The Assessment of Landslide Hazard and Risk

Steve Parry, Consulting Engineering Geologist
sparry@ParryEGS.com

Talk outline

- Are landslide a hazard we should be concerned about in the UK and what guidance is there?
- Definitions
- UK datasets
- Hazard models – “getting the geology right”
- Direct vs indirect approaches
- Quantatative vs Qualitative assessments

Are landslides a hazard in the UK?

Excluding Aberfan, there have been 16 fatalities since 1877 or approximately 1 fatality every 8.5 years (Gibson et al. 2013). If the data from pre-1959 is excluded this becomes approximately **1 fatality every 4.5 years**.

Wong et al. (2004) report 16 fatalities from natural landslides in Hong Kong between 1980 and 2003 or 1 fatality every 1.4 years. However, most of the fatalities occurred prior to 1990 and reflect fatalities associated with squatter areas which have been subject to an intensive programme of clearance. If only the fatalities post-1990 are taken into account, the rate becomes **1 fatality every 4.3 years**.

Ballantyne (2004) notes "*debris-flows have occurred intermittently at flow-susceptible sites over much or all of the past 7000 years, but there is geomorphological evidence for more frequent and more extensive hillslope flow activity within the past few centuries*".

Increase in the number of landslides noted in the UK in recent years (Although some may reflect BGS extracting from social media)

Not conclusively Climate Change but certainly "*changes in the meteorological environment*."

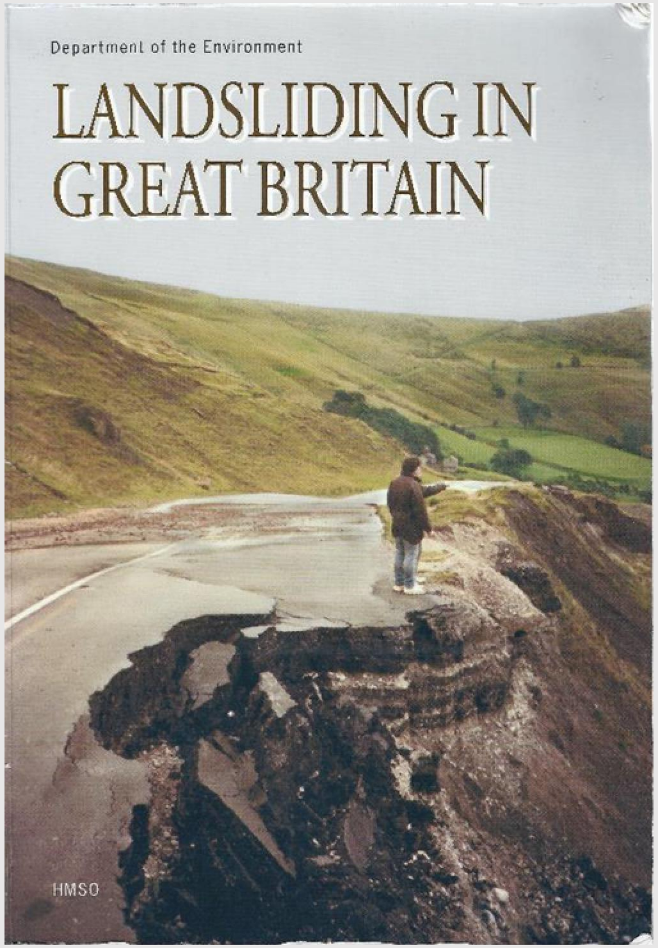
June 2012 Loch Treig

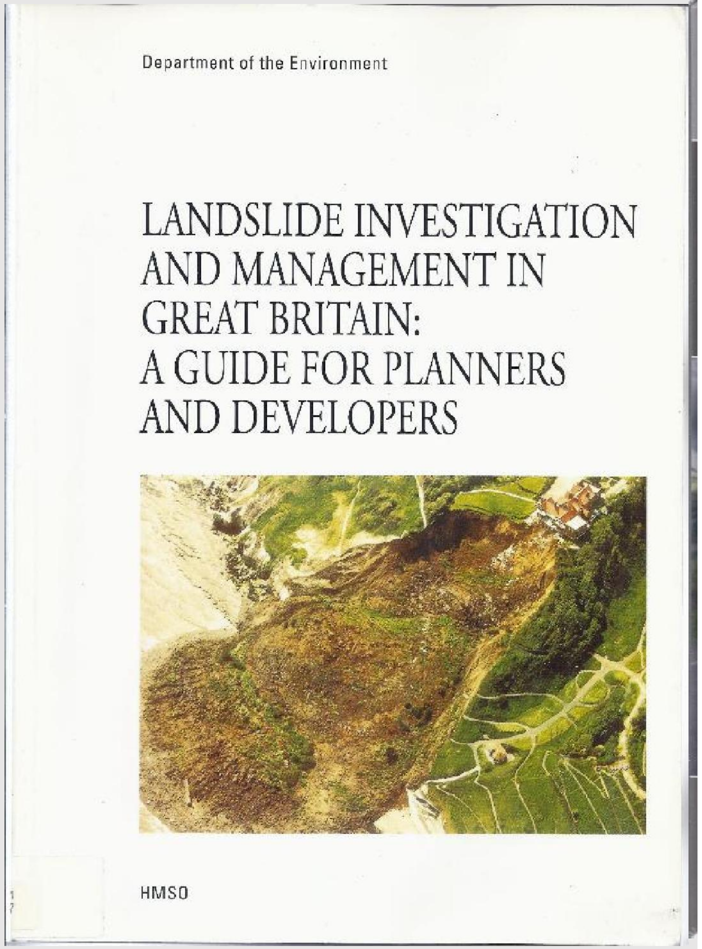
March 2018 Newquay

Jan 2018 Loch Eilt between Arisaig and Glenfinnan

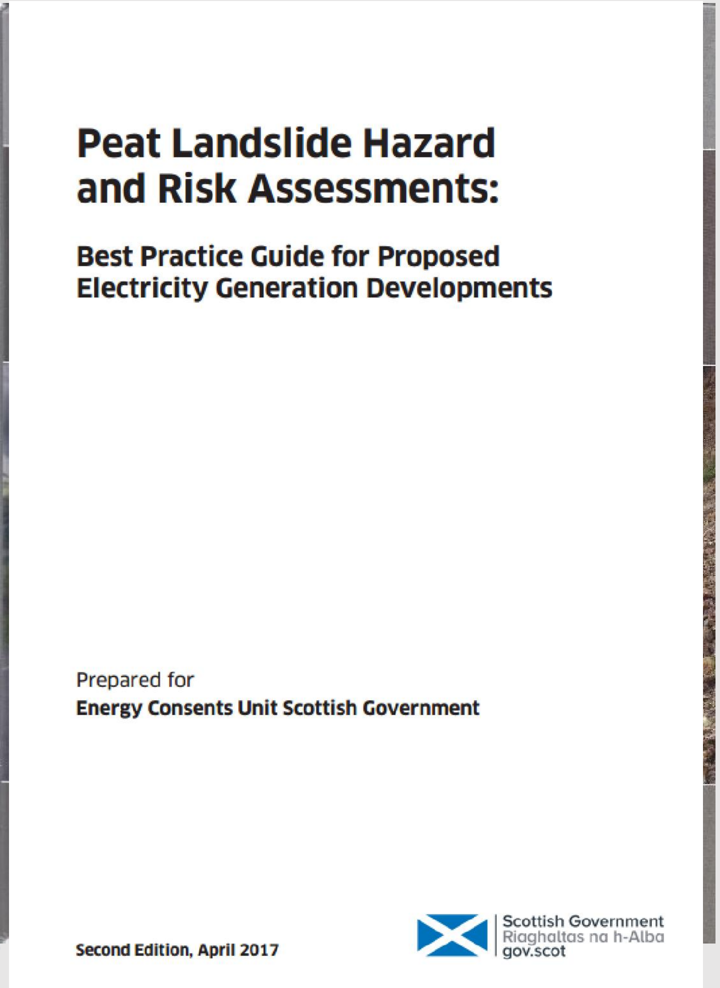
Nov 2018 Loch Quoich

What Guidance is there for UK Practice?





1994 & 1996 both out of print



2004, 2nd edition 2014

Hazard and Risk with respect to landslides

lack of standardisation of terms used e.g. susceptibility, hazard, consequence & risk

e.g. hazard used as both as a noun which refers to a source of potential harm and

as an adjective (JTC-1) which describes the probability of harm occurring[1].

[1]Miner, A.S., Paul, D.R., Parry, S., Flentje, P. (2014) What does Hazard mean? - Seeking to provide further clarification to commonly used landslide terminology. Proceedings of the International Association of Engineering Geology Conference. Turin, 2014.

HSE use of Hazard and Risk (in relationship to occupational safety)

Hazard - “a potential source of harm or adverse health affects on a person or person”

Risk - “the likelihood that a person may be harmed or suffers adverse health effects if exposed to the hazard”

Hazard and Risk with respect to landslides

International definitions

<u>Australian Geomechanics Society (2007)/Fell et al (JTC-1)2008</u>

Landslide susceptibility. "*A quantitative or qualitative assessment of the classification, volume (or area), and spatial distribution of landslides which exist or potentially may occur in an area*".

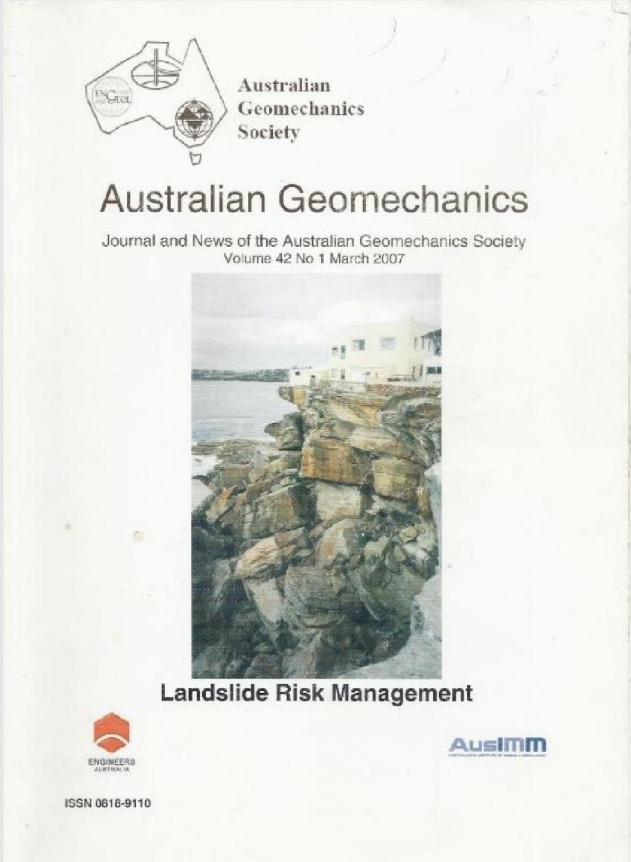
i.e. where landslides may occur

Landslide hazard "*a condition with the potential for causing an undesirable consequence"* and in relation to landslides notes that *"the description of landslide hazard should include the location, volume (or area), classification and velocity of the potential landslides and any resultant detached material, and the probability of their occurrence within a given period of time*".

i.e. the probability that a landslide of a particular type and volume will occur in a defined area within a specified time and cause impact

Landslide Risk "*A measure of the probability and severity of an adverse effect to health, property or the environment. Risk is often estimated by the product of probability of a phenomenon of a given magnitude times the consequences*"

i.e. the <u>probability</u> of loss associated with elements at risk[2] e.g. risk to life

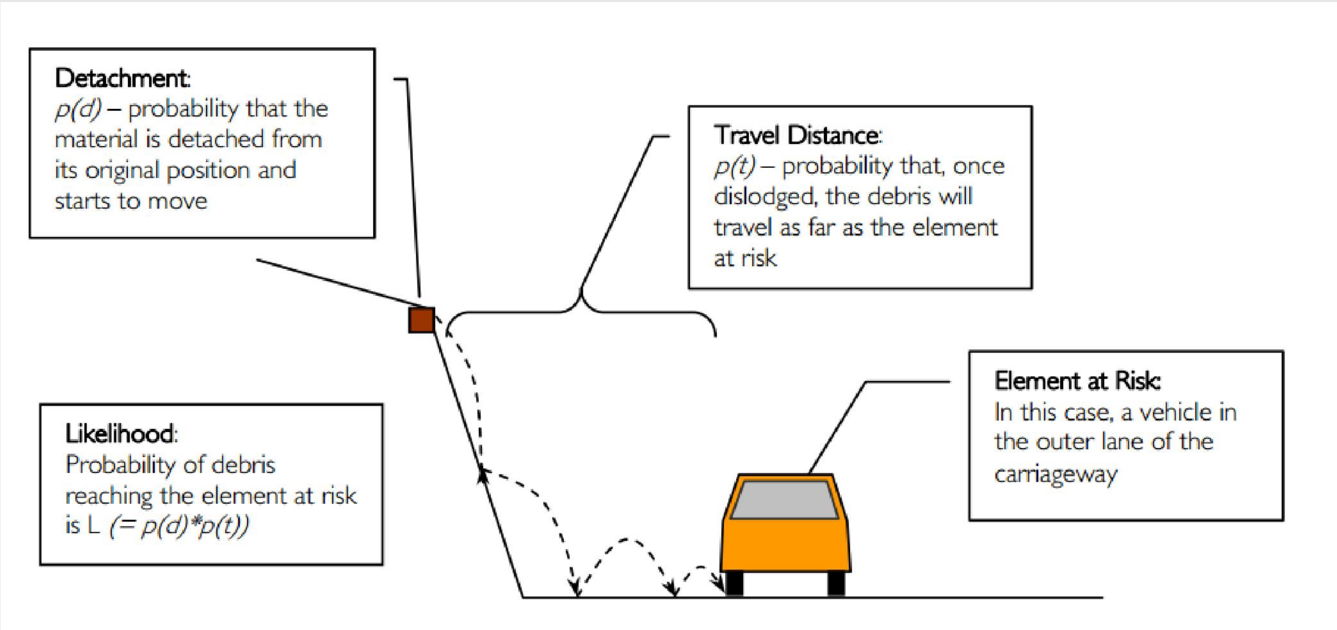


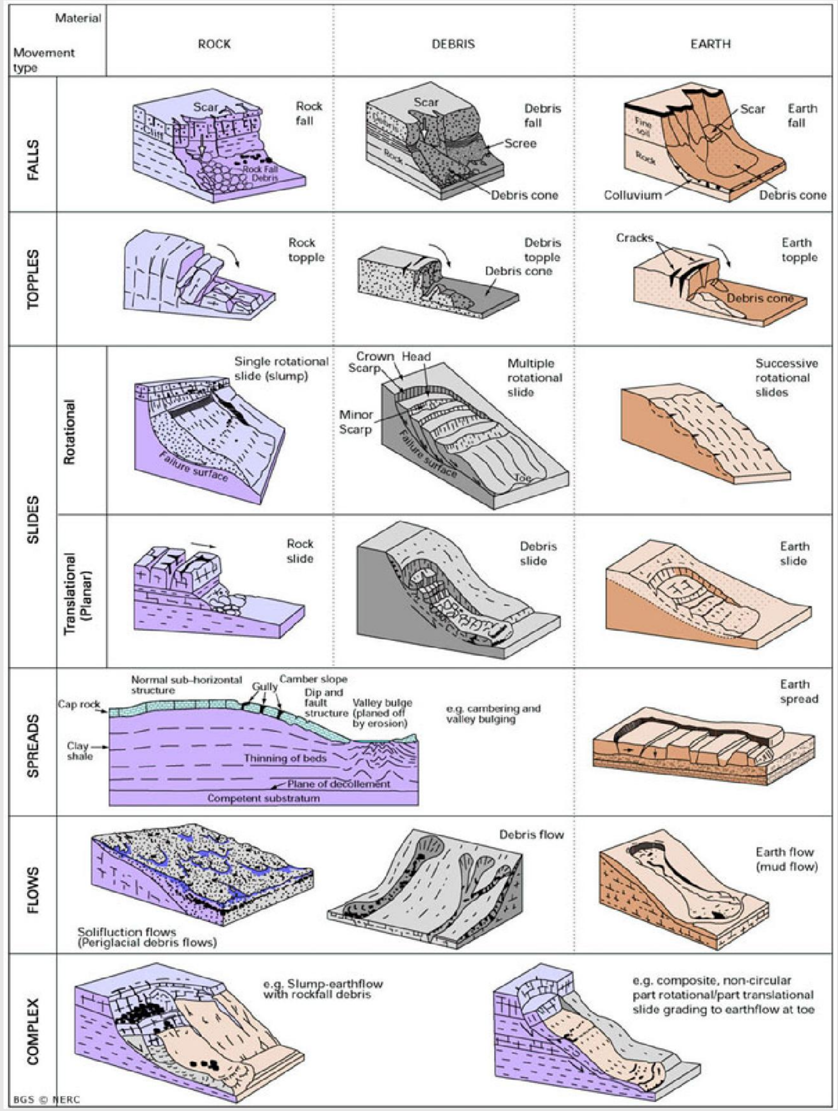
https://australiangeomechanics.org/downloads/

[2] Elements at risk -The population, buildings and engineering works, economic activities, public services utilities, other infrastructures and environmental values in the area potentially affected by the landslide hazard.

Hazard

- Can be to life, can be economic, can be environmental
- probability of impact is a function of magnitude, frequency and run out
- these are in turn a function of landslide type





Note entrainment should also be considered

Hazard vs Risk

The probability that a landslide of a particular type and volume will occur in a defined area within a specified time and cause impact

The probability of loss associated with elements at risk2 e.g. risk to life

$$Rs = P(H_i) \times \Sigma(E \times V \times E_x)$$

Where

R(s) is specific risk

$P(H_i)$ is probability of a particular magnitude of hazard H_i within a specific area and time frame

E elements at risk

V Vulnerability

E_x Exposure time

The varied components of E have to be assessed separately for each hazard assets may be fixed or mobile

Total Risk is the sum of the calculations of specific risk for the full range of landslide types and magnitudes

Why adopt a risk based approach?

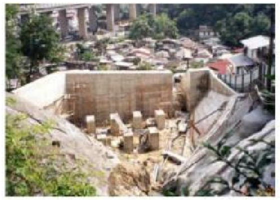
(a) There are considerable uncertainties associated with the ground which are often difficult to address in a deterministic slope assessment.

(b) A risk-based approach provides a scientific basis for evaluating risk mitigation measures at individual sites

(c) A risk-based approach provides a structured framework for formulating a rational risk management strategy to address the overall landslide risk.

(d) A risk-based approach can greatly facilitate risk communication with the politicians and the general public.

(e) What is the probability the design event/mitigation solution you have adopted will be exceeded?

Drainage provisions Bio-Engineering	**Flexible Barriers** 		**Check dams Gravity Structures** 		**Diversion walls** 
0-50m^3	50-100 m^3	100-500 m^3	500-1000 m^3	1000-5000 m^3	5000-10000 m^3

JTC-1/AGS (2007) suggests the following stages for a landslide hazard and risk assessment:

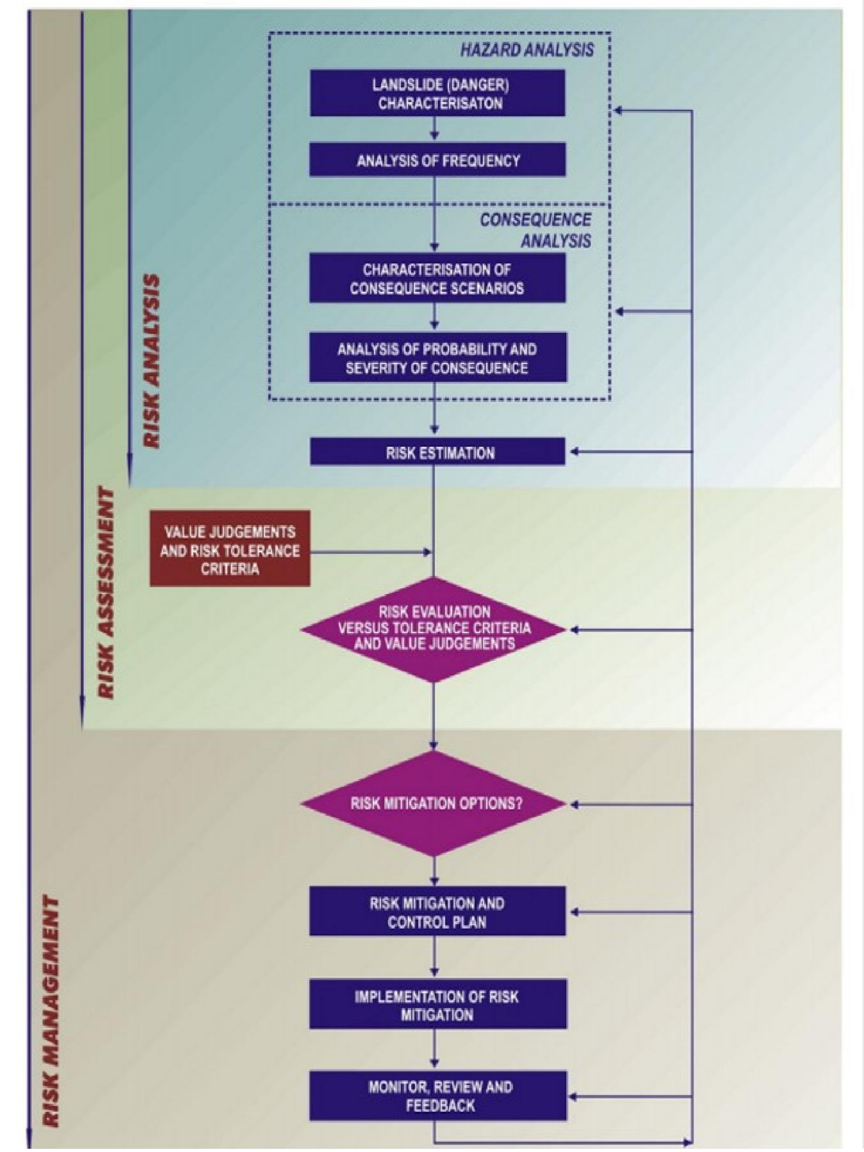
• **Hazard identification** which comprises classification of landslides, extent of landslides (area and volume), travel distance of landslides and rates of movement

• **Frequency analysis** comprising estimation of frequency e.g. historic performance, relate to initiating events

• **Consequence analysis** comprising elements at risk, temporal probability and vulnerability

• **Risk estimation**

Once these steps have been undertaken an evaluation of risk can be undertaken and risk mitigation options assessed.



