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European Geosciences Union
Committee on Education

Landslides (Mass Wasting)

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This talk funded in part by EC FP7 Grant LAMPRE

LAMPRE

LAndslide Modeling and tools for vulnerability assessment Preparedness and REcovery management

Landslides (Mass Wasting)

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1. Landslides Introduction

- ***Mass-Wasting:*** **down slope movement of rock and *regolith* near Earth's surface, mainly due to force of gravity.**
- ***Regolith:*** **unconsolidated rock debris, including the basal soil horizons, overlying bedrock.**
- **The down-slope movement of material, whether bedrock, regolith, or a mixture, is commonly referred to as a *landslide.***

1. Landslides Introduction

- **Mass-wasting important part of *erosional process*.**
  - ***Moves material from higher to lower elevations.***
  - ***Streams and glaciers can then pick up material.***
- **Mass-wasting occurs *all the time* on *all* slopes.**
- **Sometimes slow, sometimes very sudden.**
- **As human populations expand and occupy more and more of the land surface, *mass-wasting processes become more likely to affect humans*.**

1. Landslides Introduction

Year	*Location*	*Type*	*Fatalities*
1916	Italy, Austria	Landslide	10,000
1920	China	Earthquake triggered landslide	200,000
1945	Japan	Flood triggered landslide	1,200
1949	USSR	Earthquake triggered landslide	12,000–20,000
1954	Austria	Landslide	200
1962	Peru	Landslide	4,000–5,000
1963	Italy	Landslide	2,000
1970	Peru	Earthquake related debris avalanche	70,000
1985	Columbia	Mudflow related to volcanic eruption	23,000
1987	Ecuador	Earthquake related landslide	1,000

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1. Landslides Introduction

- ***Typical year in USA:*** **landslides cause >$1.5 thousand million in damages, 25–50 deaths.**
- ***In other countries*****, especially less developed, the loss is usually higher because of:**
  (1) higher population densities
  (2) lack of zoning laws
  (3) lack of information about mass-wasting hazards
  (4) lack of emergency preparedness
- ***Knowledge about relationships between local geology and mass-wasting processes can lead to better planning that can reduce vulnerability to such hazards.***

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Lots of classifications.

Cover ‘rapidly’ here without lots of detail.

Photos/videos excellent for high-school classes.

See ‘notes’ on each slide for links and details.

2. Types of Mass-Wasting Processes

- **Processes generally grade into one another, so classification is somewhat difficult.**
- **Two broad categories, but many different classification schemes exist:**

  ***2.1 Slope Failures*: sudden failure of the slope resulting in transport of debris down hill by sliding, rolling, falling, or slumping.**

  ***2.2 Sediment Flows*: debris flows down hill mixed with water or air.**

2. Types of Mass-Wasting Processes

2.1 Slope Failures

- **Types of SLOPE FAILURES:**

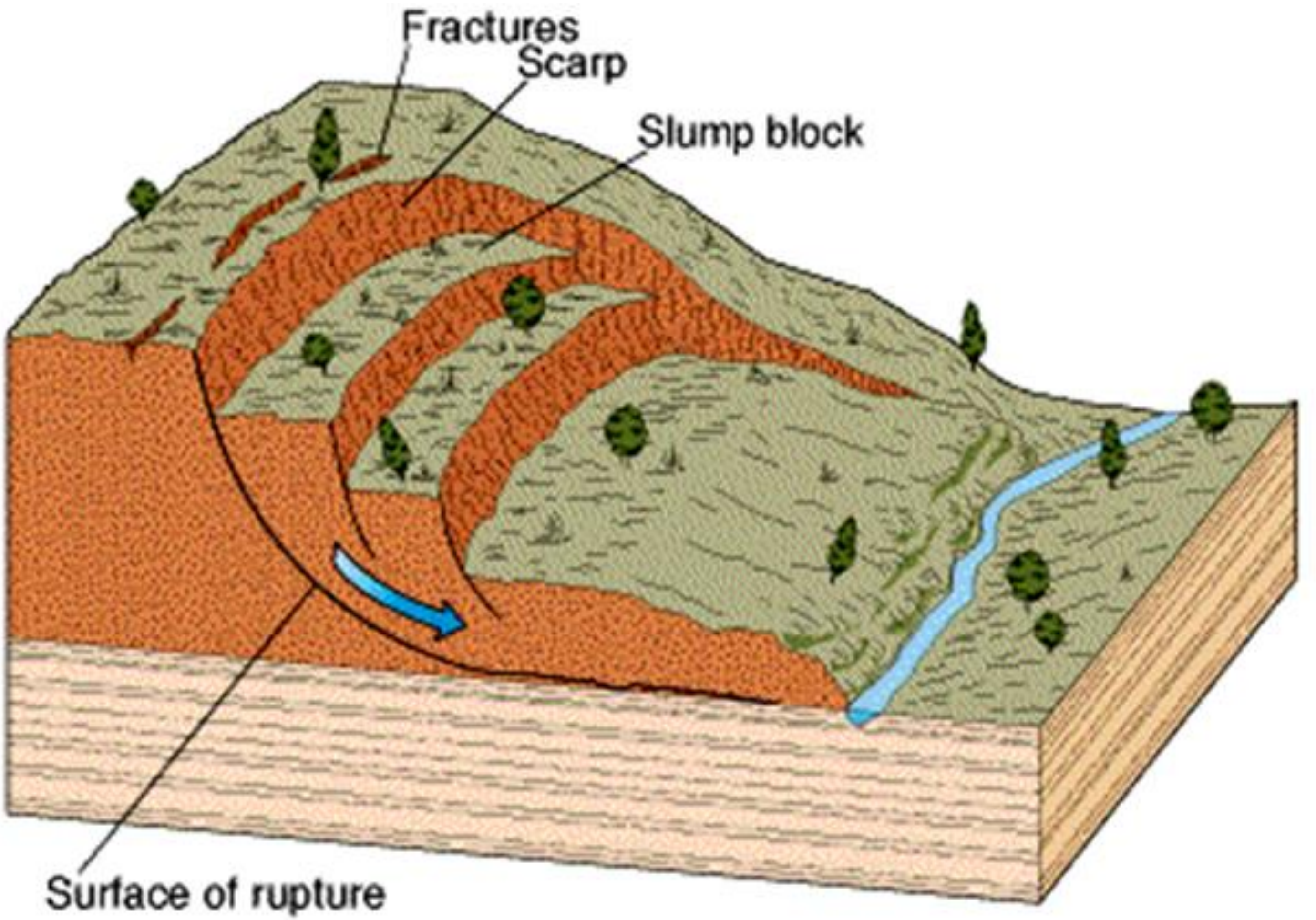
A. ***Slumps***

B. ***Falls***

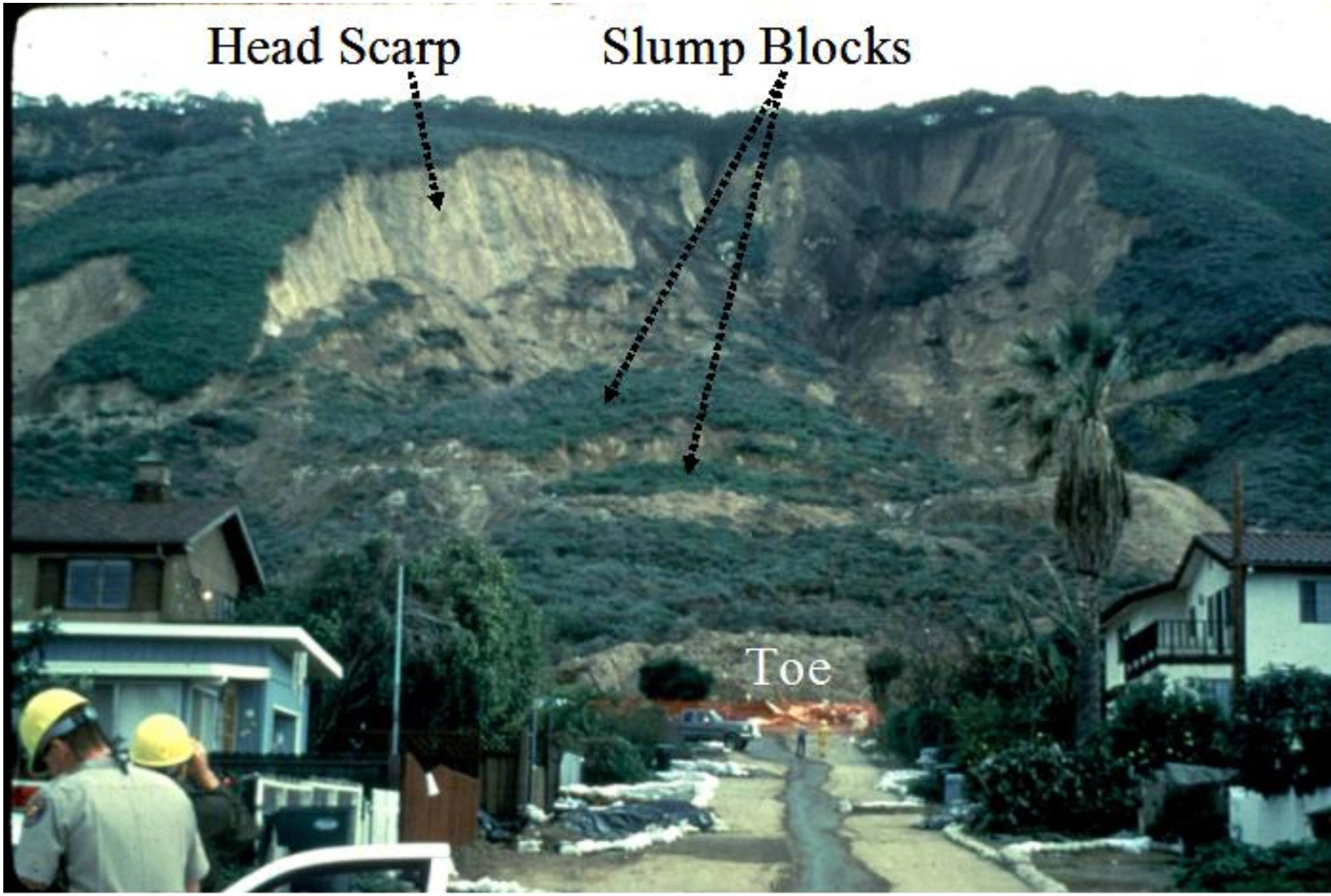
C. ***Slides***

2. Types of Mass-Wasting Processes

2.1 Slope Failures [A. Slumps]



2. Types of Mass-Wasting Processes
2.1 Slope Failures [A. Slumps]



La Conchita, California, 1995 landslide. Photograph RL Schuster (USGS)

2. Types of Mass-Wasting Processes

2.1 Slope Failures [A. Slumps]

Video showing deep-seated San Mateo slump.

- **Occurred in San Mateo County (California), USA, a few days after a 1997 New Year's storm.**
- **Slump opened a large fissure on the uphill scarp and created a bulge at the downhill toe.**
- **Movement continued at average rate of a meter per day.**
- **Uphill side dropped further, broke through a retaining wall, and created a deep depression.**
- **At the same time the toe slipped out across the road.**
- **Over 250,000 tons of rock and soil moved in this landslide.**
- **http://walrus.wr.usgs.gov/elnino/landslides-sfbay/photos.html**

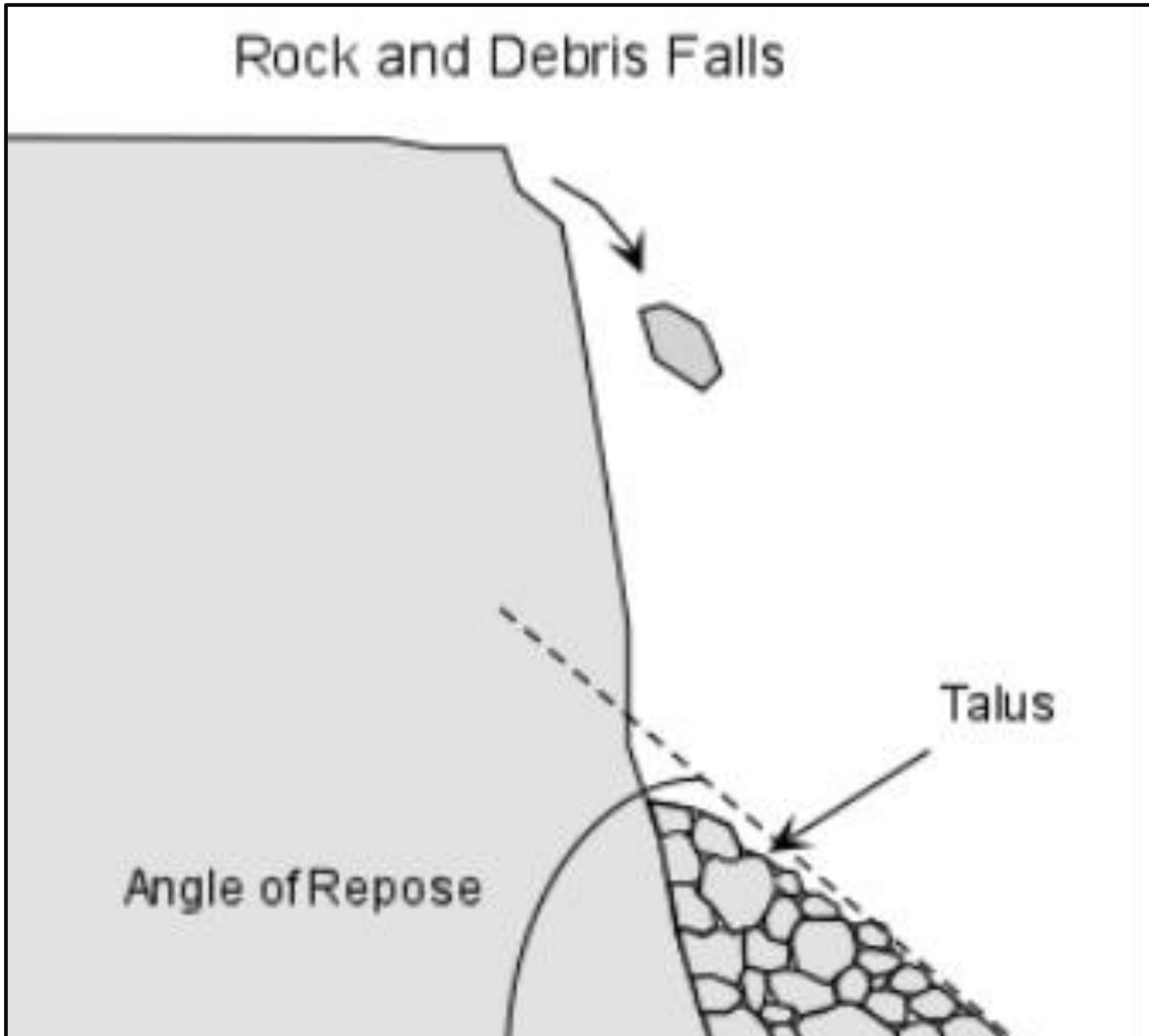
2. Types of Mass-Wasting Processes
2.1 Slope Failures [A. Slumps]

Triggered Landslide Events

Video showing deep-seated San Mateo slump.

http://walrus.wr.usgs.gov/elnino/landslides-sfbay/photos.html

2. Types of Mass-Wasting Processes
2.1 Slope Failures [B. Falls]



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2. Types of Mass-Wasting Processes

2.1 Slope Failures [B. Falls]

Rockfall in Fraser Canyon

http://www.nrcan.gc.ca/earth-sciences/products-services/mapping-product/geoscape/vancouver/6321

2. Types of Mass-Wasting Processes

2.1 Slope Failures [B. Falls]

Rockfall in 1999. Sacred Falls Park, Oahu
8 deaths and many injuries

Jibson & Baum (1999) USGS Open File Report 99-364.
http://pubs.usgs.gov/of/1999/ofr-99-0364/

2. Types of Mass-Wasting Processes

2.1 Slope Failures [B. Falls]

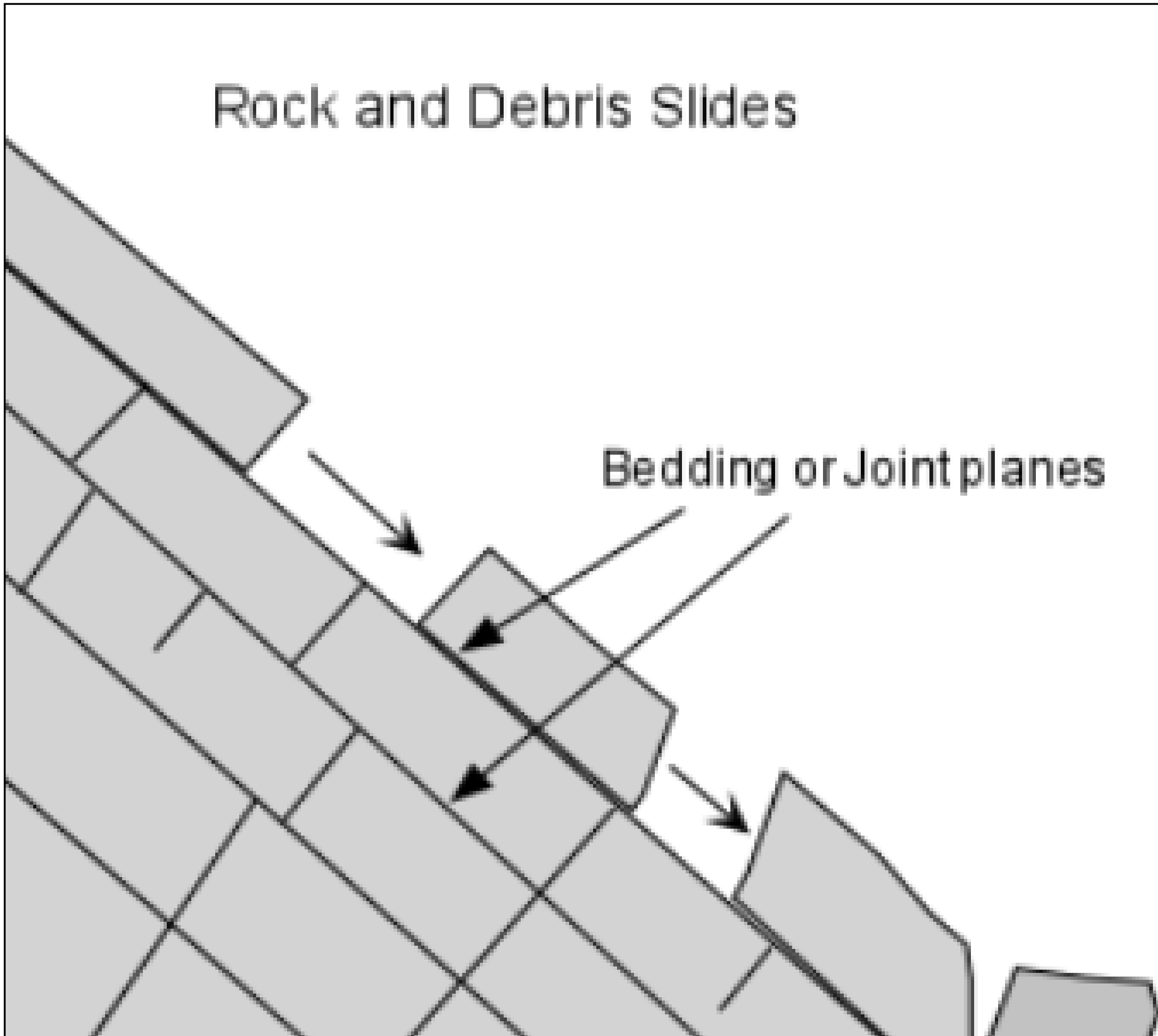
[Next Slide]
Video showing debris fall that occurred on the Sultan River, Oregon, USA on 11 December 2004. Video by Andrew Oberhardt.

http://www.youtube.com/watch?v=Qu88wb6gROg

Triggered Landslide Events

2. Types of Mass-Wasting Processes

2.1 Slope Failures [C. Slides]



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2. Types of Mass-Wasting Processes

2.1 Slope Failures [C. Slides]

Debris slides in unconsolidated glacial and fluvio-glacial deposits, Puget Sound (Dec 1996)

Triggered by record rainfalls in one week

2. Types of Mass-Wasting Processes

2.1 Slope Failures [C. Slides]

VIDEO

(next slide, not shown here in entirety due to time, but good for high-school students)

Roto-Translational Slide that EVOLVES into a FLOW
Maierato, Calabria, ITALY; 15 February 2010
No one injured. Slope had several days of preliminary movement, so roads had already been closed off. 2300 people evacuated.

VIDEOS:

http://daveslandslideblog.blogspot.com/2010/02/watch-this-extraordinary-landslide.html
http://daveslandslideblog.blogspot.com/2010/02/update-on-italian-landslides.html
See here for aftermath: http://www.youtube.com/watch?v=vJtYTbQecNE&NR=1&
Gattinoni *et al*. (2012) *Landslides*: http://www.springerlink.com/content/43ru3g5082171p45/

2. Types of Mass-Wasting Processes

2.1 Slope Failures [C. Slides]

Roto-Translational Slide that EVOLVES into a FLOW

Maierato, Calabria, ITALY; 15 February 2010

2. Types of Mass-Wasting Processes

- **Processes generally grade into one another, so classification is somewhat difficult.**
- **Two broad categories, but many different classification schemes exist:**

  ***2.1 Slope Failures*: sudden failure of the slope resulting in transport of debris down hill by sliding, rolling, falling, or slumping.**

  ***2.2 Sediment Flows*: debris flows down hill mixed with water or air.**

2. Types of Mass-Wasting Processes

2.2 Sediment Flows

- ***Sediment flows*** **occur when sufficient force is applied to rocks and regolith, so they begin to flow down slope.**
- **A sediment flow is a mixture of rock and/or regolith with some water or air.**
- **Sediment flow types** ***(depends on % water present)*****:**

2.2.1 Slurry Flows: 20–40% water present.

As water content increases above 40% slurry flows grade into streams.
Slurry flows are considered water-saturated flows.

