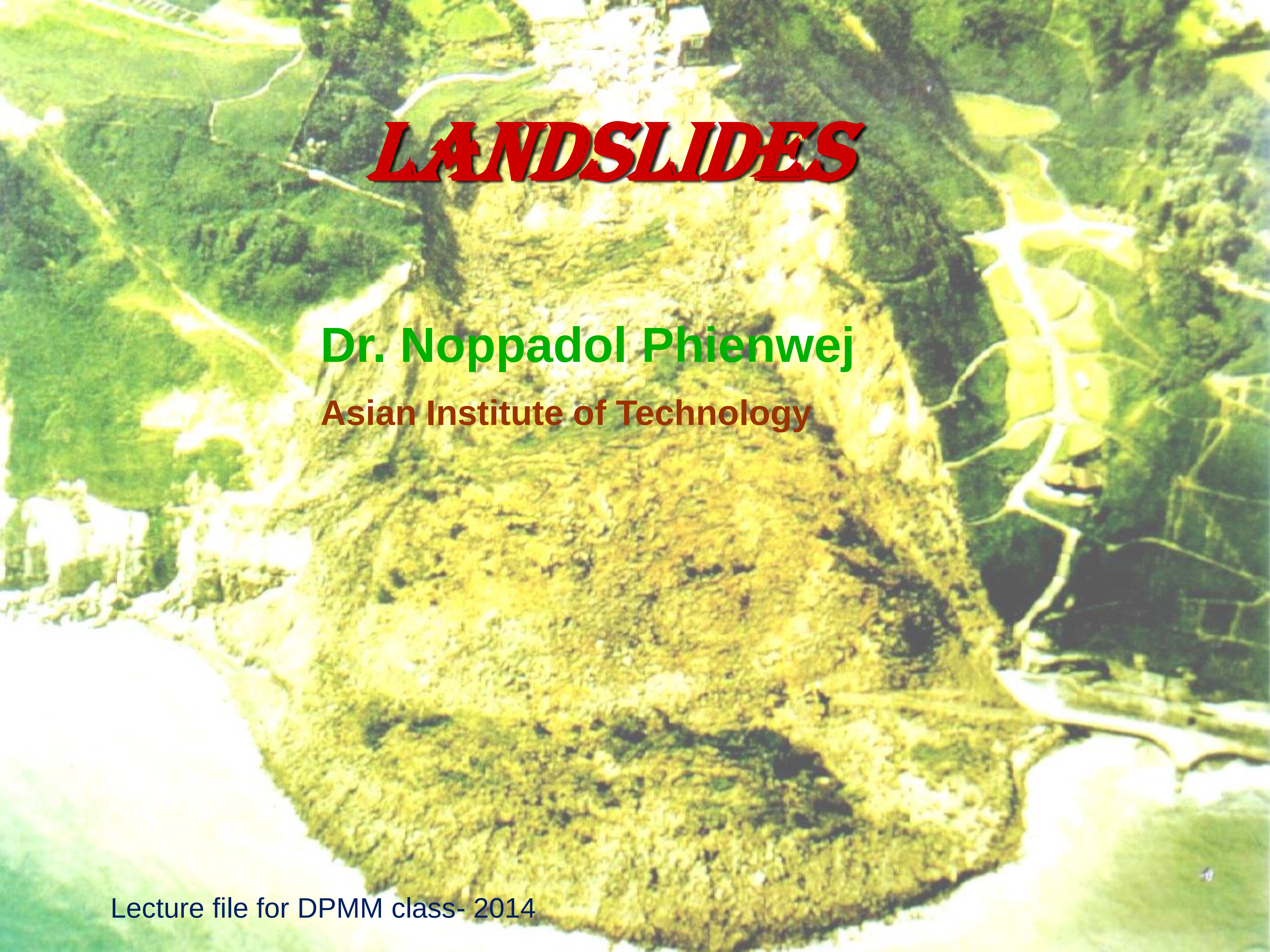


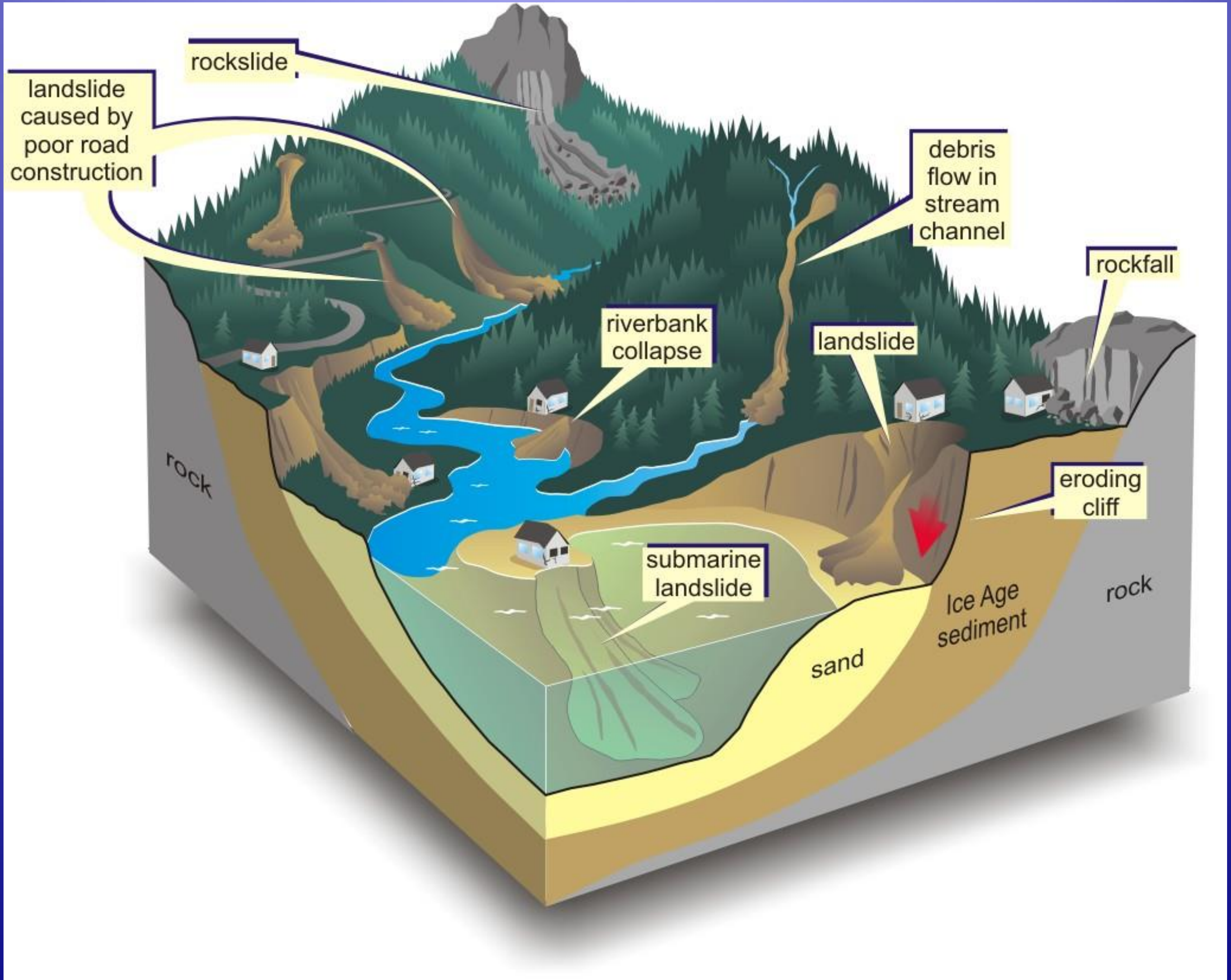
LANDSLIDES

Dr. Noppadol Phienwej

Asian Institute of Technology

Lecture file for DPMM class- 2014

Landslides and Debris flows




Norway


Malaysia


Malaysia


十津川方面→
迂回路
県道高野辻堂線
国道168号
←五條方面
Japan

Taiwan

May 2010 : Earth and rocks avalanche blocks a 6-lane freeway over a 300-meter stretch

The landslide reportedly blocked a 300-meter long of a major road, the No.3 Freeway between Taipei and Keelung earlier today, burying an unknown number of vehicles under thousands of tons of earth and rocks.

Landsildes in Brazil

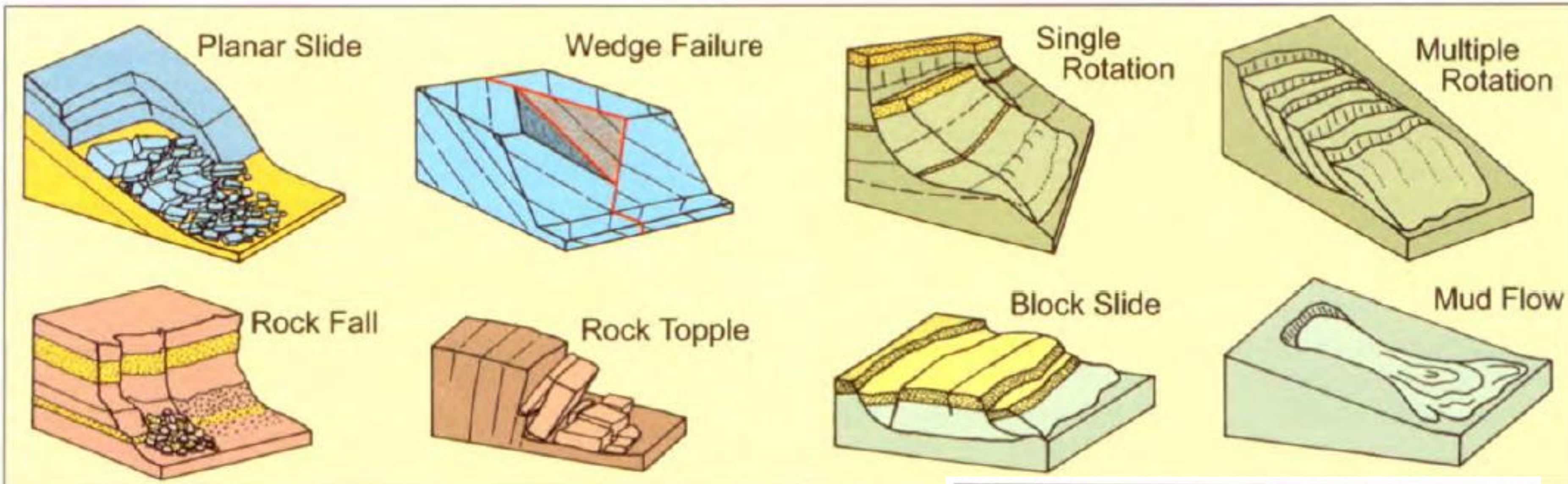
The future home of the 2014 World Cup and the 2016 Olympics was hit with a massive downpour—the heaviest on record—on April 7. The nine inches of rain in 24 hours caused destructive landslides in the hillside slums and

Landslides and Debris Flow

Processes:

- Landslides occur when a mass of soil or rock moves downslope under the influence of gravity
- Slope failure is a natural process which can be induced, accelerated or retarded by human actions

32 Slope Failure and Landslides



Head scar of a rotational slide breaks a road in Yorkshire.

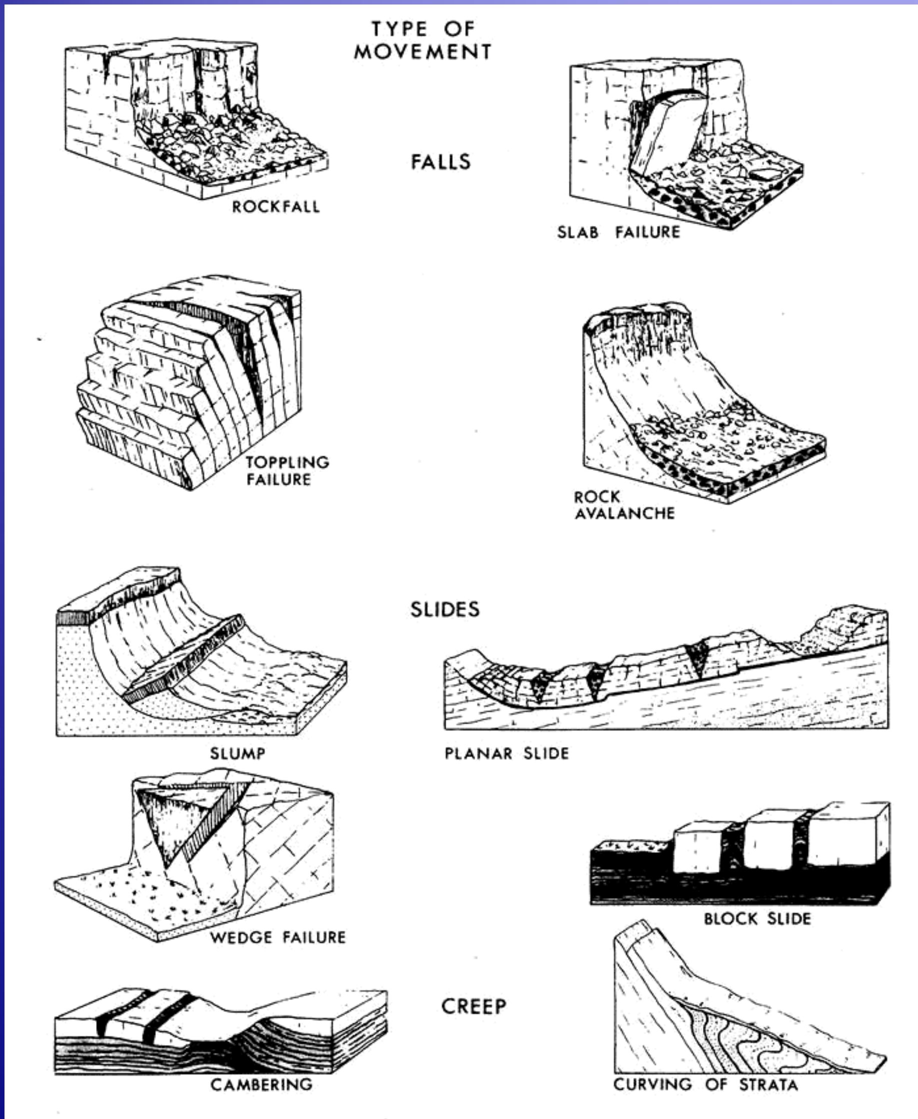
SCARBOROUGH LANDSLIDE, 1993

Single rotational slide formed in clay slope 30 m high, then retrogressive failure of head scar destroyed hotel. Full causes were not investigated; may have included changes to land drainage. Then long period of drought had weakened the dried clay with shrinkage cracks, prior to heavy rainfall that raised pore water pressure.

Classification of Mass Movement (Landslides)

Classification of Varnes (1975)

Type of Movement			Type of Material		
			Bedrock	Soils: coarse	Soils: fine
FALLS			ROCKFALL	DEBRIS FALL	EARTH FALL
TOPPLES			ROCK TOPPLE	" TOPPLE	" TOPPLE
SLIDES	rotational	few units	" SLUMP	" SLUMP	" SLUMP
			" BLOCK GLIDE	" BLOCK GLIDE	" BLOCK GLIDE
	translational	many units	" SLIDE	" SLIDE	" SLIDE
LATERAL SPREAD			" SPREAD	" SPREAD	" SPREAD
FLOWS			" FLOW (deep creep)	" FLOW	" FLOW
				(soil creep)	
COMPLEX			Combination of 2 or more types		



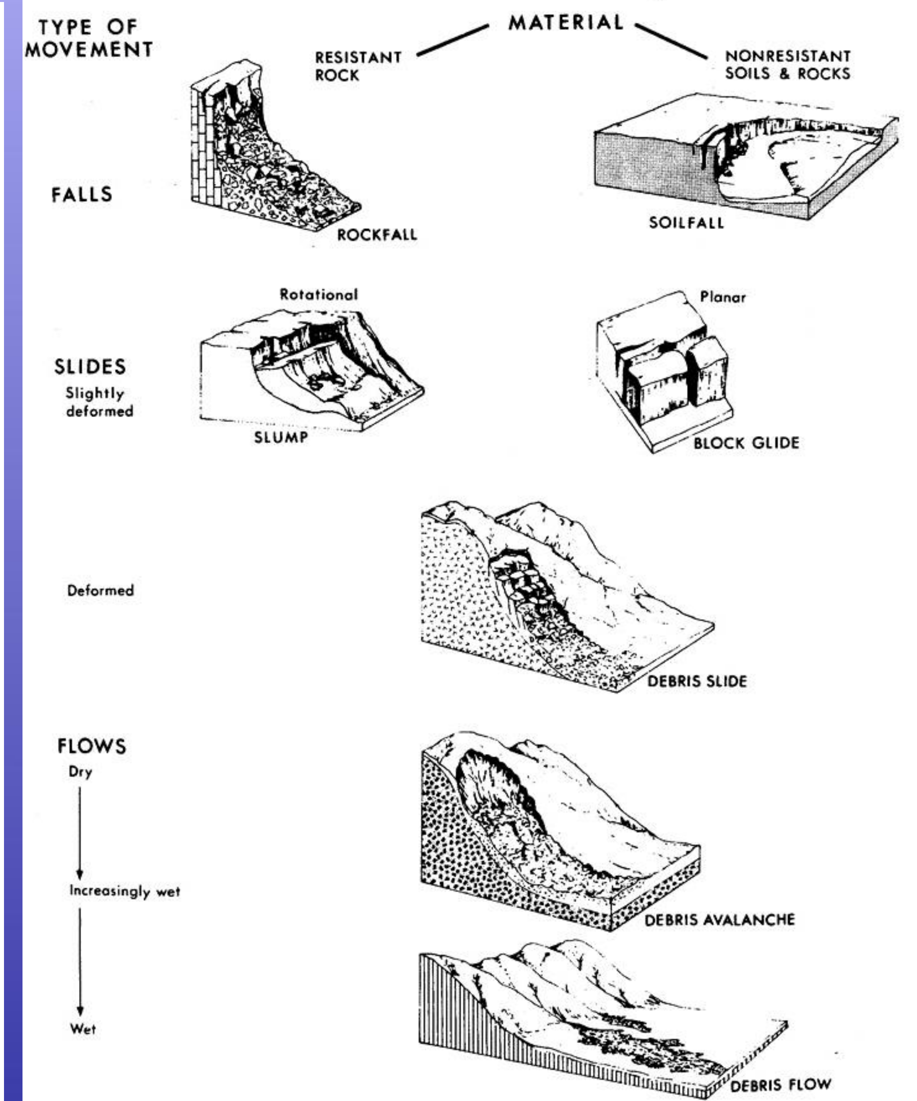
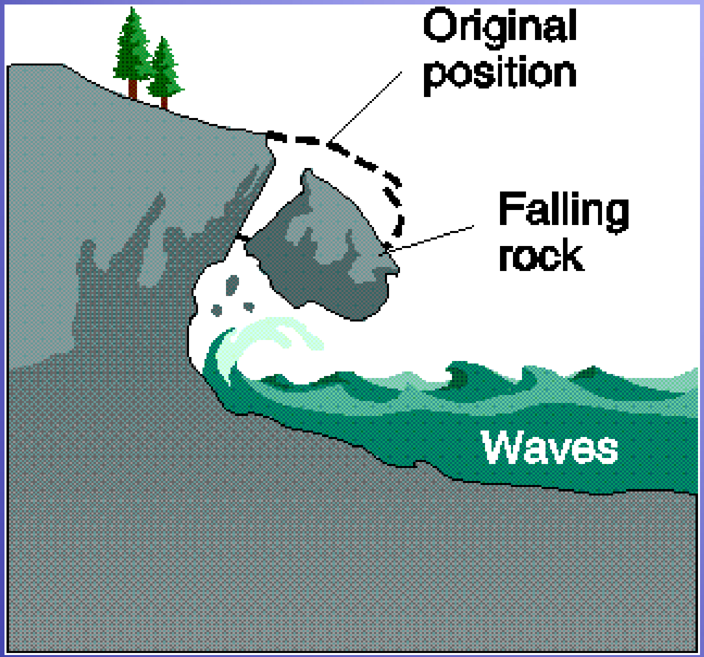
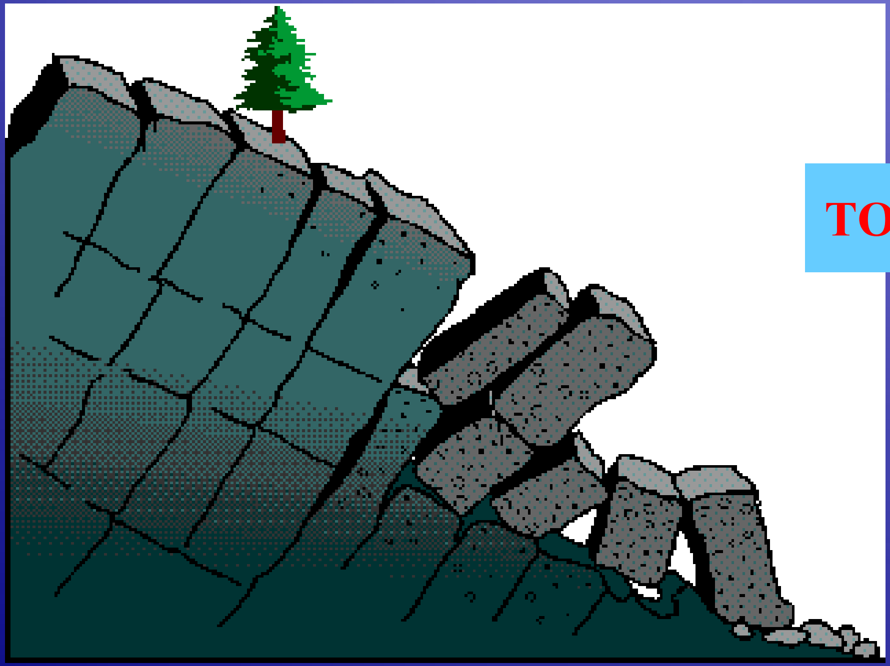


Fig. 13.1. The main mass-wasting types according to the classification of Varnes (1958).



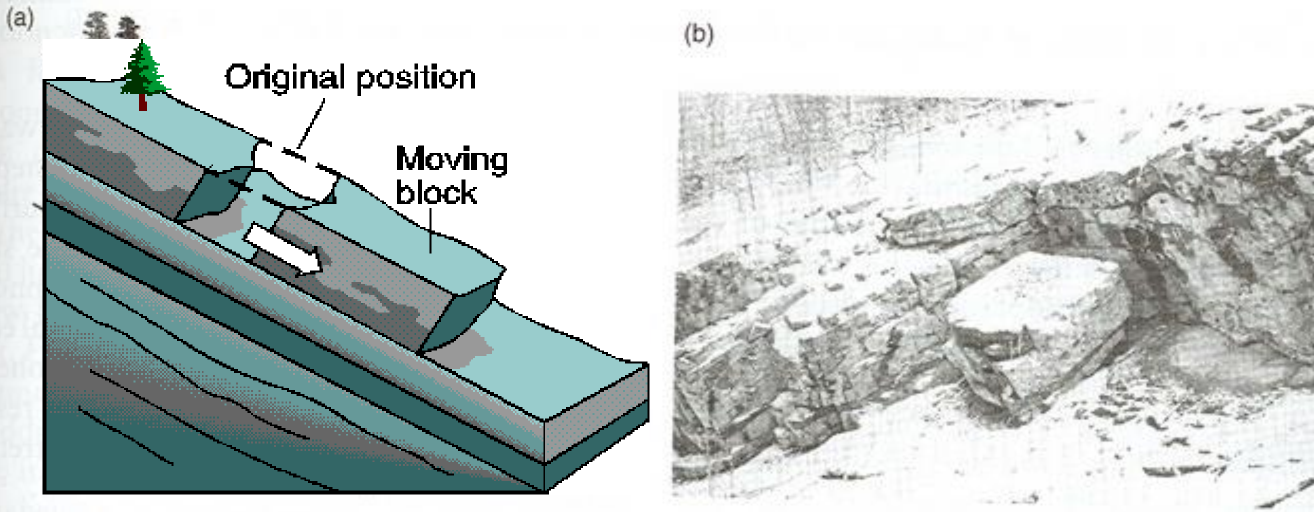
FALL



TOPPLE

COMMON LANDSLIDES TYPES

Rock Slides



ure 4.2 Plane failure on continuous bedding plane dipping out of the slope (strong, blocky limestone, owsnest Pass, Alberta, Canada).

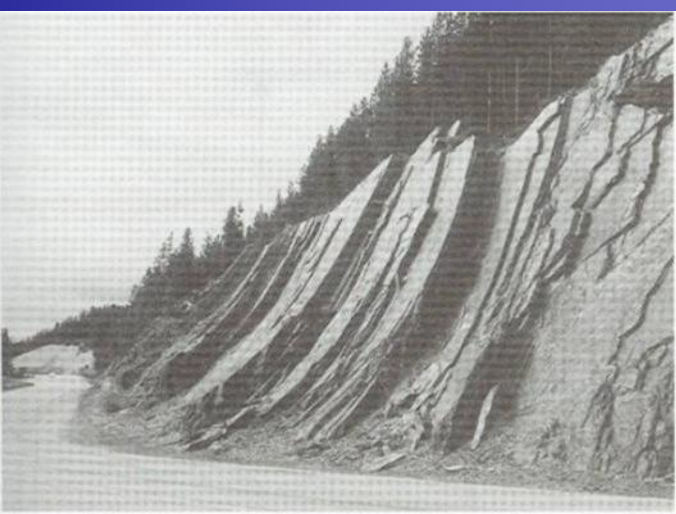
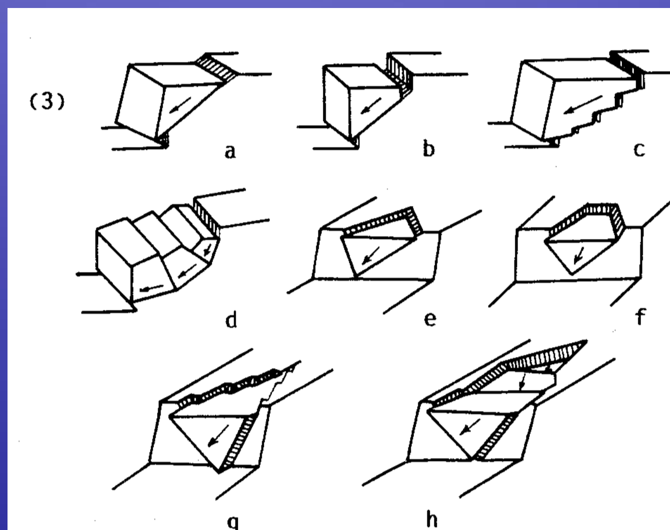
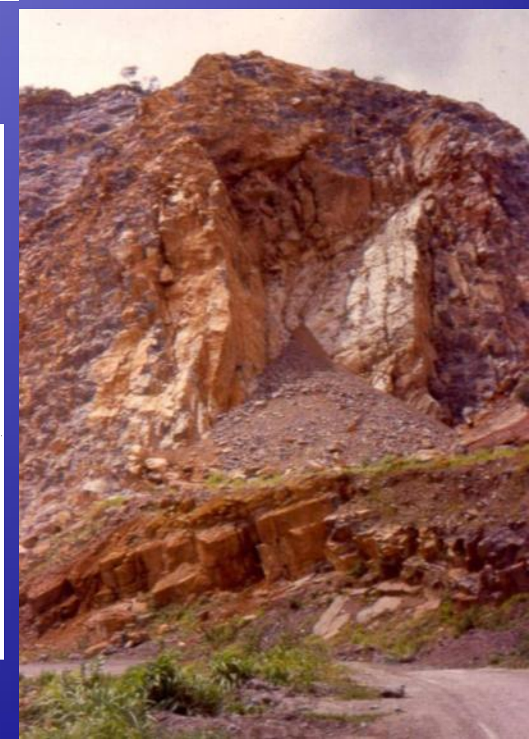
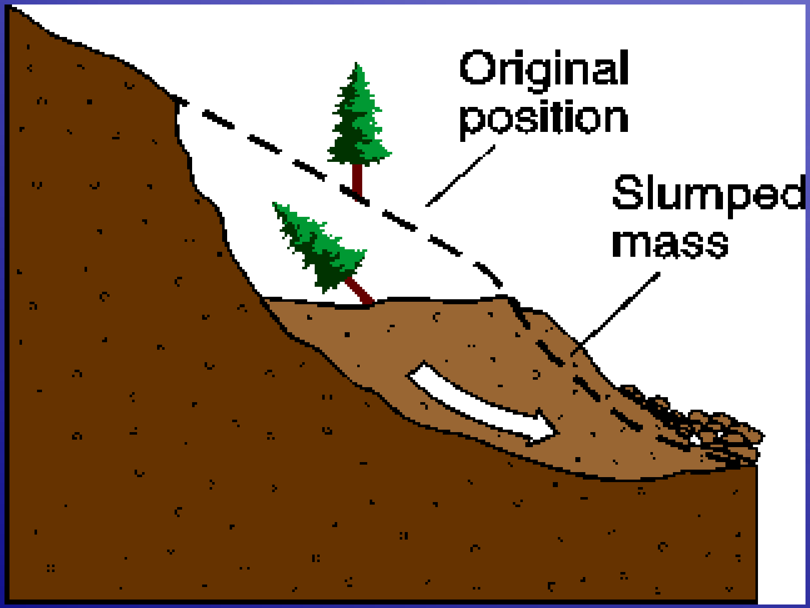


Figure 1.3 Cut face coincident with continuous, low friction bedding planes in shale on Trans Canada Highway near Lake Louise, Alberta. (Photograph by A. J. Morris.)