Hazard identification

In order to undertake this we need first need a landslide inventory

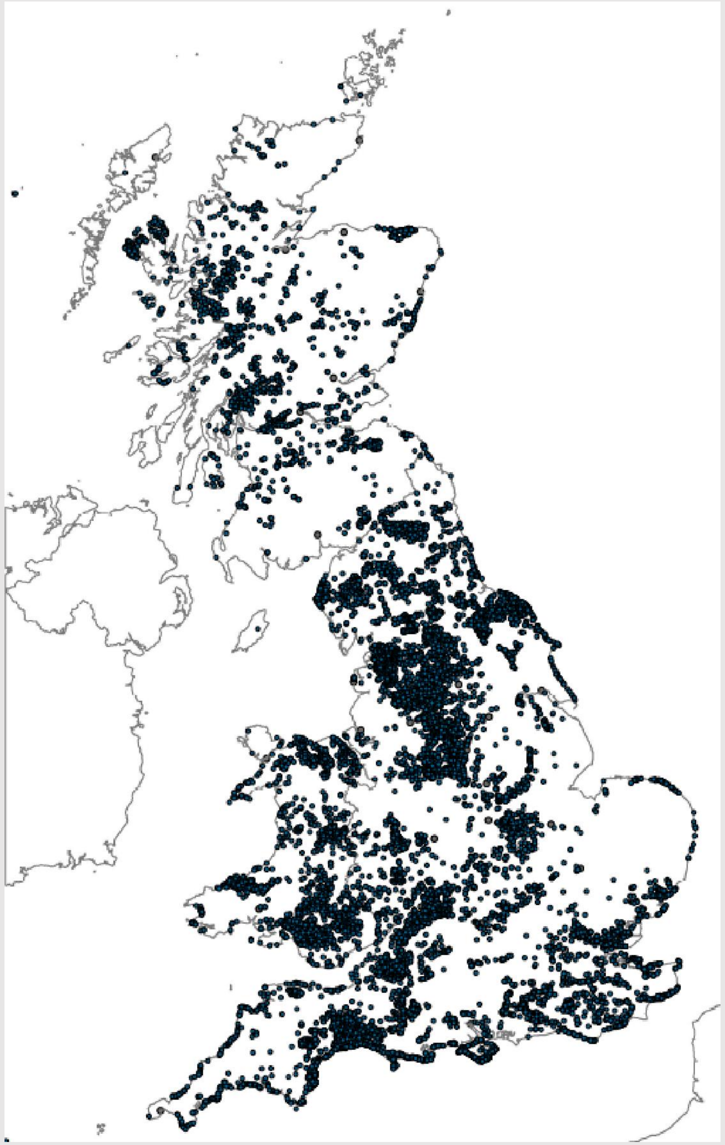
What of UK National Landslide Database?

The British Geological Survey (BGS) maintains the **National Landslide Database** (**NLD**) which contains attributes of over 17,000 landslides.

The BGS have also developed the **GEOSURE** dataset.

One of the GEOSURE layers relates to "*slope instability (landslides)*" and comprises a fivefold subdivision of increasing likelihood of "*slope instability problems*".

However, there are limitations to both these data sets.



National Landslide Database (NLD)

The NLD contains attributes of 17,000 landslides, 10,000 of which are extracted from BGS geological maps. Most of the landslides in the NLD are considered to be “*ancient and inactive”*

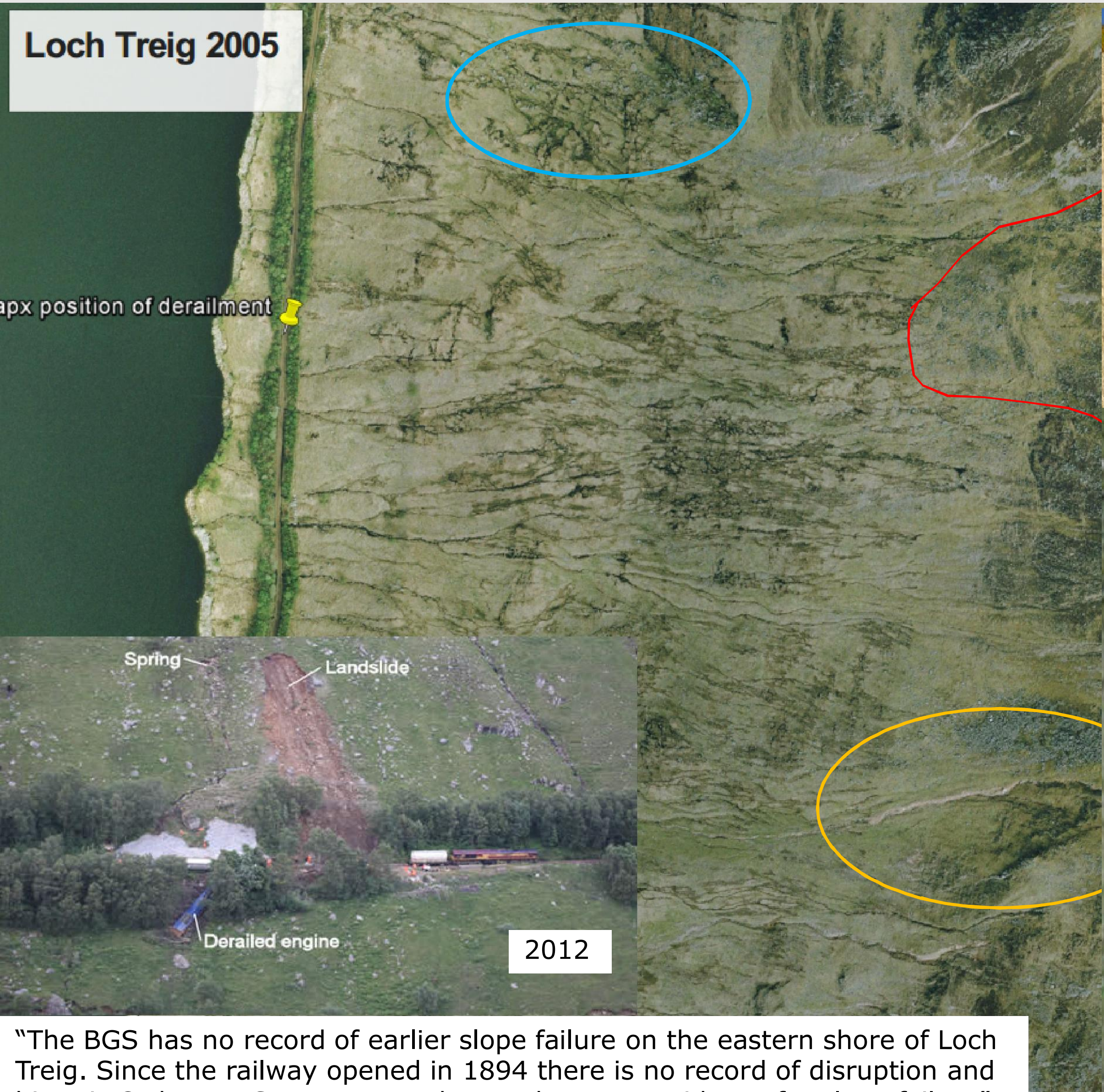
However, the emphasis on mapping landslides has varied greatly across the UK in the past, with earlier geological maps commonly not recording them.

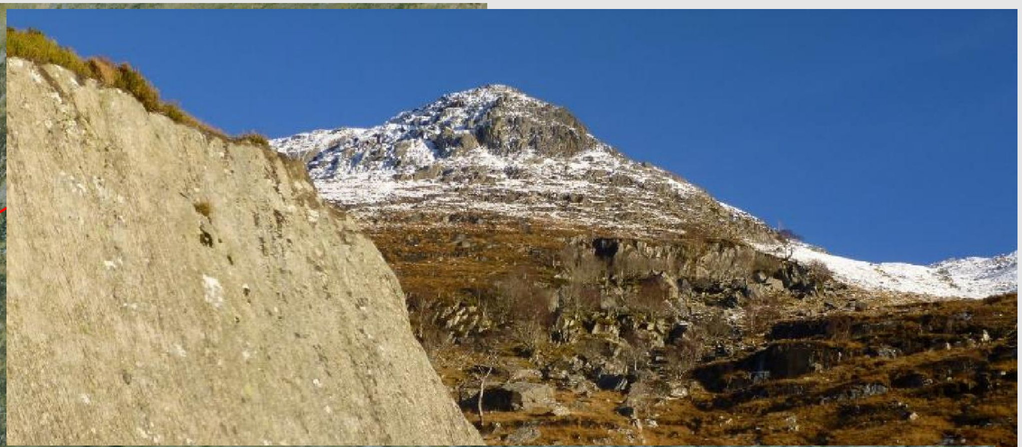
In addition, landslides without significant “footprints” such as debris flows are rarely mapped and consequently under reported.

Many of the non-BGS records are from area of concentrated and conspicuous landslide activity, e.g. South Wales, Pennines etc.

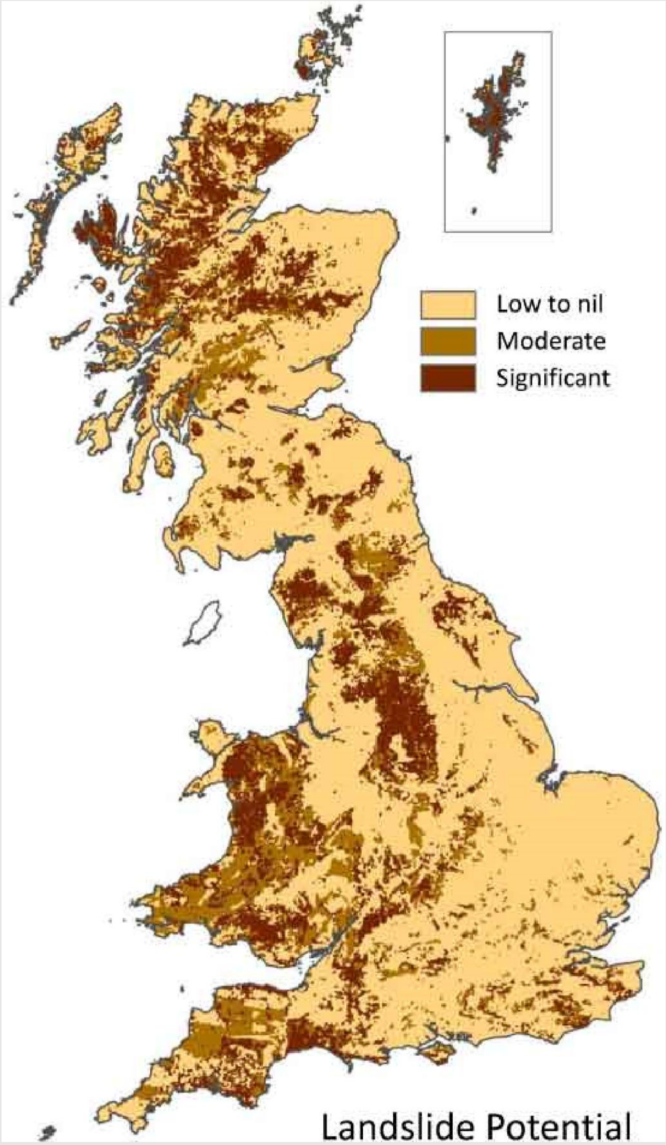
The NLD is based on earlier DoE database - the pattern of landslides revealed by the records was stated as being an "*artefact of investigation reflecting varying degrees of ignorance*“

As a result, no record in the NLD does not mean that landslides are not present





"The BGS has no record of earlier slope failure on the eastern shore of Loch Treig. Since the railway opened in 1894 there is no record of disruption and historic Ordnance Survey maps do not show any evidence for slope failure".
www.bgs.ac.uk/landslides/tulloch.html



GEOSURE (Slope Instabilities)

This GEOSURE layer is generated using three parameters, lithology, discontinuities (in rock) and slope angle. The resulting score ranges from 2 to 24 which is divided into five classes, with >20 being Class E, significant potential.

Mapped landslides are given a score of 13, which results in Class E where the slope angle is >10º.

As GEOSURE is directly linked to the NLD this introduces bias. For example Oldham East is recorded as having the largest proportion of Class E (9.5% by area) in the UK. However this is probably a reflection of its recent mapping (2012).

GEOSURE only provides qualitative assessment of landslide **susceptibility** i.e. the spatial extent of landslide phenomena with no indication of hazard type, magnitude, run out or frequency, or if a hazard will actually result.

Hazard identification

Therefore site specific landslide inventories are required

However an inventory on its own is insufficient.

Many events evident in an inventory may have relatively short return periods.

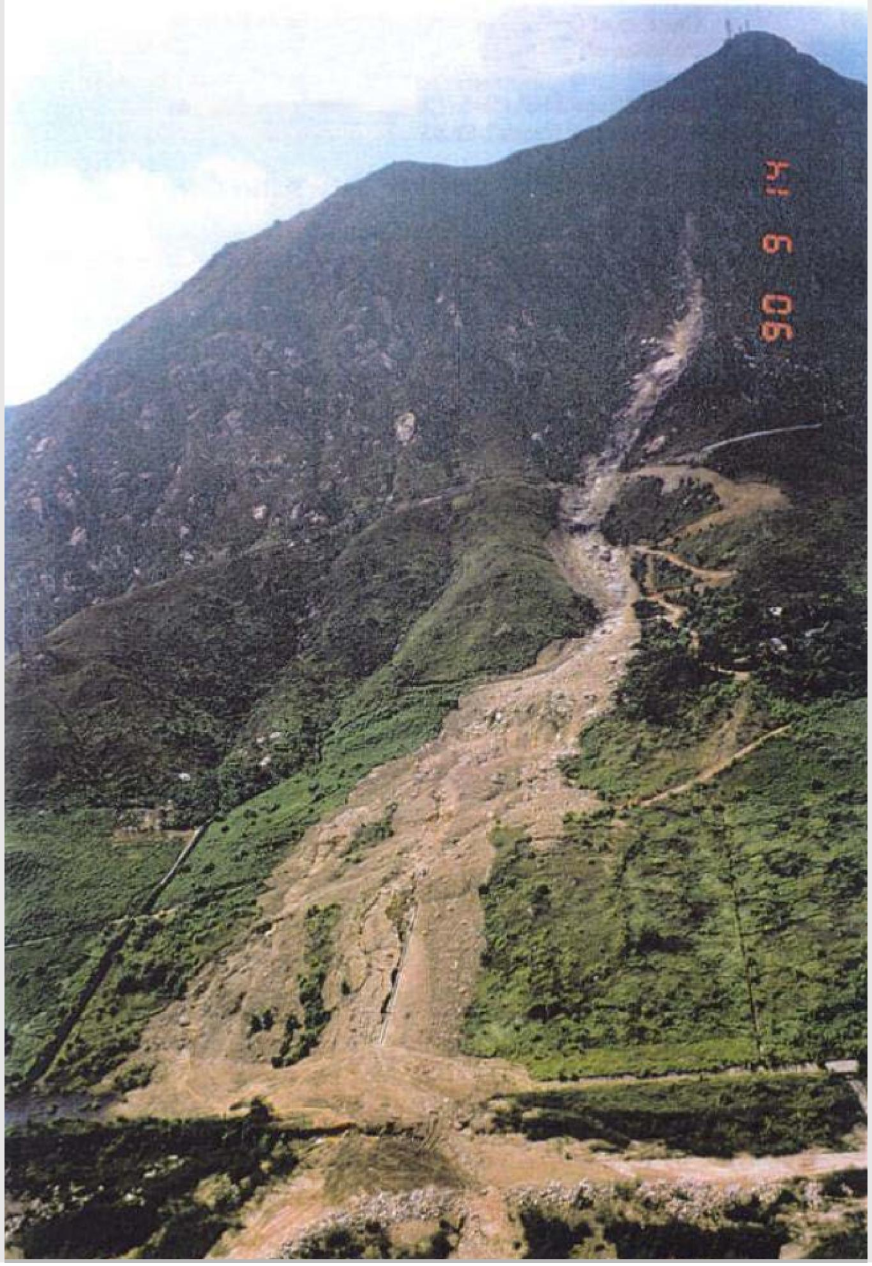
Based on the ~60-year period of aerial photograph coverage in Hong Kong, the percentage probability of a 1:100-year event being recorded at a particular site is only 31% (Lee & Jones, 2004).

Need to assess what could occur, not necessarily what has occurred.

Also landslides are not fixed process but are extremely dynamic as such a landslide inventory is the starting point

11 September 1990 Tsing Shan Debris flow

- Initiated as a 450m^3 debris slide
- accelerated over a cliff landing on an area of thick colluvium
- triggering a secondary debris side of 2500m^3
- Entered the drainage line became a debris flow
- Entrained 16,000m^3 of material
- 1km run out
- Debris deposited on platform constructed for housing



A key component of Hazard Identification is the development of a hazard model

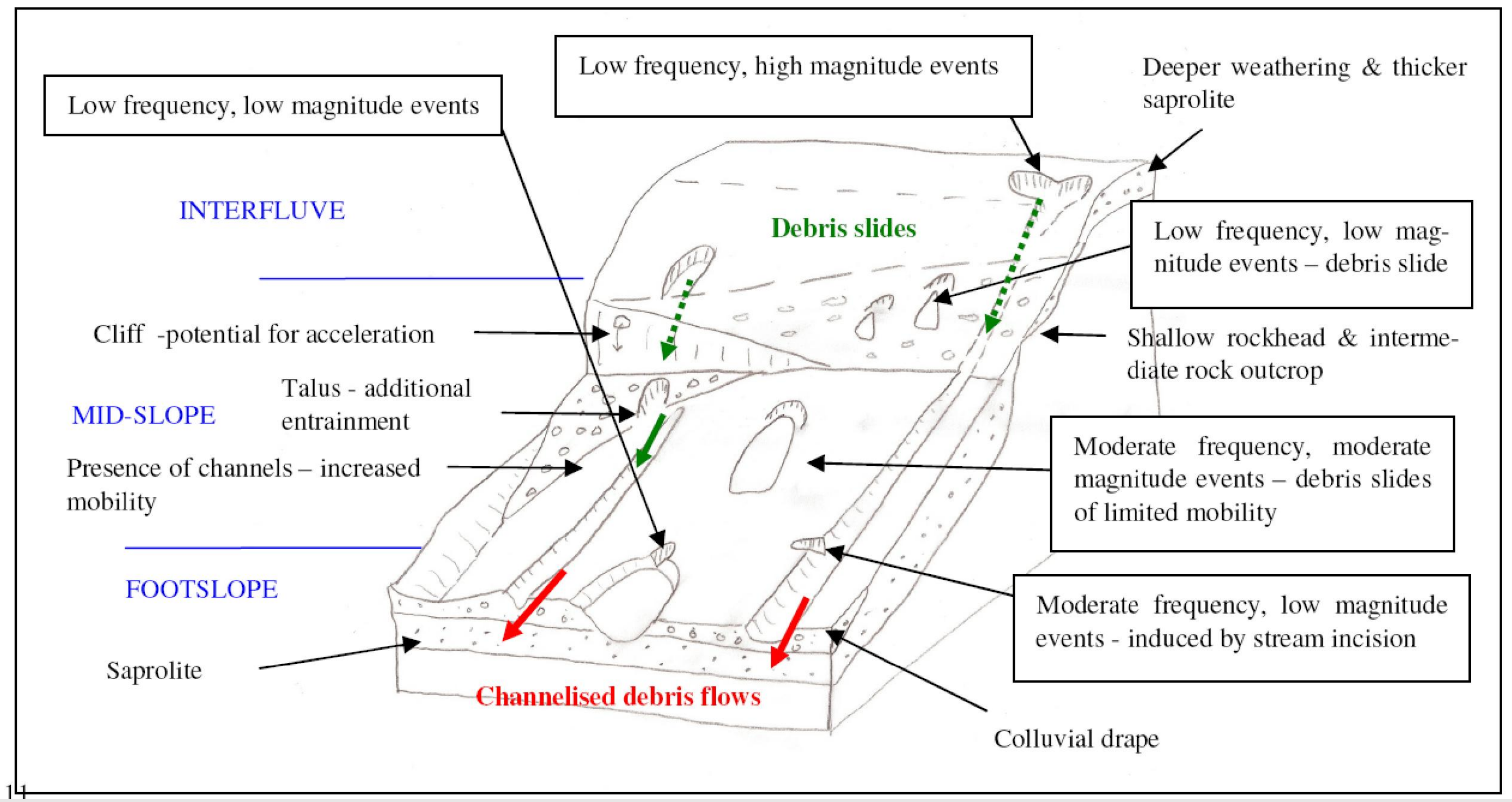
- What could happen
- Where could it happen
- Why might such events occur
- When might such events occur

Addressing these uncertainties is the key role of engineering geomorphology

"*If knowledge of geomorphology of the site is not incorporated into a Landslide Risk Assessment then the assessment is unlikely to be realistic*" Baynes & Lee, 1998

What could happen?