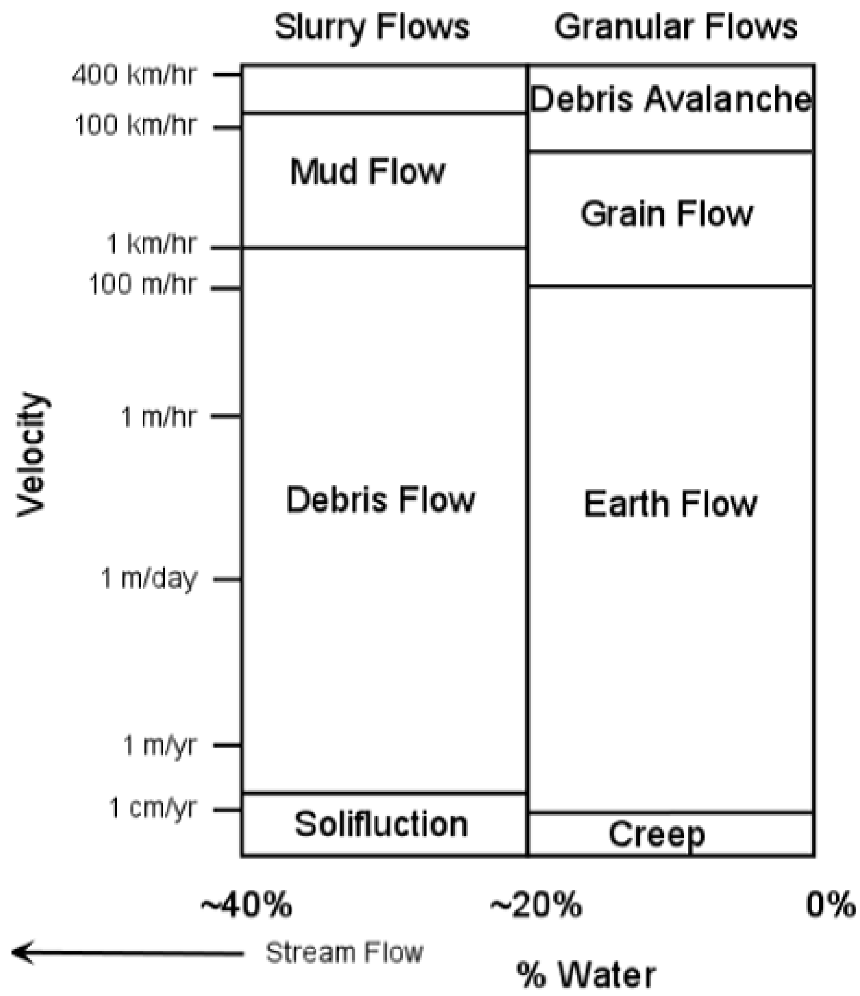
2.2.2 Granular Flows: 0–20% water present.

Granular flows are possible with little or no water.
Fluid-like behaviour is given these flows by mixing with air.
Granular flows are not saturated with water.

2. Types of Mass-Wasting Processes

2.2 Sediment Flows

- **Sediment flows can be further subdivided on the basis of the *velocity at which flow occurs.***



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2. Types of Mass-Wasting Processes
2.2 Sediment Flows

- **2.2 Sediment flow types** ***(depends on % water present)*****:**

  2.2.1 Slurry Flows: **20–40% water present.**

  A. Solifluction
  B. Debris Flows
  C. Mudflows

  2.2.2 Granular Flows: **0–20% water present.**

  A. Creep
  B. Earth Flows
  C. Grain Flows
  D. Debris Avalanches

2. Types of Mass-Wasting Processes
2.2.1 Slurry Flows [B. Debris Flows]

Animated Gif

http://elnino.usgs.gov/landslides-sfbay/photos.html

2. Types of Mass-Wasting Processes

2.2.1 Slurry Flows [B. Debris Flows]

Debris Flow, Caraballeda, Venezuela. December 1999.

USGS Slides at: http://pr.water.usgs.gov/public/venezuela/

2. Types of Mass-Wasting Processes

2.2.1 Slurry Flows

VIDEO

(not show here due to time, but good for high-school students)

Video showing debris or mud flow (some call this is Lahar) that occurred on Mount Rainier in Washington State, USA on 25th June 2011.

http://blogs.agu.org/landslideblog/2011/06/28/video-of-the-week-debris-avalanche-on-mout-rainier/20

2. Types of Mass-Wasting Processes
2.2 Sediment Flows

- **2.2 Sediment flow types** ***(depends on % water present)*****:**

  2.2.1 Slurry Flows: **20–40% water present.**

  - **A. Solifluction**
  - **B. Debris Flows**
  - **C. Mudflows**

  2.2.2 Granular Flows: **0–20% water present.**

  - **A. Creep**
  - **B. Earth Flows**
  - **C. Grain Flows**
  - **D. Debris Avalanches**

2. Types of Mass-Wasting Processes

2.2.2 Granular Flows [A. Creep]

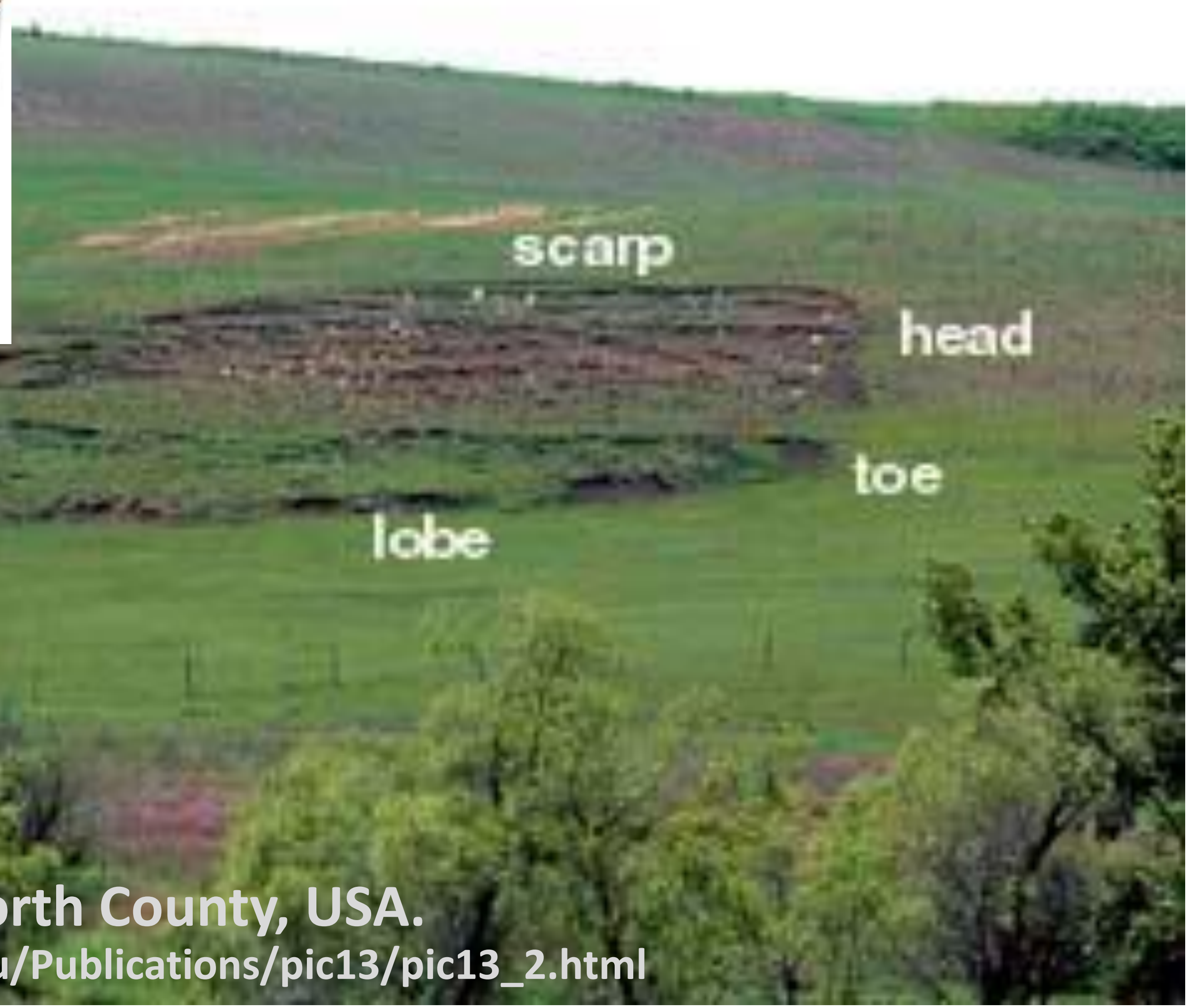
2. Types of Mass-Wasting Processes

2.2.2 Granular Flows [A. Creep]

2. Types of Mass-Wasting Processes

2.2.2 Granular Flows [B. Earth Flows]

Figure 13.19: Smithson *et al.* (2008)



Earth flow, Ellsworth County, USA.
http://www.kgs.ku.edu/Publications/pic13/pic13_2.html

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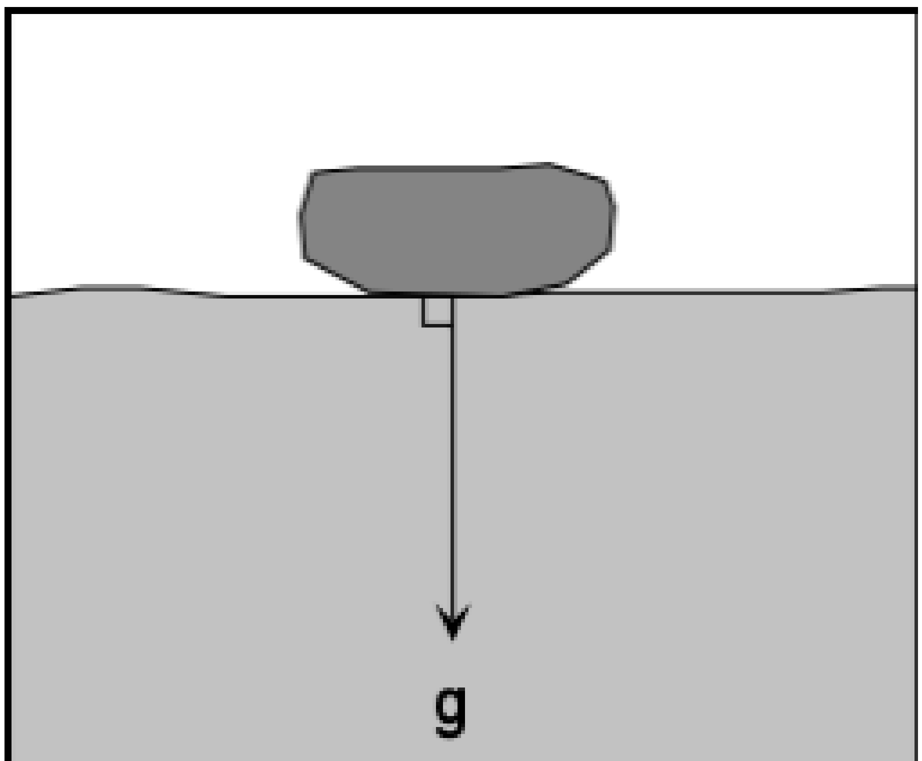
walrus.wr.usgs.gov/infobank

3. Factors Influencing Slope Stability
3.1 Gravity

- ***Gravity***: Main force responsible for mass wasting.
- On flat surface force of ***gravity acts downward***.
- So long as the material remains on the flat surface it will not move under the force of gravity.



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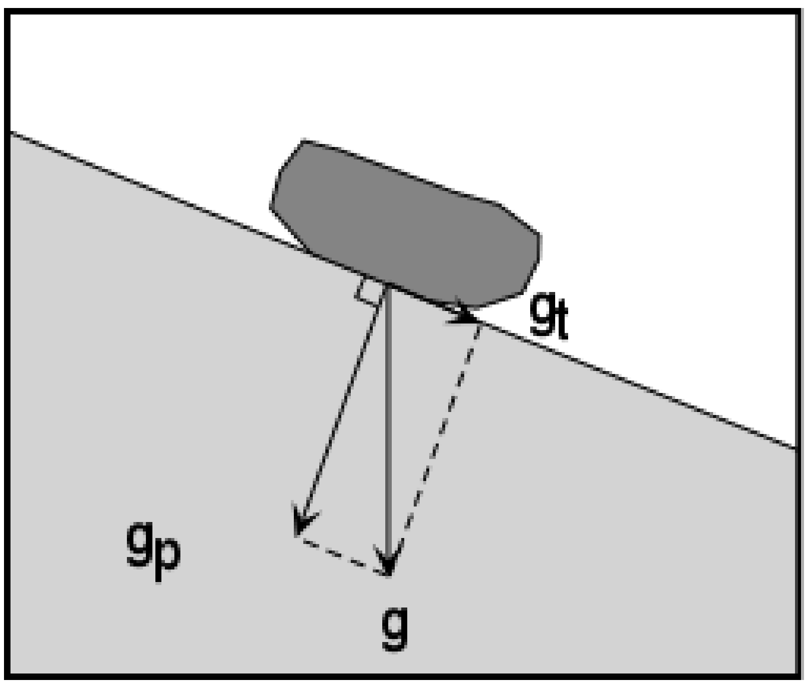
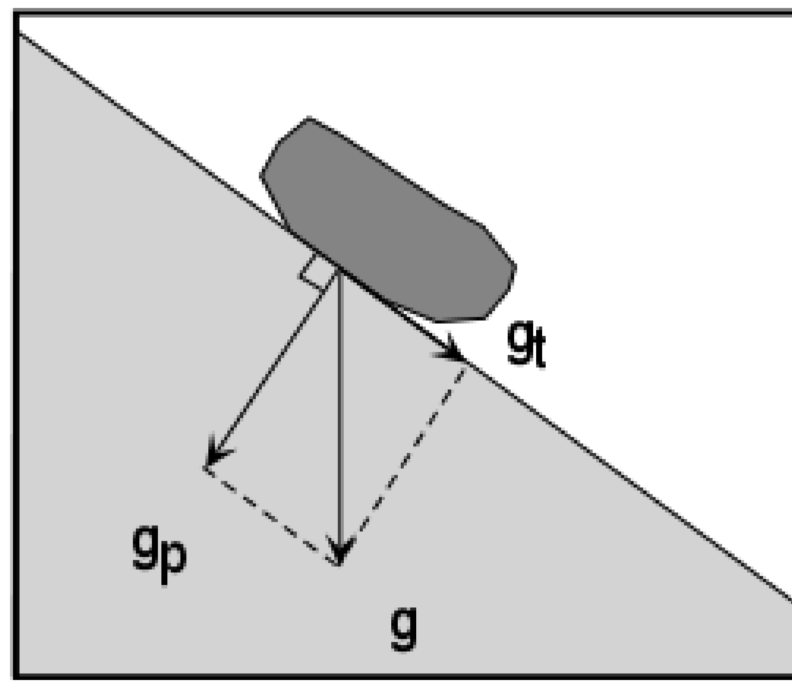
3. Factors Influencing Slope Stability

3.1 Gravity

- **Perpendicular component (g_p): helps to hold the object in place on the slope.**
- **Tangential component (g_t): causes a *shear stress* parallel to the slope that pulls the object in the down-slope direction.**





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3. Factors Influencing Slope Stability

3.1 Gravity

- **Shear strength**: All forces resisting movement down the slope including:
  - frictional resistance
  - cohesion among particles making up the object
- When ***sheer stress*** > ***shear strength***, the object will move down-slope.
- ***Shear stress*** is INCREASED by
  - steeper slope angles.
- ***Shear strength*** is DECREASED by:
  - lowering cohesion among the particles
  - lowering the frictional resistance.

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3. Factors Influencing Slope Stability

3.2 Water

- ***Water*** **not always directly involved as transport in mass-wasting processes, but plays important role.**

3. Factors Influencing Slope Stability

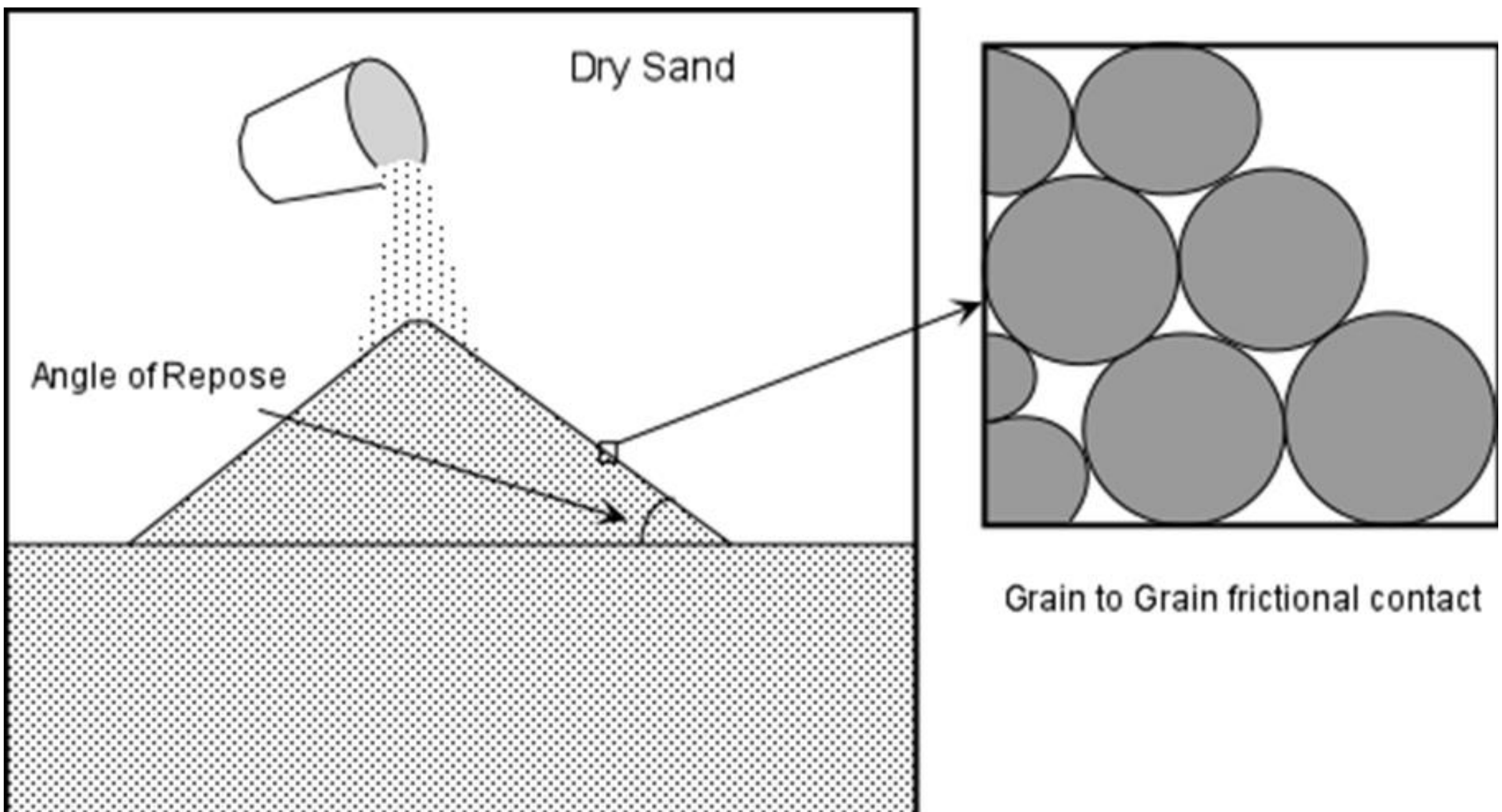
3.2 Water

- Imagine a *SAND CASTLE*.
  - *Sand totally dry*: impossible to build a pile of sand with a steep face like a castle wall.
  - *If sand a little wet*: can build vertical wall.
  - *If sand too wet*: flows like a fluid and cannot remain in position as a wall.

