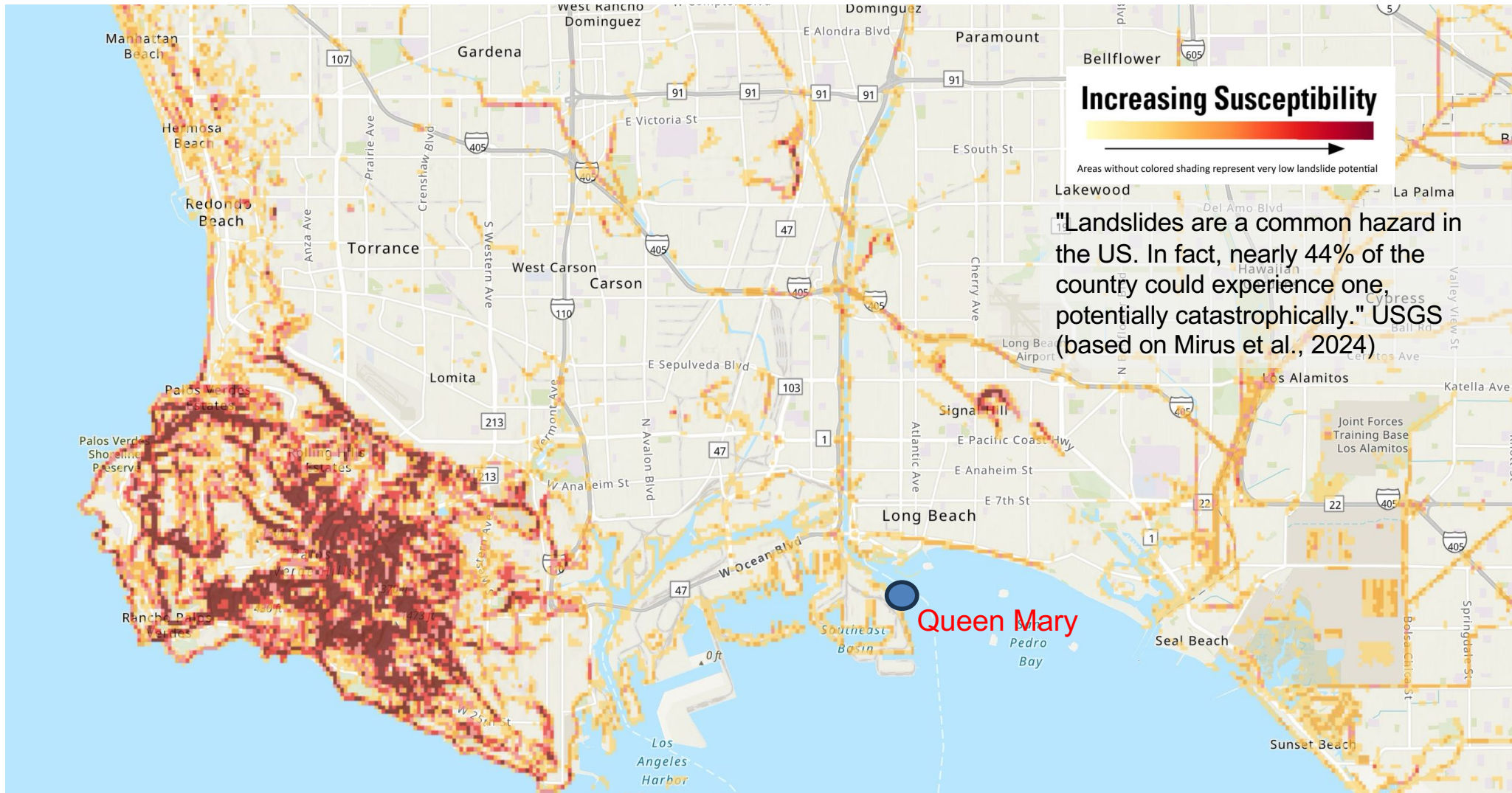


From *Susceptibility* to *Risk* —

MM₃: A New Framework for Landslide Risk Assessment and Land Use Policy



Joe Wartman

Professor; and Director, RAPID Facility



Natural Hazard and Disaster Reconnaissance





La Conchita, California





January
2005

10 years after fatal mudslide,
tiny La Conchita accepts the risks

January
2015



La Conchita resident Ernie Garcia makes his way through a hole in a chain-link fence amid damage from the 2005 mudslide. (Genaro Molina / Los Angeles Times)

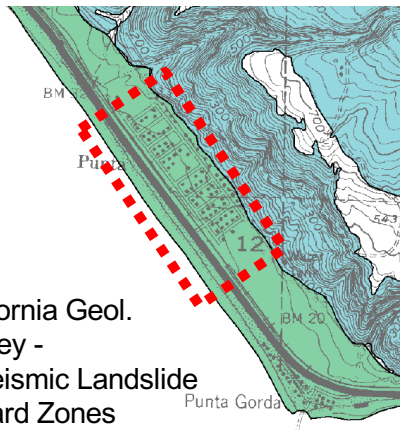
By **AMANDA COVARRUBIAS**
contact the reporter



California Geol.
Survey -
Inventory

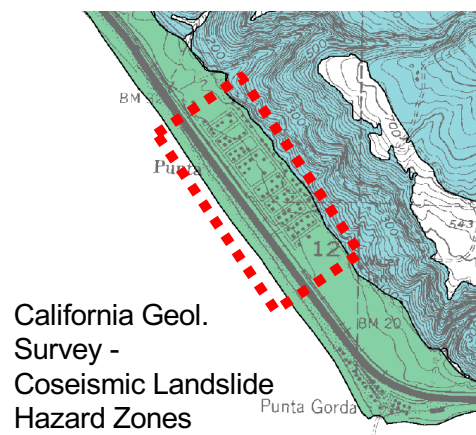


California Geol.
Survey -
Inventory

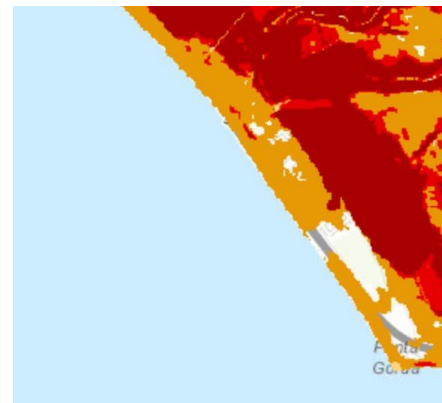


California Geol.
Survey -
Coseismic Landslide
Hazard Zones

*blue denotes
landslide
zone*



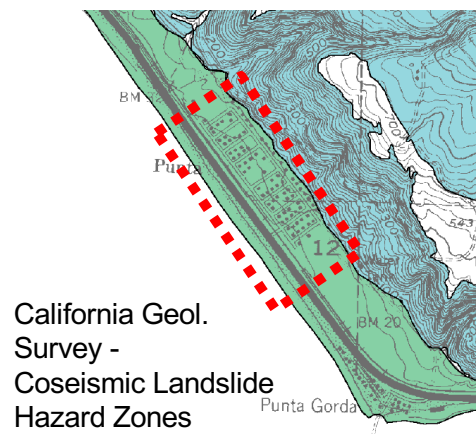
blue denotes landslide zone



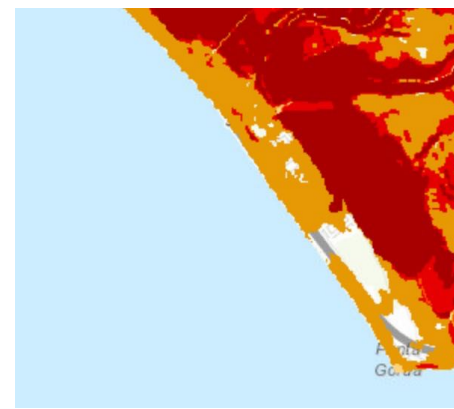
red denotes high susceptibility



- The inventory suggests the surrounding region exhibits high landslide density
- La Conchita falls outside of coseismic landslide hazard zone
- La Conchita also lies outside the zone of high deep-seated landslide susceptibility
- The recent historical record documents fatal landslides within the community
- So, what are the landslide risks to La Conchita?



blue denotes landslide zone



Red denotes high susceptibility

California Geol. Survey - Deep Seated Landslide Susceptibility

Quantitate Landslide Risk Assessment

$$R_{(Loss\ of\ Life)} = \sum_1^n (P_{l(s:T)} \times P_{r(s)} \times P_{e(s:T)} \times V_p \times N_p)$$

$$R_{(Infrastructure)} = \sum_1^n (P_{l(s:T)} \times P_{r(s)} \times (1) \times V_i \times E)$$

$P_{l(s:T)}$: spatio-temporal probability of occurrence

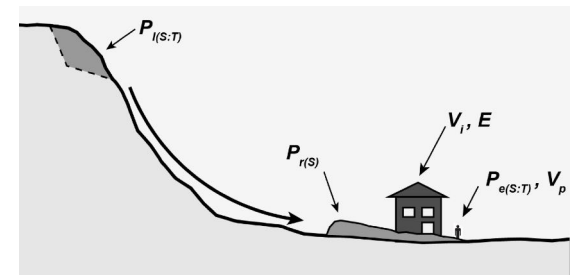
$P_{r(s)}$: spatial probability of impact

$P_{e(s:T)}$: spatio-temporal probability of occupancy

V : physical vulnerability

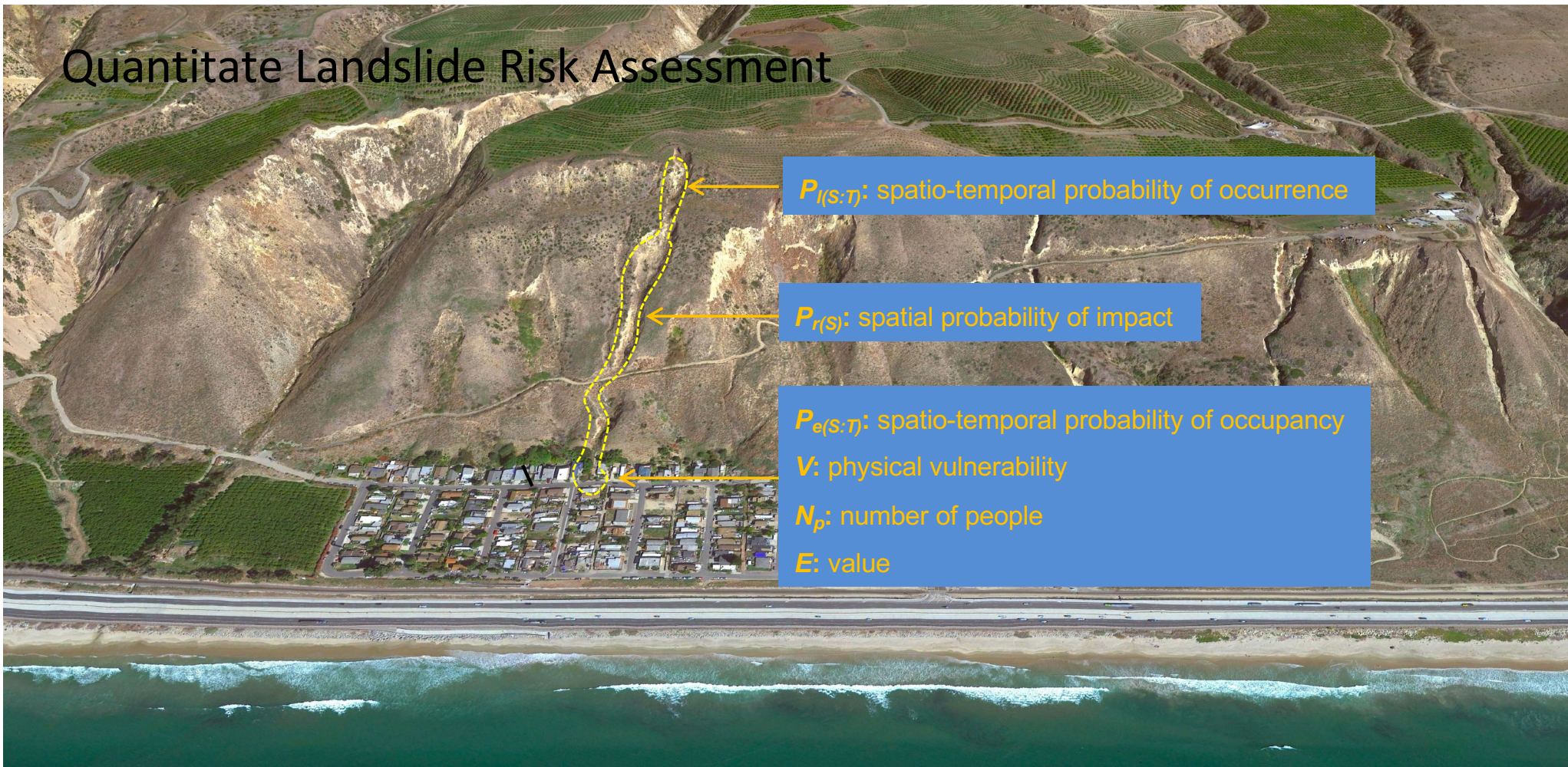
N_p : number of people

E : value



(Fell et al. 2008)

Quantitate Landslide Risk Assessment



$$R_{(Loss\ of\ Life)} = \sum_1^n (P_{l(s:T)} \times P_{r(s)} \times P_{e(s:T)} \times V_p \times N_p)$$

$$R_{(Infrastructure)} = \sum_1^n (P_{l(s:T)} \times P_{r(s)} \times (1) \times V_i \times E)$$

$P_{l(s:T)}$: spatio-temporal probability of occurrence

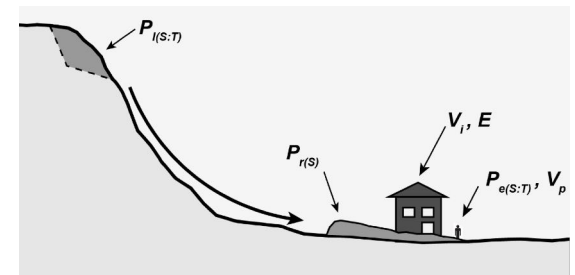
$P_{r(s)}$: spatial probability of impact

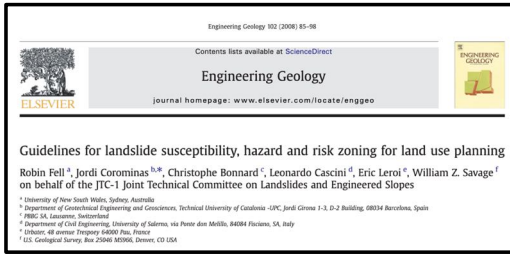
$P_{e(s:T)}$: spatio-temporal probability of occupancy

V : physical vulnerability

N_p : number of people

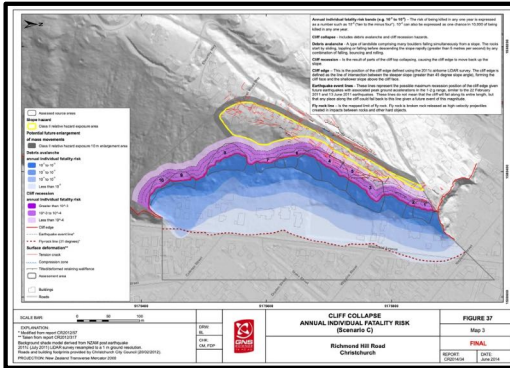
E : value



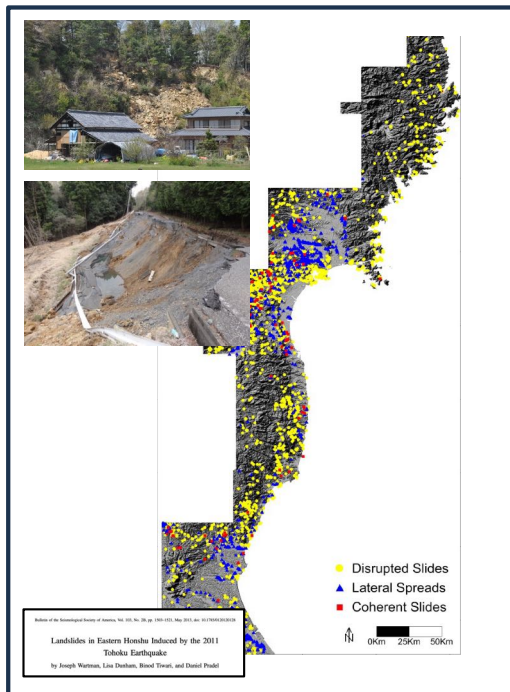


My research trajectory

Spain (UPC) visiting researcher



New Zealand Science Fellow (GNS Science)



Tohoku, Japan Earthquake ASCE Reconnaissance

22 March 2014; 10:37 a.m., Oso, Washington

Engineering Geology 92 (2008) 65–98

Contents lists available at ScienceDirect

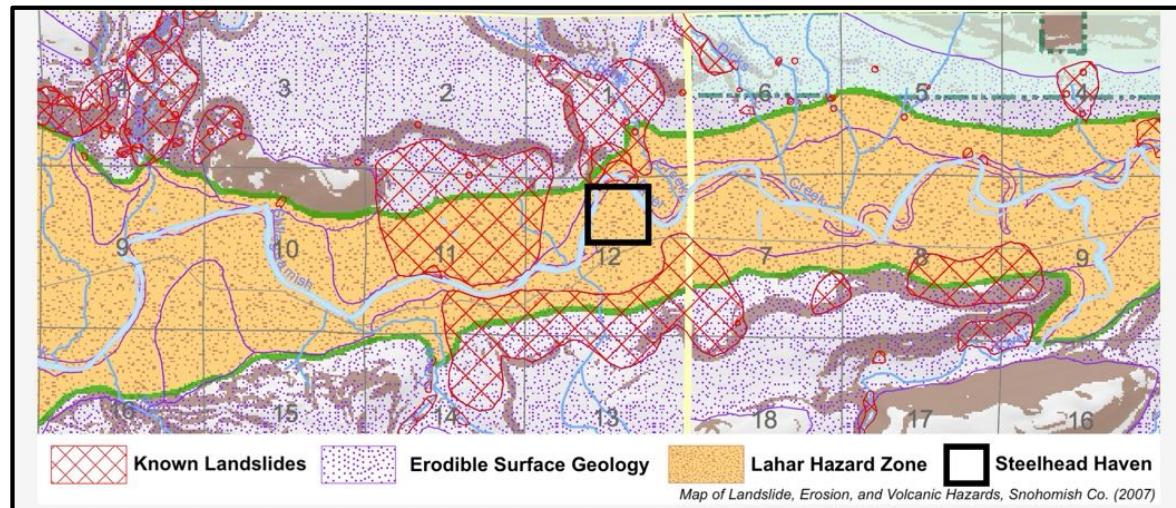
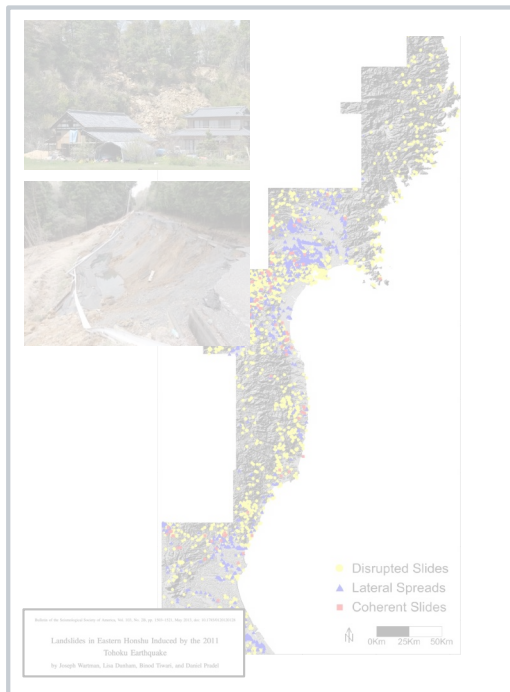
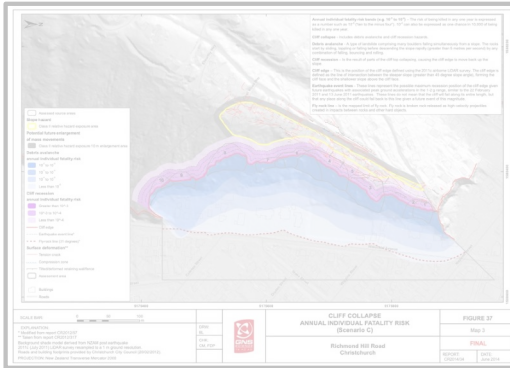
Engineering Geology

journal homepage: www.elsevier.com/locate/enggeo

Guidelines for landslide susceptibility, hazard and risk zoning for land use planning

Robin Fell¹, Jordi Corominas^{2*}, Christophe Bonnard³, Leonardo Cascini⁴, Eric Lerat⁵, William Z. Savage⁶ on behalf of the JT-C-1 Joint Technical Committee on Landslides and Engineered Slopes

¹ University of New South Wales, Sydney, Australia
² Department of Geotechnical Engineering and Geosciences, Technical University of Catalonia, UPC, Jordi Girona 1-3, D-2 Building, 08034 Barcelona, Spain
³ IFEG-IG, Lugano, Switzerland
⁴ Department of Civil Engineering, University of Salerno, via Ponte alle Mulo, 84084 Fisciano, SA, Italy
⁵ University of Geneva, Evian-les-Bains, France
⁶ US Geological Survey, Box 23000, MDS906, Denver, CO 80224



22 March 2014; 10:37 a.m., Oso, Washington

Engineering Geology 93 (2014) 65–98

Contents lists available at ScienceDirect

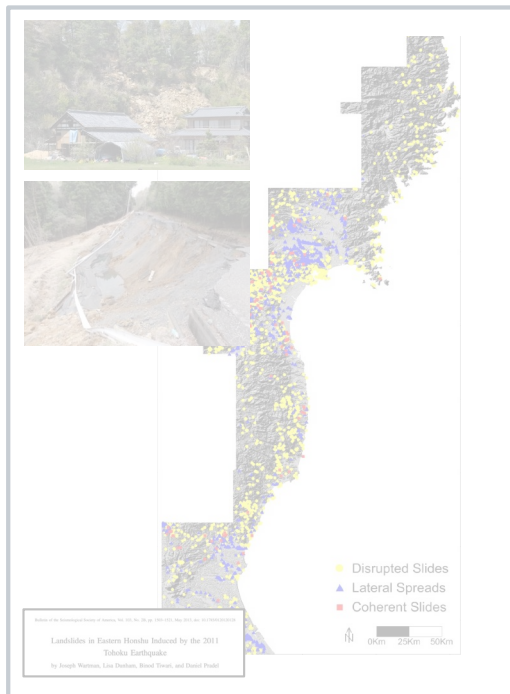
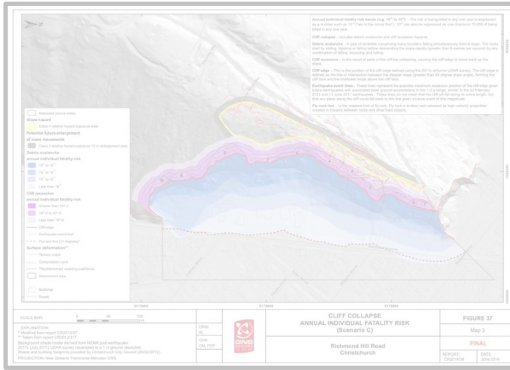
Engineering Geology

journal homepage: www.elsevier.com/locate/enggeo

Guidelines for landslide susceptibility, hazard and risk zoning for land use planning

Robin Fell^a, Jordi Corominas^{b,c}, Christophe Bonnard^d, Leonardo Cascini^e, Eric Leraud^f, William Z. Savage^g on behalf of the ITC-1 Joint Technical Committee on Landslides and Engineered Slopes

^a University of New South Wales, Sydney, Australia
^b Department of Geotechnical Engineering and Geosciences, Technical University of Catalonia, UPC, Jordi Girona 1-3, D-1 Building, 08034 Barcelona, Spain
^c ITC-1, Catalonia, Switzerland
^d Department of Civil Engineering, University of Salerno, Via Ponte Don Melillo, 84098 Fisciano, SA, Italy
^e University of Applied Sciences FH Technikum Wien, Austria
^f U.S. Geological Survey, Box 23000, Reno, Nevada, USA



The Seattle Times

OPINION

Ways to avert the next Oso landslide disaster

By Joseph Wernicke and David Priddy

The Oso landslide in Washington state in 2014 was a tragedy that has left a trail of destruction and loss. It is a tragedy that could have been averted if we had taken the time to invest in the science and engineering that would have allowed us to predict and prevent such a disaster. The Oso landslide was not a natural event; it was a human-made disaster. It was the result of a series of decisions made by government officials and engineers who prioritized cost savings over public safety. The Oso landslide was a preventable disaster, and it is our responsibility to ensure that it is not repeated.