Use of conceptual hazard models[1] – allow all possible hazards to be considered



Parry, S, Ruse, M. E,. & Ng, K. C. (2006). Assessment of Natural Terrain Landslide Risk in Hong Kong: An Engineering Geological Perspective. Accepted Paper No. 299, Proceedings of the International Association of Engineering Geology. Nottingham, 2006.

[1]Parry, S., Baynes, F. J., Baynes, Culshaw, M. G., Eggers, M., Keaton, J. F., Lentfer, K., Novotny, J., & Paul, D. (2014). Engineering Geological Models - an introduction: IAEG Commission 25. Bulletin of the International Association of Engineering Geology and the Environment. Volume 73, Issue 3, pp 689-706.

An understanding of slope/landscape evolution is fundamental to a landslide assessment.

The basic geomorphological concepts which underpin this are:

- A given set environmental conditions and constant processes over time will result in a set of characteristic landforms

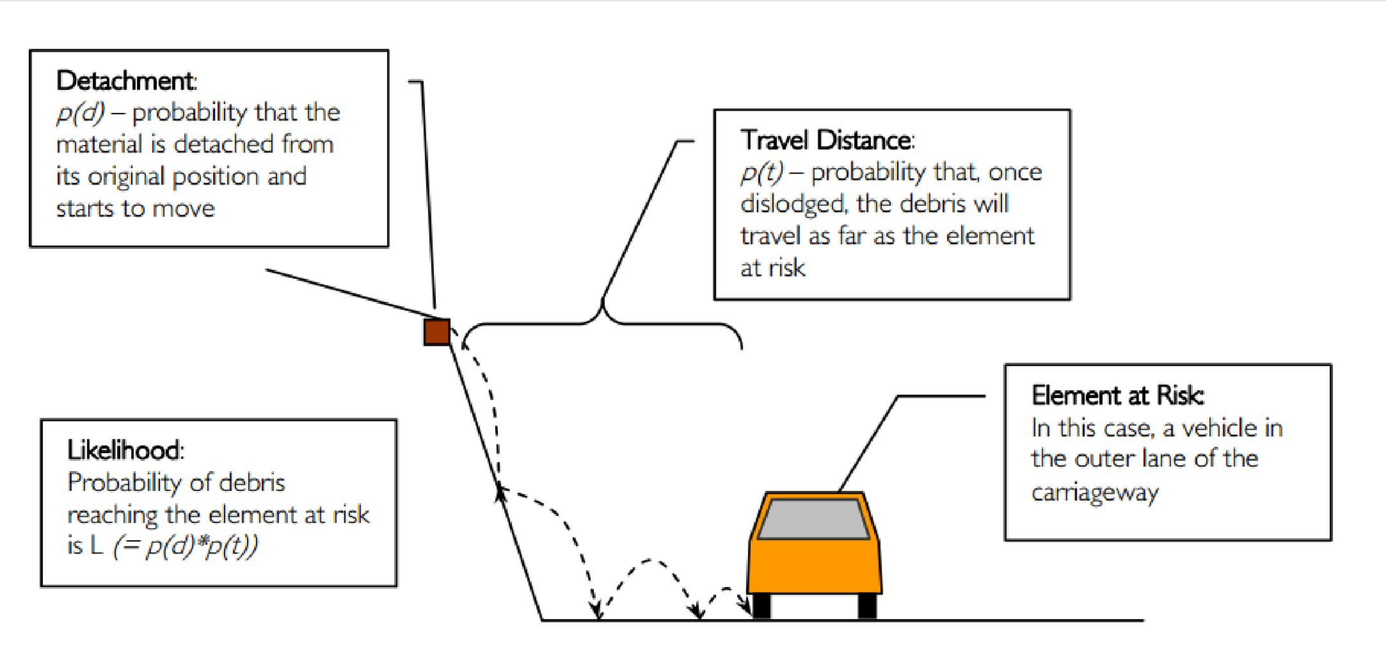
- Controls on landslide activity are not constant with time over space. Geomorphological change can be initiated by processes events which vary according to the timescales over which they operate

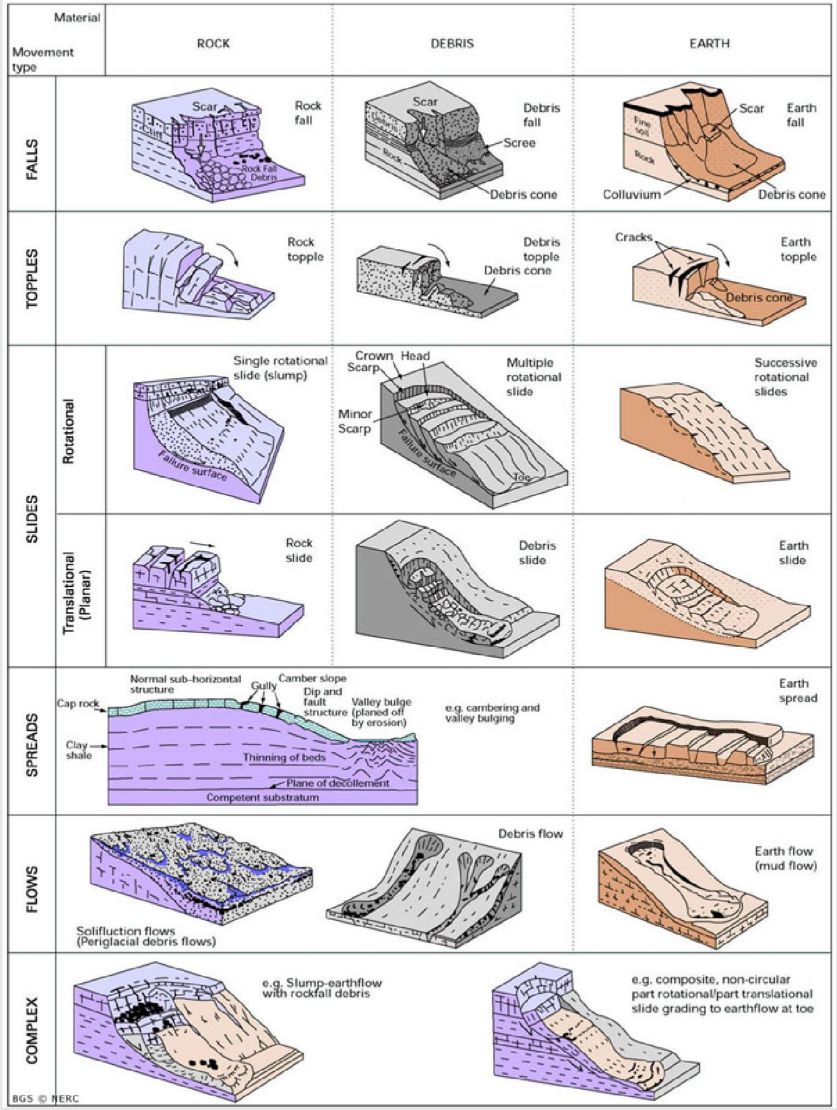
- The landscape rarely reflects any one climate or period of change, they are palimpsests of superimposed histories i.e. a mosaic of landscape features of different age and origins

- Landslides features have a finite lifetime within the landscape

Hazard Analysis

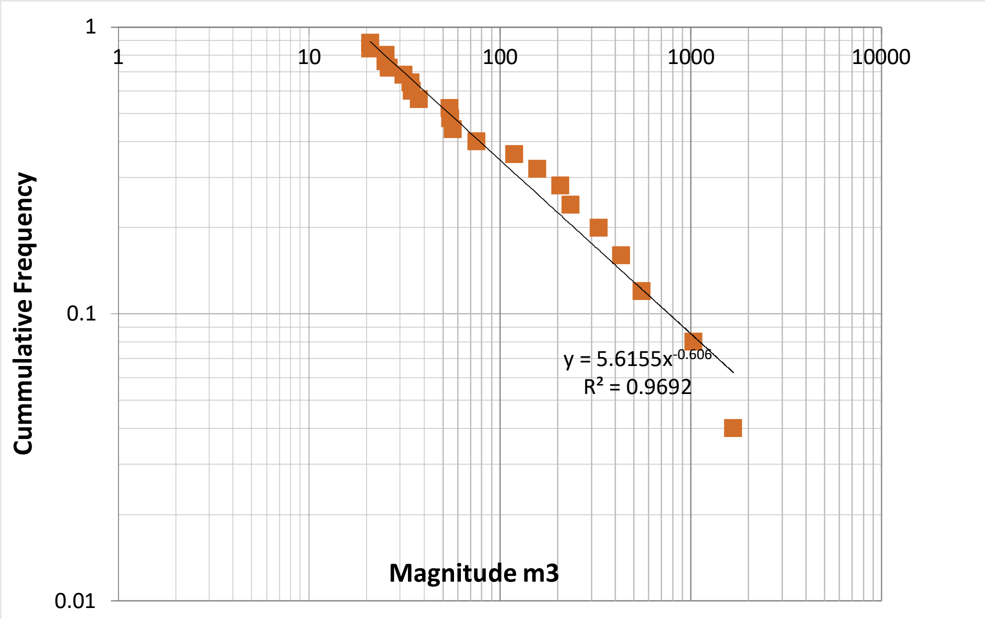
- probability of impact is a function of magnitude, frequency and run out
- these are in turn a function of landslide type





Note entrainment/depletion should also be considered

- Use the historical frequency of landslides in the area to provide an indication as to future annual probability (requires data)



- Estimate probability through expert judgement

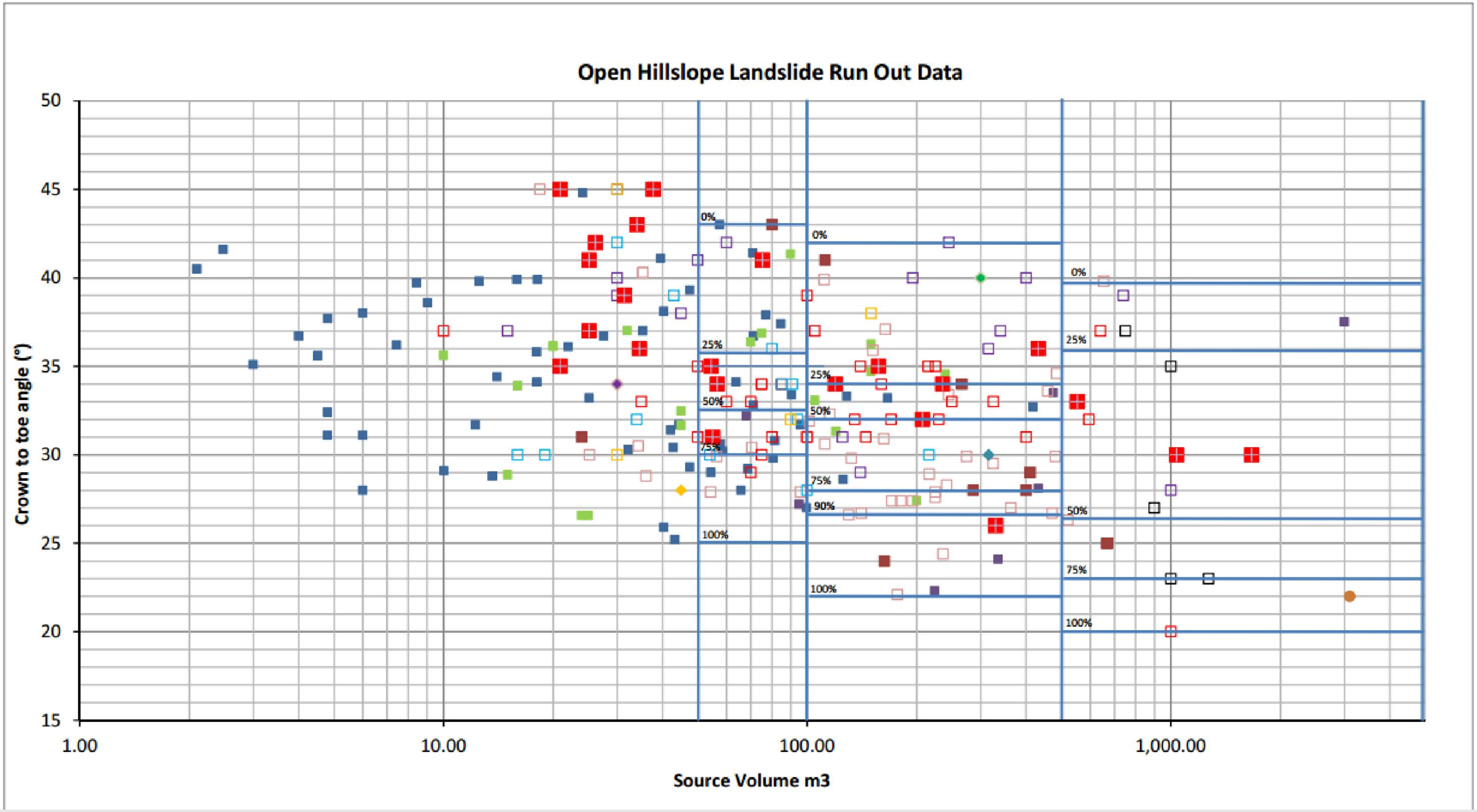
- Use the probability of a landslide triggering event as an indicator of the probability of a landslide

- Estimate probability through stability analysis, e.g. the probability FoS <1.0 over a period of time

Not only frequency of occurrence but probability of run out reaching facilities i.e. hazard not susceptibility

Hazard Analysis

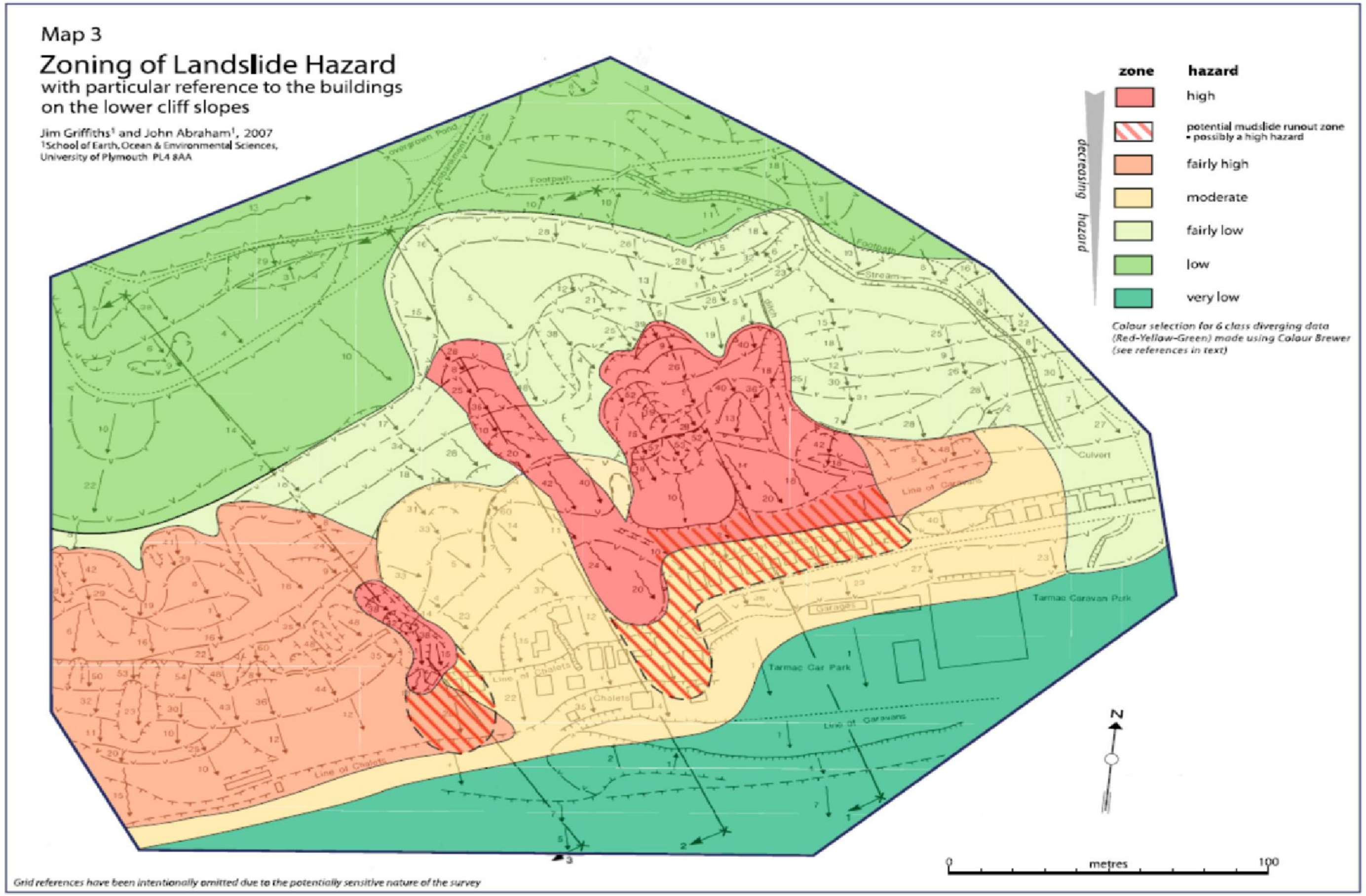
- run out

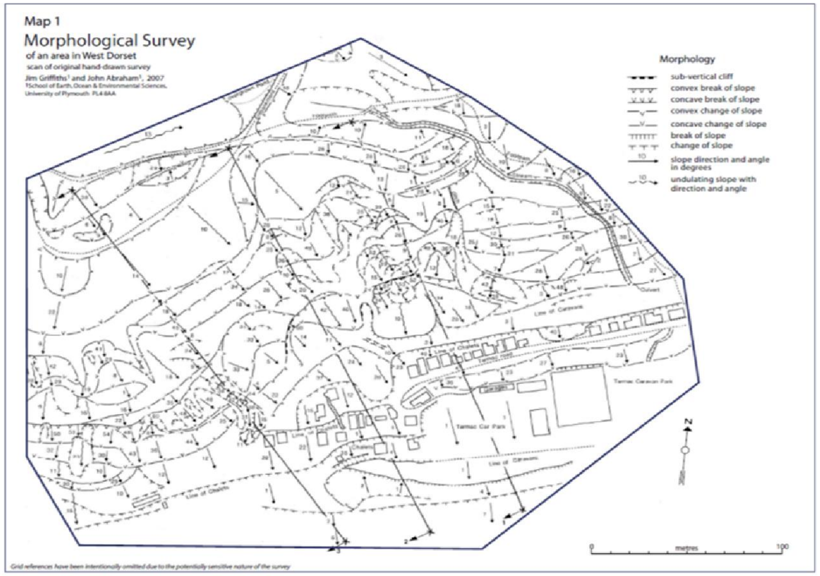


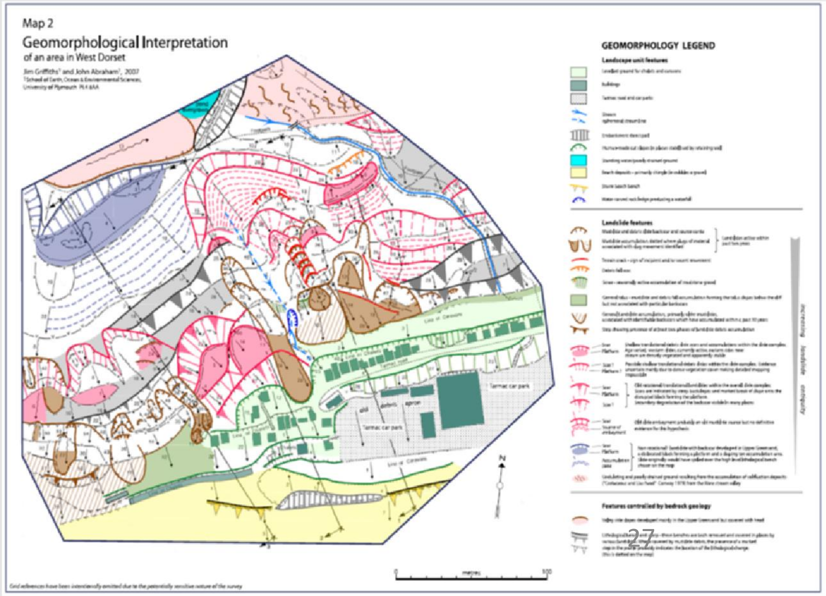
What approaches are available to assess hazard?

