# The Assessment of Landslide Hazard and Risk

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**Talk outline**

- Are landslide a hazards in the UK and what guidance is there?
- What are landslide hazard and risk assessments
- Terminology
- Types of approach
- Hazard models – “getting the geology (in particular the geomorphology) right”
- Direct vs indirect approaches
- Quantatative vs Qualitative assessments
- Case Studies
- Observations

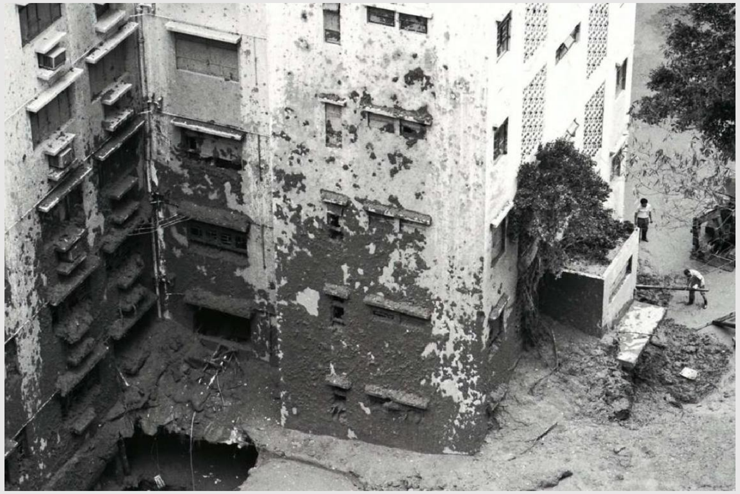
# Are landslides a hazard in the UK?

In Hong Kong, since 1990, there has been on average **1 fatality every 4.3 years** (Wong et al. (2004)

In the UK, since 1959 (i.e. excluding Aberfan), there have been on average **1 fatality every 4.5 years**. (Gibson et al. 2013).

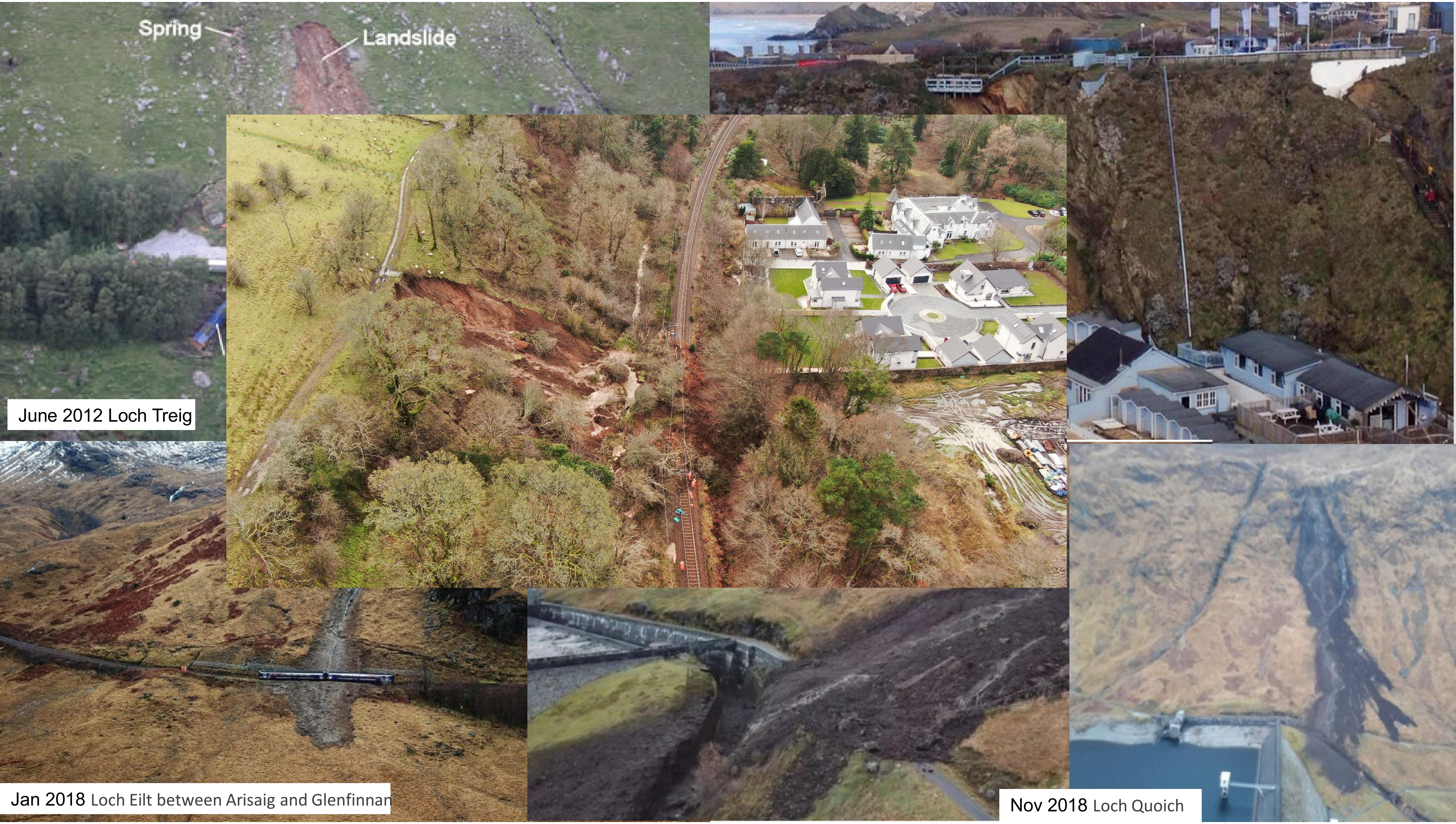
The number of **reported** landslides in the UK has been increasing in recent years (some may reflect BGS extracting from social media)

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

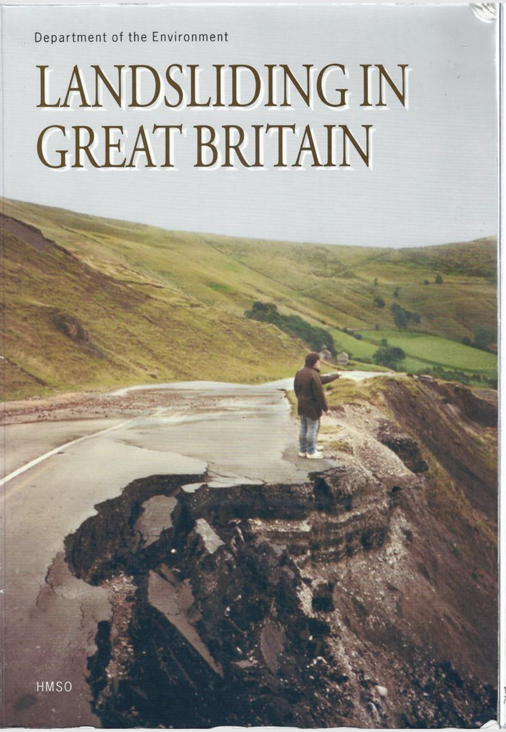


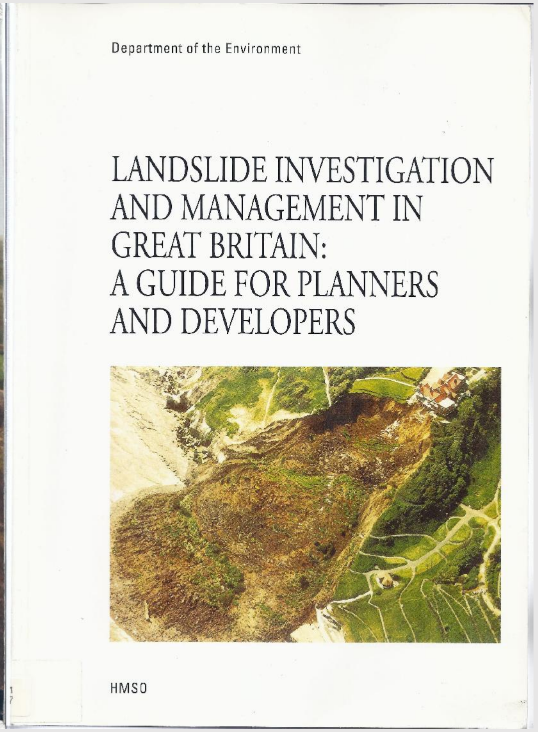
Bagio Villa landslide, 1992, 2 dead

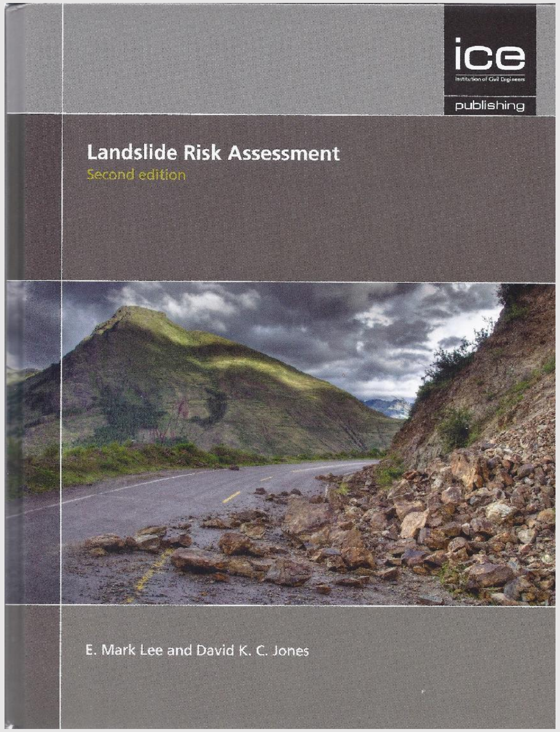
Beaminster Tunnel portal landslide, 2012, 2 dead

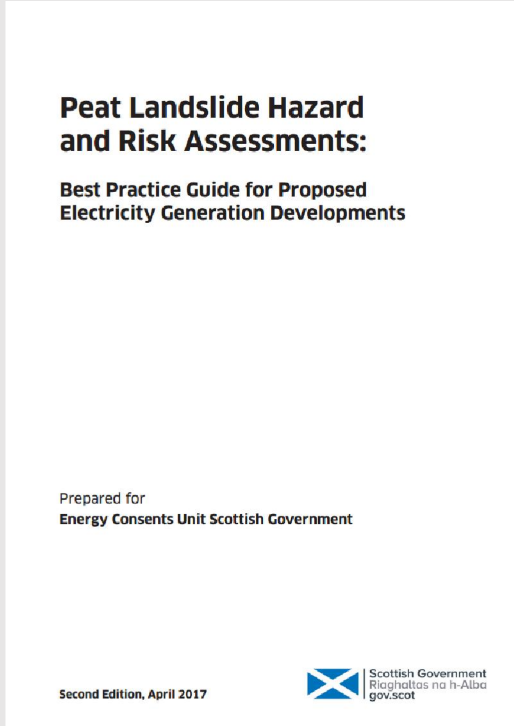

Spring
Landslide
June 2012 Loch Treig
Jan 2018 Loch Eilt between Arisaig and Glenfinnan
Nov 2018 Loch Quoich