The New York Times

How to Make Landslides Less Deadly

By David R. Montgomery and Joseph Wartman

Mapping technology can identify dangers before they happen.

The Oso landslide in Washington state in 2014 was a tragedy that has left a trail of destruction and loss. It is a tragedy that could have been averted if we had taken the time to invest in the science and engineering that would have allowed us to predict and prevent such a disaster. The Oso landslide was not a natural event; it was a human-made disaster. It was the result of a series of decisions made by government officials and engineers who prioritized cost savings over public safety. The Oso landslide was a preventable disaster, and it is our responsibility to ensure that it is not repeated.

THE ORO

Herald

What we know and what we don't 2 years after Oso slide

Early morning light catches distinct shades of grey and earth on the face of the Oso landslide in May 2014.

SHARE | PRINT | PREVIOUSLY

IN THE NEWS

Editorial: Two paths after the Oso landslide

Washington Post, March 21, 2014

US Congressman Suzan DelBene

Representing Washington's 1st District

Public Law 116-323
116th Congress

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled,

SECTION 1. SHORT TITLE.

This Act may be cited as the "National Landslide Preparedness Act."

SEC. 2. DEFINITIONS.

In this Act:

(1) 3D.—The term "3D" means 3-dimensional.

(2) 3D ELEVATION DATA.—

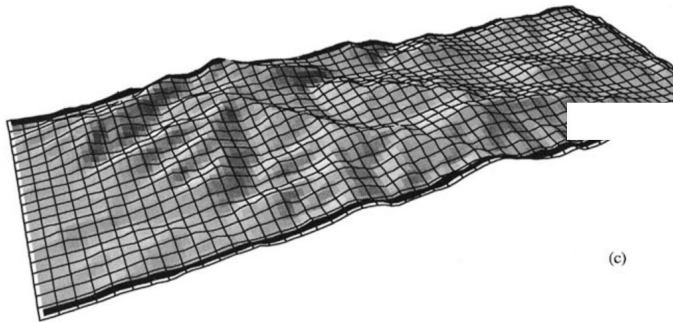
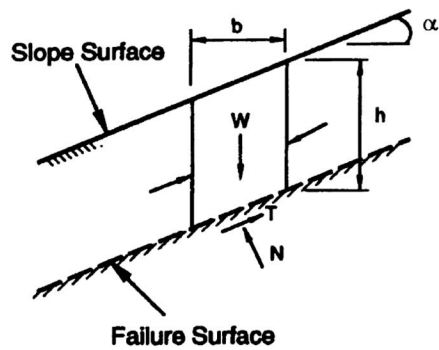
(A) IN GENERAL.—The term "3D elevation data" means 3D, high-resolution data obtained using LIDAR, ISAR, or other methods over the United States (including territories).

(B) INCLUSIONS.—The term "3D elevation data" includes terrestrial and bathymetric information.

(3) 3D ELEVATION PROGRAM.—The term "3D Elevation Program" means the 3D Elevation Program established under sec-

Multimodal Landslide Assessment

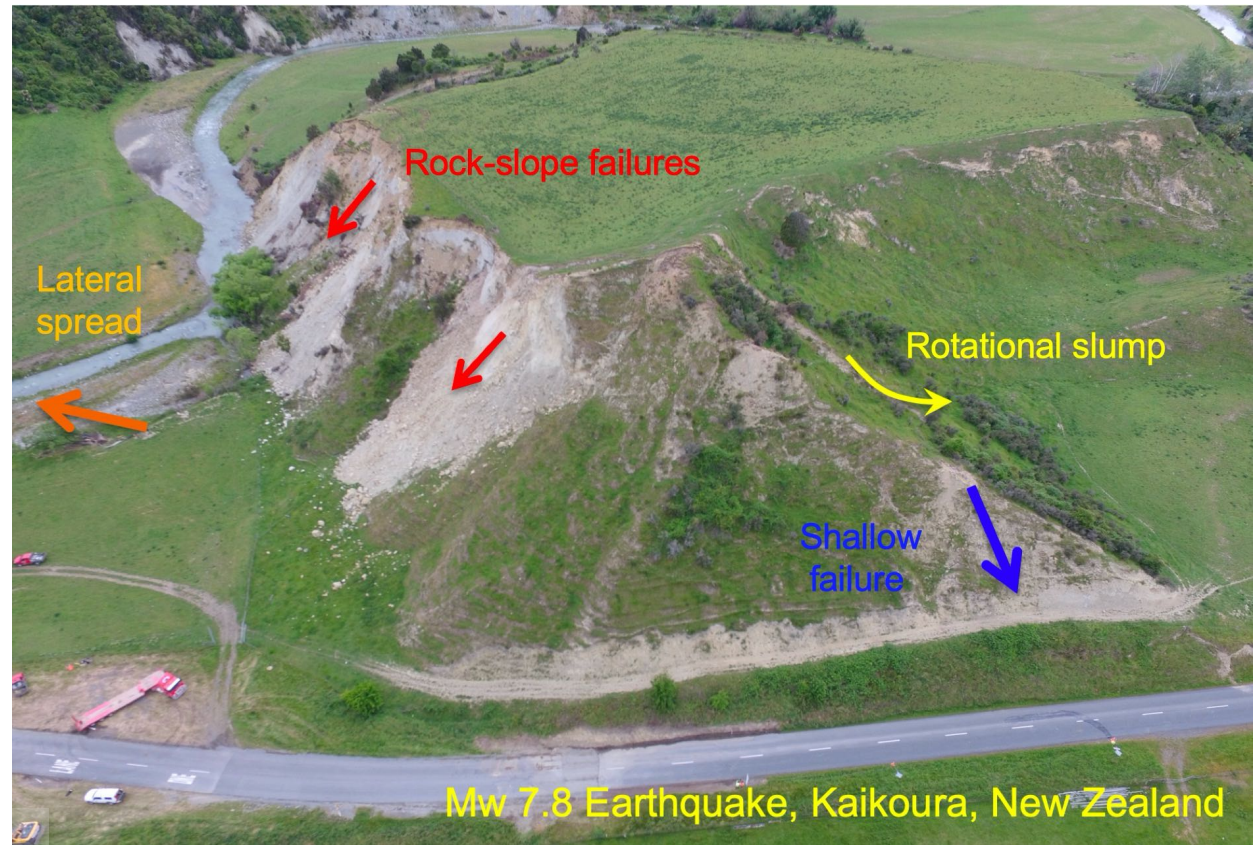
Traditional Infinite Slope Model
Used for Regional-Scale Studies



(c)

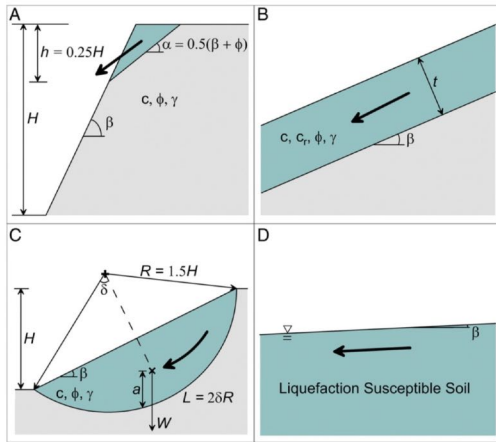
Miles and Ho (1999), *Soil Dyn. Eq. Eng.*

Landslide Modes of Failure



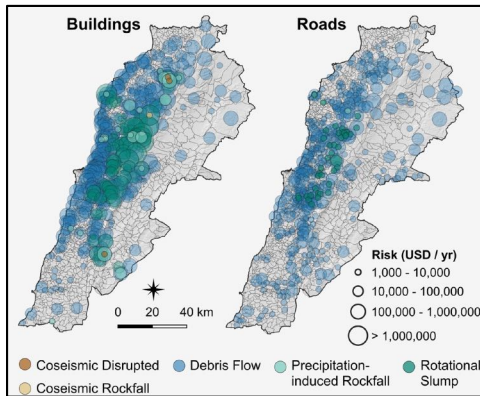
Mw 7.8 Earthquake, Kaikoura, New Zealand

Regional-Scale Landslide Assessment Research



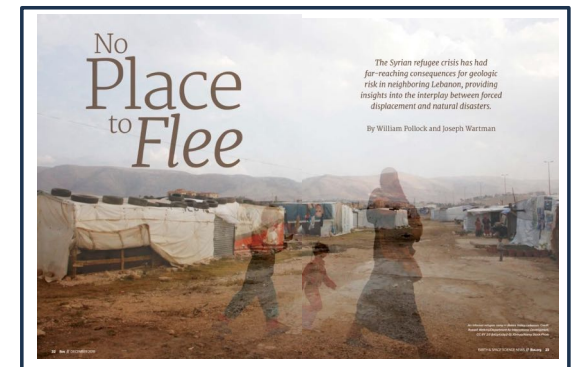
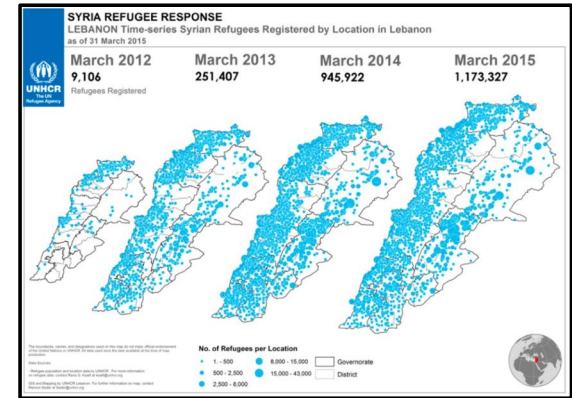
Multimodal Method, V1 (Grant et al. 2016)

- Regional-scale model
- Coseismic landslides, including
 - rock-slope failures
 - shallow, disrupted slides
 - deeper rotational failures
 - lateral spreading



Multimodal Method, V2 (Pollock et al. 2019a,b)

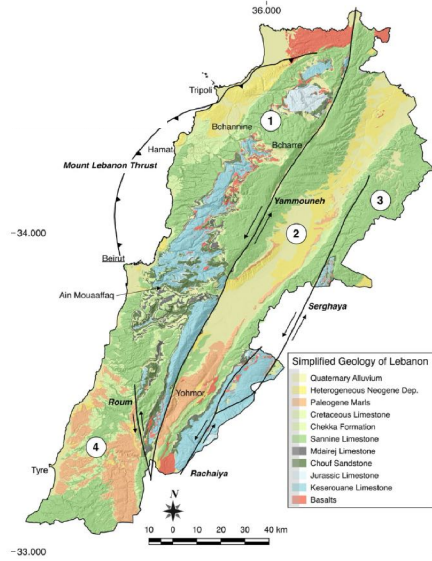
- Modifications to geotechnical models
- Precipitation-induced slides
- Runout modeling
- Risk assessment



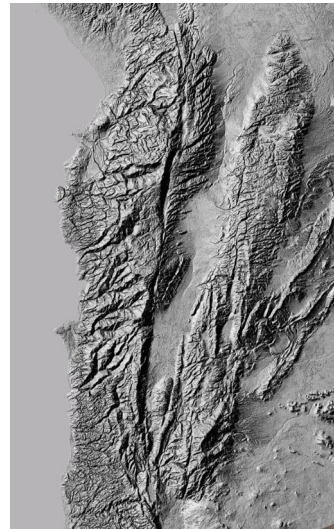
USAID
FROM THE AMERICAN PEOPLE



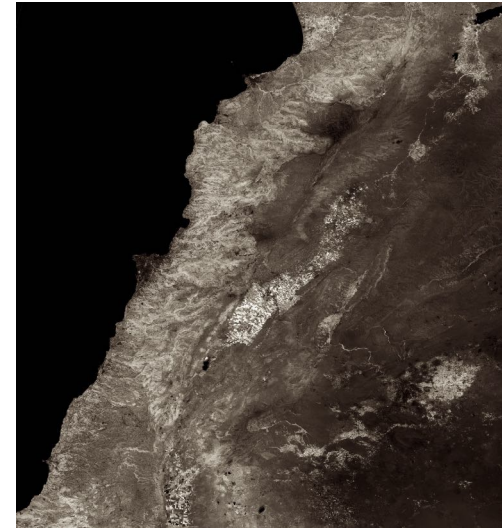
Lebanon Datasets



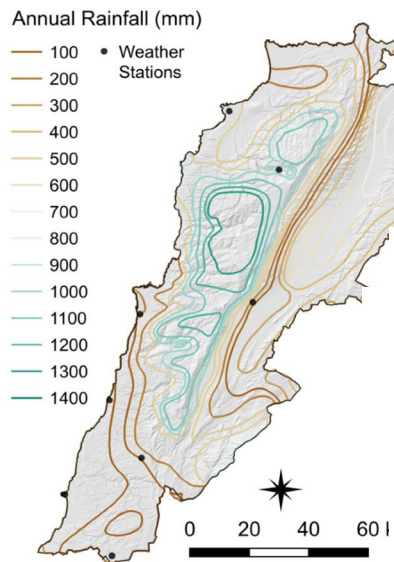
Geology (geotechnical properties)



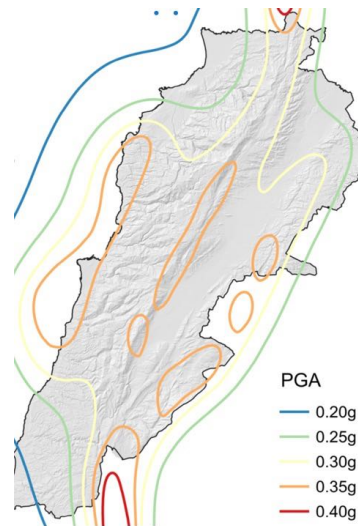
15-m DEM



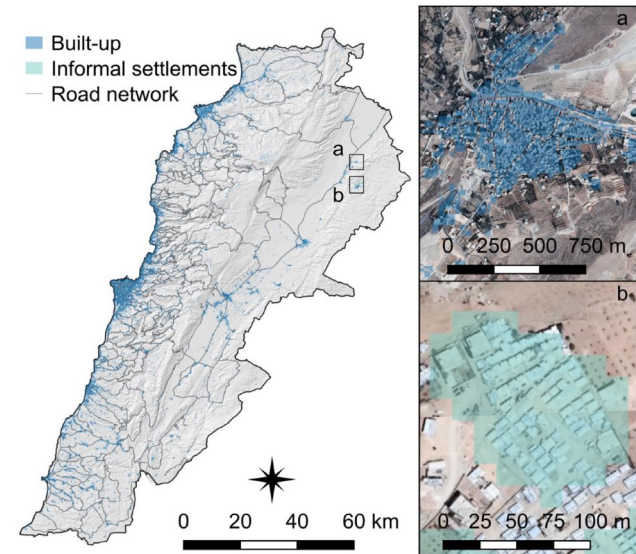
Landsat (root cohesion via NVDI)



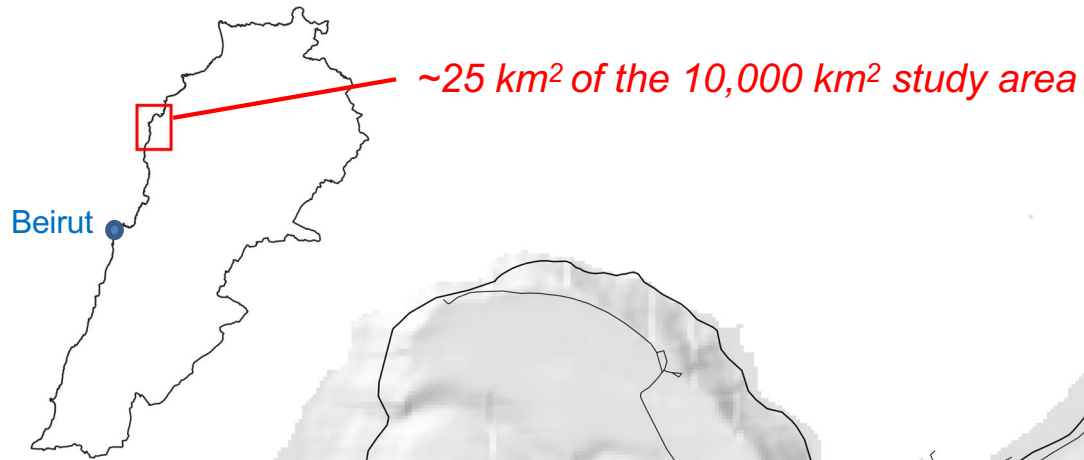
National precipitation maps



PSHA-derived ground motions



Population data from national census and NGOs



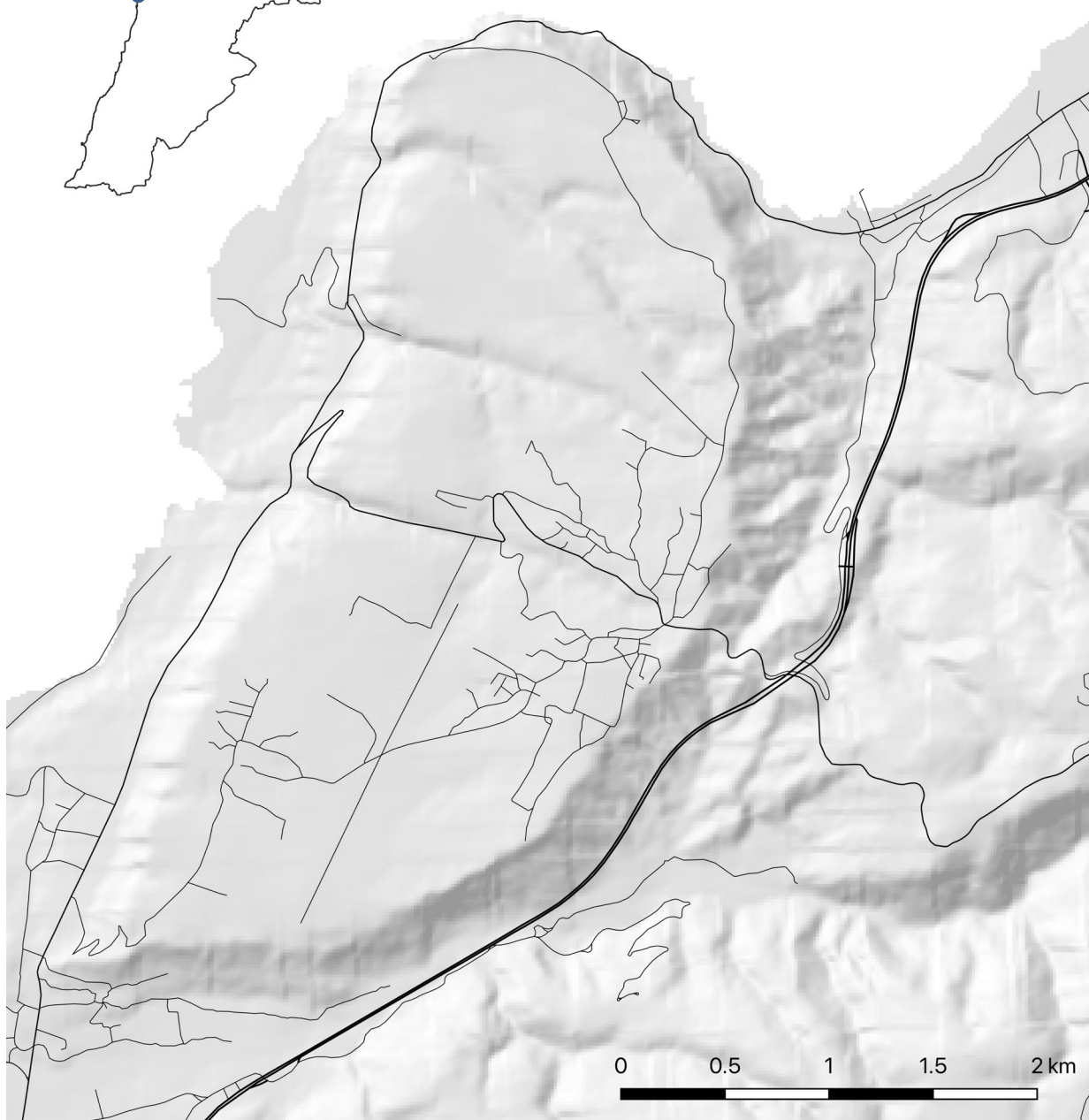
I. Hazard Assessment:

Hamat Focus Area

Step-by-step example for two forcing “scenarios”