3. Factors Influencing Slope Stability

3.2 Water

- ***Angle of repose for DRY material*: usually lies between about 30–37° [increases with increasing grain size].**



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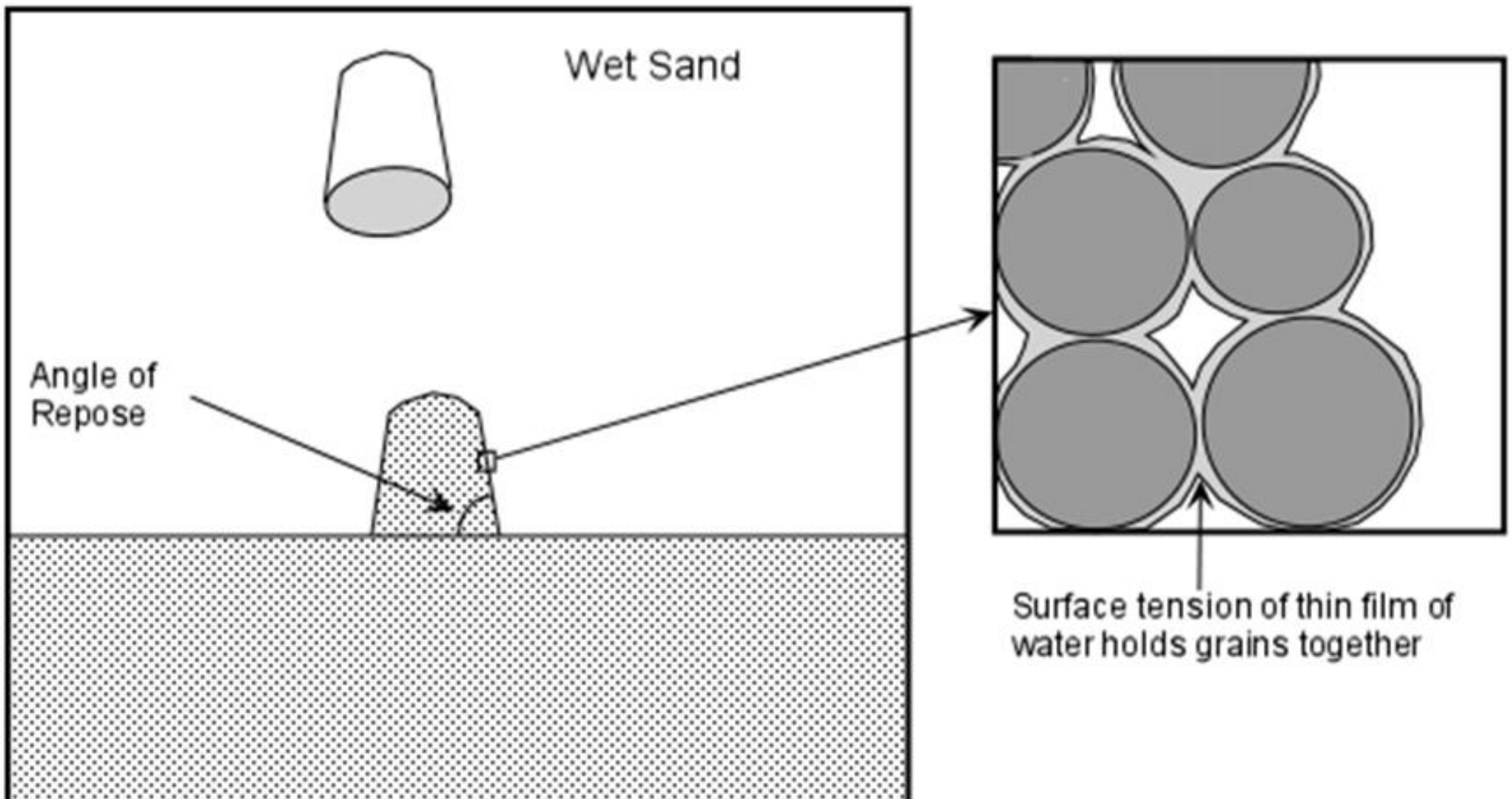
3. Factors Influencing Slope Stability

3.2 Water

- ***Angle of repose for SLIGHTLY WET unconsolidated materials*****: very high angle of repose** *[because surface tension between water & solid grains tends to hold the grains in place].*



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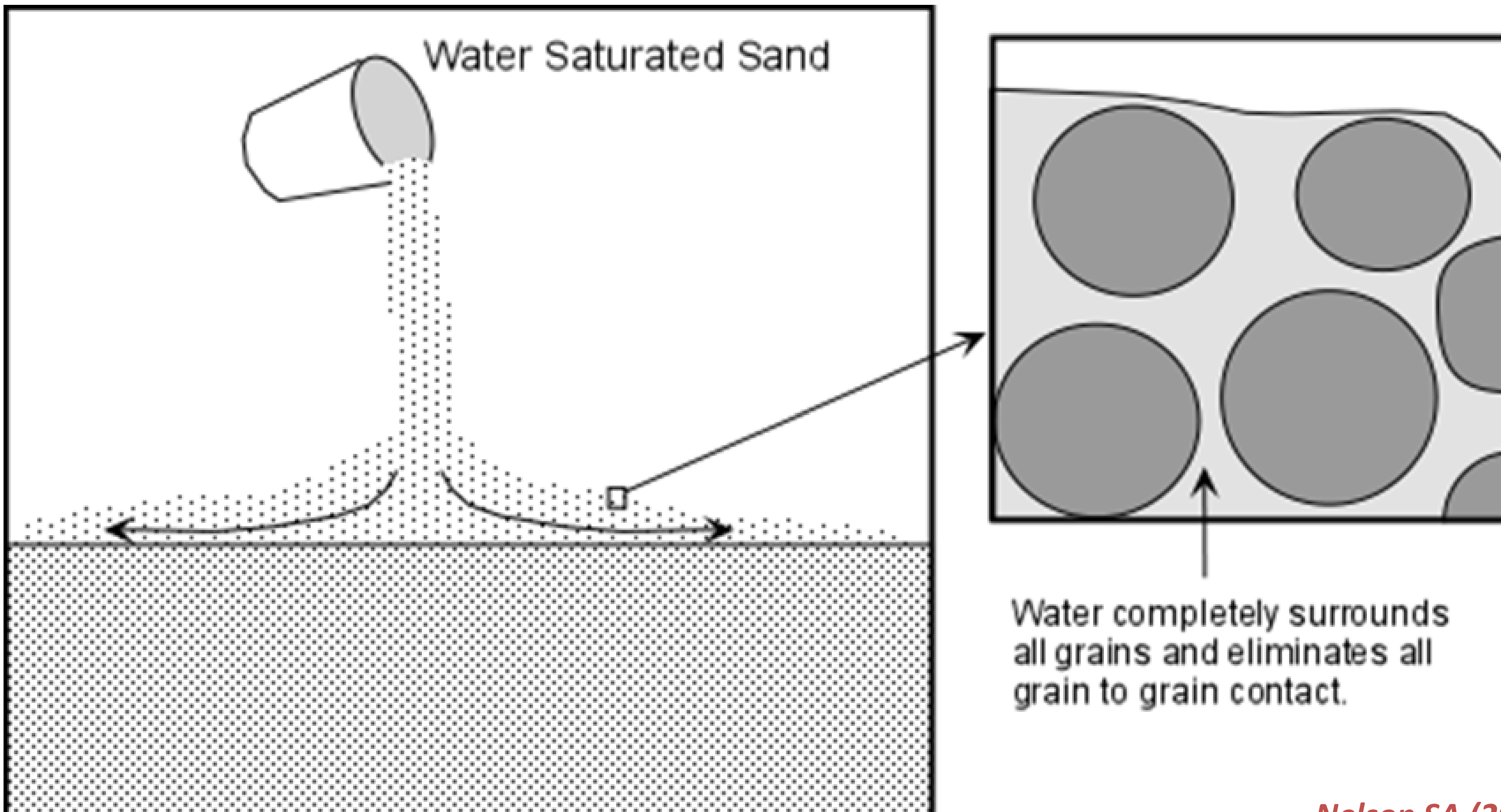
3. Factors Influencing Slope Stability

3.2 Water

- ***Angle of repose for material SATURATED WITH WATER*: very small values *[material tends to flow like a fluid]*.**



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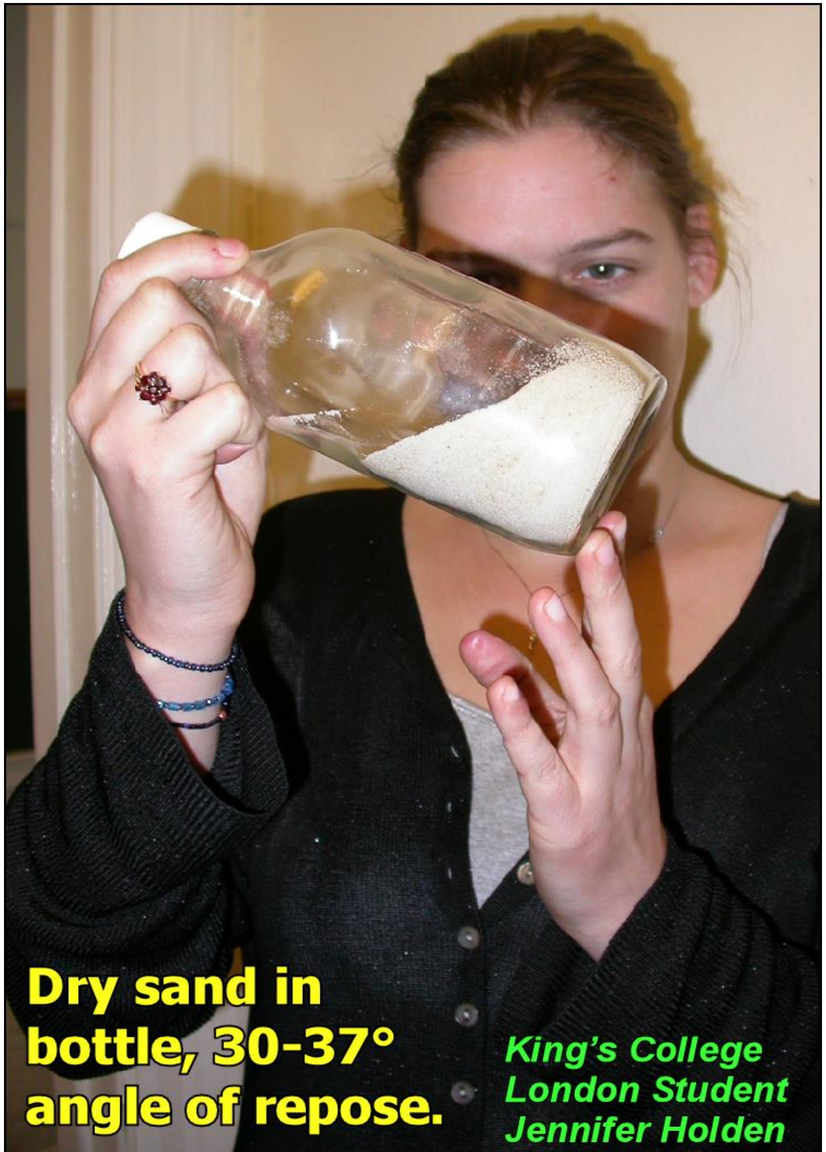
3. Factors Influencing Slope Stability

3.3 Inexpensive student demonstrations



What you need to do this demonstration: Bottle, sand and Water

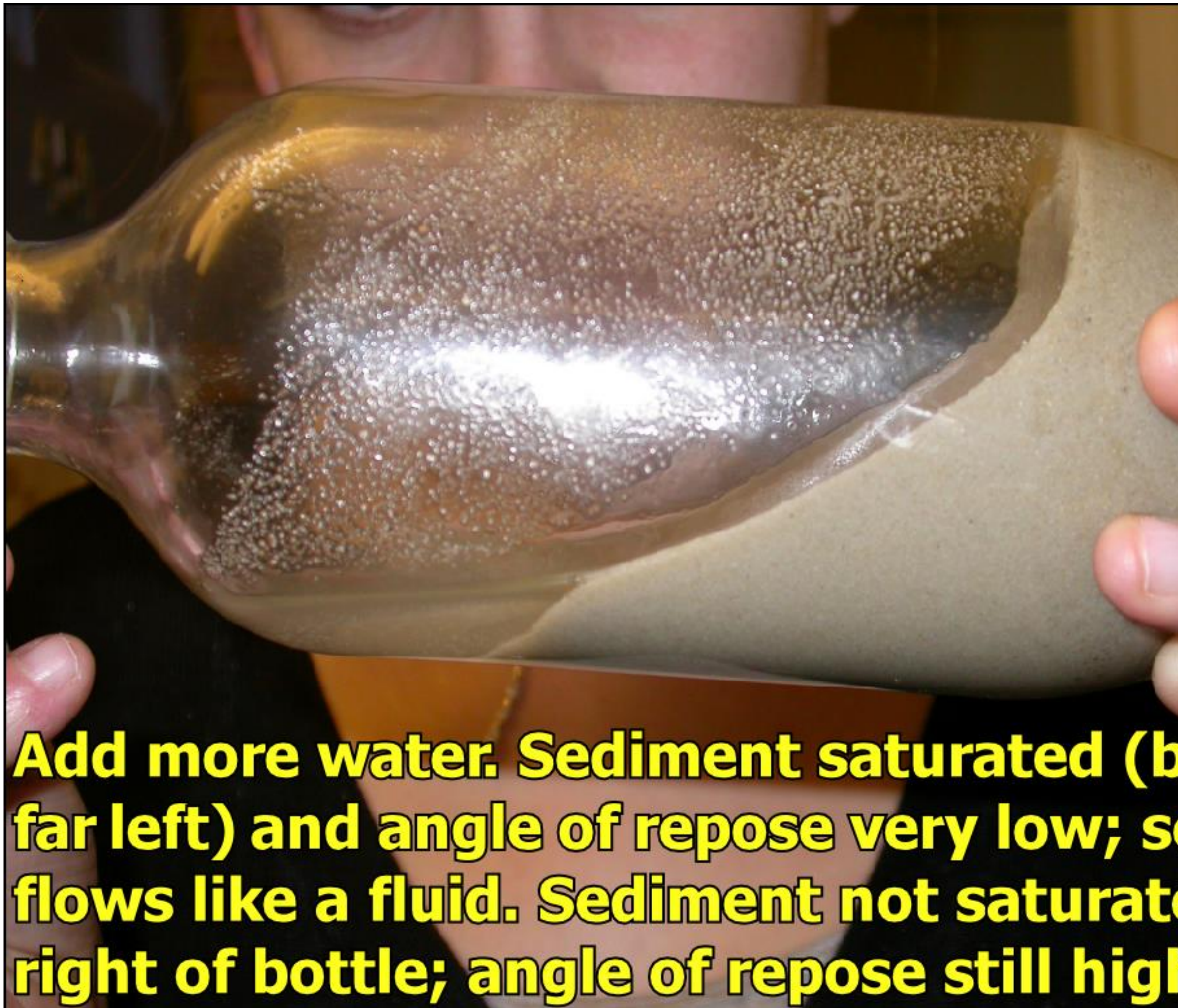
3. Factors Influencing Slope Stability

3.3 Inexpensive student demonstrations

Triggered Landslide Events

3. Factors Influencing Slope Stability

3.3 Inexpensive student demonstrations



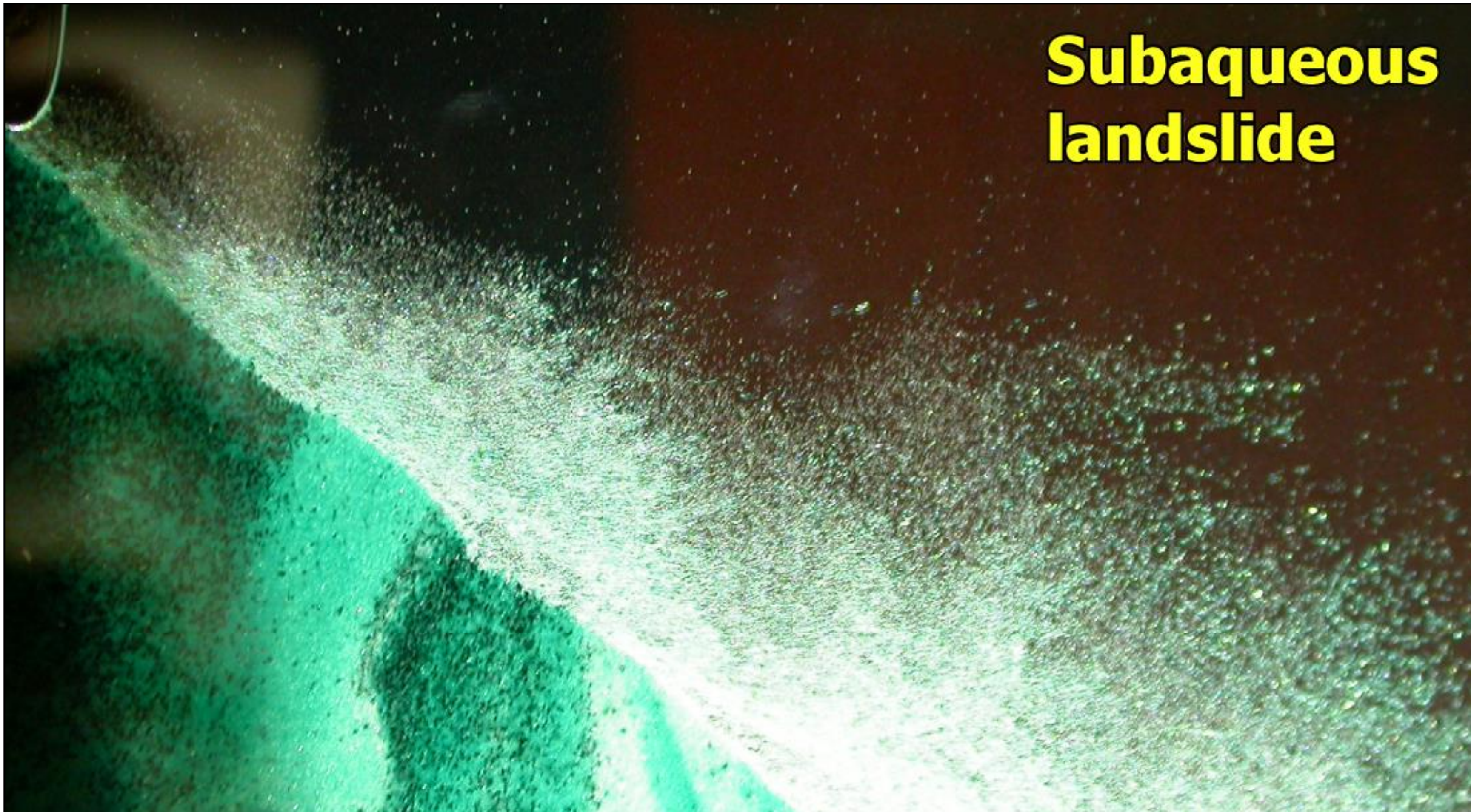
Add more water. Sediment saturated (bottle far left) and angle of repose very low; sediment flows like a fluid. Sediment not saturated in right of bottle; angle of repose still high.

3. Factors Influencing Slope Stability

3.3 Inexpensive student demonstrations

3. Factors Influencing Slope Stability

3.3 Inexpensive student demonstrations



Triggered Landslide Events

(See also Poster and Talk I have online: Natural Hazard Demonstrations for Teaching)

www.kcl.ac.uk/geography/people/academic/malamud/teaching.aspx

E-mail: bruce.malamud@kcl.ac.uk

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Triggered Landslide Events

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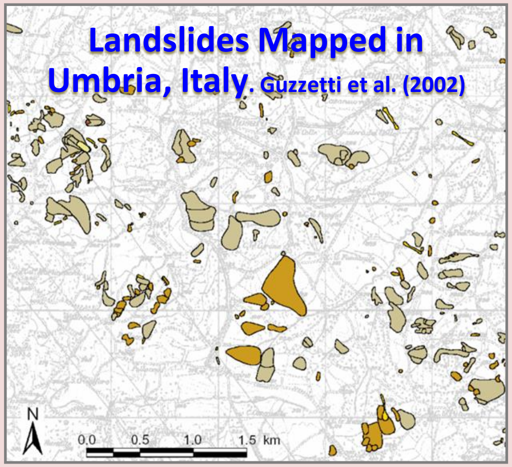

4. Triggered Landslide Events

4.1 Major Triggers

- **A mass-wasting event *can occur any time slope becomes unstable.***
- **Sometimes, as in *creep*, slope is unstable at all times and process is continuous.**
- **But other times, *triggers* can occur that cause a sudden instability to occur.**

4. Triggered Landslide Events

4.1 Major Triggers

EXAMPLES OF MAJOR TRIGGERS

- *Earthquakes* (major shock)
- *Heavy rainfall, Sudden Snowmelt*
  - changes in hydrologic conditions
  - reduce grain to grain contact, reducing angle of repose
  - saturate rock increasing its weight
- *Volcanic Eruptions*
  - shock like explosions
  - earthquakes
  - melting of snow
  - crater lakes empty

4. Triggered Landslide Events

4.1 Major Triggers

LANDSLIDES IN TRIGGERED EVENTS

Number: After a trigger, might be zero, one or many thousands of landslides that occur.

Time: Landslides occur in the minutes to weeks after the trigger occurs.

Areas: Landslide areas range over many orders of magnitude, from m^2 to km^2.

