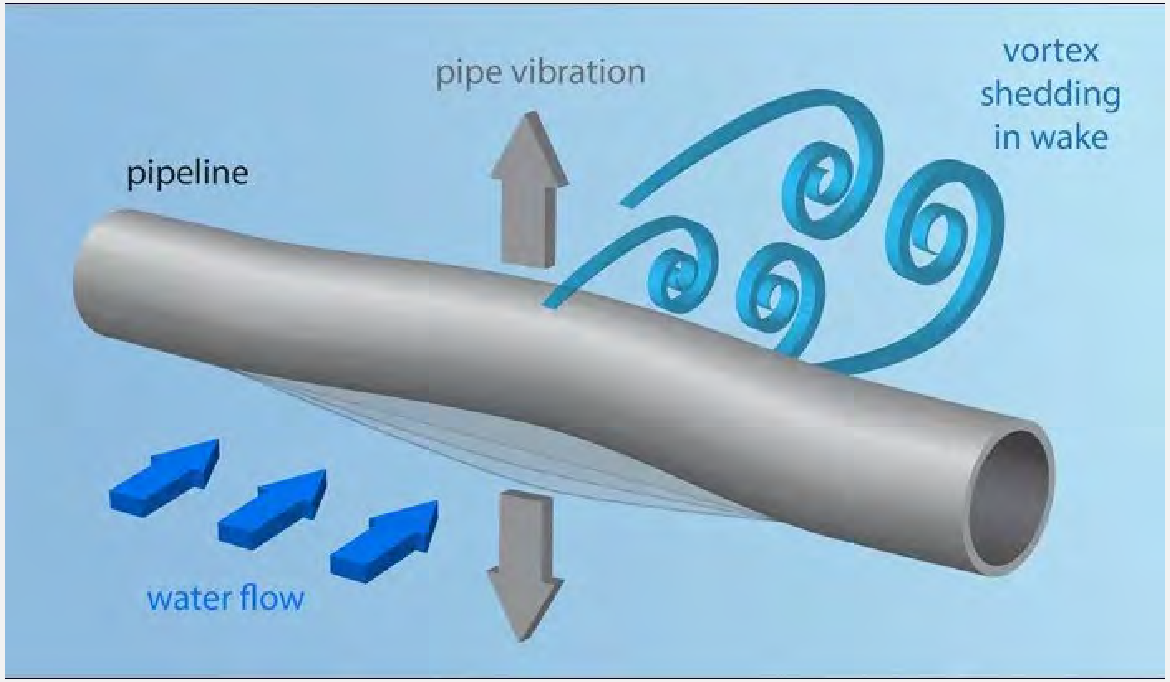
Impacts of geohazards on pipelines

Forces on pipelines from weather-induced hazards



Soil forces



Water forces and riverbed load / debris forces

Image source: Yang et al. 2020.

Pipeline exposure (Trans Mountain Pipeline)

Some locations have been impacted:

- Pipeline exposure impacted by flooding and debris
- Scouring of protective coating
- External surface dents and scratch

Response:

- Geotechnical/hydrotechnical protective measures
- Completing repairs to the pipeline to ensure integrity
- After precautionary shutdown, restarted on December 5th

As reported in Website: https://www.transmountain.com/news/2021/ensuring-safety-during-bc-and-wa-storm-impacts.

Pipeline damage / exposure examples

Red Deer River flooding in Saskatchewan. Heavy river flow eroded the soil and exposed the pipe.

36-inch ONP Oil Pipeline, Peru left without support over a 92-m span; did not rupture.

Image source: https://www.cenozon.com/2018/07/vivamus-sagittis-lacus-vel-augue-laoreet-rutrum-2-3-3-9.
Photo provided by: DG Honegger Consulting, adapted from presentation by D. Nyman.

Pipeline damage / exposure examples

Tensile failure

Buckling

Excessive bending

Other: damage to corrosion protection systems (cathodic protection systems, pipe coatings) and damage to valve/pump stations.

Image source: Left: Vasseghi et al., 2021. Middle: Strizhalo et al., 2018. Right: Strizhalo et al., 2018.

Dr. Jonathan Fannin, P.Eng.

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Flood risk management: dike integrity

Image source: J.Fannin.

Sumas Prairie floodplain

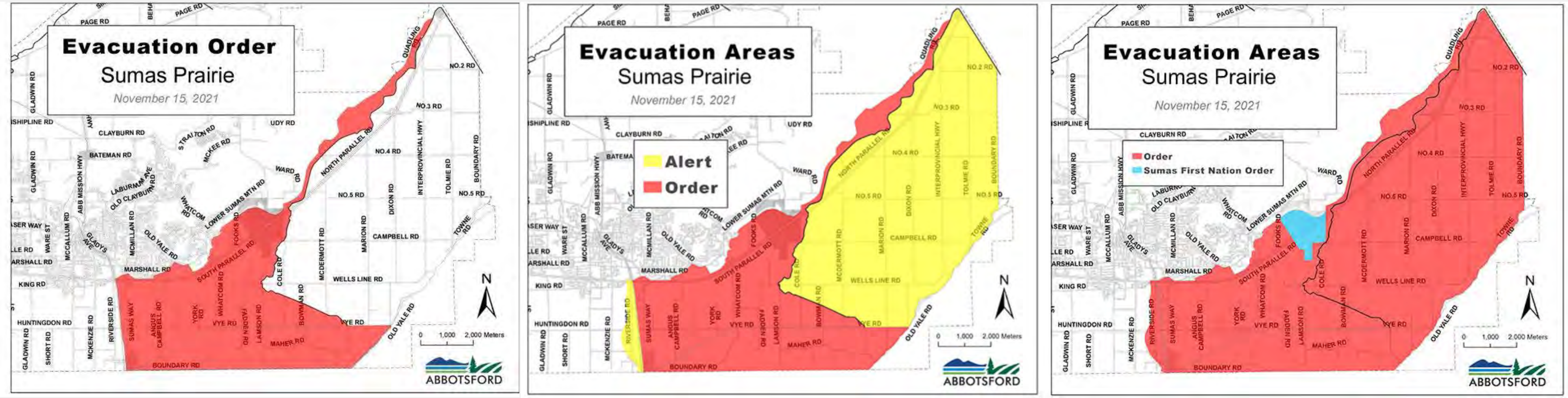


Image source: https://twitter.com/city_abbotsford.

Sumas Prairie floodplain: dike system

Image source: J.Fannin.

Dike system: breach location

Image source: J.Fannin.

Sumas Prairie floodplain: dike system

Image source: J.Fannin.

Dike system: erosion and breach locations

Image source: Left and Middle: S.Weijs. Right: J.Fannin.

Dike system: rehabilitation and reconstruction

Image source: Left: J.Fannin. Right: S.Weijs.

Dike system: reconstruction

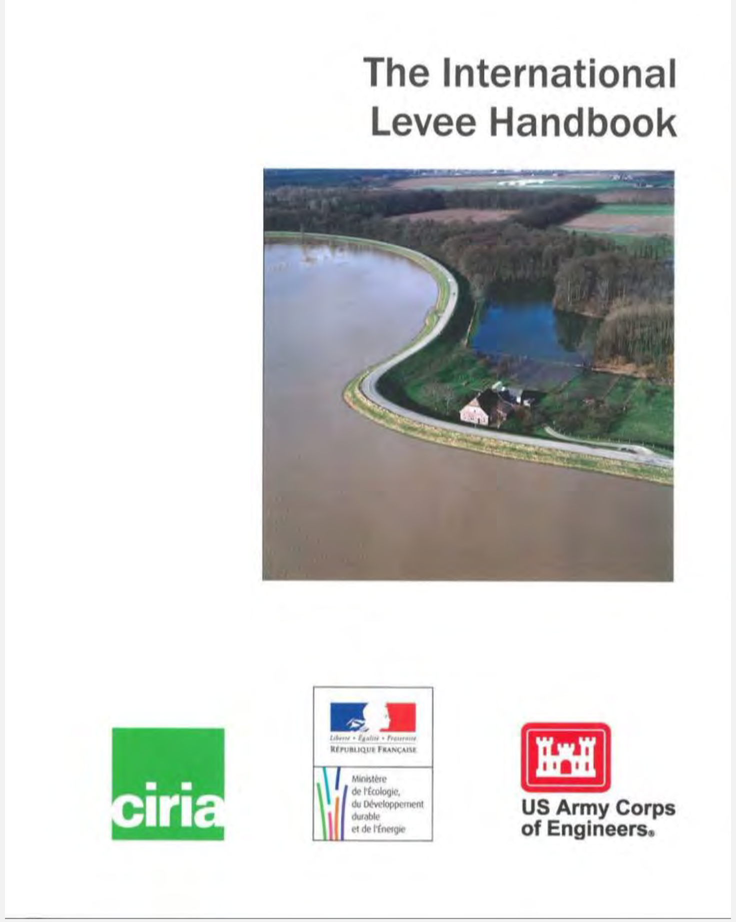


Image source: https://www.abbotsford.ca/flooding-alert#photos.