- **Direct** –based on engineering geomorphological mapping
- **Indirect** –based on GIS interpretation based on an evaluation of causal factors

- **Direct** –based on engineering geomorphological mapping

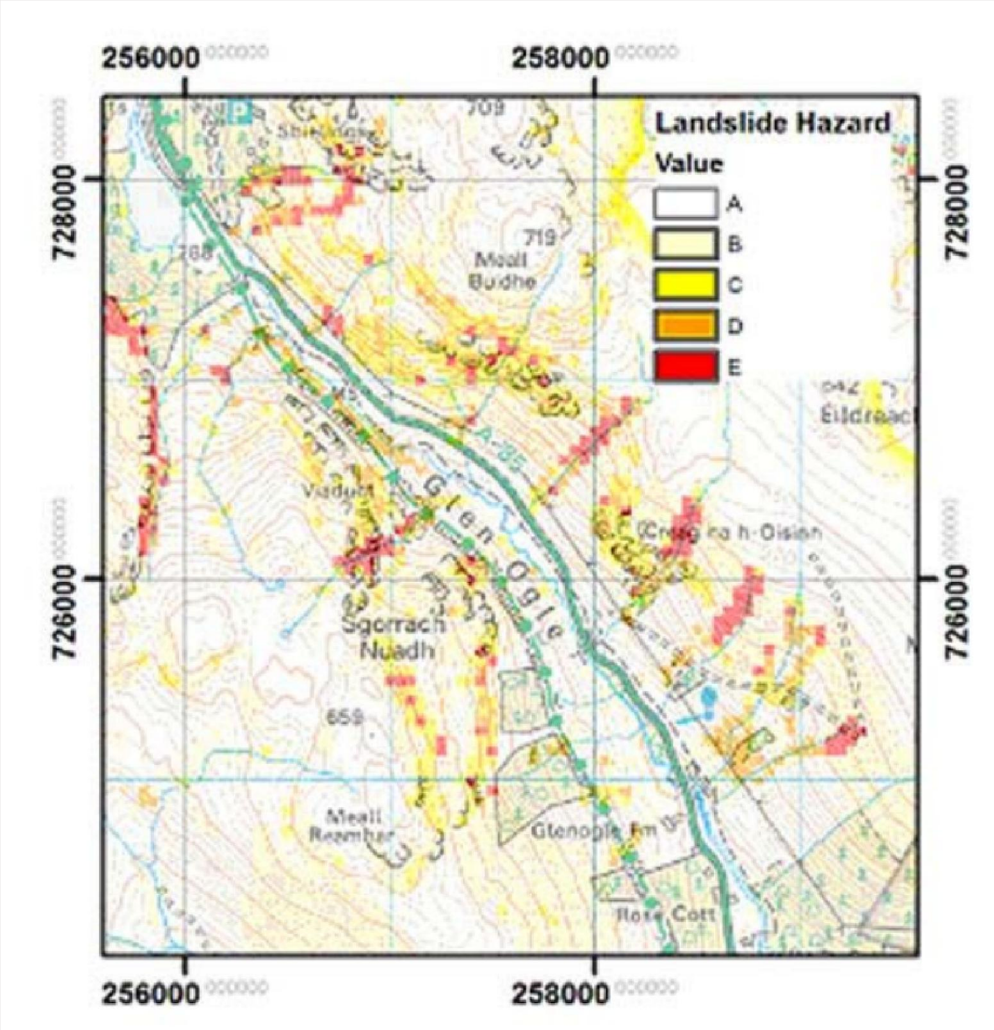


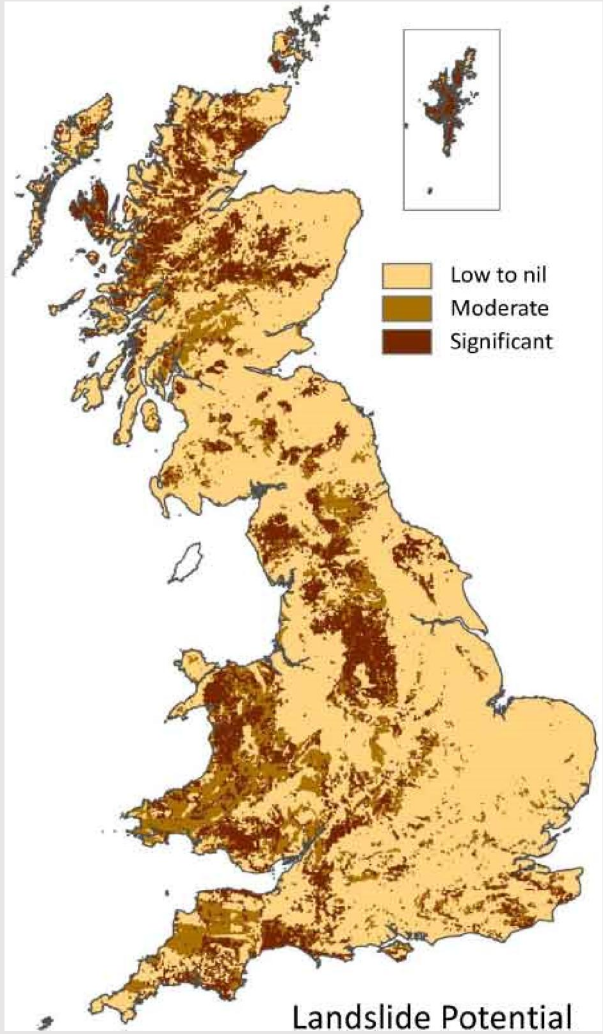




Griffiths, J. S. & Abraham, J. K. 2008. Factors affecting the use of applied geomorphological maps to communicate to different end users. Journal of Maps pp201-210

- **Indirect** – GIS interpretation based on an evaluation of causal factors





Direct Mapping

Based on knowledge and experience of interpreter

Direct mapping can produce very reliable maps such that the percentage of misclassification is zero. This cannot be obtained with indirect mapping.

The disadvantage of direct mapping is that they are based on individuals experience and hence may not be reproducible

Not particularly cost-effective over very large areas.

Indirect Mapping

The main problem is in determining the exact weighting of the various parameter maps. Often, insufficient field knowledge of the key factors limits the establishment of the factor weightings, leading to generalizations.

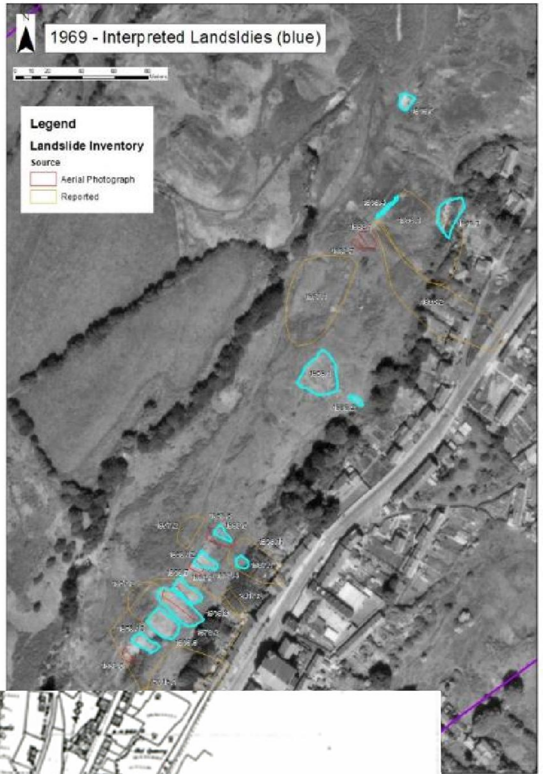
Maps produced from statistical analysis are very reproducible since the weight is derived from the attributes and not from the data. However, this is not necessarily more objective since subjectivity is involved in both the data collection and the selection of relevant factors for the analysis.

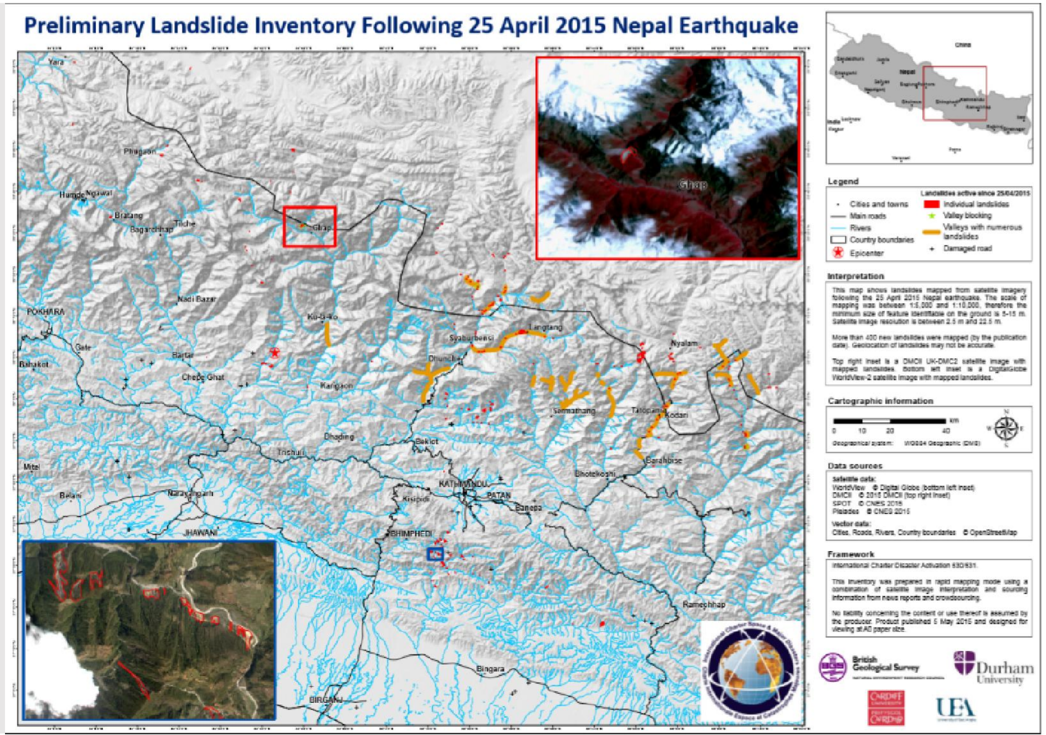
Dependant on appropriate data sets being available

Regardless of the approach a high quality landslide inventory is required with data on landslide type, age, volume (inc entrainment), run out

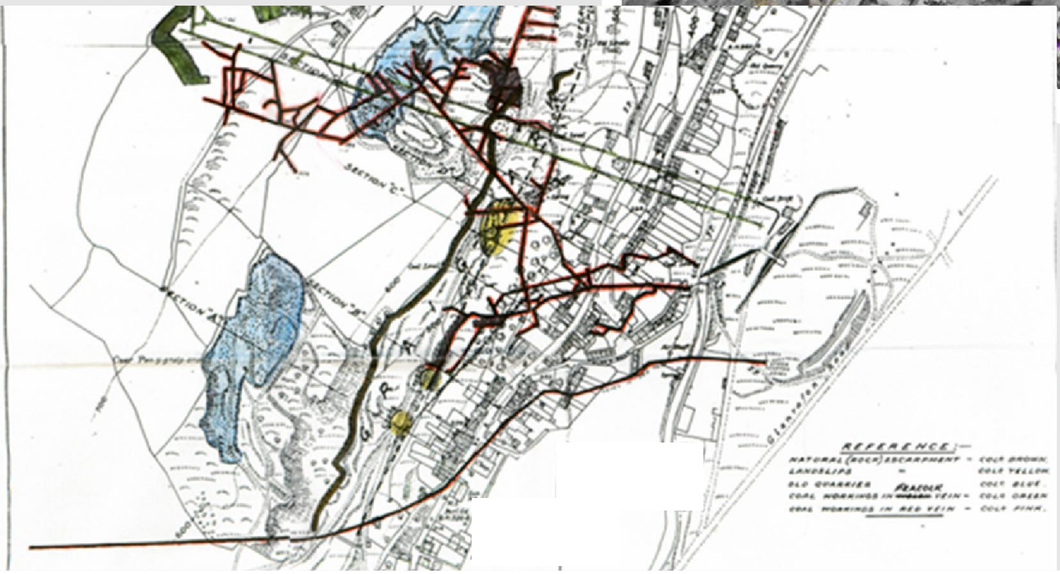
Landslide inventory

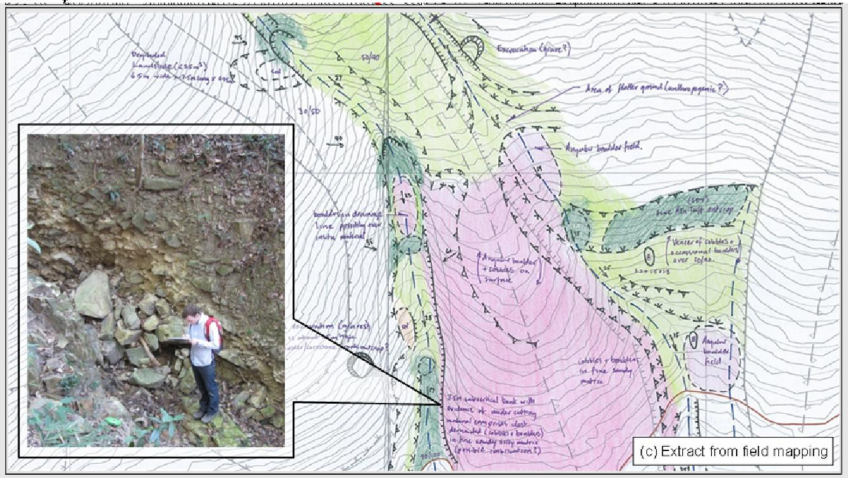
- Historic records
- Satellite
- API
- Field mapping





http://www.bgs.ac.uk/research/earthHazards/epom/documents/LandslideinventoryNepal5May2015.pdf





Consequence Analysis

Requires:

- Evaluation of spatial exposure for all elements at risk
  – fixed elements e.g. houses and mobile elements e.g., cars
- Evaluation of temporal exposure for all elements at risk
  – people in buildings, pedestrians, people in vehicles etc
- Evaluation of impact (related to, but more complex than, LS type).
  - vertical displacement
  - lateral displacement
  - undermining
  - burial
  - missile impact and air blast
- Evaluation of vulnerability
  – person in open space buried by debris,
  - person buried by debris in a building,
  - debris results in building collapse,
  - car strikes landslide,
  - landslide strikes car, etc

Table 8.9 Example 8.4: Lawrence Hargrave Drive, Australia – vulnerability values for various landslide scenarios

Volume of landslide debris crossing road: m^3	Rockfalls		Debris flows	
	Hits car	Car hits debris	Hits car	Car hits debris
0.03	0.05	0.006	NA	NA
0.3	0.1	0.002	NA	NA
3	0.3	0.03	0.001	NA
30	0.7	0.03	0.01	0.001
300	1	0.03	0.1	0.003
3000	1	0.03	1	0.003

From Wilson *et al.* (2005)

With respect to the type of hazard or risk analysis undertaken this can be:

Qualitative - descriptor e.g. high, medium or number 1, 2, 3

- Relatively rapid
- Allows the relative hazard and risk at different sites to be evaluated (when undertaken concurrently) and sites ranked
- Doesn’t generate “design events”
- No fixed methodology for their generation
- Doesn’t allow comparisons between different assessments
- Assumptions may not be explicit

Quantitative – calculated values e.g. probability of fatalities per year.

- Allows direct comparisons between sites – removes ambiguities
- Each component of the risk assessment is explicitly assessed and it generates reproducible and consistent results
- Generates a series of design events (with associated residual risk levels)
- Allows the reduction in risk from mitigation works to be evaluated i.e. cost benefit
- Allows the evaluation of defensible levels of spending on risk reduction

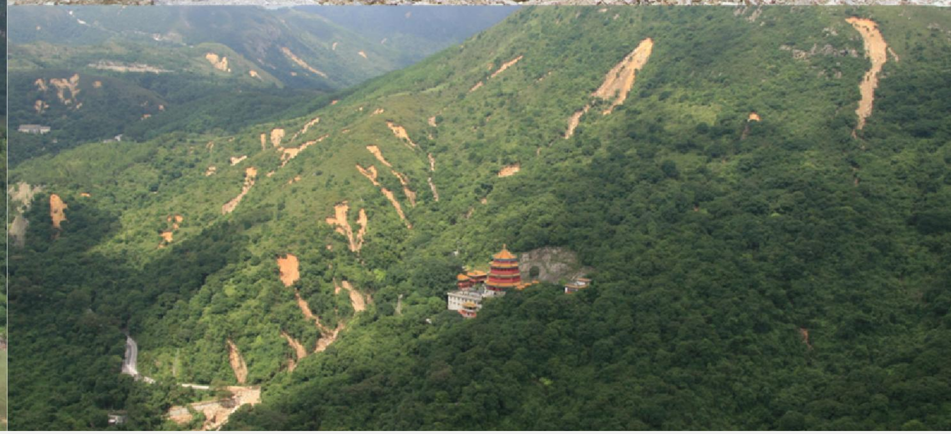
(Also quasi-quantatative)

Case Studies

Case 1- Regional Qualitative Landslide Risk Assessment – Hong Kong

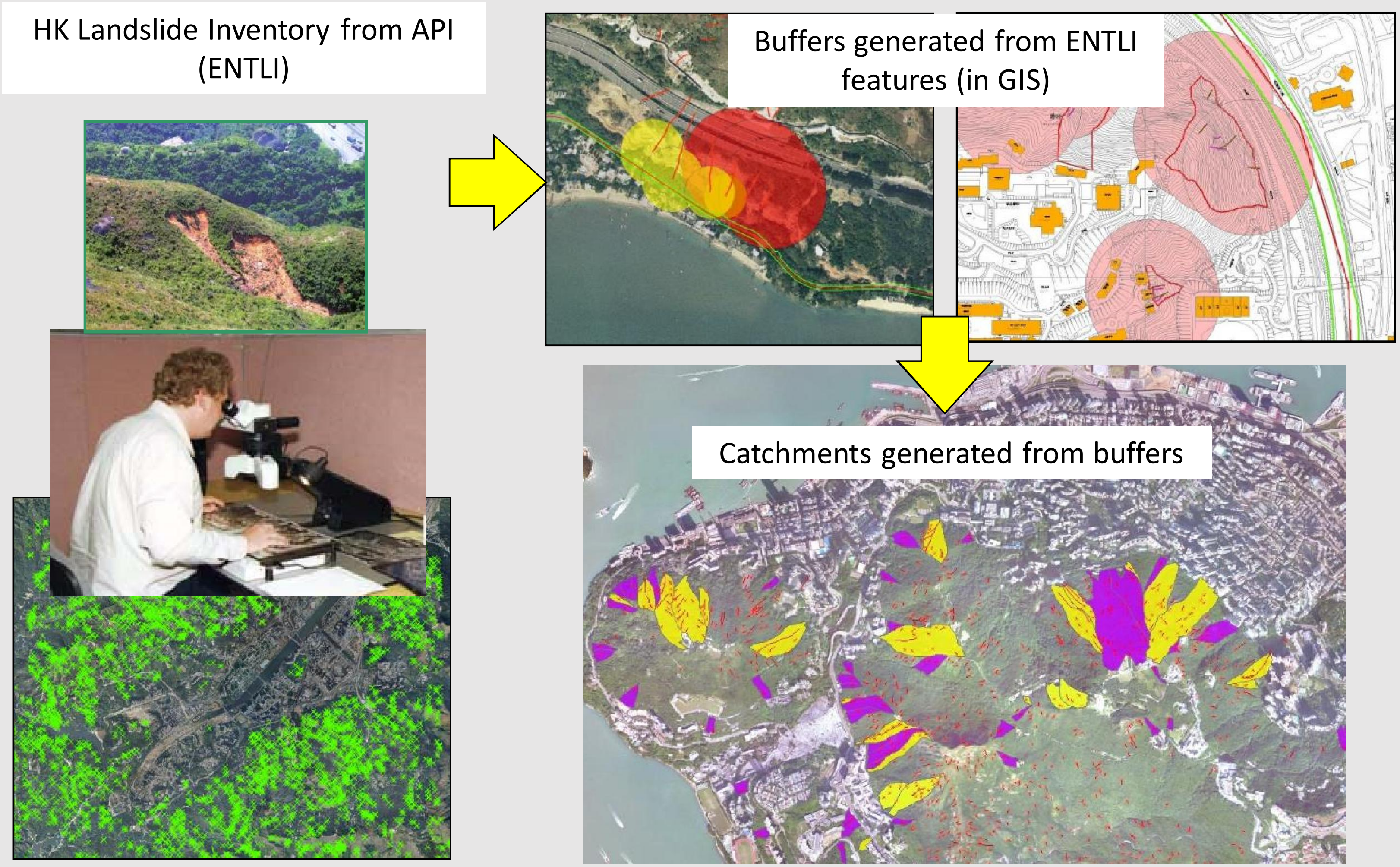
Qualitative

- Relatively rapid
- Allows the relative hazard and risk at different sites to be evaluated (when undertaken concurrently)



7 June 2008 - Peak hourly rainfalls of 145 mm/hr and a return period of 500 to 1000 years based on the 4-hour rolling rainfall