- 50-year storm

- 949 year (i.e., 10%
exceedance in 100 years)
seismic event



I. Hazard Assessment:

Hamat Focus Area



I. Hazard Assessment

Landslide Susceptible Terrain

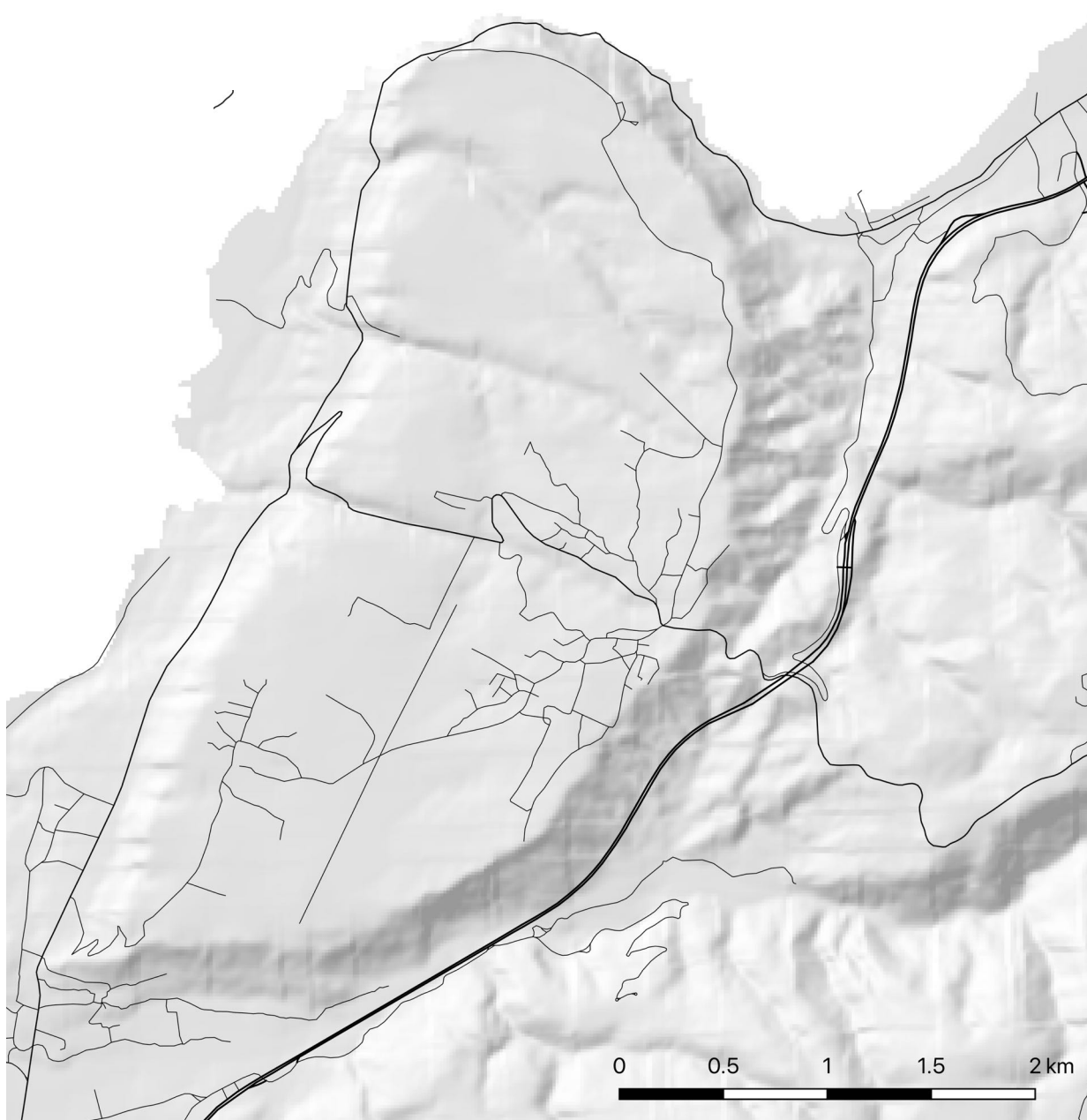
- Statistical studies show a correlation between slope and landslide mode
- Divide the terrain into slope-based zones susceptible to failure mode(s)

15-50° prone to shallow, planar slides

15-35° prone to rotational, coherent slumps in soil and rock

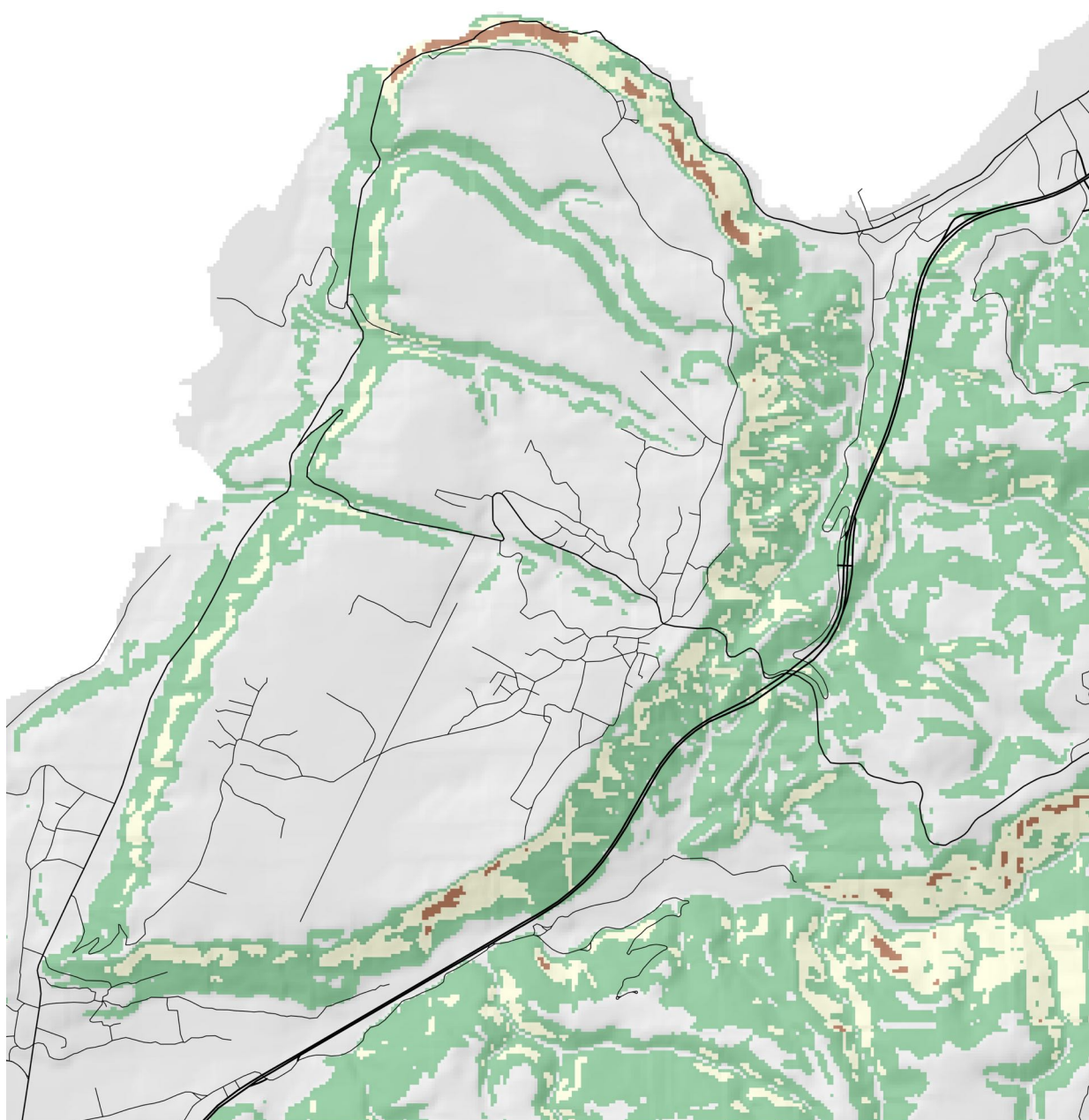
>35° prone to rockfall

<15° *not likely to fail in any mode*



Landslide Susceptibility Zones

- Rock fall
- Shallow soil slides and rock fall
- Shallow soil slides and slumps



I. Hazard Assessment

Landslide Susceptible Terrain

- Statistical studies show a correlation between slope and landslide mode
- Divide the terrain into slope-based zones susceptible to failure mode(s)

15-50° prone to shallow, planar slides

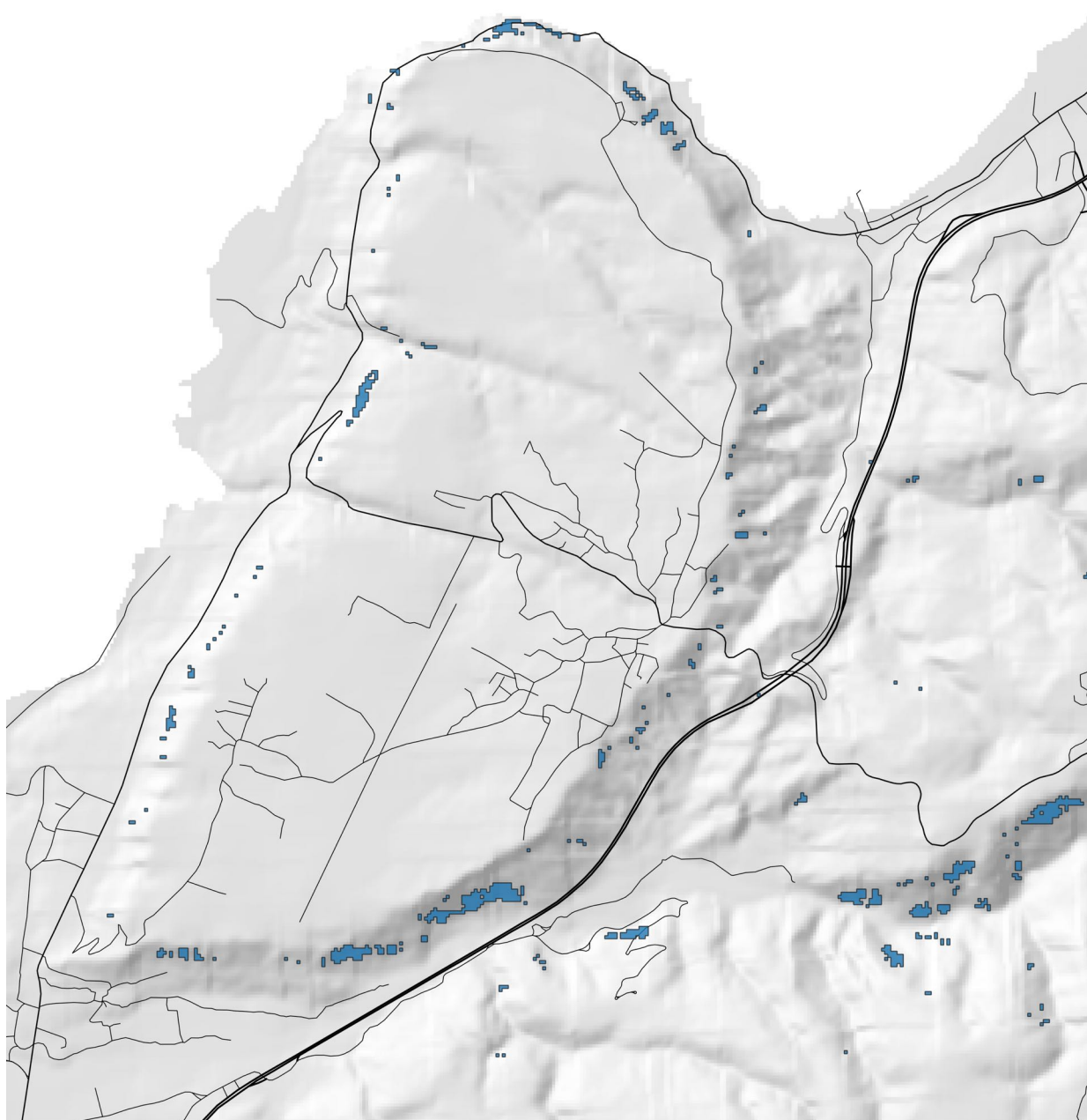
15-35° prone to rotational, coherent slumps in soil and rock

>35° prone to rockfall

<15° *not likely to fail in any mode*

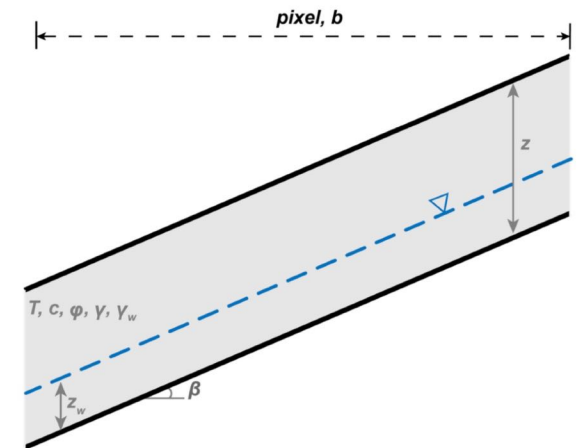
Debris flows

Source



I. Hazard Assessment

Debris flow source areas



Groundwater flow model couples hydrologic and limit-equilibrium slope stability models to compute the critical daily rainfall to trigger a shallow soil failure.

Modest root cohesion assigned based on NDVI for moderately and highly vegetated areas

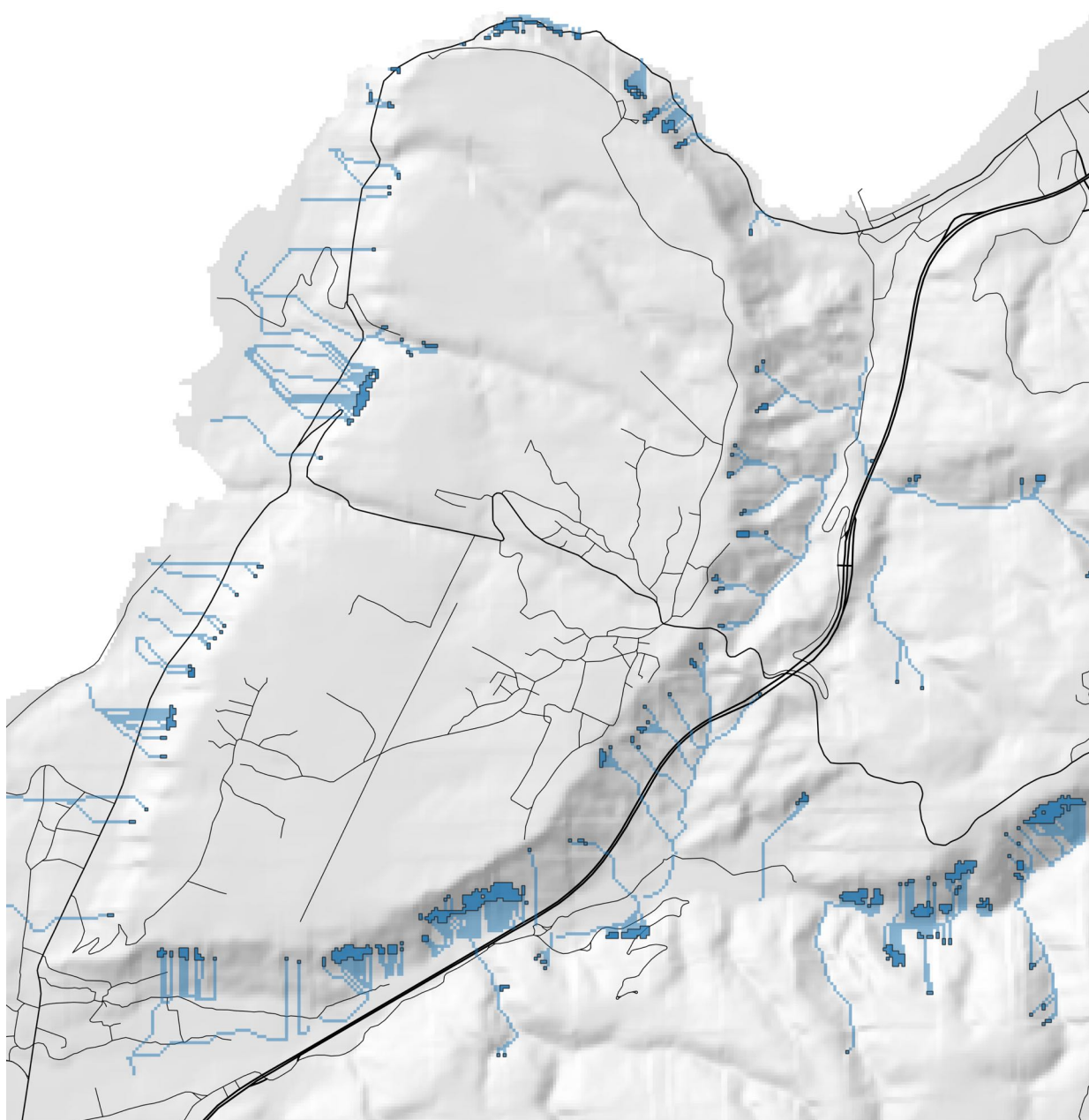
Debris flows

- Source
- Runout

II. Hazard Assessment

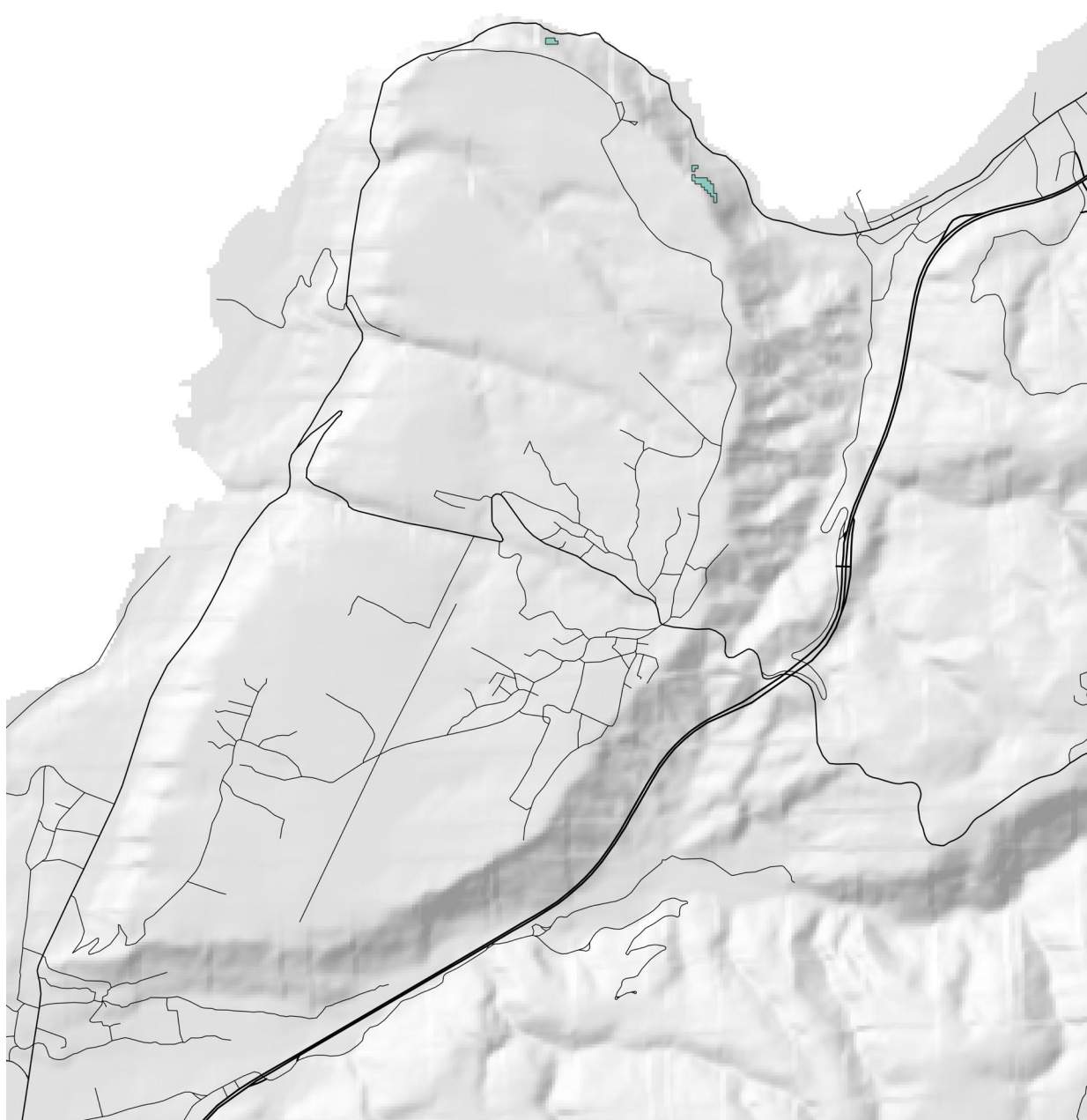
Debris flow source + runout areas

Based on flowlines from the DEM
(with limited path)



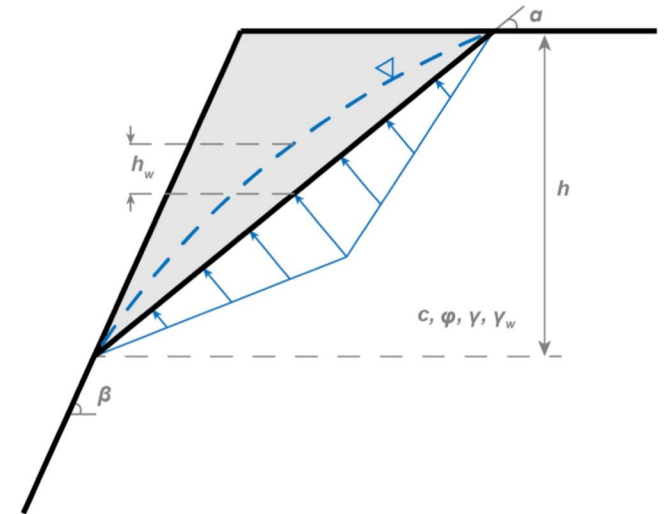
Precipitation-induced rock fall

Source



I. Hazard Assessment

Precipitation-induced rock-slope failure (rockfall)



Rainfall-induced rock slope failures are modeled as Culman wedge-like masses, including the effects of pore-pressure acting on the failure plane

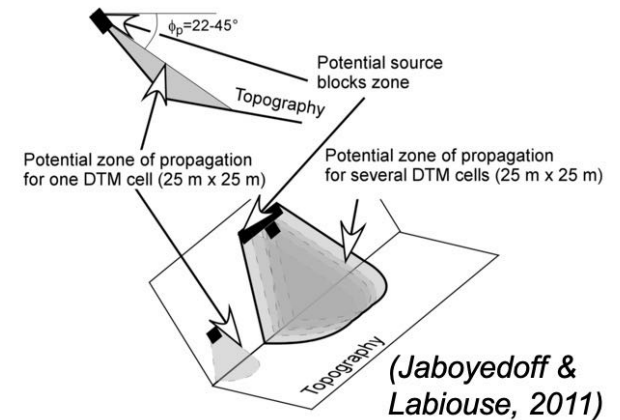
Precipitation-induced rock fall

- Source
- Runout



II. Hazard Assessment

Precipitation-induced rock fall + runout areas

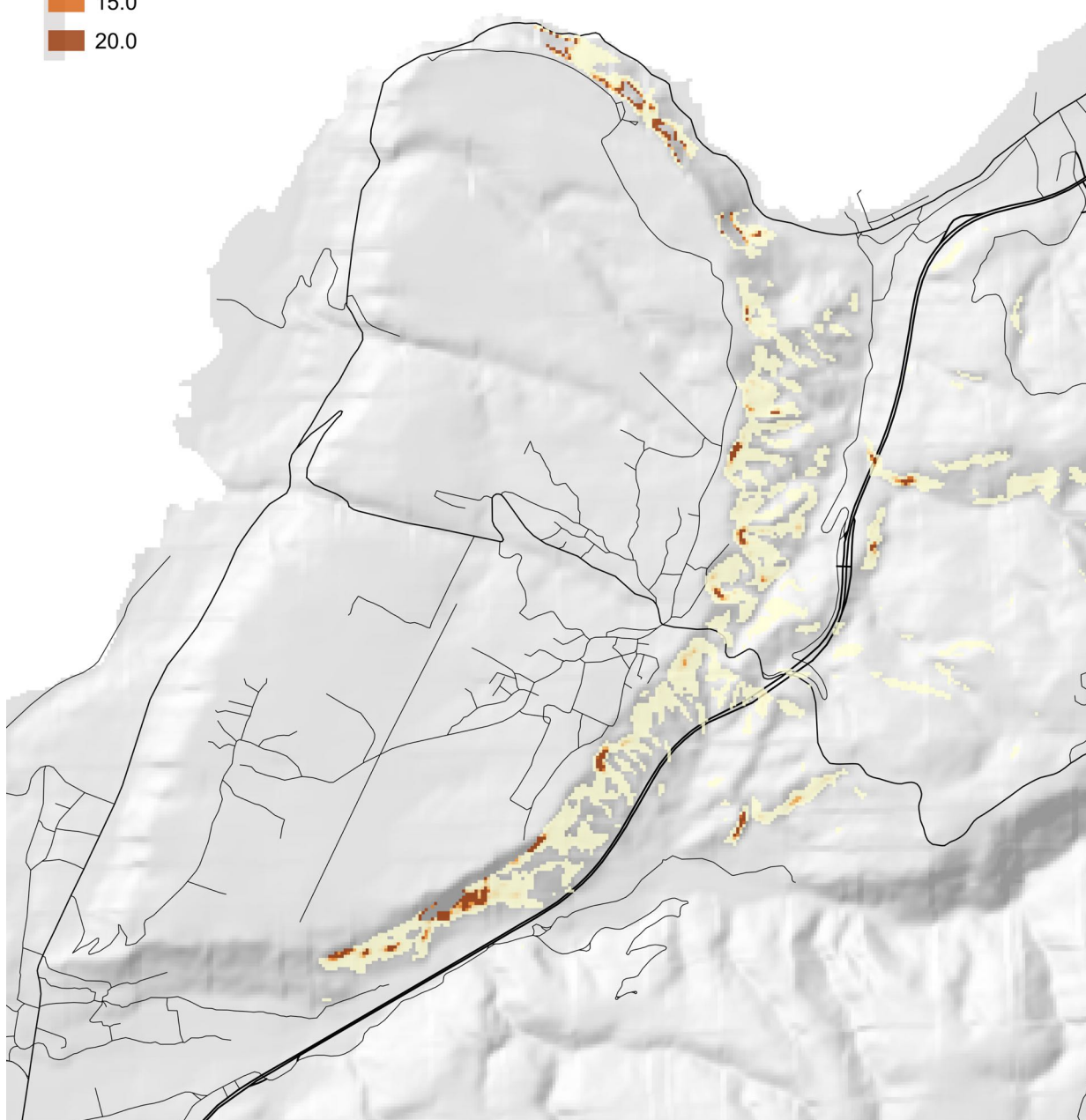
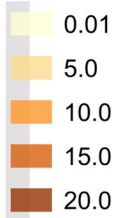


Runout zones were calculated using a viewshed analysis from each initiation point.