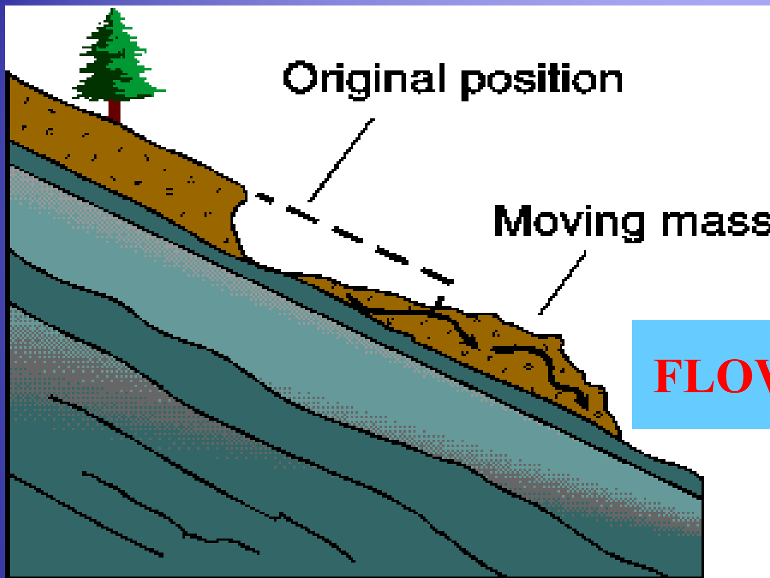


Rotational SLIDE

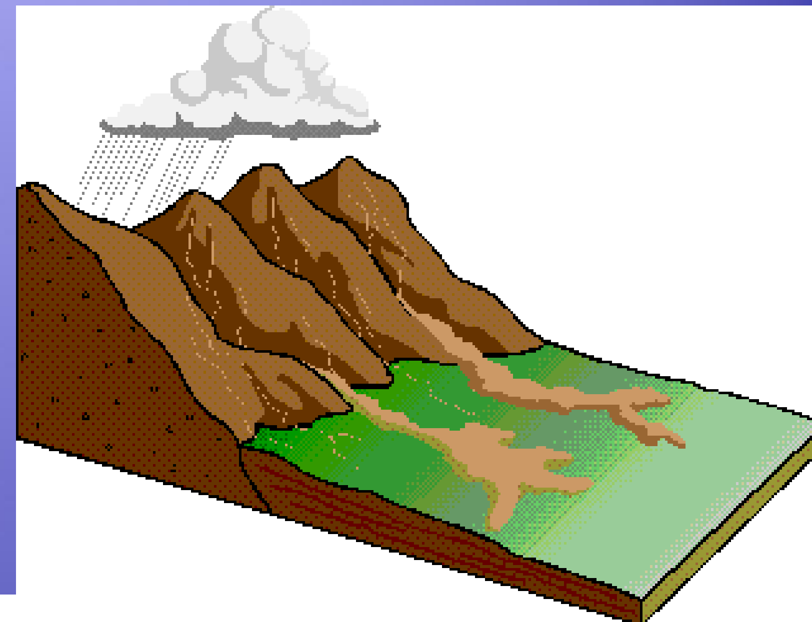
(Slump)

COMMON LANDSLIDES TYPES

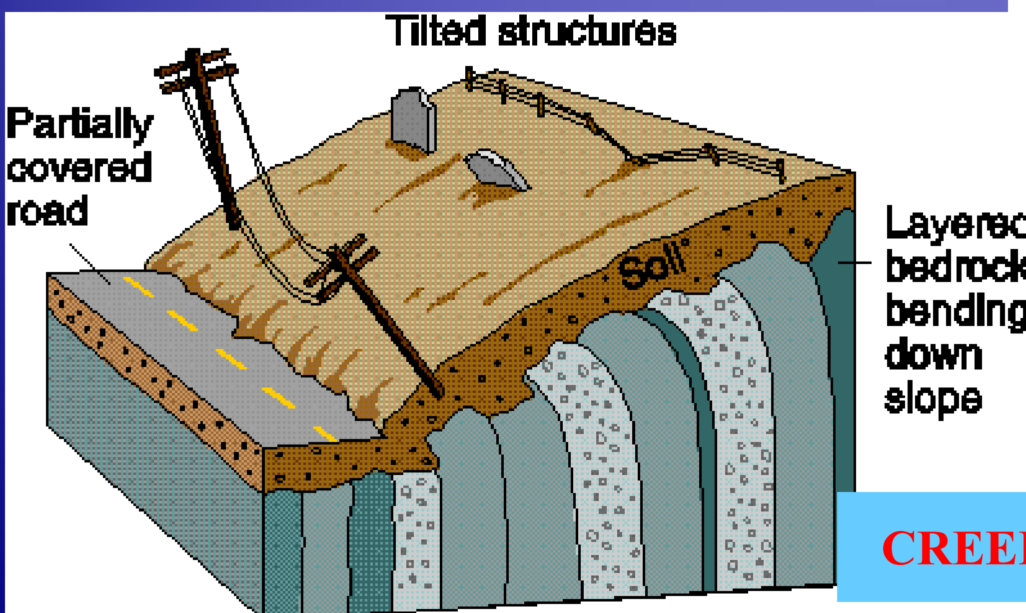
COMMON LANDSLIDES TYPES



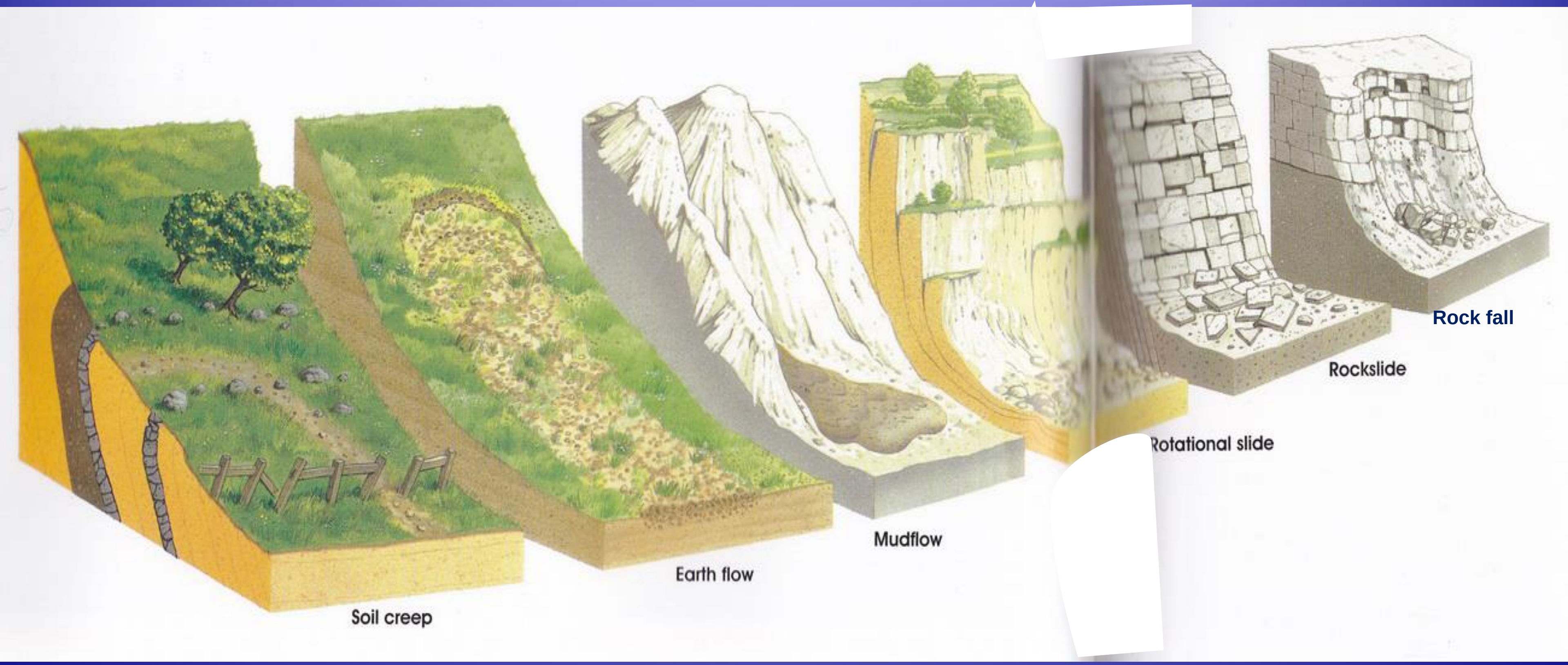
FLOW



DEBRIS FLOW



CREEP


Rock fall
Rockslide
Rotational slide
Mudflow
Earth flow
Soil creep

Slope Failures

- Increase in shear stress

- Reduction in shear strength

FACTORS CAUSING MASS MOVEMENTS

1. Change in slope gradient
2. Change in slope height
3. Overloading by embankments
4. Shocks and Vibrations
5. Change in water content

FACTORS CAUSING MASS MOVEMENTS, (Cont.)

6. Change in groundwater
7. Weathering
8. Change in vegetation cover
9. Frost effects

Examples of Landslide Cases

Soil Slump of Soft Clay in a Borrow Pit

Road Embankment Slump due to Drawdown

Catastropic rock slide, Saraburi.

Rock Plane Slide

Weak Discontinuity

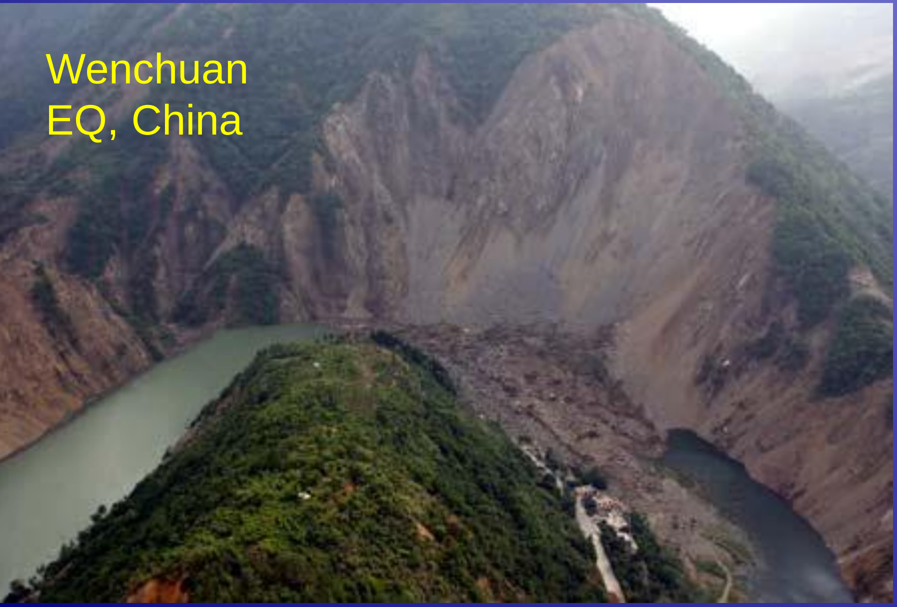
Rock Plane Slide

Weak Discontinuity

Major Natural Slide Damaging Houses in Japan

Threatening Rock Slide in the Alps

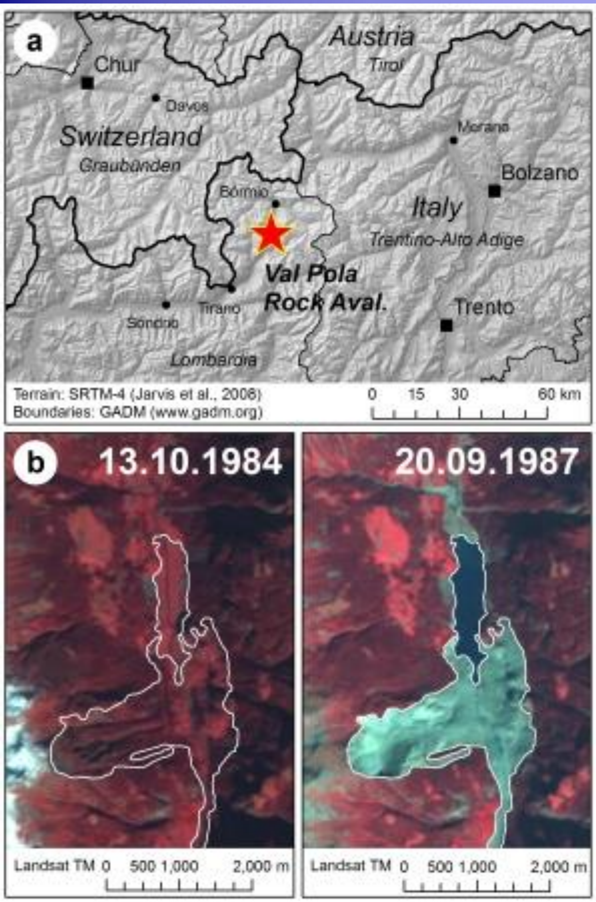

Italy


Wenchuan
EQ, China


Taiwan

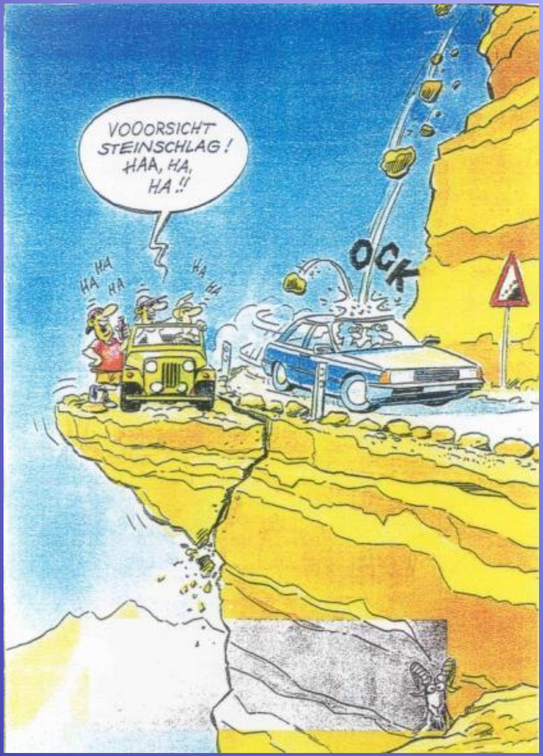
Val Pola Landslide 1987- Heavy Rain

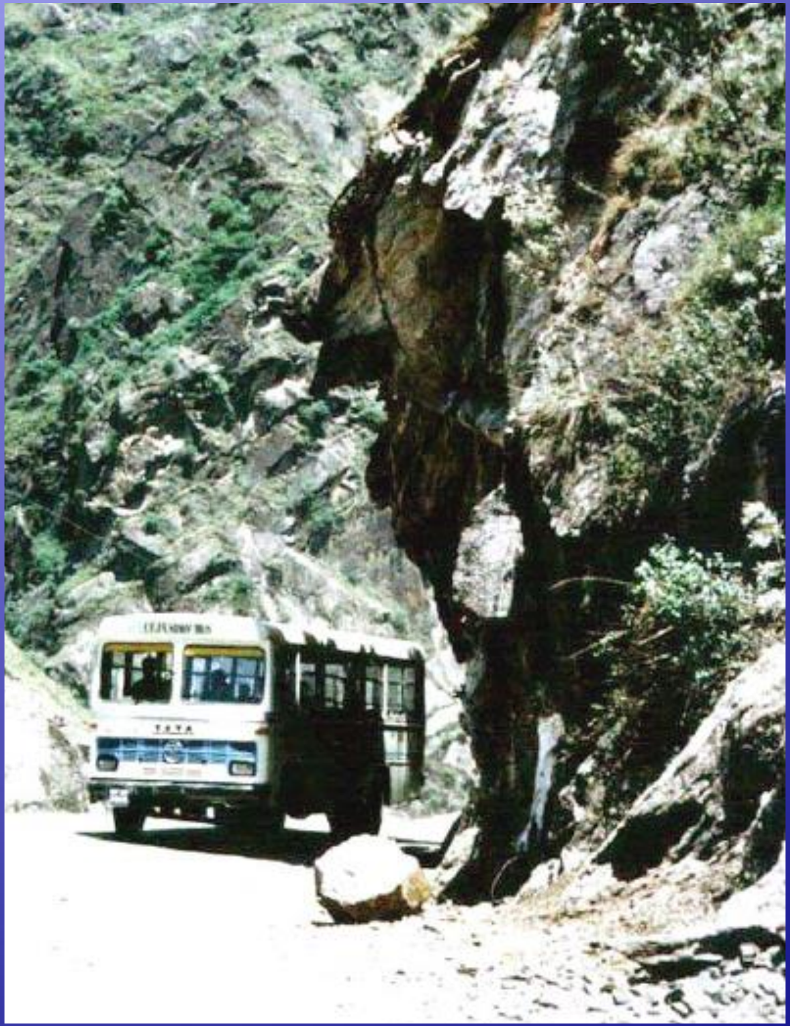
slide 1987


a
Austria
Tirol
Chur
Davos
Switzerland
Graubünden
Bolzano
Bormio
Italy
Trentino-Alto Adige
Val Pola
Rock Aval.
Sondrio
Tirano
Trento
Lombardia
Terrain: SRTM-4 (Jarvis et al., 2008)
Boundaries: GADM (www.gadm.org)
0 15 30 60 km
b
13.10.1984
20.09.1987
Landsat TM 0 500 1,000 2,000 m
Landsat TM 0 500 1,000 2,000 m

Human Intervention - Landslides

Rock Falls

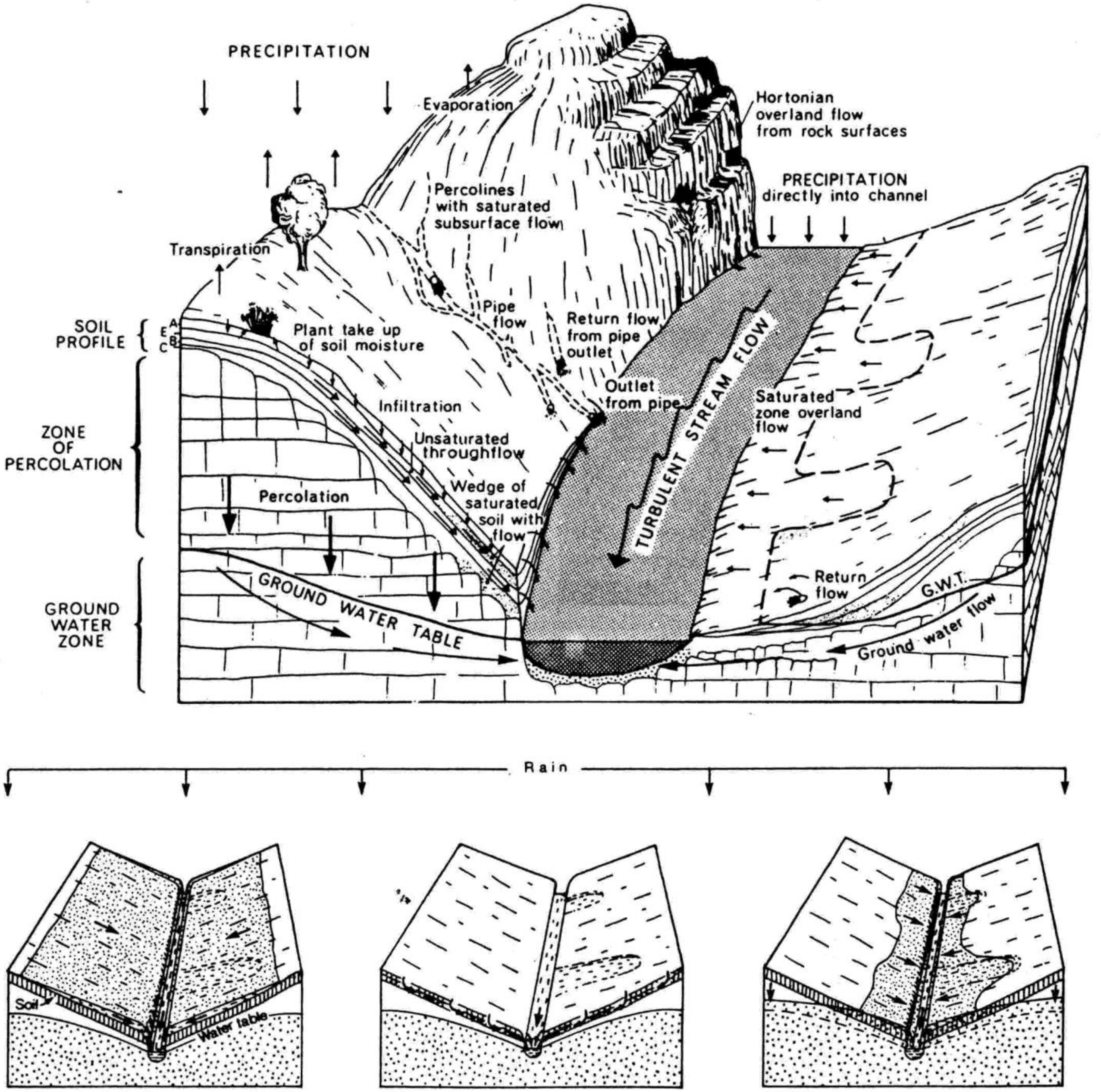




Rock Creep

Slope Erosion

Massive Gully Erosion



(b) Hortonian infiltration–excess overland flow

(c) Throughflow

(d) Saturation–excess overland flow

Water and Slope

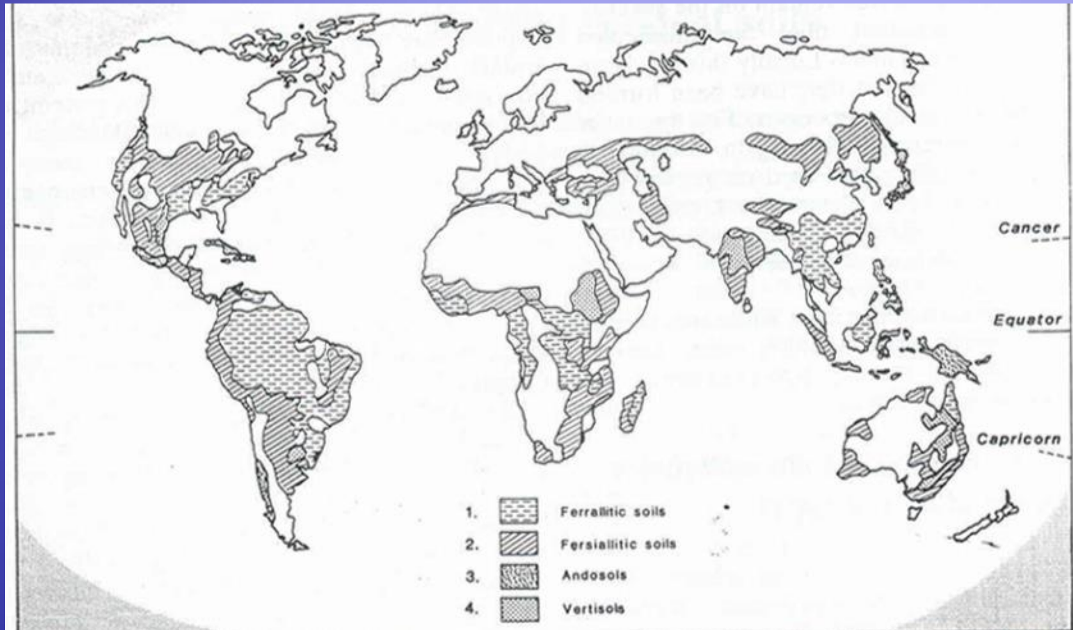
Landslide of river banks

Mekong River Nongkai

With slope protections

Landslides-Debris Flow & Flash Flood in Tropical Areas

Weathered Mountain Slope



Tropical Soils Weathering

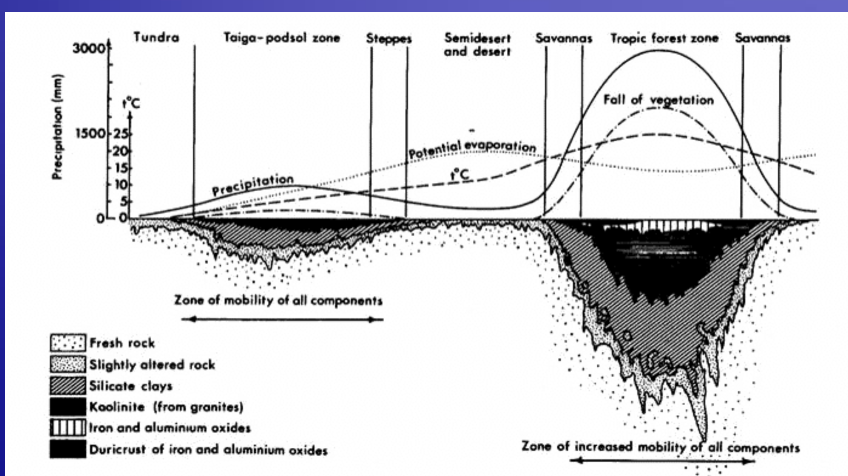


FIG. 8.1. The formation of weathering mantles in areas of tectonic stability and low relief. This scheme demonstrates a relationship between climatic factors, vegetation cover, depth of weathering, and dominant profile horizons. It does not consider relict effects. (After Strakhov 1967.)

Weathered rock slopes

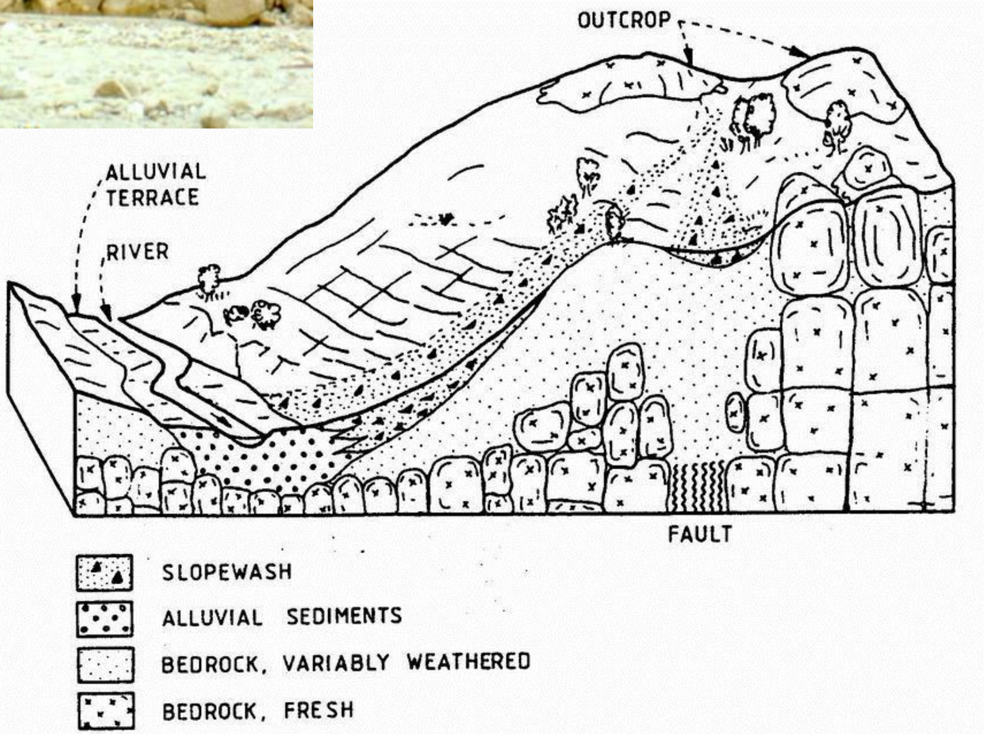


Figure 3.41. Schematic view of residual, slopewash and alluvial deposits.