Recent developments: failure processes

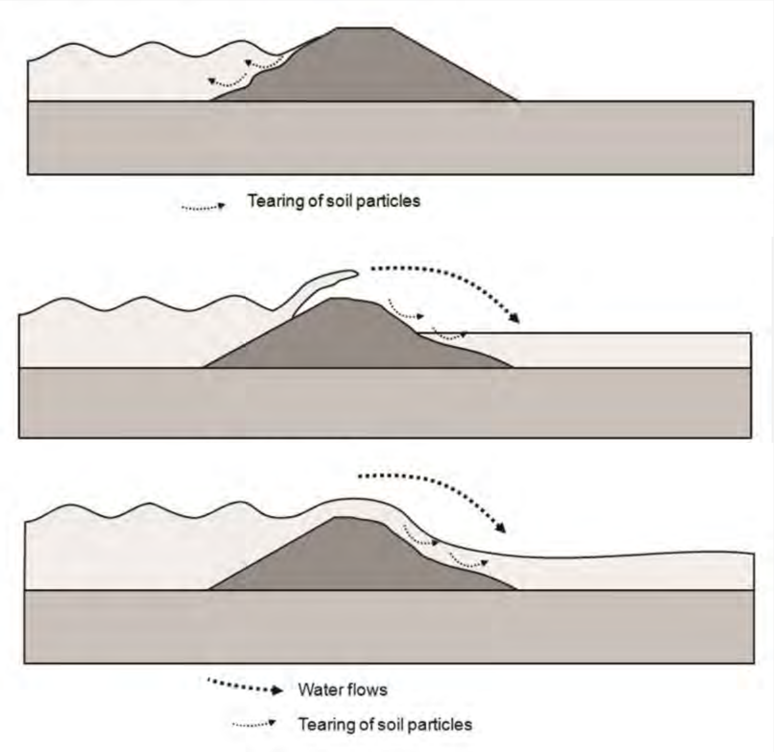
Main processes of deterioration, damage and breach:

- External erosion
- Internal erosion
- Slope instability



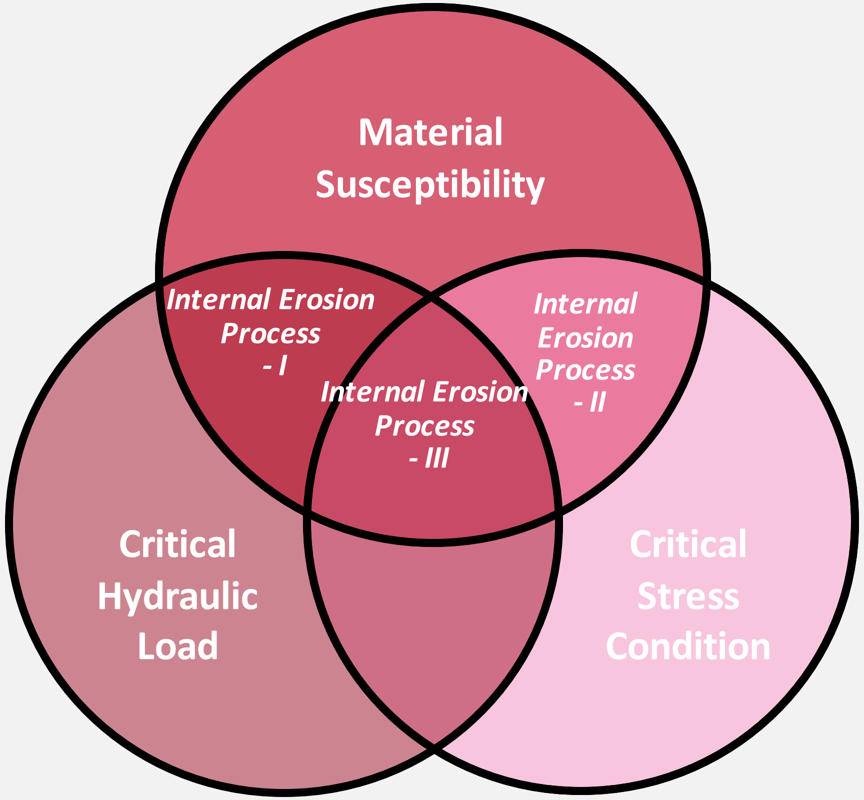
Source: CIRIA (2013) The International Levee Handbook, C731, CIRIA, London, UK (ISBN: 978-0-86017-734-0).

Failure processes: external erosion



Source: CIRIA (2013) The International Levee Handbook, C731, CIRIA, London, UK (ISBN: 978-0-86017-734-0).
Image: J.Fannin.

Failure processes: internal erosion



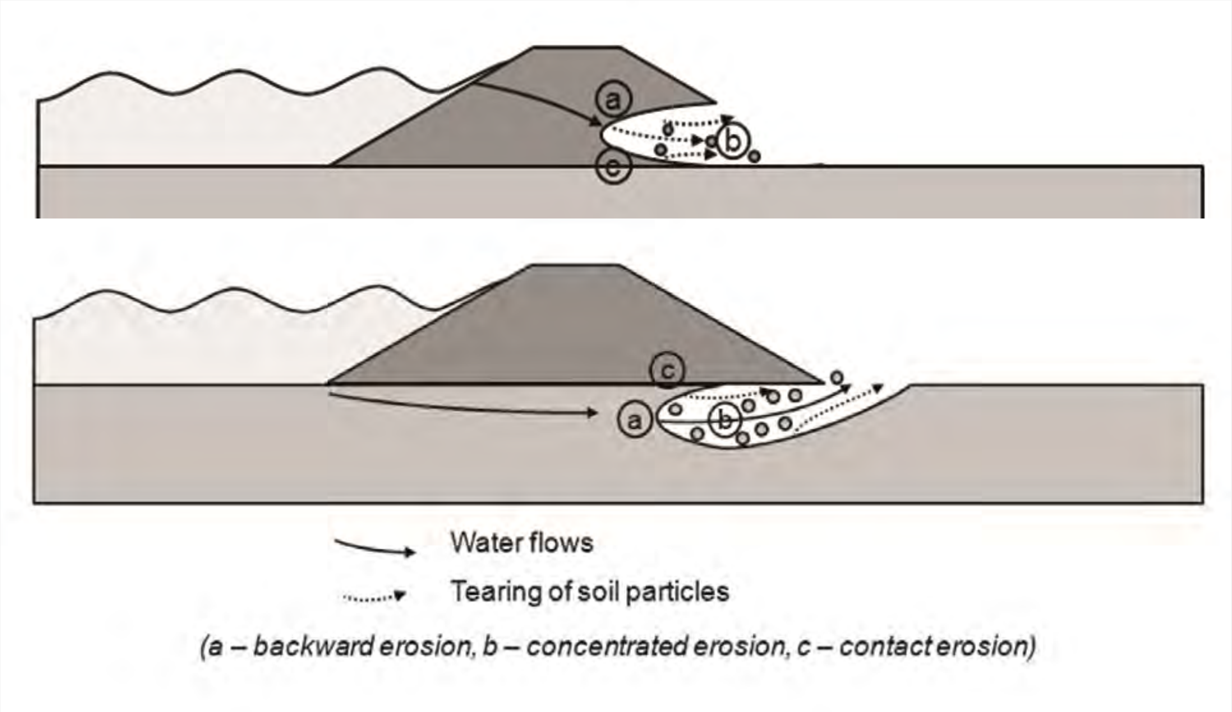
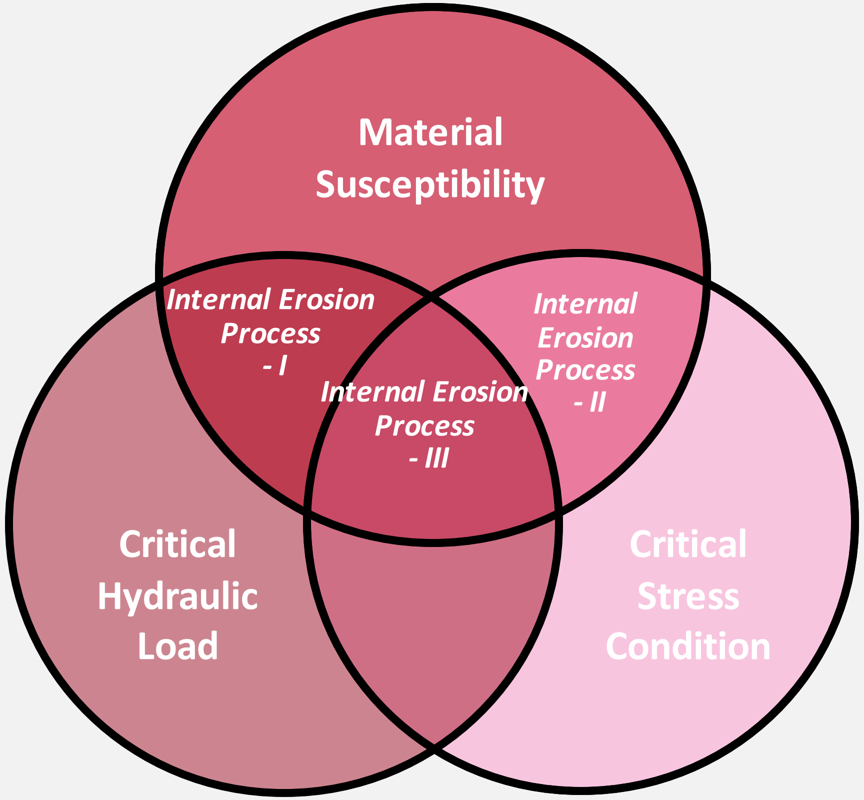


Image source: Left: ICOLD Bulletin B164 (2019) Internal erosion of dams, dikes and their foundations: fig. Adapted from S.Garner and J.Fannin original version. Right: CIRIA (2013) The International Handbook, C731 CIRIA, London, UK (ISBN: 978-0-86017-734-0).