The horizontal extent of the rockfall zone was limited by the maximum and minimum aspect of the source cliff face + 17 deg. based on observed lateral dispersion angles. The “angle of reach” from 34 to 42 deg. depending on rockfall size.

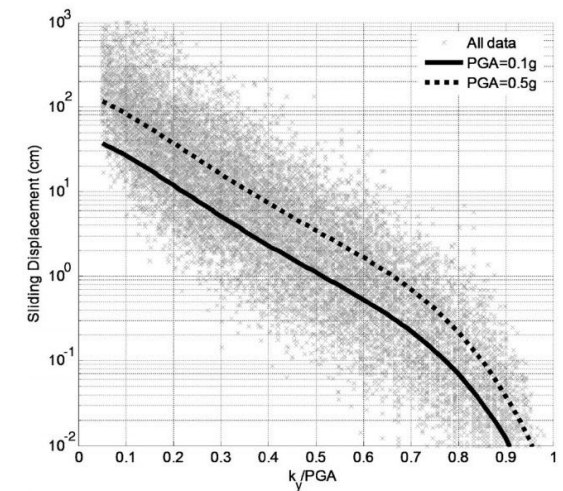
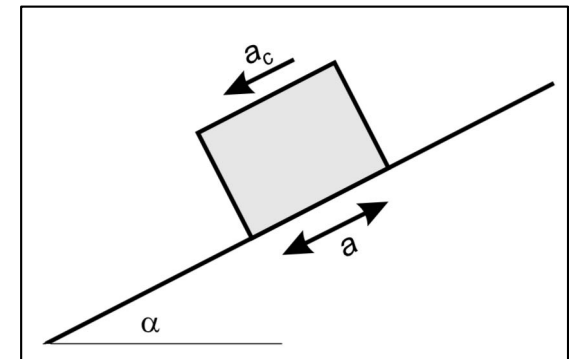
Disrupted soil slides

Coseismic Displacements (cm)



I. Hazard Assessment

Coseismic disrupted (shallow) slide displacements

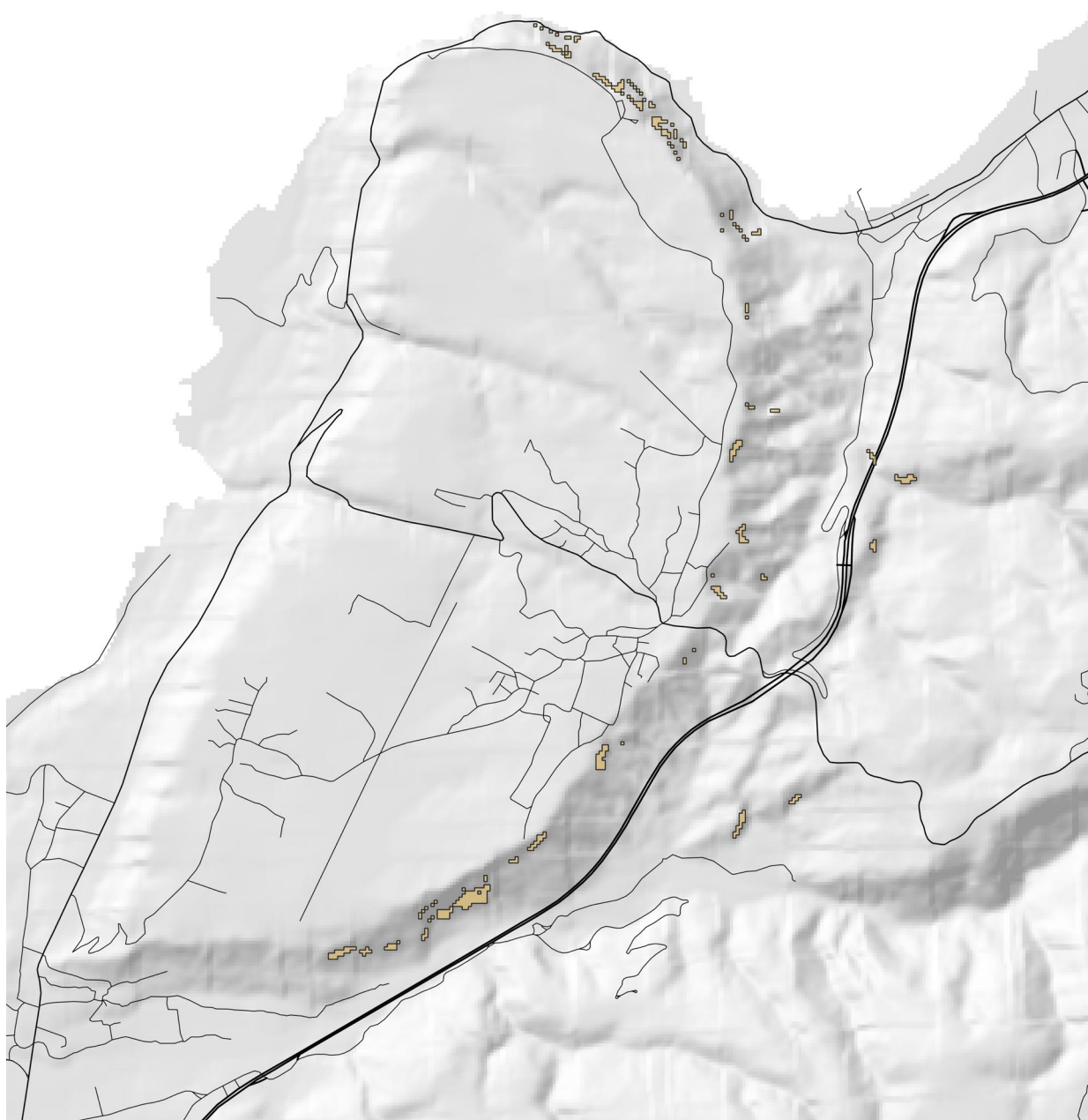


Compute critical acceleration (K_y), and combine with local PGA to estimate co-seismic displacement using regression.

(Saygili & Rathje, 2008)

Disrupted soil slides

Source



I. Hazard Assessment

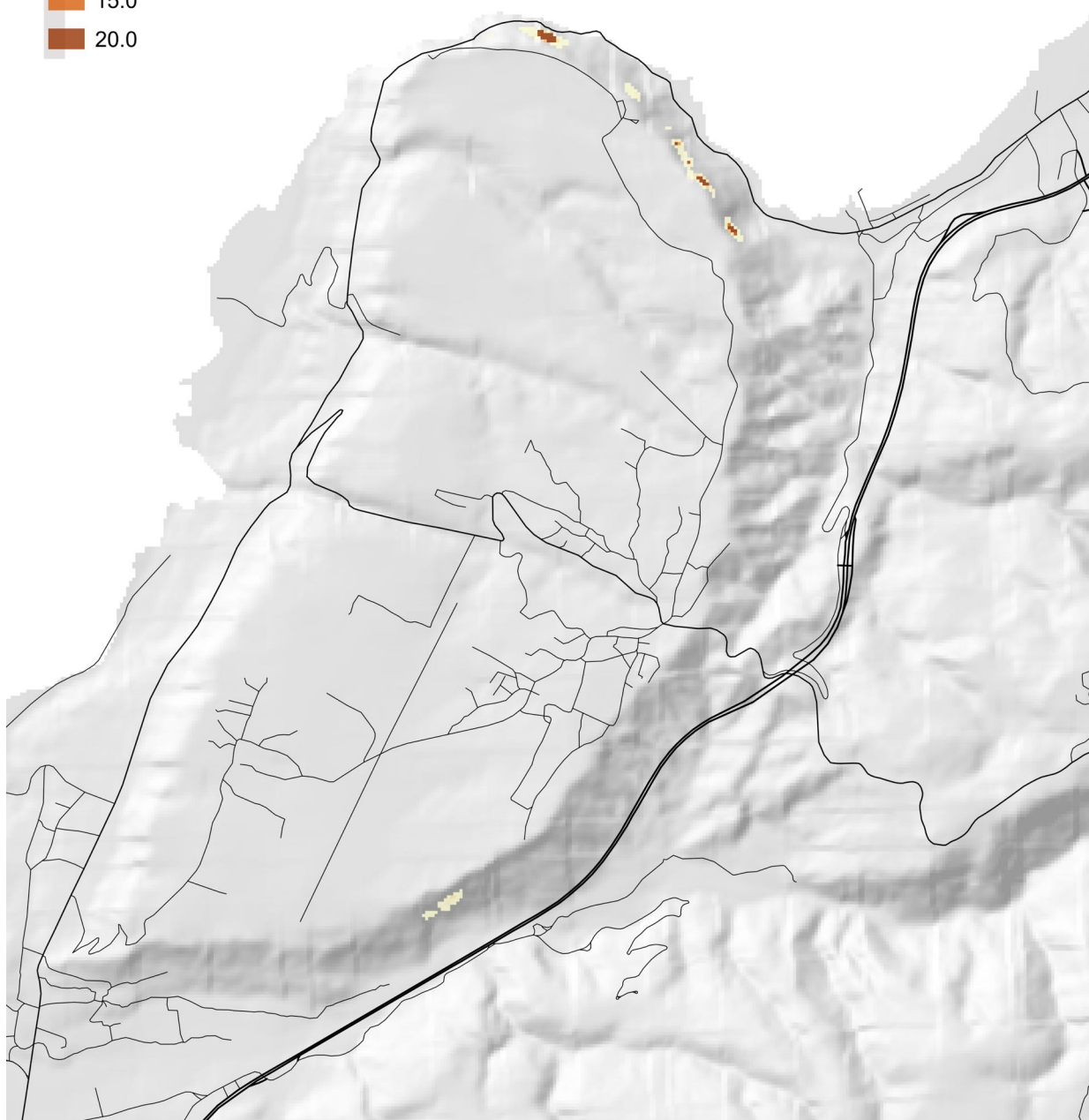
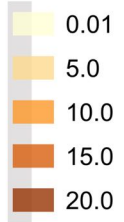
Coseismic disrupted slides

“Failure” defined as coseismic displacement of 5 cm+ based on the observed performance of slopes in past earthquakes.

(For coseismic slumps, threshold is 15 cm+)

Rock fall

Coseismic Displacements (cm)

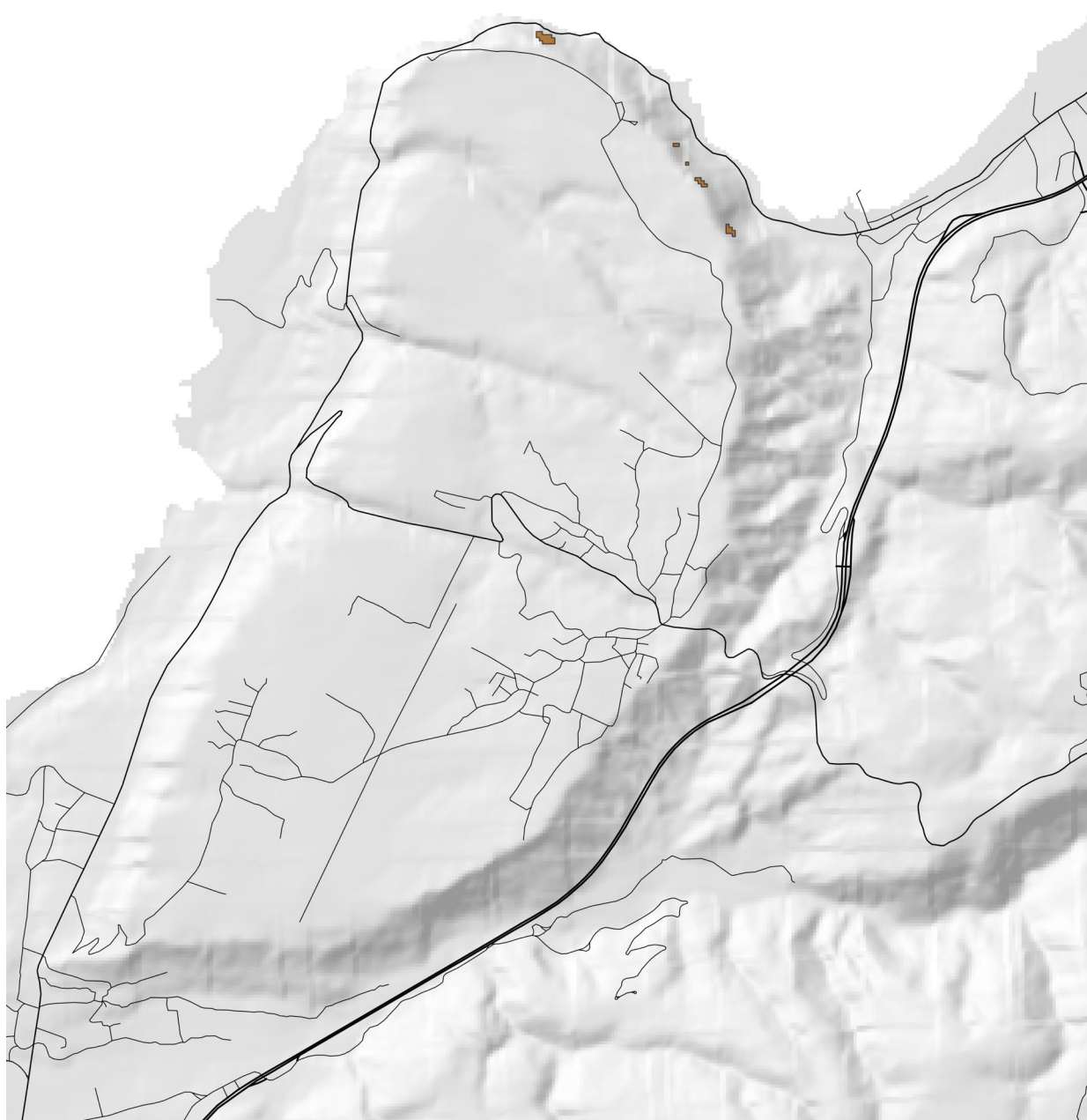


I. Hazard Assessment

*Coseismic rock slope
displacement*

Coseismic rock fall

Source



I. Hazard Assessment

Coseismic rockfall

“Failure” defined as coseismic displacement of 5 cm+.

Coseismic rock fall

- Source
- Runout

II. Hazard Assessment

Coseismic rockfall + runout areas



Precipitation-induced

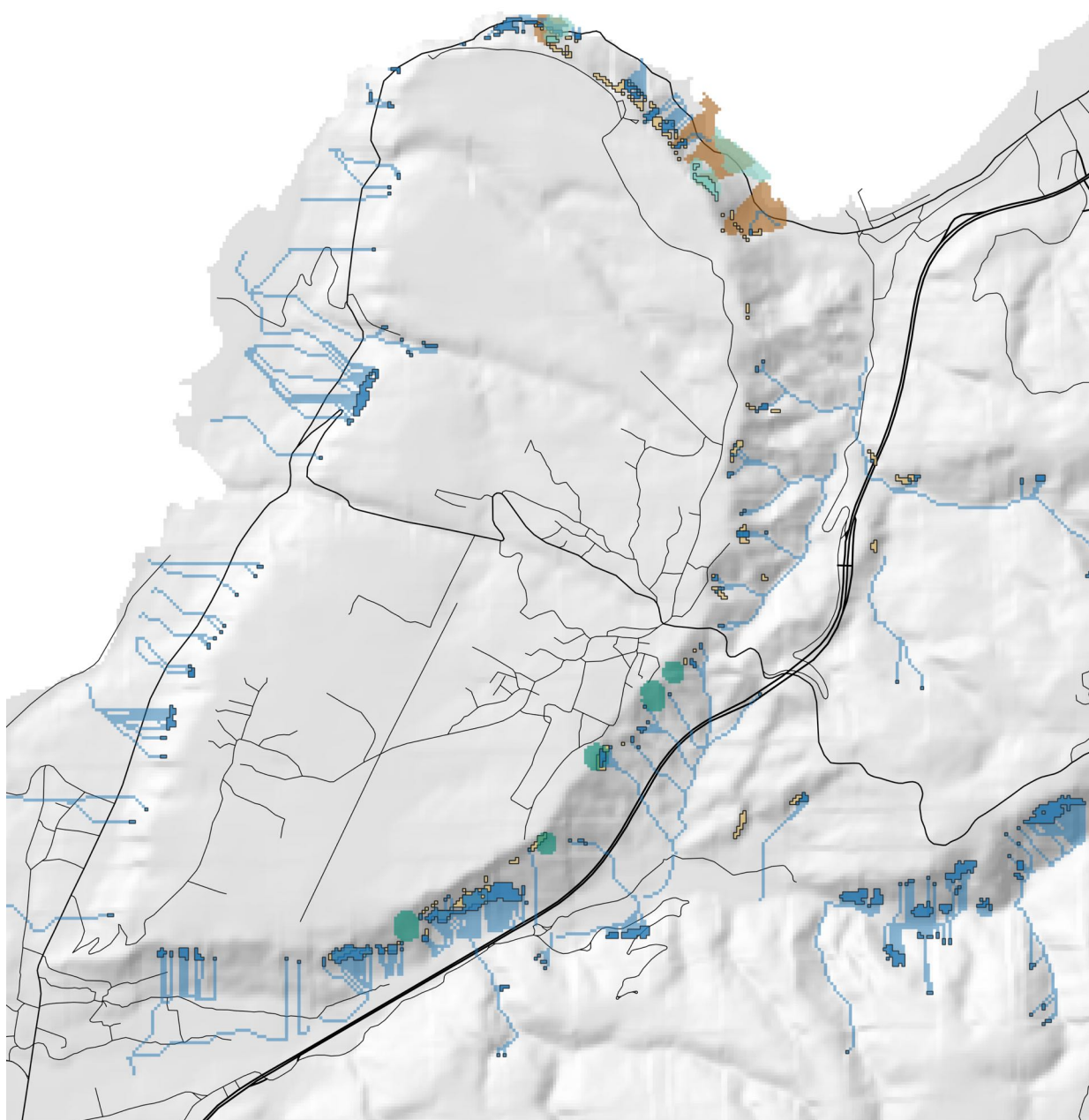
- Debris flows
- Rock fall
- Slumps

Coseismic

- Disrupted soil slides
- Rock fall

(No coseismic slumps found for this area)