# What Guidance is there for UK Practice?




1994 & 1996 both out of print

2004, 2nd edition 2014

2nd Ed 2017 Limited to peat slides for windfarm developments in Scotland - more regulatory than technical guidance

**CIRIA Guidance document RP1096 Natural Slopes – Condition, Appraisal, Mitigation – end 2021**

## 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.

## Hazard and Risk with respect to landslides

**International definitions**

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

**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*".

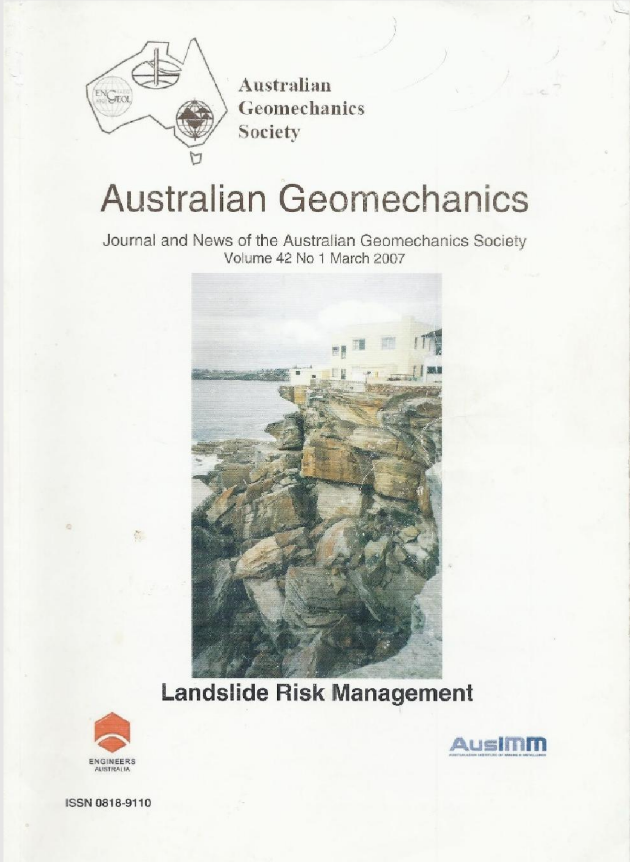
**i.e. where landslides may occur**

**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**

**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 probability of loss associated with hazard interacting with elements at risk[1] e.g. risk to life**

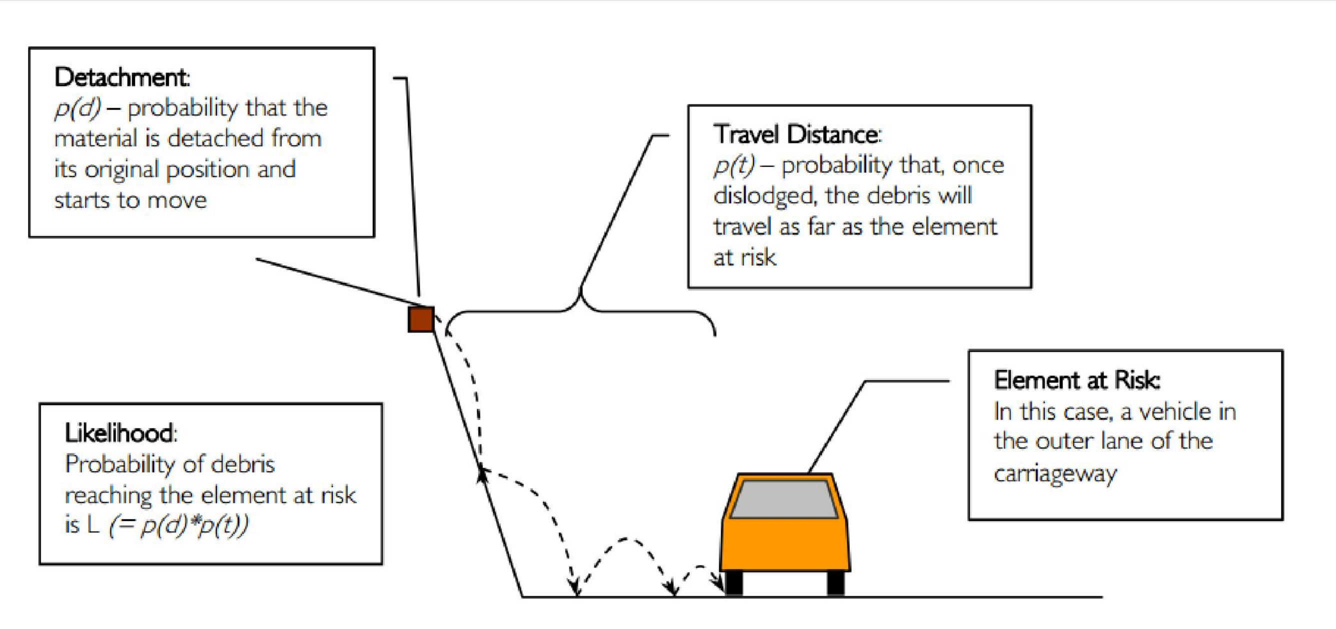


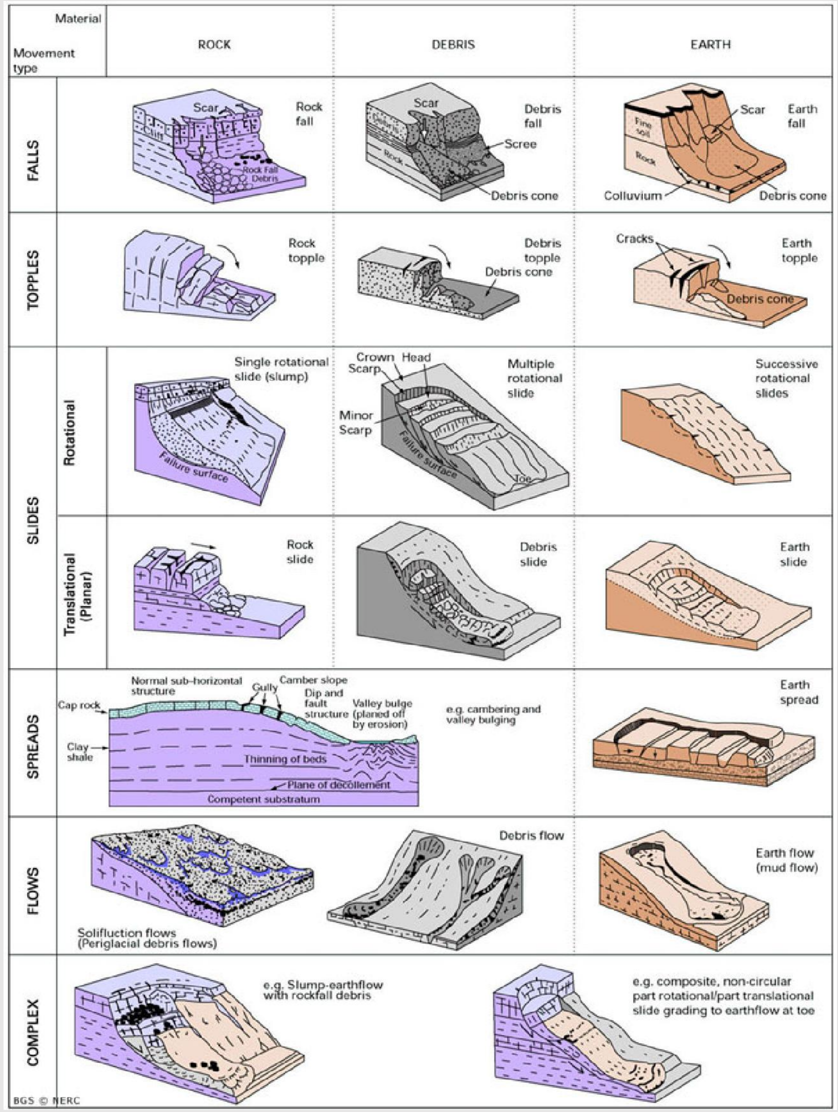

https://australiangeomechanics.org/downloads/

[1]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**

- probability of impact f(magnitude, frequency and run out)
- these are in turn a function of landslide type
- Two key components Prob of detachment & Prob of runout




(Note entrainment should also be considered with respect to magnitude)

**Risk**

- concerned with the likelihood and scale of the **conseq**

- This needs to take into account the elements at risk, t exposure time.

  = hazard x Σ(elements at risk x vulnerability x ex

- Total Risk is the sum of the calculations of specific risk

- often calculated in terms of risk to life

- But can be economic or environmental

THE TIMES

# EU seeks €1.7m fine over landslide wind farm

Seán McCárthaigh, Senior Ireland News Reporter

April 1 2019, 12:01am, The Times

Politics | European Union | UK politics | Europe

Ireland could face a minimum fine of almost €1.7 million over the dislodged peat from the Derrybrien wind farm
JOE O'SHAUGHNESSY

The European Commission is asking the EU's top court to impose large fines on Ireland over its failure to comply with a 2008 ruling on a wind farm where a two-kilometre landslide killed 50,000 fish.

Ireland could face a minimum fine of almost €1.7 million over the Derrybrien wind farm in south Galway. Tonnes of peat, dislodged during construction, polluted the Owendalulleegh river in October 2003, causing lasting damage to fish spawning beds.

## Why adopt a risk based approach?

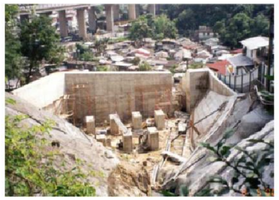
(a) Considerable uncertainty associated with the ground which are difficult to address in a deterministic slope assessment, particular over large expanses of variable terrain.

(b) A risk-based approach provides a structured framework for formulating a rational risk management strategy to address the overall landslide risk and compare that with other risks.

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

(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 occur or be exceeded?