Failure processes: internal erosion



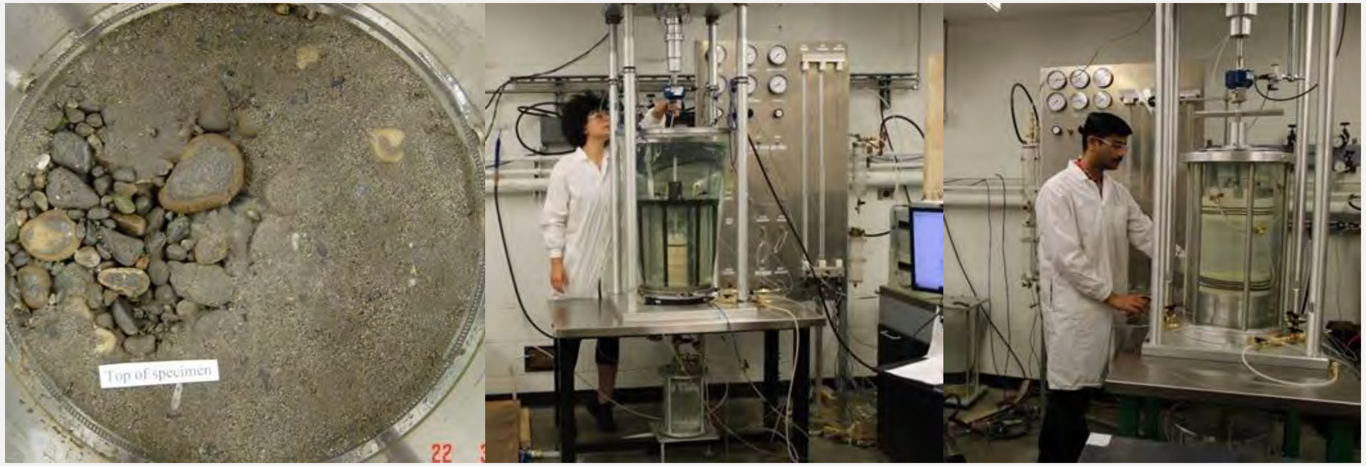


Image source: Left: ICOLD Bulletin B164 (2019) Internal erosion of dams, dikes and their foundations: fig. Adapted from S.Garner and J.Fannin original version. Right: R.Moffat and A.Sarraf.

Flood risk management: dike failure statistics

Main processes of deterioration, damage and breach:

- External erosion
- Internal erosion
- Slope instability

Image source: J.Fannin.

Dr. Steven Weijs

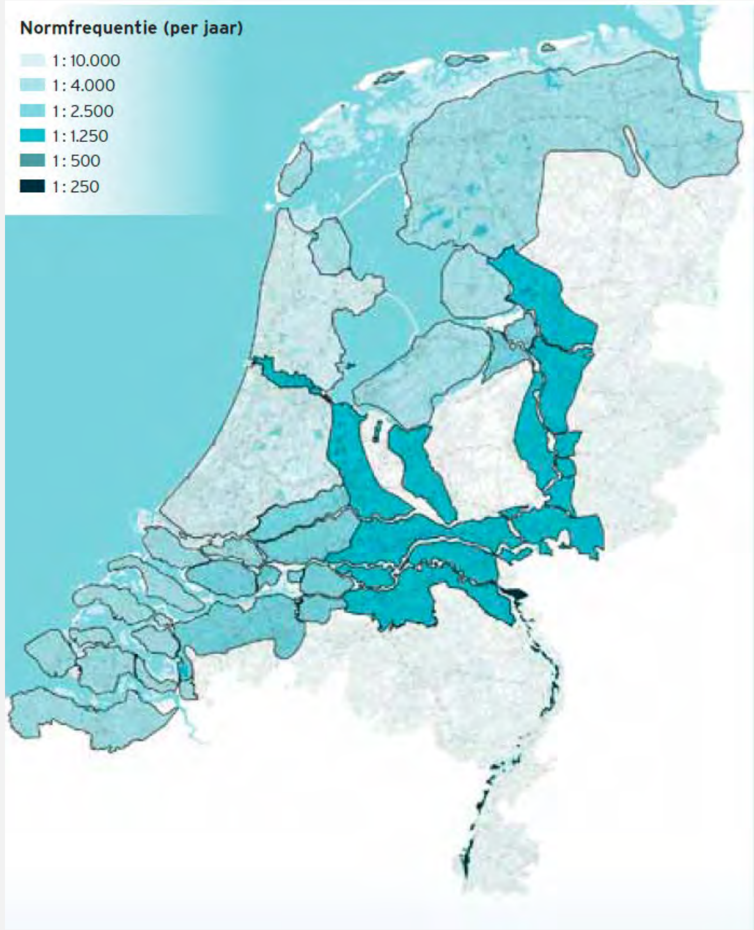
Submit / upvote on questions at sli.do [event code 452216], or scan:

Image source: UBC Civil Aerial Reconnaissance.

Dike failure mechanisms

Overtopping | Failure of inner slope | Erosion outer slope | Piping

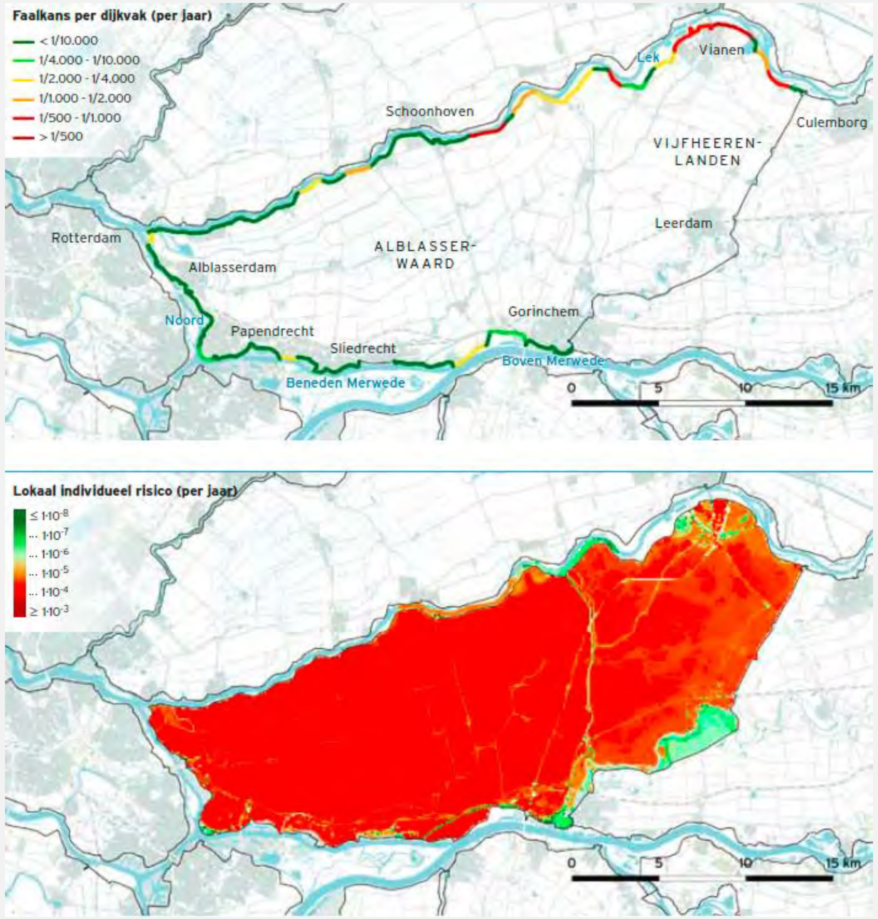
Image source: Vergouwe (2014), Report: Veiligheid Nederland in Kaart, Hydraulic Engineering Reports, Ministry of I&M, http://resolver.tudelft.nl/uuid:52035faa-43ab-4dd0-a5b0-099119085356 .



Norm frequencies (1/yr), (prior to 2016)

Economical risk (Euro/ha/yr), 2012 state of infrastructure

Image source: Source: Vergouwe (2014), Report: Veiligheid Nederland in Kaart, Hydraulic Engineering Reports, Ministry of I&M, http://resolver.tudelft.nl/uuid:52035faa-43ab-4dd0-a5b0-099119085356.



Integrated approach

Estimation of damages

Estimation of failure probabilities and risk

Prioritization

Economically optimal stricter than safety

Identification of cost-effective measures

Image source: Left: Vergouwe (2014), Veiligheid Nederland in Kaart, Hydraulic Engineering Reports, Ministry of I&M, the Netherlands http://resolver.tudelft.nl/uuid:52035faa-43ab-4dd0-a5b0-099119085356.

View on Sumas River with dike near Abbotsford

Image source: Image source: UBC Civil Aerial Reconnaissance.