I./II. Hazard + Runout Assessment For All Modes of Failure



Precipitation-induced

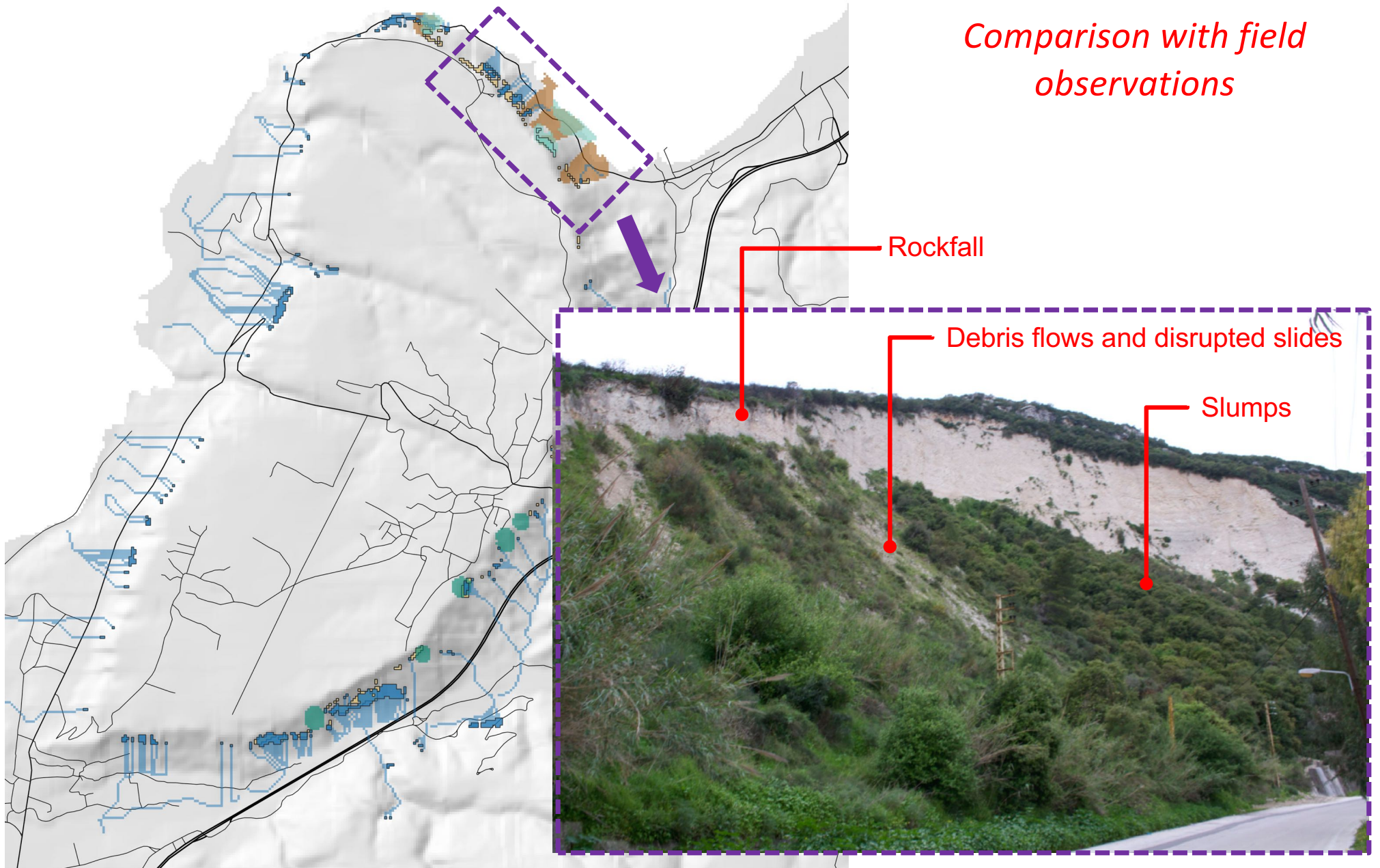
- Debris flows
- Rock fall
- Slumps

Coseismic

- Disrupted soil slides
- Rock fall

I./II. Hazard + Runout Assessment For All Modes of Failure

Comparison with field observations



Elements at risk

■ Built-up area

■ Informal refugee settlements

— Roads

III. Risk Assessment

Inventory of Population Areas at Risk



Informal settlement

Precipitation-induced

- Debris flows
- Rock fall
- Slumps

Coseismic

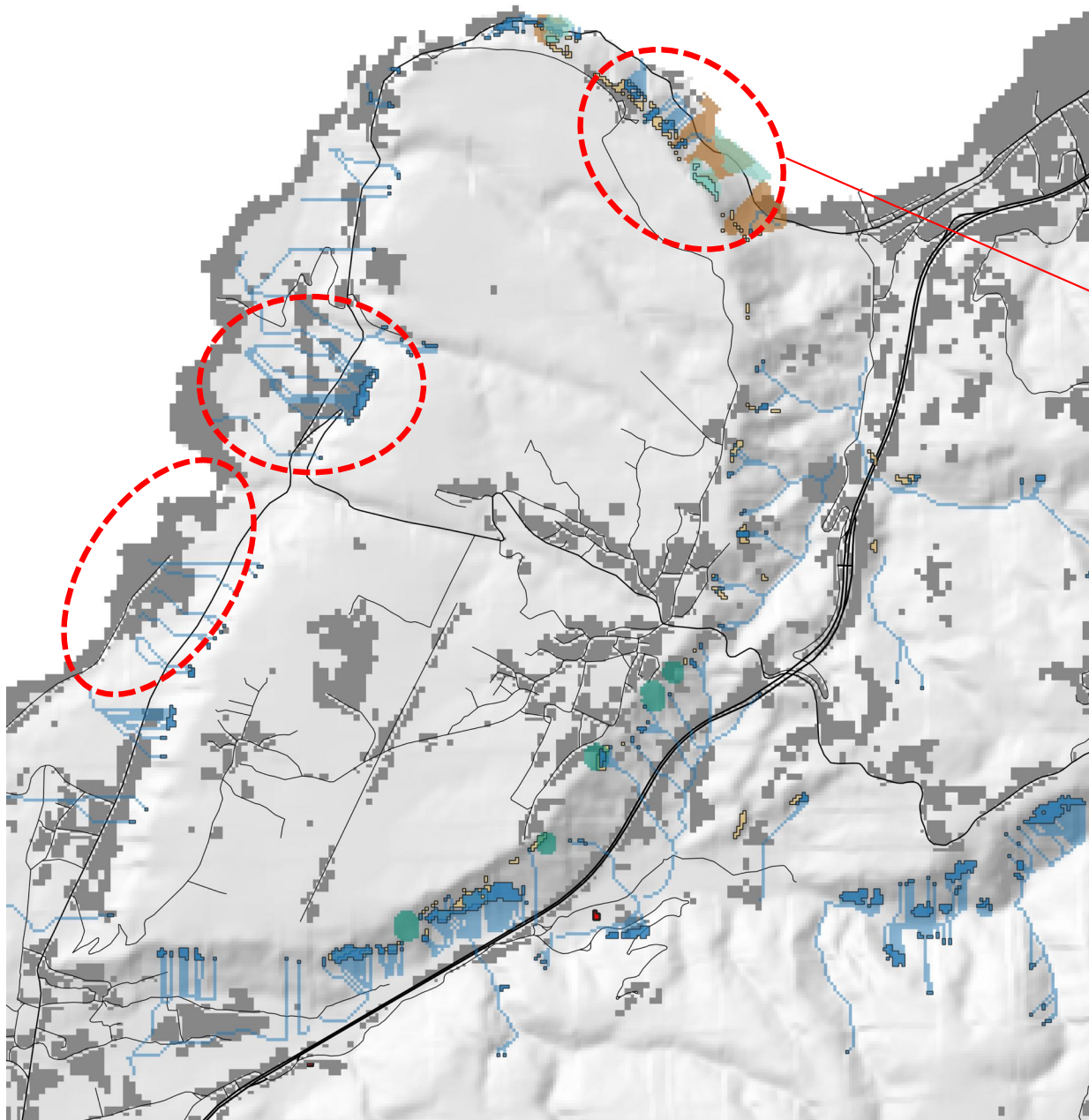
- Disrupted soil slides
- Rock fall

Elements at risk

- Built-up area
- Informal refugee settlements
- Roads

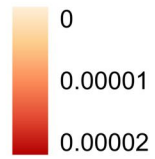
III. Risk Assessment

Elements Impacted by All Modes of Sliding

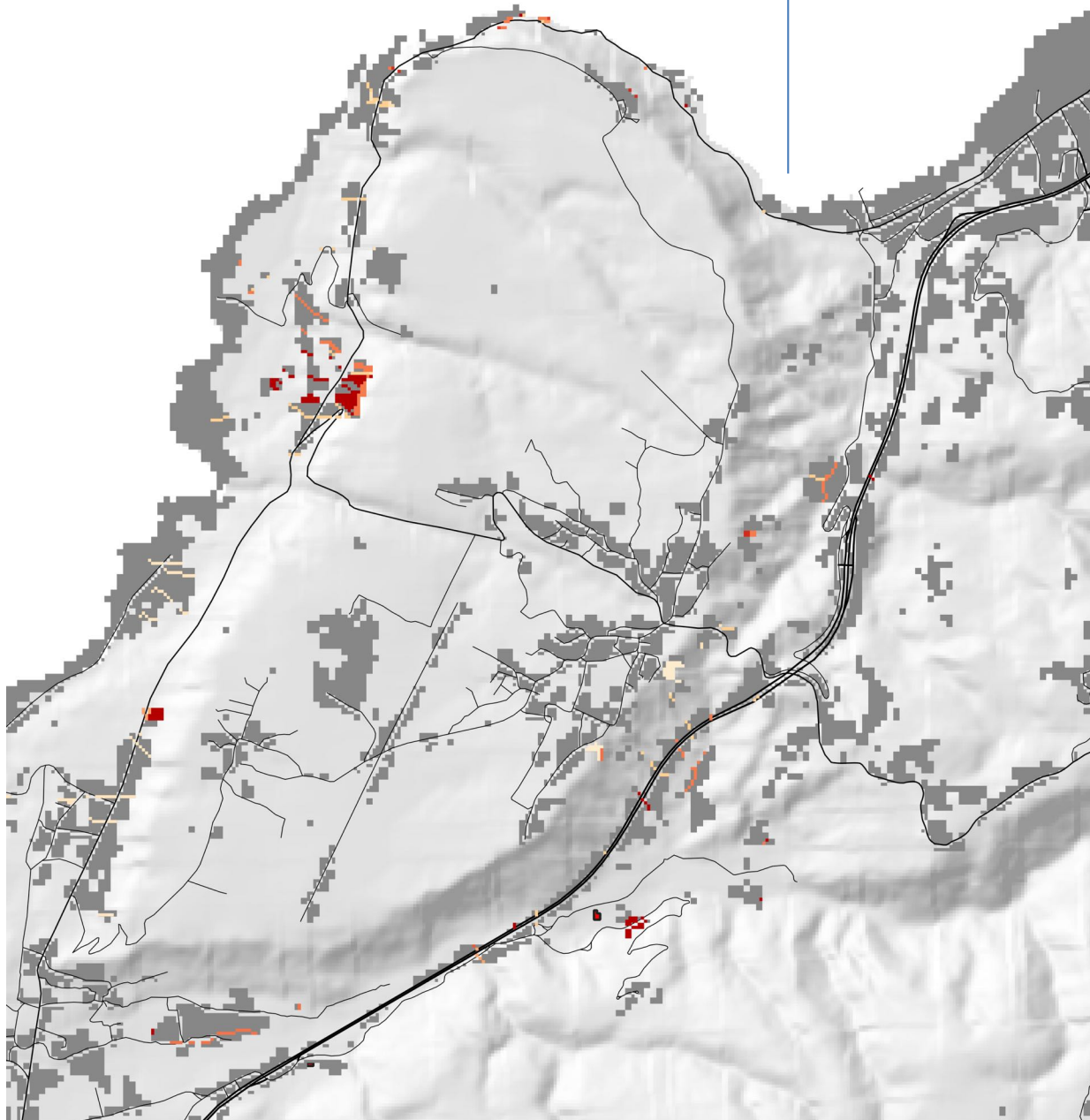


Hazards intersect populated areas

Annual risk to life (lives / yr)



no risk indicated for
precipitation slides



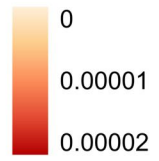
III. Risk Assessment

Results: *Mapping Risk from Precipitation-Induced Landslides*

Estimate physical vulnerability of the urban population based on data from from nations having similar building styles to Lebanon.

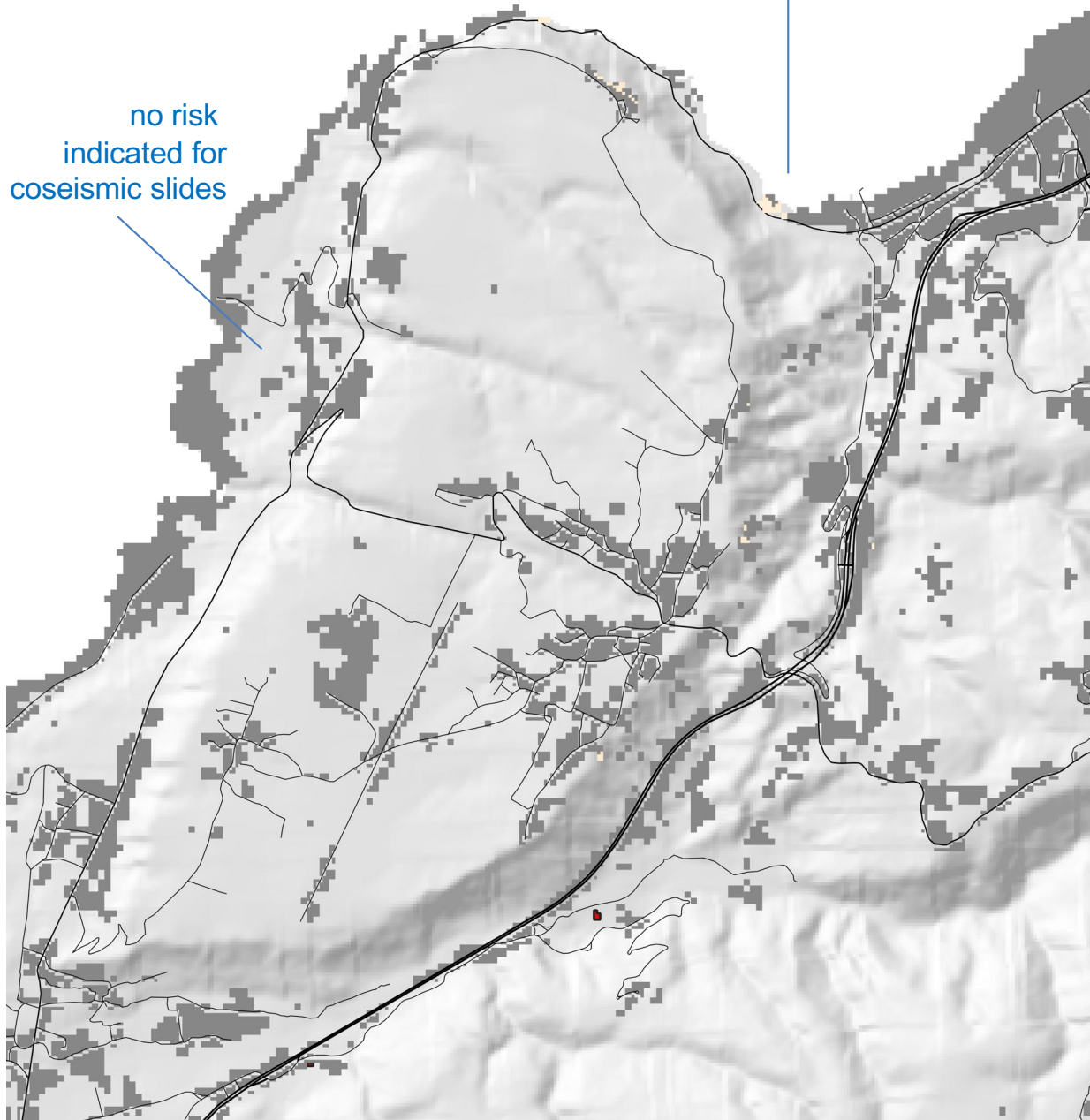
Encamped residents are assessed vulnerability values consistent with an outdoor population.

Annual risk to life (lives / yr)



minor coseismic
risk

no risk
indicated for
coseismic slides



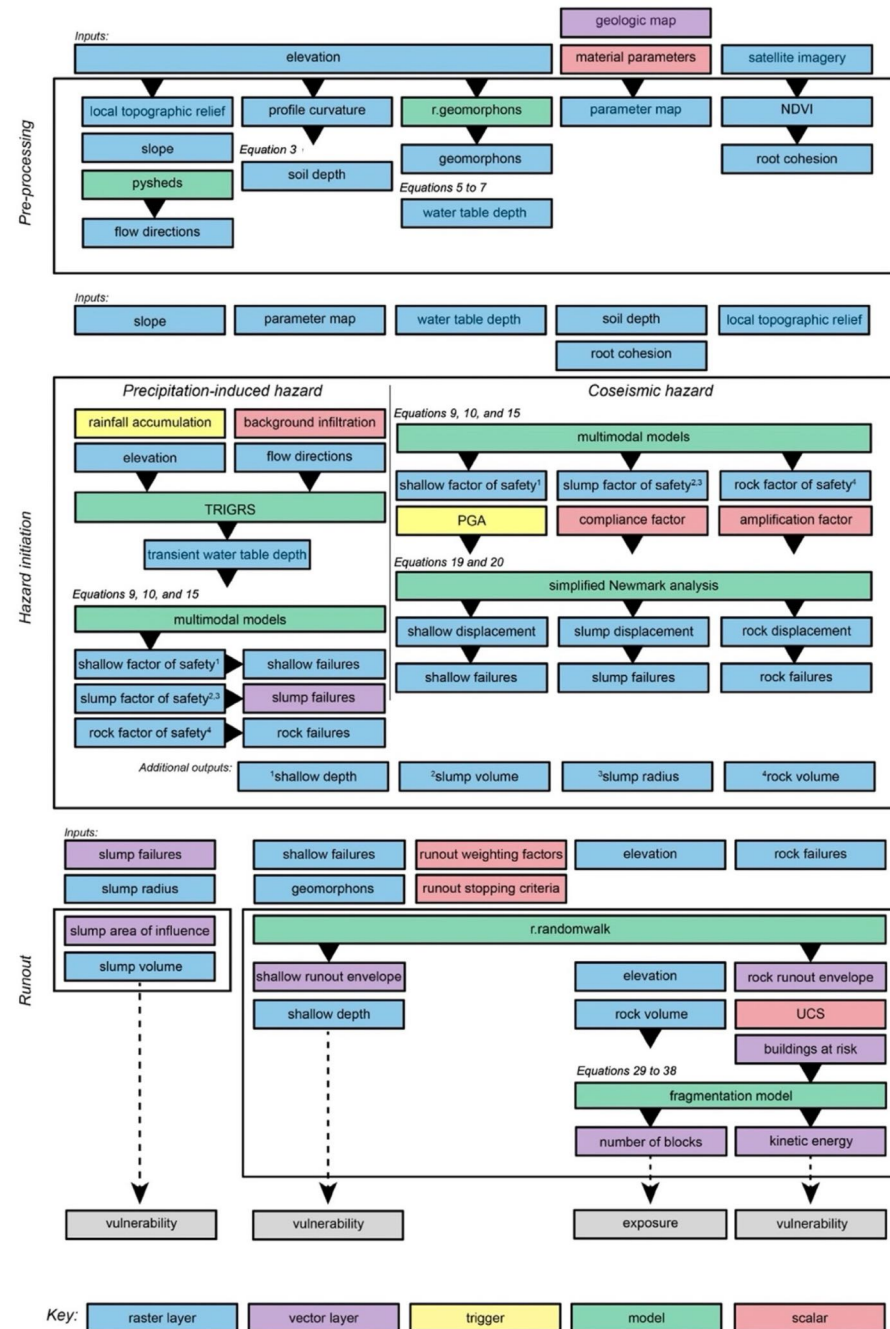
III. Risk Assessment

*Results: Mapping Risk from
Coseismic Landslides*

MM₃ – (Version 3 Multimodal Model, 2025-2026)

- Optimized 3D failure surface
- Transient rainfall infiltration model (TRIGRS¹)
- "Random-walk," 3D runout trajectory²
- Vulnerability fragility functions
- Fully probabilistic (Monti-Carlo) simulations
- Comprehensive testing against well-documented landslide event (GNS Kaikoura, New Zealand Ver. 2 landslide database)

Robust python-based, modular-type code



(1) Baum, R.. (2008) USGS; (2) Mergili et al. (2015) Geo. Mod. Dev.

MM₃ – Seattle Application

Why Seattle?

- Dense urban environment with many elements at risk
- Complex, multi-hazard landscape with both precipitation- and earthquake-induced landslide triggers
- Well-documented glacial geology producing diverse failure modes
- High-quality historical landslide and geotechnical data enabling first-order validation



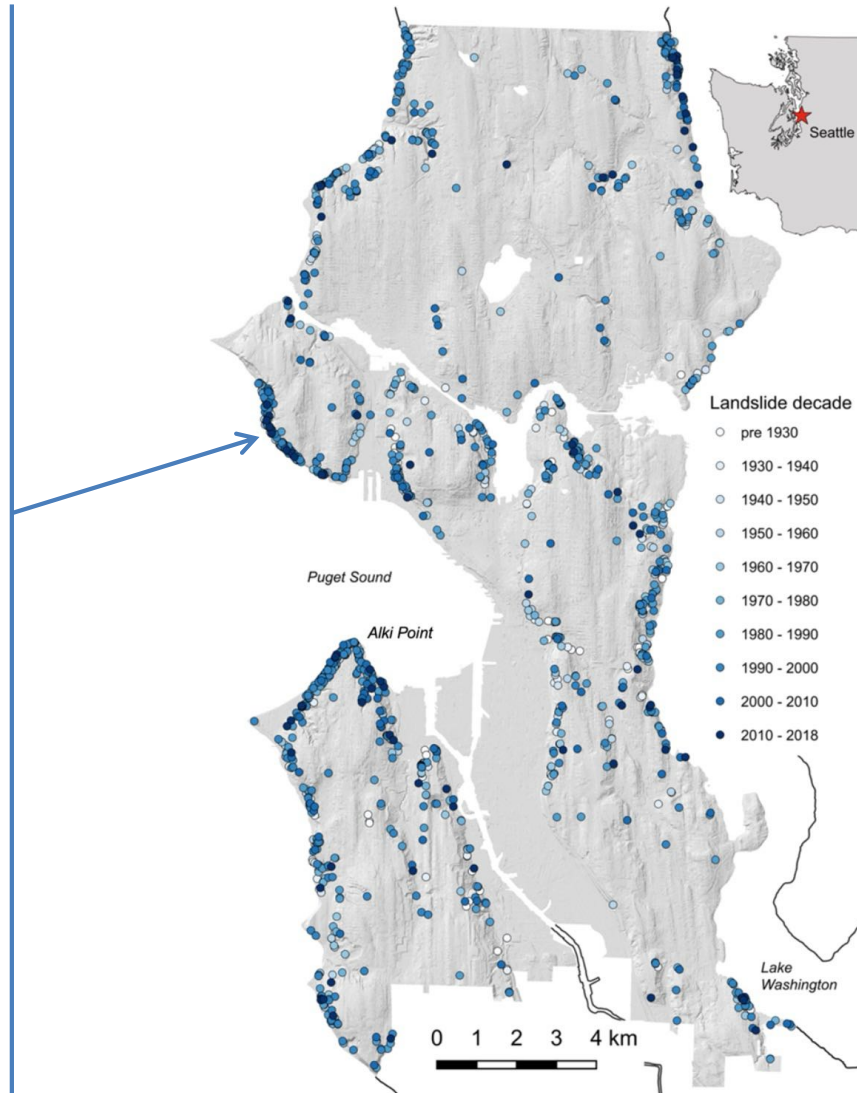
MM₃ – Seattle Application

Why Seattle?