The large scale of quake induced landslide after 921 (September, 21th) quake (1999)

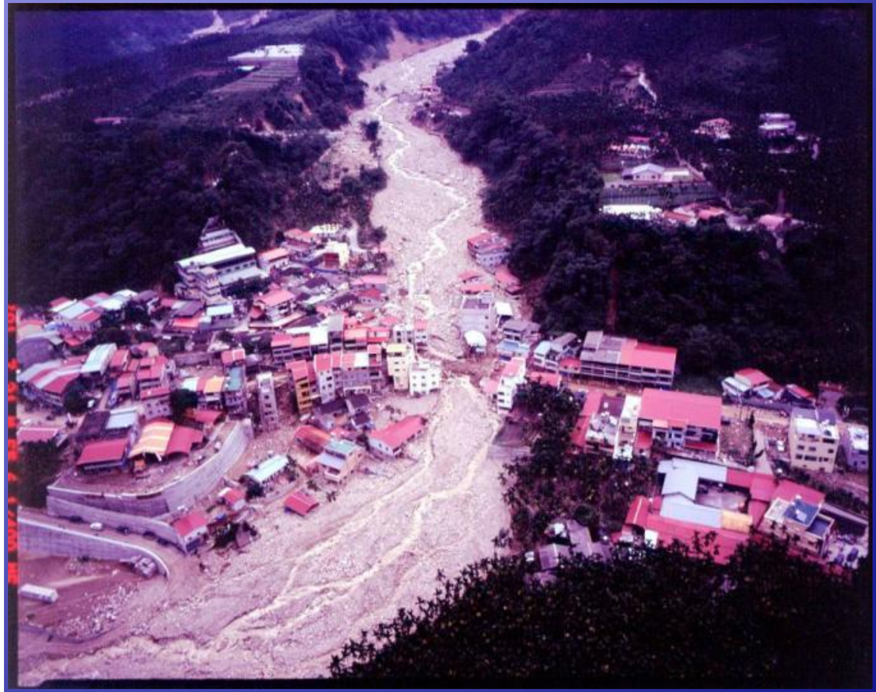
Xin-Shan Village,

Nan-Tou County

(Epicenter, Chi-Chi Town is located at Nan-Tou County)

Debris-flow disasters during Toraji typhoon (29^{th} July, 2001)

Photoed by a pilotless airplane



Shang-An Village,

Nan-Tou County

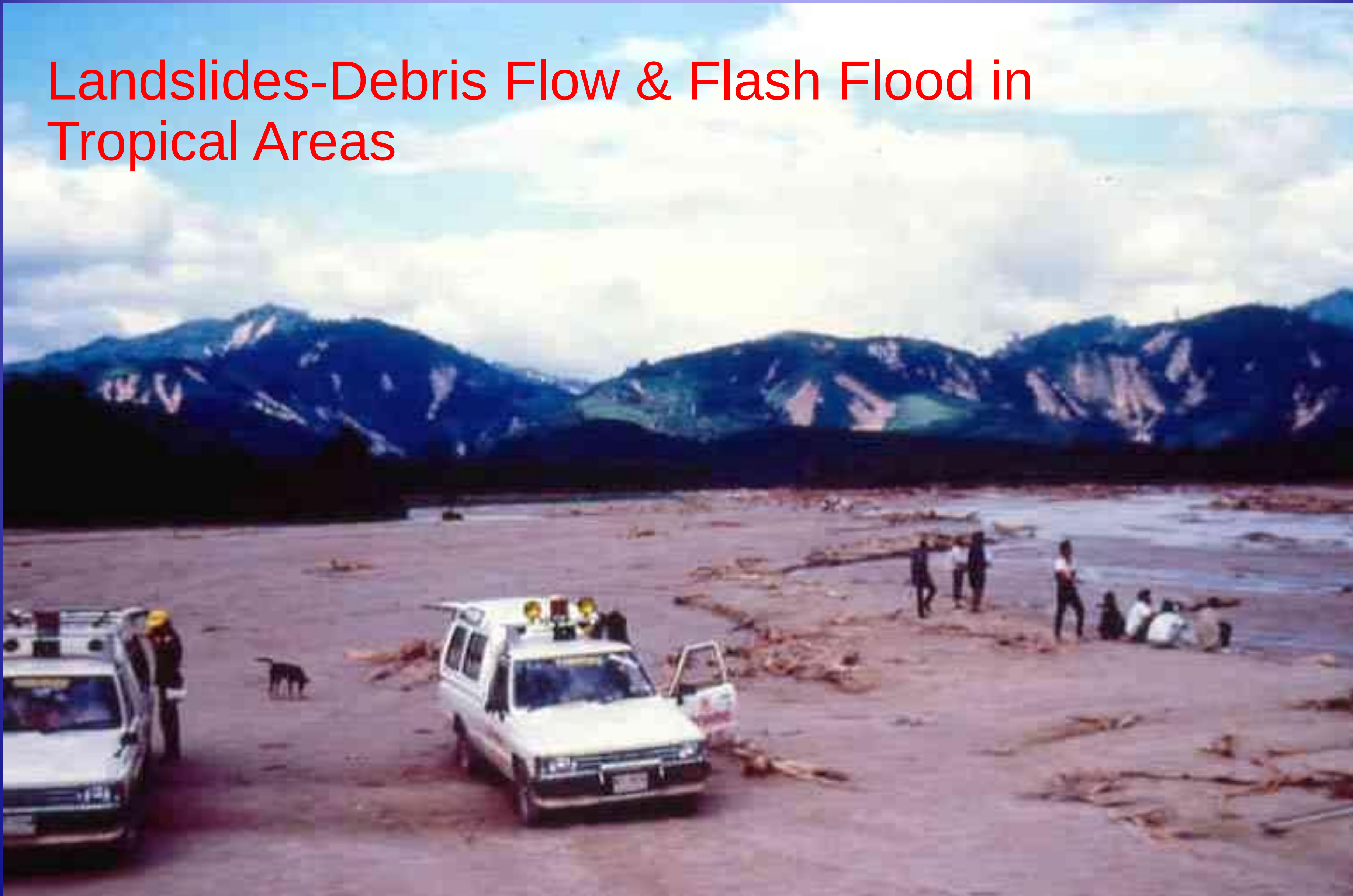
Jun-Keng Village,

Nan-Tou County

Shang-An Village,

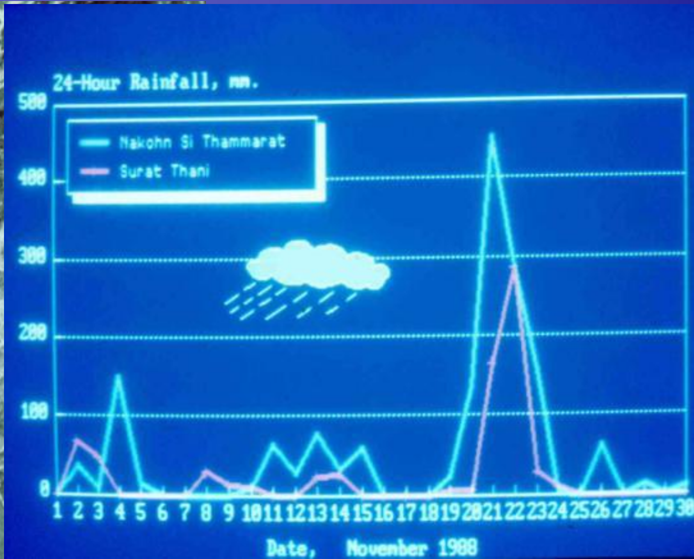
Nan-Tou County

Landslides-Debris Flow & Flash Flood in Tropical Areas



Ban Kratoon, Southern Thailand
1988: 250 Casualties

Ban Kratoon, Southern Thailand 1988: 250 Casulties



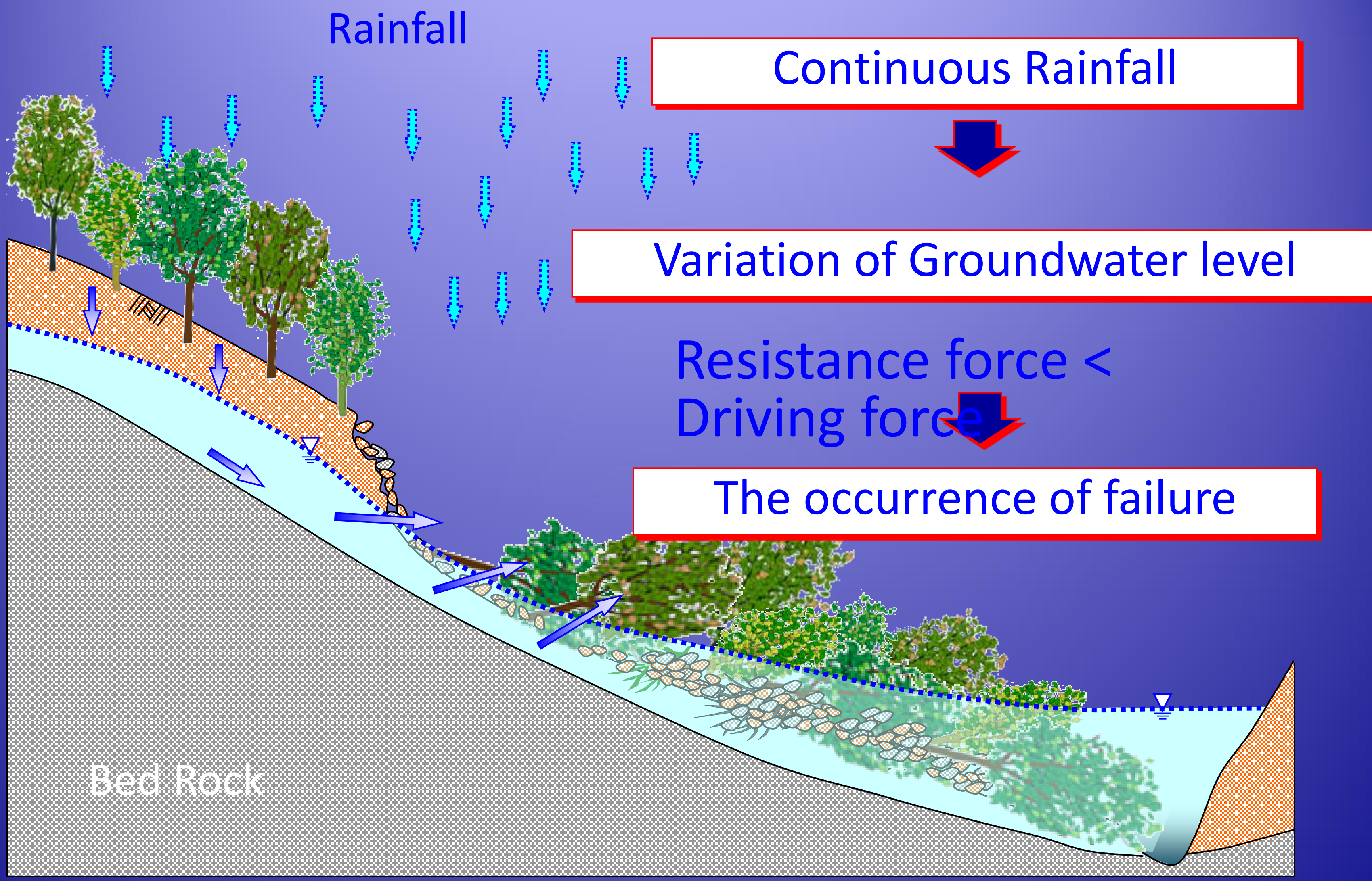
Landslide caused by rainfall in Japan (July 2004)

Slope failure such as landslide is one of the most serious natural disaster.

Society and individuals have suffered serious damages from slope failure.

Figure 3: Mudflow in Keningau, Sabah which claimed 302 lives.

Hiroshima Landslides of 2014



Schematic View of Slope Failure due to rainfall

The necessity to associate variation of groundwater level with rainfall.

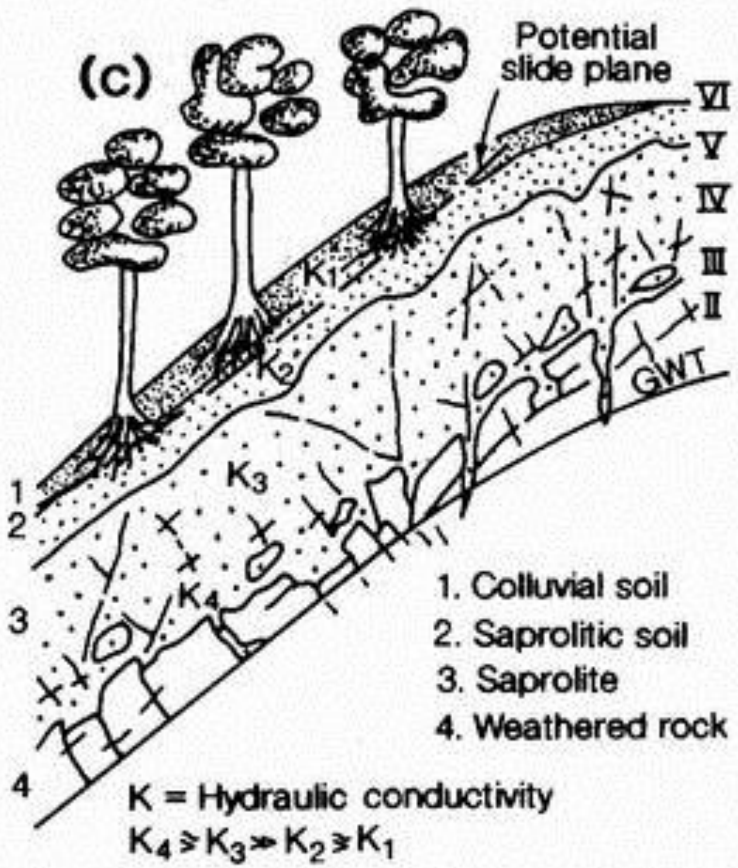


FIG. 13.25. (a) Relict joints in a saprolite with major joints providing a pre-determined failure plane. (b) The pattern of water pressure along the major joints and the assumed piezometric surface used in a stability analysis where pore-water pressure is a controlling factor (a, b, based on Massey and Pang 1988). (c) The hydraulic conductivity, *K*, and weathering grade of saprolitic soils on a hillslope. The groundwater-table is at some depth and the failure occurs in the solum and saprolitic soil as suction is lost during infiltration (based on Wolle and Hachich 1989).

CAUSES OF 1988 LANDSLIDES OF SOUTHERN THAILAND ?

* NATURAL CAUSES

  - HEAVY RAIN
  - RIPEN WEATHERING OF MOUNTAIN SLOPES

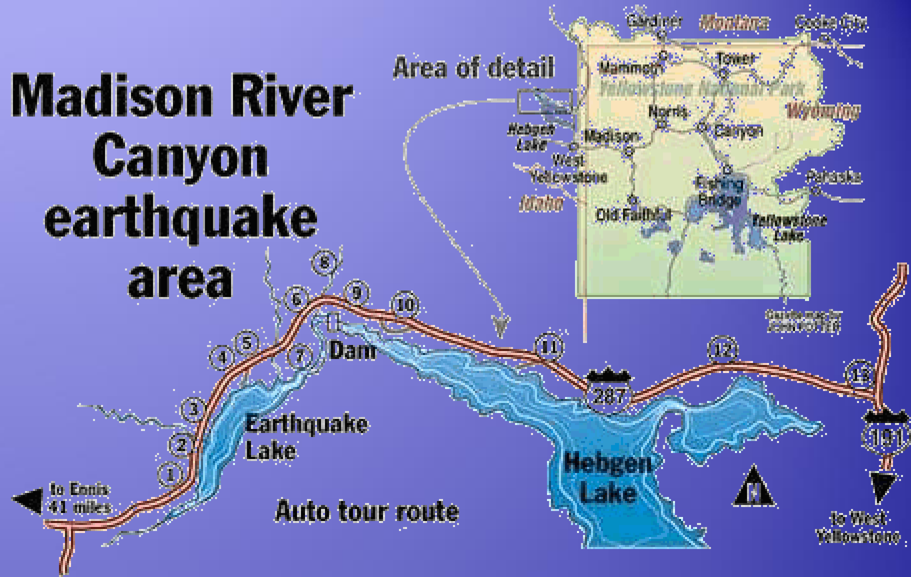
* MAN-MADE CAUSES

  - ENCROACHMENT OF MOUNTAIN SLOPES
  - DEFORESTRATION
  - MINING

Slope Erosion

Massive Mountain Slope Failure and Erosion

Photo courtesy of the Deseret News



Earthqauke M 7.2
August 1959

Madison Canyon Slide due to a Large Earthquake in USA

Landslide due to Earthquake in Nepal Mountain Road

Widespread Lateral Spreading in the Great Alaska Earthquake

Landslides in Wenchuan EQ

Fig. 5: Effect of rockfalls on powerhouse of the Shapai arch dam caused by the 2008 Wenchuan earthquake, Wall and roof punctured by high-velocity rocks (top) and electro-mechanical equipment damaged by rocks (bottom).

Fig. 6: Traces of rockfalls along valley and blockage of access roads on the right bank (Wenchuan earthquake)

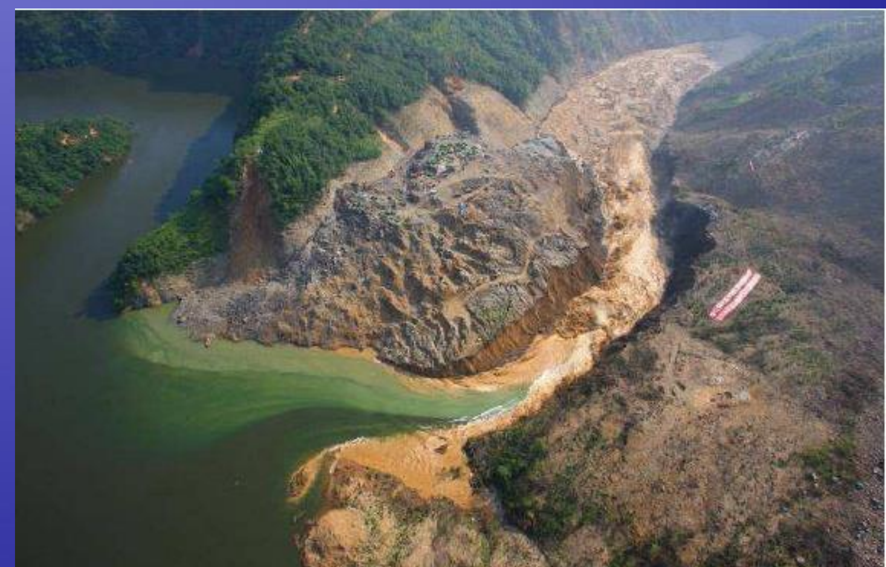


Fig. 7: Controlled release of water from Tangjiashan landslide lake (Wenchuan earthquake)

Buildings on/near Slopes

Buildings Constructed On/Near Slopes

China 2010

Landslides of Weathered Slopes due to Heavy Rainfall Hongkong: 1975

Major landslide at a housing complex, Malaysia

Figure 9: The Main Access Road, Jalan Bukit Antarabangsa, Heaved up more than 1m above its Original level.

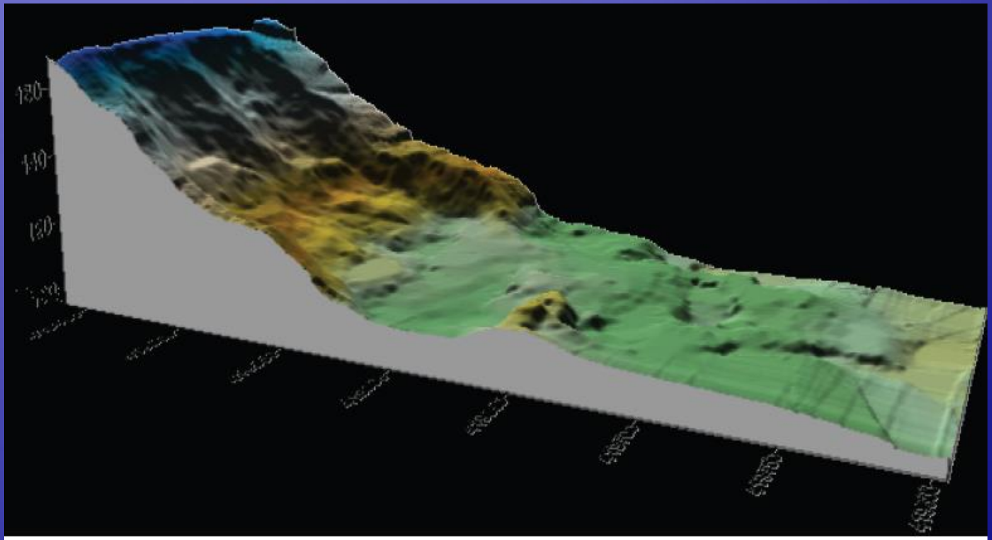


Figure 7: 3D Terrain Model produced from Terrestrial LiDAR Survey (TLS).

Building Collapse in KL due to Slope Failure after Heavy Downpours

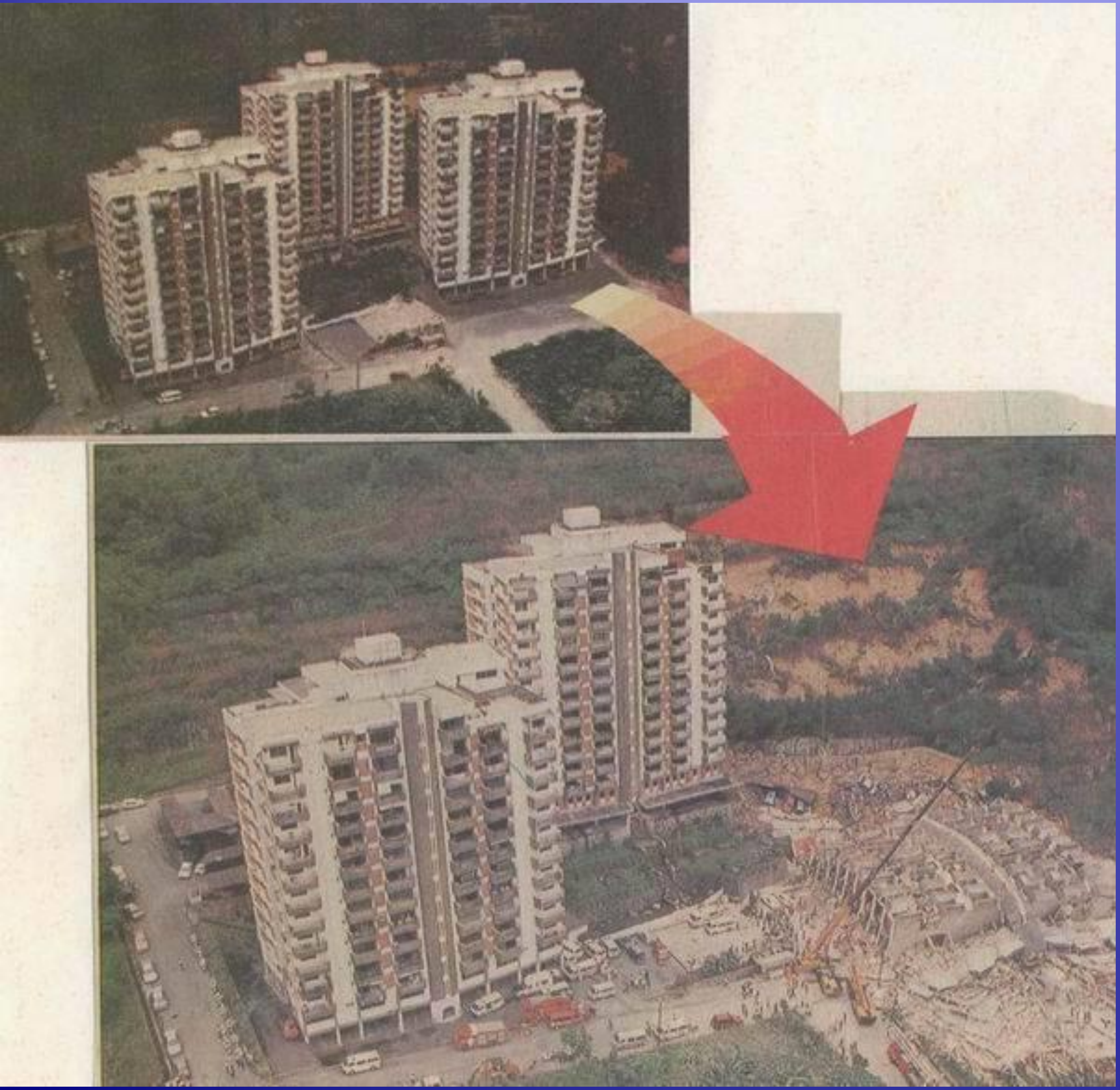
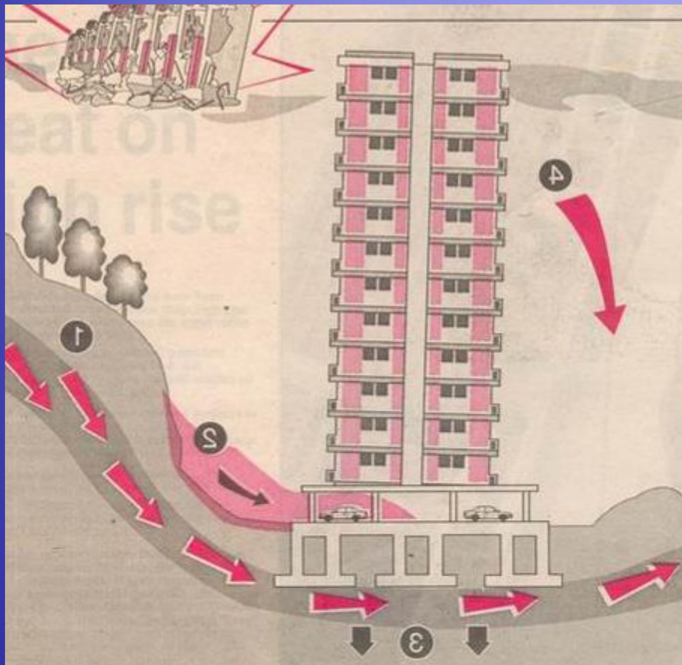


Figure 2: Highland Towers tragedy which claimed 48 lives.

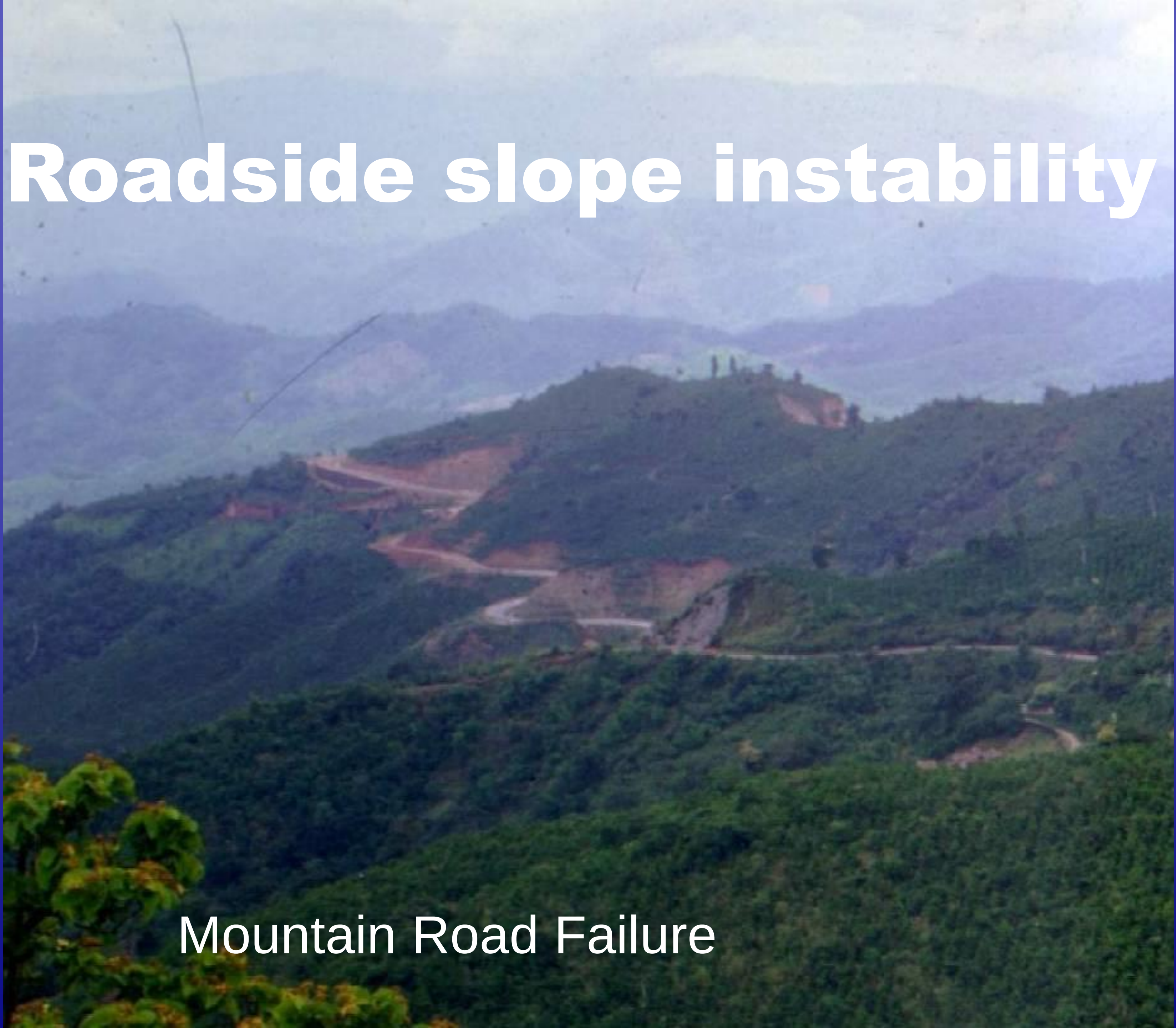
Development in Upper Hill Area !!

Increase in groundwater recharge down slope.