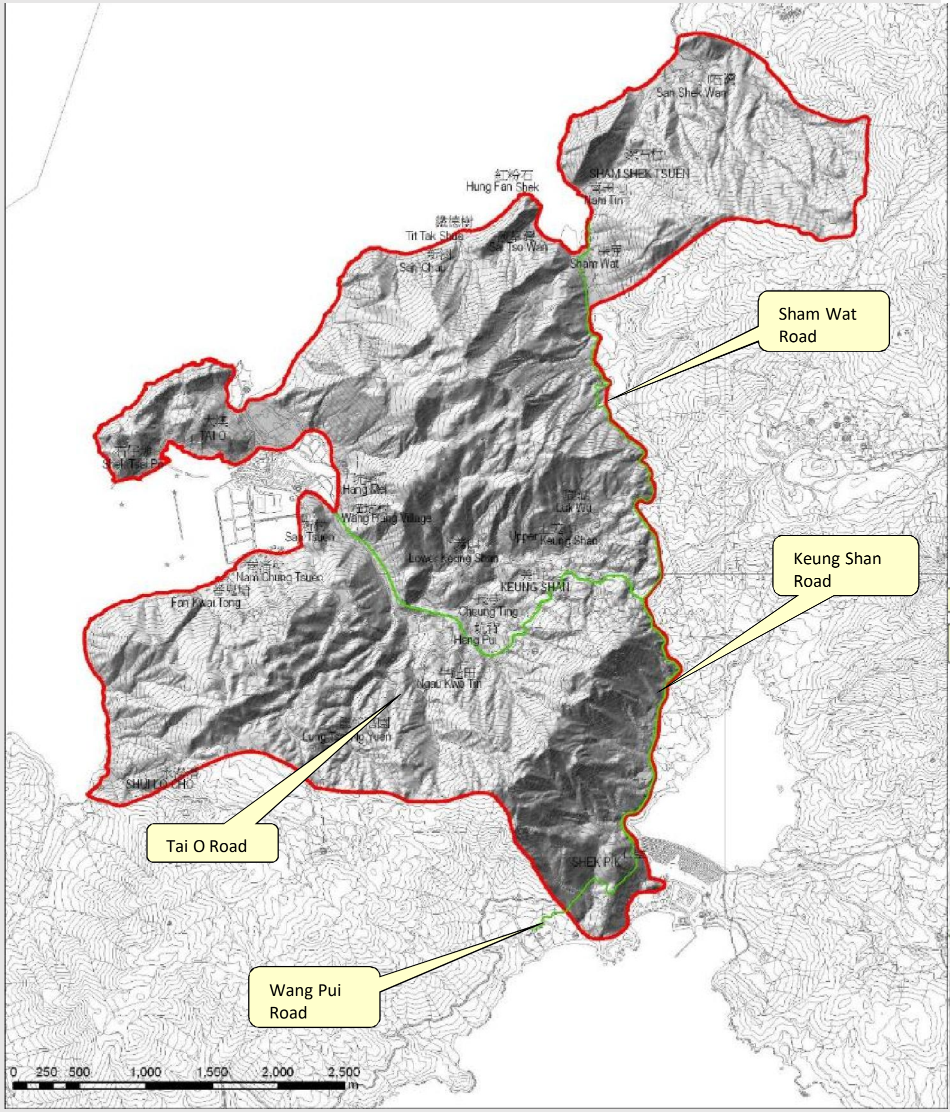
Western part of Lantau Island over 1,000 landslides including numerous long run out debris flows. blocked key road links and evacuation of over 25 houses

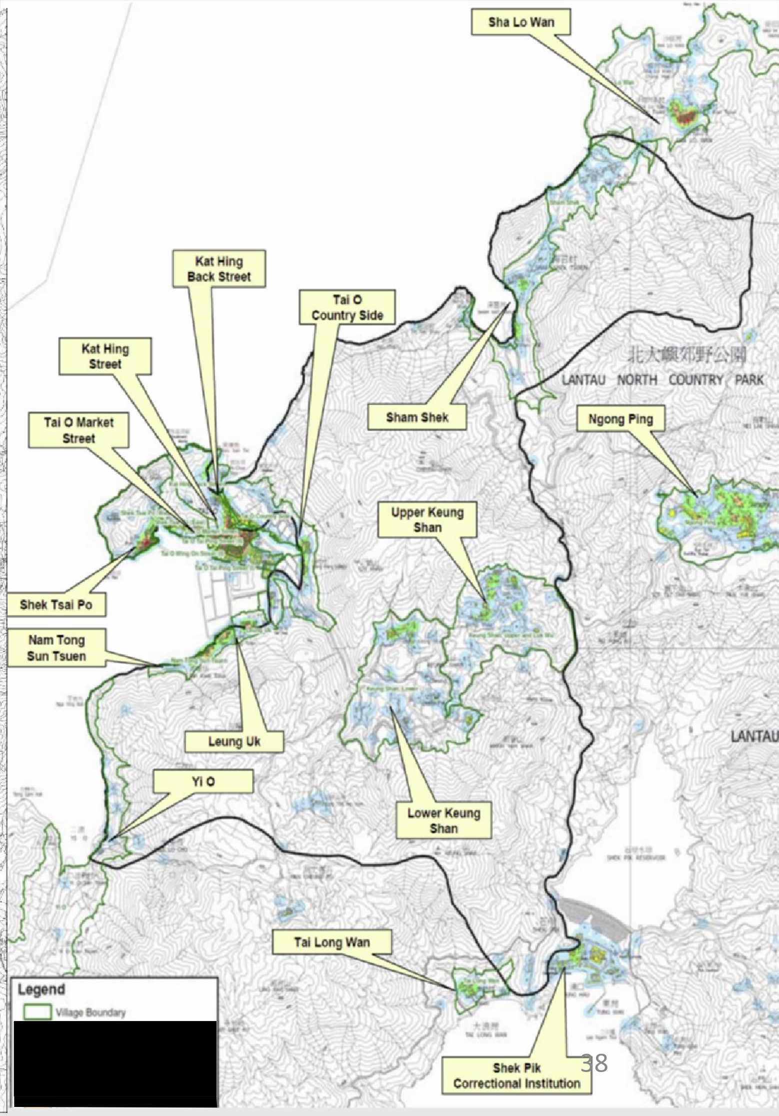

HK Landslide Inventory from API (ENTLI)
Buffers generated from ENTLI features (in GIS)
Catchments generated from buffers



Regional Qualitative Landslide Risk Assessment – Hong Kong

- **Apx 18 km^2**
- **Village areas**
- **Main Transport Routes include**
  - **Tai O Road**
  - **Keung Shan Road**
  - **Sham Wat Road**
  - **Wang Pui Road**





Regional Landslide Risk Assessment

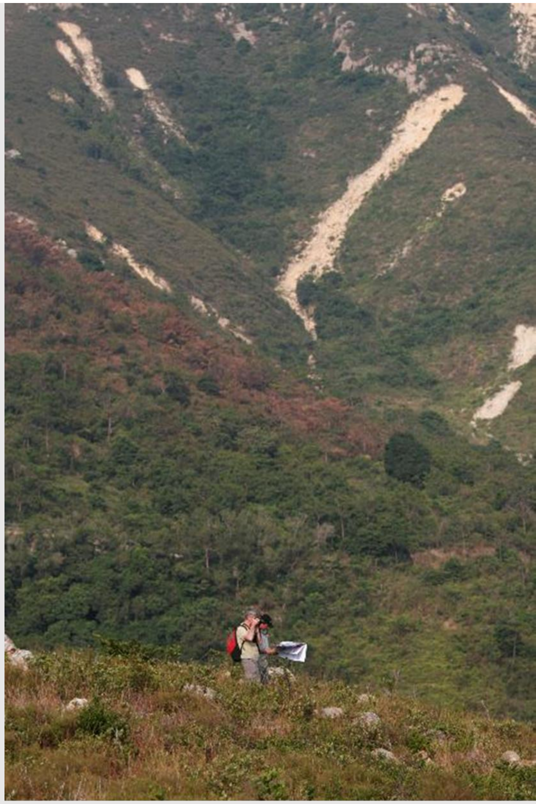
Engineering geomorphological mapping based primarily on API

The API was undertaken by the team at a single location to enable discussion, comparisons and benchmarking as well as the rapid development of the methodology.

Each map sheet was checked by a different team member from the original mapper to act as a quality control and to ensure consistency between team members.

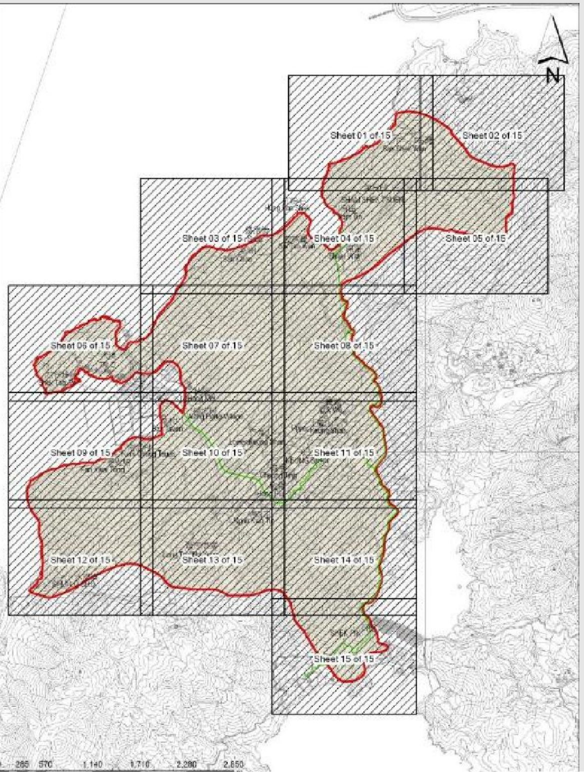
Site reconnaissance's were made by the mapping team, traversing the main footpaths and trails in the Study Area.

These included a day in the field with the Independent Technical Reviewer of the Study, Dr Fred Baynes



Engineering geomorphological approach, comprising

- morphological mapping,
- drainage line mapping
- solid geology (existing)
- superficial geological mapping,
- landform mapping,
- terrain unit mapping.



Legend

Study Area

Morphology

- Cliff (>60 degrees)
- Concave Break of Slope
- Convex Break of Slope
- Sharp Change of Slope
- Landslide Scar
- Tension Crack

Terrain Units

- Top of Incising Unit
- Top of Lower Unit
- Top of Middle Unit
- Middle Unit Sub-division
- Upper Unit Sub-division

Note: All Terrain above top of Middle Unit comprises Upper Terrain Unit

Drainage Lines

- Open
- Broad
- Confined

Landforms

- Debris fan
- Fan - Undifferentiated
- Relict Debris fan
- Distressed Terrain
- Landslide Complex
- Anthopogenic Alteration

Solid & Superficial Geology

Superficials (From API)

- Undifferentiated Colluvium
- Fluvially Reworked Colluvium
- Boulder Levees (Colluvial)
- Boulder Filled Depressions (Colluvial)
- Taluvium
- Alluvium

Saprolite (From 1:20,000 HKGS Map)

- Siltstone, tuffite and tuff (Jpk)
- Metasiltstone, metasandstone ;graphite bearing (Cmp)
- Graphite schist (gr)
- Eutaxite (Jcs)
- Rhyolite lava and tuff (JLT)
- Lapilli-bearing crystal tuff (JSM)
- Coarse ash crystal tuff (JYT)
- Sandstone (s)
- Siltstone (sl)
- Fine-grained quartz syenite (sqf)
- Undifferentiated tuff and tuffite (tt)
- Microgranite (ug)

Bedrock (From API)

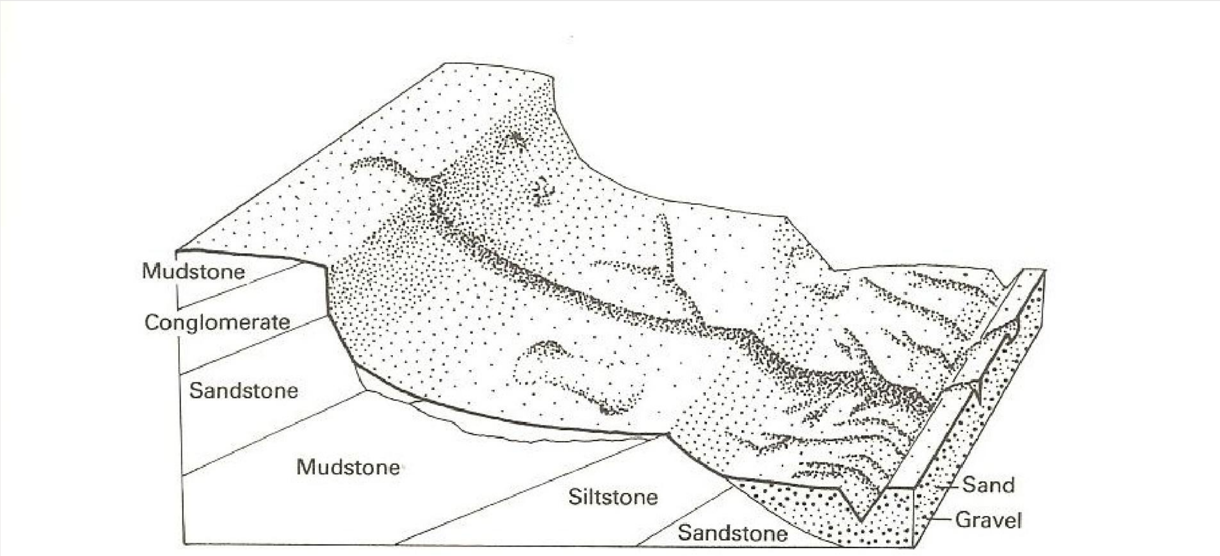
- Intermittent Rock Exposures
- Rock Outcrop

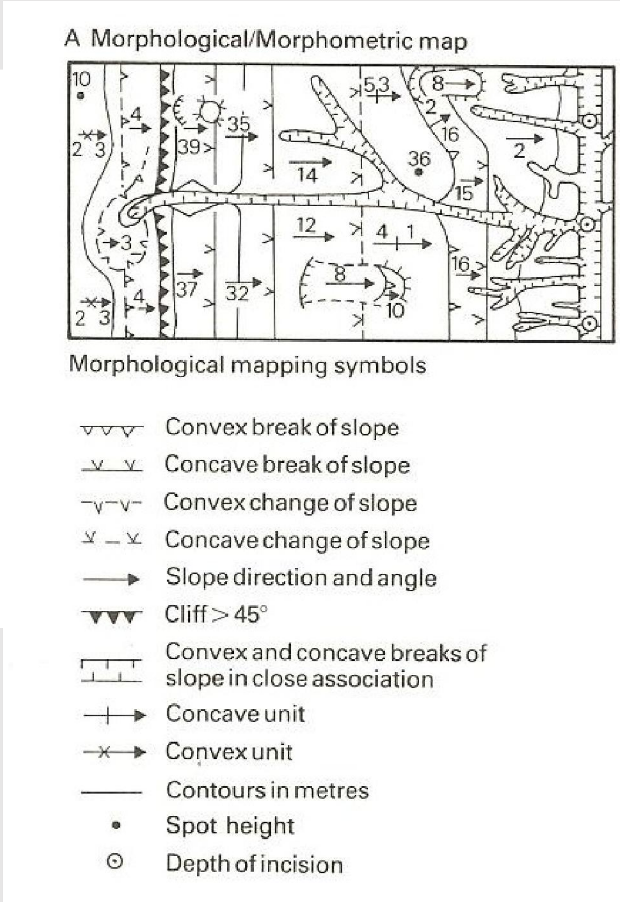
Geological Structure (From 1:20,000 HKGS Map)

- Fault, inferred
- Reverse Fault (Teeth pointing to upper Plate)
- Photolineament

Moprphological Mapping

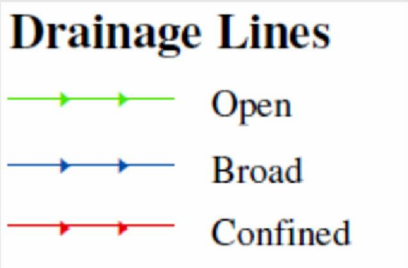
Based on Savigear (1965)





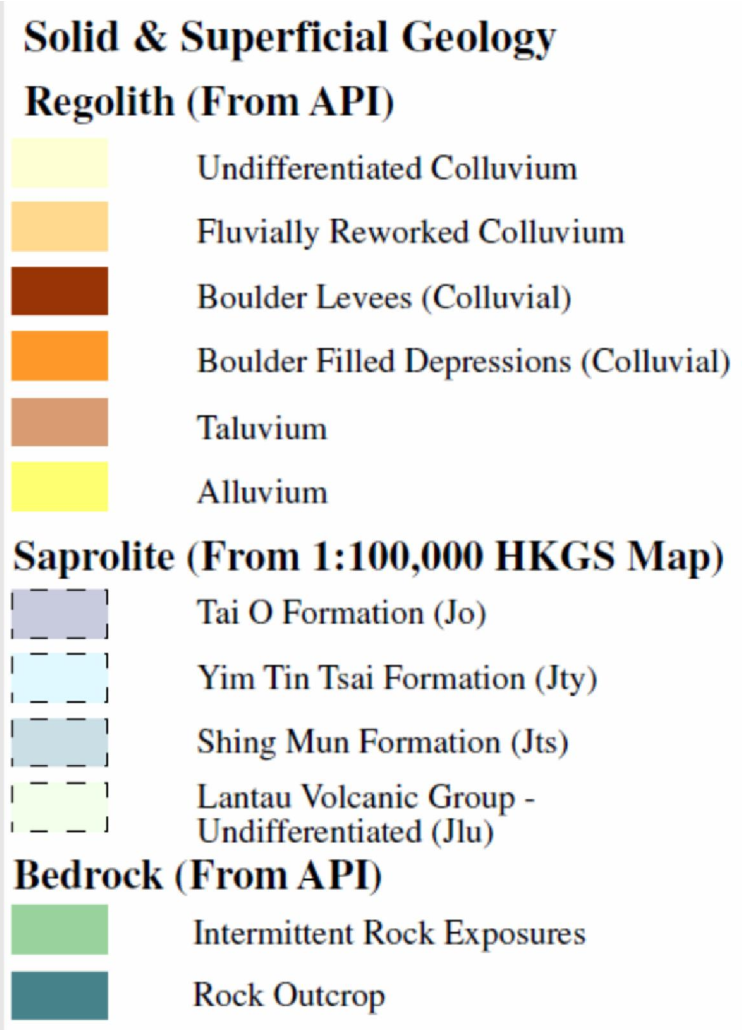
Drainage Lines

- Record Drainage Line location and characteristic based on their anticipated channelisation potential:
  - **Open** – Drainage line not significantly incised and within relatively planar hillside
  - **Broad** – Drainage line situated within broad widely separated but laterally continuous morphological boundaries
  - **Confined** – Drainage line is notably incised and located within laterally continuous morphological boundaries

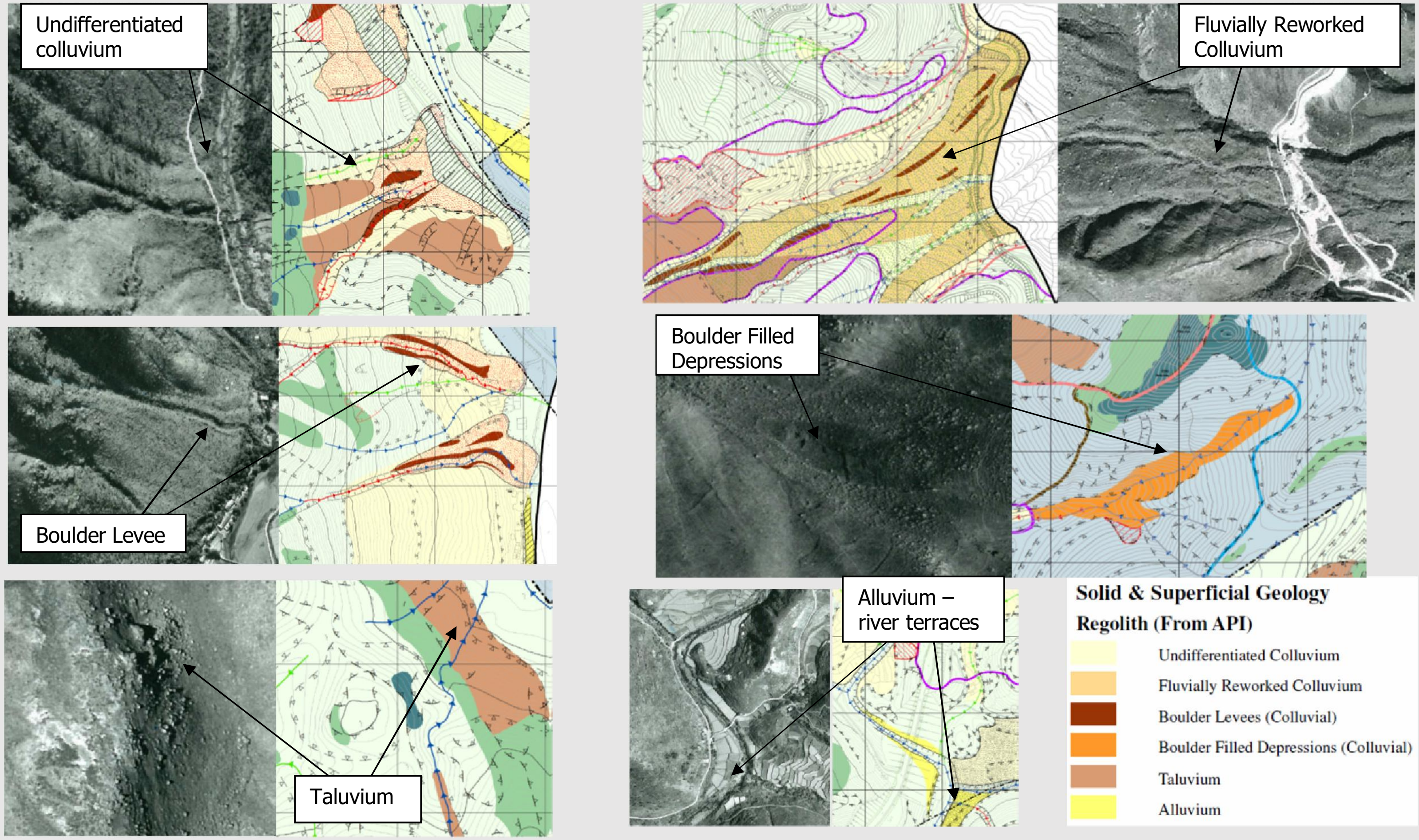


Superficial Geology

- Superficial geology mapped:
  - Colluvium (several sub-types)
  - Taluvium
  - Alluvium
- These units also indicate dominant geomorphological process
- Also recorded the extent of Saprolite, Intermittent Rock Outcrops and Rock Outcrops
- Solid geology adopted from existing geological maps