- Dense urban environment with many elements at risk
- Complex, multi-hazard landscape with both precipitation- and earthquake-induced landslide triggers
- Well-documented glacial geology producing diverse failure modes
- High-quality historical landslide and geotechnical data enabling first-order validation



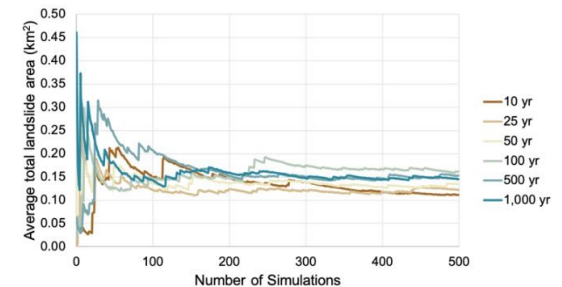
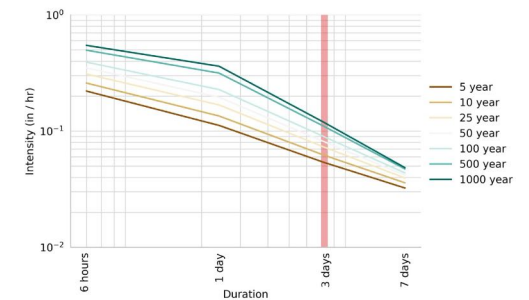
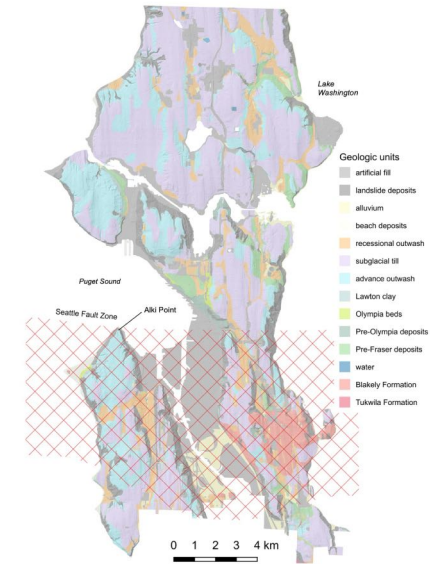
Images: Marilyn McClellan White



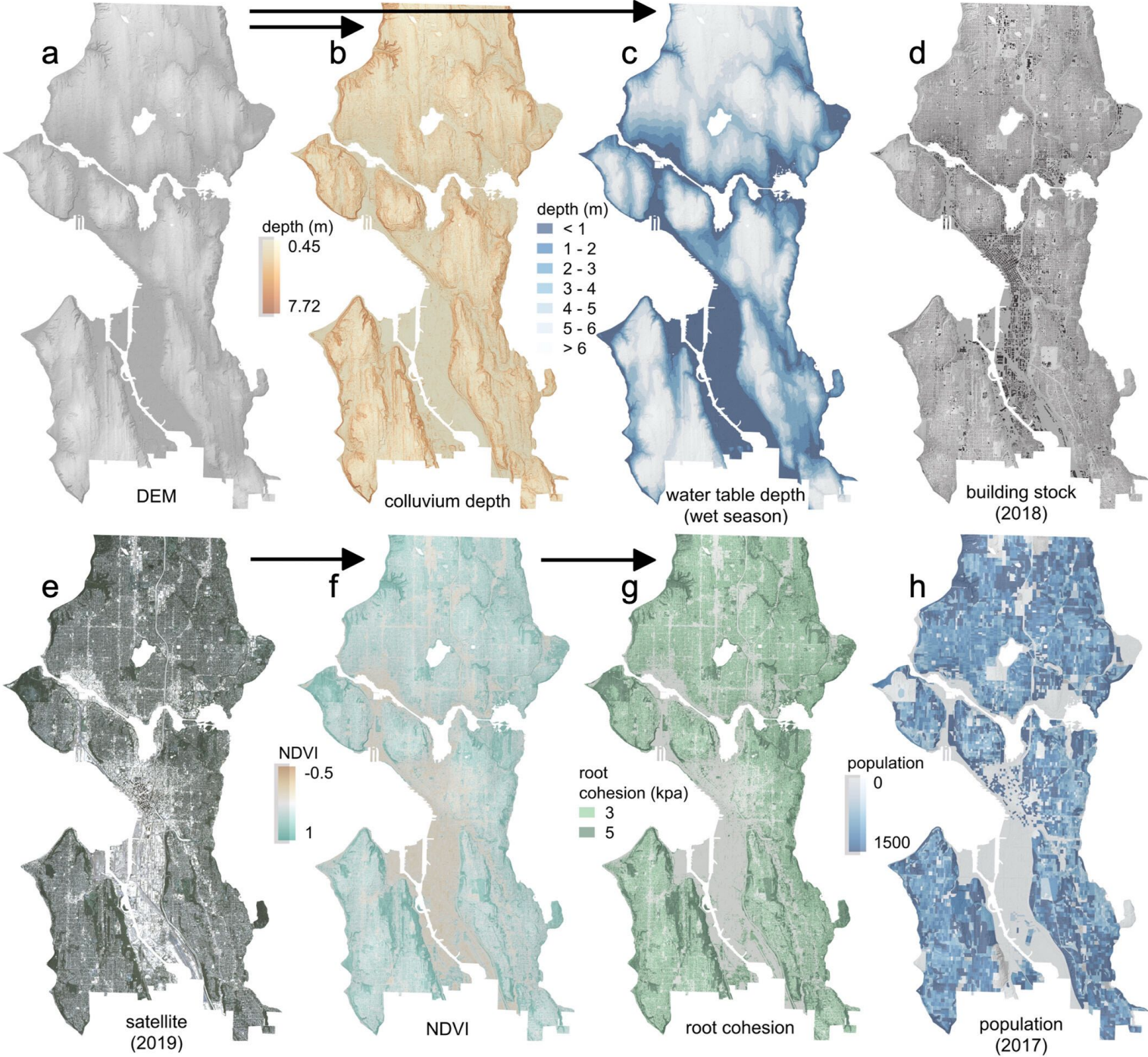
Key Details, Models, and Assumptions

MM₃ – Seattle Application

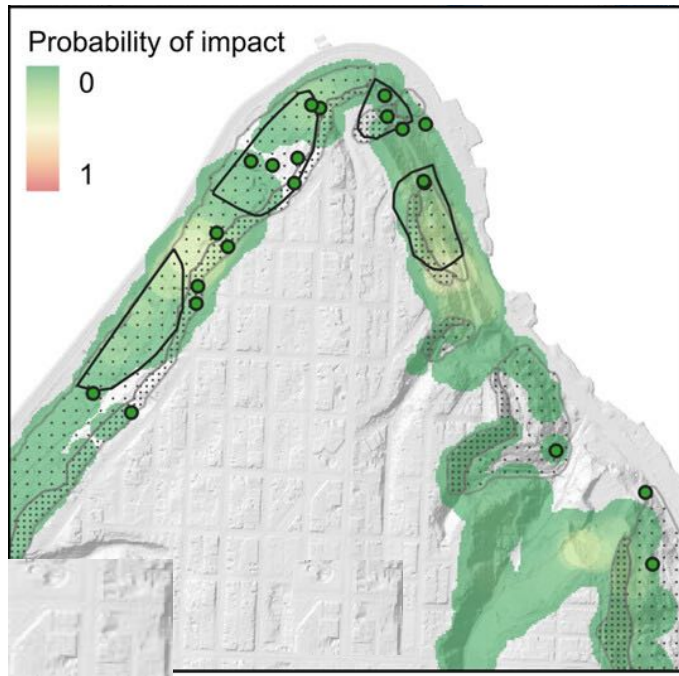
- **Colluvium Depth** — Depth modeled as an exponential function of topographic slope (Godt et al., 2008); ranges from ~7.7 m on flat terrain to ~0.5 m on 68° slopes
- **Material Parameters** — Two parameter sets per geologic unit (colluvium for shallow failures; underlying material for deep-seated and rock/debris falls); sampled from distributions based on prior Seattle geotechnical studies
- **Root Cohesion** — Derived from 3-m satellite NDVI imagery; assigned values of 3 or 5 kPa for moderate and dense vegetation, respectively
- **Water Table Depth** — Estimated from 630 DNR boring logs; modeled as a linear function of land surface elevation, with separate wet-season (Nov–Apr) and dry-season (May–Oct) relationships
- **Runout** — Local regression relationship developed from 250 mapped shallow flowslides and debris flows north of Seattle (Baum et al., 2000); log-linear volume-length scaling ($R^2 = 0.74$)
- **Elements at Risk** — City of Seattle building inventory and 2017 ACS census data; only ground-floor occupants considered at risk; fixed temporal exposure factor of 0.65
- **Precipitation Triggering** — Six rainfall intensities (10- to 1,000-year return periods) modeled using TRIGRS; 3-day duration selected based on Seattle's documented shallow landslide sensitivity
- **Seismic Triggering** — Peak ground accelerations at five return periods (224–975 years) from the 2018 USGS National Seismic Hazard Map; represent aggregated source contributions, not scenario-specific events
- **Scenario Combination** — Monte Carlo framework with 500 simulations per precipitation scenario and 250 per seismic scenario; adjacent failing pixels clustered into synthetic source zones to initialize runout modeling



MM₃ – Seattle Application



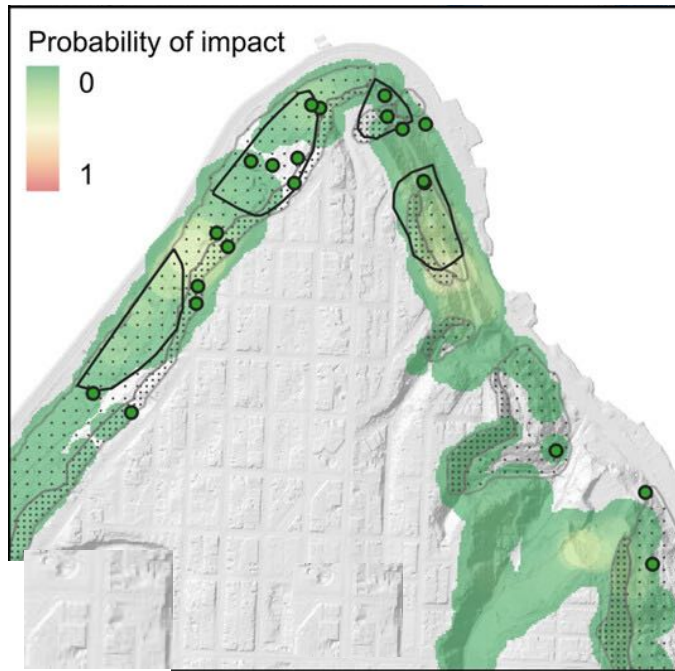
MM₃ – Seattle Application: *Influence of Trigger Type for Deep Seated Slides*



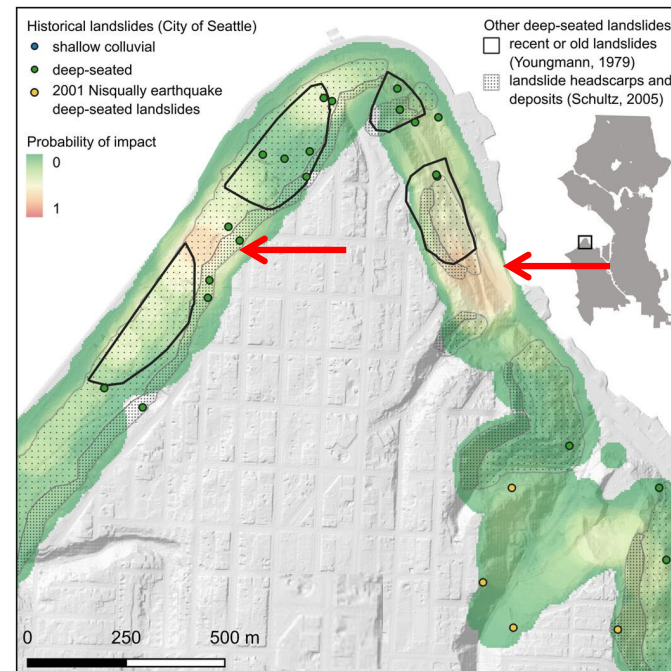
475 y return period rainfall

- Forecasted hazard area correspond well with the historic deep-seated landslide record

MM₃ – Seattle Application: *Influence of Trigger Type for Deep Seated Slides*



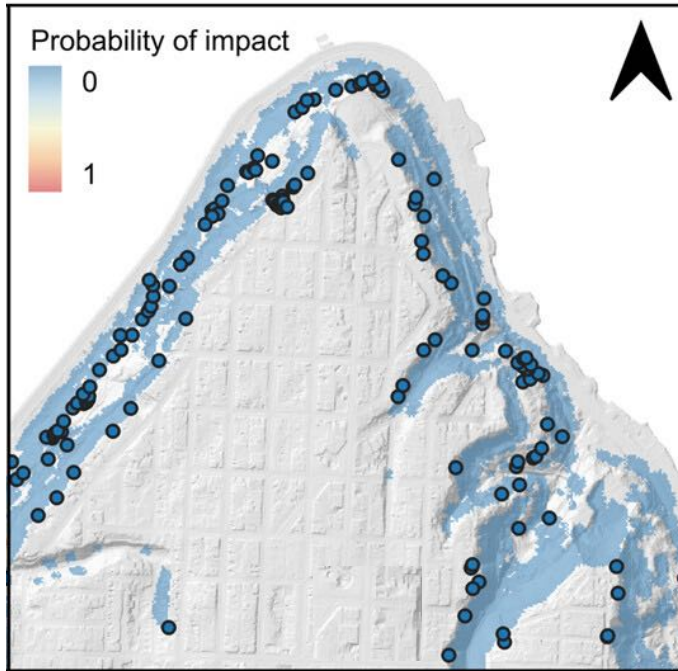
475 y return period rainfall



475 y return period earthquake

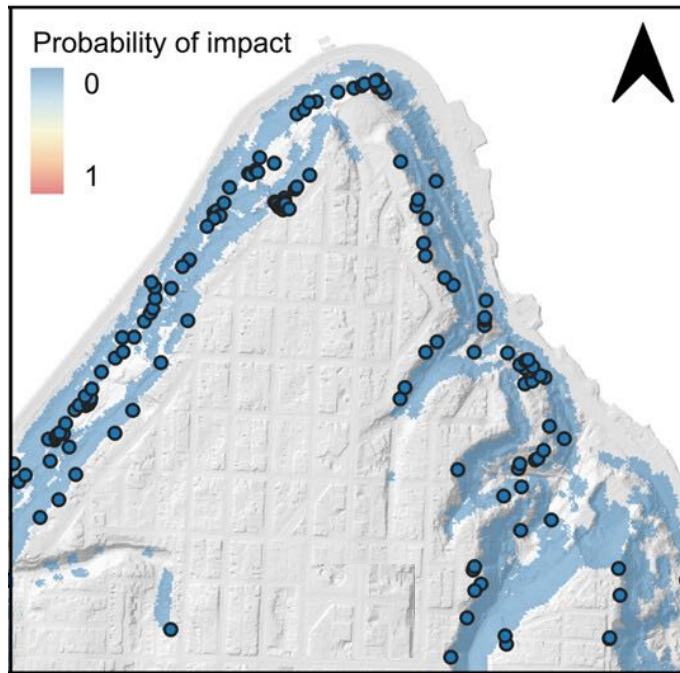
- Forecasted hazard area correspond well with the historic deep-seated landslide record
- Similar landslide footprint conditions, except that shaking mobilizes two high hazard locations

MM₃ – Seattle Application: *Influence of Trigger Type for Shallow Slides*

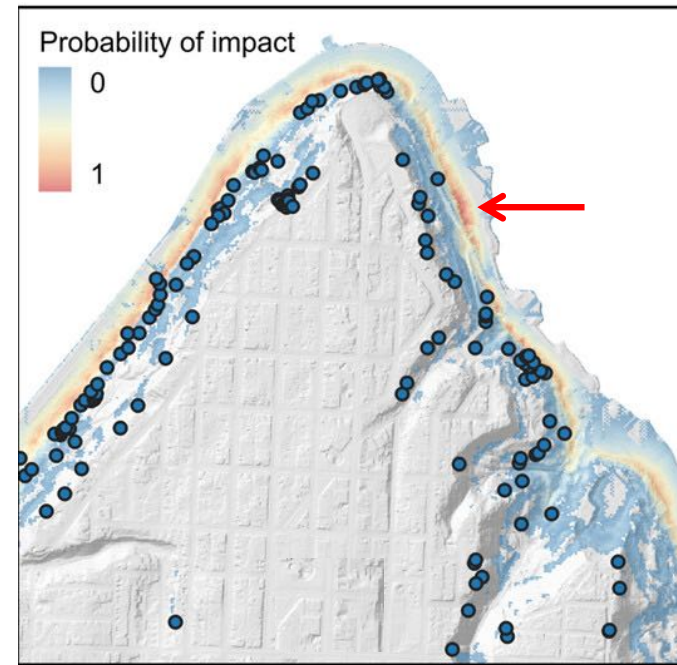


- Forecasted hazard area correspond well with the historic shallow landslide record
- Shallow landslide hazard is low for rainfall, but widespread across coastal bluffs.

MM₃ – Seattle Application: *Influence of Trigger Type for Shallow Slides*



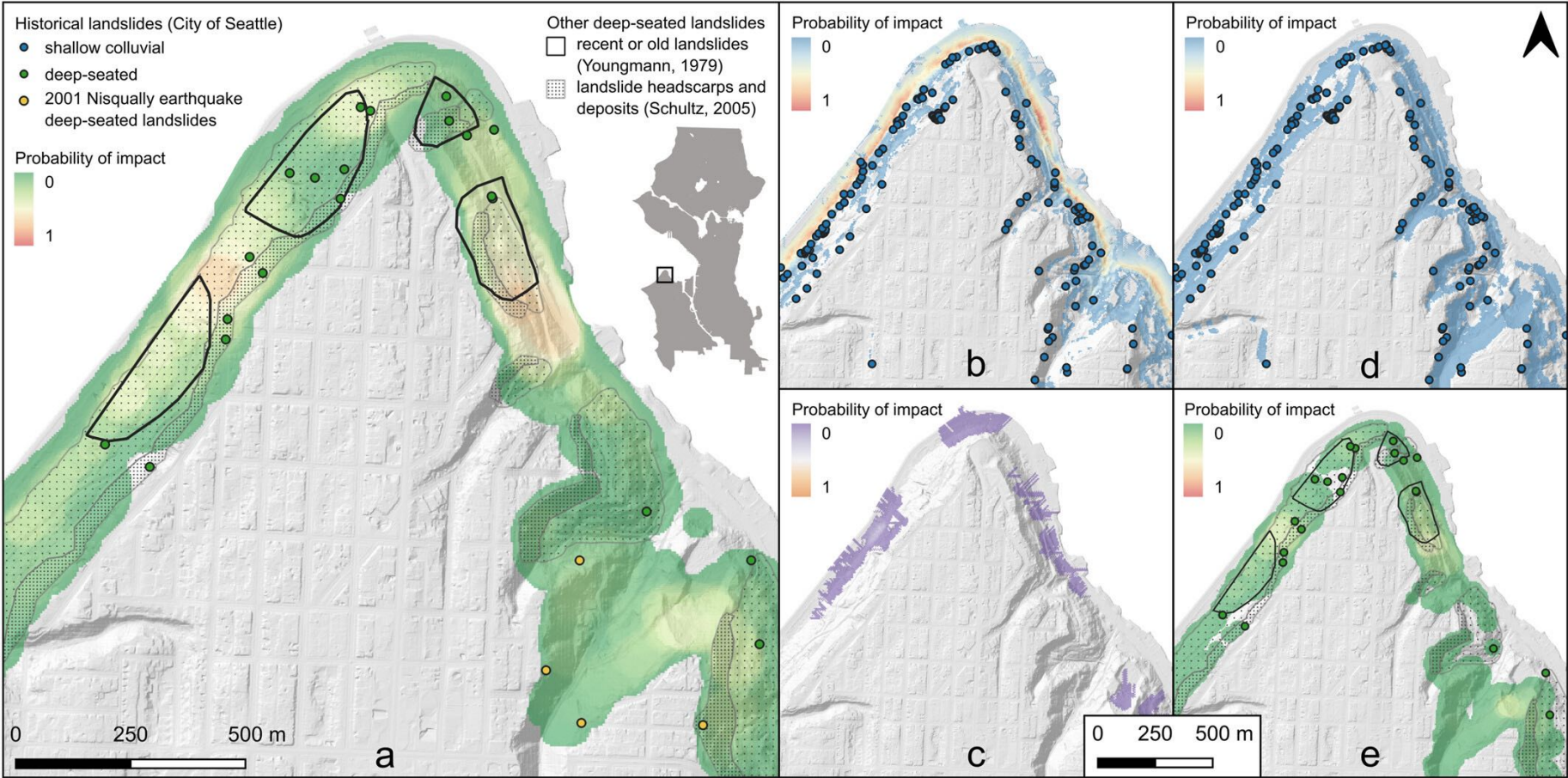
475 y return period rainfall



475 y return period earthquake

- Forecasted hazard area correspond well with the historic shallow landslide record
- Shallow landslide hazard is low for rainfall, but widespread across coastal bluffs.
- Coseismic landslides are concentrated below a high-relief, mid-slope bench

MM₃ – Seattle Application: *Influence of Trigger Type*

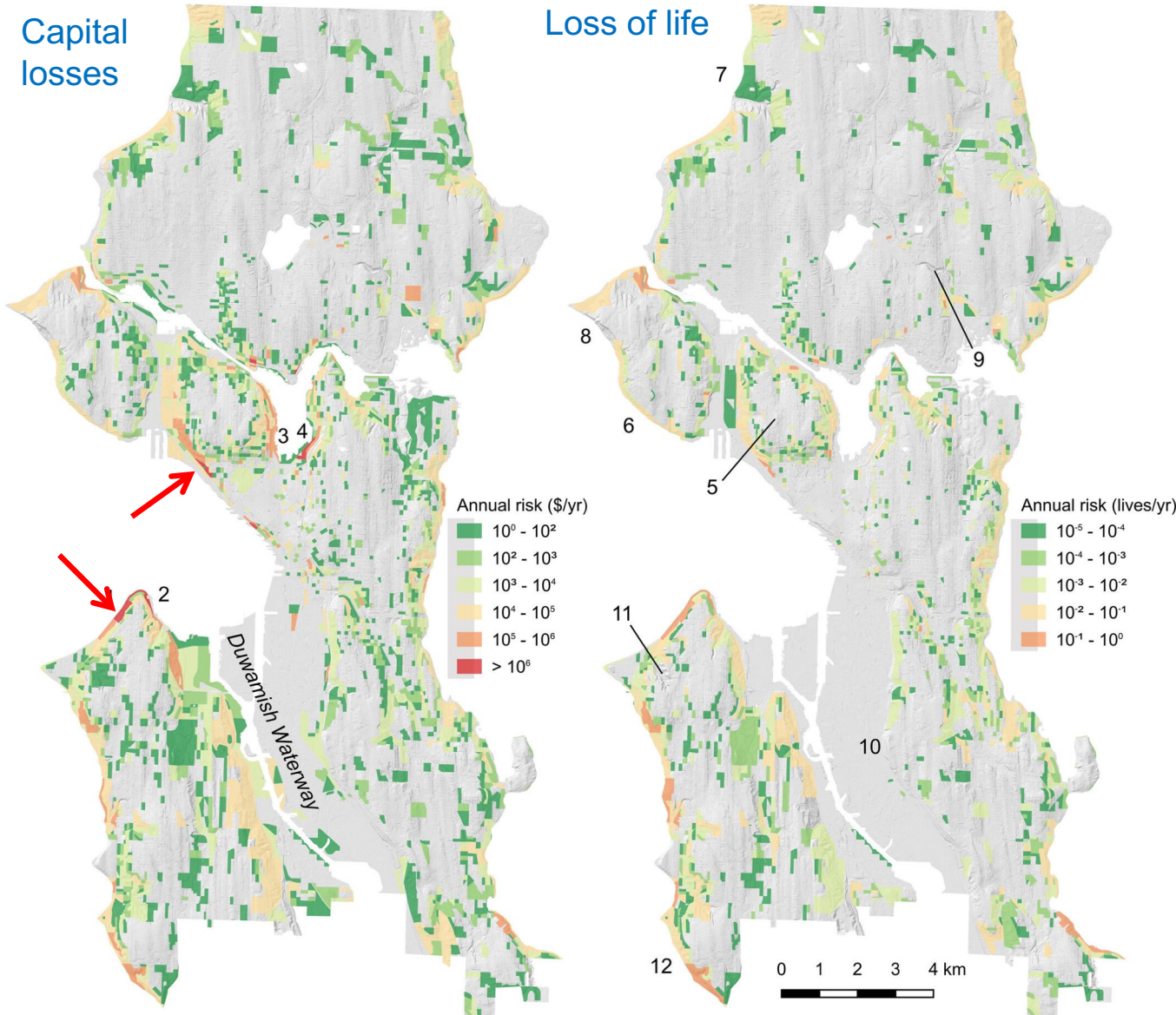


- Soil falls shown in purple (seismic conditions only)