<table>
<tr><td>Drainage provisions Bio-Engineering</td><td colspan="2">Flexible Barriers<br></td><td colspan="2">Check dams Gravity Structures<br></td><td>Diversion walls Land Resumption</td></tr>
<tr><td>0-50$m^3$</td><td>50-100 $m^3$</td><td>100-500 $m^3$</td><td>500-1000 $m^3$</td><td>1000-5000 $m^3$</td><td>5000-10000 $m^3$</td></tr>
</table>

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

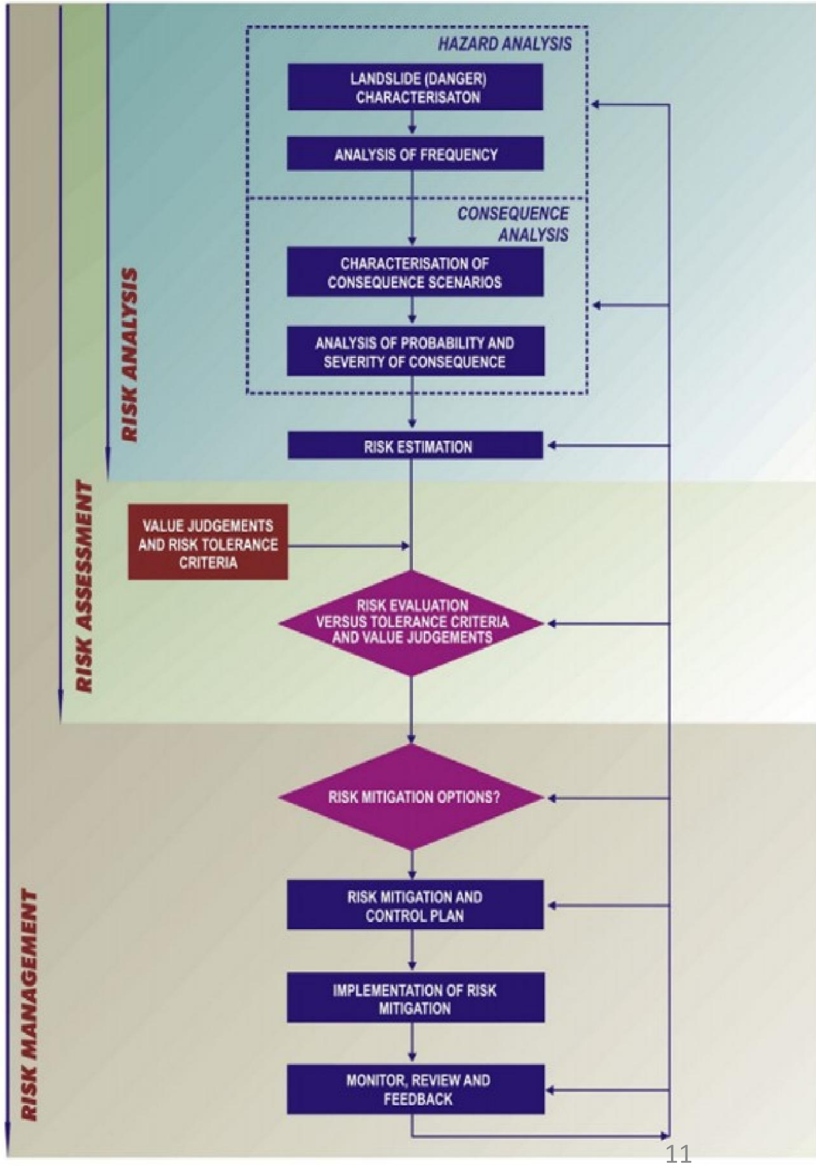
**Hazard identification** which comprises classification of landslides, extent of landslides (area and volume), travel distance of landslides and rates of movement

**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.

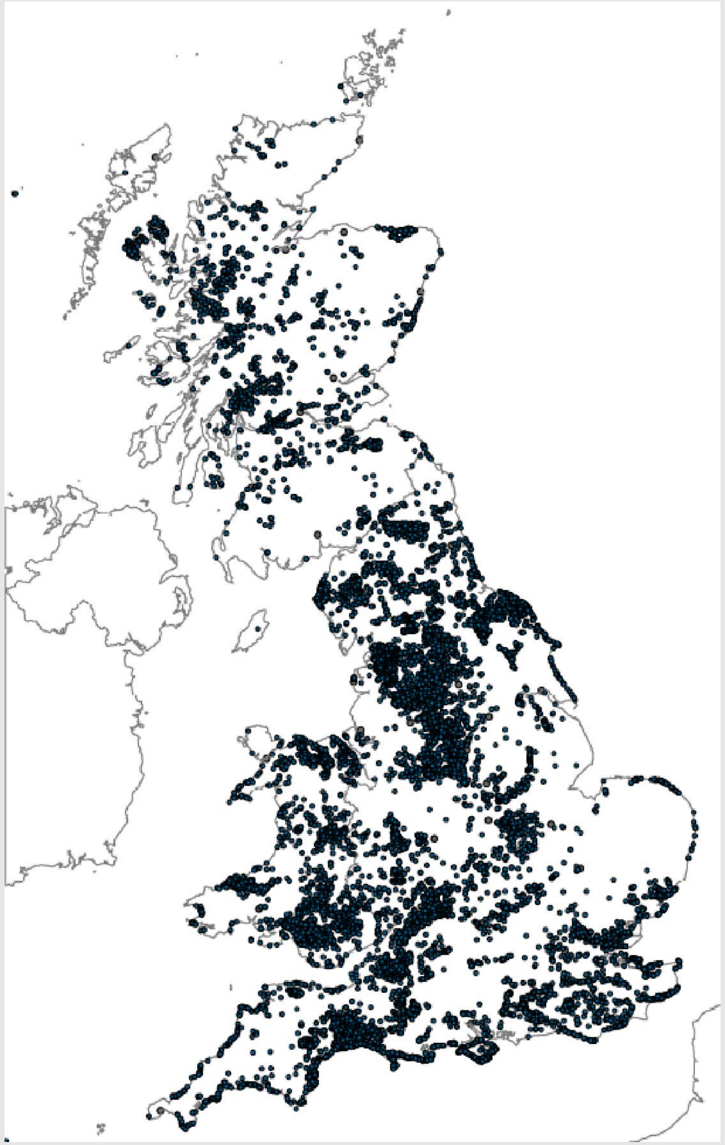


## Hazard identification

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.



**National Landslide Database (NLD)**

Of 17,000 landslides, 10,000 are extracted from BGS geological maps. Most of the landslides in the NLD are considered to be "*ancient and inactive"*

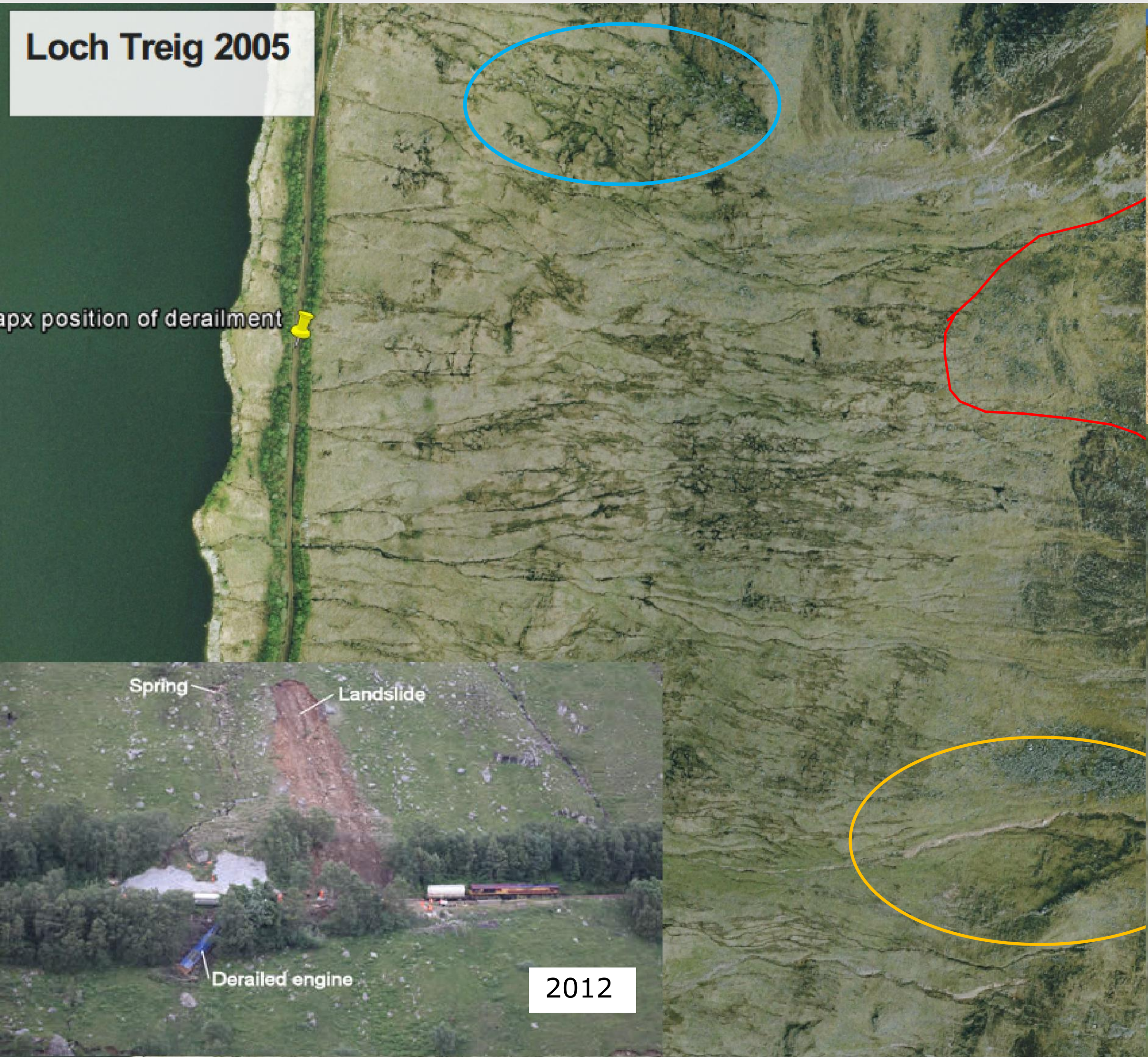
Earlier geological maps did not record them and if recorded tend to be the ancient and inactive.

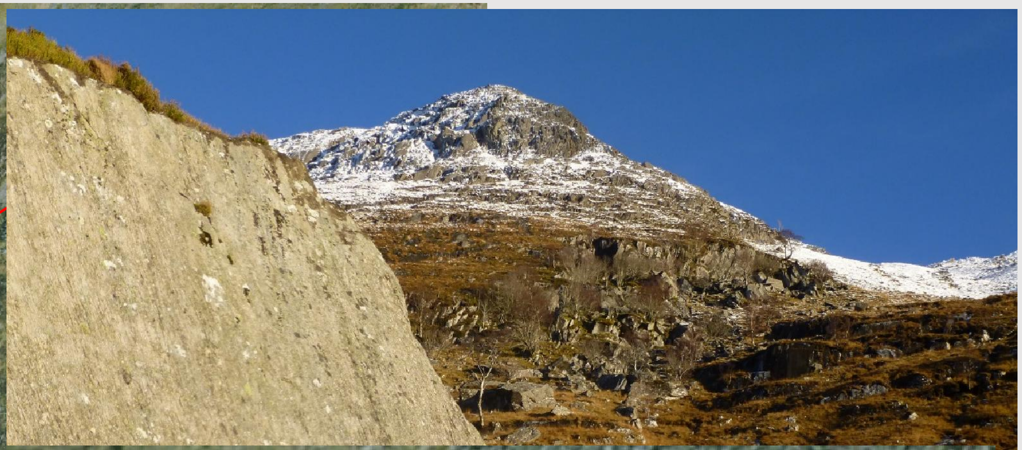
Landslides without significant "footprints" such as debris flows are rarely mapped and consequently are significantly under reported.