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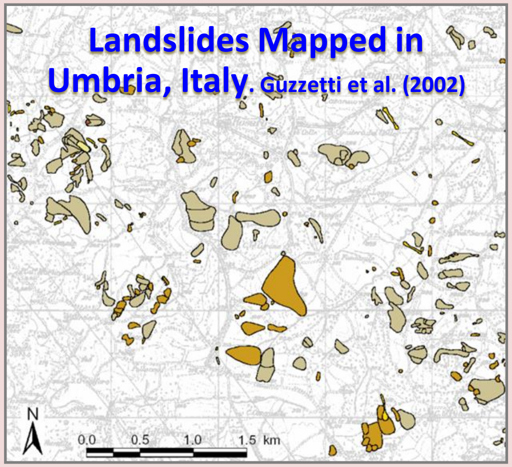


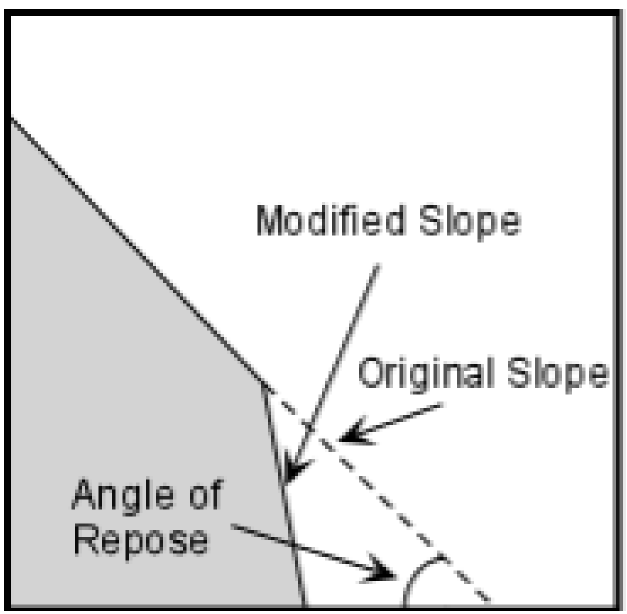
Landslides Mapped in Umbria, Italy. Guzzetti et al. (2002)

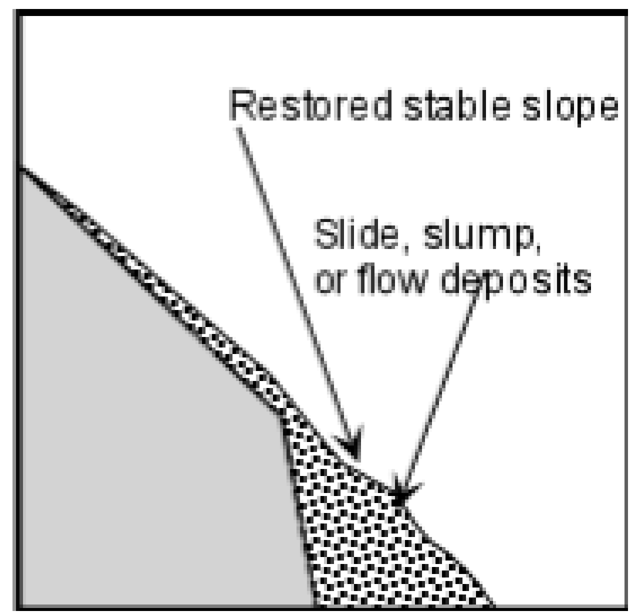
4. Triggered Landslide Events
4.2 Other Triggers of Landslides

➢ **OTHER EXAMPLES OF LANDSLIDE TRIGGERS:**

(i) SLOPE MODIFICATION.

- **By humans or by *natural causes*.**
- **Changes *slope angle* so no longer at angle of repose.**
- **A mass-wasting event can restore slope to its angle of repose.**





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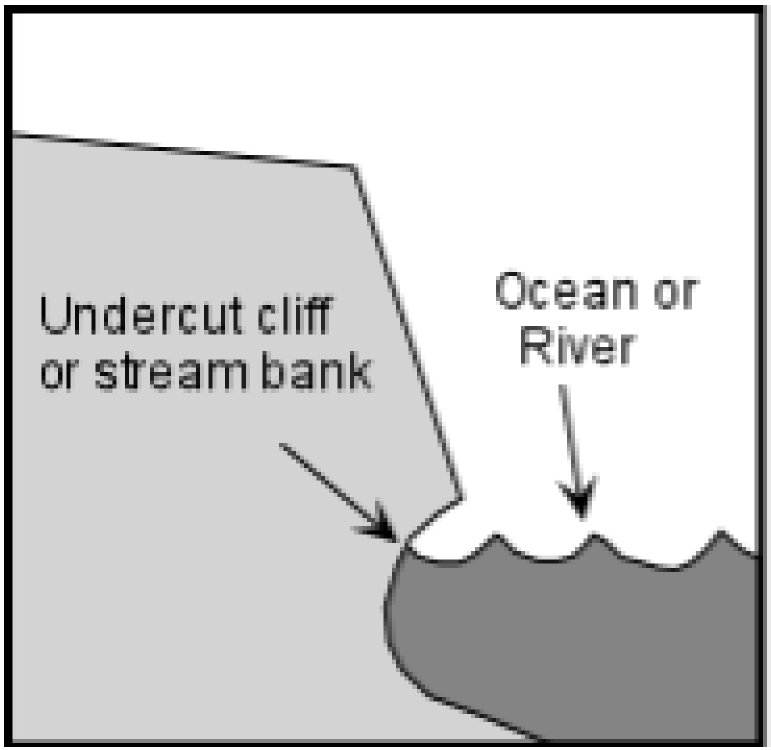
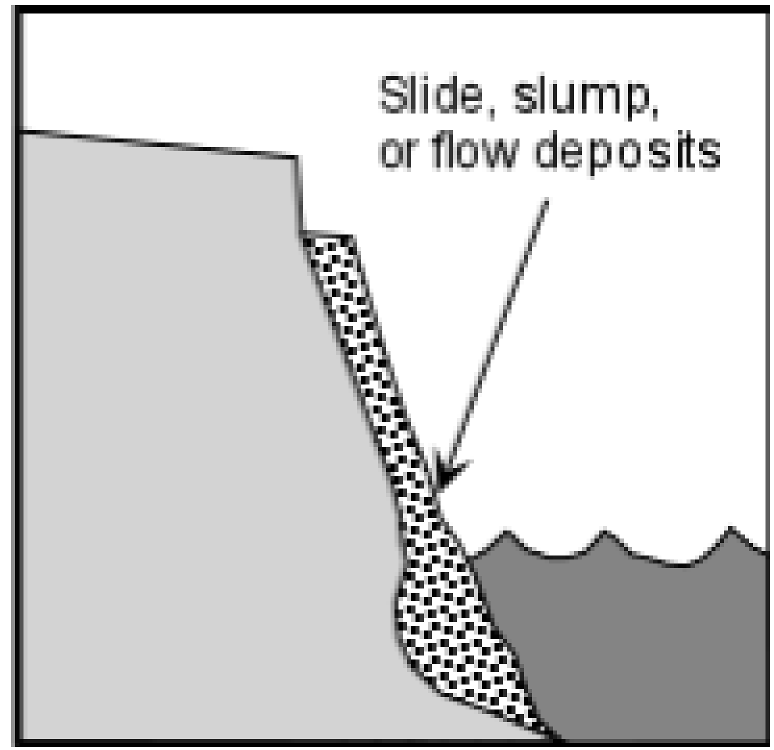
4. Triggered Landslide Events

4.2 Other Triggers of Landslides

➢ **OTHER EXAMPLES OF LANDSLIDE TRIGGERS:**

(ii) *UNDERCUTTING*





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4. Triggered Landslide Events
4.2 Other Triggers of Landslides

➢ ***OTHER EXAMPLES OF LANDSLIDE TRIGGERS:***

(iii) *FIRE* can cause *removal of vegetation*, resulting in the regolith becoming less fixed over time.

(iv) *ADDED MASS* can make a region more prone to mass wasting.

Examples

- **waste material**
- **mining tailings**
- **structures**
- **water leakage**

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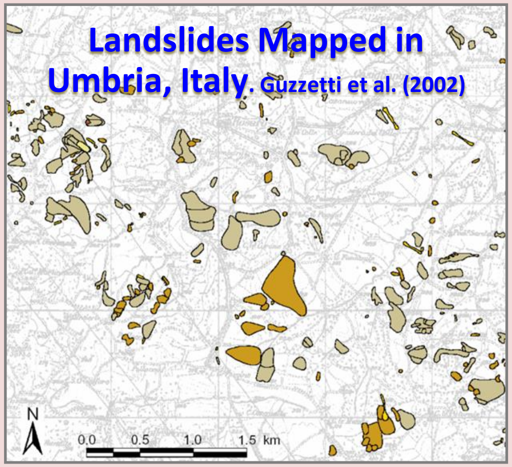

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4. Triggered Landslide Events

4.3 Examples of Triggered Landslide Events

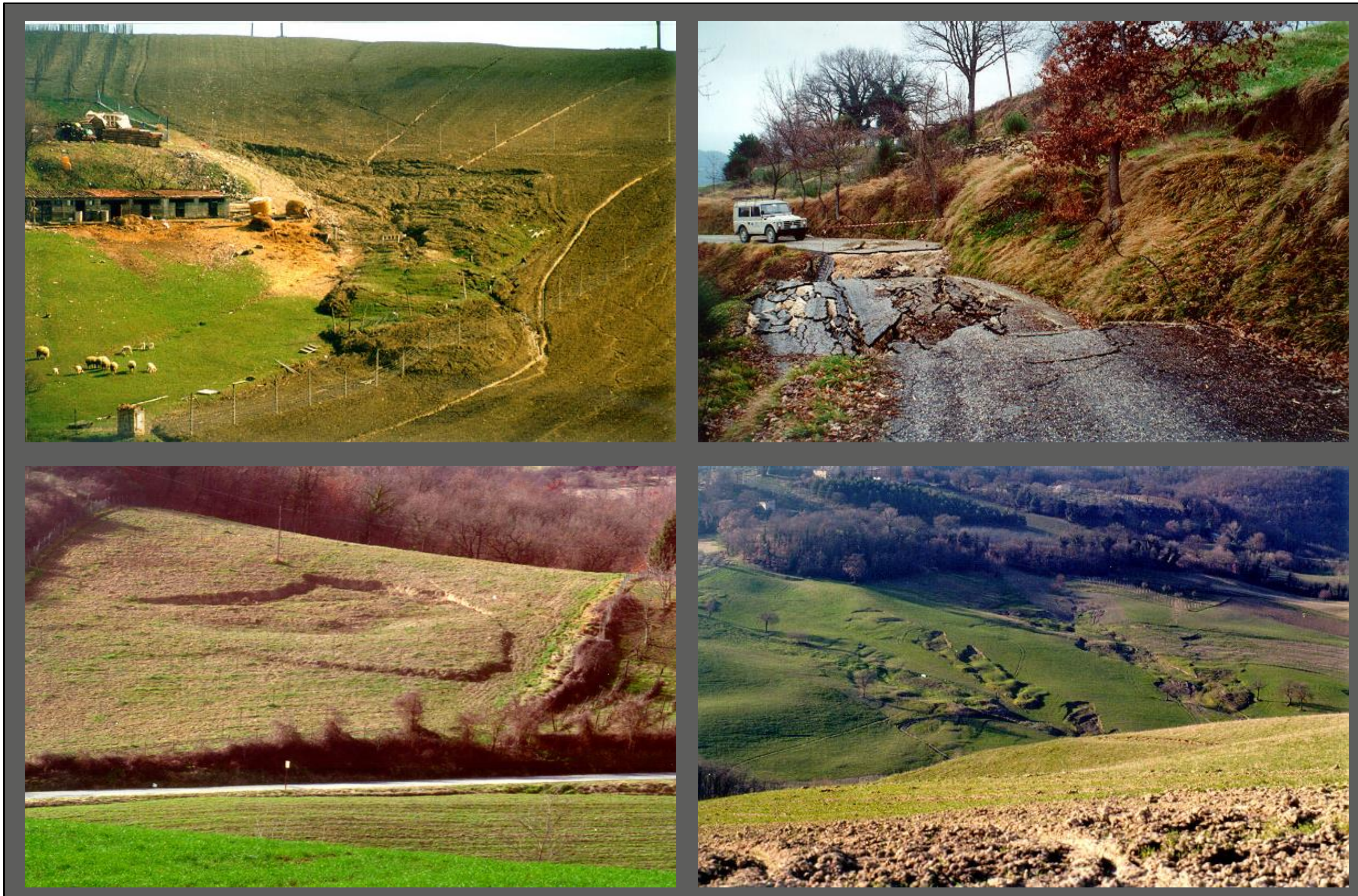
Location *[Trigger]*	**Study area** (km^2)	**# of landslides**	***Total area of landslides*** **(km^2)**
Umbria, Central Italy[a] [rapid snowmelt, 1/1/1997]	**2,000**	**4,233**	**12.7**
Northridge, California[b] [earthquake, 1/17/1994]	**10,000**	**11,111**	**23.8**
Guatemala[c] [heavy rainfall, 10–11/1998, Hurricane Mitch]	**10,000**	**9,594**[d]	**29.5**

a. **Guzzetti *et al.* (2002) *Earth Plan. Sci. Lett.***

b. **Harp and Jibson (1995) *USGS Open File Rep.***

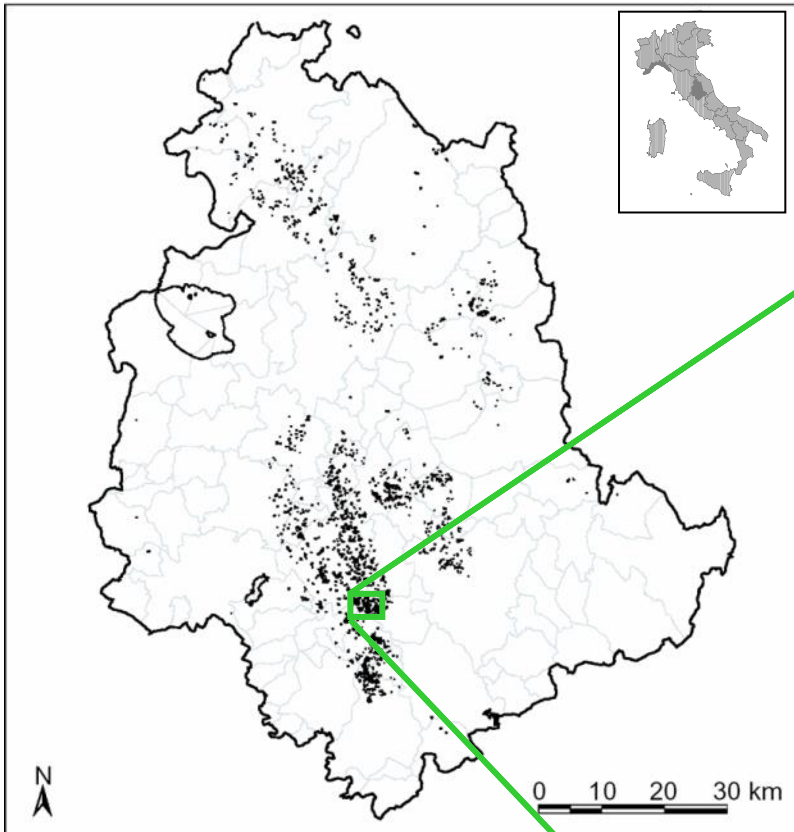
c. **Bucknam *et al.* (2001) *USGS Open File Rep.***

Landslides Triggered by Rapid Snow-Melt Jan 1997, Umbria Region, Italy

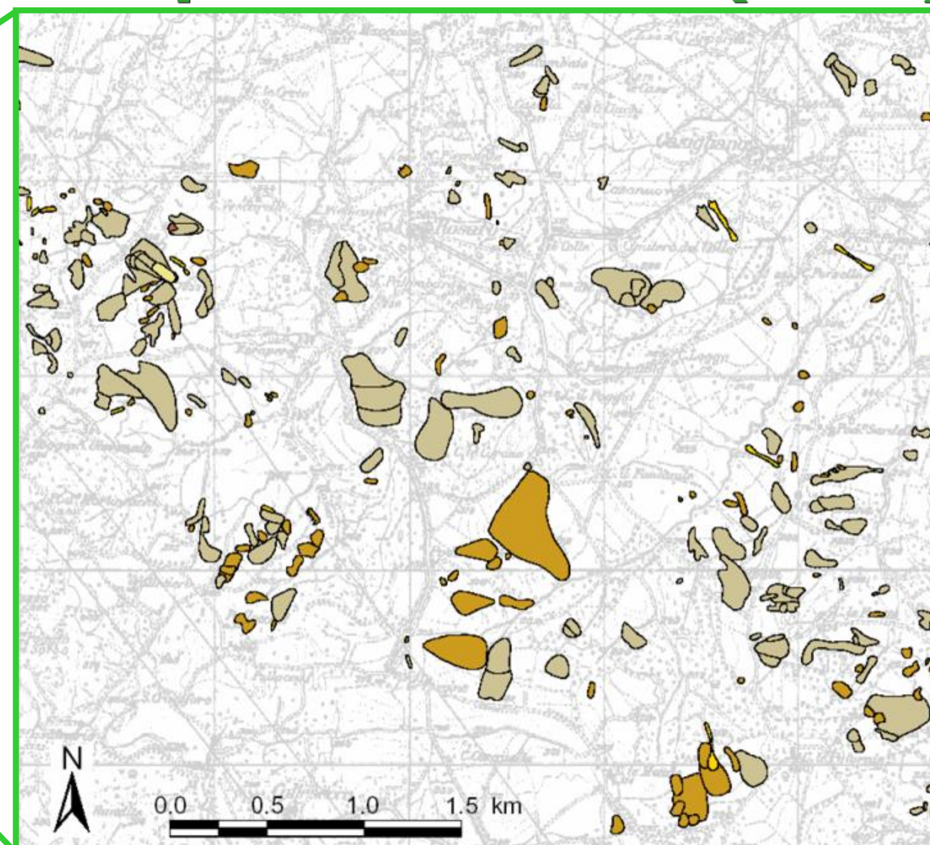


Guzzetti *et al.* (2002) *EPSL*

Landslides Triggered by Rapid Snow-Melt Jan 1997, Umbria Region, Italy



Shallow soil-slips (53%)
Slump earth-flows (9%)
Deep-seated slides (38%)



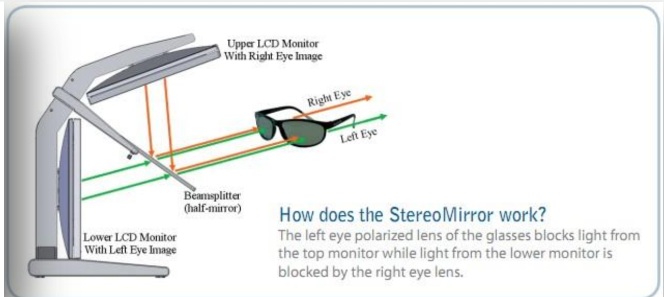
4,233 landslide areas

Guzzetti *et al.* (2002) *EPSL*

STEREOSCOPES

Mirror, Double stereoscope

HARDWARE AND SOFTWARE VISUALIZATION SYSTEM

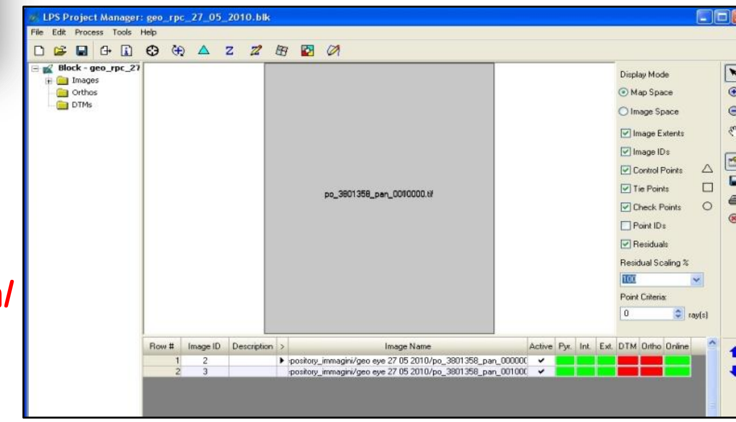


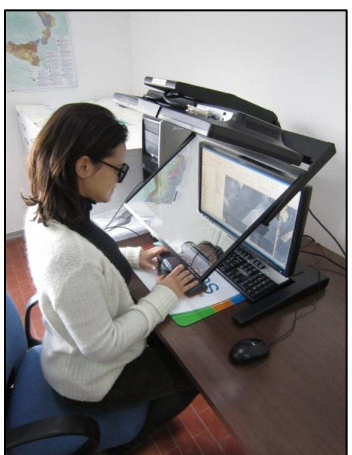
http://www.planar3d.com/

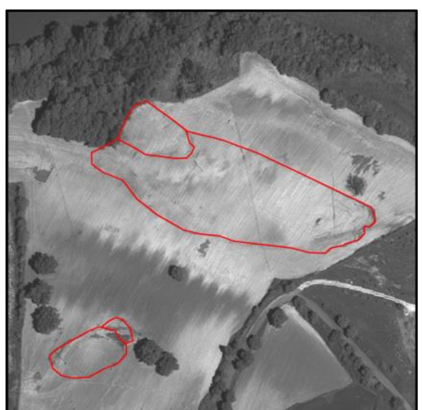
Planar StereoMirror™ HW to obtain 3-D view.