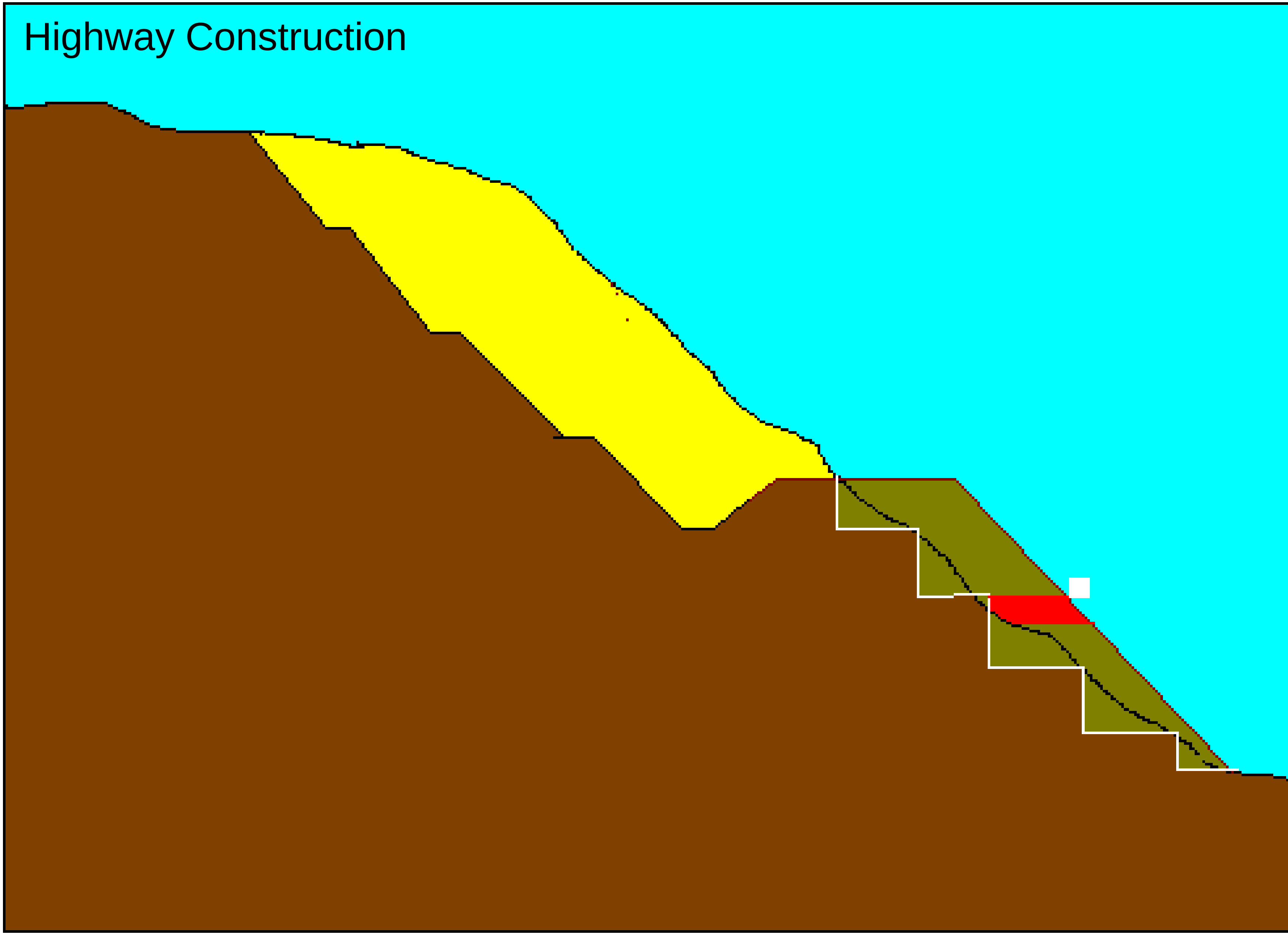



Landslide &
Building damages
25/06/08

Roadside slope instability

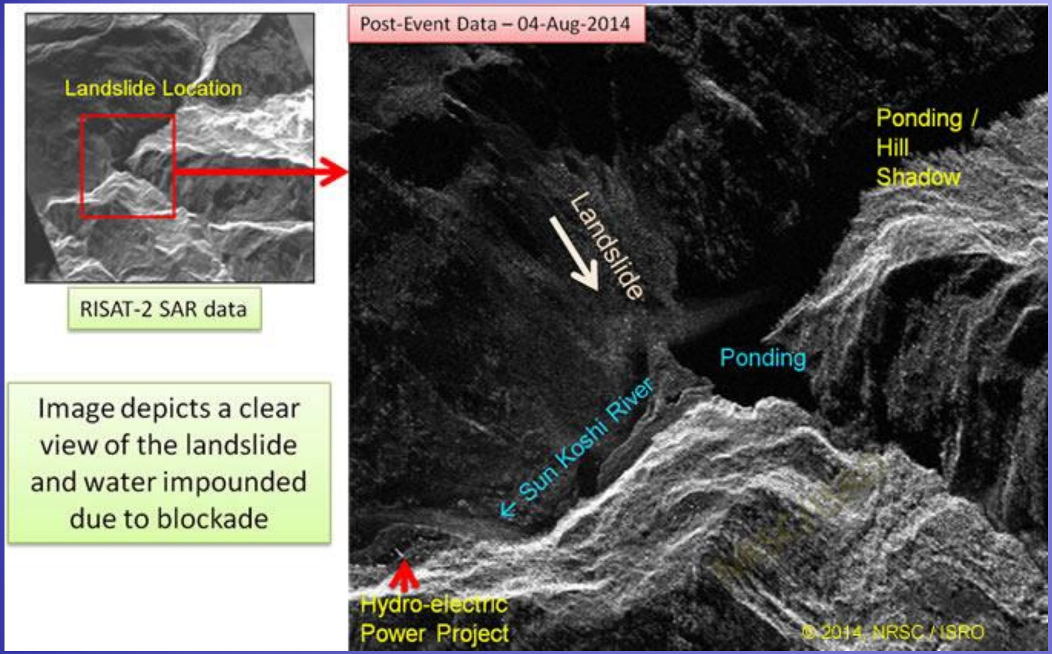


Mountain Road Failure


Highway Construction

Mountain Roads & Failures

Cut & Throw


Post-Event Data – 04-Aug-2014
Landslide Location
RISAT-2 SAR data
Image depicts a clear view of the landslide and water impounded due to blockade
Ponding / Hill Shadow
Landslide
Ponding
Sun Koshi River
Hydro-electric Power Project
© 2014, NRSC / ISRO


Pre-event LISS IV MX
Landslide crown
Depletion zone
Depletion zone
Accumulation zone
Accumulation zone
Landslide dammed lake
Landslide debris
HP site
© 2014, NRSC / ISRO
• The landslide that blocked the Sunkoshi river, is a deep seated rockslide (length 1.3 km and width 0.652 km) resulting in formation of a dammed lake
• The debris and boulders has blocked the river and moved onto the river terrace on the opposite bank.
• Analysis of historical imagery shows that it is an unstable zone with existence of small landslides.
New landslide (02.08.2014)
Depletion zone
Accumulation zone
Depletion zone
Accumulation zone
ekantipur


Sun Koshi Slide of 2014
www.upthethoughts.blogspot.com

Sliding Induced by Toe Erosion

Sliding Induced by Runoff Erosion

2010 Major highway slide in Taiwan-Heavy rain

翻攝自／Google Earth

Vaiont Dam Catastrophic Landslide in 1963

2400 Casualty

Vaiont Dam Landslide, Italy

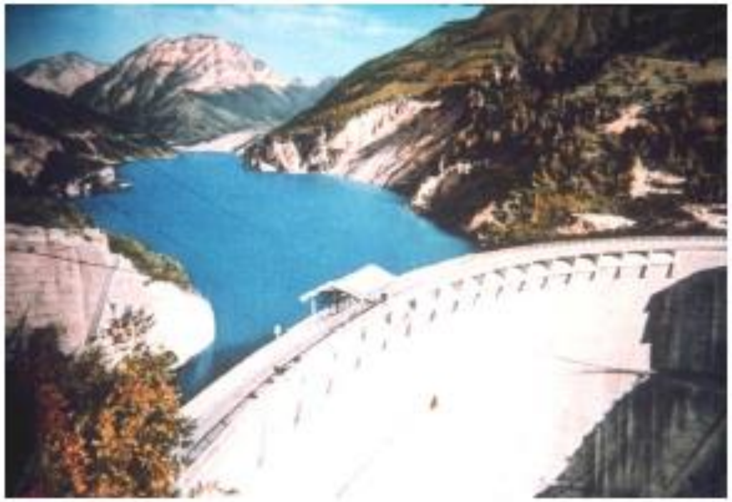


Figure 1.1a: The Vajont dam during impounding of the reservoir. In the middle distance, in the centre of the picture, is Mount Toc with the unstable slope visible as a white scar on the mountain side above the waterline.

Figure 1.1b: During the filling of the Vajont reservoir the toe of the slope on Mount Toc was submerged and this precipitated a slide. The mound of debris from the slide is visible in the central part of the photograph. The very rapid descent of the slide material displaced the water in the reservoir causing a 100 m high wave to overtop the dam wall. The dam itself, visible in the foreground, was largely undamaged.

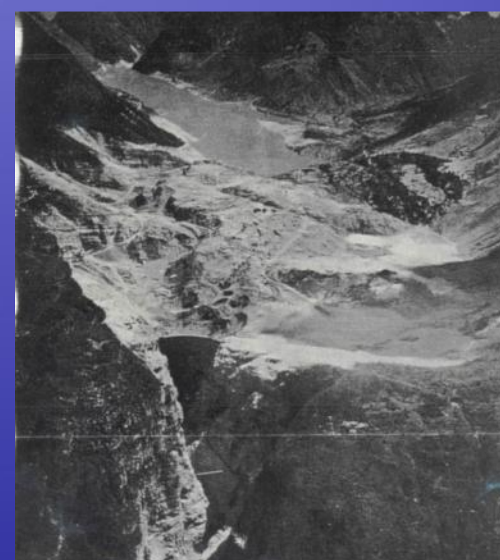


Figure GI4A - March, 1964. Fig. GI4A is an aerial view of the slide mass. The sketch shown in Fig. GI4B shows all the location names used in the text.

VAIONT RESERVOIR SLIDE, Italy, 1963

The Vaiont slide involved a magnificent dam, an awful reservoir site, and the world's worst disaster caused by civil engineering – leaving 2043 people dead.

Vaiont Dam: in Alps north of Venice; cupola (double arch) dam 266 m high, of concrete 4–23 m thick.

Landslide on 9 October 1963; 270M m^3 of rock, forming a slab 200 m thick, moved 400 m at 20–30 m/s. Landed in reservoir and created huge waves.

Wave 100 m high overtopped dam (which survived), but then destroyed Longarone and other villages.

Limestones, strong and impure, form slide mass; thin bedded with many clay horizons in lower part; interbed horizons are 5–100 mm thick, of plastic clay, PI = 30–60, ϕ = 8–10°; below slide is pure limestone.

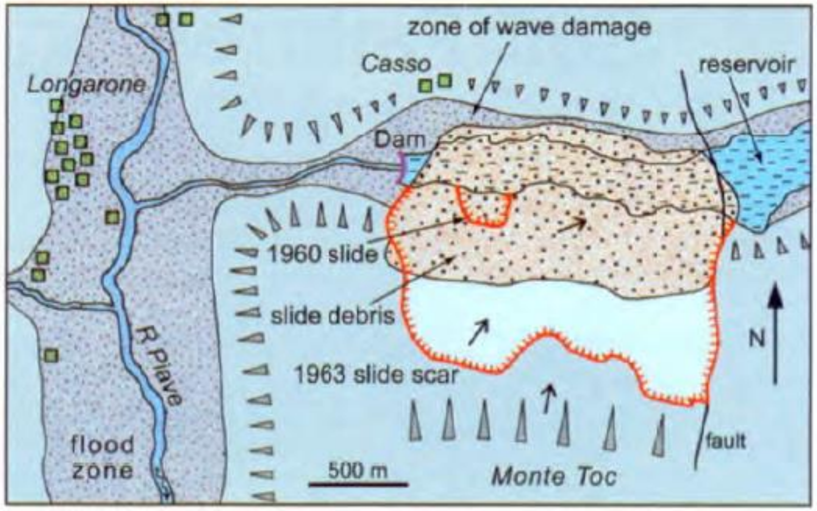
Dip = 30–45° N (downslope) at slide head, easing to 10–15° (and more towards east) near valley floor.

Slide mass was massive wedge on bedding plane slip surfaces and along faults on eastern edge. It moved as a single slab. It was a preglacial landslide mass, reactivated because new movement was possible into post-glacial Vaiont river gorge through old slide toe (this was only fully recognized after the event).

Groundwater pressures were raised by impounding the reservoir; also rose due to rainfall; high pressures beneath slide's basal clays, in limestone fed by karst sinkholes high to south. Heavy rain just before failure.

Movement of hillside was monitored since dam completed 1960; slip of 0–35 mm/day correlated with discontinuous reservoir filling; also correlated with rainfall in previous 60 days. Small part of slide failed in 1960.

Slip surface largely followed the preglacial slip plane in the clay beds; also broke across some limestone beds. Resistance to shear mainly on eastern side of the wedge, where ϕ = 36° along fractures.



Stability analysis, completed after the event and in the knowledge of the preglacial landslide slip surface, suggests factors of safety (FS) for different states. Reservoir was designed to fill to 722 m; it failed at 701 m during a wet period; but it would have failed anyway when filled to 722 m, even in dry weather.

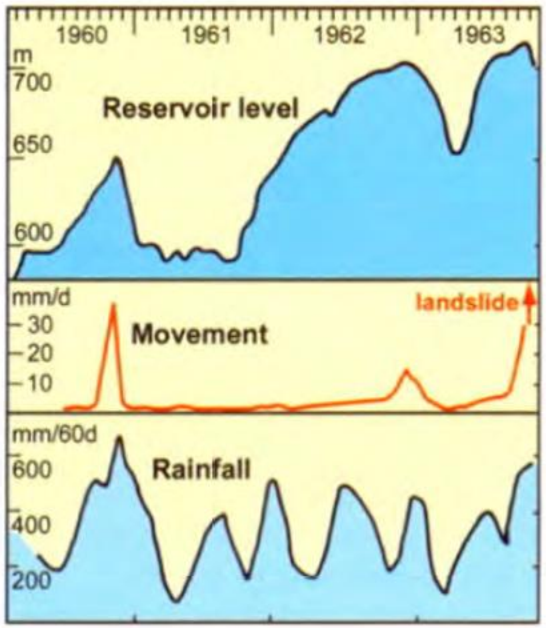
Reservoir level	Rainfall	FS
none	low	1.21
none	high	1.12
710 m	low	1.10
710 m	high	1.00
722 m	low	1.00

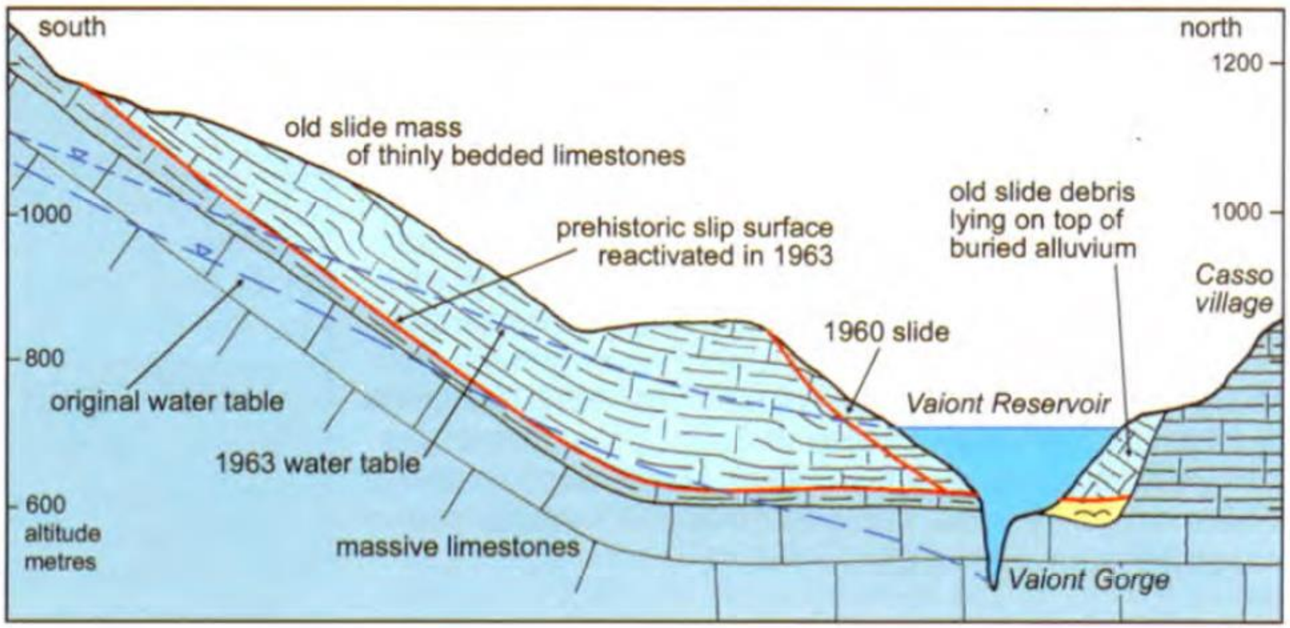
Cause: unstable dipping limestone forming old slide.

Triggers: high rainfall and reservoir impoundment.

Rapid failure: due to brittle rupture of some key limestone beds and rock units, after years of creep had reduced mass strength; borehole monitoring data suggests lack of movement and stress accumulation in toe of slide while surface was creeping.

Fatal error was to assume slide-mass would creep until it stabilized on the flatter toe. Potential instability was recognizable; a reservoir was therefore inappropriate.


1960
1961
1962
1963
m
700
650
600
Reservoir level
mm/d
30
20
10
Movement
landslide
mm/60d
600
400
200
Rainfall


south
north
1200
1000
800
600
altitude metres
old slide mass
of thinly bedded limestones
prehistoric slip surface
reactivated in 1963
old slide debris
lying on top of
buried alluvium
Casso village
1960 slide
Vaiont Reservoir
original water table
1963 water table
massive limestones
Vaiont Gorge

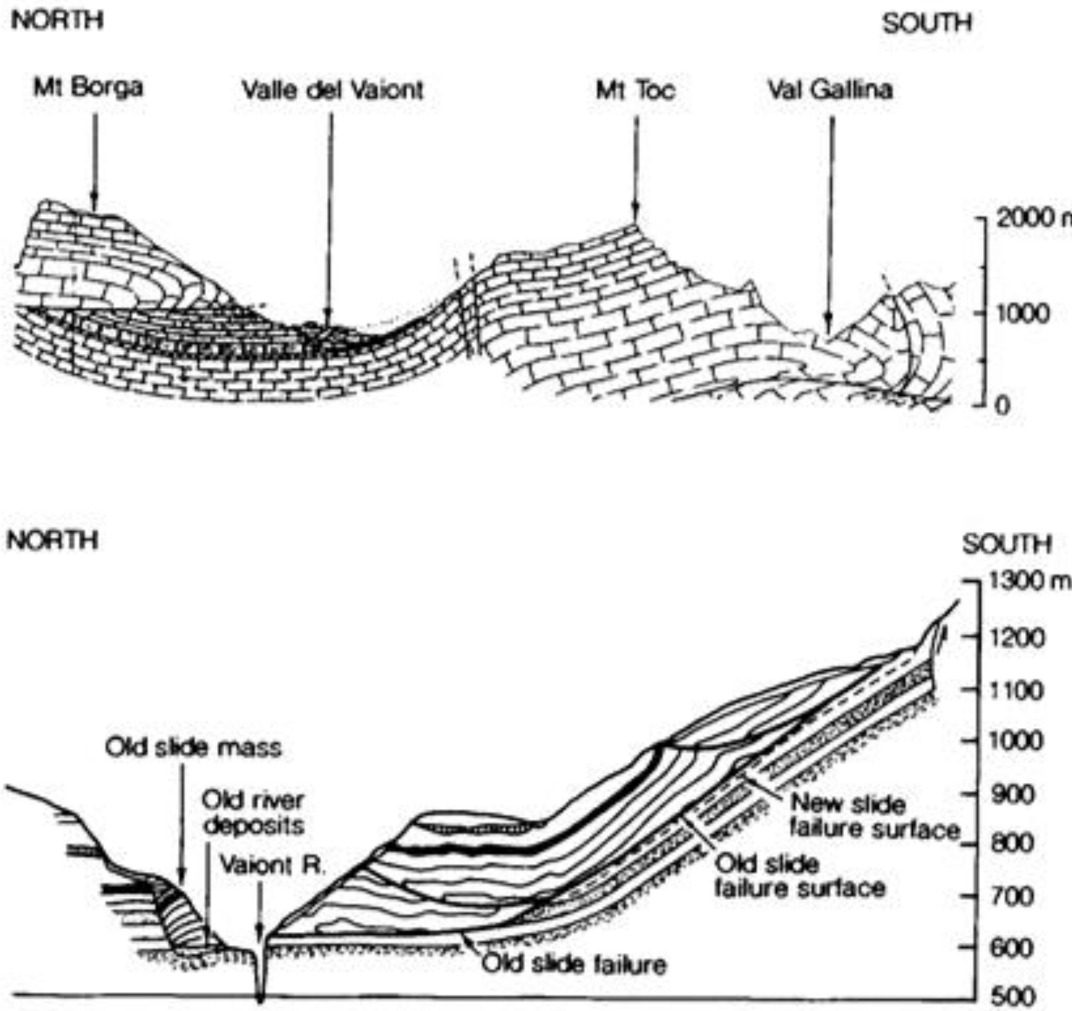
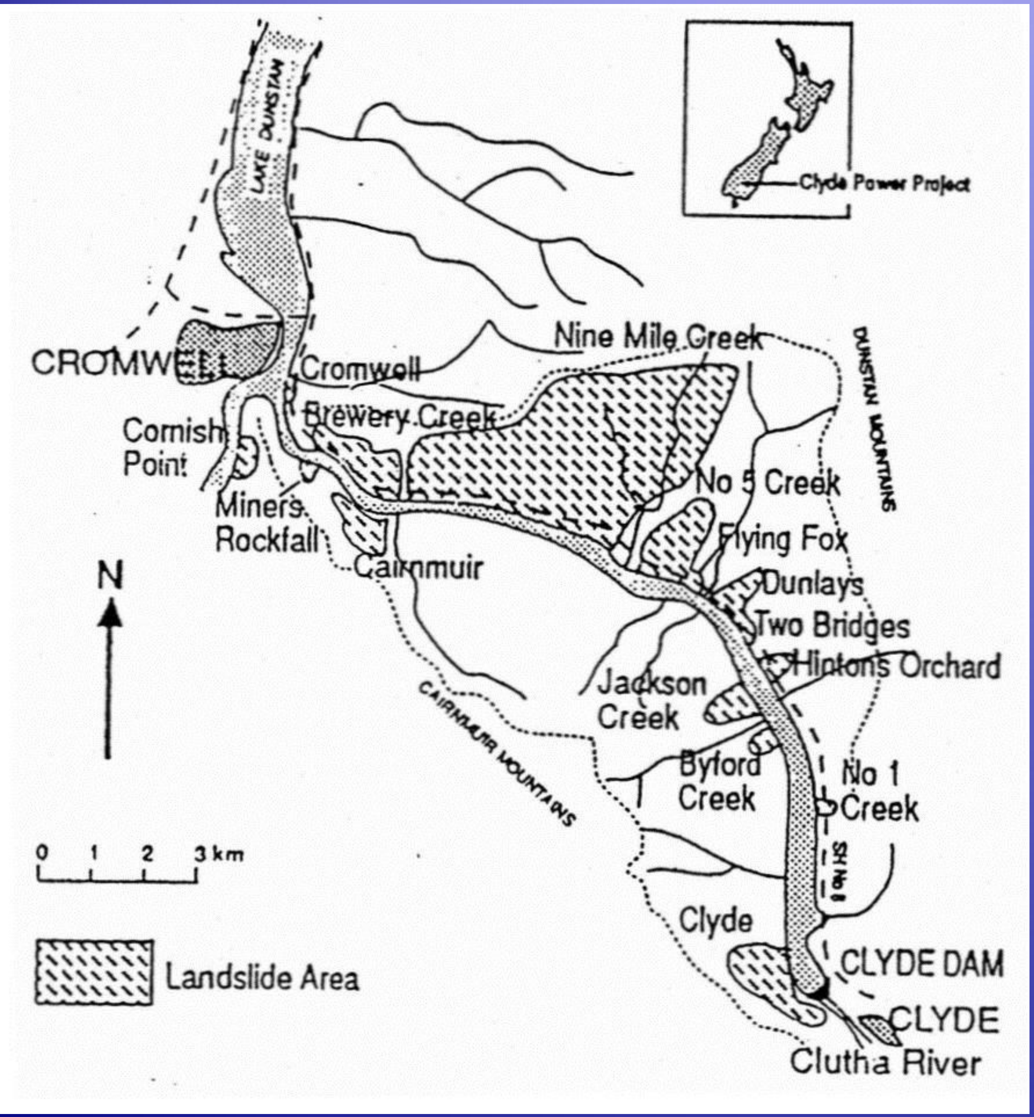
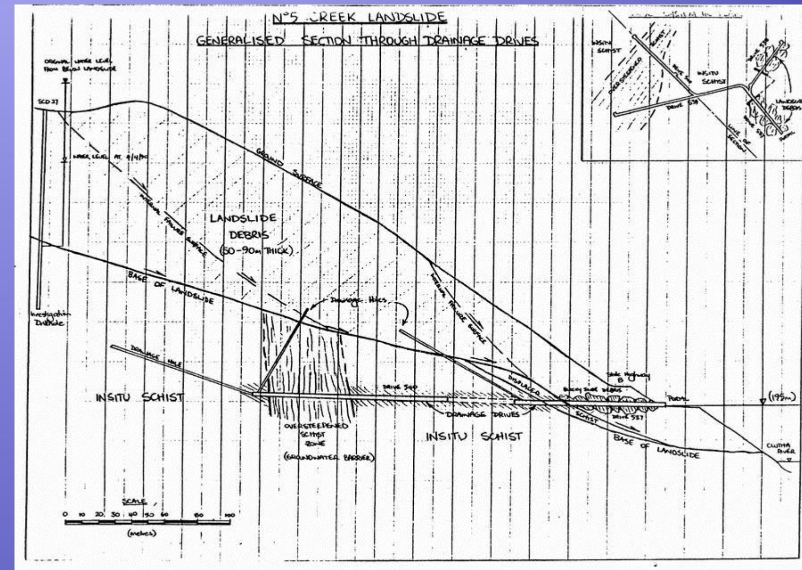


Fig. 15.20. (a) Cross-section showing the general geological structure of the Vaiont Valley (after Hendron and Patton 1985, based on the work of Semenza and Dal Cin). (b) A section across the Vaiont Valley, before the 1963 slide, showing the locations of failure planes and dip of the sedimentary rocks (after Hendron and Patton 1985, based on the work of Rossi and Semenza). In both sections the horizontal and vertical scales are the same.