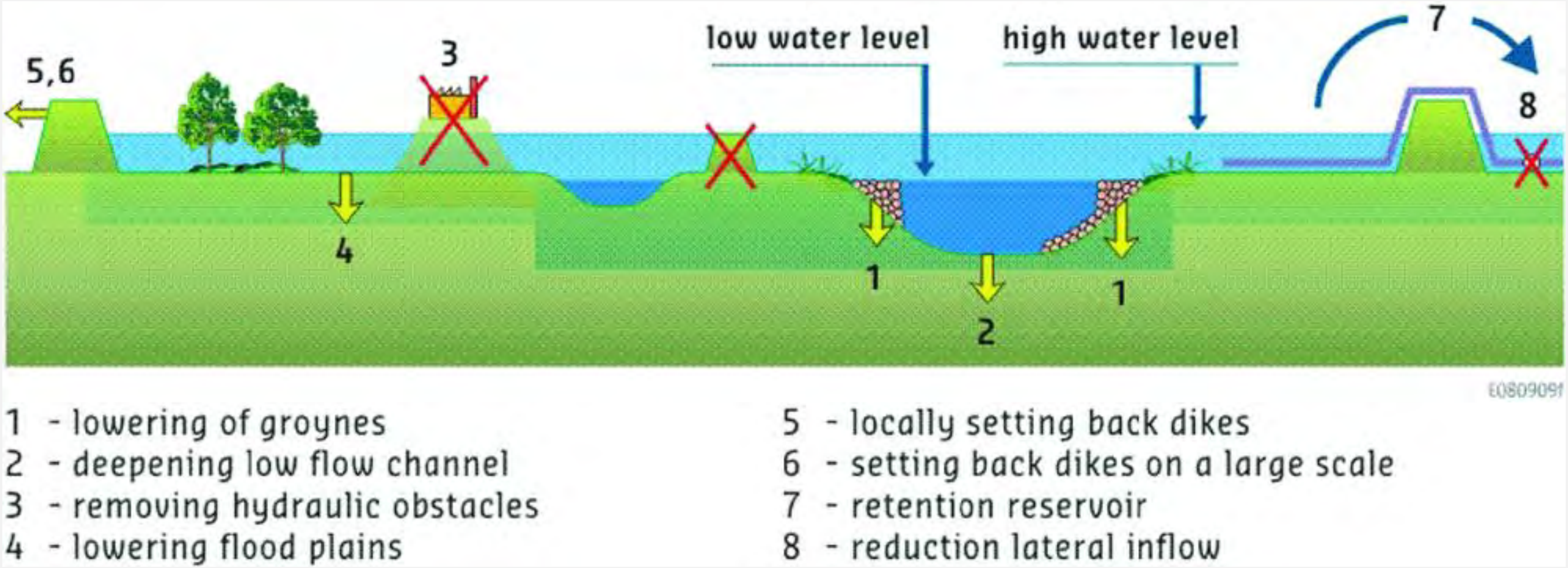
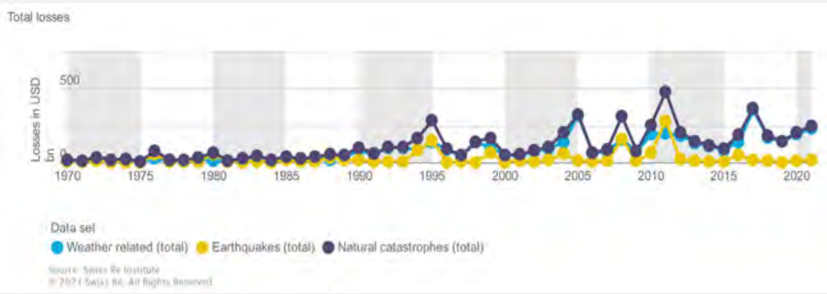
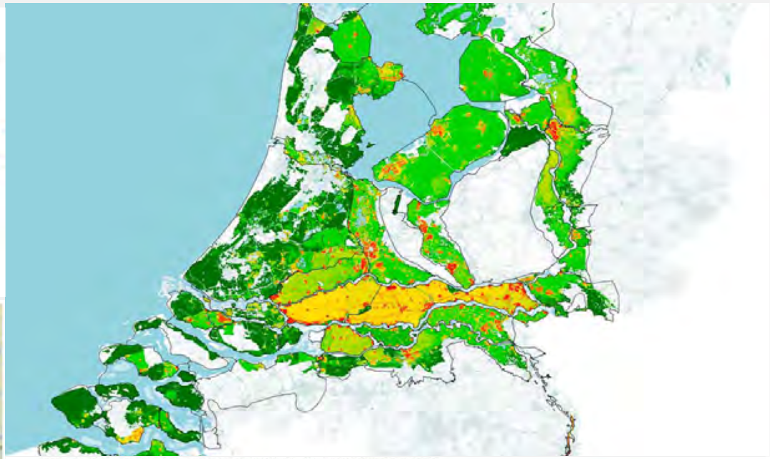
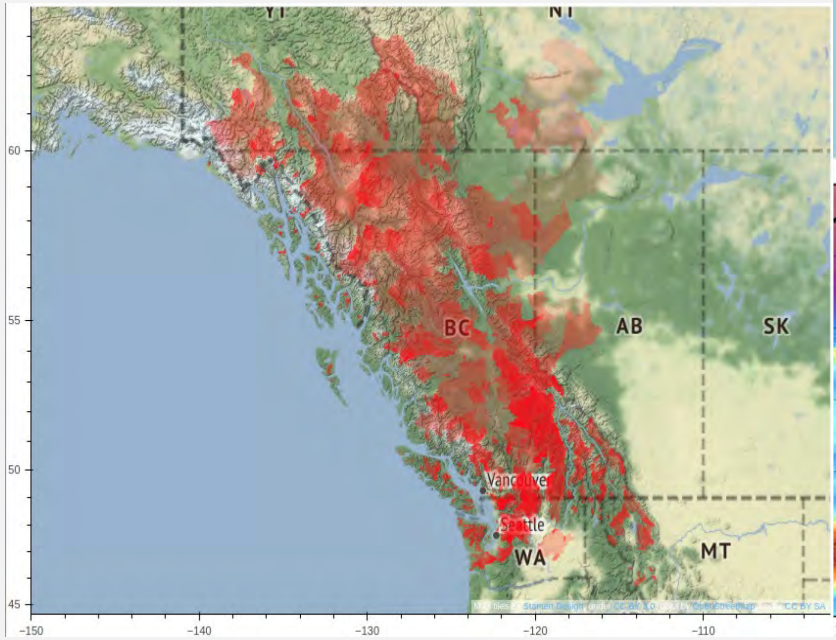
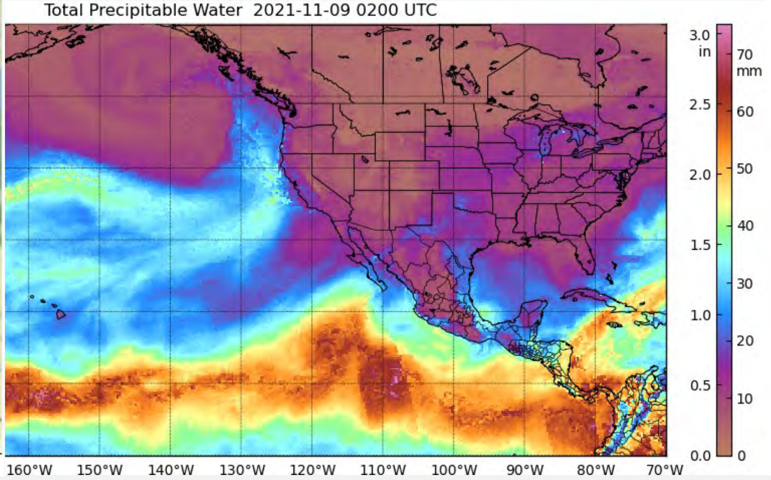


Image source: Source Silva, W., Klijn, F. and Dijkman, J.P.M. Room for the Rhine branches in the Netherlands, what the research has taught us. Arnhem: Deltares (WL)/Rijkswaterstaat RIZA. p. 56;









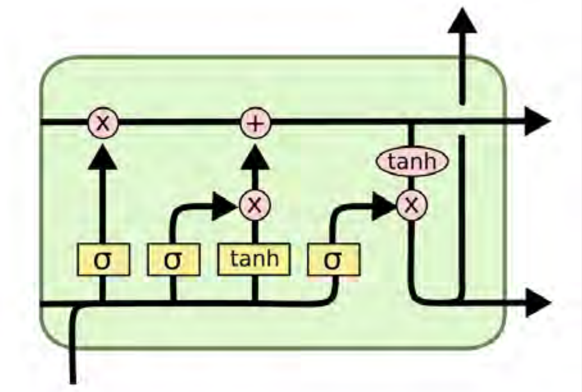


Image source: Top Left: SwissRe https://www.sigma-explorer.com/ ; Hydrometric station density, Hydro-info-theory lab, UBC Right: see earlier references, Bottom left: LSTM cell, http://colah.github.io/posts/2015-08-Understanding-LSTMs.

Dr. Dharma Wijewickreme, P.Eng.