ERDAS IMAGE®, Leica Photogrammetry Suite (LPS) SW to obtain block orientation.

http://www.erdas.com/



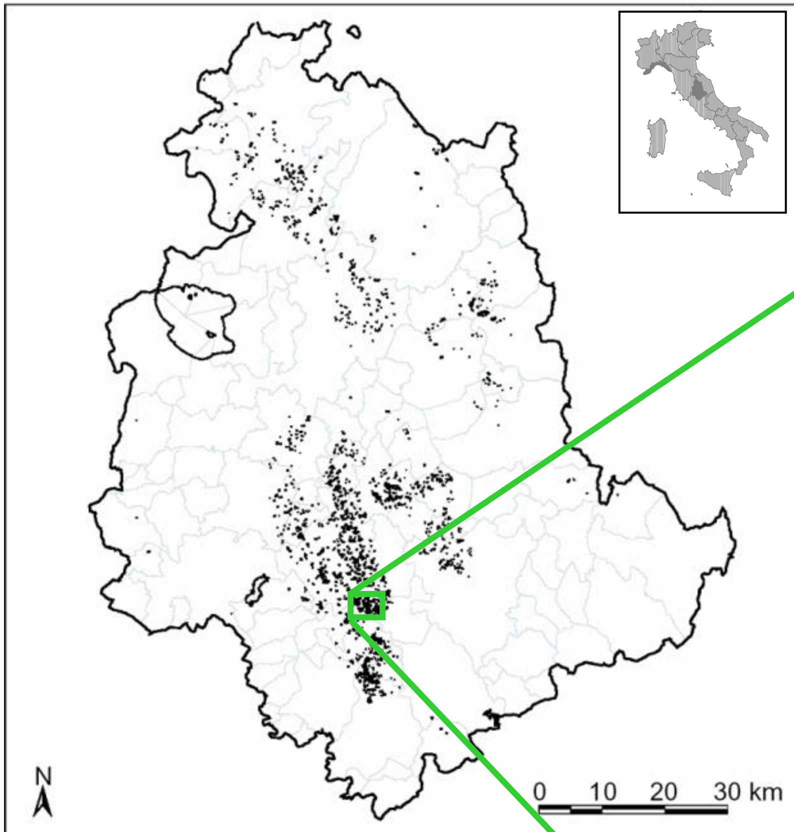




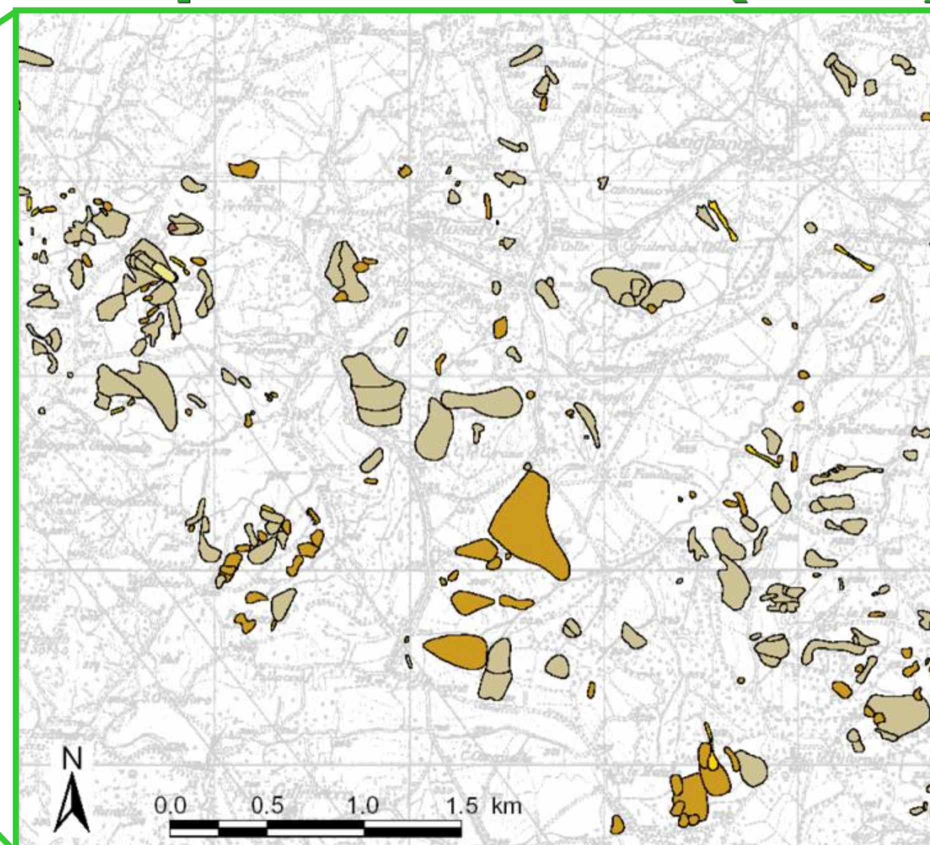
Stereo Analyst for ArcGIS® SW for 3-D visualization of large area, landslide mapping and features storing directly in a GIS database.

Slide Courtesy of CNR-IRPI (www.irpi.cnr.it)

Landslides Triggered by Rapid Snow-Melt Jan 1997, Umbria Region, Italy



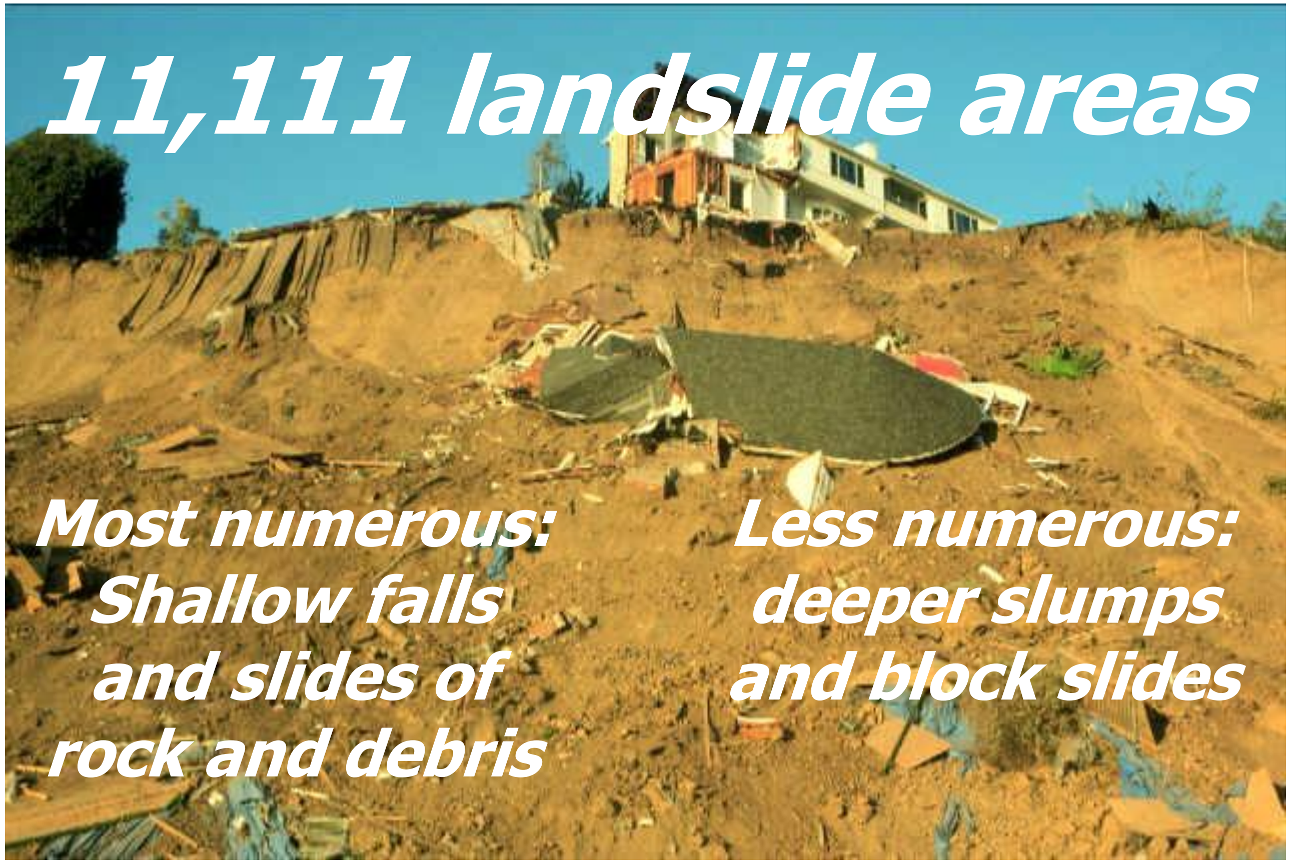
Shallow soil-slips (53%)
Slump earth-flows (9%)
Deep-seated slides (38%)



4,233 landslide areas

Guzzetti *et al.* (2002) *EPSL*

INVENTORY OF LANDSLIDES TRIGGERED BY THE 1994 NORTHRIDGE, CALIFORNIA EARTHQUAKE



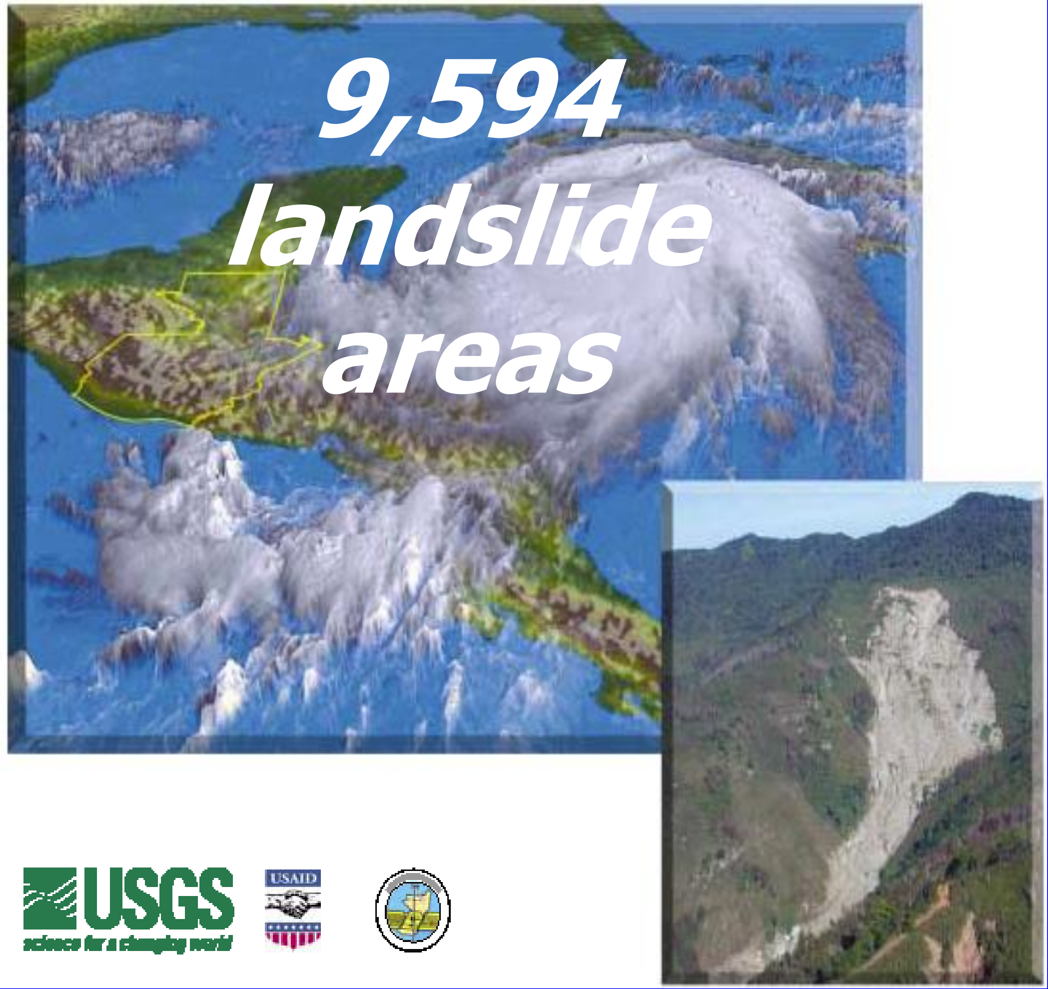
OPEN-FILE REPORT 95-213

Edwin L. Harp and Randall W. Jibson

DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Landslides Triggered by Hurricane Mitch in Guatemala – Inventory and Discussion

by RC Bucknam,
JA Coe,
MM Chavarria,
JW Godt,
AC Tarr,
LA Bradley,
S Rafferty,
D Hancock,
RL Dart, *and*
ML Johnson



Open-File Report 01-443 **2001**

U.S. Department of the Interior
U.S. Geological Survey

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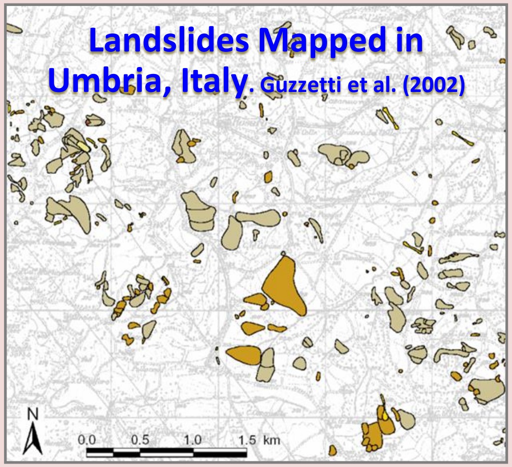
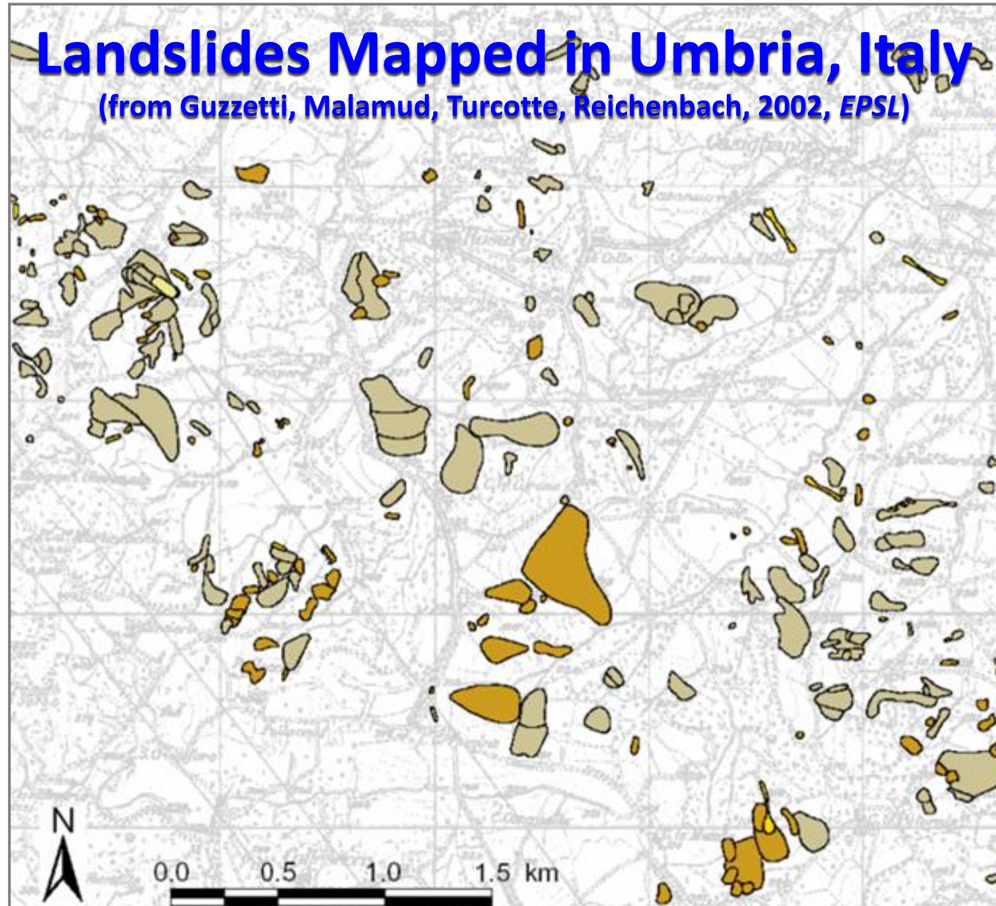


4. Triggered Landslide Events
4.4 Frequency-Size Statistics

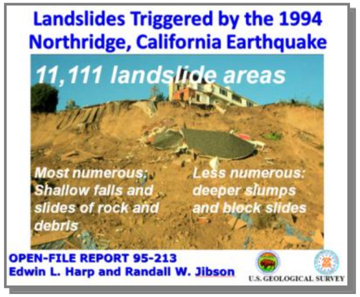
Examine number of landslides with sizes:

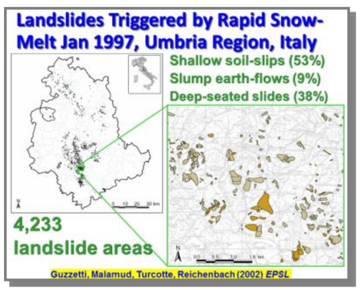
- ❑ *Very Small*
- ❑ *Small*
- ❑ *Medium*
- ❑ *Large*
- ❑ *Very Large*

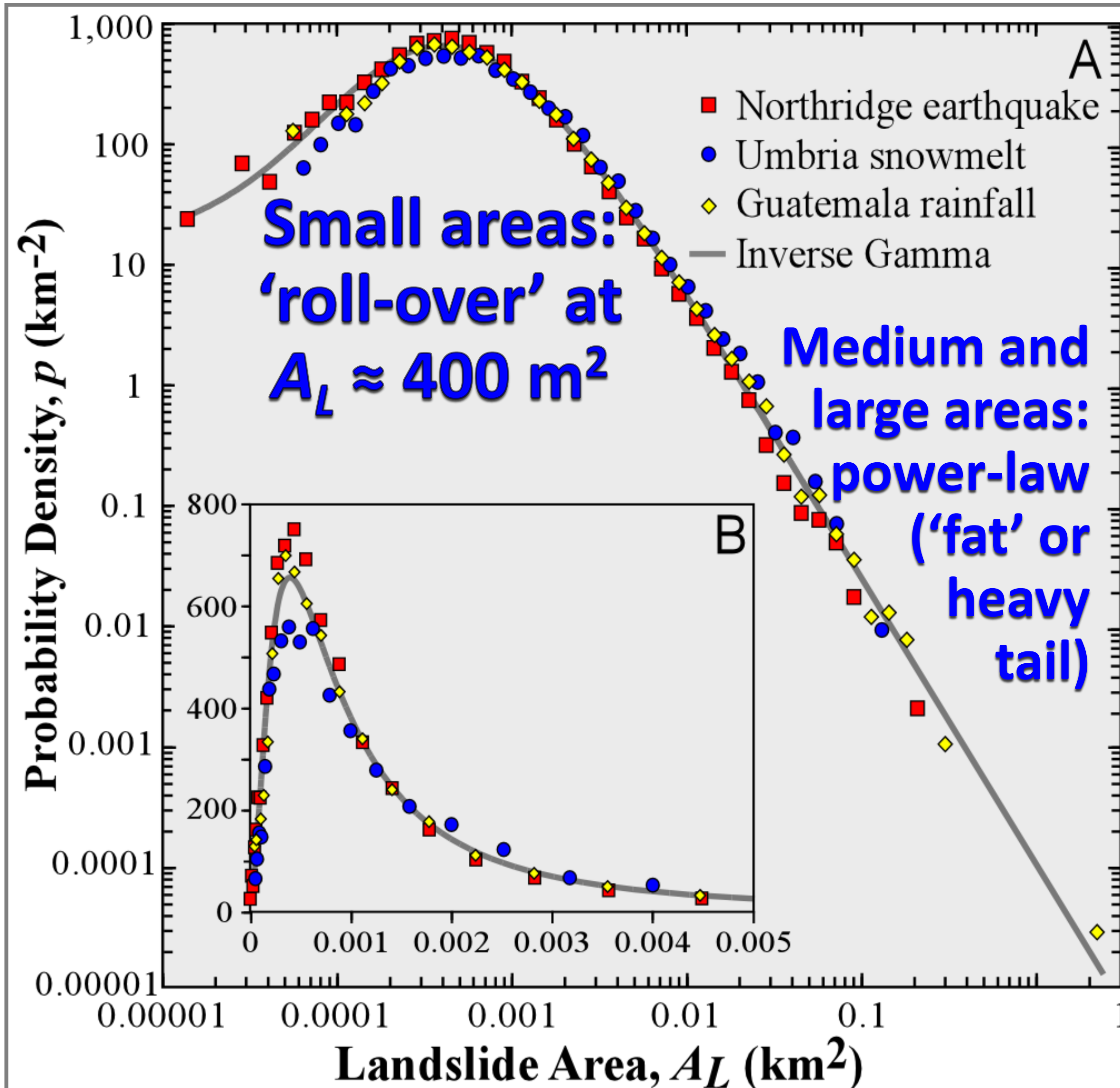


4. Triggered Landslide Events

4.4 Frequency-Size Statistics







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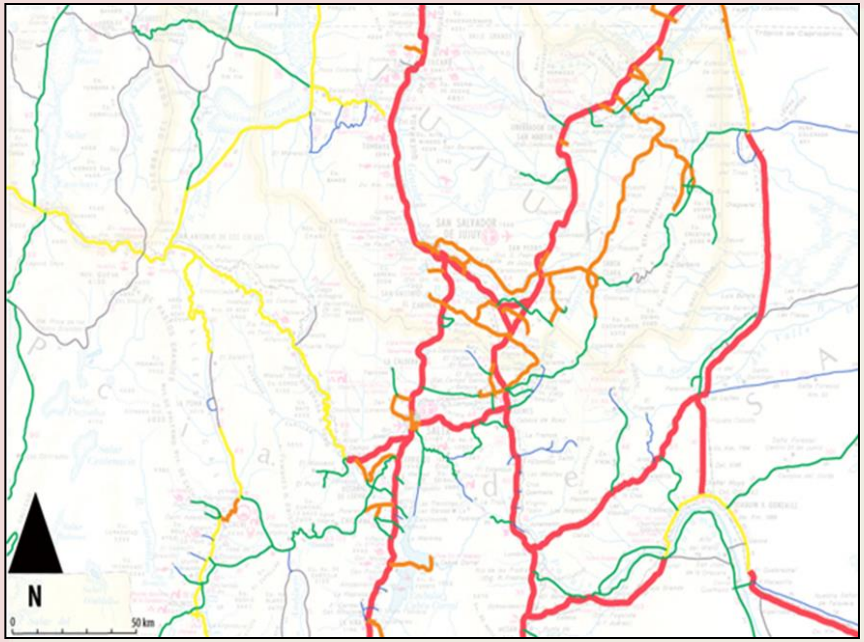