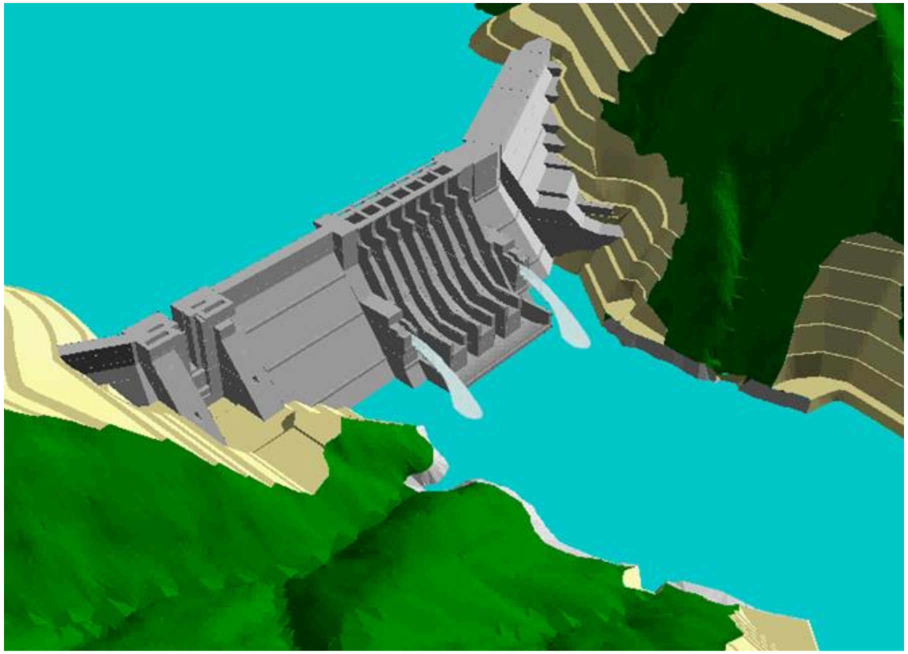
Landslide Risk of Clyde Dam, New Zealand



Clyde Dam Landslide Subsurface Drain Tunnels



Landslides in Dam Construction: Longtan Dam- Quangxi, China



2004 年 12 月龙滩水电工程施工面貌

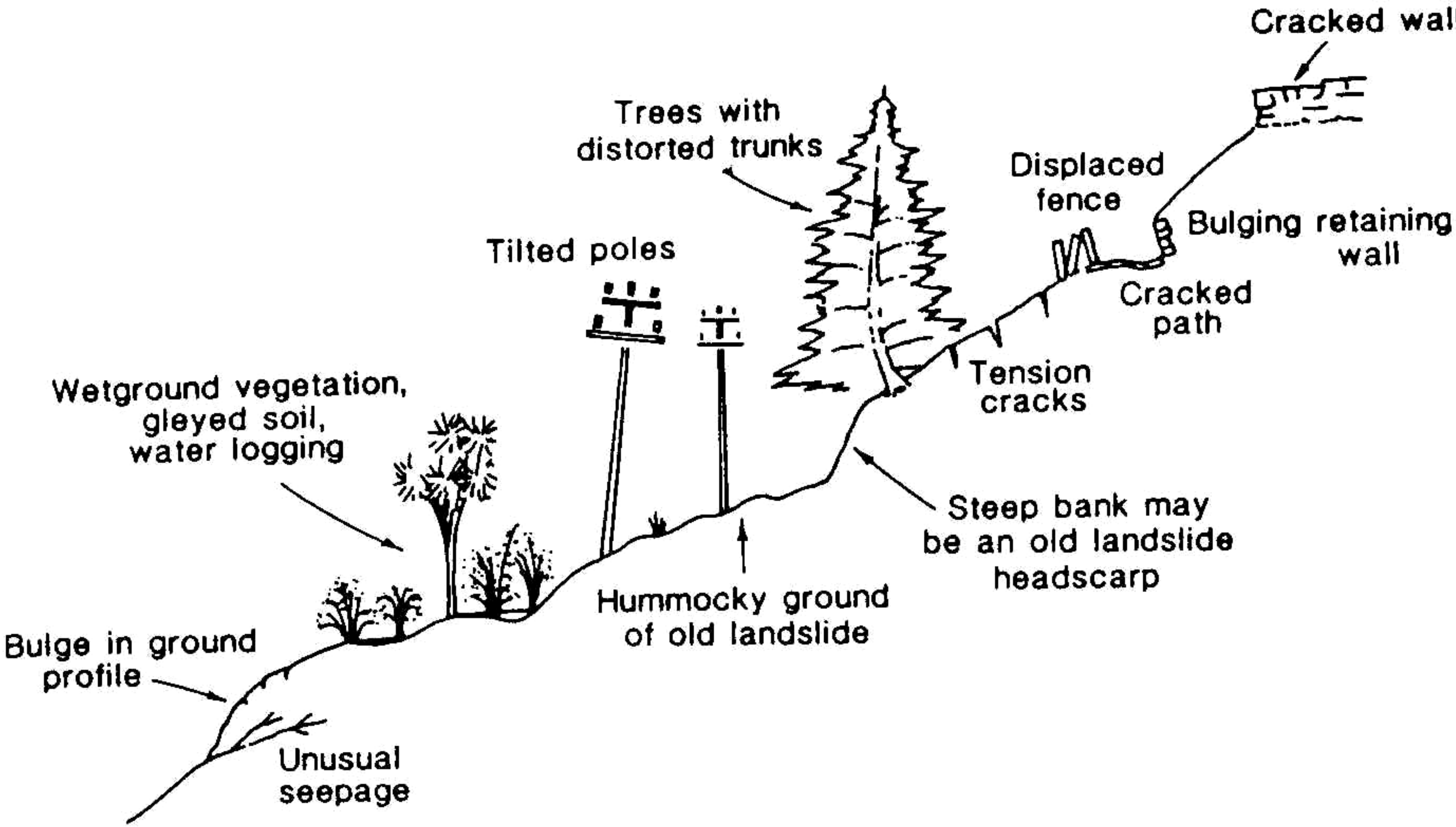
2003 年 11 月龙滩水电工程截流前面貌

Land Slide Recognition

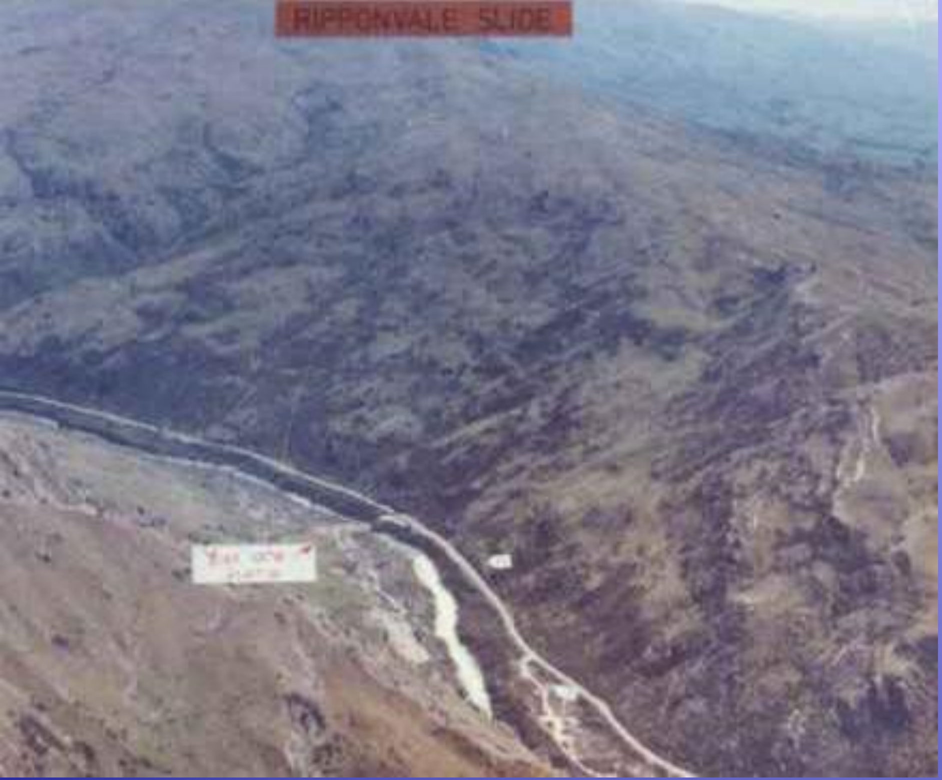
TABLE 4.5 Features Indicating Active and Inactive Landslides

Active	Inactive
Scarp, terraces, and crevices with sharp edges	Scarps, terraces, and crevices with rounded edges
Crevices and depressions without secondary infilling	Crevices and depressions infilled with secondary deposits
Secondary mass movement on scarp faces	No secondary mass movement on scarp faces
Surface-of-rupture and marginal shear planes show fresh slickensides and striations	Surface-of-rupture and marginal shear planes show old or no slickensides and striations
Fresh fractured surfaces on blocks	Weathering on fractured surfaces of blocks
Disarranged drainage system; many ponds and undrained depressions	Integrated drainage system
Pressure ridges in contact with slide margin	Marginal fissures and abandoned levees
No soil development on exposed surface-of-rupture	Soil development on exposed surface-of-rupture
Presence of fast-growing vegetation spp.	Presence of slow-growing vegetation spp.
Distinct vegetation differences "on" and "off" slide	No distinction between vegetation "on" and "off" slide
Tilted trees with no new vertical growth	Tilted trees with new vertical growth above inclined trunk
No new supportive, secondary tissue on trunks	New supportive, secondary tissue on trunks

Source: Crozier (1984).


Cracked wall
Trees with
distorted trunks
Displaced
fence
Bulging retaining
wall
Tilted poles
Cracked
path
Tension
cracks
Wetground vegetation,
gleyed soil,
water logging
Steep bank may
be an old landslide
headscarp
Hummocky ground
of old landslide
Bulge in ground
profile
Unusual
seepage

Airphotos



Hummocky Topography

Landslide a serious geologic Hazard (after Bichler et al. 2004)


Hazard Mitigation

LANDSLIDE HAZARD ASSESSMENT

↓

LANDSLIDE RISK MANAGEMENT

Disaster Management Cycle

Mitigation - Minimizing the effects of disaster.

Examples: building codes and zoning; vulnerability analyses; public education.

Preparedness - Planning how to respond.

Examples: preparedness plans; emergency exercises/training; warning systems.

Response - Efforts to minimize the hazards created by a disaster.

Examples: search and rescue; emergency relief .

Recovery - Returning the community to normal.

Examples: temporary housing; grants; medical care.

http://www.gdrc.org/uem/disasters/1-dm_cycle.html

www.unisdr.org/wcdr/preparatory-process/meetings/African-regional-consultation-2-3-jun-04/IWRM-and-DR.ppt

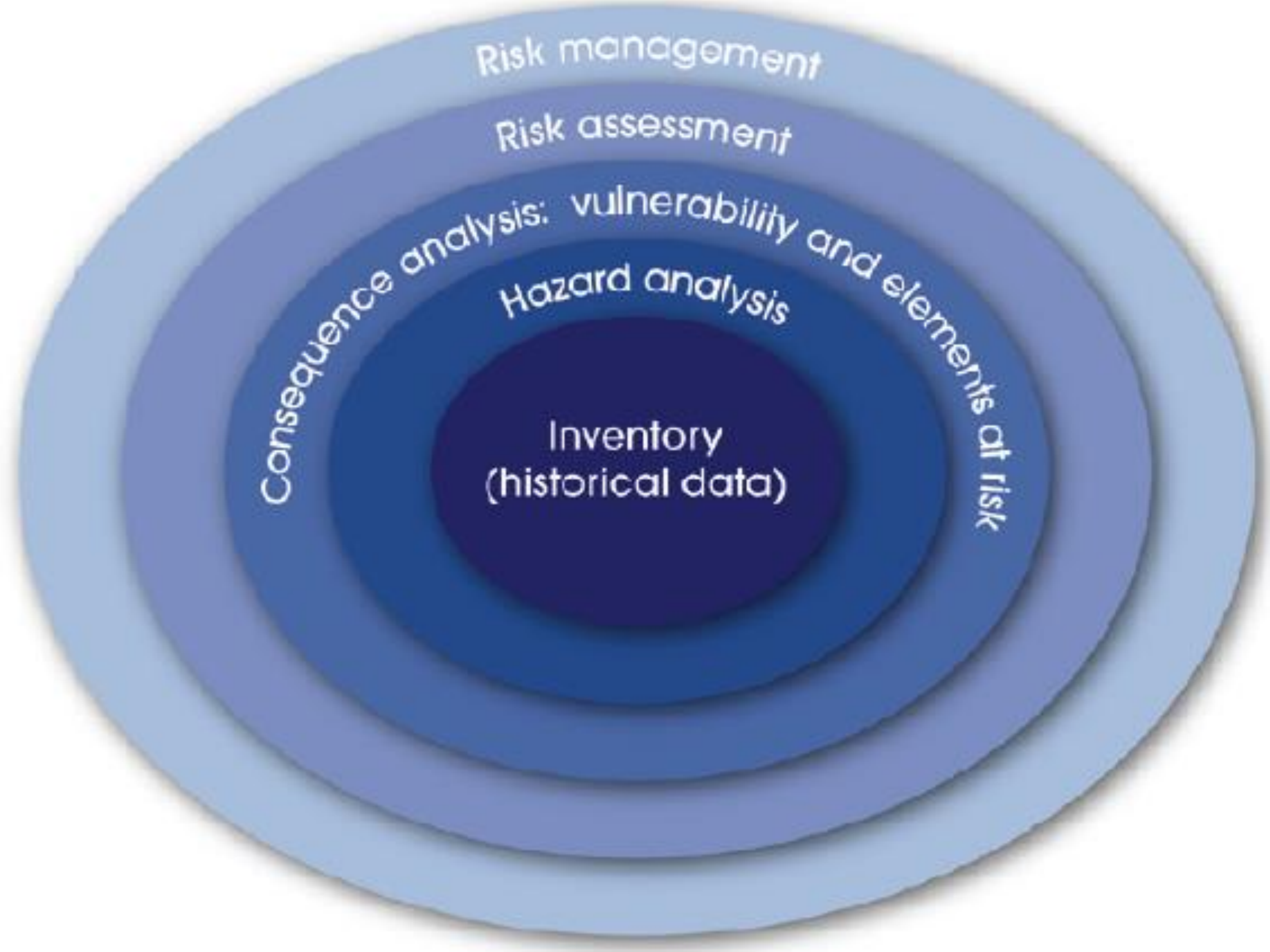
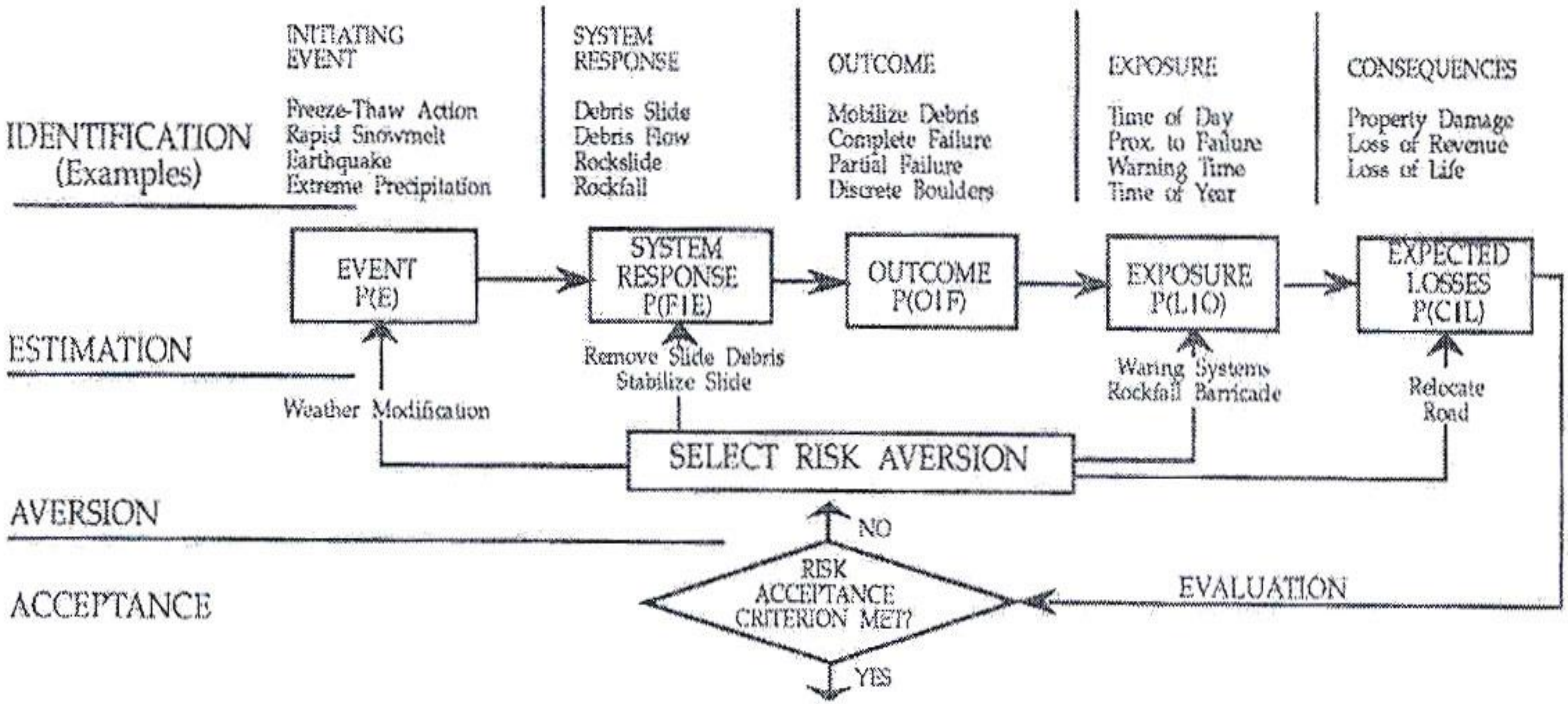


Figure 1: Integrated risk management process including risk.

Landslide Risk Management Framework



Anderson et al. (1996)

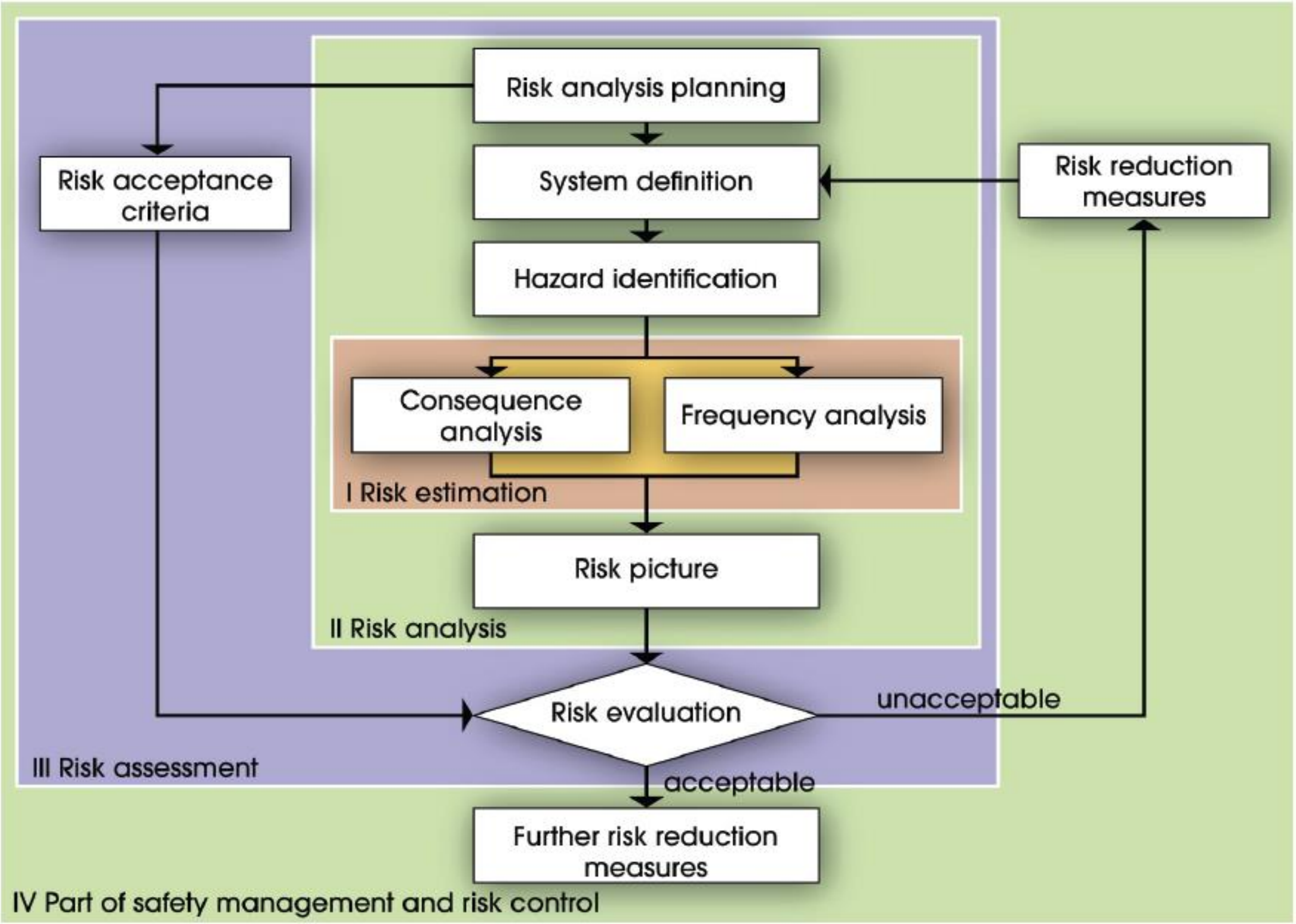
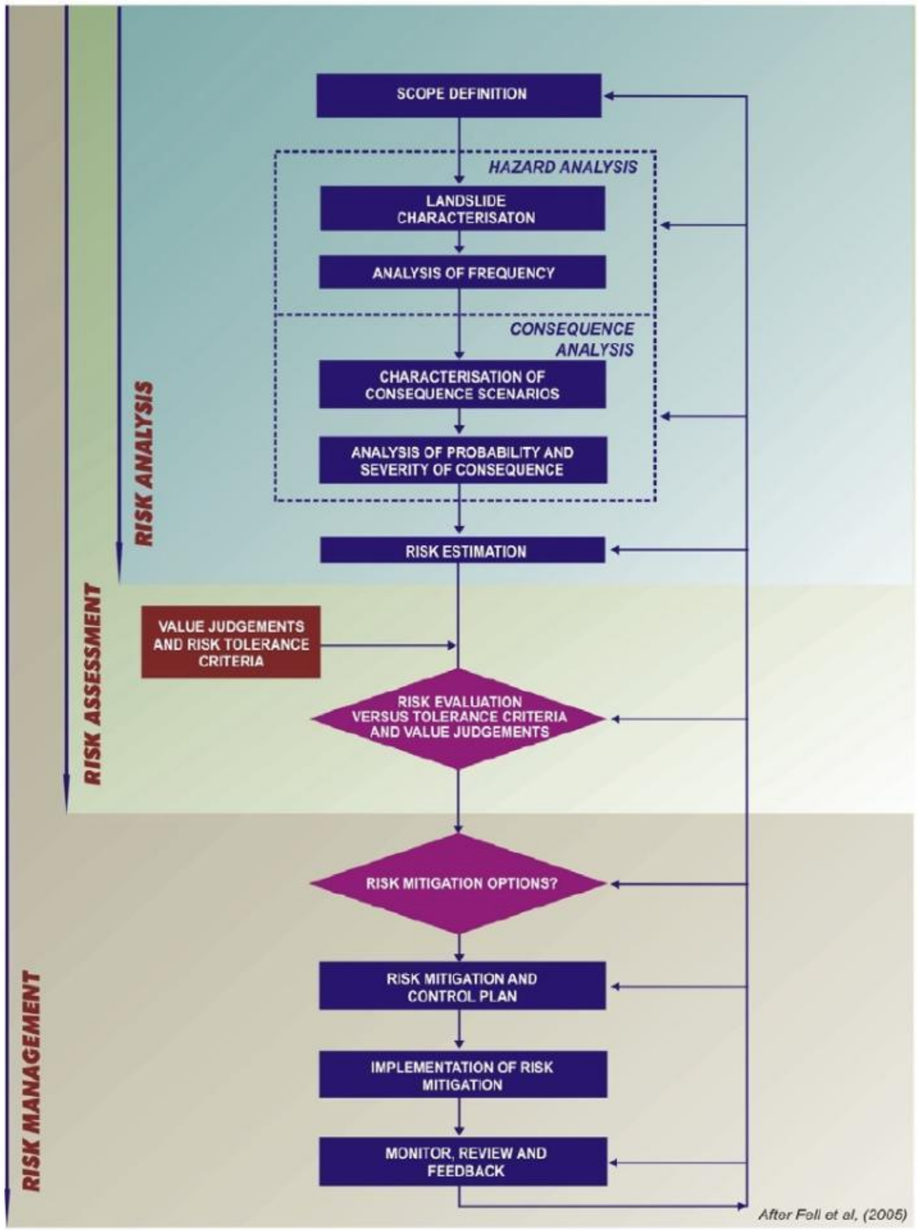


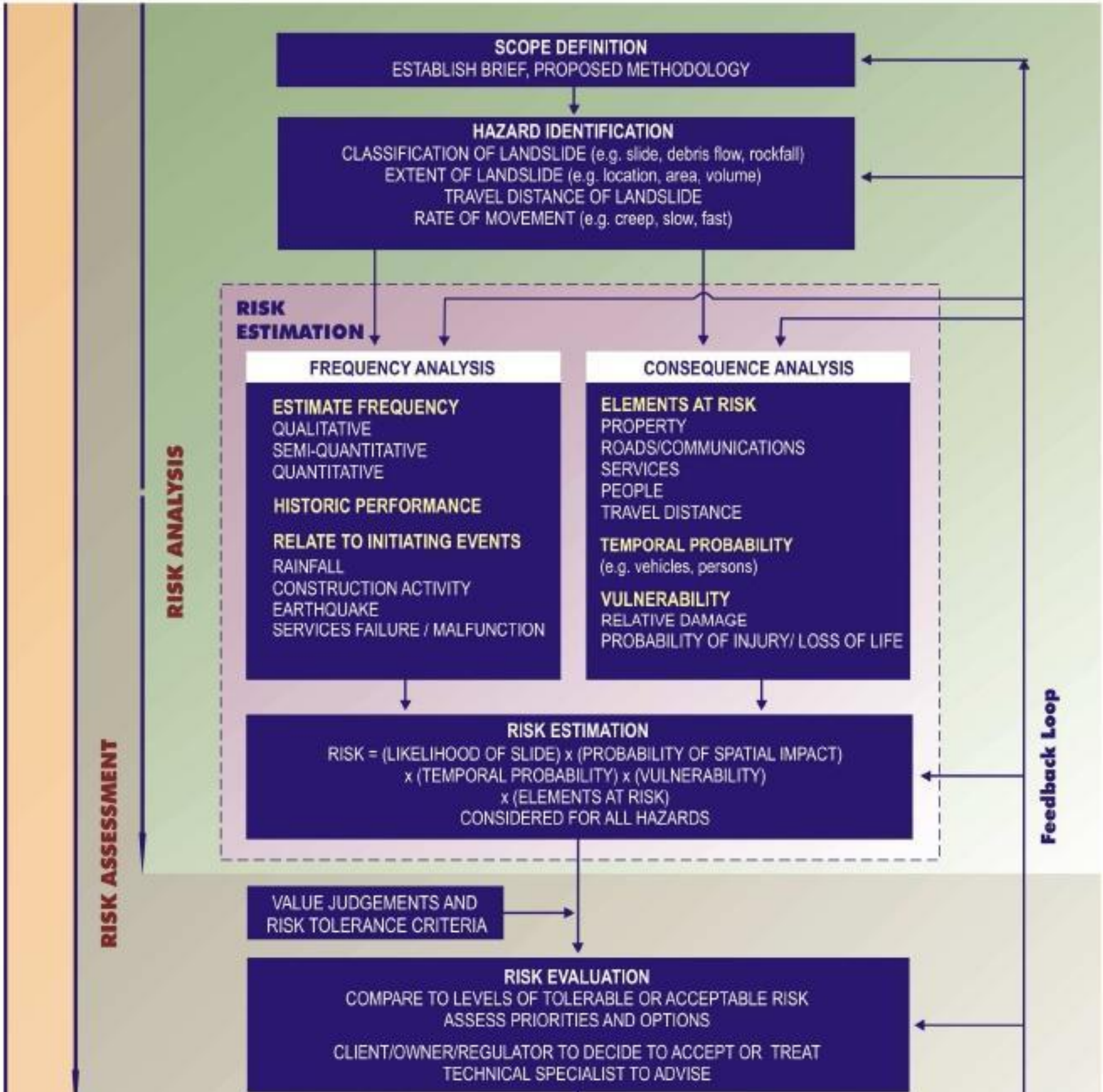
Figure 2: Risk estimation, analysis and evaluation as part of risk management and control assessment, starting wit inventory of landslides at a location. (NORSOK Standard Z-013, 2001).

GUIDELINE FOR LANDSLIDE SUSCEPTIBILITY, HAZARD AND RISK ZONING

Figure 1. FRAMEWORK FOR LANDSLIDE RISK MANAGEMENT



LANDSLIDE RISK ASSESSMENT & MANAGEMENT



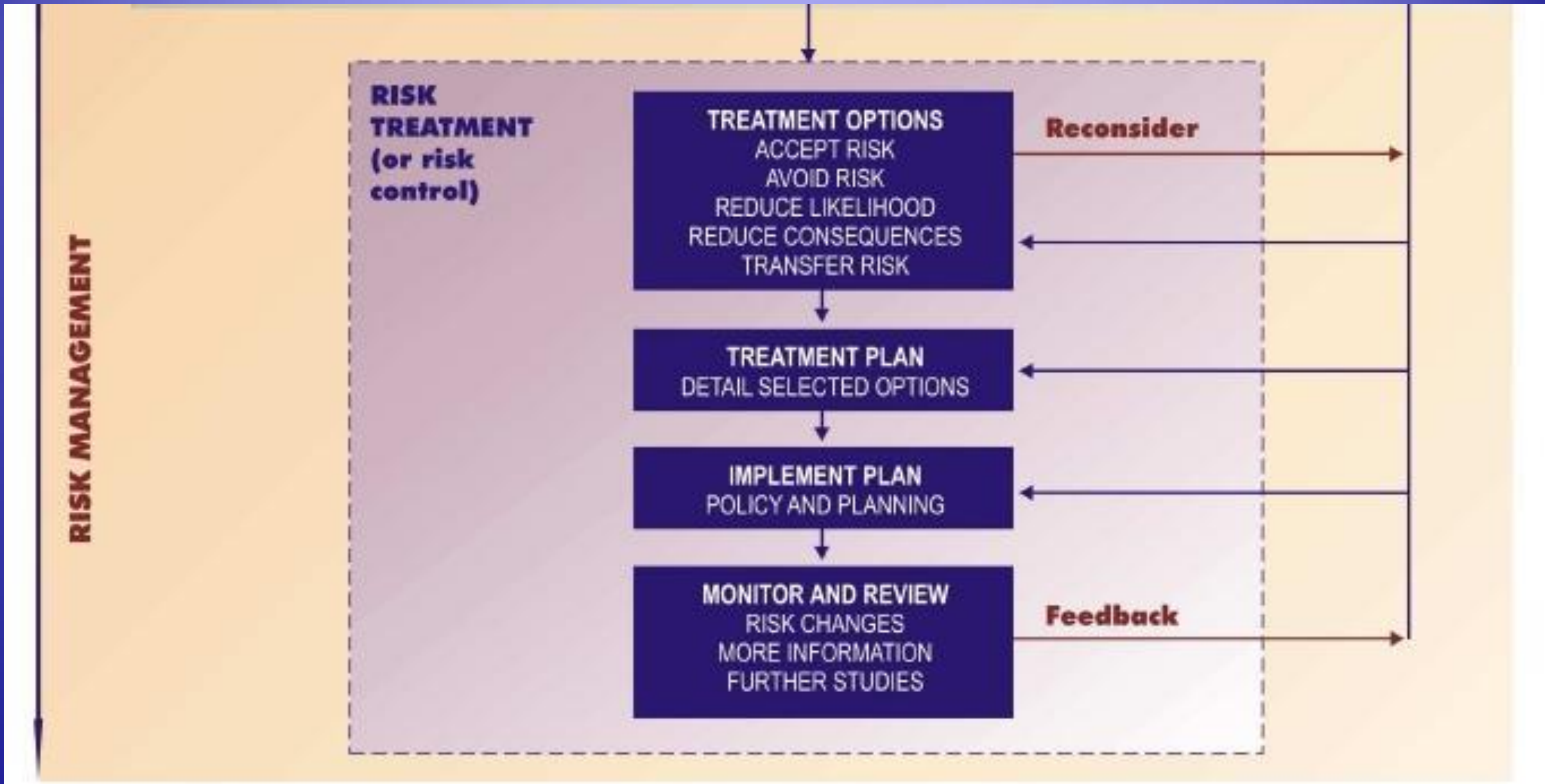


Figure 1: Flowchart for Landslide Risk Management
(after AGS 2000).