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

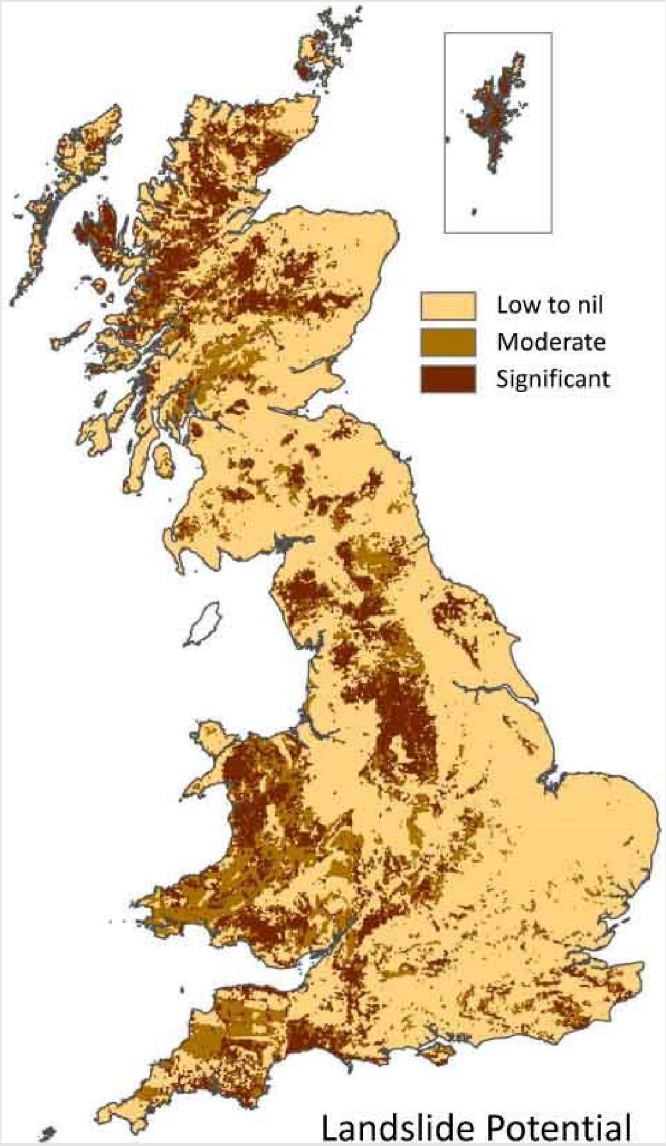
The NLD is based on earlier DoE database - the pattern of landslides revealed by the records was stated as being an "*artefact of investigation reflecting varying degrees of ignorance*"

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)**

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.

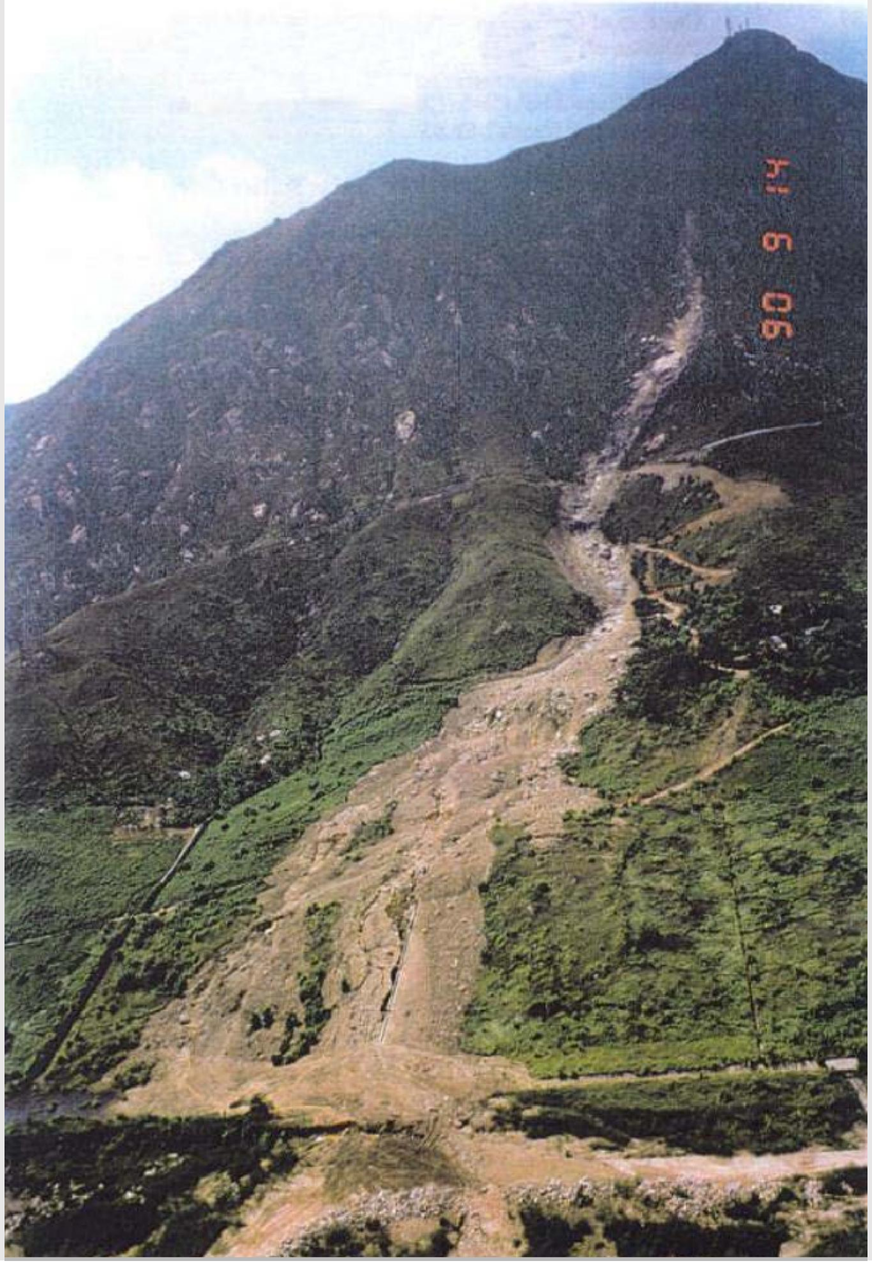
Even using the extensive aerial photograph coverage in Hong Kong, which covers a 60 year period, the percentage probability of a 1:100-year event being recorded at a particular site is only 31%

Need to assess what could occur, not simply what has been recorded.

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

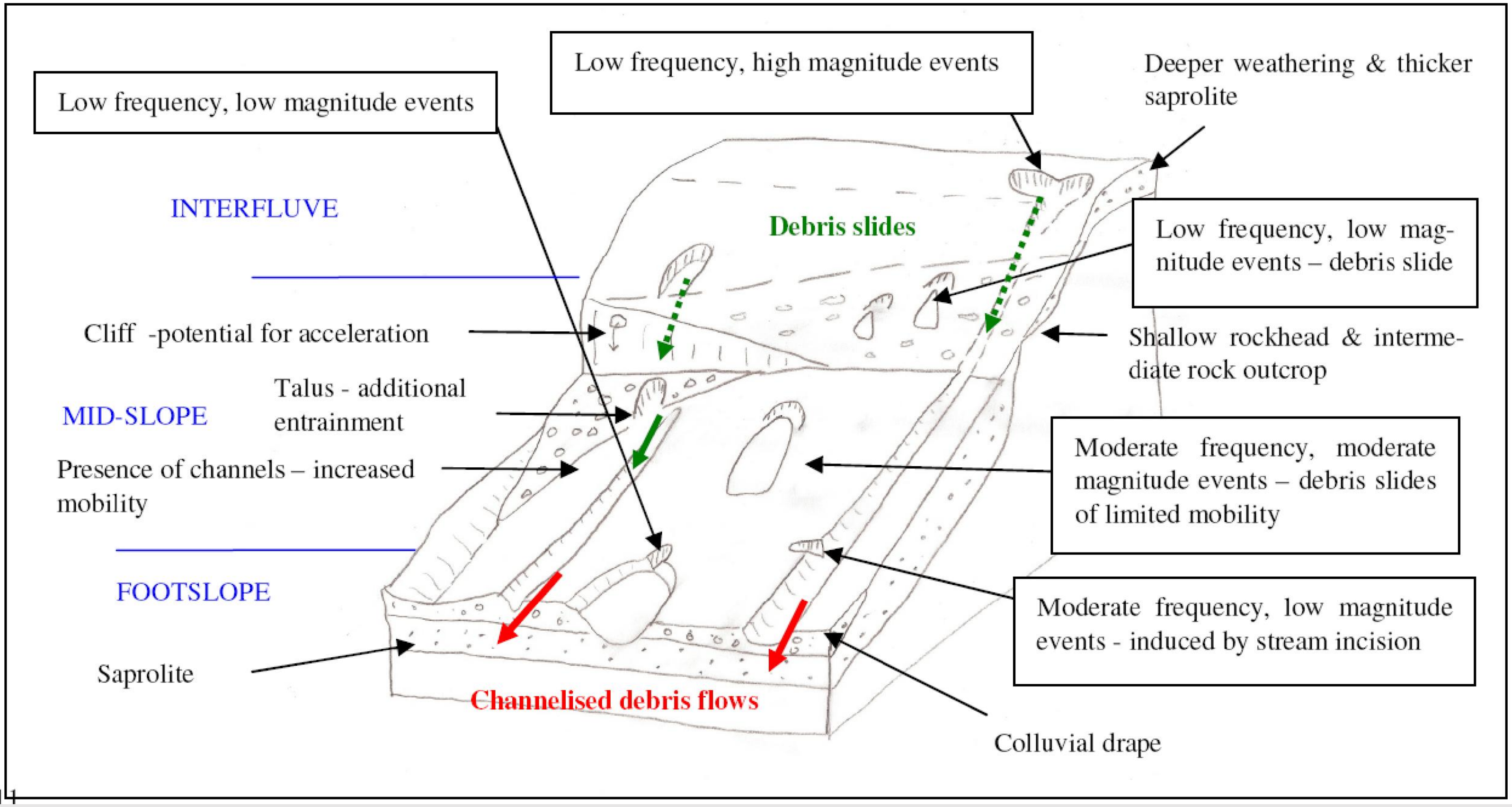
Addressing these uncertainties is the key role of engineering geomorphology

"*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 – allow all possible hazards to be considered