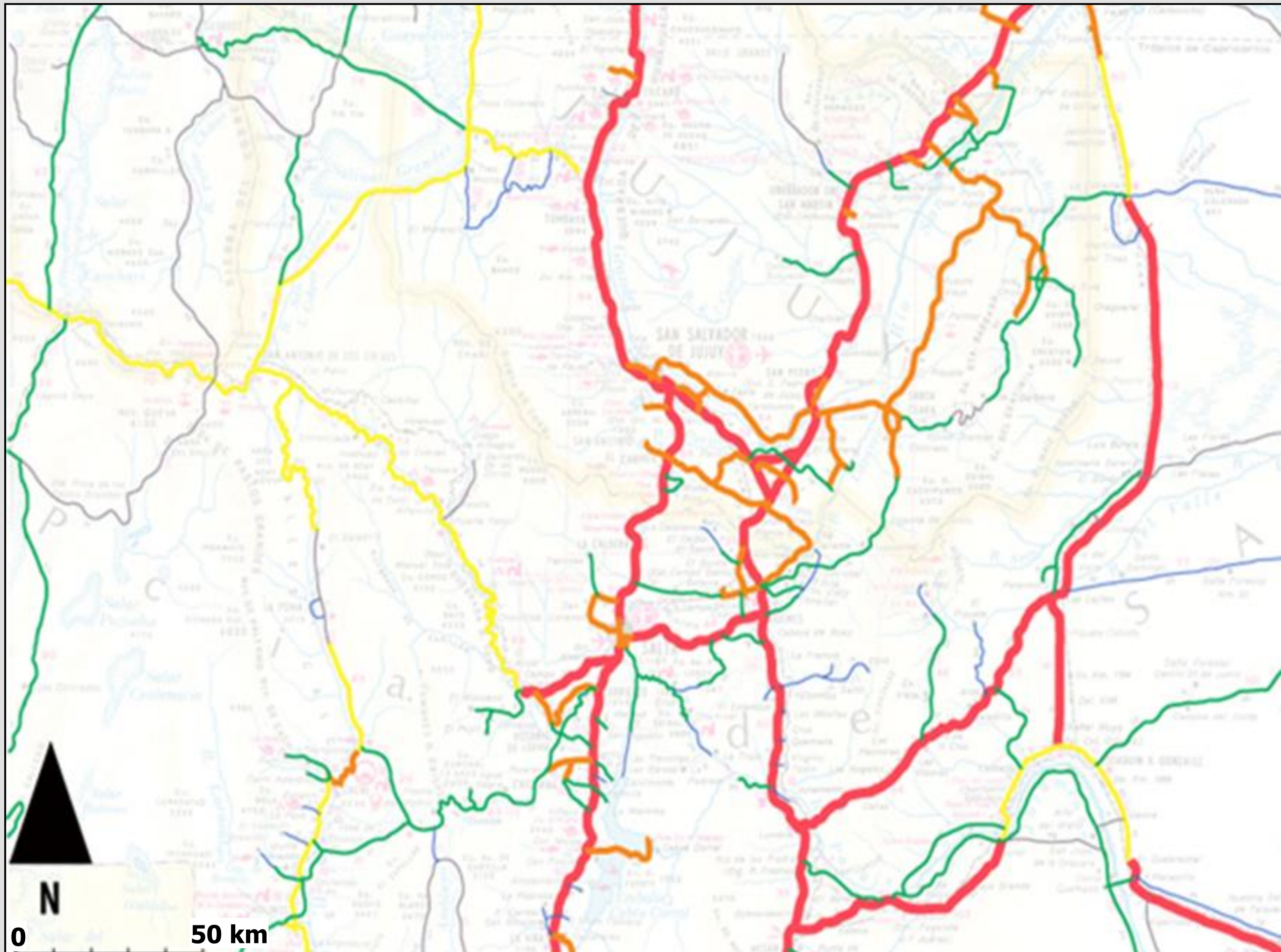
5. Triggered Events & Road Networks

(Research with *PhD Student* Faith Taylor)

Landslides (Mass Wasting)

Current Research: The intersection of landslides with road networks (NERC funded PhD student in 2nd year, Faith Taylor).

- Principal Paved Roads
- Secondary Paved Roads
- Primary unpaved roads
- Secondary unpaved roads
- Tracks
- Other



Road Network from Salta Province, NW Argentina

Figures: courtesy of Faith Taylor.

Landslides (Mass Wasting)

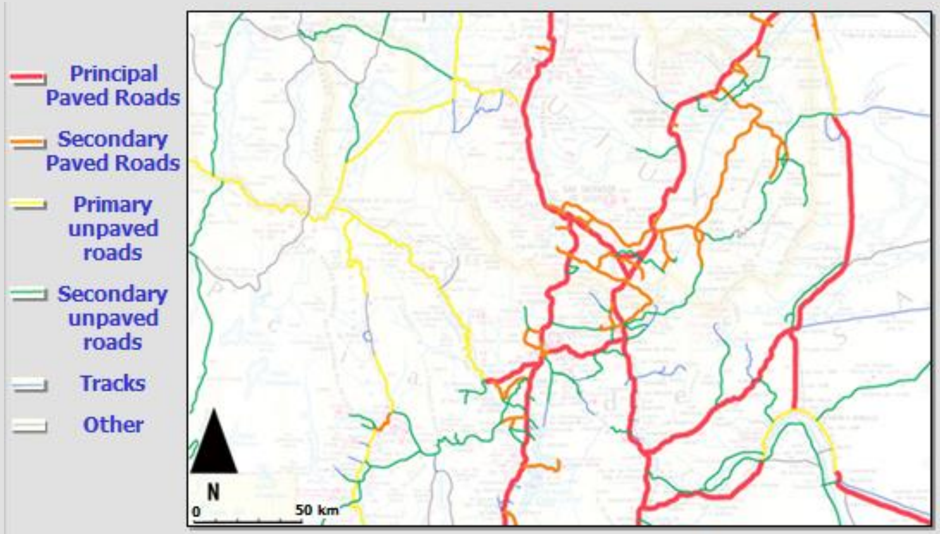
Current Research: The intersection of landslides with road networks (NERC funded PhD student in 2nd year, Faith Taylor).

Route 14, Utah, USA after a landslide destroyed 400 m of road.
(Image: MSNBC Photoblog, 2011)

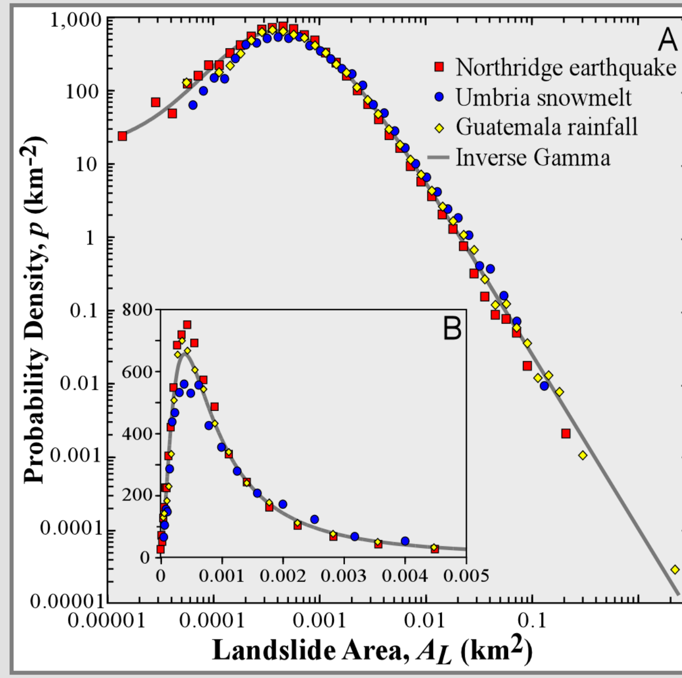
Attabad Landslide (Jan 2010), Karakoram Highway.
(Image: Parmir Times, 2010)

Landslides (Mass Wasting)

Current Research: The intersection of landslides with road networks (NERC funded PhD student in 2nd year, Faith Taylor).



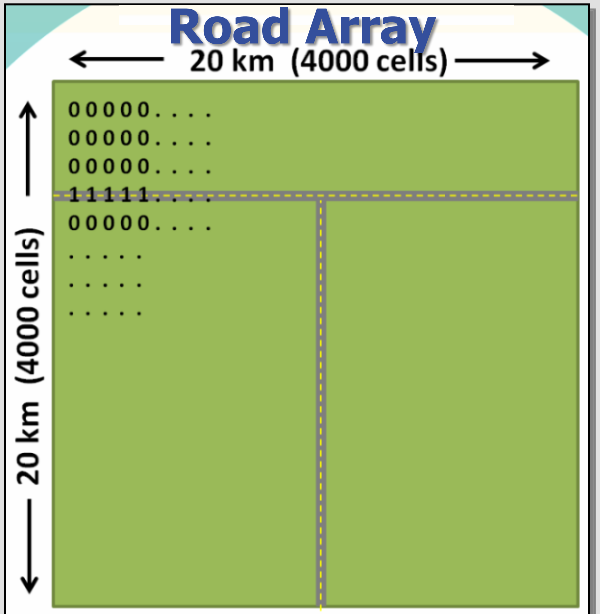
Road Network from Salta Province, NW Argentina



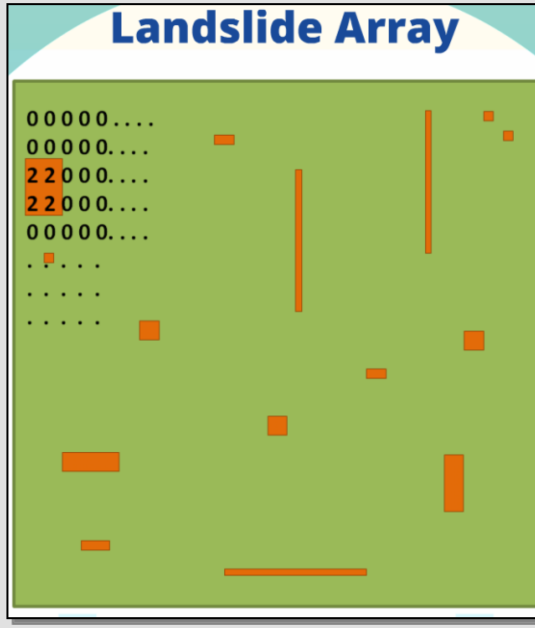
Create a computer model to randomly drop landslides on road networks.

Use ‘general’ probability distribution for landslide areas.

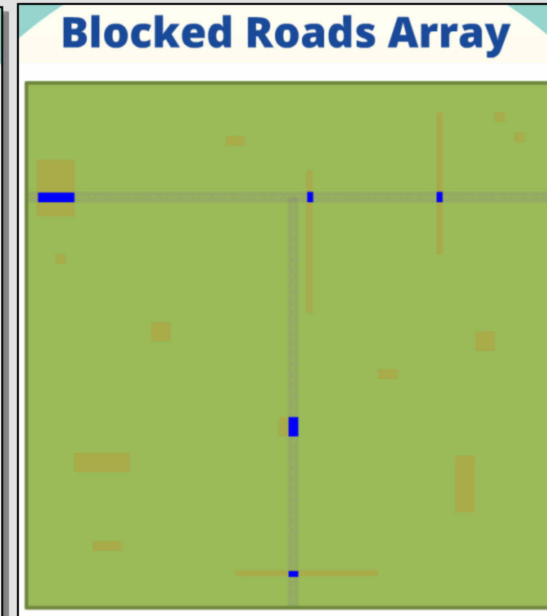
Current Research: The intersection of landslides with road networks (NERC funded PhD student in 2nd year, Faith Taylor).



- 4000 x 4000 cell array
- 5 m x 5 m cell 'resolution'
- 20 km x 20 km study region



- Landslide areas from **'general' landslide probability distribution.**
- 200–800 landslides.
- Variable length to width ratio



- Location, number, and size of road blockages.

Figures: courtesy of Faith Taylor.

Landslides (Mass Wasting)

Current Research: The intersection of landslides with road networks (NERC funded PhD student in 2nd year, Faith Taylor).

Run model thousands of times ('Monte Carlo' simulations).

Vary length of Road Network

Vary landslide density

Model in Python/GRASS

Future: Add more 'reality'.

- 20 km x 20 km study region

distribution.
- 200–800 landslides.
- Variable length to width ratio

blockages.

Figures: courtesy of Faith Taylor.

Figures: courtesy of Faith Taylor.

Current Research: The intersection of landslides with road networks (NERC funded PhD student in 2nd year, Faith Taylor).

16 km (approx.)

Example from Collazone, Italy

A. 'Real' Road Network

B. 'Simulated' Landslides

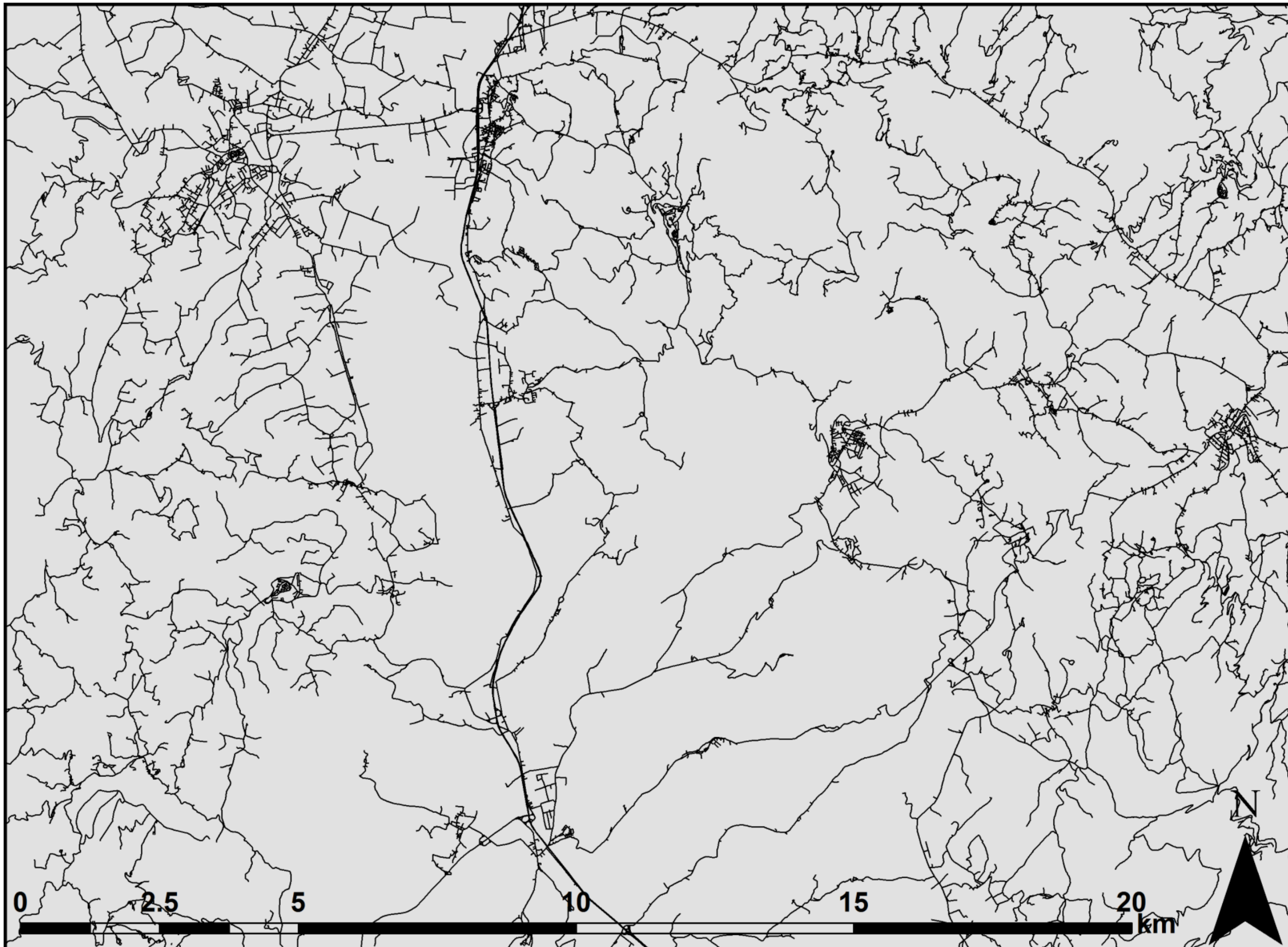
C. Road Network, Simulated Landslides, & Resulting Road Blockages

D. Just Resulting Road Blockages

25 km (approx.)

N

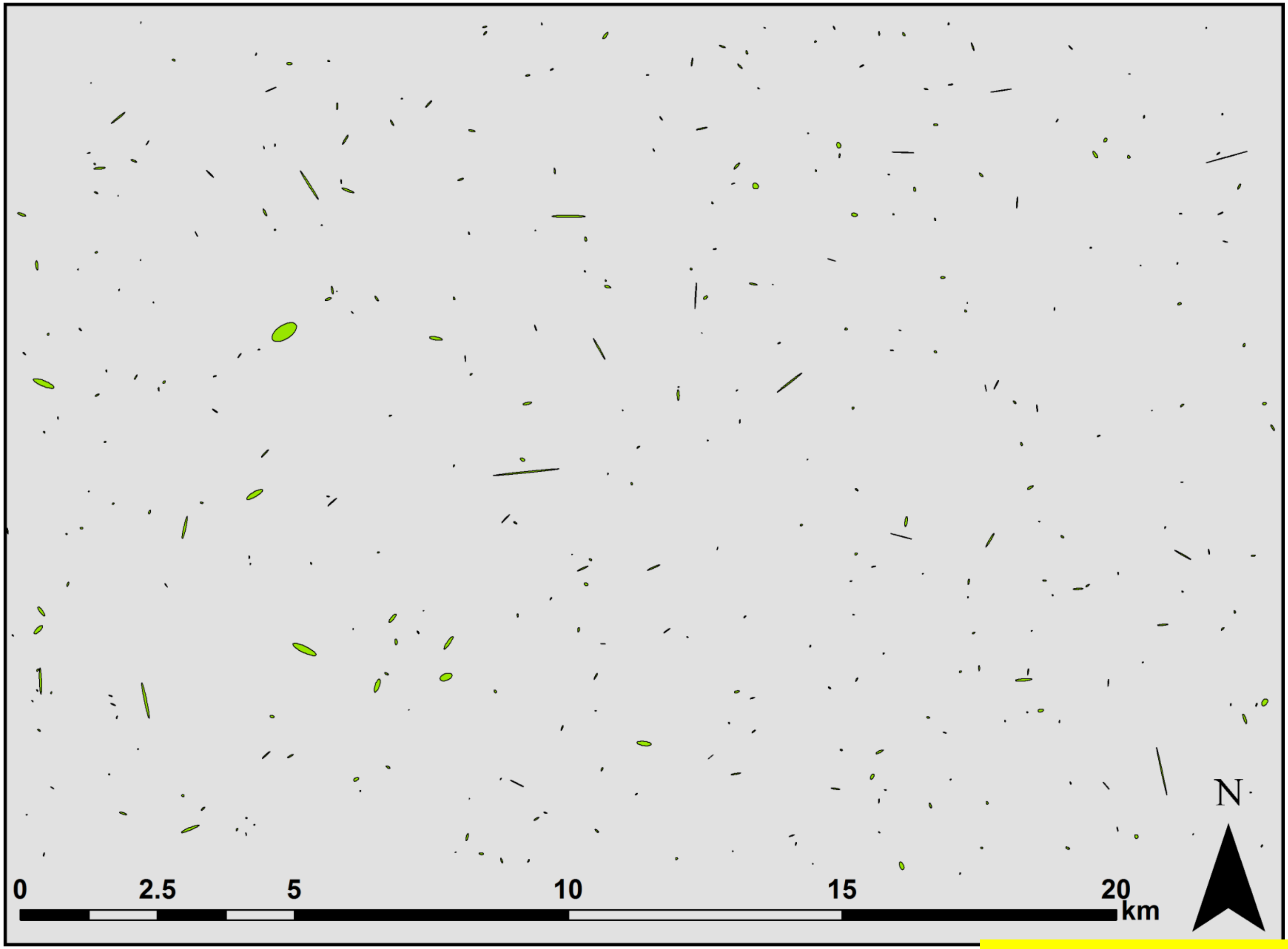
A. Collazone (Italy) Road Network 1359 km of roads



Figures: courtesy of Faith Taylor.