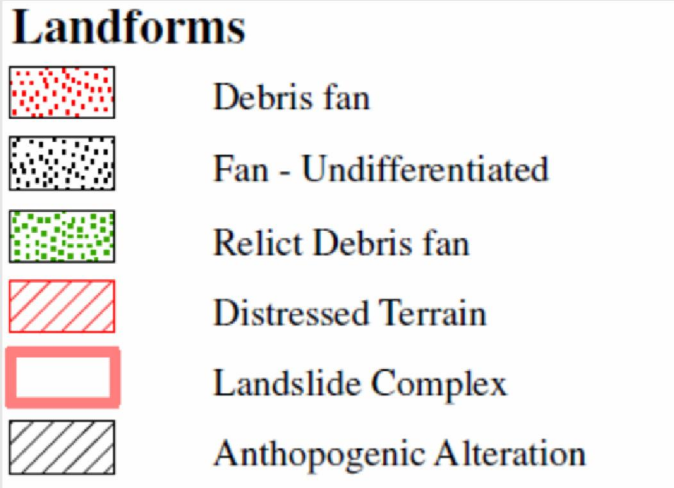


Superficial Geology



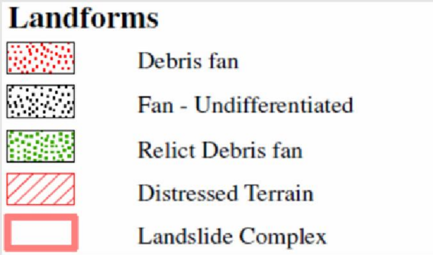
Landforms

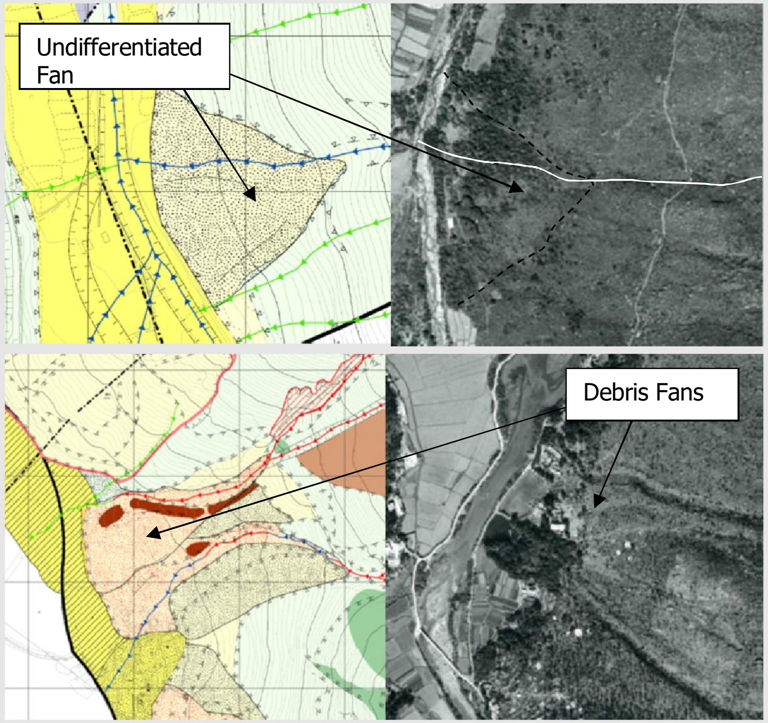
- Key landform features recorded were:

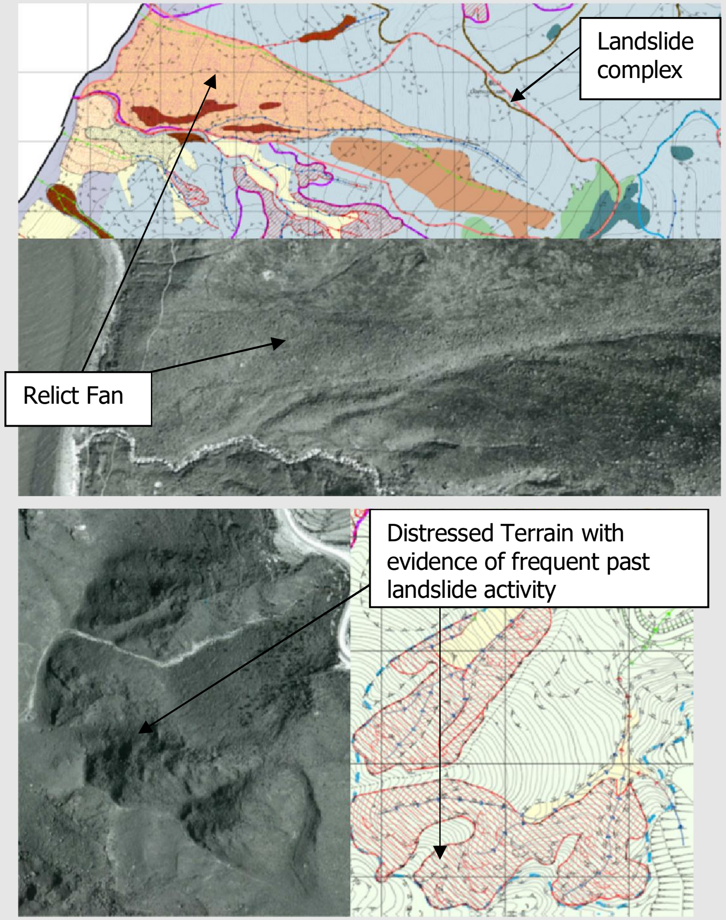


Provide valuable indicators of landslide process and rates of activity

Landforms

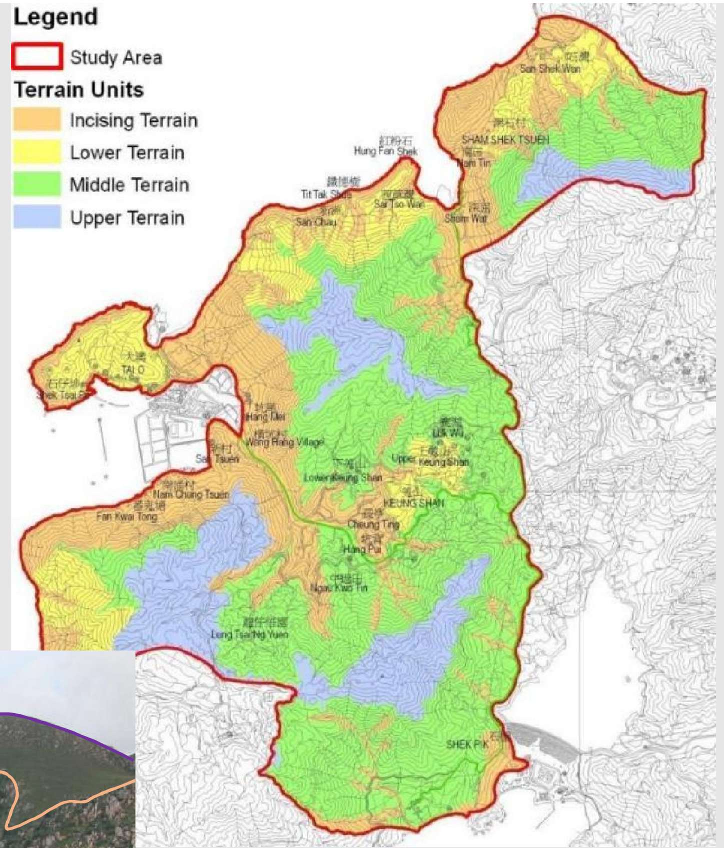

Landforms
Debris fan
Fan - Undifferentiated
Relict Debris fan
Distressed Terrain
Landslide Complex

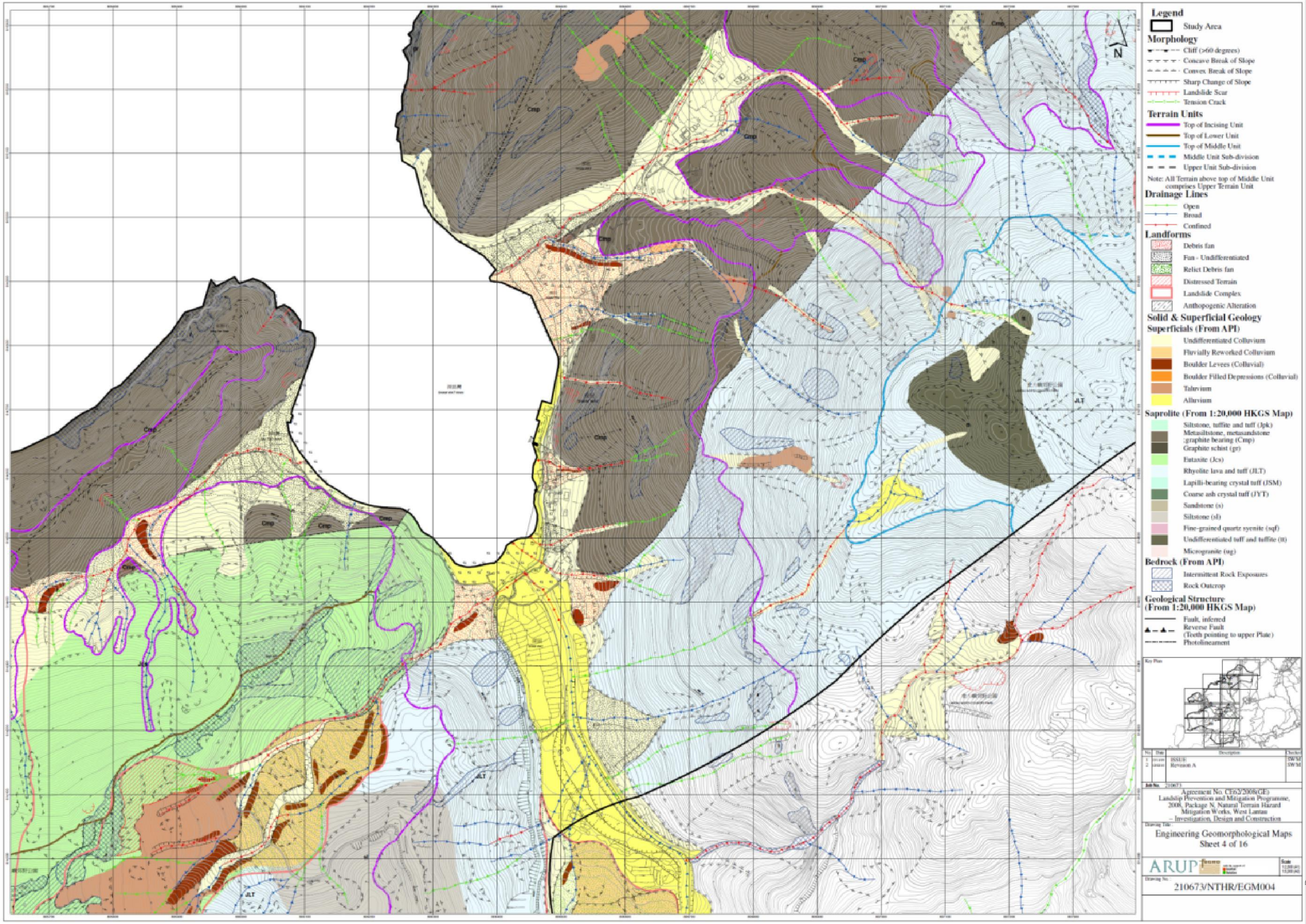

Undifferentiated Fan
Debris Fans


Landslide complex
Relict Fan
Distressed Terrain with evidence of frequent past landslide activity

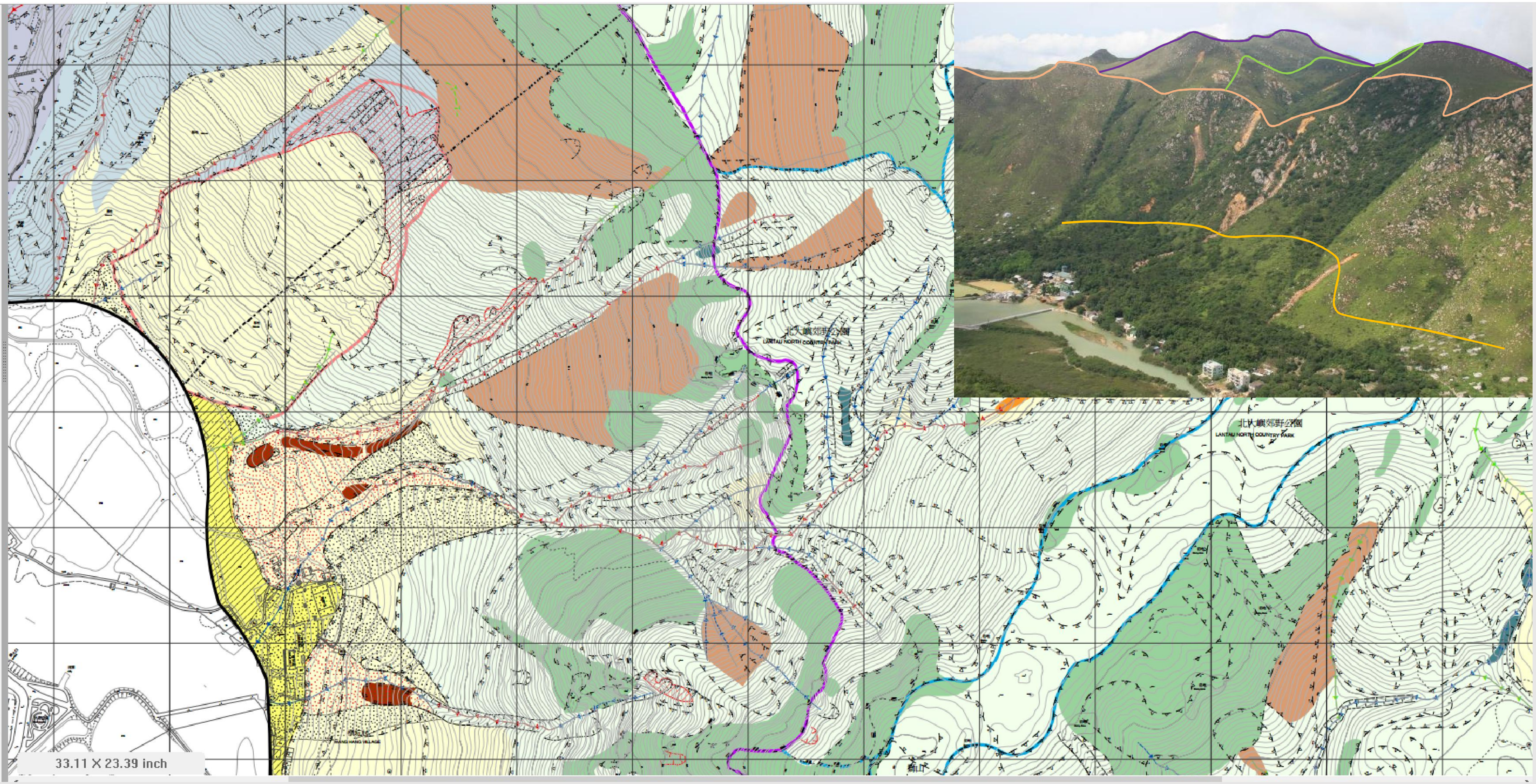
Terrain Units

- Regional scale geomorphological units that define distinct and unique groups of superficial materials and landforms:
  - Incising Terrain
  - Lower Terrain
  - Middle Terrain
  - Upper Terrain
- Typically occurring within a set range of altitude
- Related to the different initial ages of landscape formation plus geological control



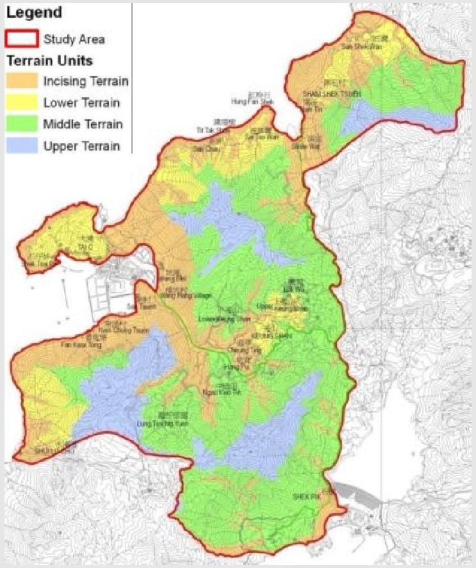


Legend
Study Area
Morphology
Cliff (>60 degrees)
Concave Break of Slope
Convex Break of Slope
Sharp Change of Slope
Landslide Scar
Tension Crack
Terrain Units
Top of Incising Unit
Top of Lower Unit
Top of Middle Unit
Middle Unit Sub-division
Upper Unit Sub-division
Note: All Terrain above top of Middle Unit comprises Upper Terrain Unit
Drainage Lines
Open
Broad
Confined
Landforms
Debris fan
Fan - Undifferentiated
Relict Debris fan
Distressed Terrain
Landslide Complex
Anthopogenic Alteration
Solid & Superficial Geology
Superficials (From API)
Undifferentiated Colluvium
Fluvially Reworked Colluvium
Boulder Levees (Colluvial)
Boulder Filled Depressions (Colluvial)
Talluvium
Alluvium
Saprolite (From 1:20,000 HKGS Map)
Siltstone, tuffite and tuff (Jpk)
Metasiltstone, metasandstone ;graphite bearing (Cmp)
Graphite schist (gr)
Eutaxite (Jcs)
Rhyolite lava and tuff (JLT)
Lapilli-bearing crystal tuff (JSM)
Coarse ash crystal tuff (JYT)
Sandstone (s)
Siltstone (sl)
Fine-grained quartz syenite (sqf)
Undifferentiated tuff and tuffite (tt)
Microgranite (ug)
Bedrock (From API)
Intermittent Rock Exposures
Rock Outcrop
Geological Structure (From 1:20,000 HKGS Map)
Fault, inferred
Reverse Fault (Teeth pointing to upper Plate)
Photolineament
Key Plan
No.
Date
Description
Checked
1
ISSUE
SWM
2
Revision A
SWM
Job No.
210673
Agreement No. CE62/2008(GE)
Landslip Prevention and Mitigation Programme, 2008, Package N, Natural Terrain Hazard Mitigation Works, West Lantau – Investigation, Design and Construction
Drawing Title :
Engineering Geomorphological Maps
Sheet 4 of 16
ARUP
Scale
Drawing No. :
210673/NTHR/EGM004
N
Cmp
JLT


北大嶼郊野公園
LANTAU NORTH COUNTRY PARK
33.11 X 23.39 inch

Hazard Assessment

- Landslide Density (predominantly ENTLI):
  - Incising Terrain - 413 Landslides/km^2
  - Lower Terrain - 250 Landslides/km^2
  - Middle Terrain - 295 Landslides/km^2
  - Upper Terrain - 130 Landslides/km^2



- Other key indicators of Hazard
  - Debris/Undifferentiated Fans – sign of active/past deposition
  - Distressed Terrain – sign of active landsliding (Landslide Density of 1,377 Landslides/km^2)
  - Confined Drainage Lines – potential for channelised debris flow

Hazard Assessment

Key hazard types are channelised debris flows, especially as many coastal settlements are located on fans.

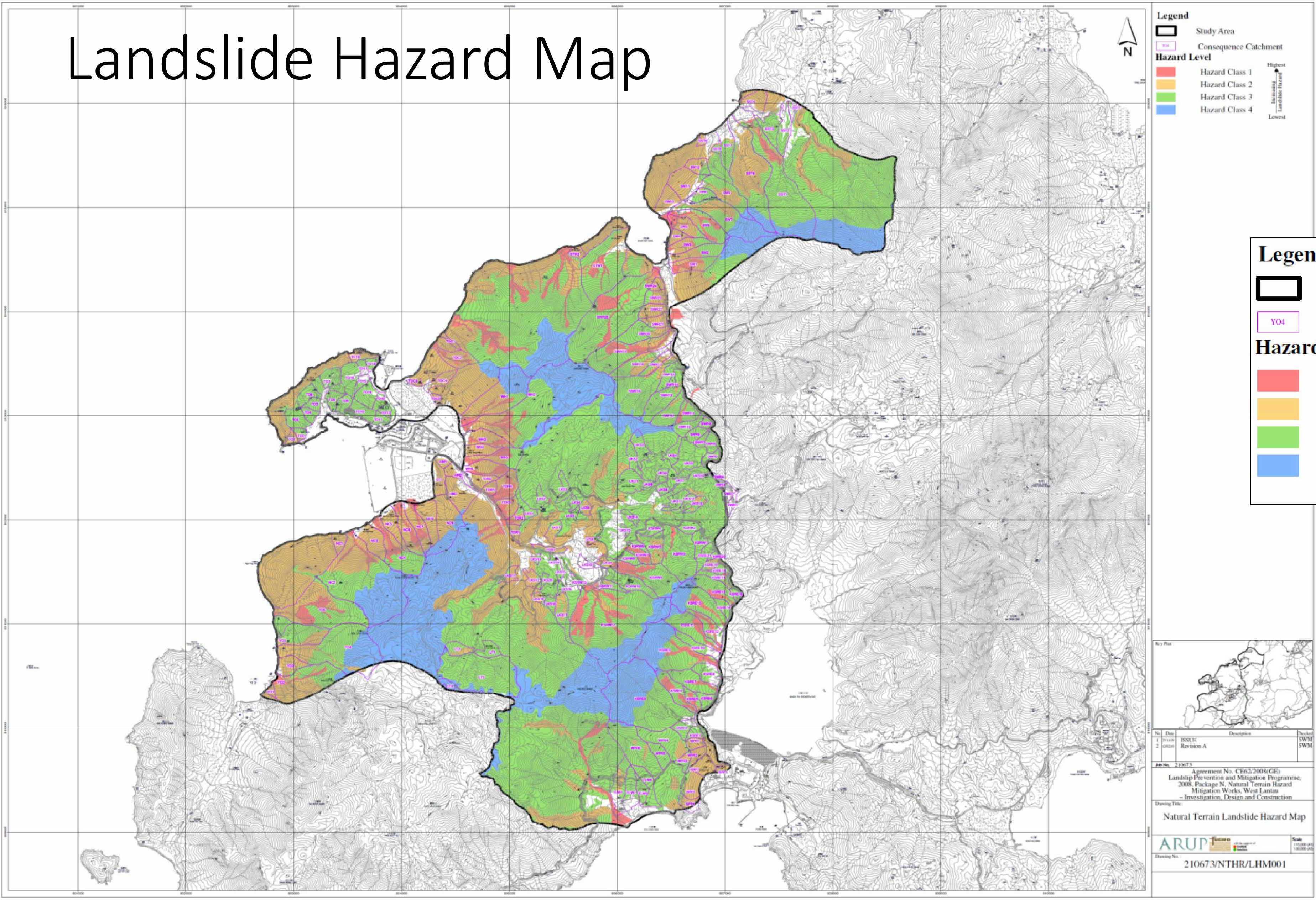
Consequently, fan areas were used as surrogates for relatively high magnitude, low frequency channelised debris flows.