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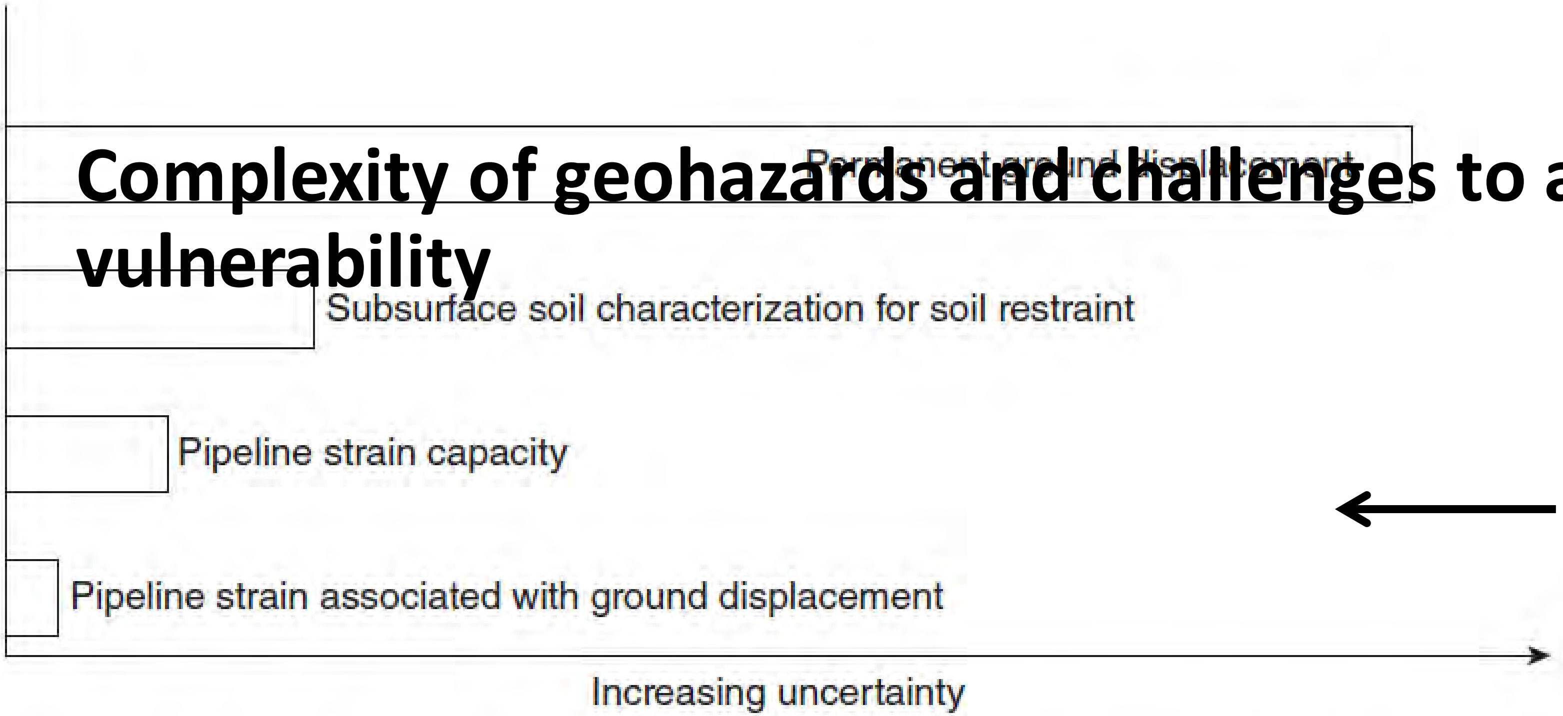
Complexity of geohazards and challenges to assessing pipeline vulnerability



25.1 Qualitative depiction of relative uncertainty in key vulnerability assessment parameters.

Load (Demand)

High Uncertainty!

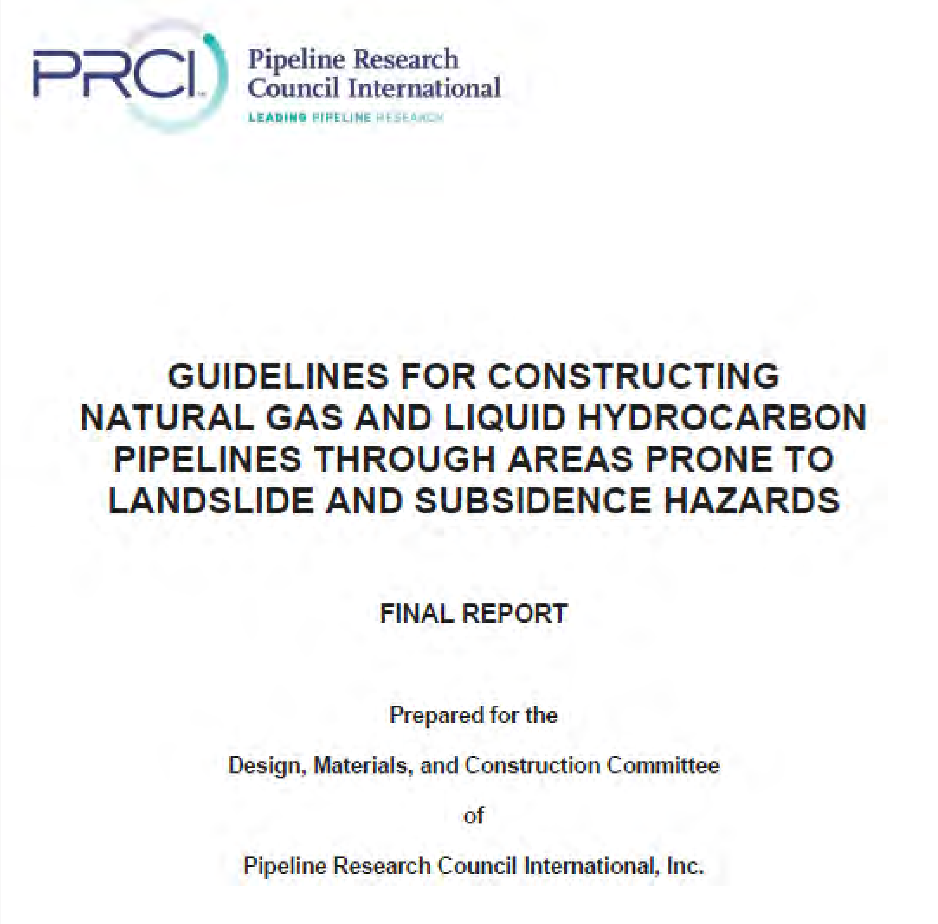
Resistance (Capacity)

Image source: Honegger and Wijewickreme (2013).

Pipeline integrity management for geohazards - PRCI (2009) guidelines

Pipeline integrity management strategies to:

- Assess the complex problem of ground displacement hazard
- Methods to mitigate hazards
- Monitor ground displacement or pipeline response



PRCI Pipeline Research Council International
LEADING PIPELINE RESEARCH

GUIDELINES FOR CONSTRUCTING NATURAL GAS AND LIQUID HYDROCARBON PIPELINES THROUGH AREAS PRONE TO LANDSLIDE AND SUBSIDENCE HAZARDS

FINAL REPORT

Prepared for the

Design, Materials, and Construction Committee

of

Pipeline Research Council International, Inc.

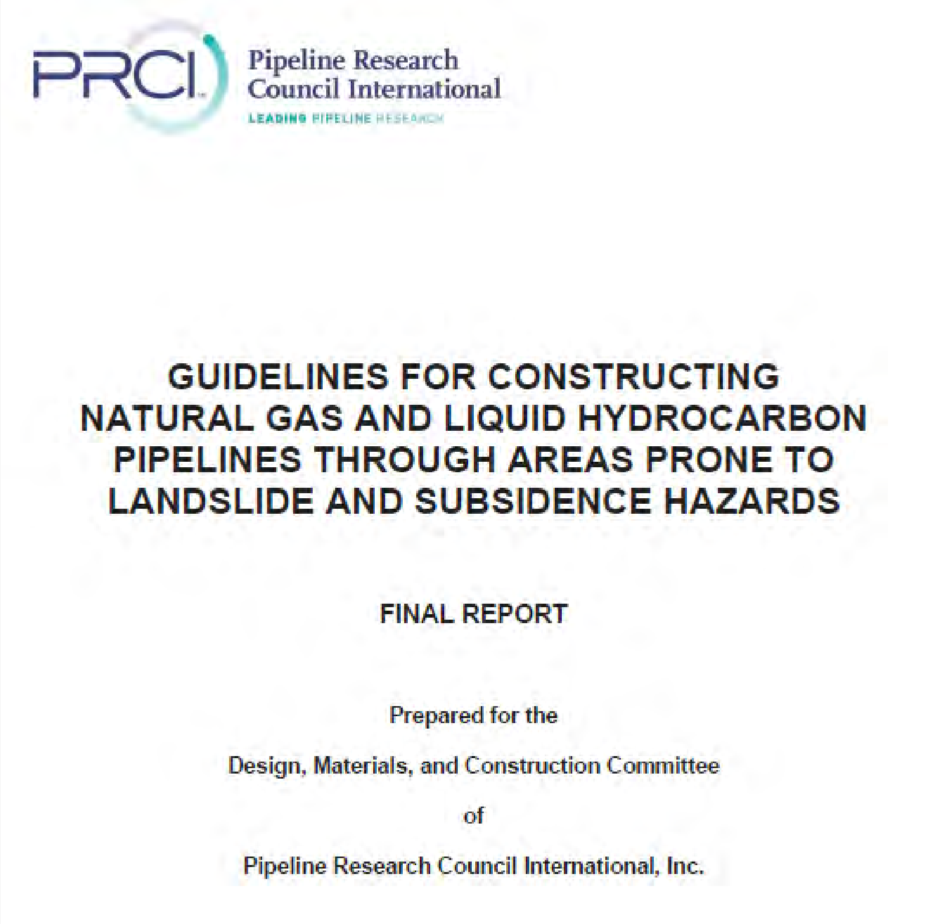
Pipeline integrity management for geohazards - PRCI (2009) guidelines

Pipeline mitigation alternatives:

- Isolate from the hazard
- Tolerate the hazard
- Eliminate the hazard
- Relocate away from the hazard