**Directly related to the type and amount of existing data, and the knowledge and experience of those involved[1]**




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]Baynes, F., Parry, S., & Novotny, J. (2020). Engineering geological models, projects and geotechnical risk. Quarterly Journal of Engineering Geology and Hydrogeology,

An understanding of 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

- However, such controls are not constant over time or space. Geomorphological change can be initiated by processes which vary according to the timescales over which they operate

- Landslides have a finite lifetime within the landscape

- Consequently, 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

**Frequency Analysis**

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

- Use the probability of a landslide triggering event as an indicator of the probability of a landslide e.g. rainfall, seismic

- Estimate probability through expert judgement

Often a combination of all approaches

(Not only frequency of occurrence but probability of run out reaching facilities)

## Consequence Analysis

Requires:

- Evaluation of exposure for all elements at risk – people in buildings, pedestrians, people in vehicles etc

Exposure - P(spatial) “wrong place” and P(temporal) “wrong time” e.g for vehicles

P(spatial) depend on length of vehicle, length of hazard zone and width of LS

P (temporal) journey time through hazard zone

No. of cars

- Evaluation of hazard type – 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

- Evaluation of vulnerability – related to landslide type, landslide volume and “fragility” of element

Moving into other areas of expertise

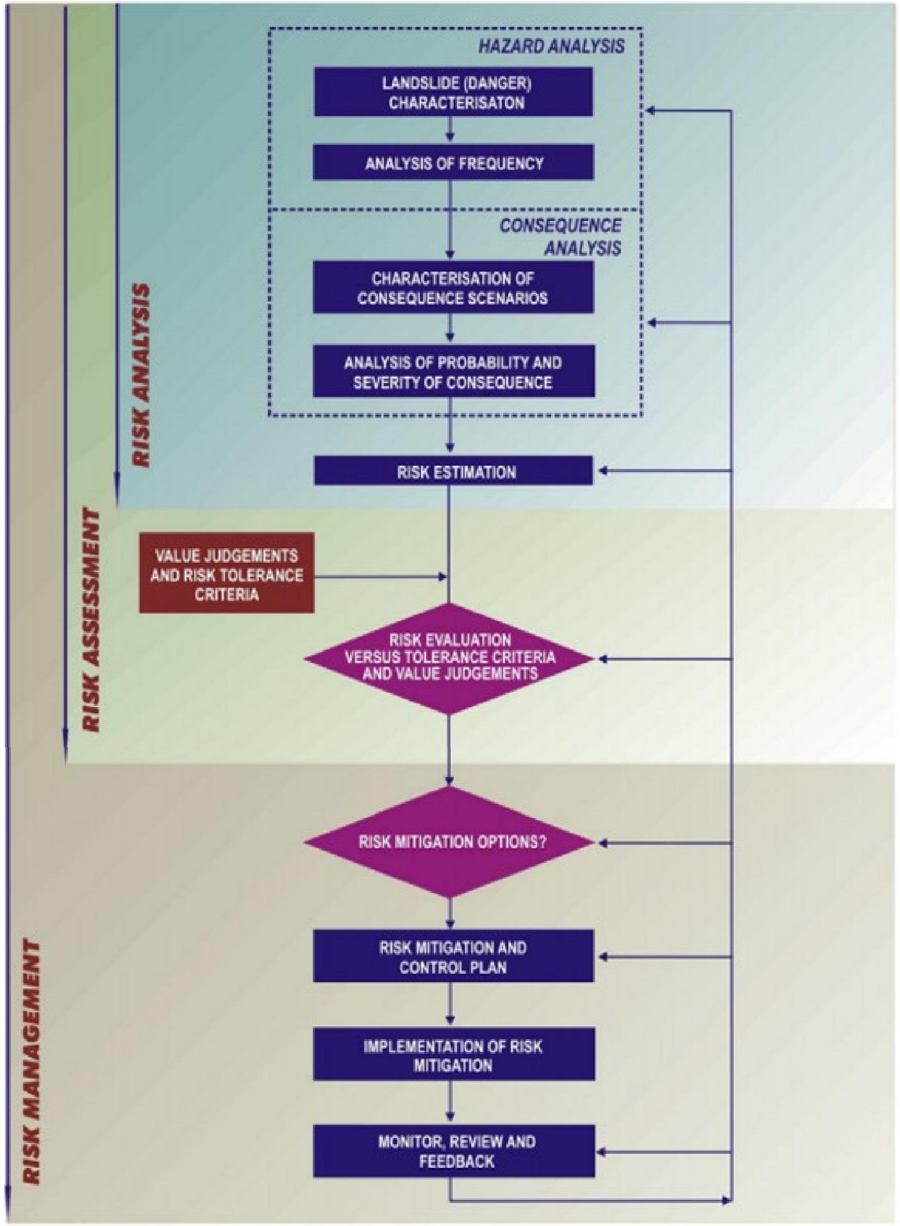
**Table 8.9** Example 8.4: Lawrence Hargrave Drive, Australia – vulnerability values for various landslide scenarios

| 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)

## Risk Management

- Risk management frameworks
- Risk mitigation – accept, avoid, reduce hazard, reduce consequences, monitoring and warning, transfer risk, postpone – no single measure.
- Monitor review and feedback
- Maintenance

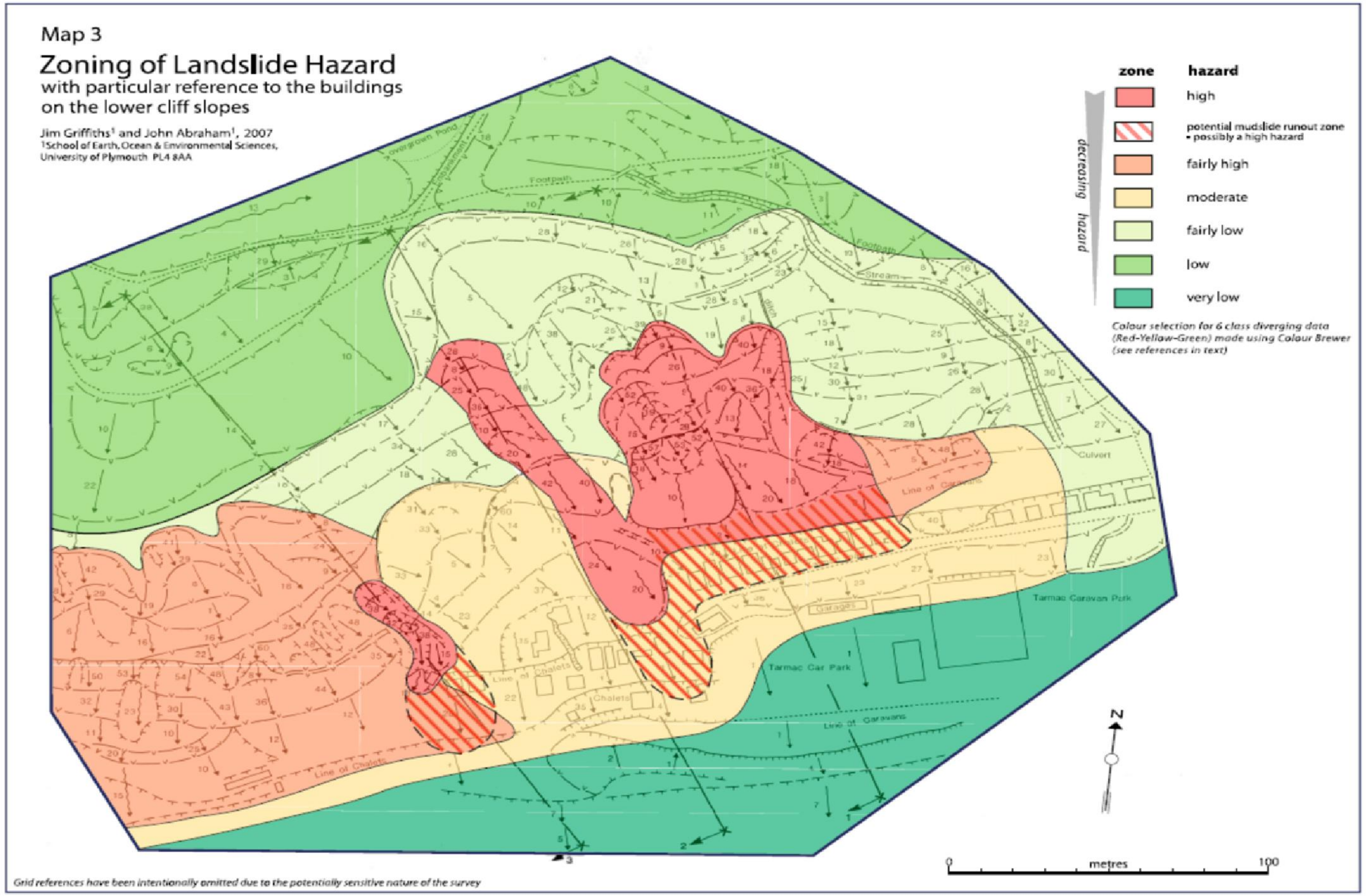


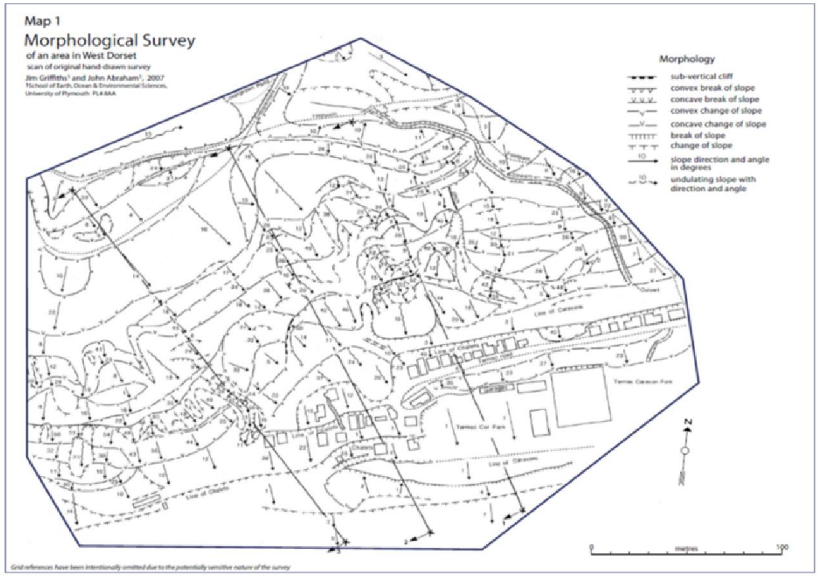
## What methodologies are available to assess hazard?