Such hazards are under-represented in the existing landslide datasets in Hong Kong

	Hazard Class 1	**Hazard Class 2**	**Hazard Class 3**	**Hazard Class 4**
Primary Classifier	Debris Fan present	within Incised Terrain Unit	within Middle or Lower Terrain Unit	within Upper Terrain Unit
Secondary Classifier	Undifferentiated Fan and Distressed Terrain present	within Upper, Middle or Lower Terrain and contains Distressed Terrain	Confined drainage line present within the Upper Terrain	N/A
Tertiary Classifier	N/A	Undifferentiated Fan present but no upslope area of Distressed Terrain	N/A	N/A

Parry et al (2010) The Importance of Reading the Landscape: The use of Engineering Geomorphology in Regional Landslide Hazard Assessments. Proceedings of the International Association of Engineering Geology Conference. Auckland, 2010.

Landslide Hazard Map



Legend

Study Area

Consequence Catchment (YO4)

Hazard Level

Hazard Class 1

Hazard Class 2

Hazard Class 3

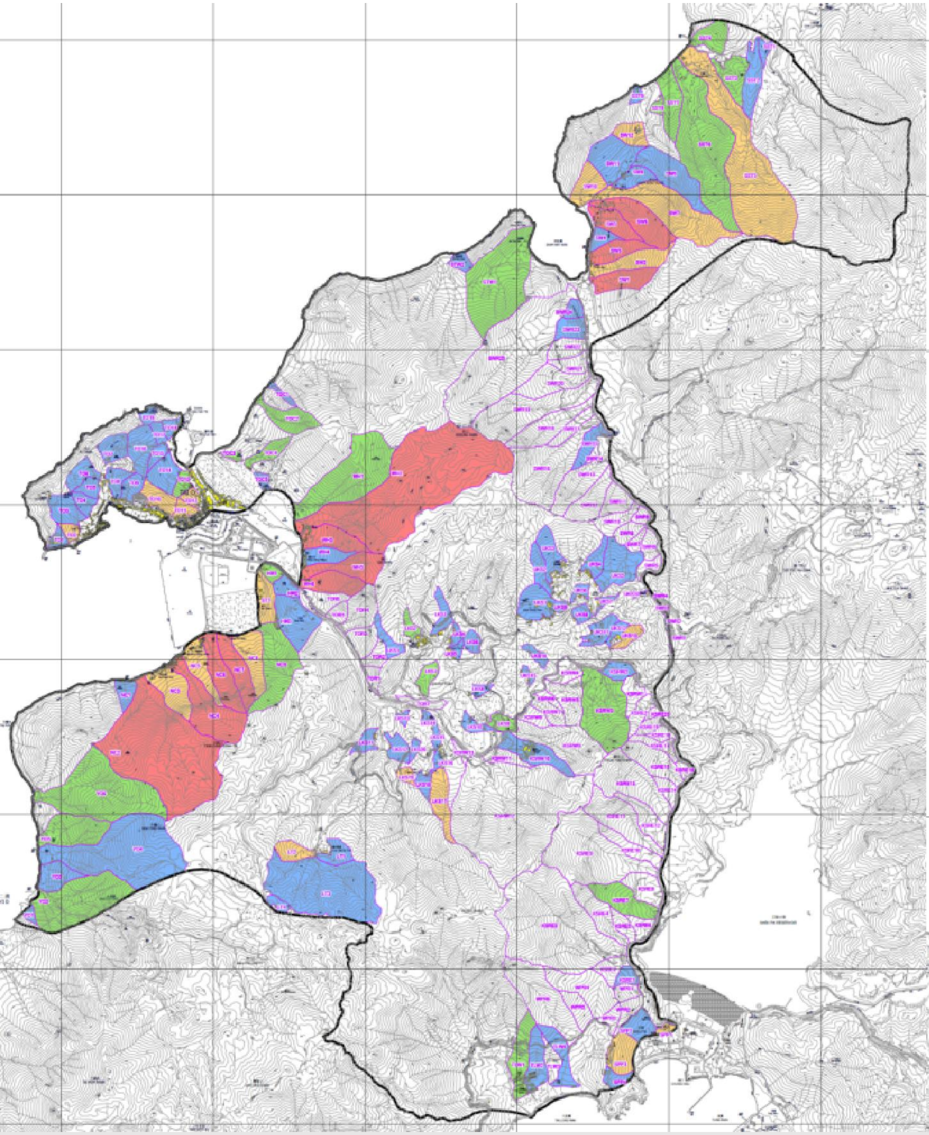
Hazard Class 4

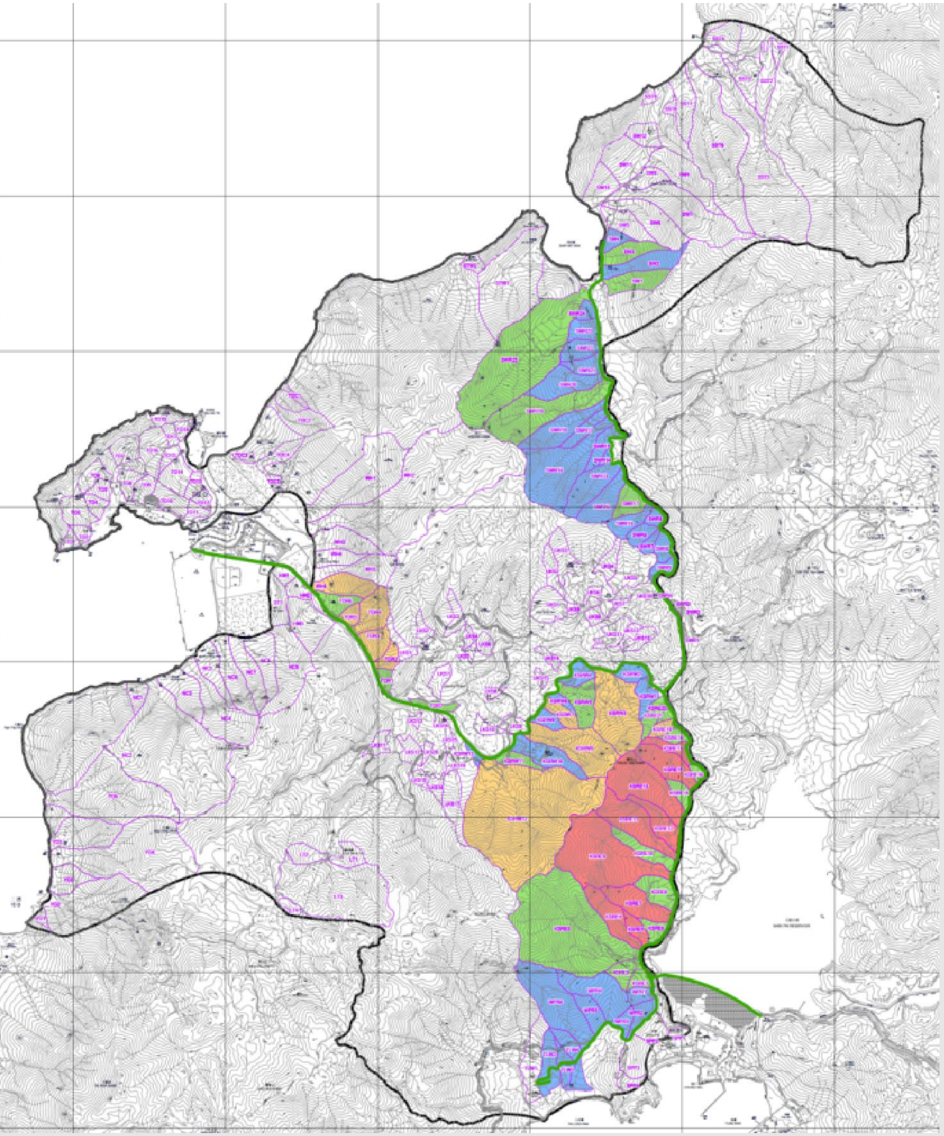
Highest ↑ Increasing Landslide Hazard — Lowest

Catchment Risk Screening Matrix

Consequence	Hazard	V. High	High	Moderate	Low	
		Fan + Confined Drainage + Distressed Terrain	Fan + Conf or Conf + Dist	Fan or Dist or Conf	Nil	CDF
		Multiple Recenet ENTLI within 100m of Facility	Isolated Recent ENTLI within 100m of Facility	Multiple Relict ENTLI within 100m of Facility	Isolated Relict ENTLI within 100m of Facility	OHL
V.High	>70 bldg per ha Schools Hospital	VERY HIGH	VERY HIGH	HIGH	MODERATE	
High	30-70 bldgs per ha Tai O Road Shek Pik Road Keung Shan Road	VERY HIGH	HIGH	MODERATE	LOW	
Moderate	<30 bldgs per ha Sham Wat Road Wang Pui Road	HIGH	MODERATE	LOW	LOW	
Low	Other non-designated Roads Uninhabited Structures (bus-shelets / sub-stations)	MODERATE	LOW	LOW	LOW	

Millis, S, W., Clahan, K. B. & Parry S, Regional Scale Natural Terrain Landslide Risk Assessment: An Example from West Lantau, Hong Kong. Proceedings of The 17th Southeast Asian Geotechnical Conference Taipei, Taiwan, May 10~13, 2010

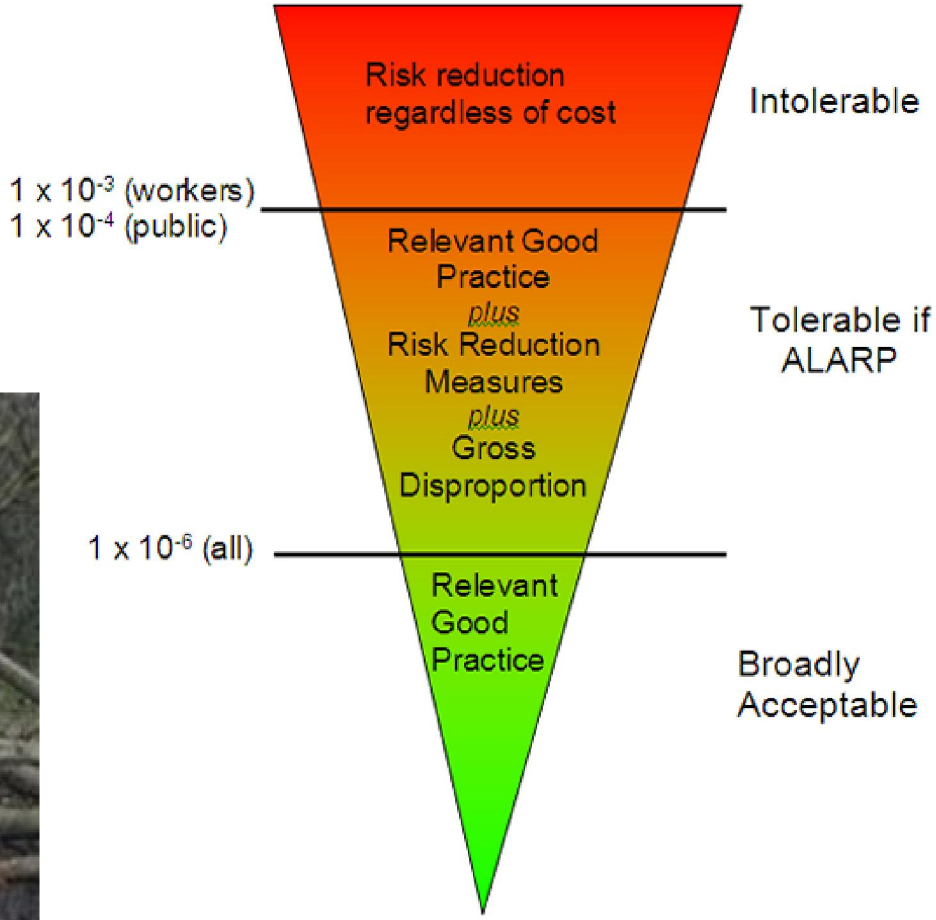




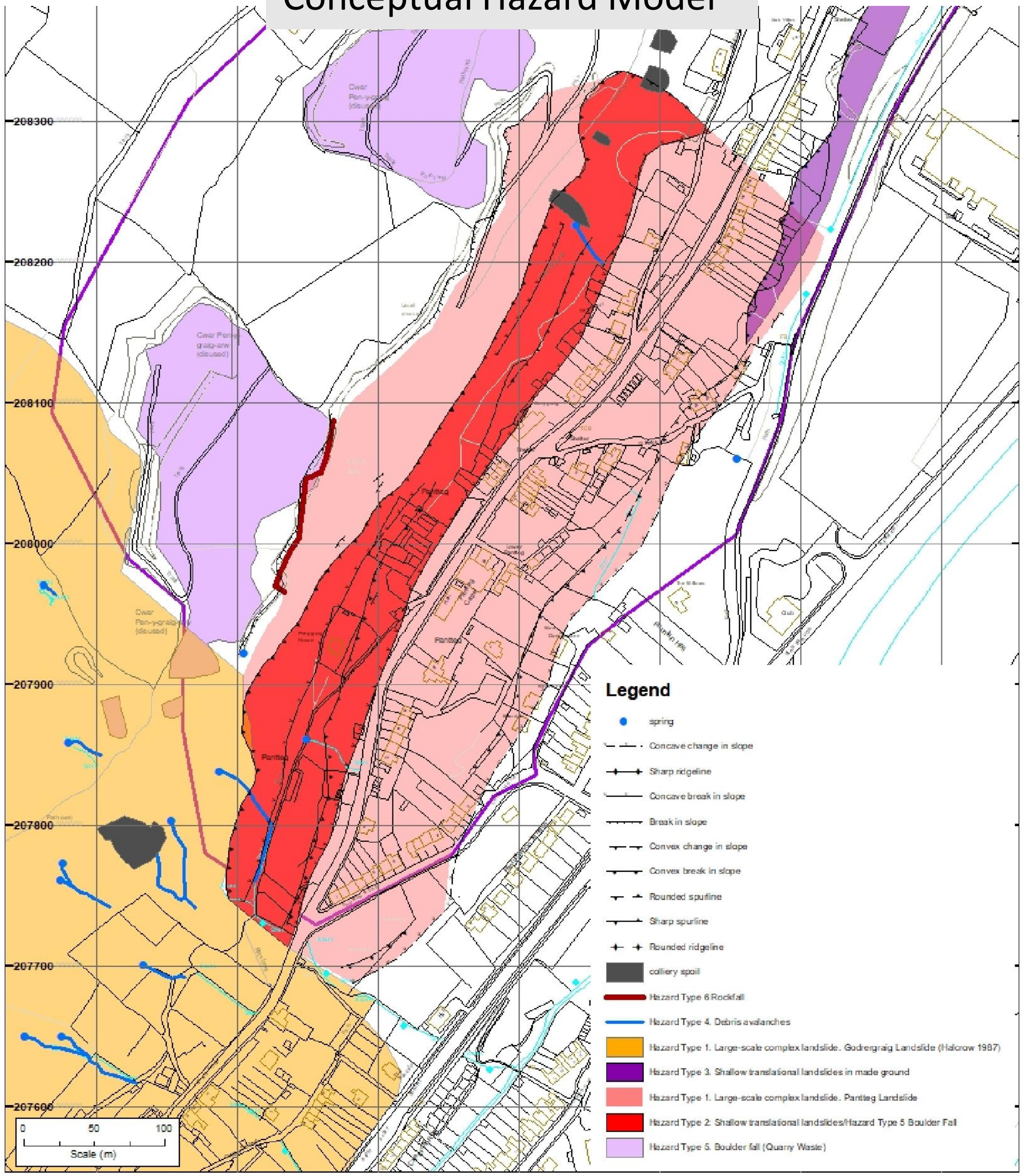
Case 2 - Quantitative Risk Assessment

- Allows meaningful comparisons between sites
- Allows the reduction in risk from mitigation to be calculated
- Allows the evaluation of defensible levels of spending on risk reduction

South Wales - 2012 Landslide



Conceptual Hazard Model



Hazard Type 1. Slow ground displacement leading to vertical or lateral displacement or undermining of structures and infrastructure related to large-scale complex landslide.

Hazard Type 2, Debris impacts from shallow translational landslides – impact loading on structures, impact/burial of people, impact on vehicles, burial of people inside buildings (ground floor) if of sufficient volume

Hazard Type 3, regressing shallow translational landslides in made ground resulting in structural damage and potentially building collapse

Hazard Type 4. More mobile debris avalanches impact loading on structures, impact/burial of people, impact on vehicles, burial of people inside buildings (ground floor) if of sufficient volume

Hazard Type 5. Boulder Fall, possible structural damage, impact on people/vehicles

Hazard Type 6 Rockfall, possible structural damage, impact on people/vehicles

Quantitative – calculated values.

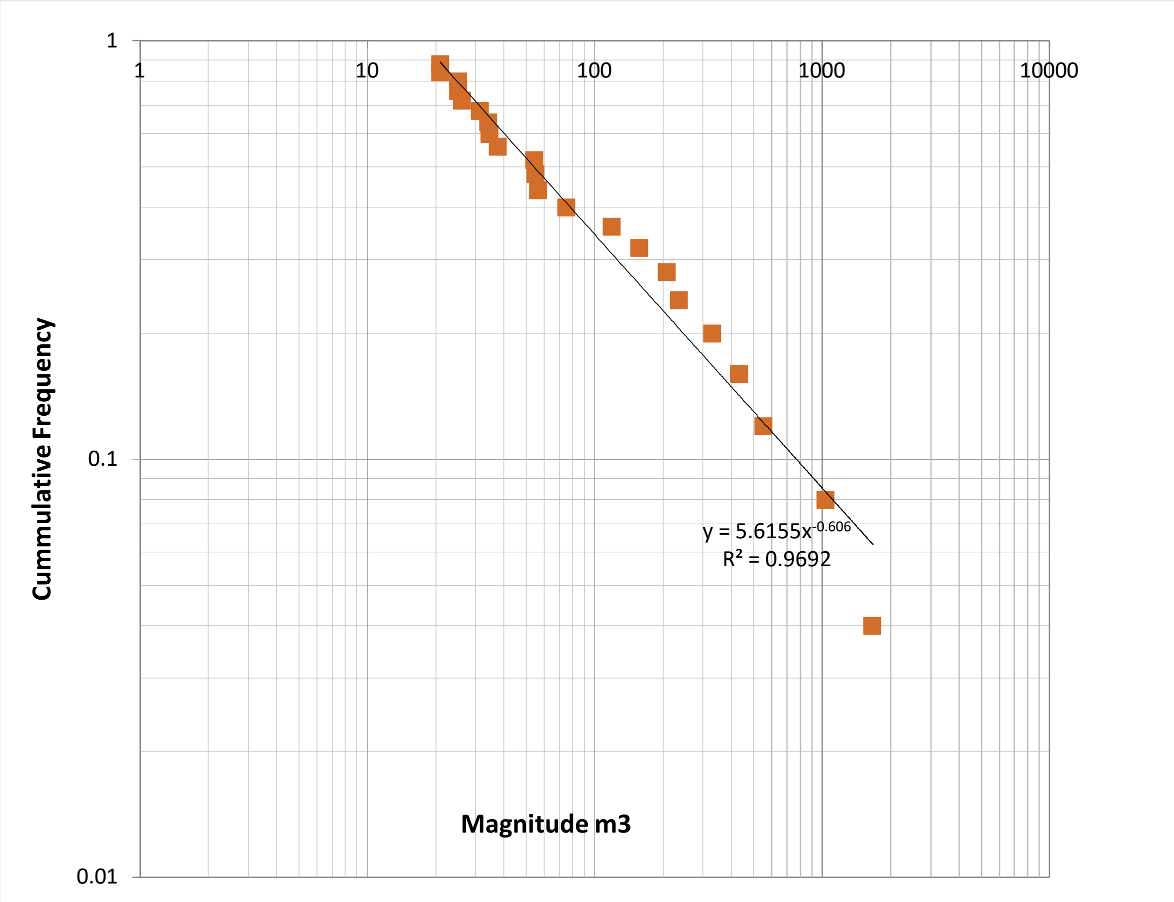
What is the probability that an event of a certain size will impact the elements at risk?