Operational monitoring:

- Pipeline monitoring
- Landslide monitoring



PRCI Pipeline Research Council International

LEADING PIPELINE RESEARCH

GUIDELINES FOR CONSTRUCTING NATURAL GAS AND LIQUID HYDROCARBON PIPELINES THROUGH AREAS PRONE TO LANDSLIDE AND SUBSIDENCE HAZARDS

FINAL REPORT

Prepared for the

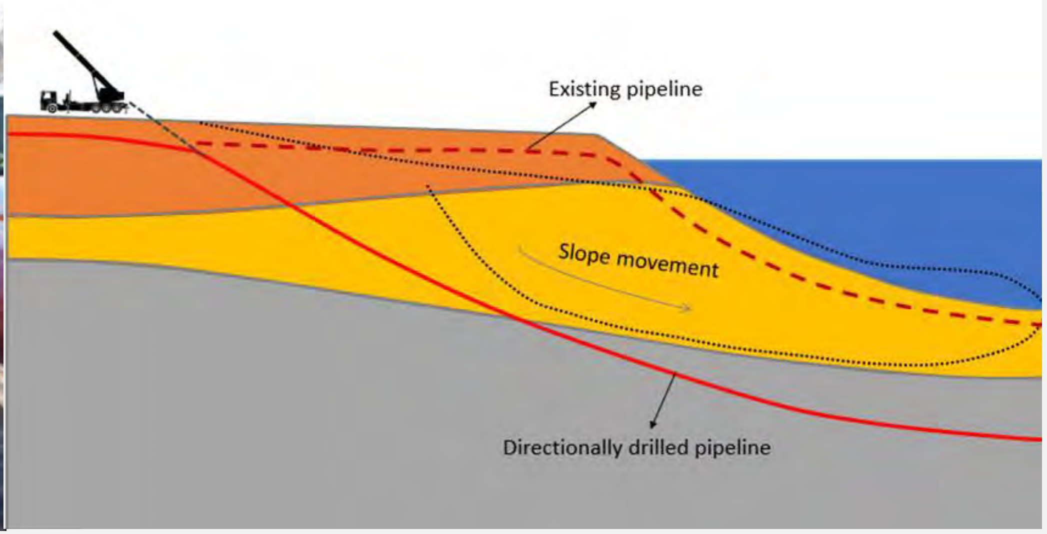
Design, Materials, and Construction Committee

of

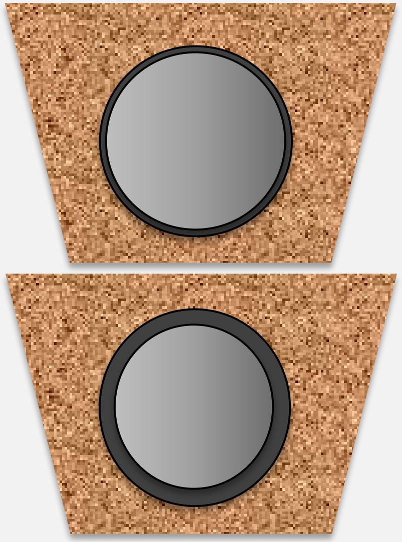
Pipeline Research Council International, Inc.

Hazard mitigation examples

Use of geosynthetic wrapping to reduce axial forces



Modify pipeline alignment



Increase pipe wall thickness

Hazard mitigation examples

Ground improvement against slope instability

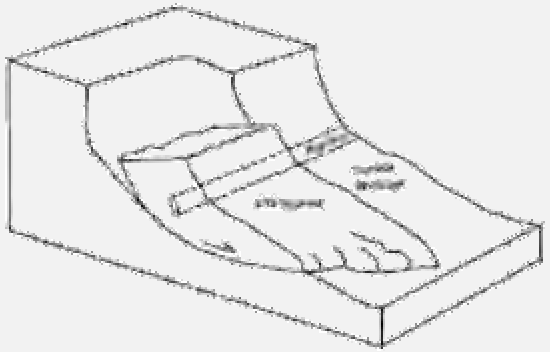
Debris flow barriers

Image source: Left: Wijewickreme et al. (2005). Right: https://gea.ca/whistler-creek-debris-barrier.

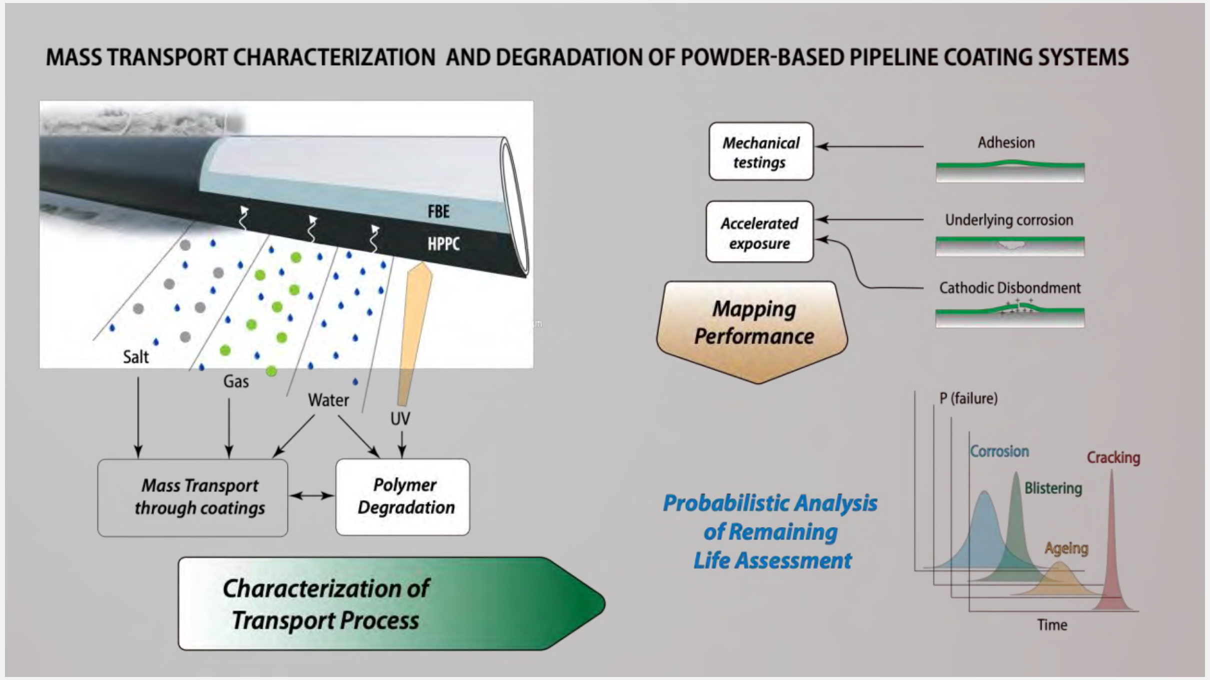
Research at UBC Pipeline Integrity Institute

PIPELINE INTEGRITY INSTITUTE
INSTITUT D'INTÉGRITÉ DE PIPELINE

Low strength backfill materials to manage axial soil loads



Simulating pipe failures in slopes using large ASPIRe chamber



Research on coating degradation/corrosion

Dr. Amy Kim, P.Eng.

Submit / upvote on questions at sli.do [event code 452216], or scan:

Major road closures and advisories, southern BC

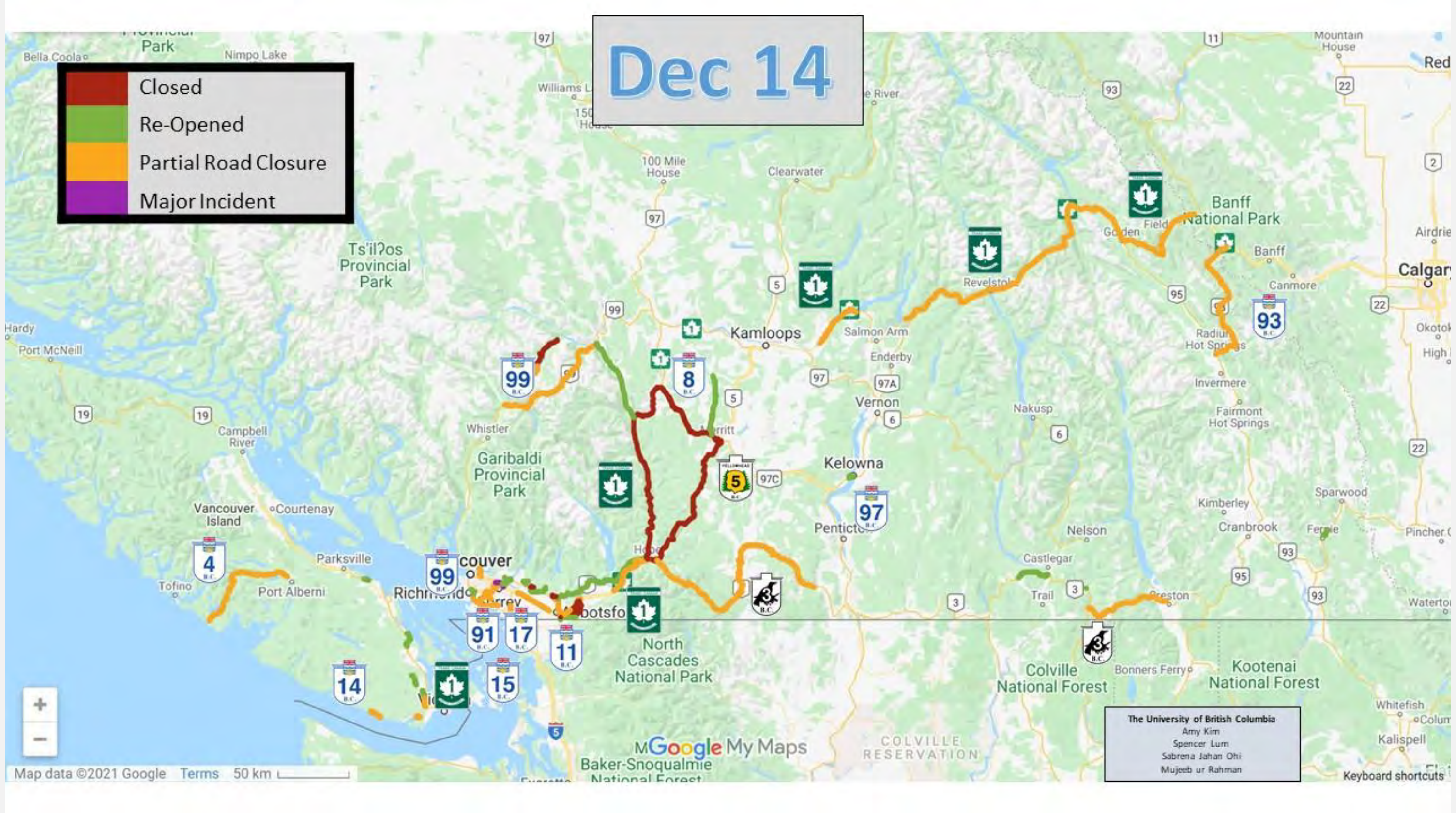
Landslide and flood hazards

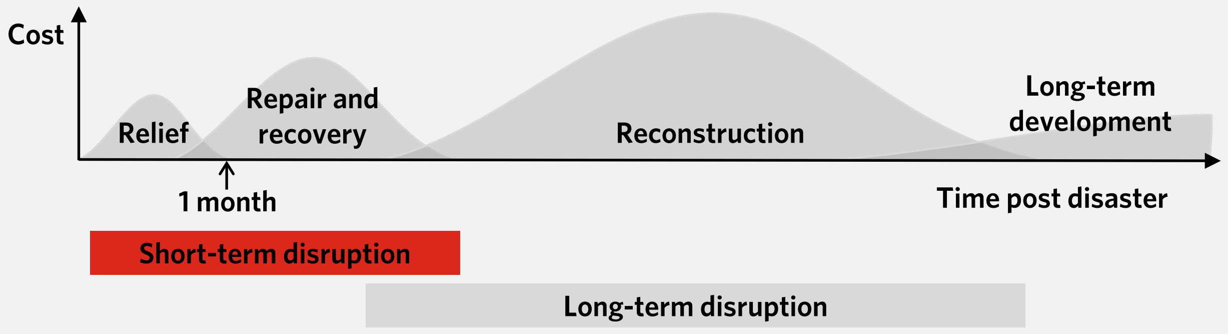
Infrastructure disruptions, damage, failures

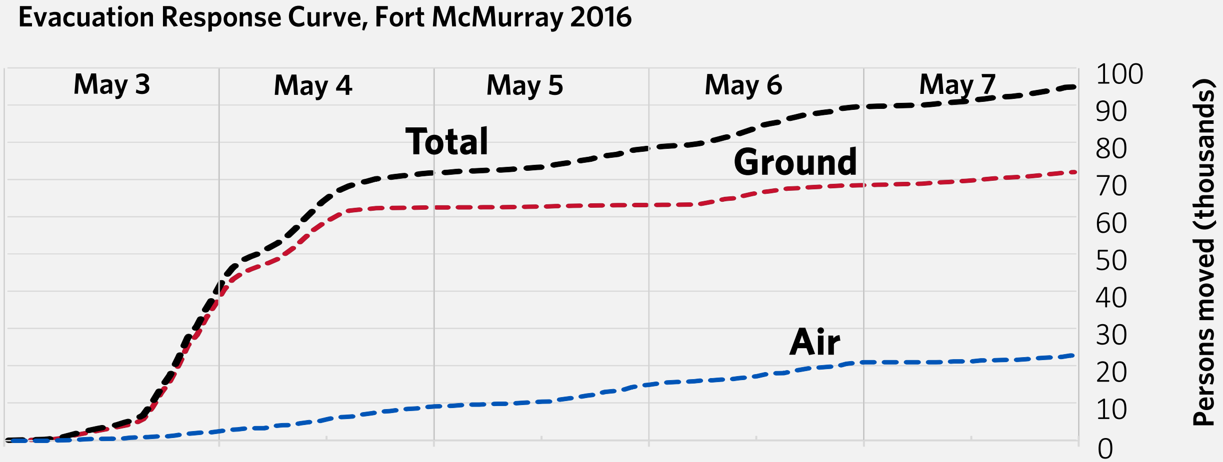
Operational disruptions on transportation network

Short-term

Long-term







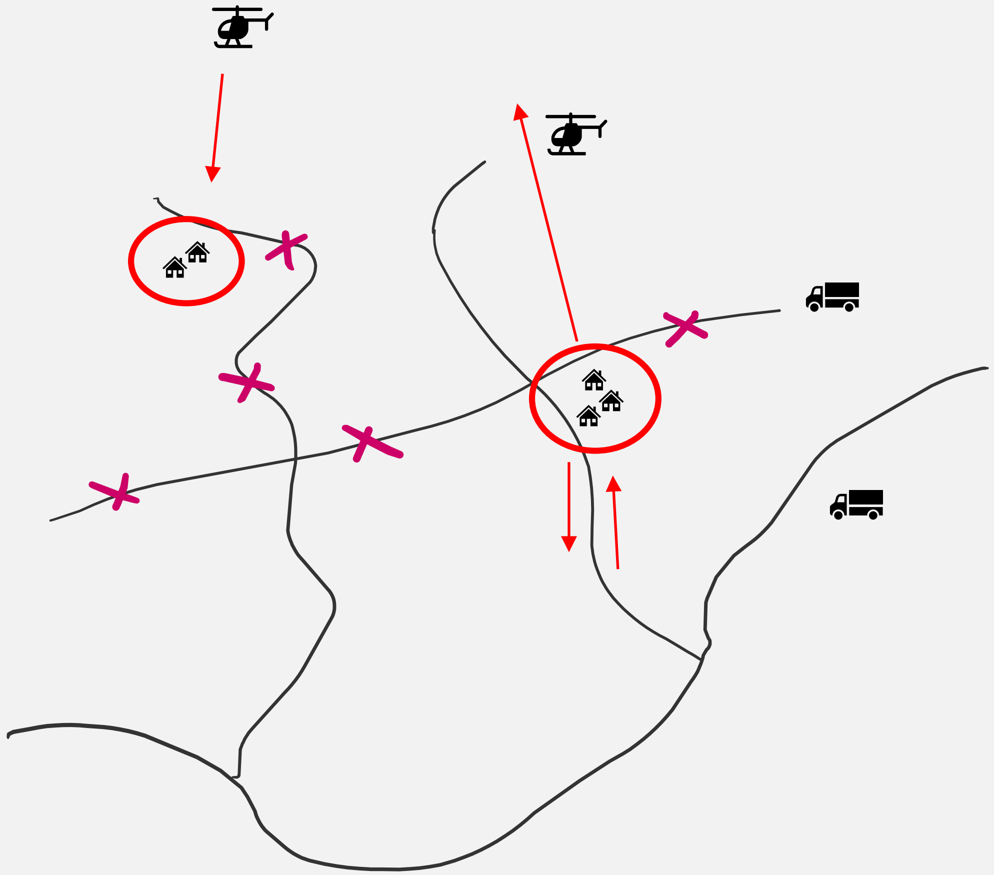
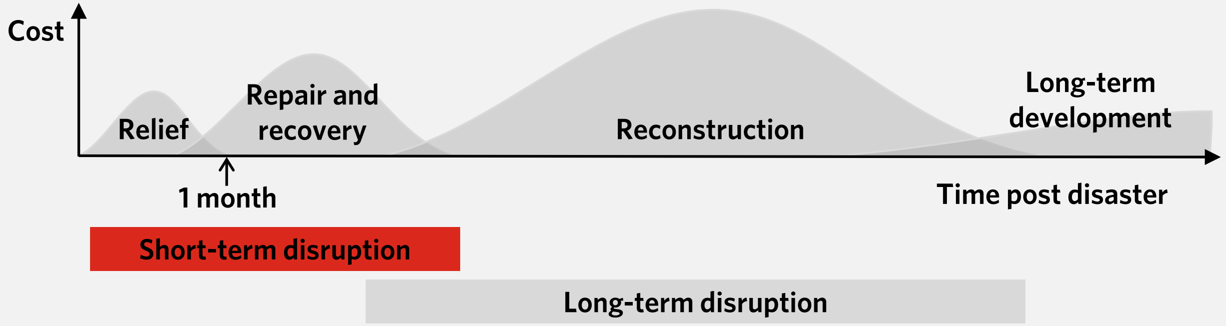


Figure adapted and modified from Chester et al. (2021), Post-Disaster Infrastructure Delivery for Resilience, *Sustainability*, 13, 3458.