Landslides (Mass Wasting)

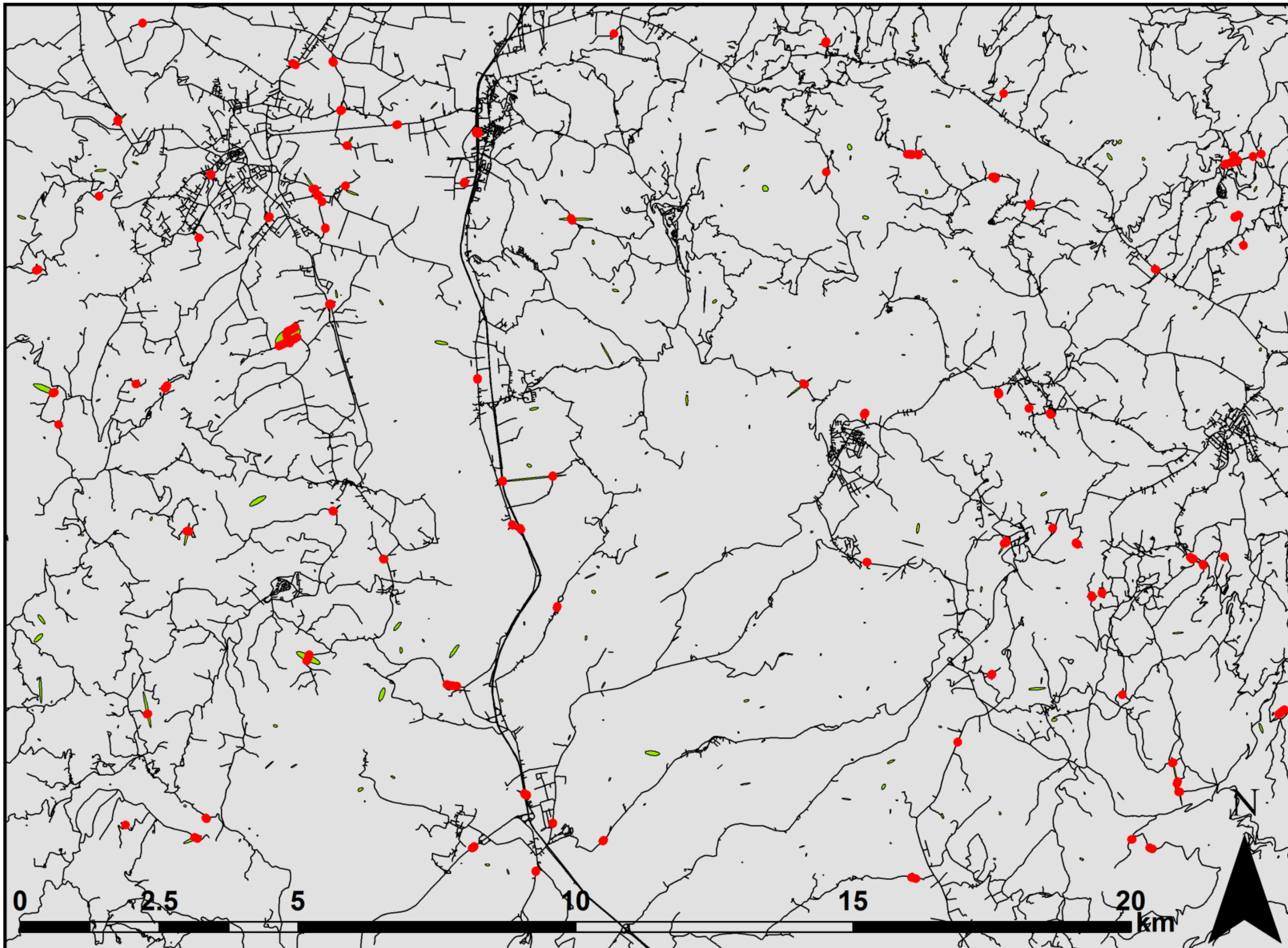
B. 'Simulated' landslides (400)



Figures: courtesy of Faith Taylor.

Landslides (Mass Wasting)

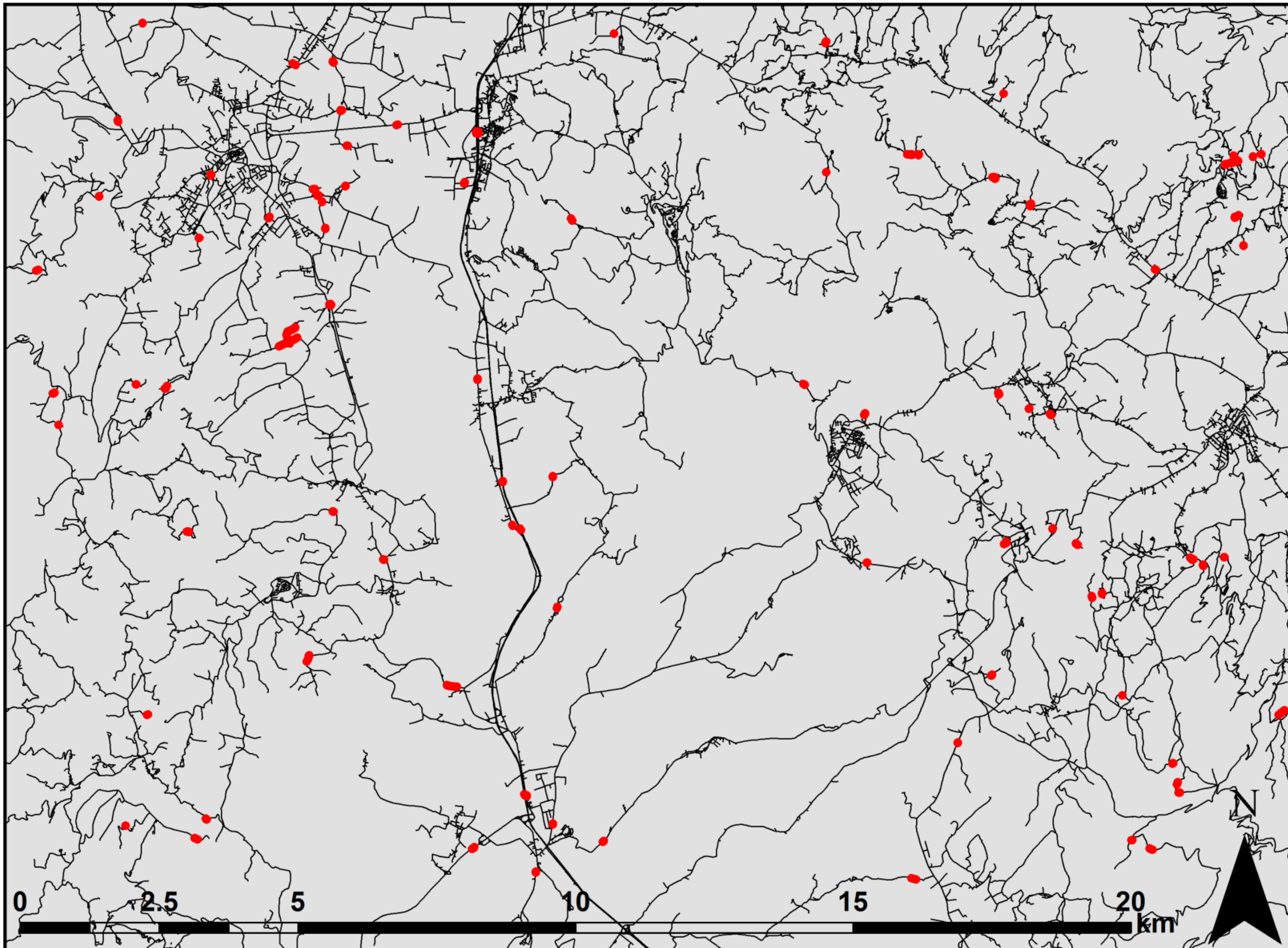
C. Collazone Road Network, Simulated Landslides & 108 Resulting Road Blockages



KING'S College LONDON

Landslides (Mass Wasting)

D. Collazone Road Network, & 108 Resulting Road Blockages



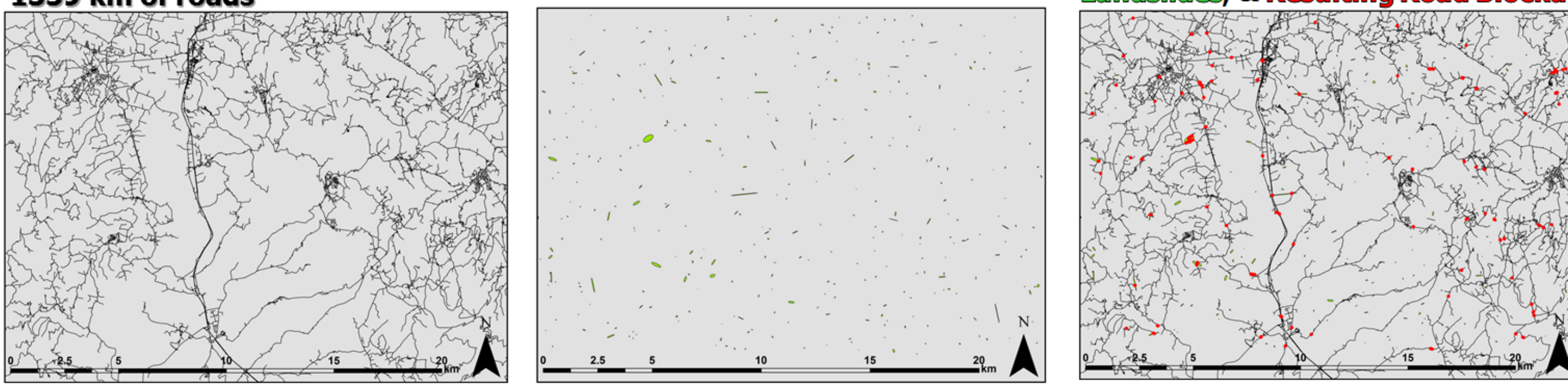
Figures: courtesy of Faith Taylor.

KING'S College LONDON

Landslides (Mass Wasting)

Collazone (Italy) Simulation of Landslides Interacting with Road Networks

A. Collazone (Italy) Road Network 1359 km of roads | **B. 'Simulated' landslides (400)** | **C. Collazone Road Network, Simulated Landslides, & Resulting Road Blockages**



- **400 km^2 region, 1359 km of roads.**
- **400 'simulated' landslides dropped.**
- **On average: One landslide blocked road for every 12.5 km of roads.**
- **Event of similar magnitude (Guzzetti *et al.*, 2003): 1 landslide per 13 km of roads.**

Figures: courtesy of Faith Taylor.

KING'S College LONDON

VIDEO of Collazone (Italy) Simulation of Landslides Interacting with Road Networks

25 km (approx.)

Video: courtesy of Faith Taylor.

25 km (approx.)

Video: courtesy of Faith Taylor.

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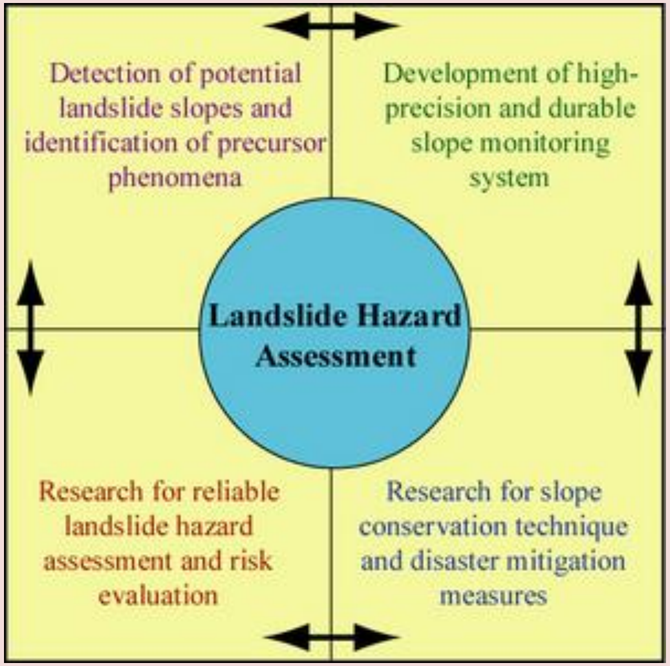


http://www.unicaen.fr/mountainrisks/spip/spip.php?article11

6. Hazard Assessment of Mass Wasting

- **Mass-wasting events can be extremely hazardous and result in extensive loss of life and property.**
- **In most cases:**

  (i) ***Areas prone to such hazards can be recognized with some geologic knowledge.***

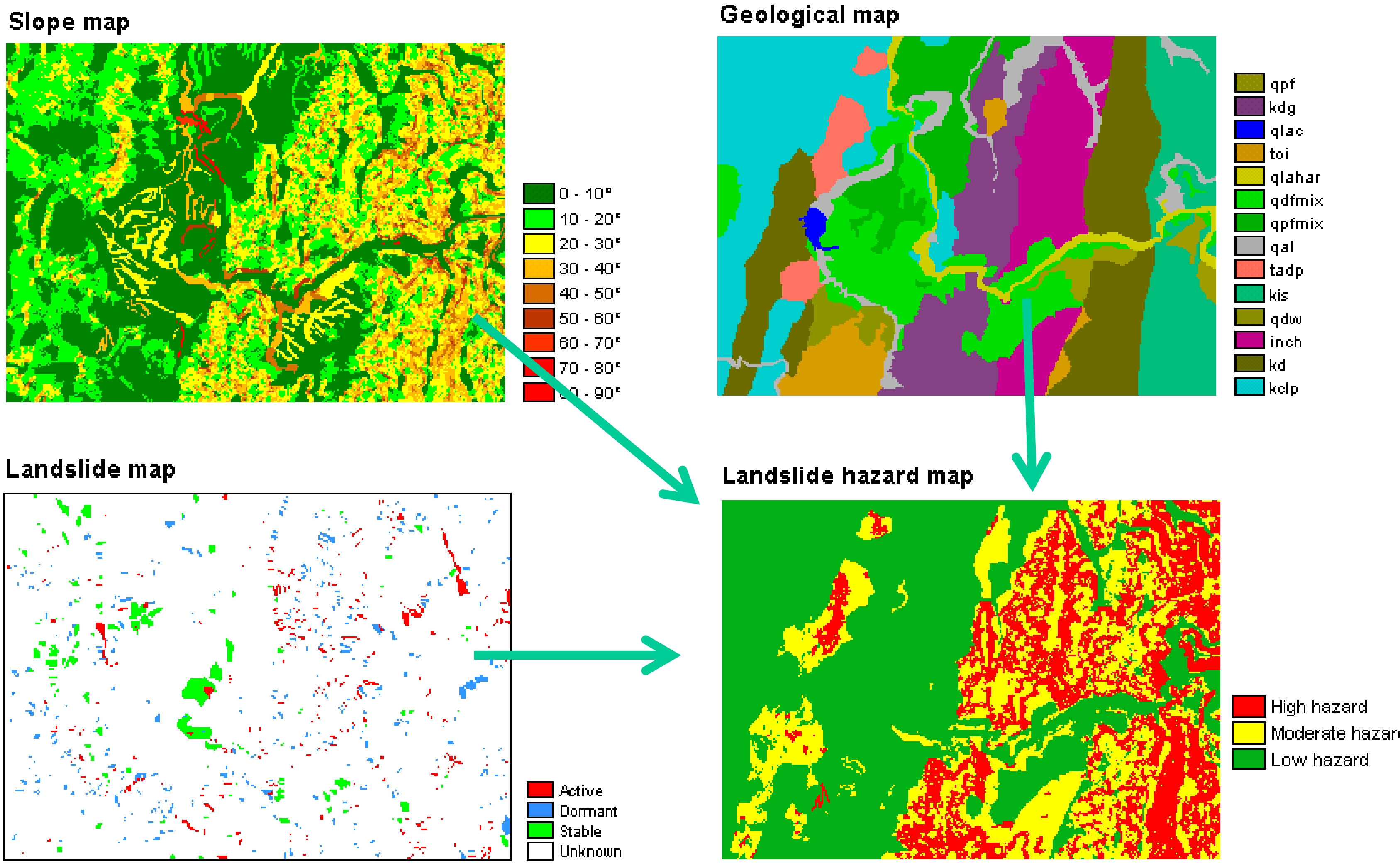
  (ii) ***Slopes can be stabilized or avoided.***

  (iii) ***Warning systems can be put in place that minimize the hazard.***

Landslides (Mass Wasting)

6. Hazard Assessment of Mass Wasting

Chinchiná area, department of Caldas, central Colombia



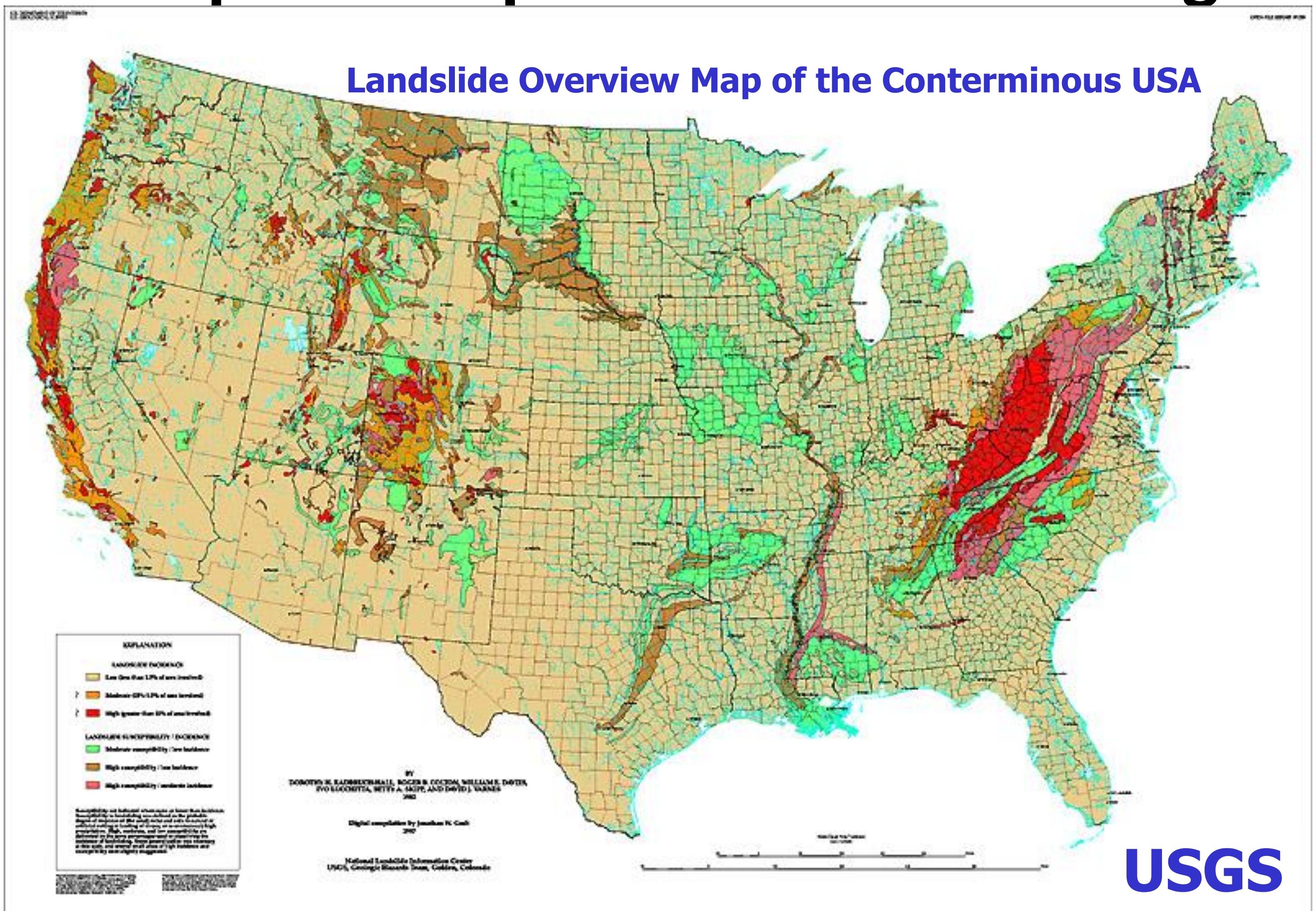
(http://www.itc.nl/ilwis/applications/application05.asp)

6. Hazard Assessment of Mass Wasting

- ***Many case histories of mass-wasting disasters:*** **looking at event in hindsight shows us that** ***hazardous conditions*** **and** ***previous history of mass wasting*** **existed prior to the event.**

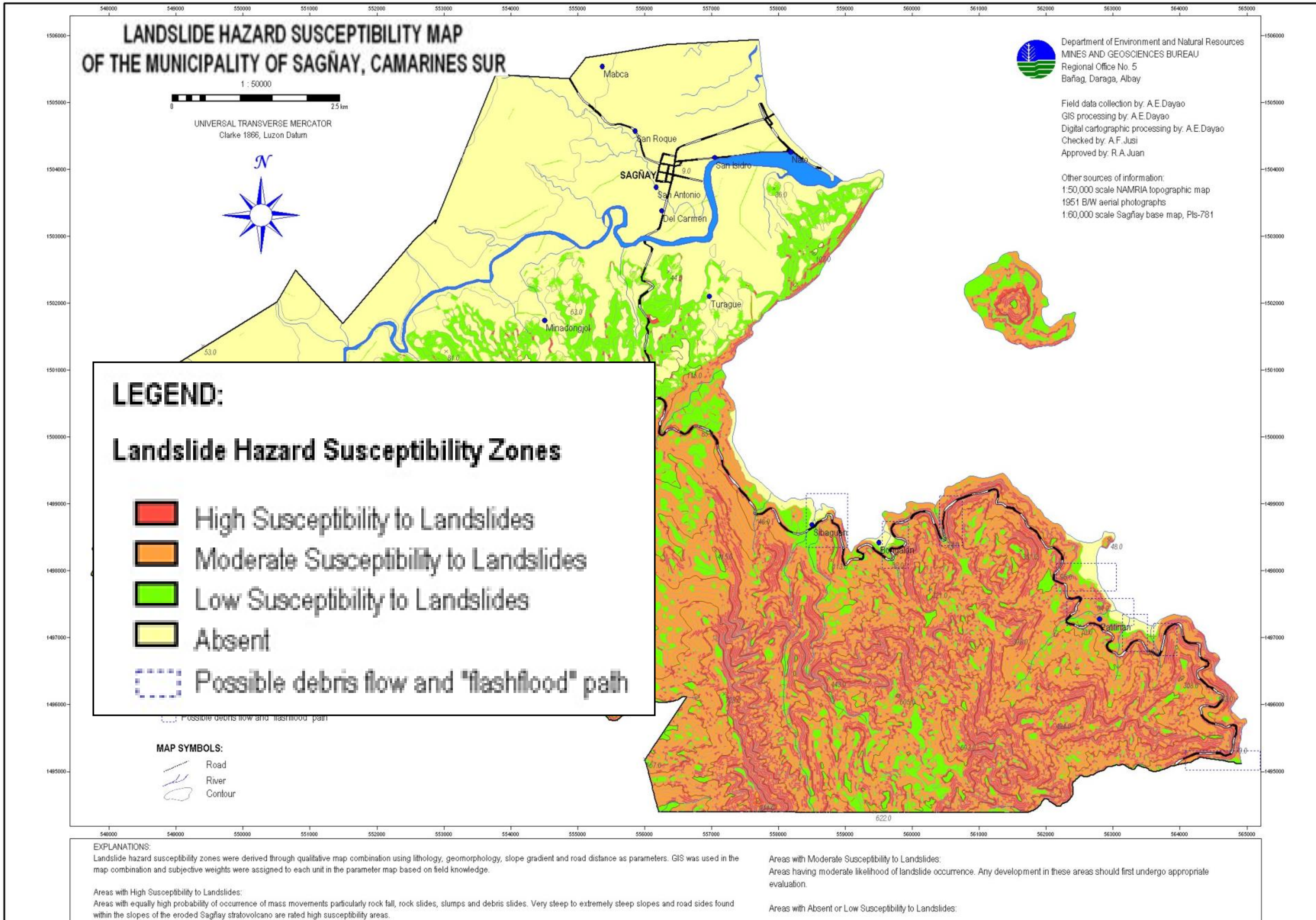
6. Hazard Assessment of Mass Wasting

- ***If resources available***, construct maps of all areas prone to possible mass-wasting.