Evaluation of magnitude and frequency of each hazard type
Evaluation of run out for each hazard type

ID	Map ID	Halcrow ID	Month	Year	Location	LS type	Width	Length	Depth	API runout	Mapped run out	Est Vol	Top elevation	Base elevation	Vertical displacment	Angle of reach	Notes
		A	January	1946	1	NA											Soil from the garden of 8 Mount hill road sliding onto road as a result of disruption of the drainage system from Quarry Q2. Probaly not a LS
1		B	February	1951	39 Mount Hill Road ?	BF											Boulder fall hits house. 3 or 4 boulders later removed
2		C	August	1954	Twyncerdinen ?	DS?											Table 4.3 Four houses evacuated due to "water and mud" "not known if a true landslide or the result of flooding"
		D	June	1955	Church road/Graig Road Junction												Cracks in retaining wall
3			12-Aug	1957		BF											Reported BF Dilwyn & Jones, 1957
4 to 7	1957.1-1957.4		12-Aug	1957		DS	61	33									Landslides associated with reported rockfall 4 recorded at this location. Dilwyn & Jones, 1957
8	1957.5		oct?	1957		DS?	20	11									Dilwyn & Jones, 1957
9	1957.6		Oct?	1957		DS?	23	18									Dilwyn & Jones, 1957
10		E	October	1957	Mount Hill	DS?	100					1500?					Road Blocked three houses damaged. 100m wide "thousands of tons of mud rocks and trees" road blocked 4 days. Electricity and telephone cables destroyed. "clear the quarry drainage was primarily responsible"
		F	October	1957	Church road/Graig Road Junction												Cracks in retaining wall
		G	October	1957	41-49 Graig Road												Cracks in retaining wall
		H	November	1957	45 Mount Hill ?	NA											Threat of boulder slide - not an actual occurrence
		J	December	1959	Graig Road No of No 60		100m?										100m road blocked 3 houses damaged 56-60 Graig Road damaged by lateral and vertical movement. Golden Lion Public House damaged. Single line traffic introduced. 24 inch water main disturbed for 70 yards. Clearance affecting 53, 55, 56, 58 Graig Road
		K	November	1964	Mount Hill ?	NA											Threat of boulder slide - not an actual occurrence
11		L	December	1965	41,43,44,69 and 71 Mount Hill	DS?											Landslide and threat of boulder slide 5 houses affected failure diverts water into 43 and 44 Pantteg. 41, 69 & 71 Mount Hill and 41 Pantteg evacuated. Further boulder imminent of falling.
		M	December	1965	93 Graig Road												landslide house and lorry engulfed road blocked
		N	December	1965	As J but on downhill side of road												displacement of road
		O	October	1967	AS J and N												displacement of road and water main
		P	November	1967	As J N and O												extending over 300m
12	1969.1			1969?		DS	25	22	1	22		288	146	130	16	36	API
13	1969.2			1969?		DS	4	10	1	10		21	128	118	10	45	API
14	1969.3			1969?		DS?	22	12	1	12		138	134	128	6	32	API
	1969.4			1969?		TC	18										API
15	1969.5			1969?		DS	9	8	1	8		38	174	166	8	45	API
16	1969.6			1969?		DS	5	12	1	12		31	136	126	10	39	API
17	1969.7			1969?		DS	6	18	1	18		57	135	123	12	34	API
18	1969.8			1969?		DS	10	30	1	30		157	137	116	21	35	API
19	1969.9			1969?		DS	12	19	1	19		119	133	120	13	34	API
20	1969.10			1969?		DS	7	15	1	15		55	133	124	9	31	API
21	1969.11			1969?		DS	6	8	1	8		25	120	114	6	37	API
22	1969.12			1969?		DS	8	13	1	13		54	135	126	9	35	API
		Q		1970	opposite school	NA											Threat of boulder slide - not an actual occurrence
23		R	January	1975	35-48 Mount Hill and Bush Inn	DS?											Landslide and excessive water flow. Text says No. 41-48 Table 35-48.Pantteg school closed 41-48 evacuated. 33 to 44 abandoned by owners. Subsequent Bush Inn Danygraig 21, 23 , 25, 25A, 29, & 31 Pantteg compulsory purchased.
24	1978.1																API
25	1978.2																API
26	1978.2																API
27		S	March	1981	Bush Inn	DS?											minor surface slide no damage
28	1982.1			1982		DS?	6	11	1	11		35	138	130	8	36	API
29	1986.1		November	1986	Graig y Merched	RF	33	20	3	60	60	1037	152	117	35	30	"Rotational slump of colluvium and debris flow" 6 houses affected Halcrow 1989 . Associated with a spring on old OS maps over tipped by spoil from Vine colliery. Incipient movement on 1972 aerial .
30	1986.2					DA	Est to be 30% of volume of LS29			100		330	150	101	49	26	Halcrow 1989
31	1987.1			1987	29 Craig Road	RF	22	16	3	37		553	125	101	24	33	Halcrow 1989
32	1993.1			1993		DS	5	13	1	13		34	154	142	12	43	API
33	1993.2			1993		DS	4	10	1	10		21	154	147	7	35	API
34	1993.3			1993		DS	10	30	1	30		157	136	116	20	34	API
35	1993.4			1993		DS	6	8	1	8		25	136	129	7	41	API
36	1993.5			1993		DS	9	16	1	16		75	138	124	14	41	API
37	1993.6			1993		DS	5	10	1	10		26	133	124	9	42	API
38	2012.1		December	2012		RF	85	25	1	47		1113	122	95	27	30	Significant ground movement was observed to the east and north-east of Penygraig house in the two years prior to the December 2012 event. This coincided with severe weather experienced in the area over two winters in addition to the wet summer of 2012.blocked the highway at Pantteg Chapel, and partially blocked the road opposite 49 Pantteg. Access to Penygraig house was severed. Youtube video suggest 15-32mm thick translational landslide. Relatively intact raft probably bound by tree roots affected from of Chapel. Remainder of LS partially blocked one carriageway
39			February	2017		DS?											Landslide above river apparently shallow translational failure affecting fill in gardens on steep former riverine slope
40			February	2018		DS?											Reported by council no details recorded

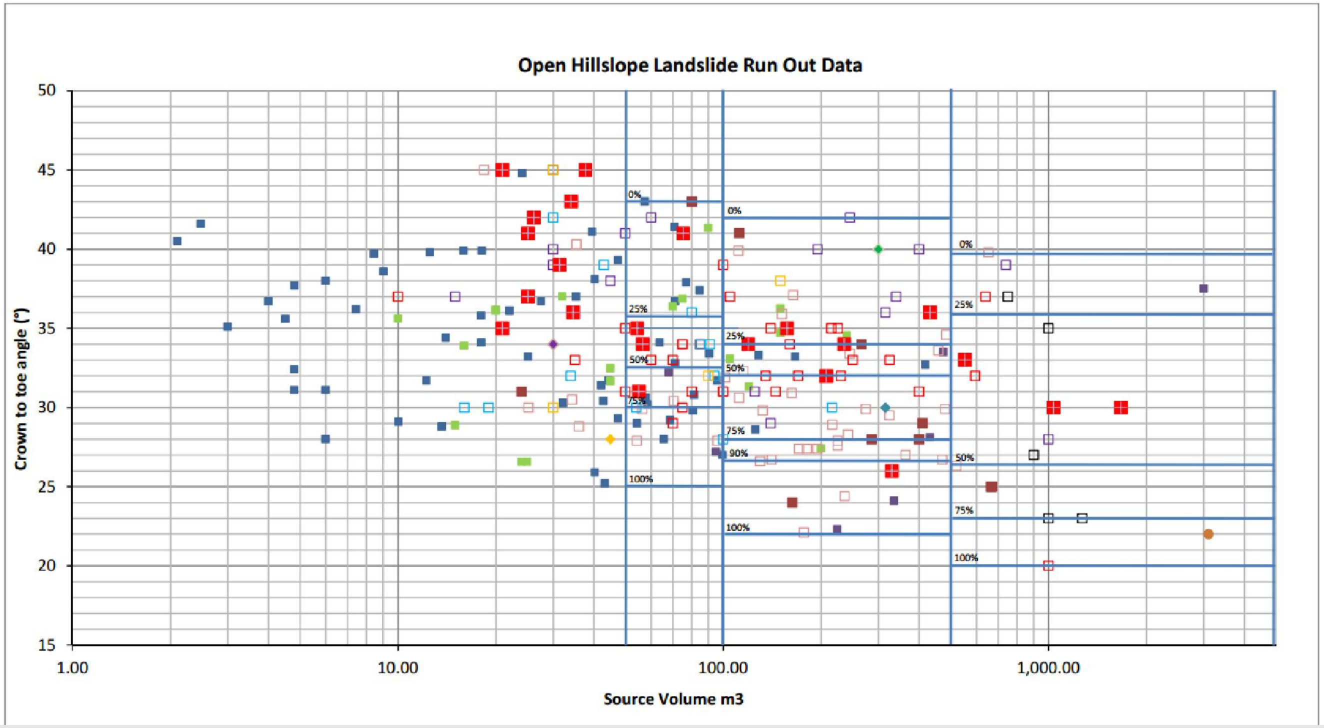
NA	Excluded on the basis of information available
BF	Boulder fall
DS	Debris slide
DA	Debris avalanche
RF	Rotational
TC	Tension crack

LEGEND
- API
- Related to Godrergraig LS
- Not considered to be a LS
- To be evaluated further if original data can be obtained



Cumulative magnitude–frequency plot for debris slides within the study area

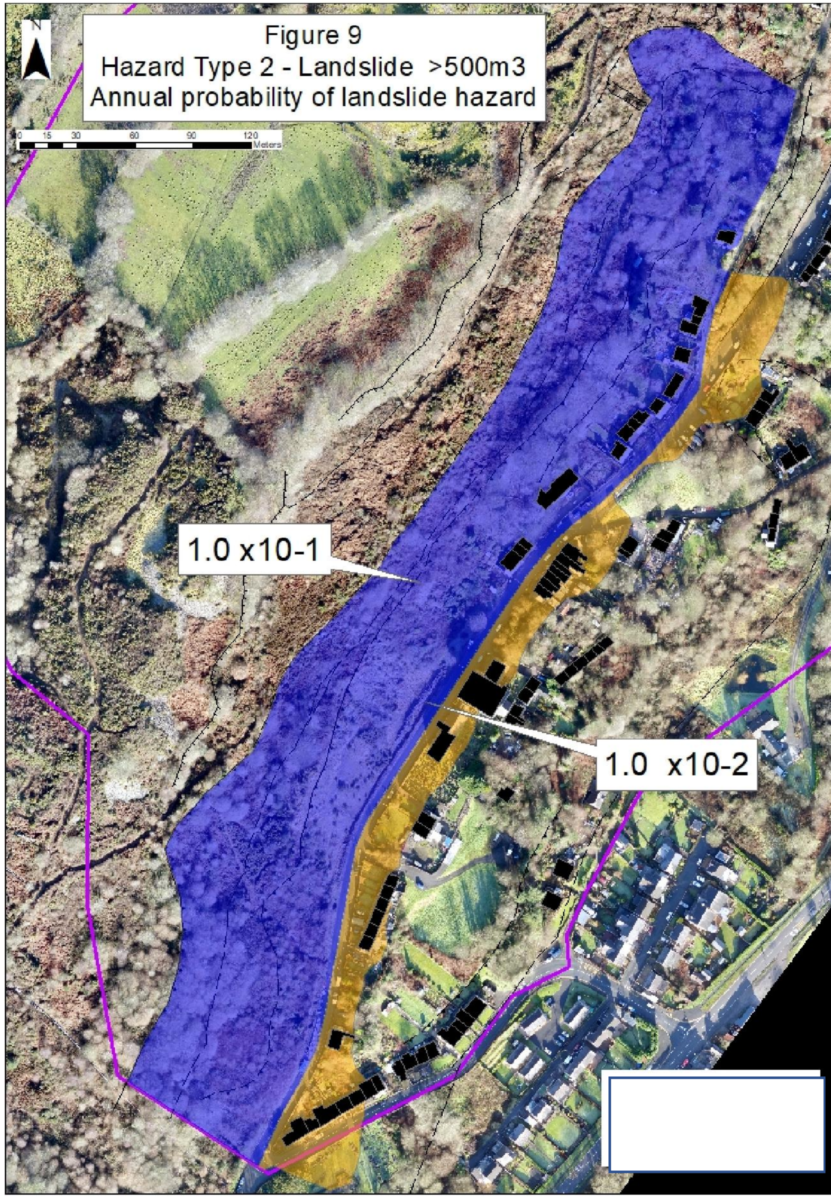
Landslide Volume Range	Adopted Volume	Annual Probability
0-100m^3	50m^3	0.524
100-500m^3	300m^3	0.177
>500m^3	750m^3	0.102



Assessment of travel distance vs landslide volume

Same probability but different associated risk

	North Side Road			South Side Road		
Landslide Vol	P (Landslide)	P (Run-out Hit)	Hazard	P (Landslide)	P (Run-out Hit)	Hazard
<100m3	0.524	0.2	1x10-1	0.524	0.002	1x10-3
100-500m3	0.177	0.2	3.5x10-2	0.177	0.02	3.5x10-3
>500m3	0.102	1.0	1x10-1	0.102	0.1	1x10-2



Evaluation of Risk

North side of Road – Buildings – LS 500m3 (100m wide)

Scenario	P (Landslide)	P (Run-out Hit)	P (spatial)	P (Occupied)	Vulnerability	P (Fatality)
Buried by debris	0.102	1	0.2	0.67	0.1	1.4×10^{-3}
Collapse of building	0.102	1	0.2	0.67	0.01	1.4×10^{-4}

For a >500m3 landslide volume impacting the rear of a building, the relatively slow-moving debris will be >2m thick and debris enter through the windows. People will have some forewarning about the debris coming in through the windows from the noise and should be able to get out of that room. V = 0.1

The impact will cause structural damage which may over a few hours lead to partial collapse of the rear of the building. V = 0.01

<u>Requires</u>

Evaluation of temporal exposure - It was assumed that a house is occupied between 8pm and 8am and for 50% of the time between 8am and 8pm, i.e. a total of 16 hours or 0.67.

Evaluation of hazard scenario – buried vs collapse

Evaluation of vulnerability

In the UK there are no legally defined values for acceptable risk. AGS suggest that 10^{-4} is tolerable for existing developments and advise against new development where risk > 10^{-5}

Risk to life – people in buildings

Landslide Volume	N of Pantteg Road	S of Pantteg Road
<100m3	2x10^{-6}	2x10^{-8}
100-500m3	1.23x10^{-5}	1.41x10^{-6}
>500m3	1.44x10^{-3}	1.44x10^{-4}
Total	1.45x10^{-3}	1.45x10^{-4}

Risk to life – people in gardens

Landslide Volume	N of Pantteg Road	S of Pantteg Road
<100m3	3x10^{-6}	3x10^{-8}
100-500m3	8.8x10^{-6}	8.8x10^{-6}
>500m3	2.1x10^{-4}	2x10^{-5}
TOTAL	2.2x10^{-4}	2.9x10^{-5}

Risk to life – people in pedestrians

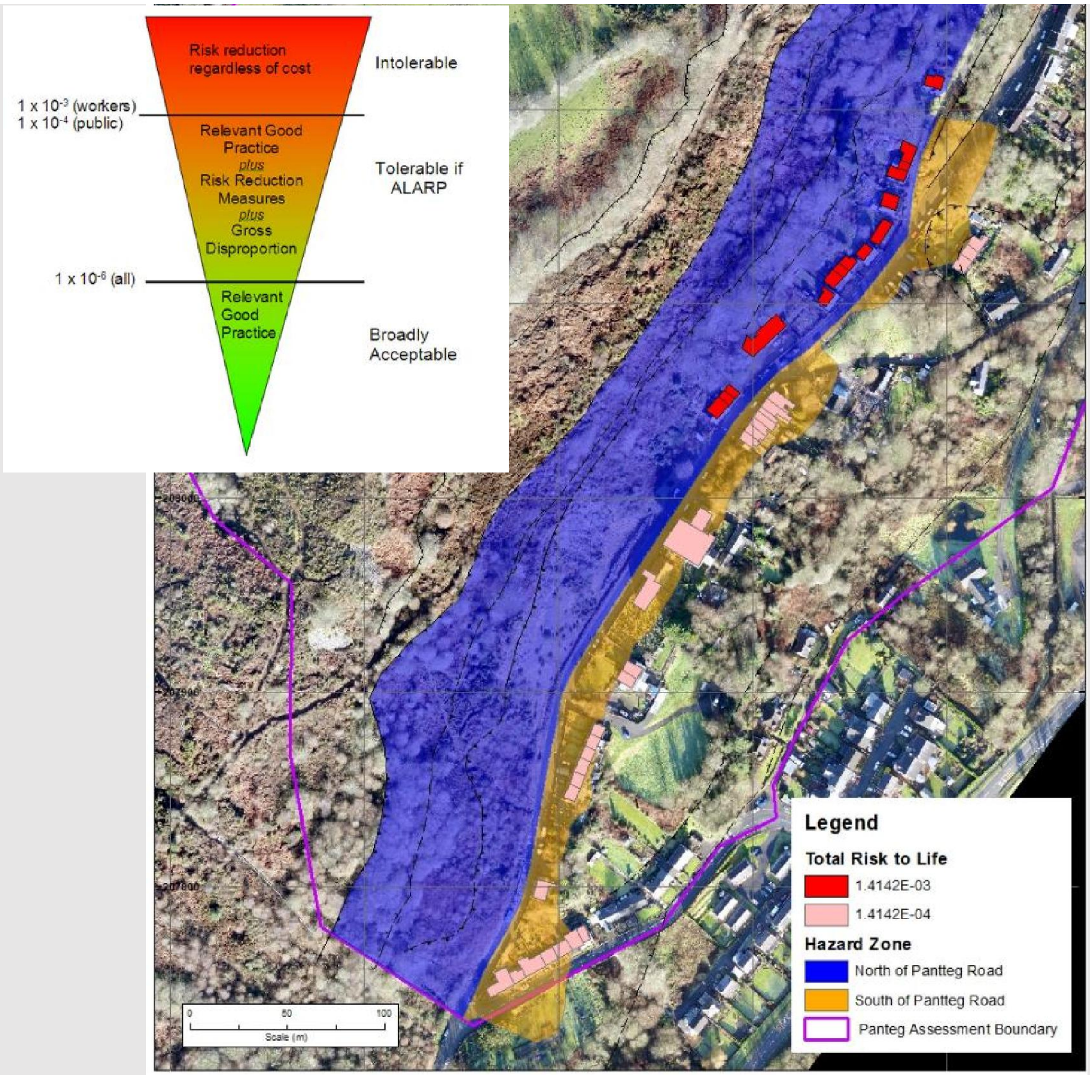
Landslide Volume	N of Pantteg Road	South of Pantteg Road
<100m^3	5.6x10^{-8}	4.7x10^{-8}
100-500m^3	1.3x10^{-7}	8.5x10^{-7}
>500m^3	3.9x10^{-7}	6.7x10^{-8}
TOTAL	5.5x10^{-7}	9.6x10^{-7}

Risk to life – people in car (car hits landslide)

Landslide Volume	North	South
<100m3	2.4x10^{-8}	2.6x10^{-10}
100-500m3	1.6x10^{-7}	1.5x10^{-8}
>500m3	2.9x10^{-6}	2.8x10^{-7}

Risk to life – people in car (landslide hits car)

Landslide Volume	North	South
<100m3	3.4x10^{-8}	3.2x10^{-10}
100-500m3	1.1x10^{-8}	1.1x10^{-9}
>500m3	3.3x10^{-8}	3.3x10^{-9}



The assessment approach adopted will be dependant on various factors including

- Time
- Resources
- Data availability
- Desired outcome

In the past the majority of assessments in the UK were qualitative, however issues with consistency and the move towards more rigorous and systematic assessments means quantatative assessments are increasingly used

Fell et al. note that “*Qualitative methods are often used for susceptibility zoning, and sometimes for hazard zoning. When feasible it is better to use quantitative methods for both susceptibility and hazard zoning. Risk zoning should be quantified. More effort is required to quantify the hazard and risk but there is not necessarily a great increase in cost compared to qualitative zoning*”.

Framework for Assessing Natural Slopes (P3161)
Workflows and Approaches to Natural Slope Hazard and Risk Assessments

CIRIA undertook a scoping exercise between March and July 2018.

Two workshops undertaken to identify potential research topics associated with engineered and natural slopes.

Re natural slopes the workshops identified and agreed the need for:

- Guidance on undertaking natural slope hazard and risk assessments
- Guidance on the selection of practical, economic and defensible mitigation measures varying from monitoring and warning to hard engineering
- Communication to none specialists e.g. education that some hazards cannot be mitigated (due to cost or practicality) and all sites will have some form of residual risk
- Guidance for the good of all – not just the main stakeholders
- Should be aspirational and best practice (which may not be UK based)

Currently finalising the project scope. Team comprises: Atkins, Bill Murphy (Uni of Leeds) and myself.

Final Observations

Terminology is commonly misused for hazard and risk assessments

Engineering approaches tends to be reactive i.e. localised mitigation after failure rather than proactive assessment of future hazards, often based on what did occur rather that what could occur

Lack of use of conceptual hazard models and often a lack of appreciation of the dynamics of landslide processes

When proactive assessments are undertaken tend to be qualitative – difficult to compare between sites, difficult to determine a defensible design event

Quantatative assessments although more difficult are more defensible, their assumptions are explicit, they allow a justifiable expenditure to be calculated

Thank You