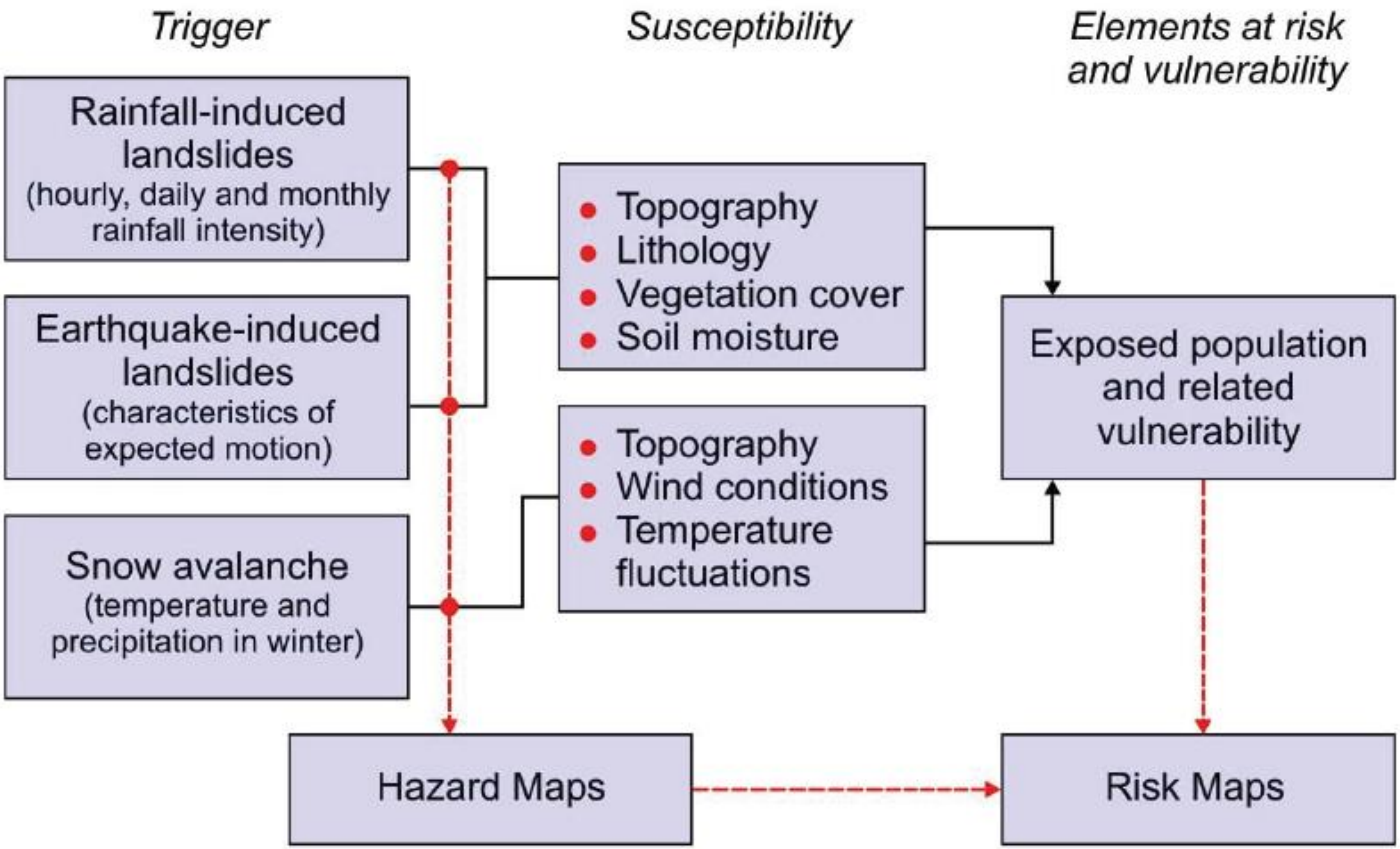


Figure 6: Schematic approach for landslide hazard and risk evaluation (Nadim *et al*., 2006).

Terminology

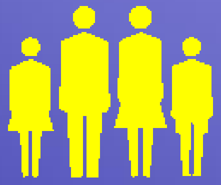
- Elements at Risk
- Vulnerability
- Landslide Hazard
- Risk
- Consequences
- Landslide inventory
- Landslide susceptibility

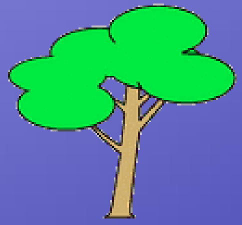
Terminology

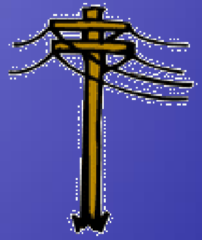
- **Element at Risk**

"humans, property, the environment, and other things of value, or some combination of these that are put at risk"

E =







Terminology

- **Vulnerability**

“the degree of loss to a given element or set of elements within the area affected”

$$V = P_{spatial} \times P_{temporal} \times P_{loss}$$

Terminology

- **Consequence**

“the effect on human well being, property, the environment, or other elements of value ”

$$C = E \times V$$

Terminology

- **Hazard**

“a source of harm, in terms of health, property, the environment, and other things of value”

H = P or P(SL) or P(H)

Terminology

- Element at Risk (E)    
- Vulnerability (V) $V = P_{spatial} \times P_{temporal} \times P_{loss}$
- Consequence (C) $C = E \times V$
- Hazard (H) $H = P$ or $P(SL)$ or $P(H)$
- Risk

"the chance of injury or loss as defined as a measure of the probability and vulnerability of human injury, property, the environment, or other elements of value"

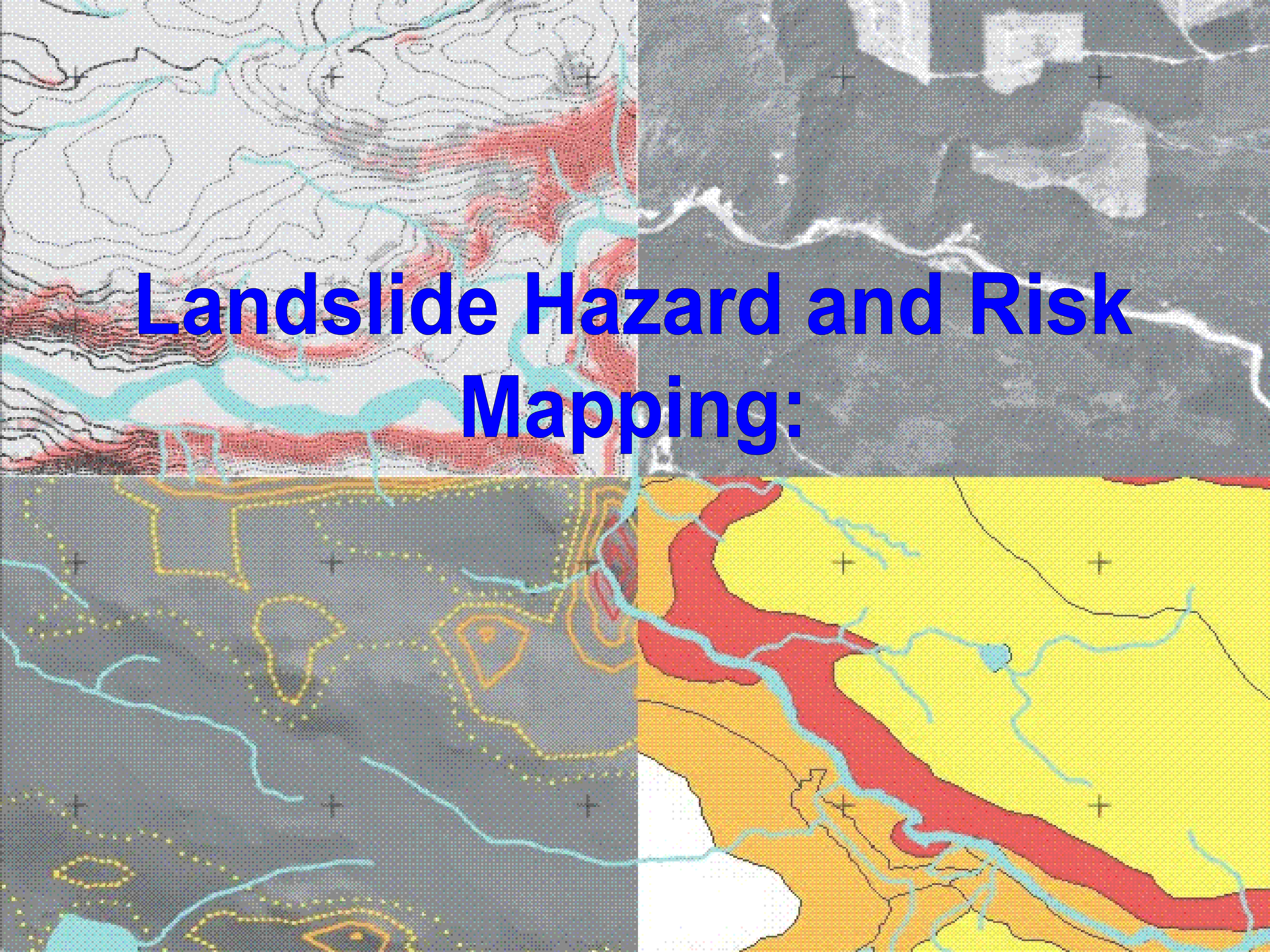
$$R = P(H) \times E \times V \quad \text{or} \quad P(H) \times C$$

Terminology

- Element at Risk (E)

- Vulnerability (V) — $V = P_{spatial} \times P_{temporal} \times P_{loss}$
- Consequence (C) — $C = E \times V$
- Hazard (H) — H = P or P(SL) or P(H)
- Risk (R) — $R = P(H) \times C$

Landslide Hazard and Risk Mapping:



Landslide Hazard Zonation

- Landslide hazard zonation is the division of the land surface into homogeneous areas or domains and their ranking according to different degrees of hazard due to mass-movement
  - help the planners to choose favorable location for site development schemes
  - help to adopt suitable precautionary measures

Landslide Hazard Assessment

- The first step to avoid, to limit the damage from any kind of mass movement is to assess the possible hazard realistically.
- Can be Qualitative or Quantitative.
- Aims:
  - The nature, severity and the frequency of the hazards,
  - The areas likely to be affected and
  - The time and duration of the impact

Landslide Map Types

Landslide maps can be divided into three broad types

depending on the information displayed and the level

of interpretation.

- **Landslide Inventory Map**
- **Landslide Susceptibility (Hazard) Map**
- **Landslide Risk Map**

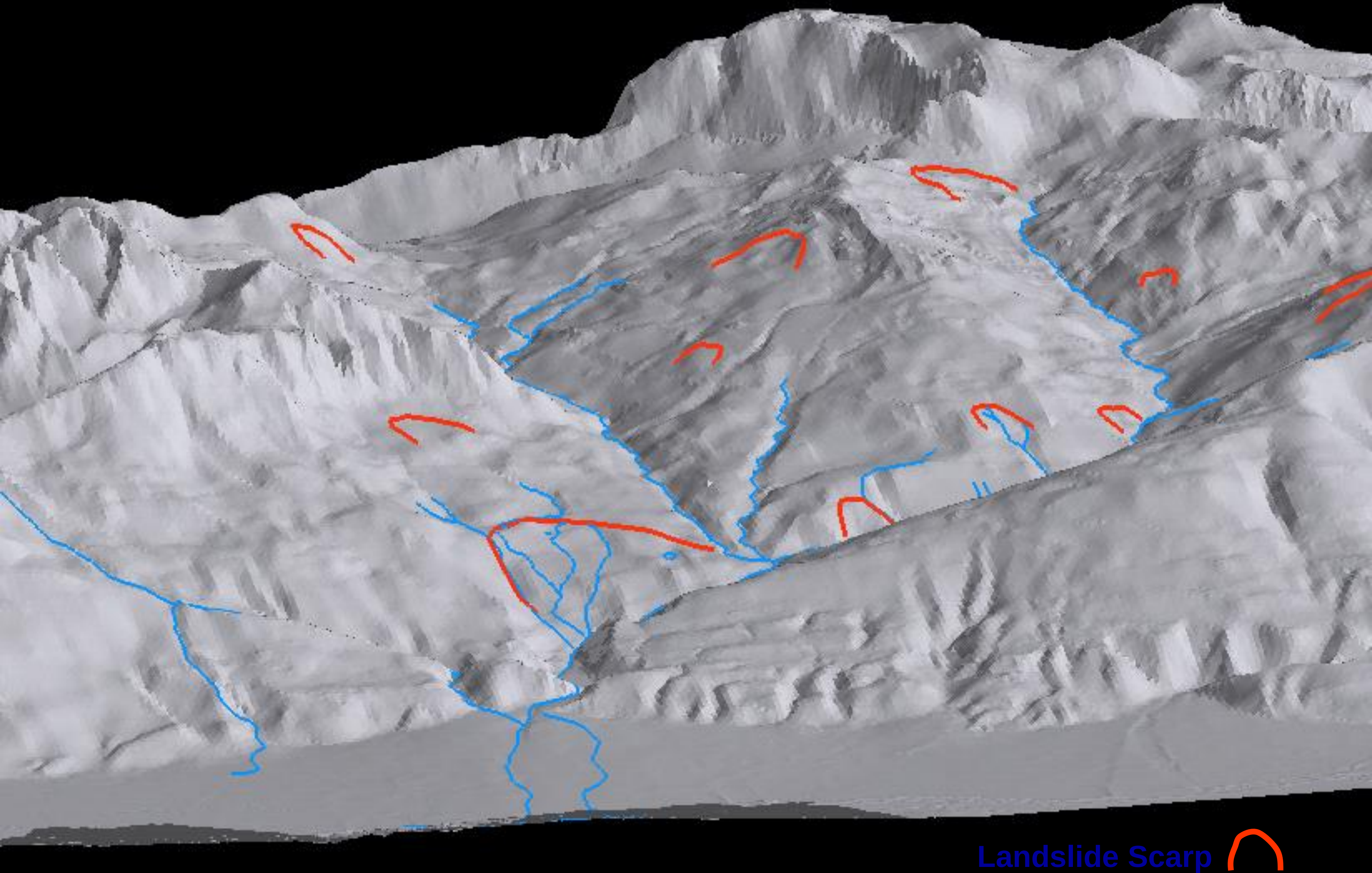
Landslide Inventory Map

Shows the spatial distribution of past and active landslides, or landslide attributes, within a region

- Provide no interpretation about the relationship between landslides, landslide attributes and slope stability or consequences

- Special case is the 'elements at risk' map

Landslide Inventory Map



TRIGGERING FACTORS

- **Rainfall -** decrease the shear resistance of soil
- **Bedrock geology -** weathered condition, discontinuities, dips and strikes
- **Slope -** most debris flows on slopes of 26° - 45°
- **Vegetation cover** - root system reinforce the soil, hydrological or mechanical in nature
- **Earthquake**
- **Anthropogenic activities**

Environmental Attributes

- Anthropogenic Activity
- Bedrock Geology
- Climate
- Geomorphology
- Geotechnical Properties
- Hydrogeology
- Hydrology
- Landslides
- Neotectonics
- Quaternary Geology
- Vegetation
- Weathering

Environmental Attributes

- Anthropogenic Activity
- Bedrock Geology
- Climate
- **Geomorphology**
- Geotechnical Properties
- Hydrogeology
- Hydrology
- Landslides
- Neotectonics
- Quaternary Geology
- Vegetation
- Weathering

Depositional environment	
Elevation	
Expression	**Aerial extent**
	Form
	Thickness
Processes	**Deposition**
	Erosion
	Gullying
	Landslides
	Seepage
Slope morphology	**Aspect**
	Curvature
	Gradient
	Length
	Position
	Uniformity

Rating for the parameters used to determine the state of nature (SN)

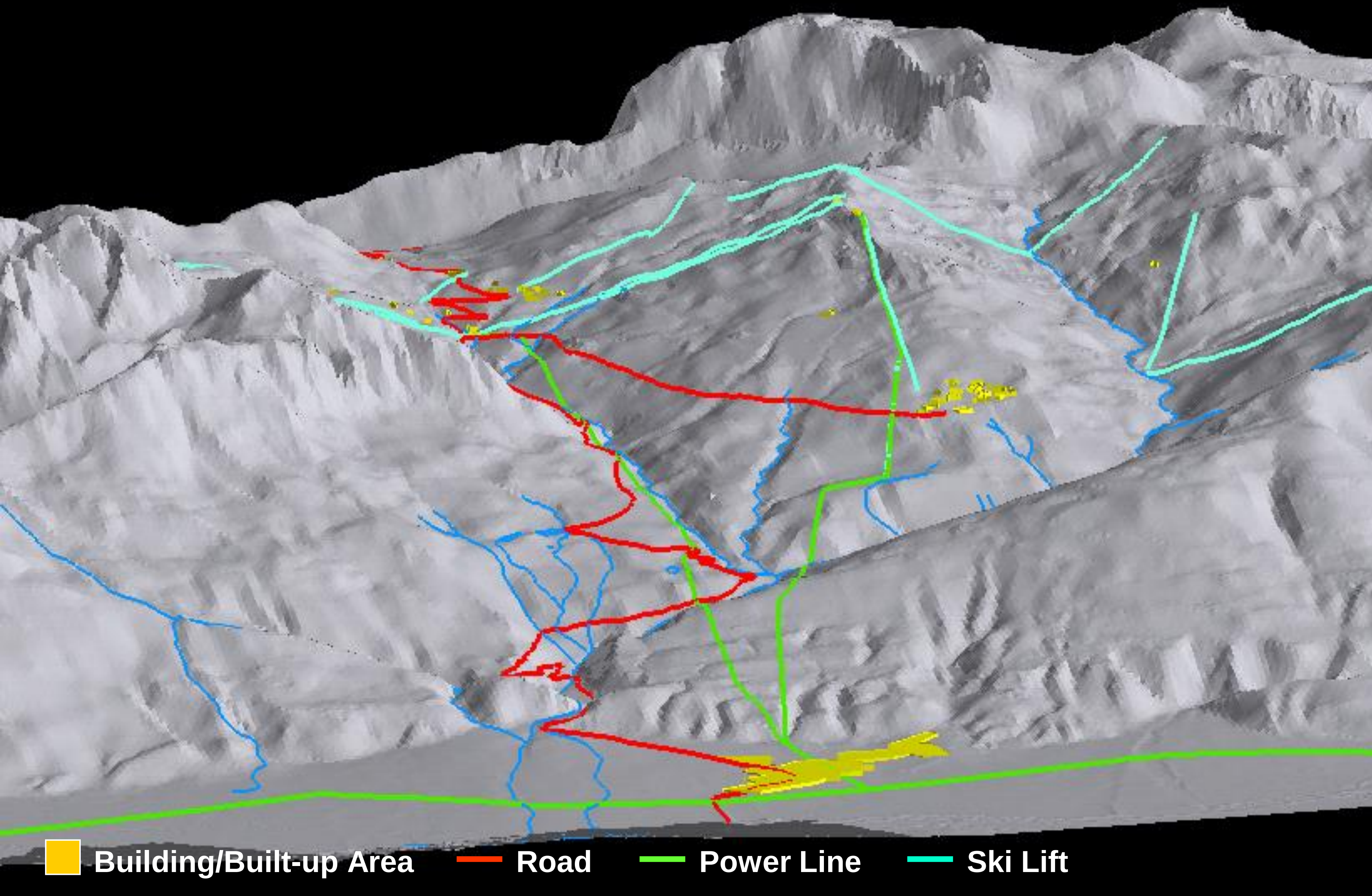
Topography				Drainage			
Slope Deg.	Rating	Relative Relief (m)	Rating	Surface drainage type	Rating	Ground water depth (m)	Rating
Soil Slope		0-50	0	Simple	0	Dry	0
0-5	0	51-100	0.03	Active	0.04	Wet	0.04
15-25	0.05	101-150	0.06	Very		Flowing	0.09
16-25	0.1	150-200	0.09	Active	0.08		
26-35	0.14	>200	0.12				
36-45	0.12						
>45	0.1						
Rock Slope							
<45	0						
46-60	0.03						
>60	0.14						

Landuse		Fault		Soil			
Type	Rating	Distance from Road (m)	Rating	Soil Type	Rating	Soil depth (m)	Rating
Thick vegetation	0	>50	0.16	Compact alluvium	0- 0.04	<1	0
Mod Vgtn	0.03	51 – 100	0.08	Loose alluvium	0.07 - 0.12	1-3	0.04
Sparse	0.06	>100	0.04	Colluvium	0.06 - 0.08	4-6	0.06
Barren	0.09			Eluvium	0.04 - 0.06	7-10	0.10
Cultivated	0.09			Talus	0.08 - 0.12	11-15	0.12
				Till	0.06 - 0.12	16-20	0.08
				Debris	0.06 - 0.12	>20	0.05

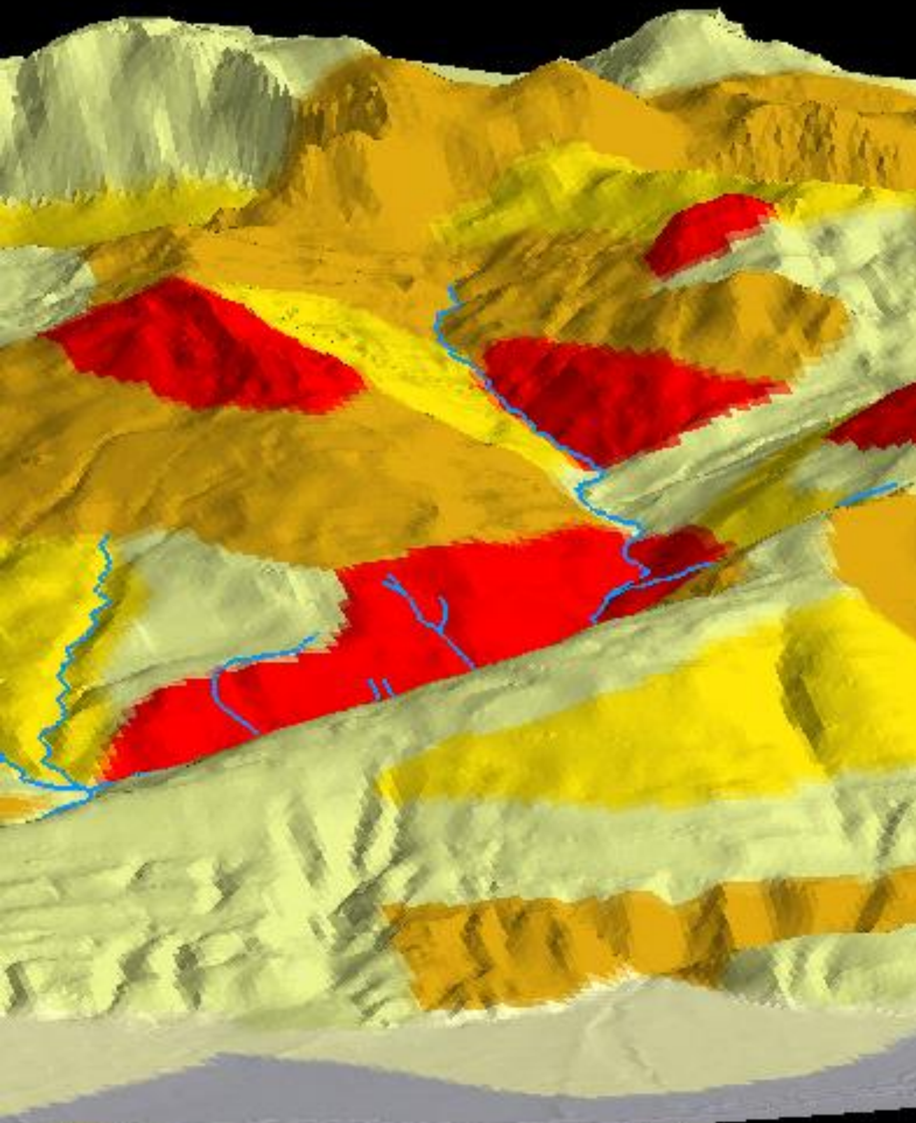
Lithology/Structure							
Rock	Rating	Weathering Grade	Rating	Joint spacing	Rating	Orientation of discontinuity	Rating
Massive, Resistant Limestone quartzite	0	Fresh	0	Wide, >1m	0	Slope oblique to joint/beding> 30°	0
Highly cemented, conglomerate	0.01	Moderate	0.02	Medium 51-100cm	0.03	Dip slope of* joint+15°	0.04
Soft rock	0.02	High	0.04	Close, 50-10 cm	0.04	Dip slope of beding+15°	0.08
*Alternative phylite quartzite	0.04	Complete	0.06	Tight. <10cm	0.06		
Weak rock crushed	0.06						

Landslide Hazard/Susceptibility Map

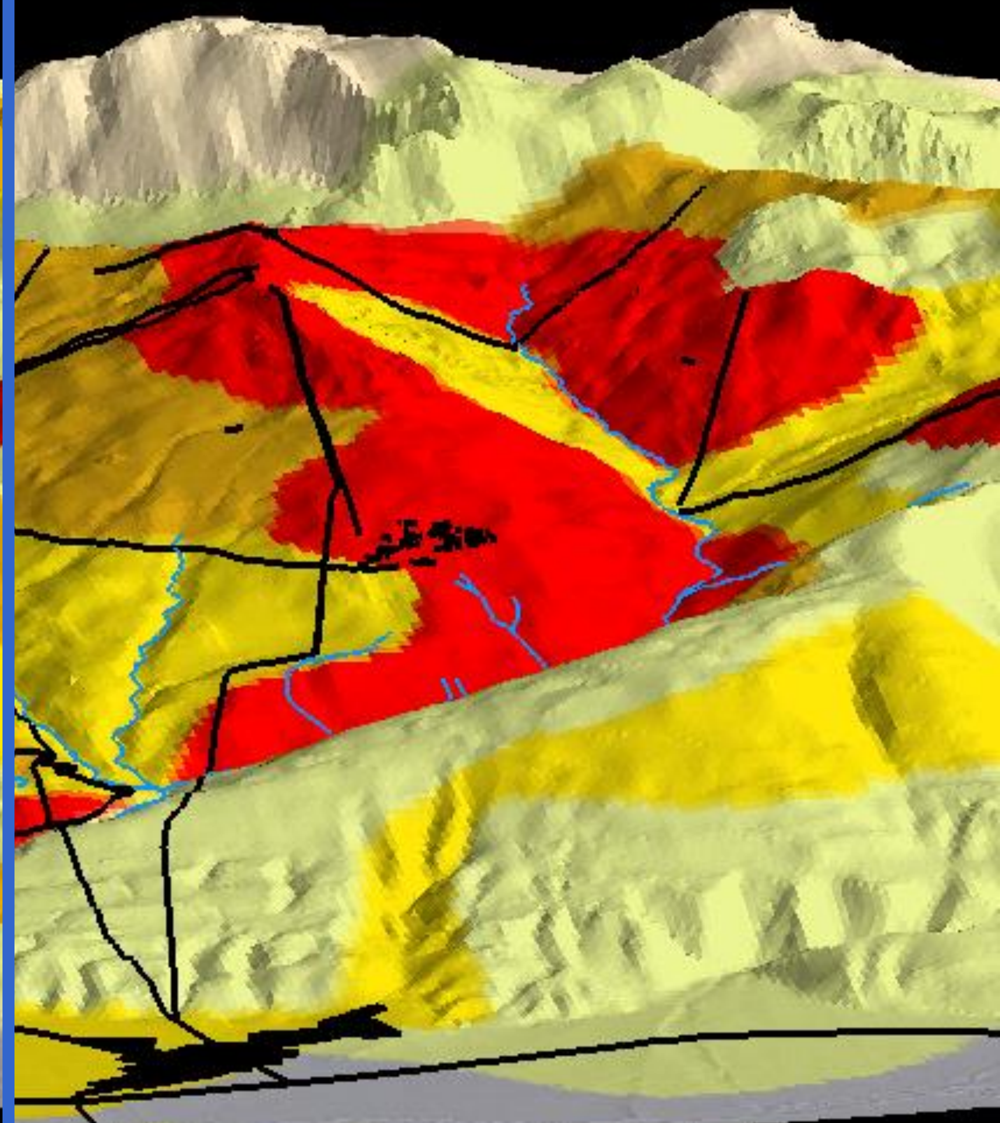
- Shows the spatial distribution of the susceptibility of an area to landslides
  - Derivative maps and are interpreted from one or more inventory maps
  - Can only be considered a “Hazard” map if it takes into account the elements at risk
  - Degree of interpretative subjectivity is dependant on the method used