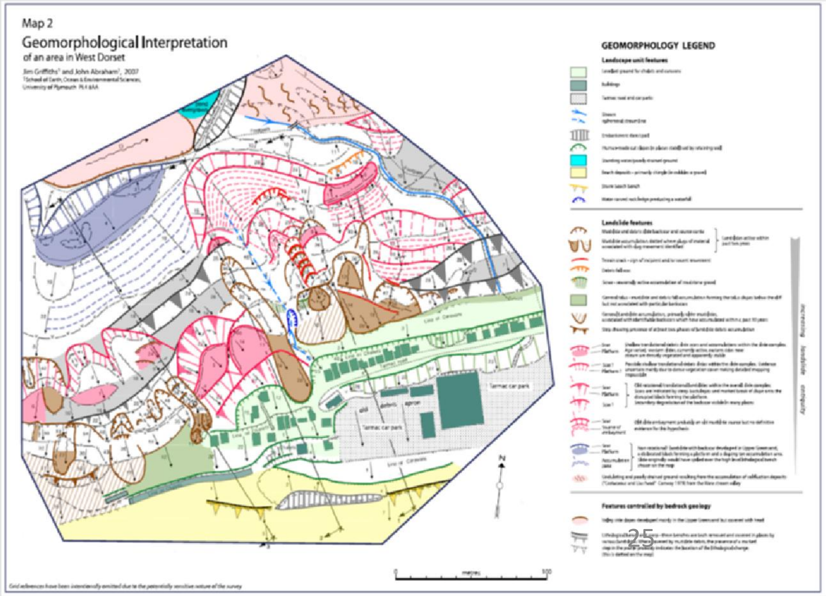
Geomorphological approaches

- **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

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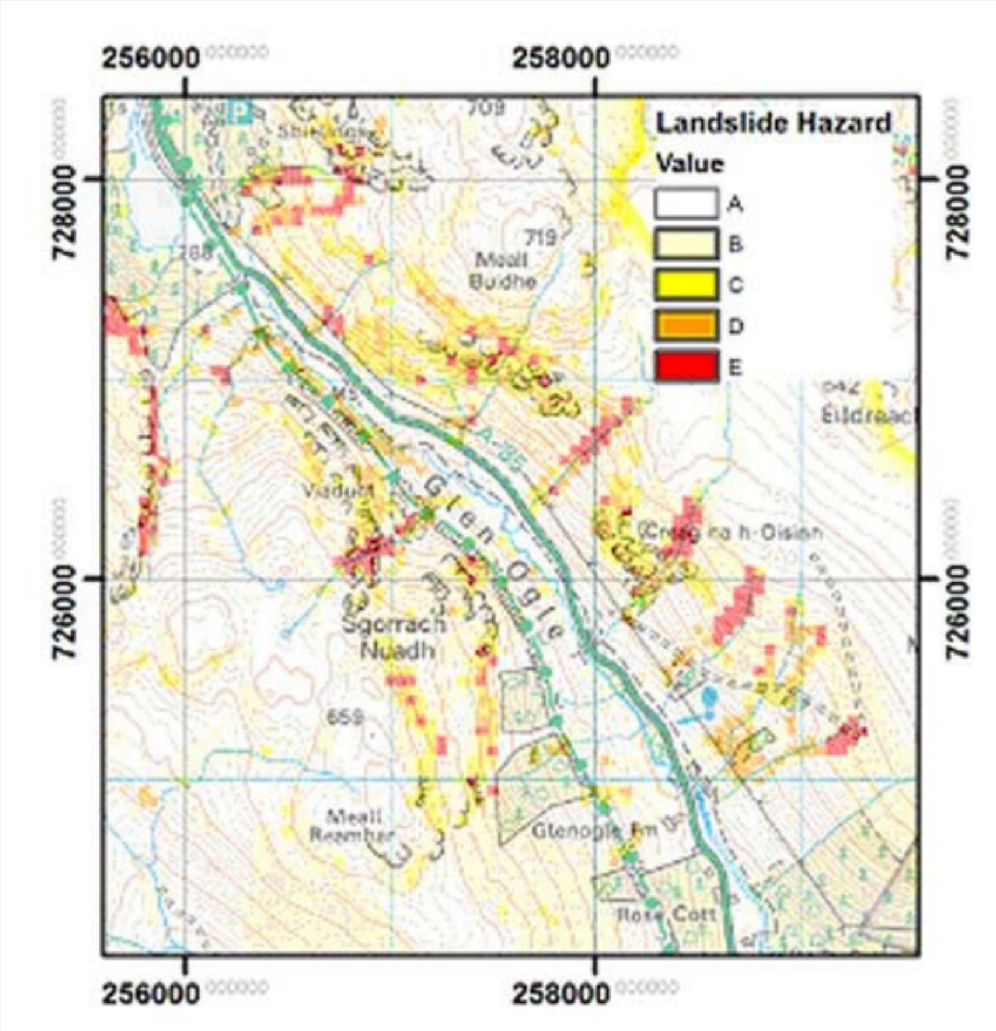
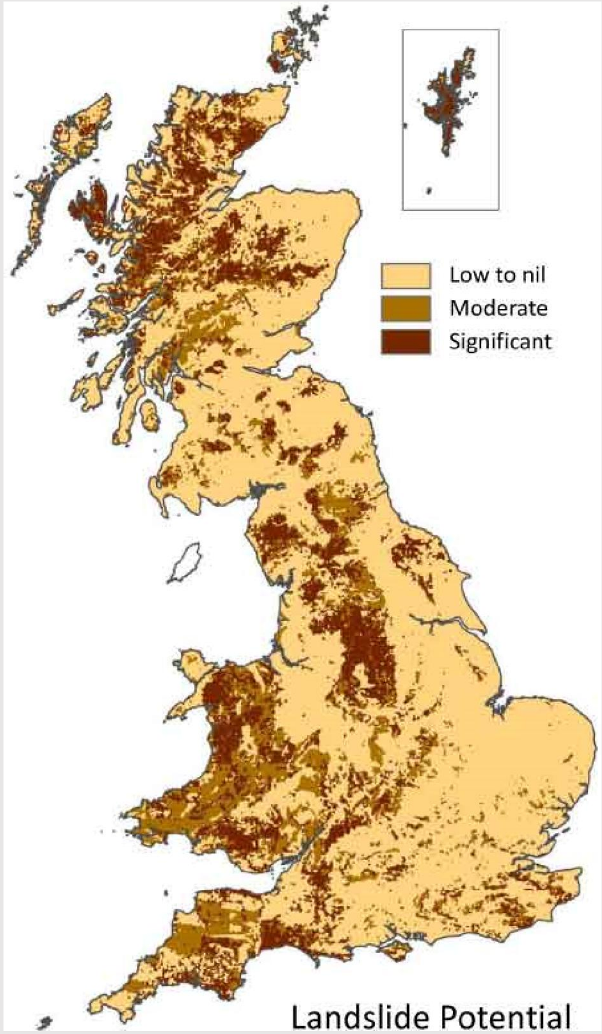
- **Indirect** – GIS interpretation based on an evaluation of causal factors



## Direct Mapping

Based on knowledge and experience of interpreter

Can produce very reliable maps with zero misclassification. This cannot be obtained with indirect mapping.

However, 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.

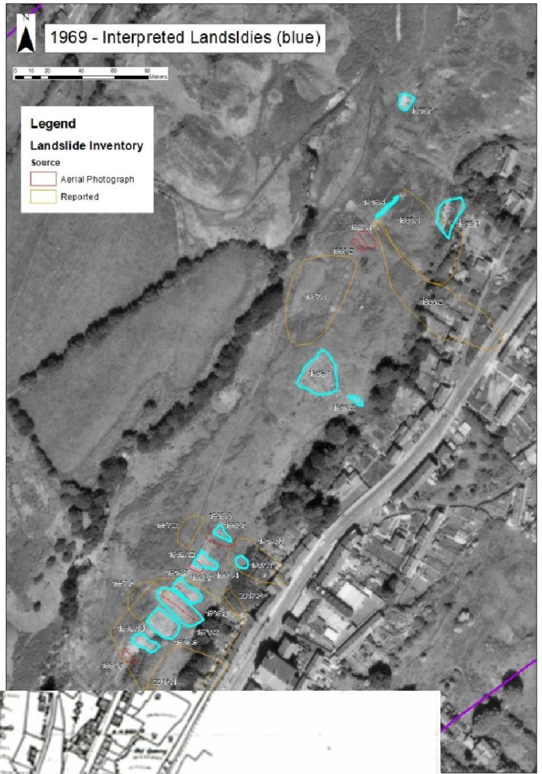
Maps produced from statistical analysis are very reproducible since the weight is derived from the attributes and not from the data. However, this is not necessarily more objective since subjectivity is involved in both the data collection and the selection of relevant factors for the analysis.

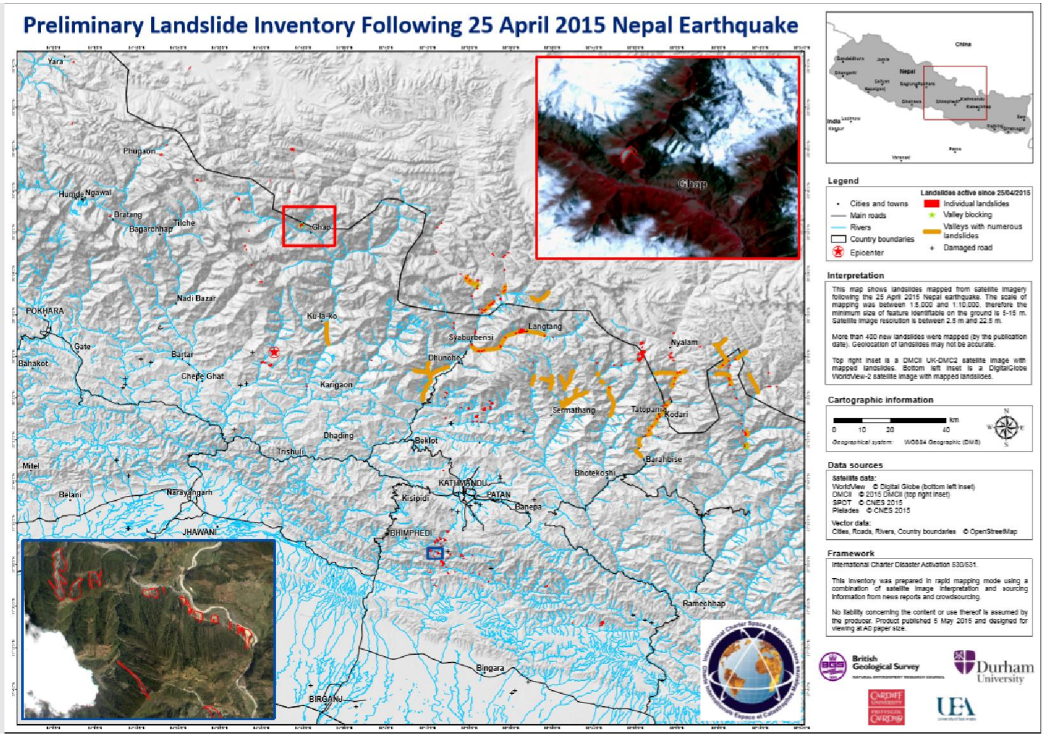
***Dependant on appropriate data sets being available***