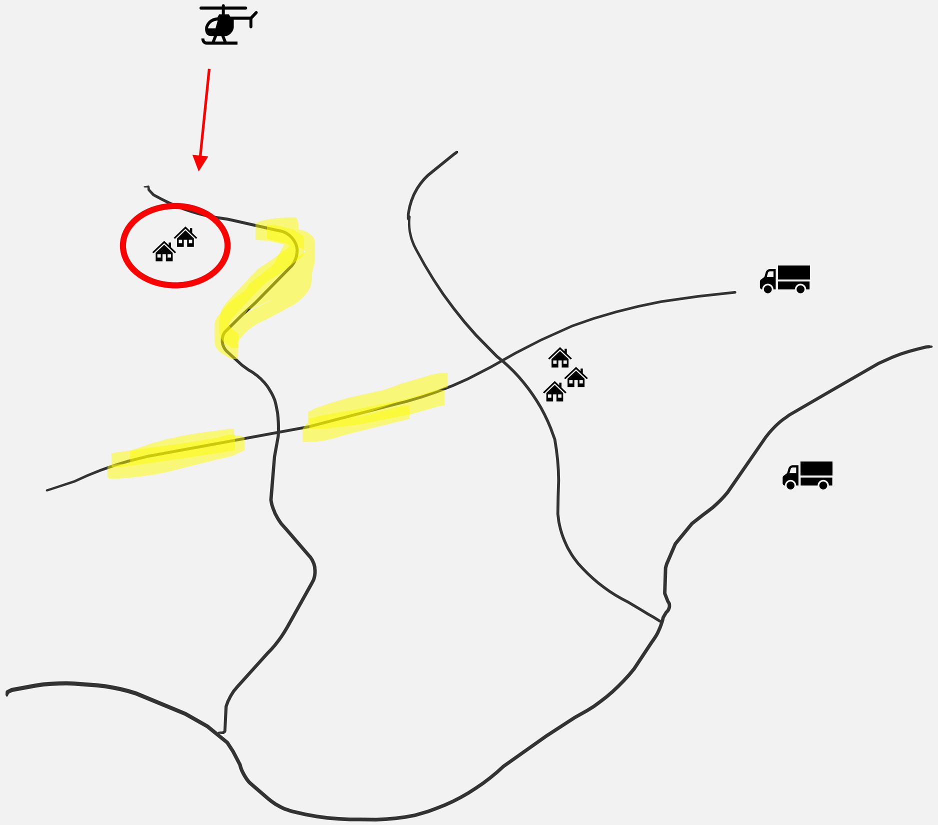


Figure adapted and modified from Chester et al. (2021), Post-Disaster Infrastructure Delivery for Resilience, *Sustainability*, 13, 3458.

Image source: BC Highway 5 - Jessica Bridge Southbound Panel Installation by BC Ministry of Transportation and Infrastructure, licensed under CC BY-NC-ND 2.0.

What does it mean to have a more resilient, adaptable network?

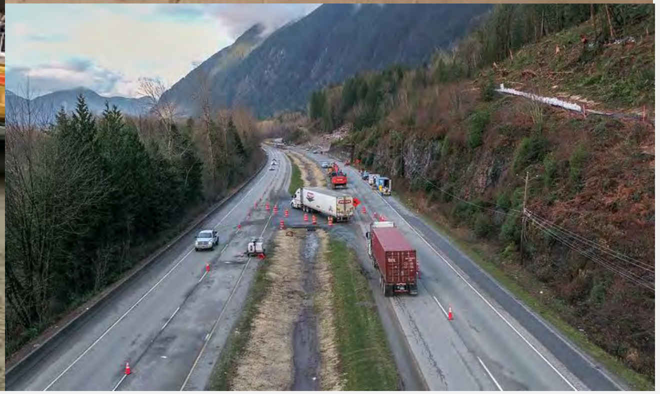


Photo credits: (all BC Ministry of Transportation and Infrastructure, licensed under CC BY-NC-ND 2.0). Middle: BC Highway 99 - Mt. Currie Checkpoint. Top Right: BC Highway 5 - Bottletop Bridge repairs. Bottom Right: Hwy 1- Popkum.

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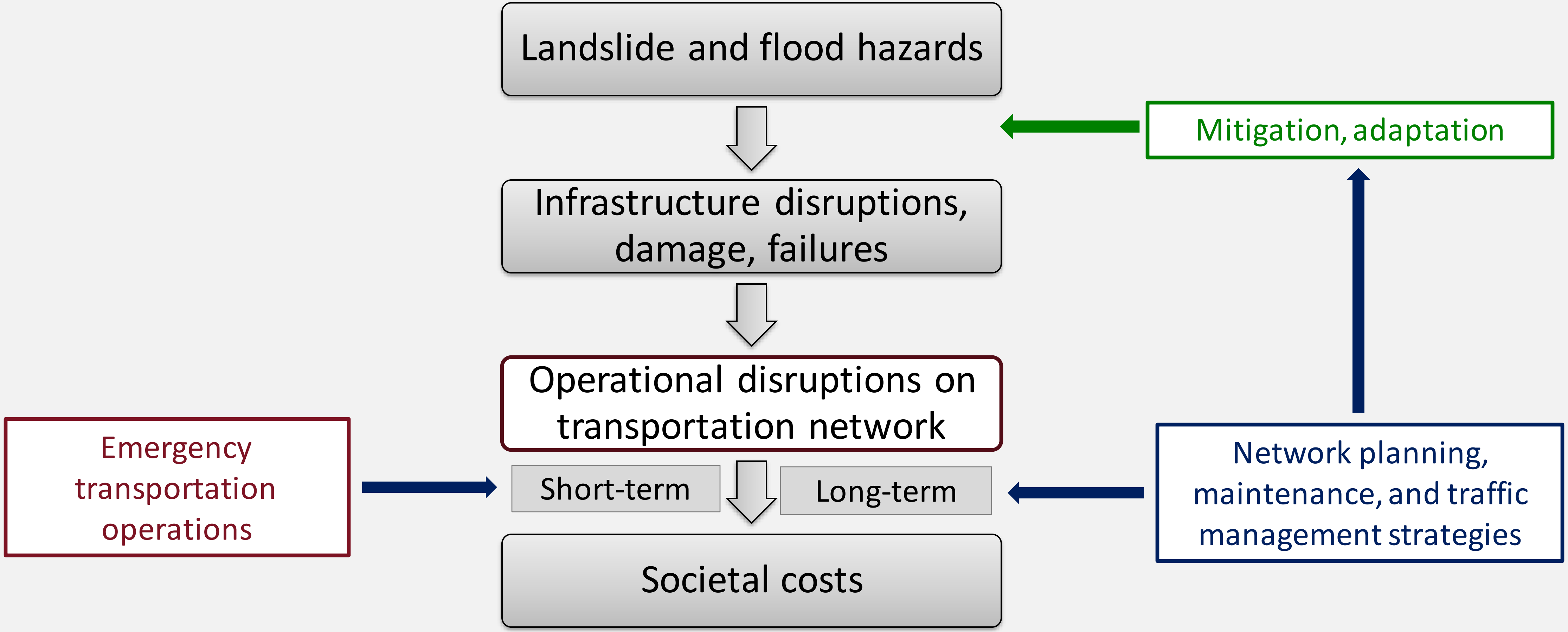
System design: Route planning, hub location



Building resilience for the long term: making adaptive network resource allocation decisions under uncertainties

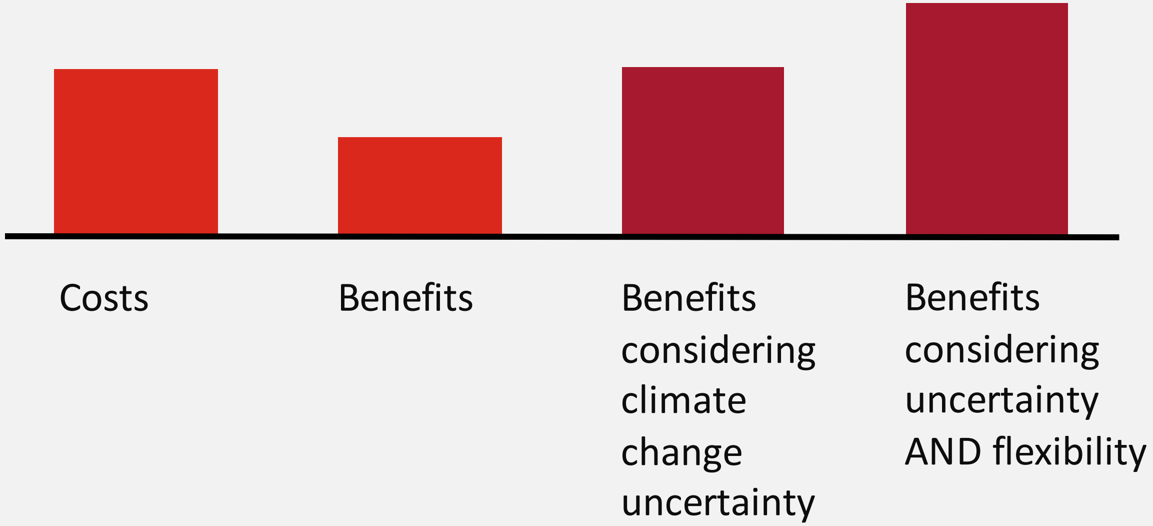


Photo credits: BC Highway 1 Malahat flooding repairs 2 by BC Ministry of Transportation and Infrastructure, licensed under CC BY-NC-ND 2.0.