Building/Built-up Area
Road
Power Line
Ski Lift

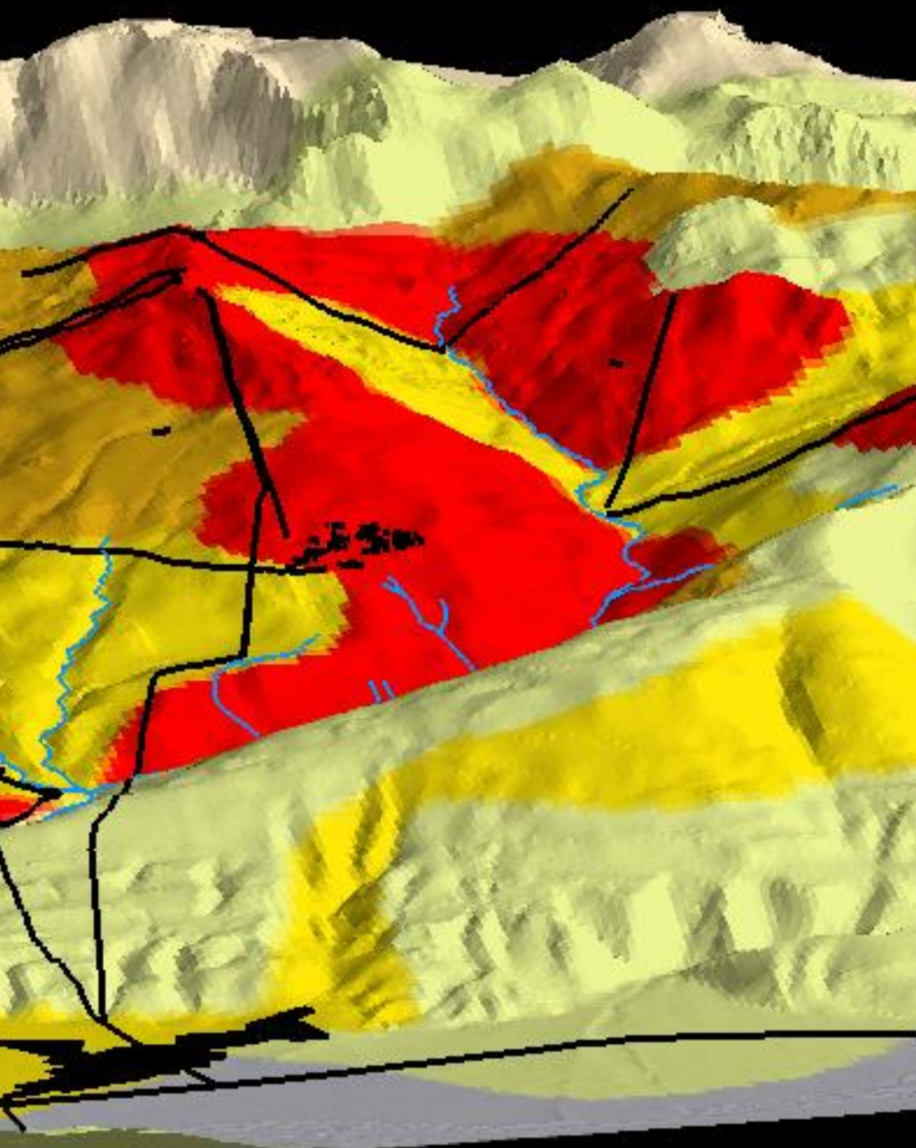
Landslide Susceptibility Map



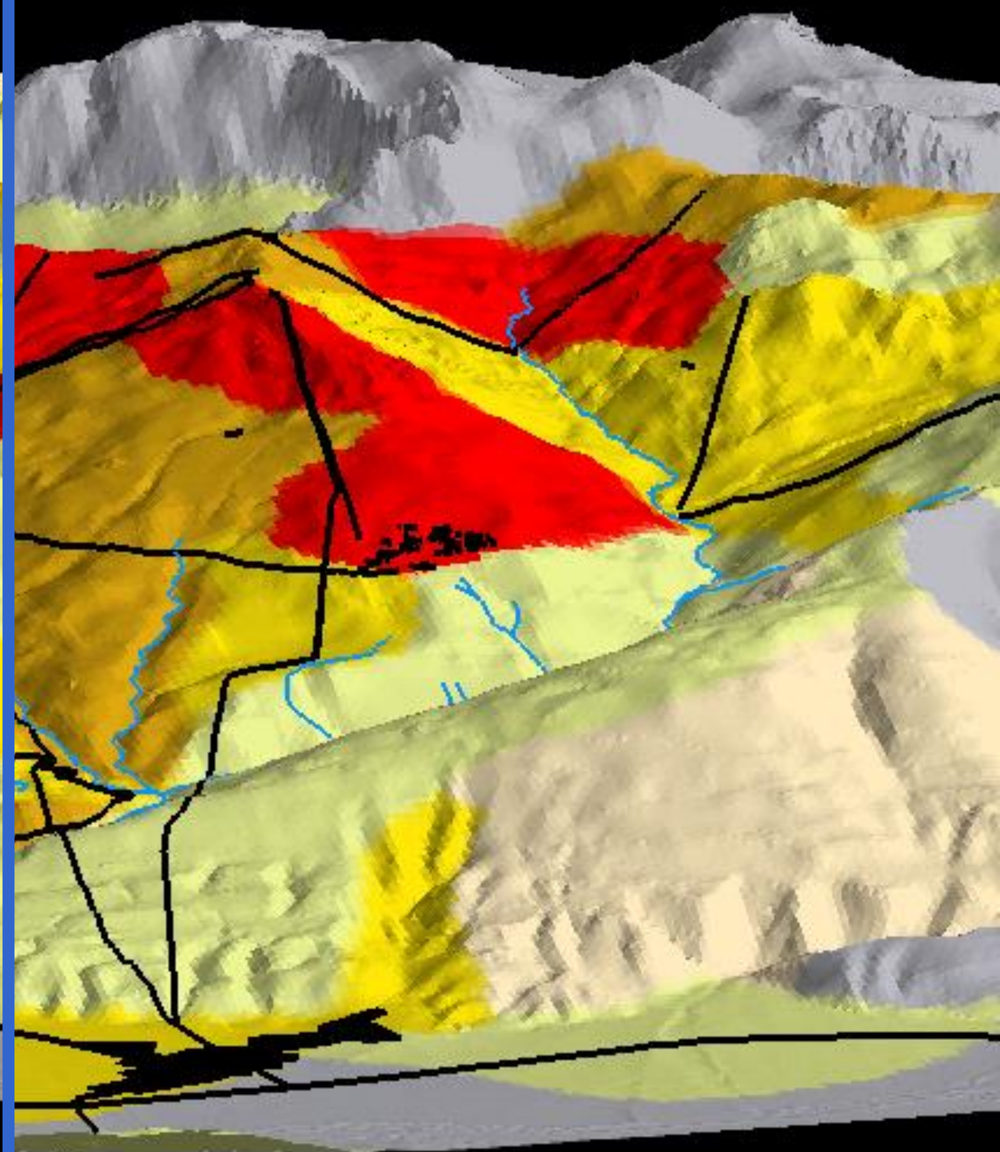
Landslide Hazard Map



Landslide Hazard Map



Landslide Risk Map



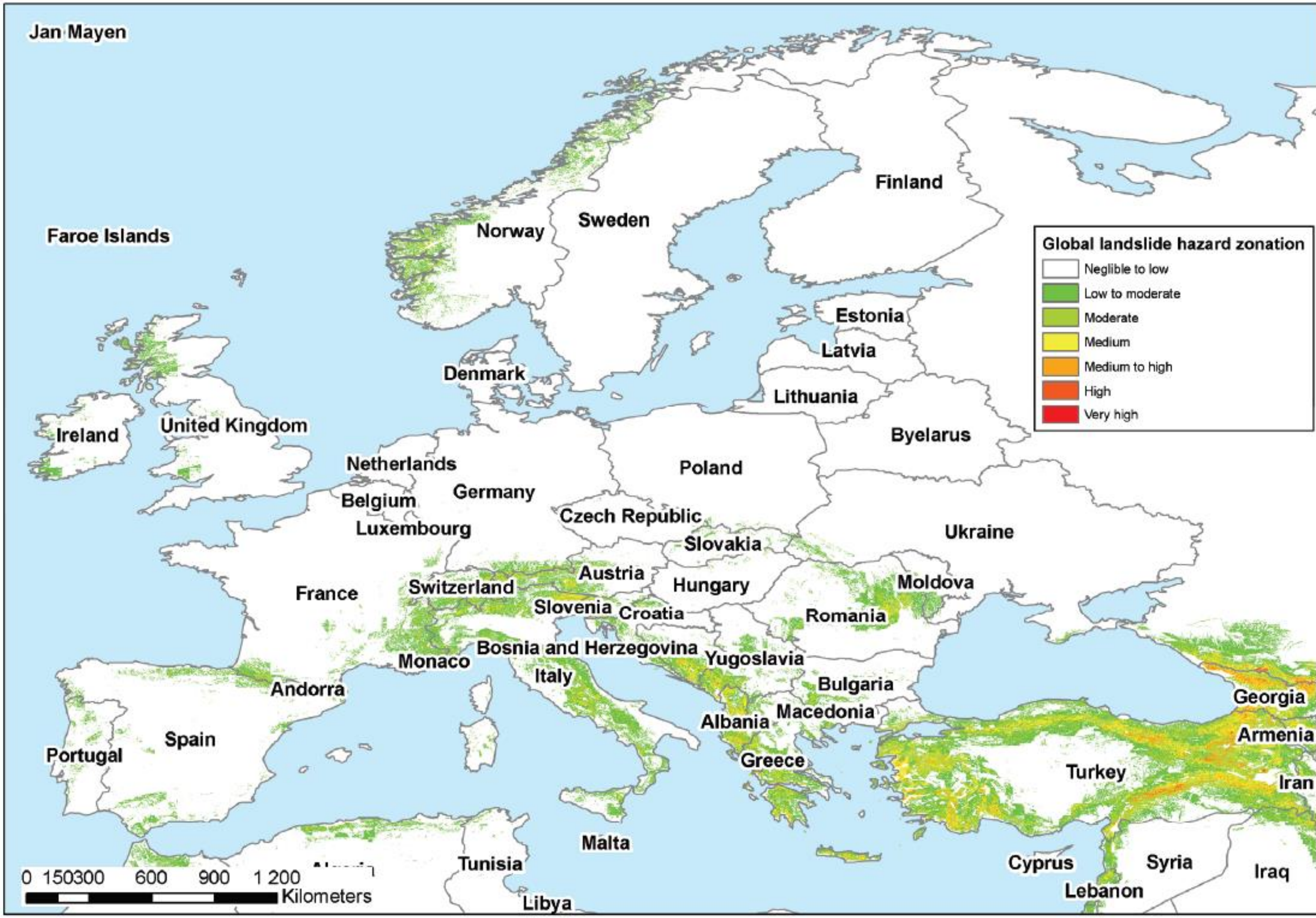
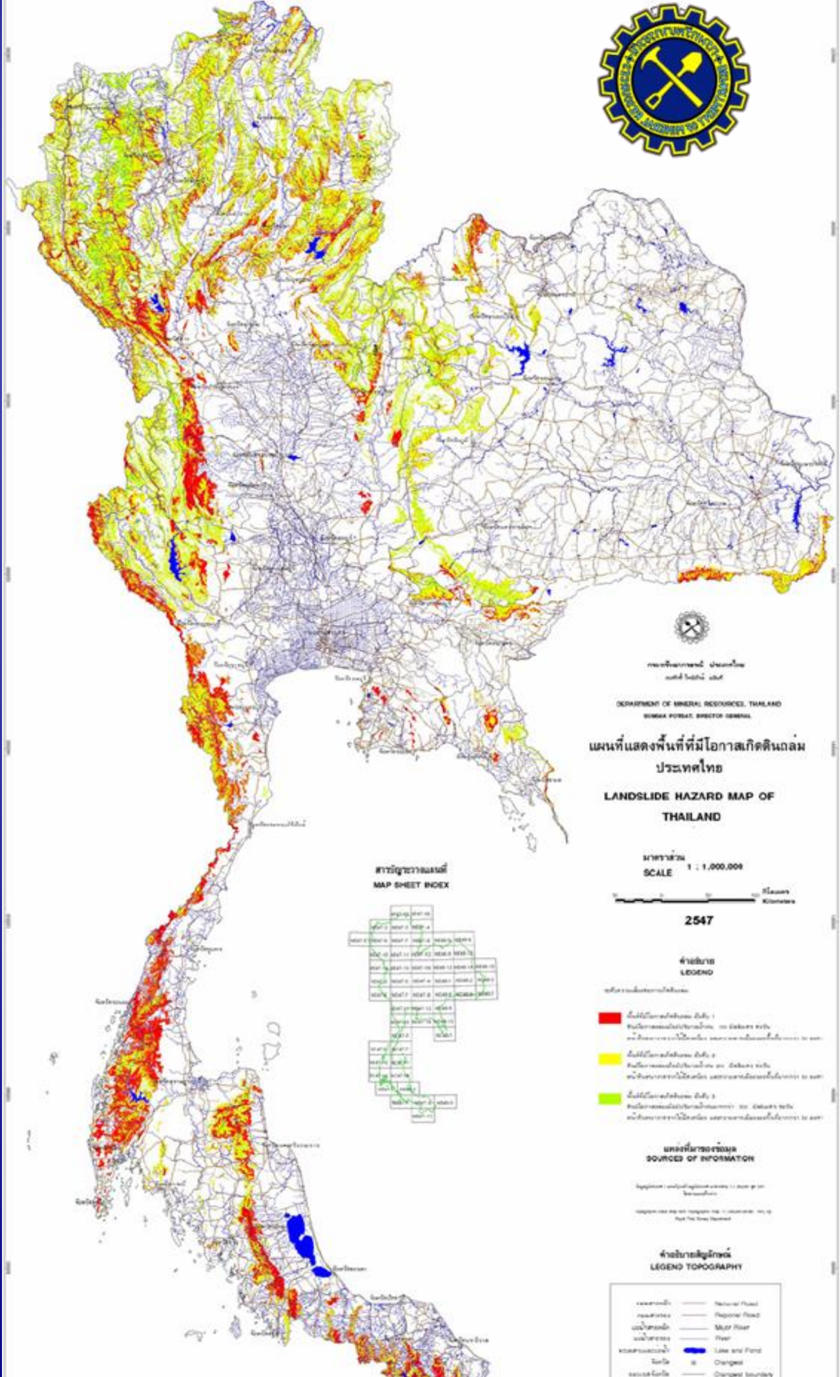
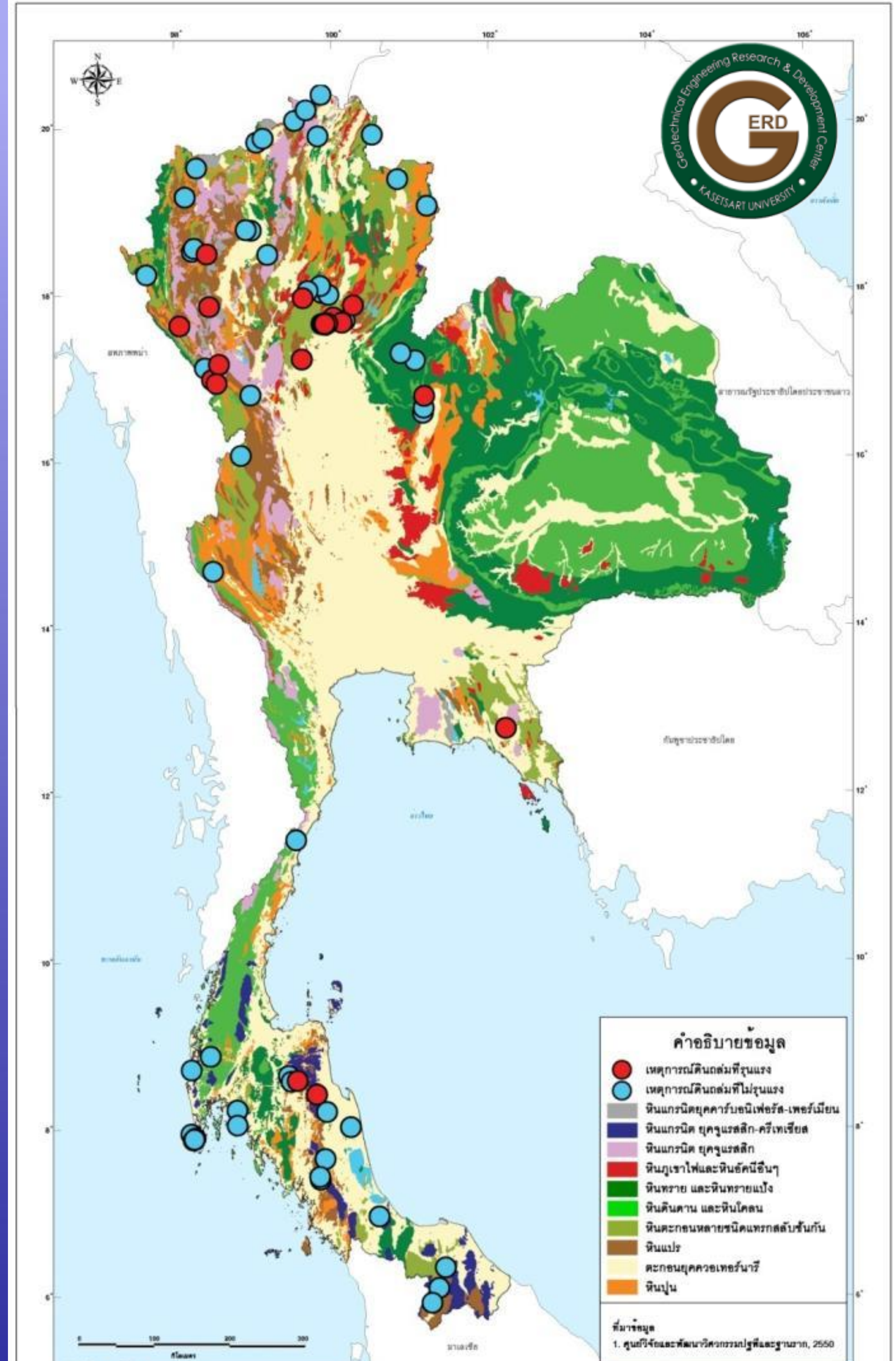


Figure 7b: Landslide hazard map for Europe developed by NGI for the GAR 2009 report (UNISDR 2009a).



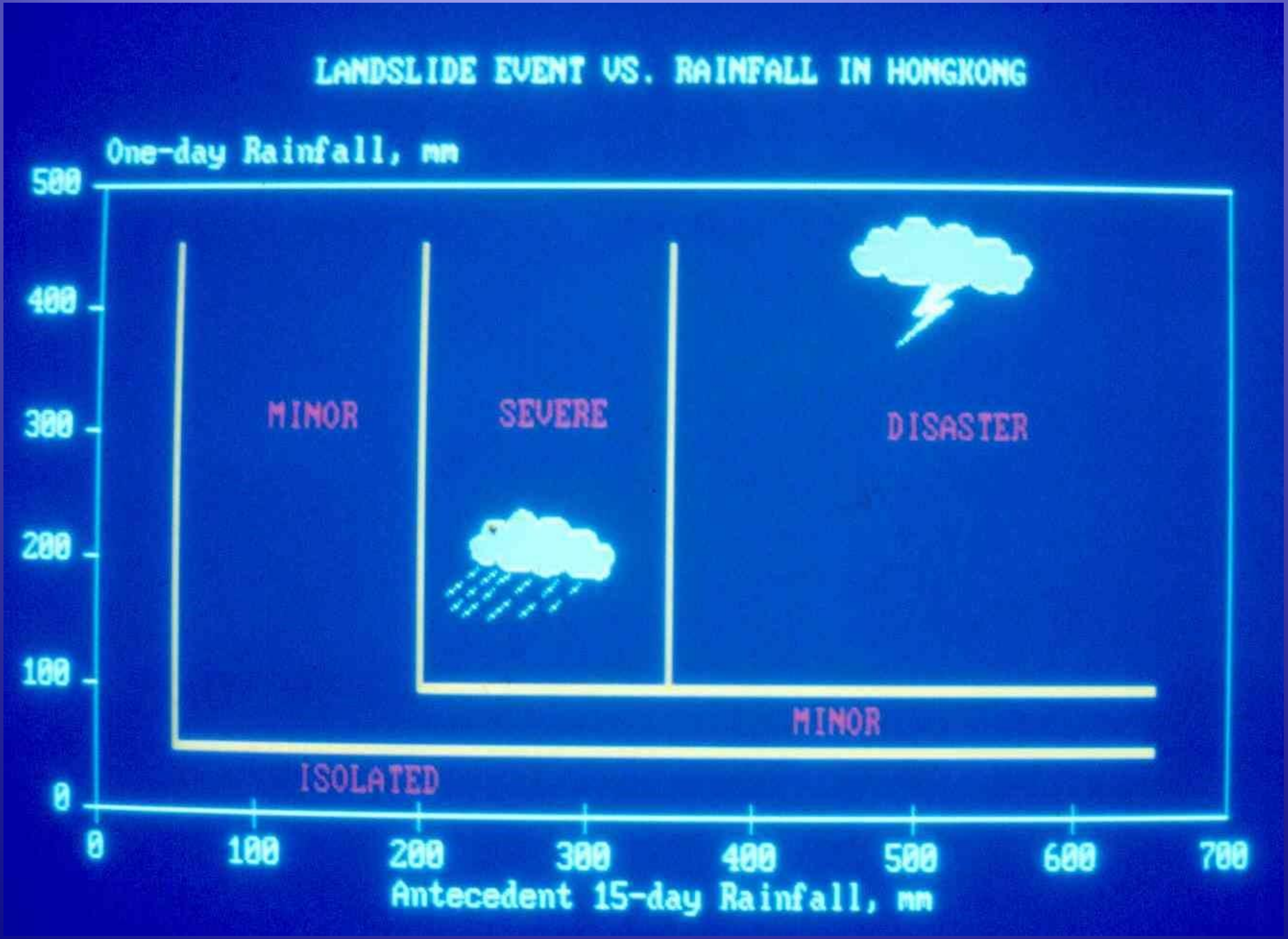
Department of Mineral Resource (2001)



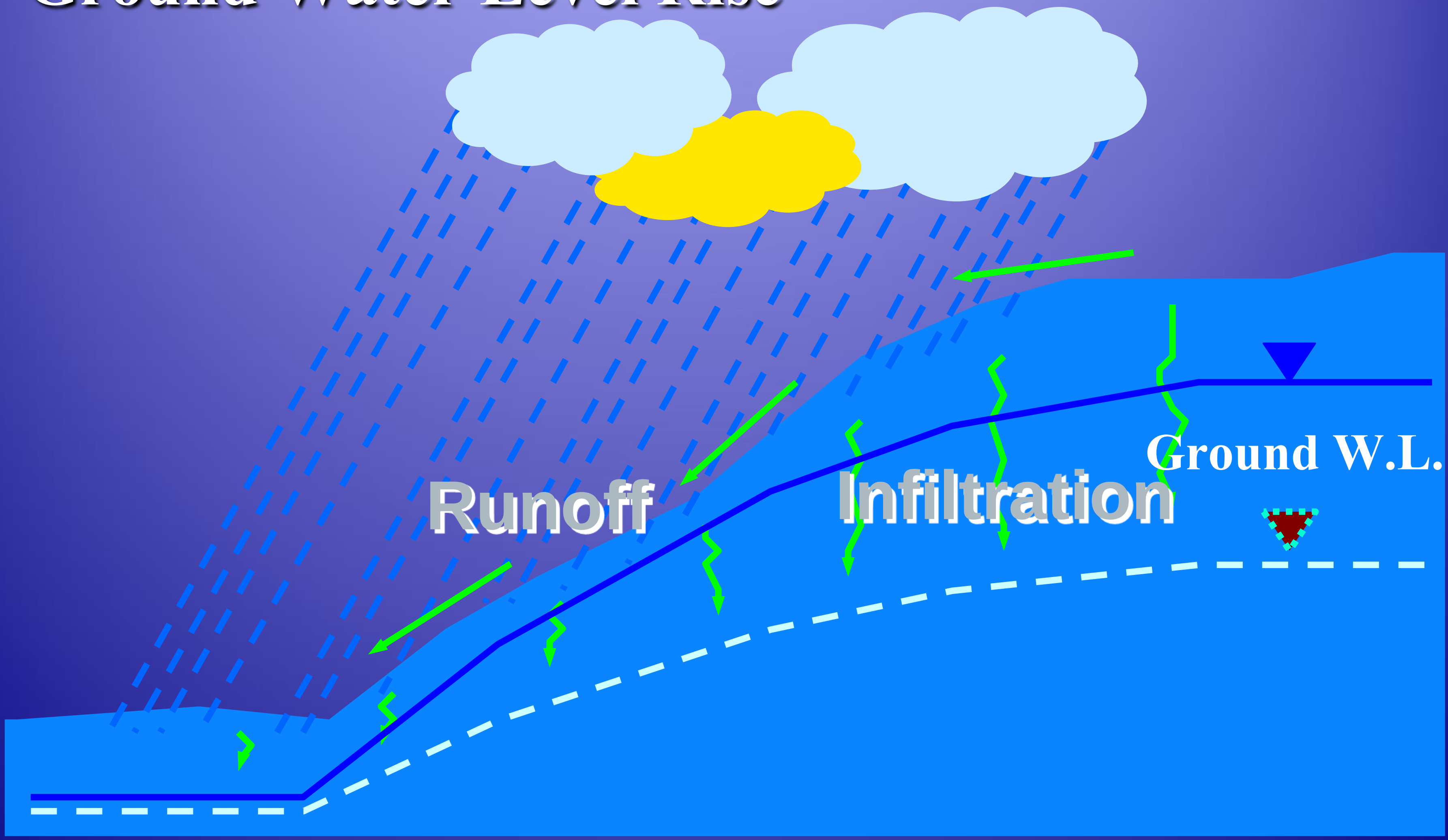
Suttisak Soralump (2008)

Risk Management &

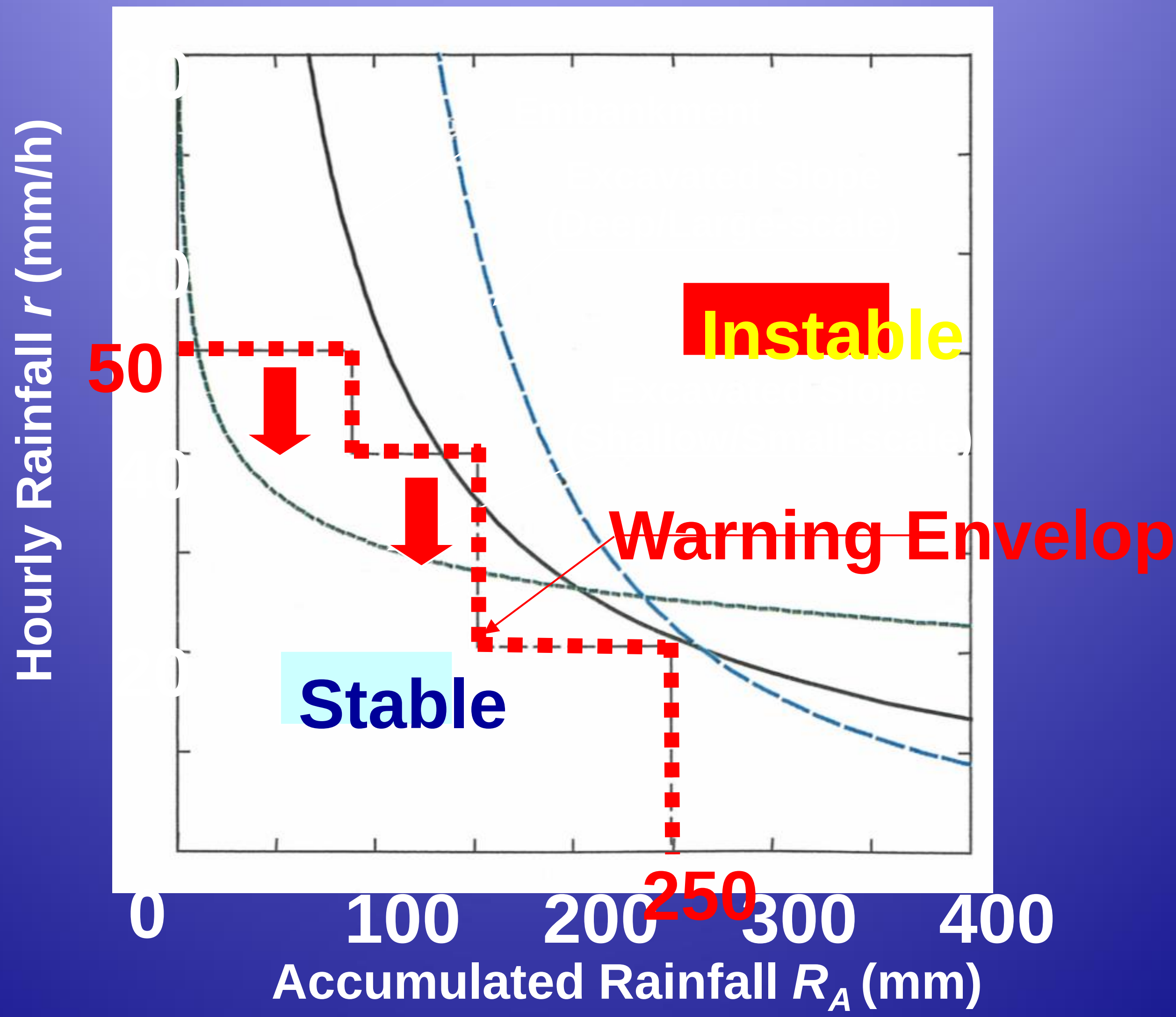
Warning System


LANDSLIDE EVENT VS. RAINFALL IN HONGKONG
One-day Rainfall, mm
500
400
300
200
100
0
MINOR
SEVERE
DISASTER
MINOR
ISOLATED
0
100
200
300
400
500
600
700
Antecedent 15-day Rainfall, mm