MM₃ – Seattle Application: Annual Losses (Aggregated by Census Block)

Capital losses

Loss of life



- Structural risk is spatially concentrated—driven by high property values

- Human risk is more spatially diffuse, distributed across hillside residential areas

- Some neighborhoods carry disproportionately high risk driven by dense population and high building values

- High hazard does not necessarily equal high risk—e.g. parks have elevated hazard but low risk due to sparse development

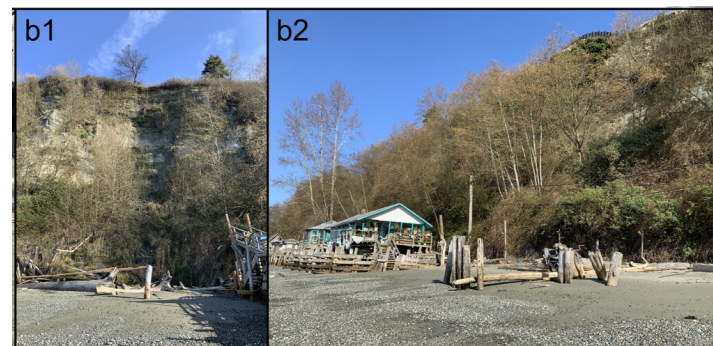
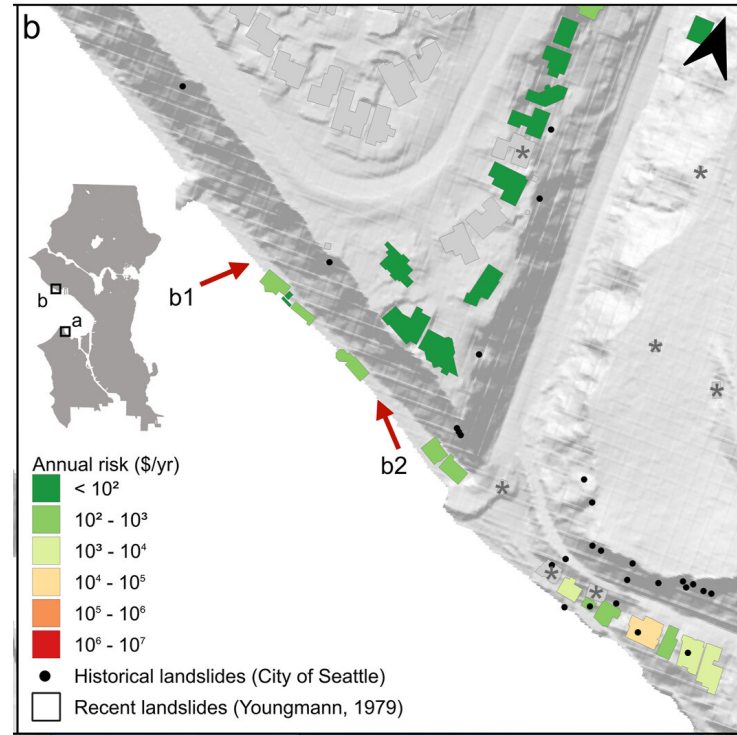
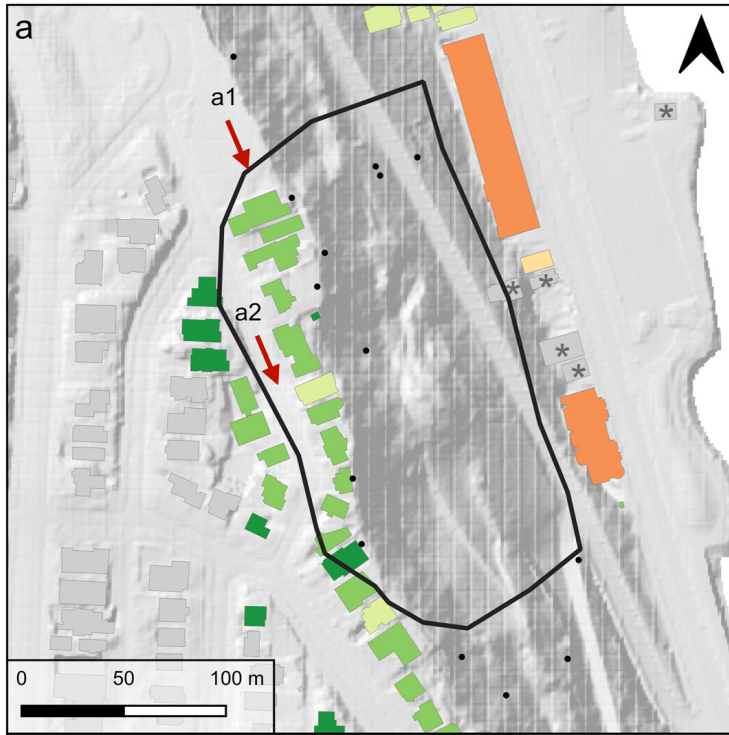
1) Alki Ave	3) Westlake	5) Queen Anne	7) Carkeek Park	9) Ravenna	11) West Seattle drainages
2) Harbor Ave	4) South Lake Union	6) Magnolia Ave	8) Magnolia Bluff	10) South Beacon Hill	12) Arroyos Natural Area

MM₃ – Seattle Application: *Building-level Assessment*



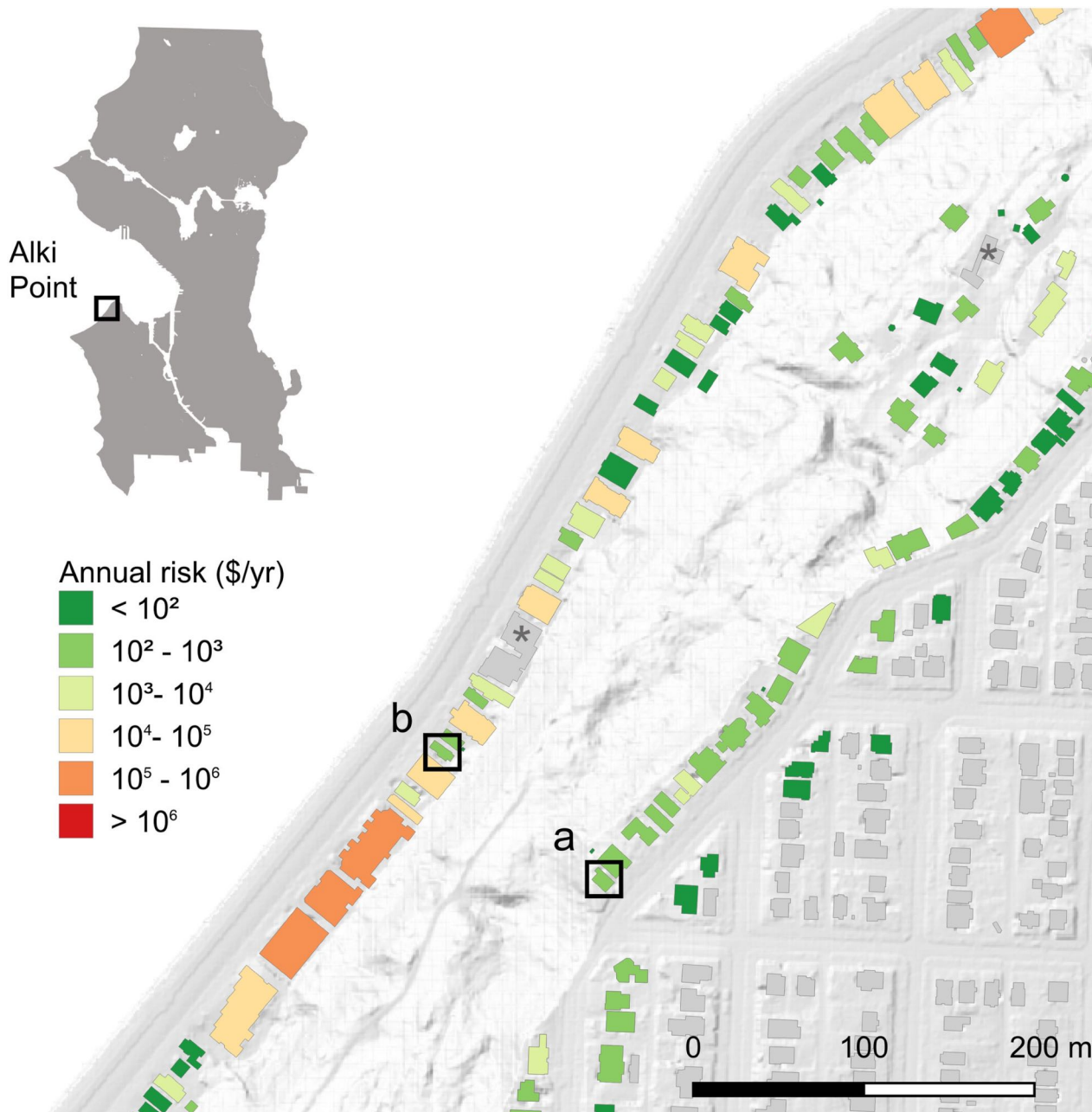
- Field verification

MM₃ – Seattle Application: *Building-level Assessment*



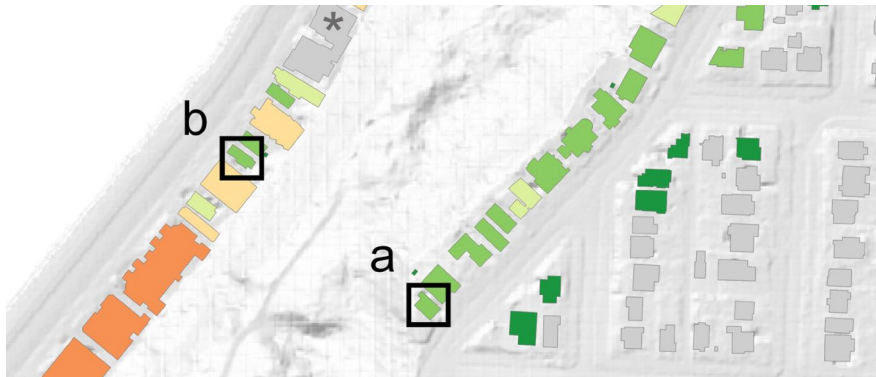
- Field verification
- Slow landslides vs. fast moving landslide (debris)

MM₃ – Seattle Application: *Building-level Annual Structural Risk*



- Risk varies dramatically over short distances — neighboring buildings can differ by orders of magnitude

MM₃ – Seattle Application: Risk Disaggregation for 2 Adjacent Buildings

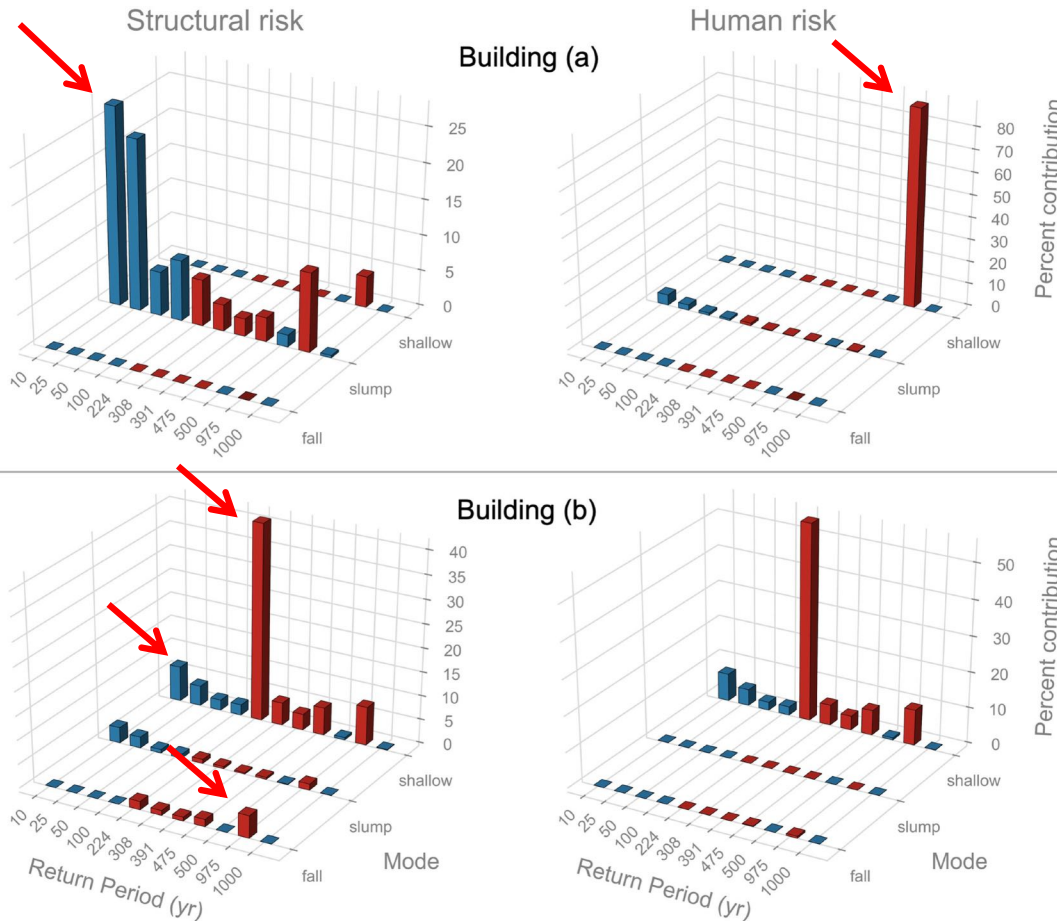


- Building "a" at slope crest:
 - Structural risk dominated by precipitation-induced slumps (68%)
 - Human risk dominated by infrequent shallow coseismic slides (89%)

- Building "b" at slope toe:
 - Structural risk split between seismic (63%) and precipitation (16%) shallow slides; slumps and debris falls contribute an additional ~20%

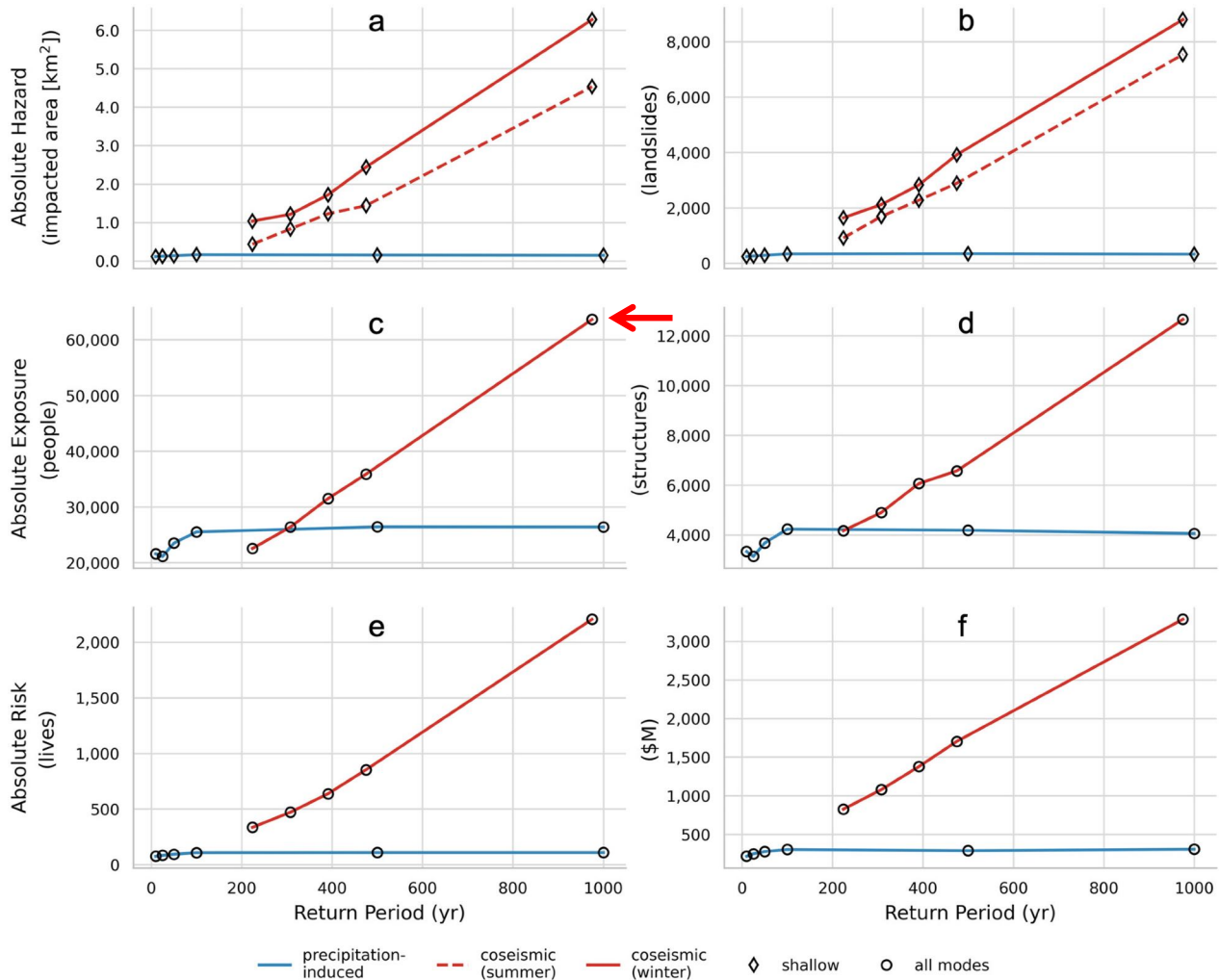
- Highlights that structural and human risk at the same building can be controlled by entirely different modes and triggers

- Disaggregated risk profiles directly inform tailored mitigation



Red = Earthquake
Blue = Rainfall

MM₃ – Seattle Application: *Absolute (Non-annualized) Hazard, Exposure, and Risk*

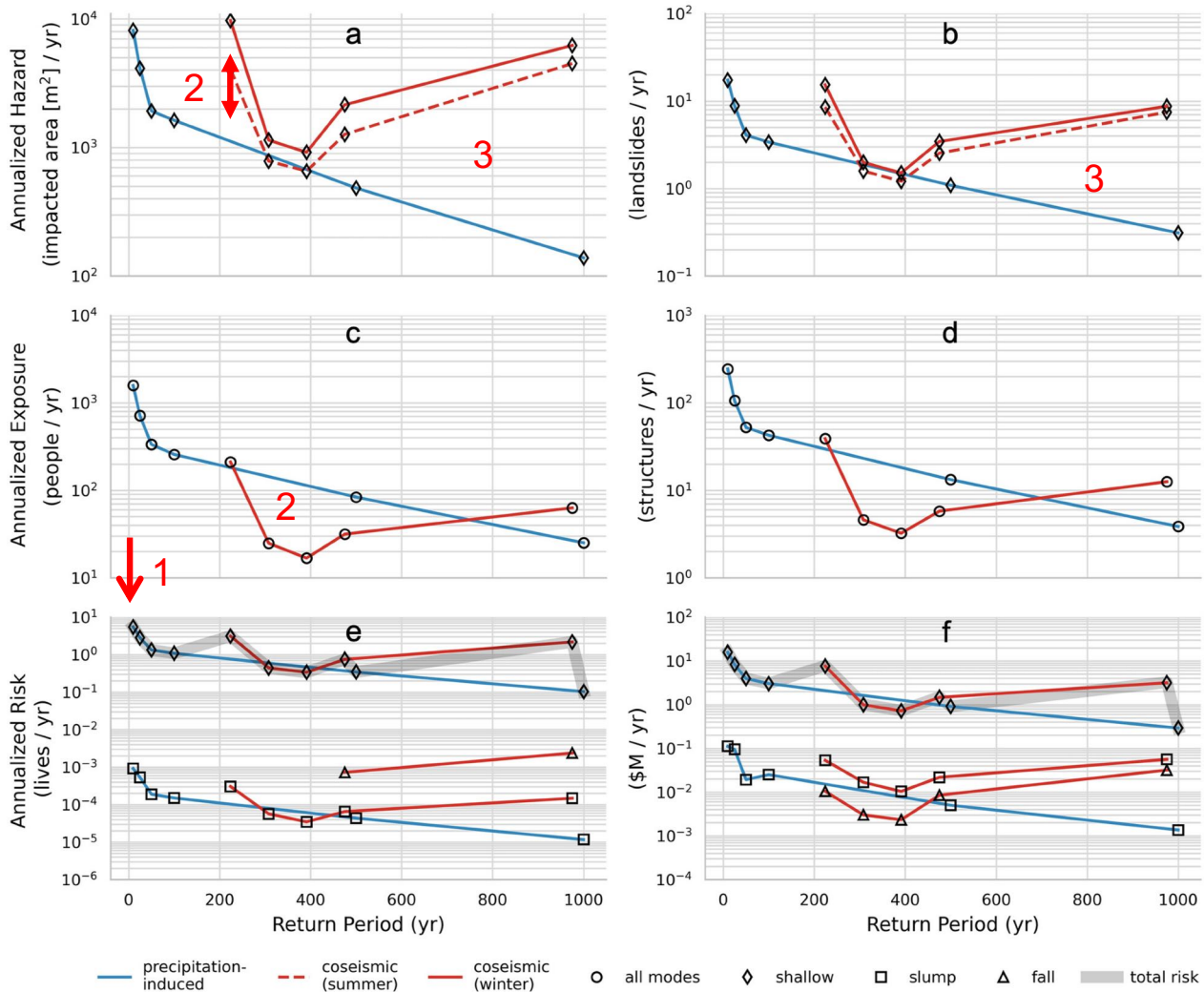


- Precipitation-induced hazard and risk "saturate" near the 100-year rainfall intensity, interpreted as a threshold above which surface water routes downslope as runoff rather than infiltrating

- Seismic hazard and risk scale approximately linearly with ground shaking intensity — no comparable saturation effect observed

- A ~975-year seismic event could expose over 60,000 residents to landslides, potentially resulting in many fatalities and billions in damage