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

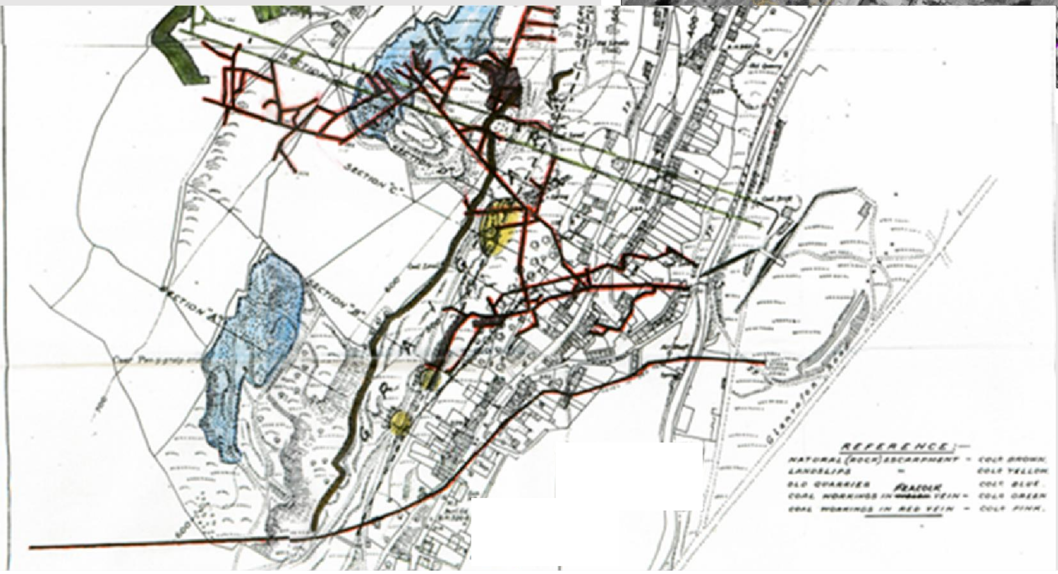
## Landslide inventory

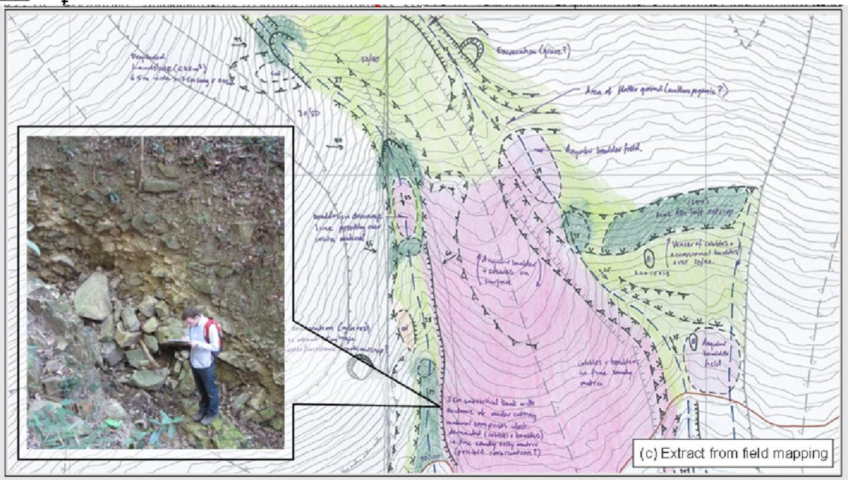
- Historic records
- Satellite
- API
- Field mapping




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





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
- 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
- Allows evaluation 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)

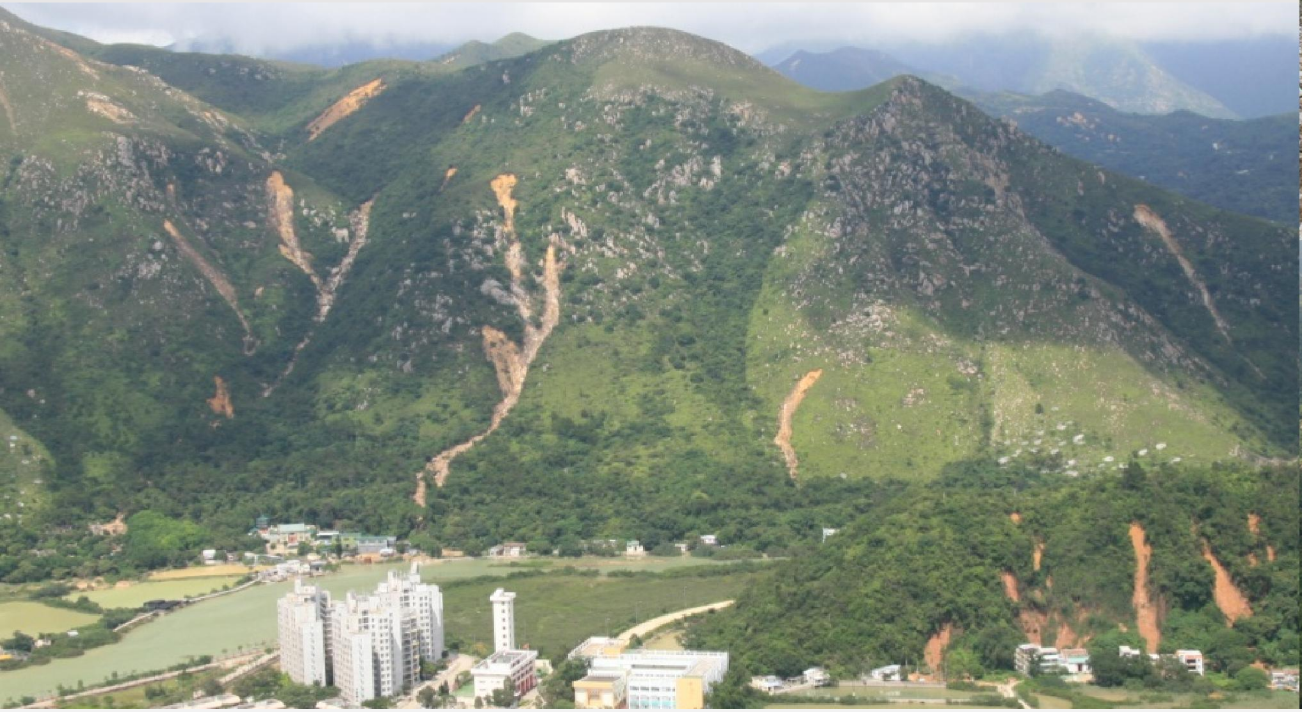
# Case Studies

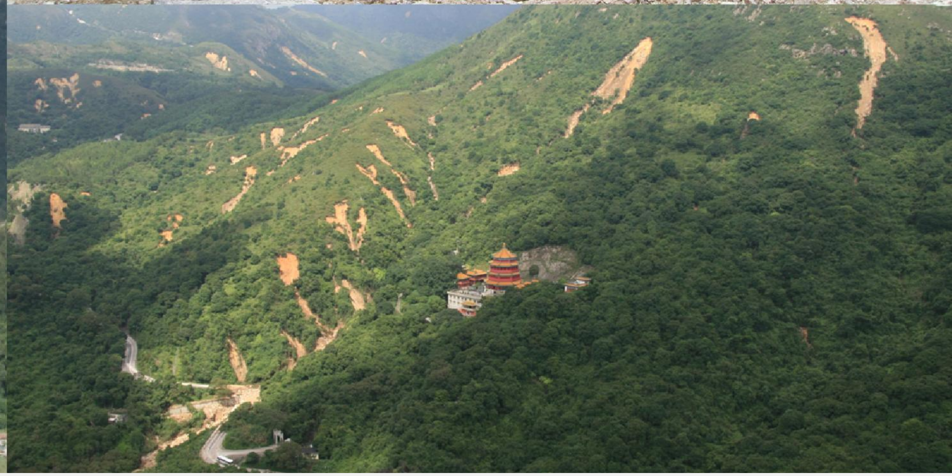
Regional Qualitative Risk Assessment
Site Quantitative Risk Assessment

# 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 debris flows. blocked key road links and evacuation of over 25 houses

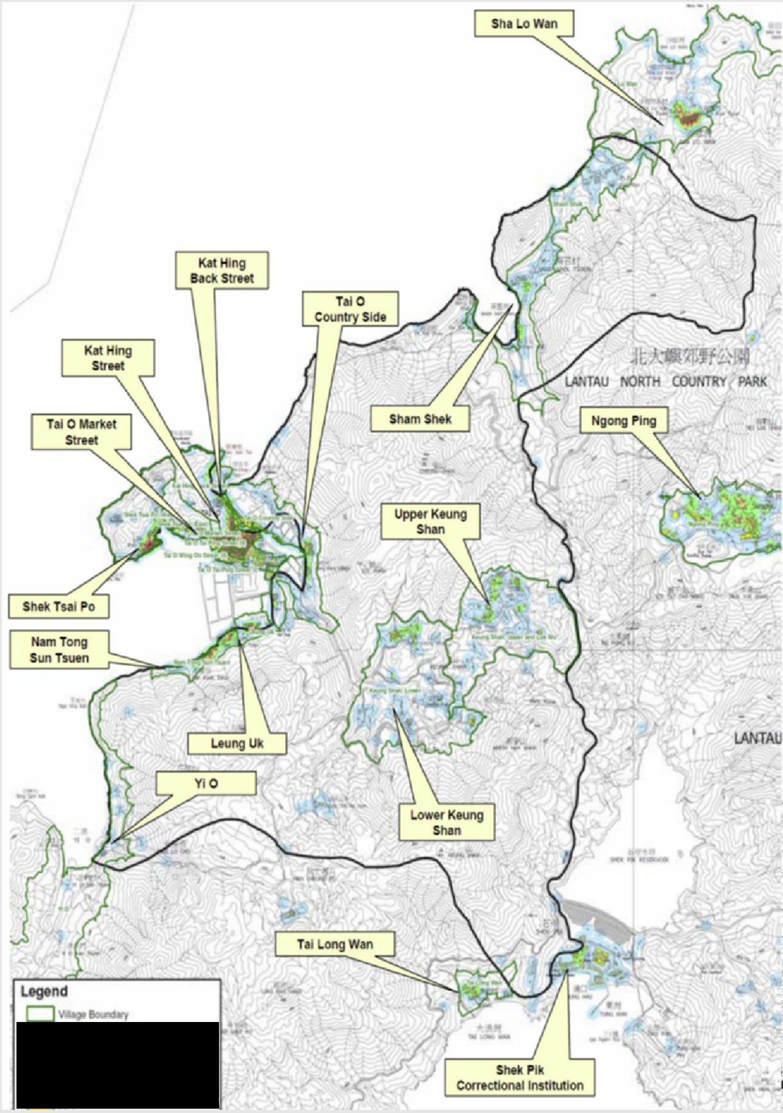
# Regional Qualitative Landslide Risk Assessment – Hong Kong