Increase soil saturation & Ground Water Level Rise



Revision of Early warning system
for interruption of road service & evacuation



Slope Movement Monitoring

Surface monitoring

- GPS-network with 8 antennas
- total station with 30 prisms
- ground-based radar with 10 reflectors
- 5 extensometers measuring crack opening
- 2 lasers measuring opening of the 2 largest cracks
- geophones that measure vibrations

Monitoring in borehole

- inclinometers measuring displacements
- piezometers measuring pore pressure
- temperature
- electrical resistivity of water

Meteorological station

- temperature
- precipitation and snow depth
- wind speed
- ground temperature
- radiation

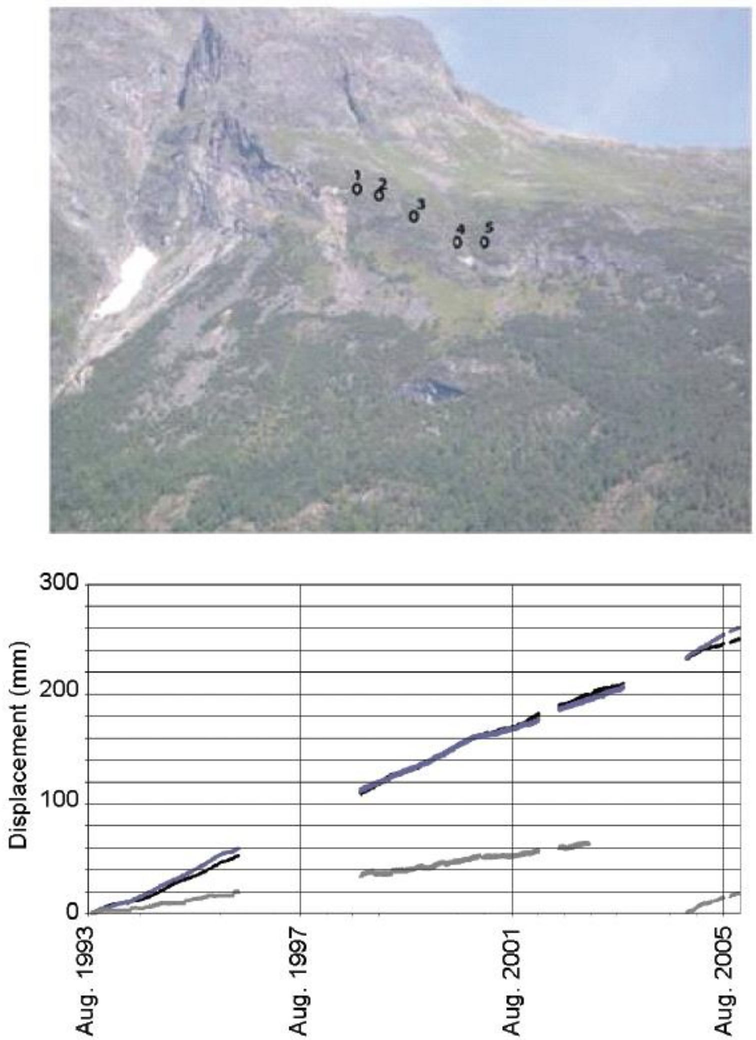


Figure 13: Location of extensometers and displacements from extensometer 1, 2, 3, 4 and 5 at the top scarp at Åknes (Kveldsvik *et al.* 2006).

Table 6: Sketch of alarm levels and response at Åknes (see Figure 14 for colour code).

Alarm level	Activities and alarms	Response
Level 1 Normal situation	Minor seasonal variations No alarm	EPC staff only Technical maintenance
Level 2 Awareness	Important seasonal fluctuations for individual and multiple sensors Values<excess thresholds for Level 2	Increase frequency of data review, compare different sensors Call in geotechnical/geological/monitoring expert
Level 3 Increase awareness	Increased displacement velocity, seen on from several individual sensors Values<excess thresholds for Level 3	Do continuous review, do field survey, geo-expert team at EPC full time Inform police and emergency/preparedness teams in municipalities
Level 4 High hazard	Accelerating displacement velocity observed on multiple sensors Values<excess thresholds for Level 4	Increase preparedness, continuous data analysis Alert municipalities to stand prepared for evacuation
Level 5 Critical situation	Continuous displacement acceleration Values>excess thresholds for Level 4	Evacuation

EPC = Emergency Preparedness Centre in Stranda

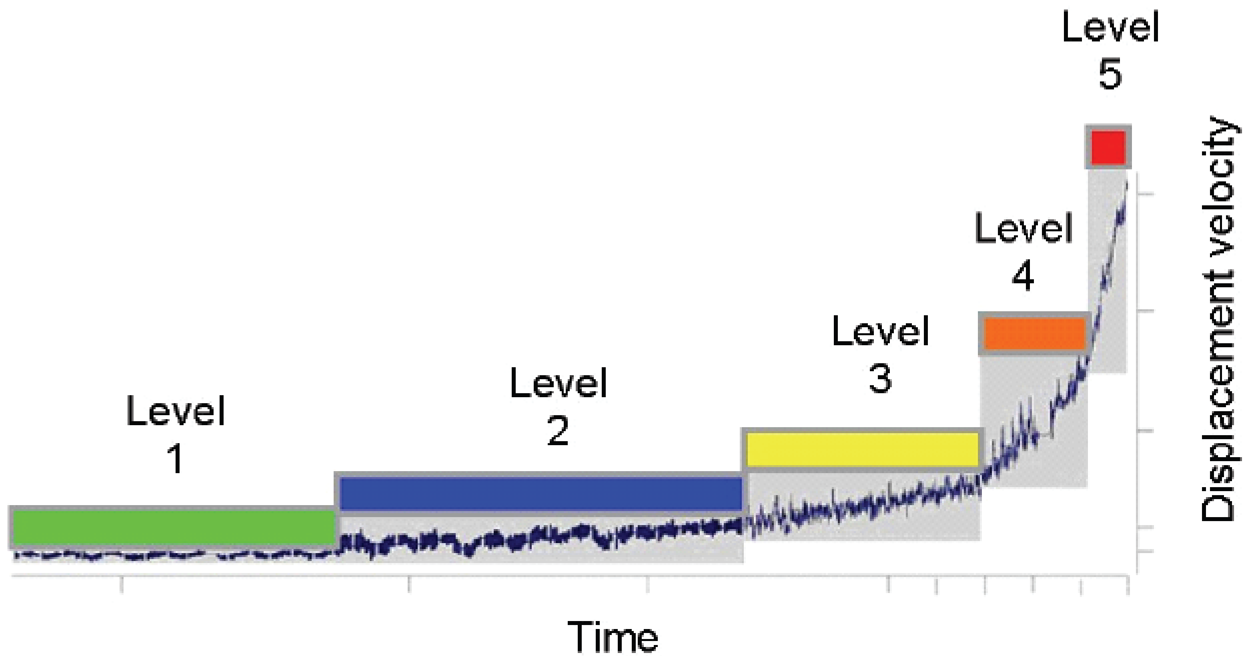
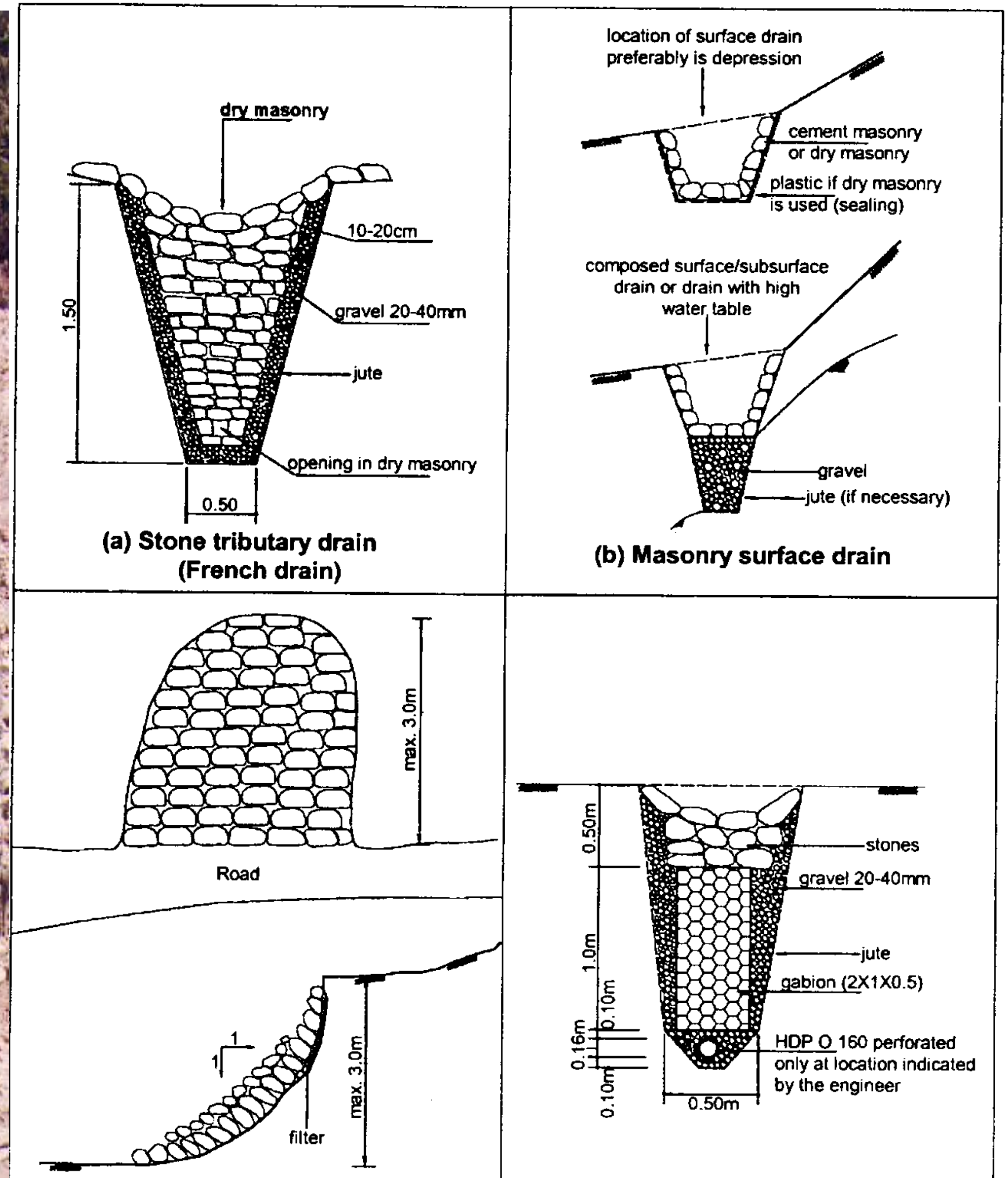


Figure 14: Illustration of the alarm levels as function of displacement velocities (vertical axis: displacement rate in mm/day; horizontal axis: relative time before failure).

Stabilization Measures

- Drainage
- Structural Measures
- Bioengineering

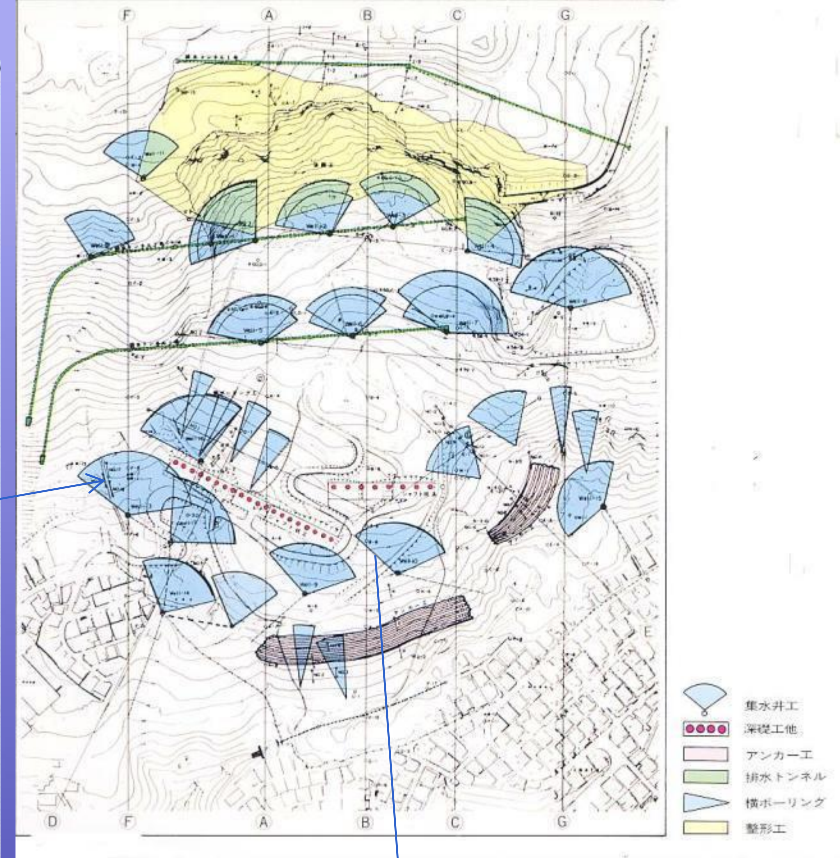


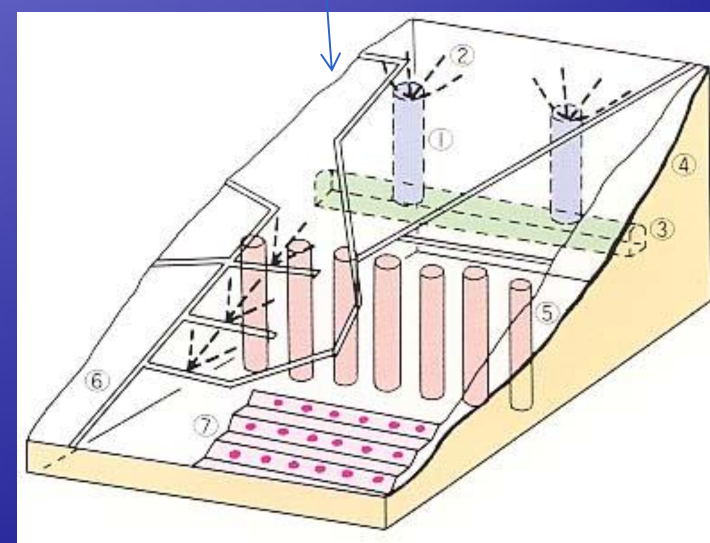
(a) Stone tributary drain
(French drain)

(b) Masonry surface drain

(c) Stone pitching

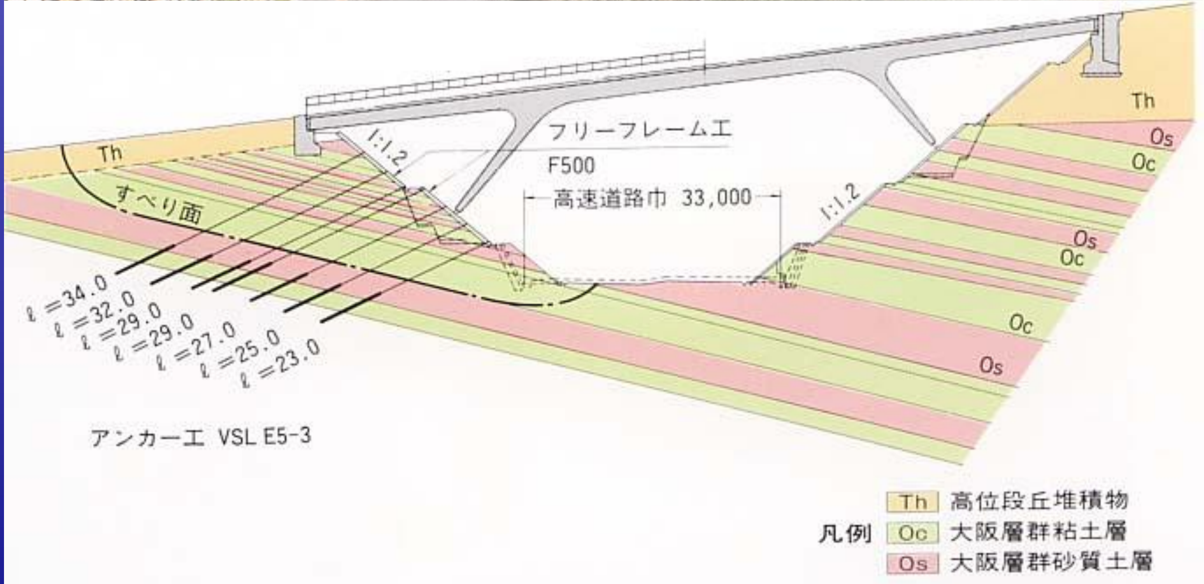
(d) Gabion tributary drain


F
A
B
C
G
D
E
集水井工
深礎工他
アンカー工
排水トンネル
横ボーリング
整形工


①
②
③
④
⑤
⑥
⑦

Structural Measures


95 4 13


フリーフレーム工
F500
高速道路巾 33,000
1:1.2
1:1.2
Th
すべり面
Os
Oc
Os
Oc
Oc
Os
ℓ=34.0
ℓ=32.0
ℓ=29.0
ℓ=29.0
ℓ=27.0
ℓ=25.0
ℓ=23.0
アンカー工 VSL E5-3
凡例
Th 高位段丘堆積物
Oc 大阪層群粘土層
Os 大阪層群砂質土層

標準断面図

Rockfall Protection

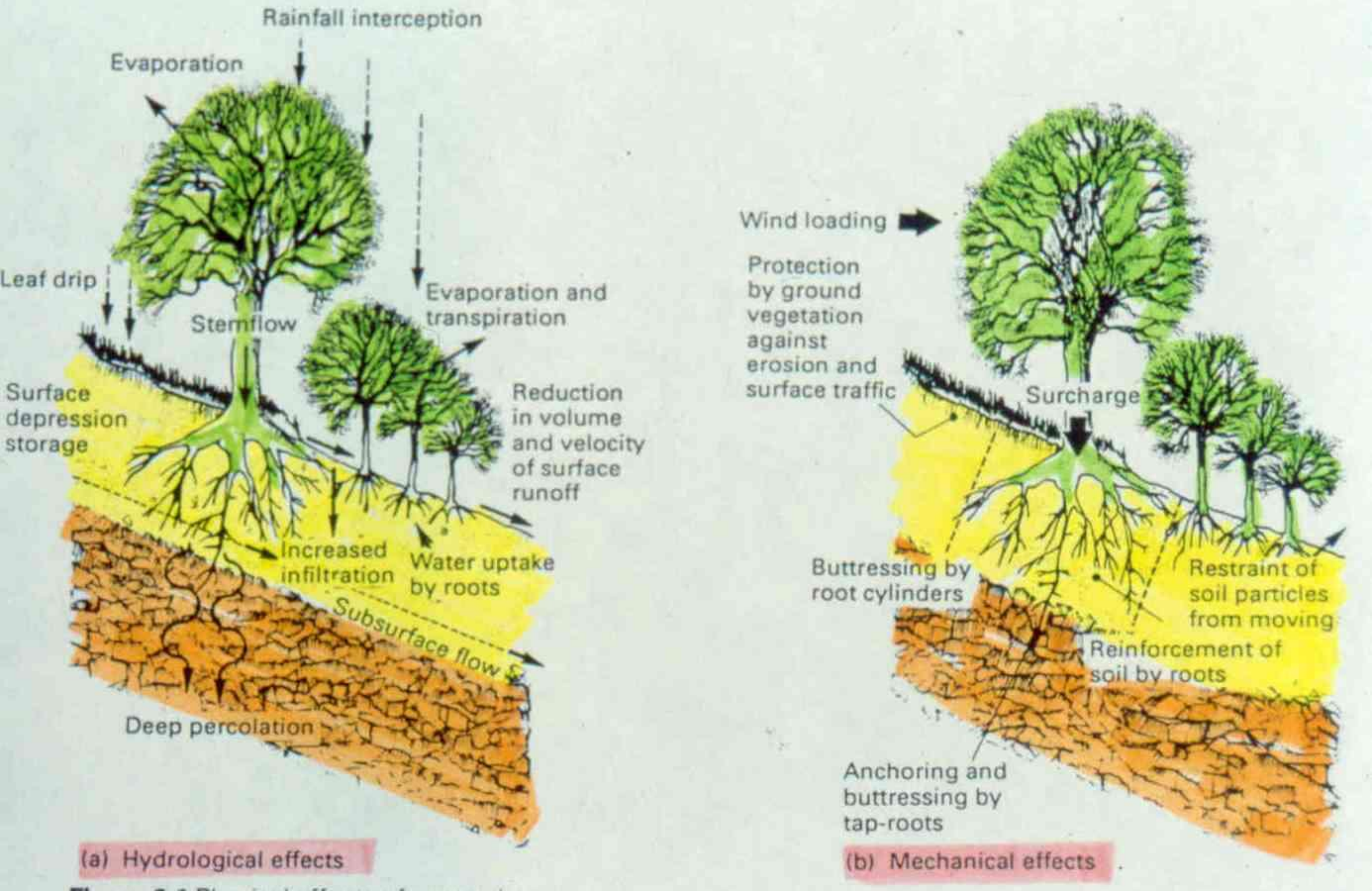
Tunnel Portal, coastal highway,
St. Denis, La Réunion

Catch Fence

Check Dams at the Downstream of Debris Flow

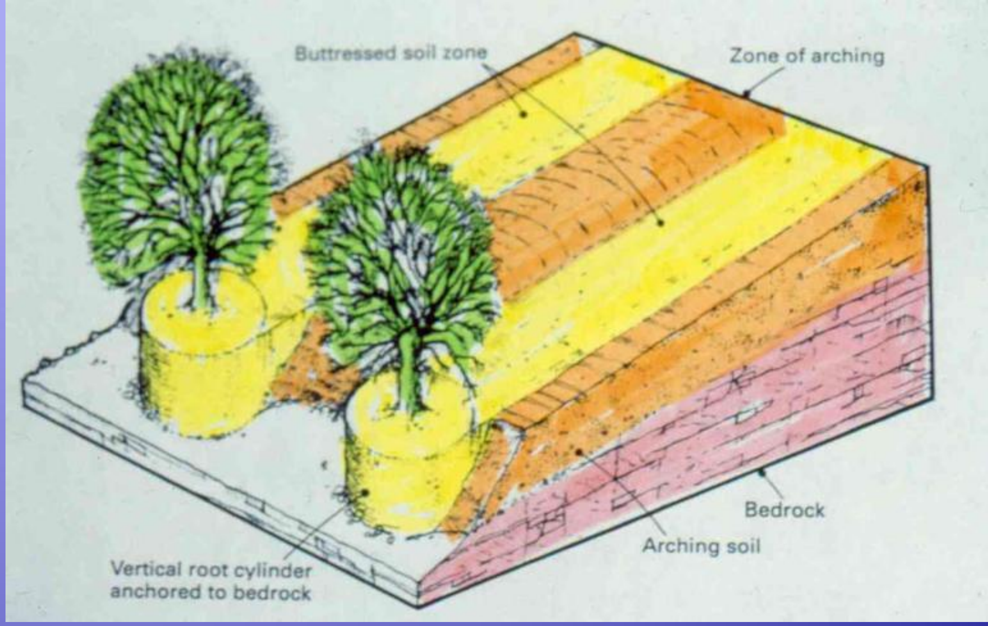
Bio-Engineering Measures

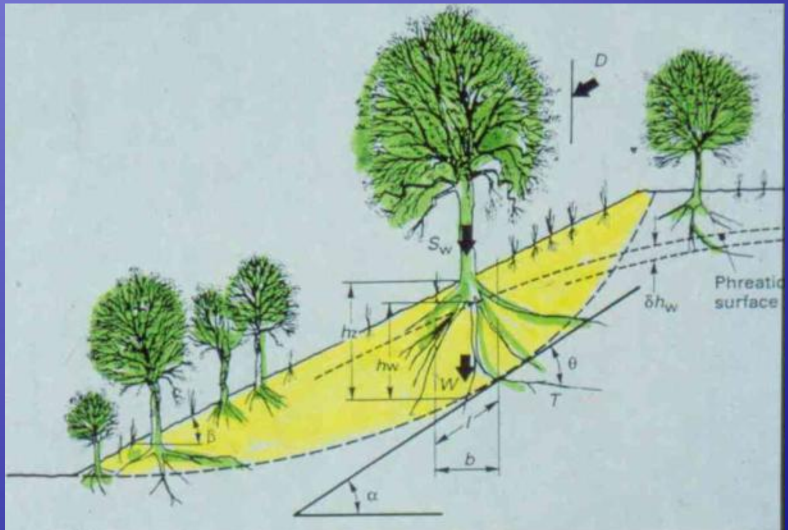
Effects of Vegetations on Slopes



PHYSICAL EFFECTS OF VEGETATION ON SLOPE STABILITY

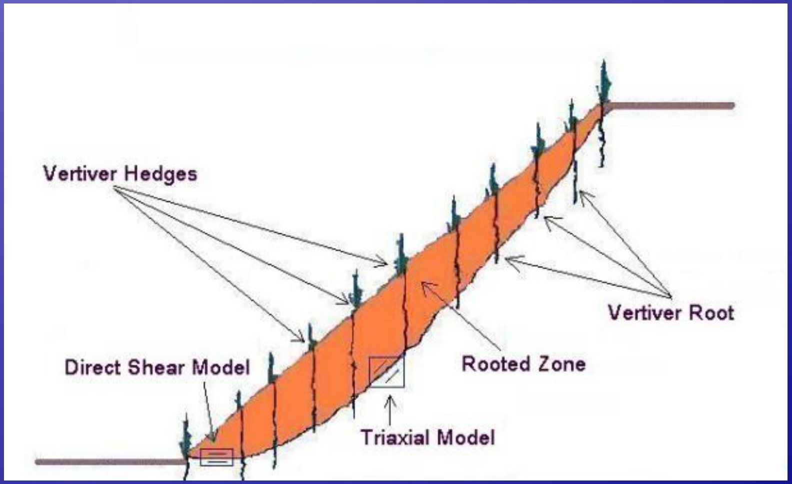
EFFECT	*PHYSICAL CHARACTERISTICS*
Root Reinforcement	Root area ratio, distribution and morphology Tensile strength of roots
Soil Arching Buttressing and Anchorage	Spacing, diameter and embedment of trees, thickness and inclination of yielding strata Shear strength properties of soils
Surcharge	Mean weight of vegetation
Wind Loading	Design wind speed for required return period; mean mature tree height for groups of trees
Soil Moisture	Moisture content of soil Level of ground-water Pore pressure/soil suction
Interception	Net rainfall on slope
Infiltration	Variation of moisture content of soil with depth





Due to vegetation

u_v	Decrease in pore-water pressure to evapotranspiration by vegetation at slip surface, kN/m^2 (2)
c'_R	Enhanced effective soil cohesion due to root matrix reinforcement by vegetation along slip surface, kN/m^2
c'_S	Enhanced effective soil cohesion due to soil suction due to evapotranspiration by vegetation at slip surface, kN/m^2 (2)
S_w	Surcharge due to weight of vegetation, kN/m
D	Wind loading force parallel to slope, kN/m
T	Tensile root force acting at base of slice, kN/m (assumed angle between


Vertiver Hedges
Vertiver Root
Rooted Zone
Direct Shear Model
Triaxial Model

THE END