MM₃ – Seattle Application: Annualized Hazard, Exposure, and Risk



- 1. Frequent, short-return-period precipitation events dominate cumulative annualized hazard, exposure, and risk
- 2. At comparable return periods, coseismic landslides impact up to 45 times more area than precipitation-induced events — yet expose fewer buildings and people due to sparser development in impacted areas
- 3. Individual coseismic landslides are larger, but comparatively less numerous than rainfall landslides

MM₃ – Seattle Application:
*Comparison of policy maps with MM₃-modeled hazard zones
(source and runout aggregated across all return periods/triggers)*



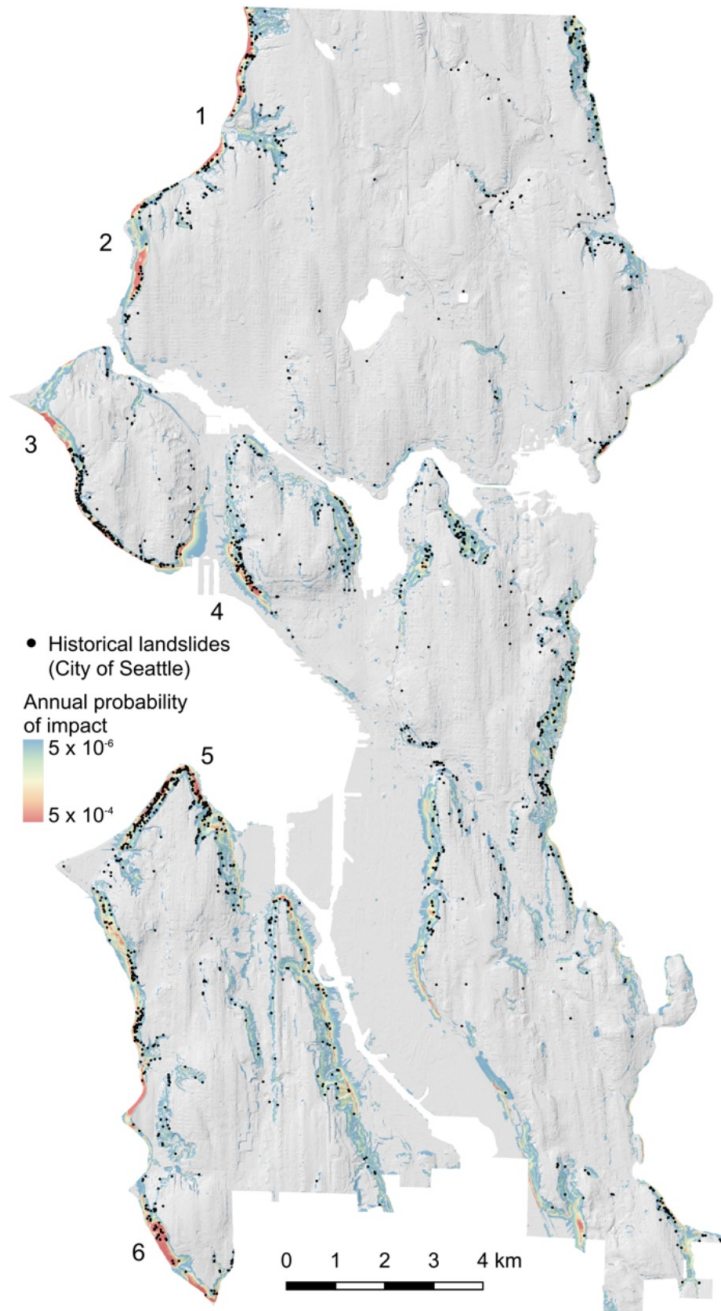
- Including landslide runout expands the potentially impacted area by 80%, to nearly 33 km²

- Approximately 6,770 buildings carry annual structural risk exceeding \$100 — about 58% of these fall outside the City's designated landslide-prone areas

- Most significant gaps between susceptibility mapping and modeled hazard occur at where runout, infrequent triggers, and post-failure behavior are not captured in the landslide inventory underpinning current policy

1) Interbay 2) Duwamish Waterway 3) Seward Park 4) Arroyos Natural Area

MM₃ – Seattle Application: *How does MM₃ Compare with Seattle's Comprehensive Landslide Inventory?*



- Probability of landslide impact from all modes, overlain by the historical Seattle Landslide Inventory
- 42% of inventoried historical landslides fall within zones of annual impact probability exceeding 1×10^{-4} — providing first-order validation of MM₃'s predictive ability
- Inventory under-representation is evident: 52% of recorded landslides show documented human influence, suggesting many occurred in otherwise low-susceptibility terrain

MM₃ – Seattle Application: *Other Issues Worth Noting*

Model Overforecasting

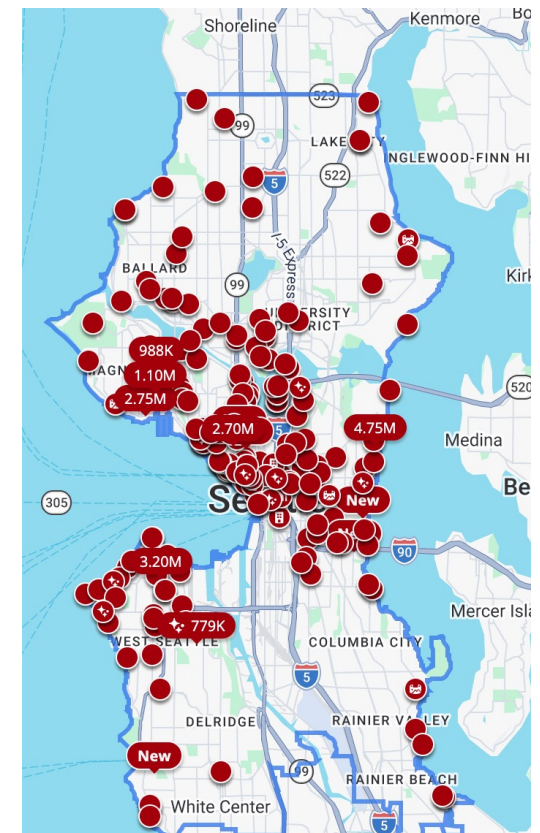
- MM₃ does not account for direct slope stabilization/mitigation measures implemented by the City since 1933
- Human evasion significantly reduces actual fatality risk but cannot currently be modeled; historical records suggest 2–3 individuals escaped for every 1 killed
- Existing vulnerability curves are derived largely from single-family residences, which may not reflect the growing prevalence of dense, multistory construction in landslide-prone areas

Who is at risk?

- Landslide risk in Seattle is disproportionately held by whiter and wealthier residents, reflecting the premium placed on slope-proximal waterfront and view properties
- Social stratification away from higher-risk areas appears limited, suggesting market forces are not effectively communicating landslide risk



Panoramic Views - Seattle WA Real Estate

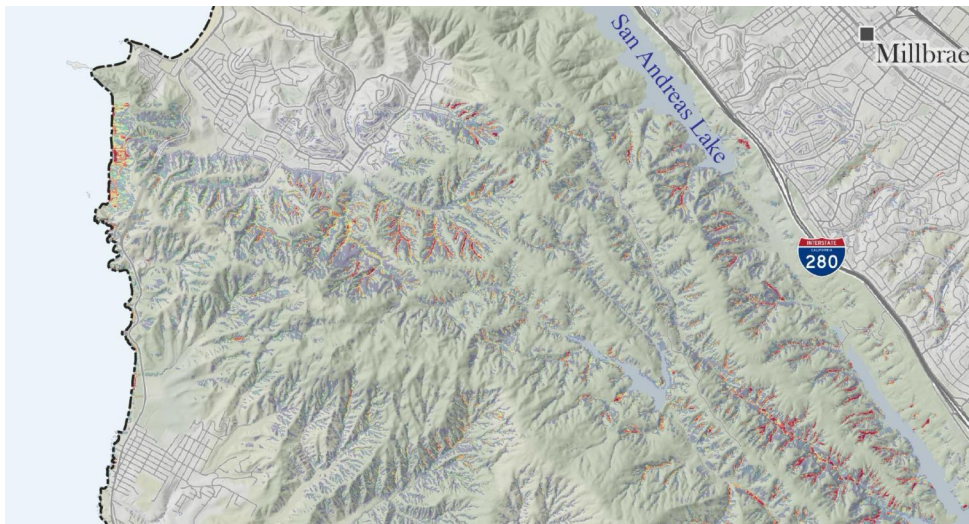


MM₃ – Three Closing Thoughts

1. A Low-Cost, High-Resolution Platform for Regional-Scale Parcel-Level Landslide Risk Mapping

- **Low-cost:** MM₃ operates primarily on remotely sensed and publicly available inputs (DEMs, satellite imagery, geologic maps, building and census data) — making it applicable to many places without expensive field campaigns.

100 km by 100 km San Francisco Bay Area study



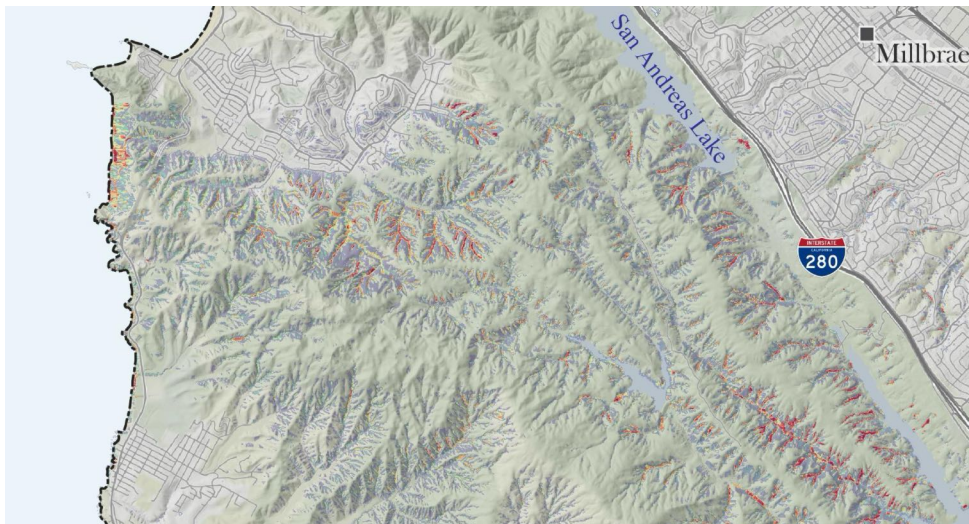
Greenfield et al. 2024 (ASCE Geocongress) **Ground Zero Projects LLC**

MM₃ – Three Closing Thoughts

1. A Low-Cost, High-Resolution Platform for Regional-Scale Parcel-Level Landslide Risk Mapping

- **Low-cost:** MM₃ operates primarily on remotely sensed and publicly available inputs (DEMs, satellite imagery, geologic maps, building and census data) — making it applicable to many places worldwide without expensive field campaigns.
- **High-resolution:** By resolving risk to the individual parcel, MM₃ transforms landslide science from a community-level abstraction into actionable, personally relevant information.

100 km by 100 km San Francisco Bay Area study



Greenfield et al. 2024 (ASCE Geocongress) **Ground Zero Projects LLC**



MM₃ – Three Closing Thoughts

1. A Low-Cost, High-Resolution Platform for Regional-Scale Parcel-Level Landslide Risk Mapping

What Can We Do With MM₃ Landslide Risk Maps?

- **Fundamental Science:** E.g., (i) Quantifying the relative contributions of precipitation versus seismic triggering to landslide risk in a complex, multi-hazard urban environment, (ii) Projecting precisely how landslide risk profiles will evolve under future climate scenarios.
- **Policy and Planning:** e.g., (i) providing a quantitative basis for updating and expanding landslide-prone area designations in land use codes, (ii) Enabling impact-specific mitigation by targeting investments to the specific locations, failure modes, and triggers that drive risk, rather than applying uniform solutions across broad susceptibility zones.
- **Insurance and Finance:** e.g., (i) Creating a viable landslide insurance market where one currently does not exist, (ii) Informing mortgage lending, property disclosure, and real estate valuation in landslide-prone areas.
- **Individual and Community Action:** e.g., (i) Empowering property owners with personally relevant risk information to make informed decisions about where to live, (ii) Personalized risk information transforms passive exposure into active preparedness—empowering residents to take concrete, site-specific steps that can significantly enhance their own safety (and note, not everyone will welcome this knowledge...)

MM₃ – Three Closing Thoughts

2. Landslide "Forecasting": Spatial Confidence, Temporal Uncertainty

- We can identify with confidence where slopes are susceptible, where failures will travel, and who and what lies in the path of debris
- Forecasting the precise timing of landslide failure requires site-specific knowledge of subsurface conditions, pore pressure dynamics, and material properties that is rarely available at the regional scale and remains an active area of research
- Spatial and temporal forecasting are complementary — rainfall thresholds and real-time monitoring play an important role, particularly for life-safety warning in high-risk corridors
- For most communities, however, the most immediate and durable risk reduction will come from knowing where risk is concentrated and acting on that knowledge through land use policy, mitigation, and individual preparedness

PUBLIC LAW 116–323—JAN. 5, 2021

(5) DEBRIS FLOW EARLY WARNING SYSTEM.—In carrying out the program, the Secretary, in coordination with the Secretary of Commerce and the Secretary of Homeland Security, shall expand the early warning system for debris flow by—

(A) expanding the early warning system for post-wild-fire debris flow to include recently burned areas across the western United States;

(B) developing procedures with State, territorial, local, and Tribal governments to monitor stormwater drainage in areas with high debris flow risk; and



[LANDSLIDE HAZARDS PROGRAM](#) | [SCIENCE](#)

Early Warning System

By [Landslide Hazards Program](#) June 23, 2018

GeoHealth

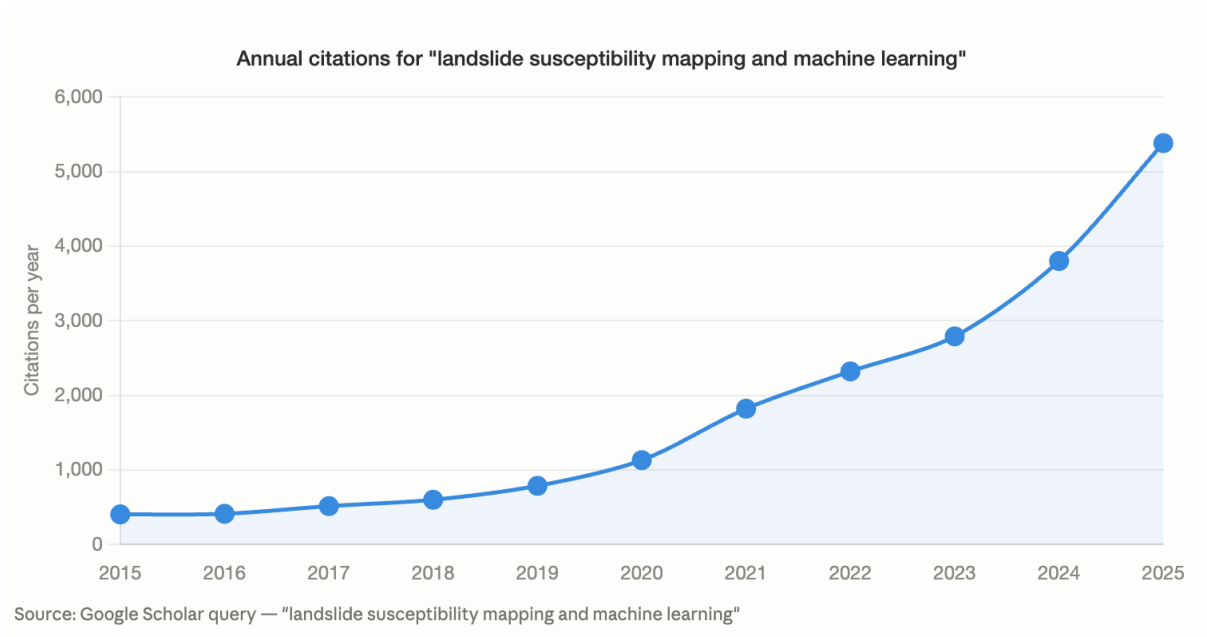
Research Article | [Open Access](#) | [CC](#) [BY](#)

Human Vulnerability to Landslides

William Pollock [✉](#) Joseph Wartman


First published: 21 September 2020 | <https://doi.org/10.1029/2020GH000287> |


MM₃ – Three Closing Thoughts



3. Landslide Mapping in the Age of Machine Learning



- A physically-based model like MM₃ is fully interrogable — every parameter has a physical meaning, every result has a mechanistic/process explanation, and every assumption can be examined, challenged, and refined. When MM₃ identifies a high-risk building, we can tell you exactly why — the failure mode, the trigger, the runout path, the vulnerability of the occupants — information that is simply not recoverable from a machine learning prediction
- Transparency is not merely a scientific virtue — it is a prerequisite for stakeholder trust, regulatory defensibility, and meaningful community engagement with risk information
- Most landslide inventories used to train machine learning models are mapping artifacts — polygons drawn around the entire affected area of a landslide event, conflating initiation zone, runout path, and deposit into a single undifferentiated object
- Why should machines be the only ones that enjoy the pleasure of learning? The process of building and implementing MM₃ — assembling inputs, calibrating parameters, interrogating outputs — generates deep knowledge about how landslides work in a given landscape.







MethodsX
 Volume 14, June 2025, 103218


MM₃: Multimodal framework for regional-scale quantitative landslide risk analysis

William Pollock ^{a, b}  , Joseph Wartman ^b

[Show more](#) 

[+](#) Add to Mendeley [🔗](#) Share [📄](#) Cite

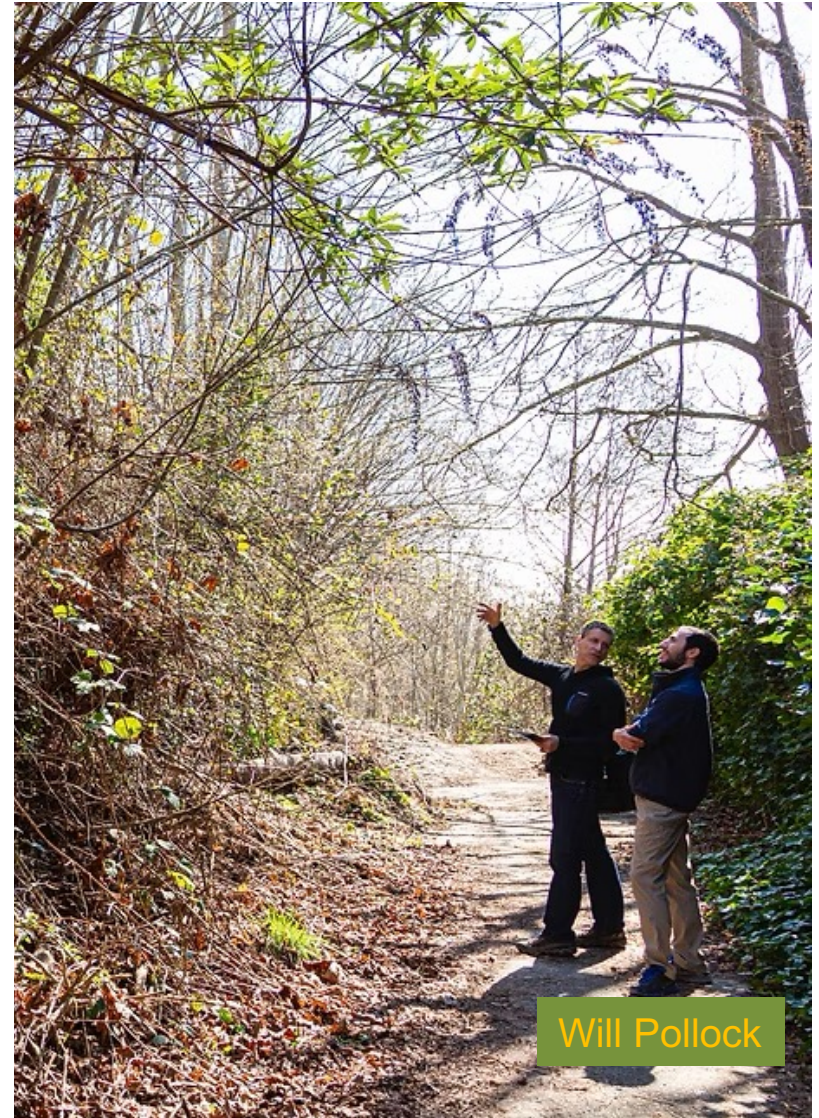
<https://doi.org/10.1016/j.mex.2025.103218> [Get rights and content](#) 

[Under a Creative Commons license](#)  Open access

Abstract

Quantified estimates of landslide consequences in space and time (risk) facilitate rational land use decisions such as zoning for new development, protecting existing communities, allocating finite resources, designing mitigation works, and educating the public about natural hazards. Probabilistic landslide risk analysis (PLRA) should include all landslide modes, magnitudes, and triggering scenarios that could credibly cause harm and is most useful on a regional scale where landslide risk at a location can be compared across a broader area and in the context of other natural and anthropogenic sources of risk. However, to date, no readily transferable, regional-scale method for PLRA exists. In this work, we expand an existing deterministic multimodal method for landslide risk analysis developed in the country of Lebanon into a linked framework of code-based modules that are location-agnostic and computationally efficient for regional end-to-end risk estimation.

Learn and more about MM₃ and how you can use this model





Earth's Future

RESEARCH ARTICLE

10.1029/2025EF007594

Disaggregation of Landslide Risk

William Pollock¹  and Joseph Wartman¹ 

¹Department of Civil and Environmental Engineering, University of Washington, Seattle, WA, USA

Abstract Quantifying and disaggregating landslide risk through probabilistic landslide risk analysis (PLRA) is critical for land use regulation and risk reduction. However, no transferable model for PLRA currently exists that resolves landslide consequences to individual buildings at regional scales. We introduce the physically-based MM₃ model for multimodal landslide risk analysis and apply it to Seattle, Washington, USA. Frequent precipitation-induced shallow landslides govern landslide risk in Seattle, although ground shaking from infrequent earthquakes, such as those anticipated on the Seattle Fault and Cascadia Subduction Zone, could expose over 60,000 people and 12,000 buildings to landslides. Critically, building-specific risk profiles vary by orders-of-magnitude even at neighboring properties, with different landslide modes and triggers posing distinct threats to human life versus structural integrity—enabling highly tailored mitigation strategies. Significantly more buildings face landslide risk than are currently designated as landslide-prone under susceptibility-based policies, primarily due to runoff being excluded in susceptibility mapping. By quantifying and disaggregating landslide risk at building resolution across regional scales, MM₃ provides a foundation for translating landslide science into actionable, risk-informed land use policy.

Key Points:

- A transferable probabilistic landslide risk analysis model quantifies building-level landslide risk—a critical capability absent from traditional susceptibility maps
- Risk disaggregation reveals that dominant landslide hazards and triggers can vary dramatically between neighboring properties
- Current susceptibility-based policies can be dangerously incomplete: landslide runoff is a primary, yet often overlooked, driver of risk

Supporting Information:

Supporting Information may be found in the online version of this article.