6. Hazard Assessment of Mass Wasting

Landslides (Mass Wasting)



6. Hazard Assessment of Mass Wasting

- Planners can use such hazards maps to:
  - make decisions about land use policies
  - take steps can be taken to stabilize slopes to attempt to prevent a disaster.
- ***What are the barriers to making these hazard maps in ALL mass-wasting prone region of the world?***

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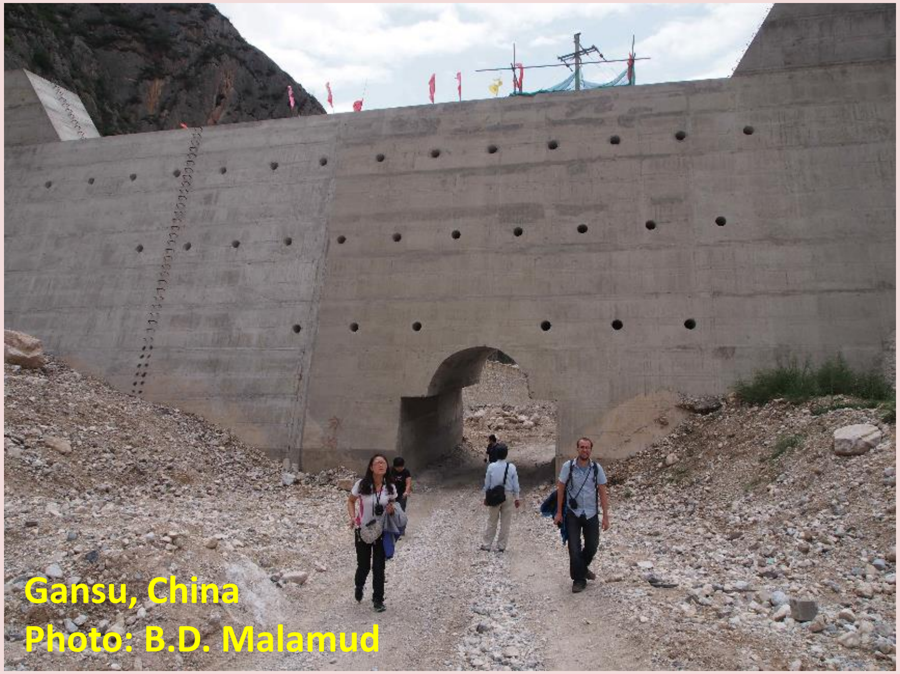


Gansu, China
Photo: B.D. Malamud

7. Prevention & Mitigation of Mass Wasting

- ***Slope Assessment:***
  - ***All slopes are susceptible to mass-wasting hazards if a triggering event occurs.***
  - ***Thus, all slopes should be assessed for potential mass-wasting hazards*.**
- **Mass-wasting events can sometimes be avoided by employing *engineering techniques* to make slope more stable.**
- ***Engineering mitigation technique examples*:**

  (i) Steep slopes can be covered or sprayed with *SHOTCRETE*, CONCRETE, or METAL MESH.

  (ii) *RETAINING WALLS* can be built to stabilize slope.

7. Prevention & Mitigation of Mass Wasting

- ***Engineering mitigation technique examples (SHOTCRETE)***

7. Prevention & Mitigation of Mass Wasting

- ***Engineering mitigation technique examples (SHOTCRETE)***

http://www.geotechnical-engineer.com/landslide-prevention.html

7. Prevention & Mitigation of Mass Wasting

- ***Engineering mitigation technique examples (RETAINING WALLS)***

Scotia Hollow Road, Allegheny County, Pennsylvania, USA

http://www.earthincorp.com/projects.html

7. Prevention & Mitigation of Mass Wasting

➢ ***Engineering mitigation technique examples***

7. Prevention & Mitigation of Mass Wasting

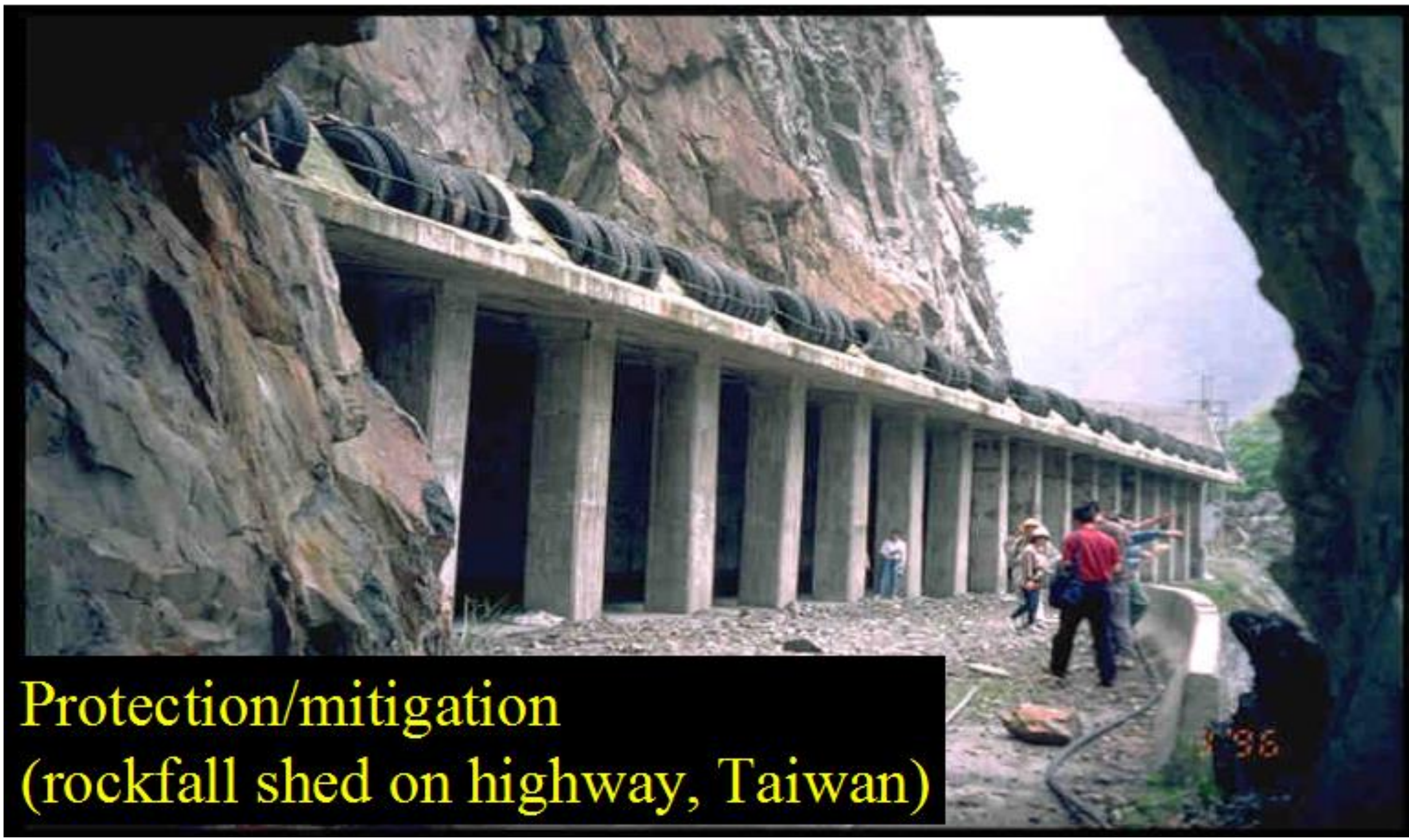
- ***Engineering mitigation technique examples***:

(iii) ***DEBRIS CHUTES*** **can be used to channel flows.**

7. Prevention & Mitigation of Mass Wasting

- ***Engineering mitigation technique examples***:

  (iv) ***ROCKFALL SHEDS*** **can protect road/railway.**



7. Prevention & Mitigation of Mass Wasting

- ***Engineering mitigation technique examples***:

  (v) ***Drainage pipes*** **inserted in slope to more easily allow water to get out** **[thus avoiding fluid pressure increase, liquefaction possibility, or increased weight due to water addition].**

7. Prevention & Mitigation of Mass Wasting

- ***Engineering mitigation technique examples*:**
  - **(vi) *Over-steepened slopes could be graded* to reduce the slope to the natural angle of repose.**
- ***Other mitigation technique examples*:**
  - **(i) In mountain valleys subject to mudflows, plans could be made to *rapidly lower levels of water in human-made reservoirs* to catch and trap the mudflows.**
  - **(ii) *Land use planning*: humans should avoid high risk areas (*what might be problem with implementation of this?*).**

7. Prevention & Mitigation of Mass Wasting

- ***Other mitigation technique examples***:

(iii) *WARNING SIGNS*.

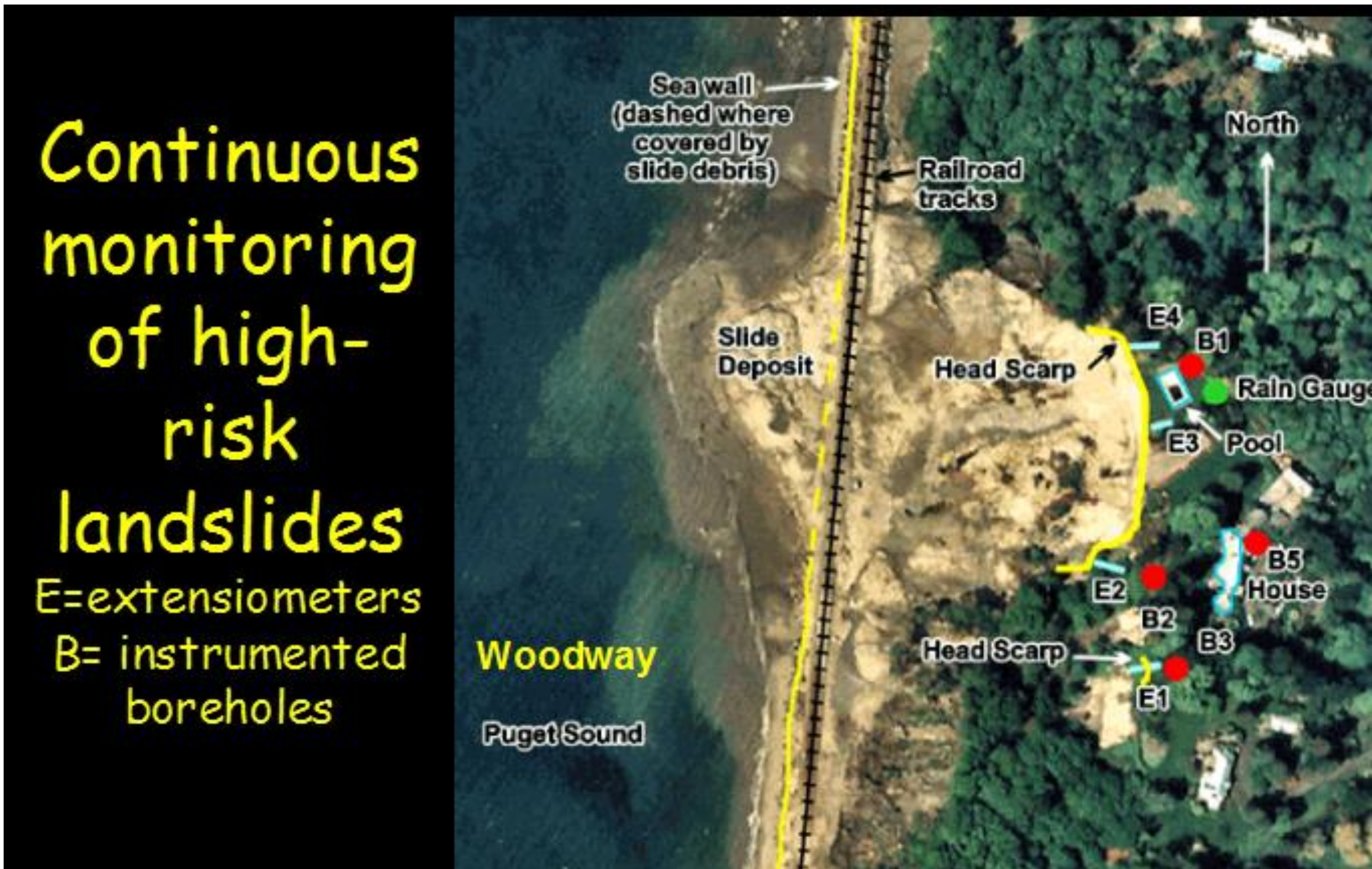
Isle of Wight

Taiwan

7. Prevention & Mitigation of Mass Wasting

➢ ***Other mitigation technique examples***:

(iv) ***MONITOR high risk slopes***.



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8. Further Resources

➢ WEB: GENERAL LANDSLIDE INFORMATION

BeSafe.net (2013) Landslides FAQ. [Online] Available at: http://www.besafenet.net/267,0,0,0,2-Landslide.aspx [Accessed 5 April 2013]. *Extensive FAQs about landslides designed for the public and teachers.*

How Stuff Works (2013) How Landslides Work. [Online] Available at: http://science.howstuffworks.com/environmental/earth/geology/landslide.htm [Accessed 5 April 2013]. Clear explanation of landslide types and causes including underwater landslides.

National Geographic (2013a) Encyclopaedia: Landslide. [Online] Available at: http://education.nationalgeographic.com/education/encyclopedia/landslide/?ar_a=1 [Accessed 5 April 2013]. *Good photos and landslide vocabulary/glossary.*

Nelson SA (2012) Mass Movements [Online] Available at: http://www.tulane.edu/~sanelson/eens1110/massmovements.htm [Accessed 4 April 2013]. *Good university lecture on mass movements.*

Petley DN (2013) The Landslide Blog. [Online] Available at: http://blogs.agu.org/landslideblog/ [Accessed 5 April 2013]. *Analysis & Discussion of recent landslide events, updated regularly.*

United States Geological Survey (USGS) (2013a) Landslides Hazards Programme [Online] Available at: http://landslides.usgs.gov/ [Accessed 5 April 2013]. *This web site contains many publications (e.g., under 'Learning and Education'), photographs, and other information on landslides not only in the USA, but also other parts of the world.*

United States Geological Survey (USGS) (2013b) Landslide Hazard Information. [Online] Available at: http://geology.com/usgs/landslides/ [Accessed 5 April 2013]. *General information about different landslide types & causes.*

Washington State Department of Ecology (2013) Heavy Rain Brings Landslides, Be Prepared. [Online] Available at: http://www.ecy.wa.gov/programs/sea/landslides/ [Accessed 5 April 2013]. *Information on preparedness and prevention.*

8. Further Resources

➢ WEB: LANDSLIDE VIDEOS (V) & PHOTOS (P)

Boston Globe[P] (2010 & 2011) The Big Picture [Online] Landslides in (a) Zhouqu, China. http://www.boston.com/bigpicture/2010/08/landslides_strike_zhouqu_count.html. (b) Brazil. http://www.boston.com/bigpicture/2011/01/landslides_in_brazil.html. *Emotive pictures showing landslide damage. ***Some photos may be upsetting, please vet accordingly****.

National Geographic[V] (2013b) Landslides 101. [Online] Available at: http://video.nationalgeographic.com/video/player/environment/environment-natural-disasters/landslides-and-more/landslides.html [Accessed 10 January 2013]. *Some really amazing footage of landslides narrated with background information.*

National Geophysical Data Centre[P] (2013) Landslide Photos. [Online] Available at: http://www.ngdc.noaa.gov/nndc/struts/results?eq_1=39&t=101634&s=0&d=4&d=44 [Accessed 5 April 2013]. *Collection of photos and maps.*

Petley DN[V] (2012) The Ultimate Compilation of the Best Landslide Videos. [Online] Available at: http://blogs.agu.org/landslideblog/2012/01/21/the-ultimate-compilation-of-the-best-landslide-videos/ [Accessed 5 April 2013]. *Collection of good videos of landslides as they happen. Updated regularly. More videos found on this page by searching for "video" in search bar.*

United States Geological Survey (USGS)[P] (2012) Landslide Photo Collections. [Online] Available at: http://landslides.usgs.gov/learning/photos/ [Accessed 5 April 2013]. *Collection of landslide photos*.

United States Geological Survey (USGS)[V] (2013c) Educational Videos & Animations. [online] Available at: http://education.usgs.gov/videos.html#landslides [Accessed 5 April 2013]. *Collection of documentaries.*

8. Further Resources

➤ WEB: ACTIVITIES & TEACHING RESOURCES

Australian Geomechanics (2013) Landslide Risk Management Education Empowerment. [Online] Available at: http://lrm.australiangeomechanics.org/ [Accessed 5 April 2013]. *Quizzes and detailed answers about landslides.*

Australian Government (2011) Geoscience Australia. Teachers Notes and Student Activities. [Online] Available at: http://www.ga.gov.au/education/classroom-resources.html [Accessed 5 April 2013]. *Comprehensive pack of student activities.*

Discovery Education (2013) Lesson Plan: Landslides. [Online] Available at: http://www.discoveryeducation.com/teachers/free-lesson-plans/landslides.cfm [Accessed 5 April 2013]. *Lesson plan, activity, discussion questions & standards.*

DLESE Teaching Boxes (2013) Landslides, Liquefaction and Structural Failure. [Online] Available at: http://www.teachingboxes.org/earthquakes/lessons/lesson6.jsp [Accessed 5 April 2013]. *Four lesson plans including activities looking at liquefaction*.

Evergreen (2013) In Harm's Way: Natural Disasters in My Community. [Online] Available at: http://www.evergreen.ca/en/lg/lessons/natural_disasters.pdf [Accessed 5 April 2013]. *Lesson plans to get students thinking about natural hazards within their locale.*

Nature Education (2013) Lesson 8: Landslides Hazards. [Online] Available at: http://www.nature.com/scitable/partner/earthquake-science-8666053/lesson-8-landslides-hazards-lt-br-gt-8704578 [Accessed 5 April 2013]. *Lesson plan, table top exercises & discussion questions. Site also has lesson ideas for Earthquake hazards.*

OIKOS (2013) Risk Management Game. [Online] Available at: http://www.e-oikos.net/gmap/oikos.htm [Accessed 6 April 2013] *'Game' 6 hazards in 9 languages*

Teach Engineering (2013) Mini Landslide. [Online] Available at: http://www.teachengineering.org/view_activity.php?url=collection/cub_/activities/cub_natdis/cub_natdis_lesson05_activity1.xml [Accessed 5 April 2013]. *Great exercise to understand what structures would withstand a landslide.*

9. QUESTIONS and COMMENTS

Gansu, China landslide 13 September 2012
(Video B.D. Malamud, http://vimeo.com/50837463)