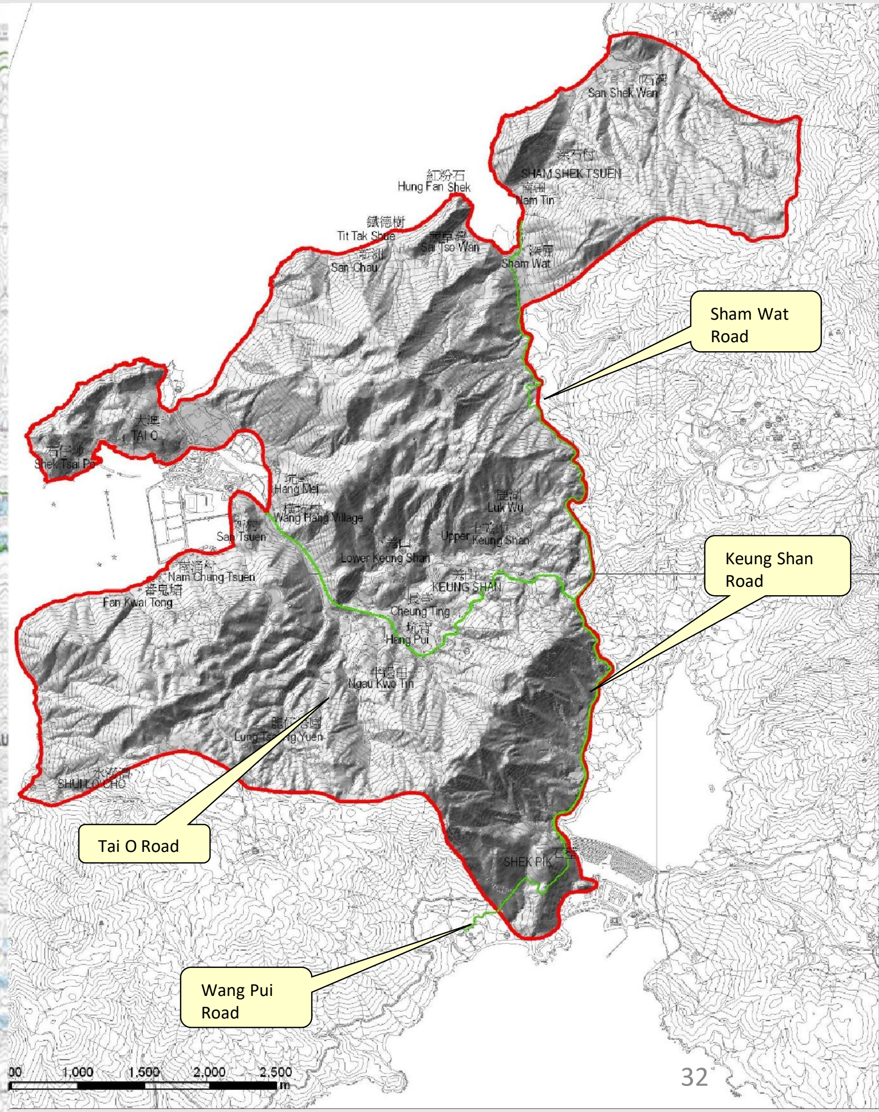
**Apx 18 km$^2$**

**Two distinct elements at risk**

- **Village areas**

- **Main Transport Routes include**
  - **Keung Shan Road**
  - **Tai O Road**
  - **Sham Wat Road**
  - **Wang Pui Road**



Direct engineering geomorphological mapping based primarily on API

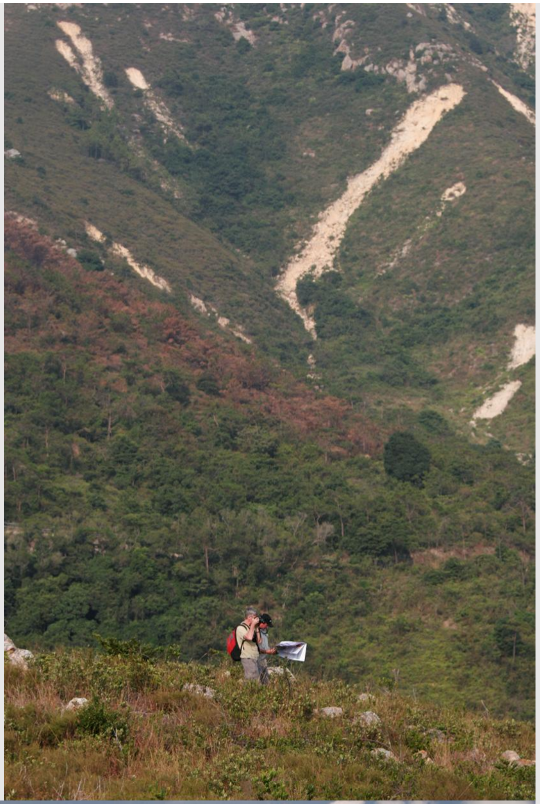
Undertaken by team of 4 senior EGs from 3 consultants at a single location to enable discussion, comparisons and benchmarking as well as the rapid development of the methodology.

18km$^2$ over 5 months

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.

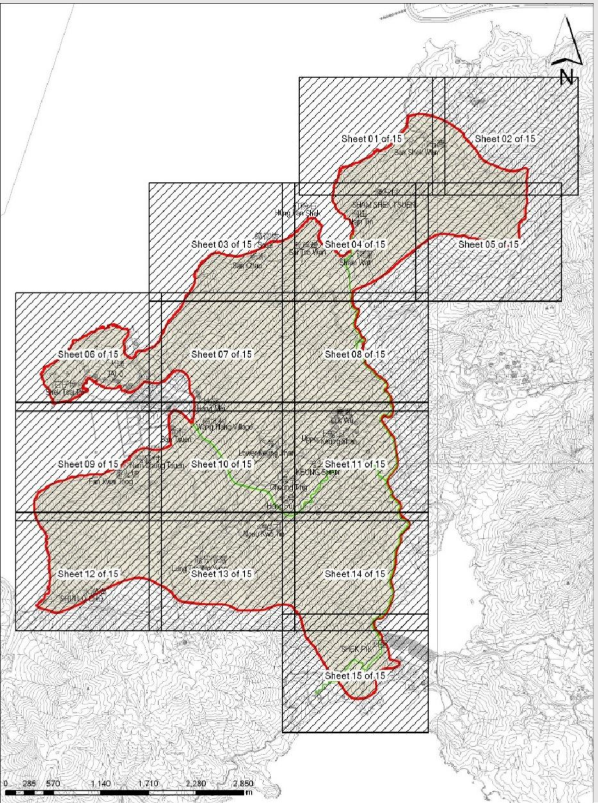
Site reconnaissance's were made by the mapping team, traversing the main footpaths and trails in the Study Area.

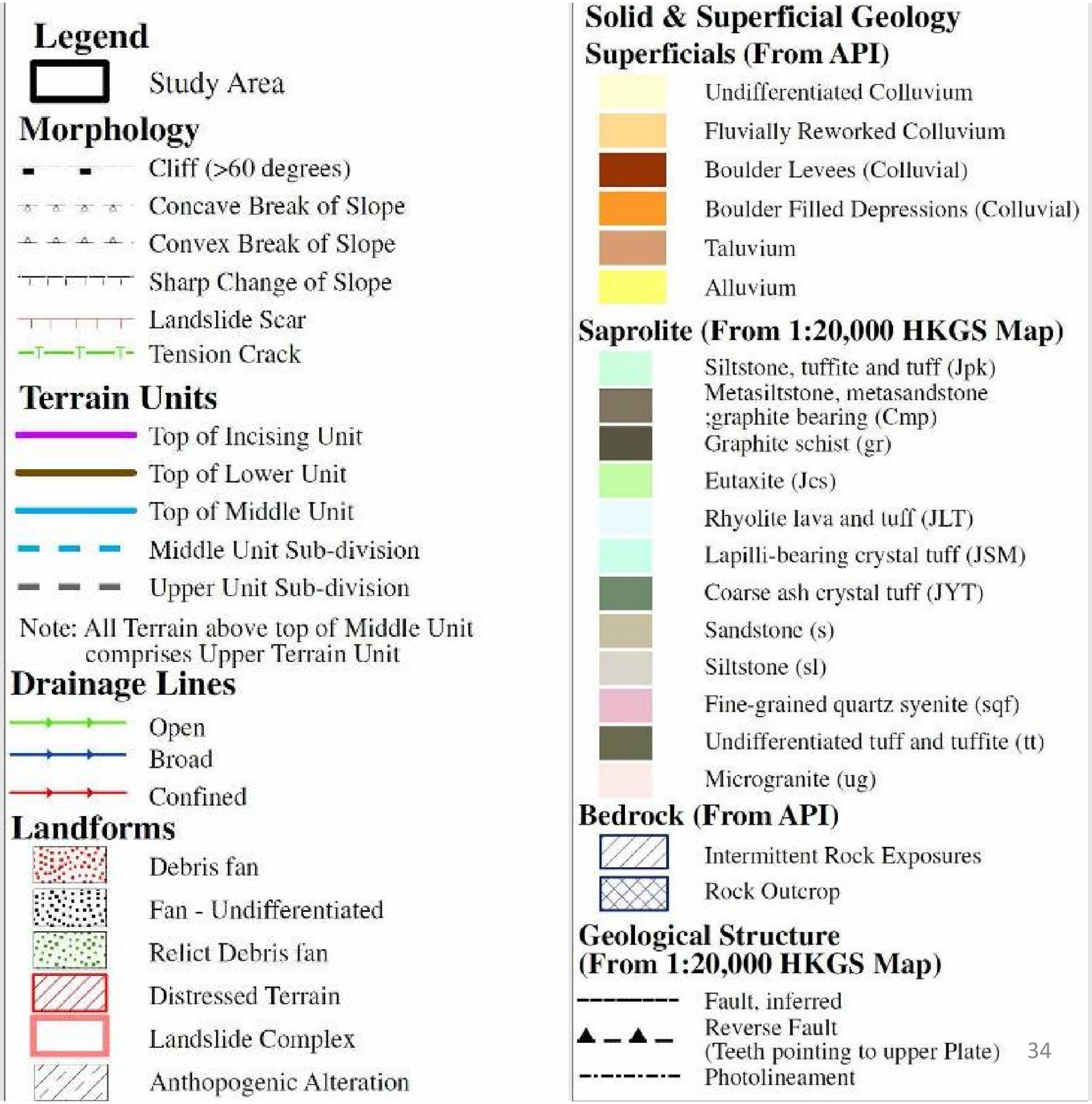
These included a day in the field with the Independent Technical Reviewer of the Study (Fred Baynes)



Engineering geomorphological mapping comprised

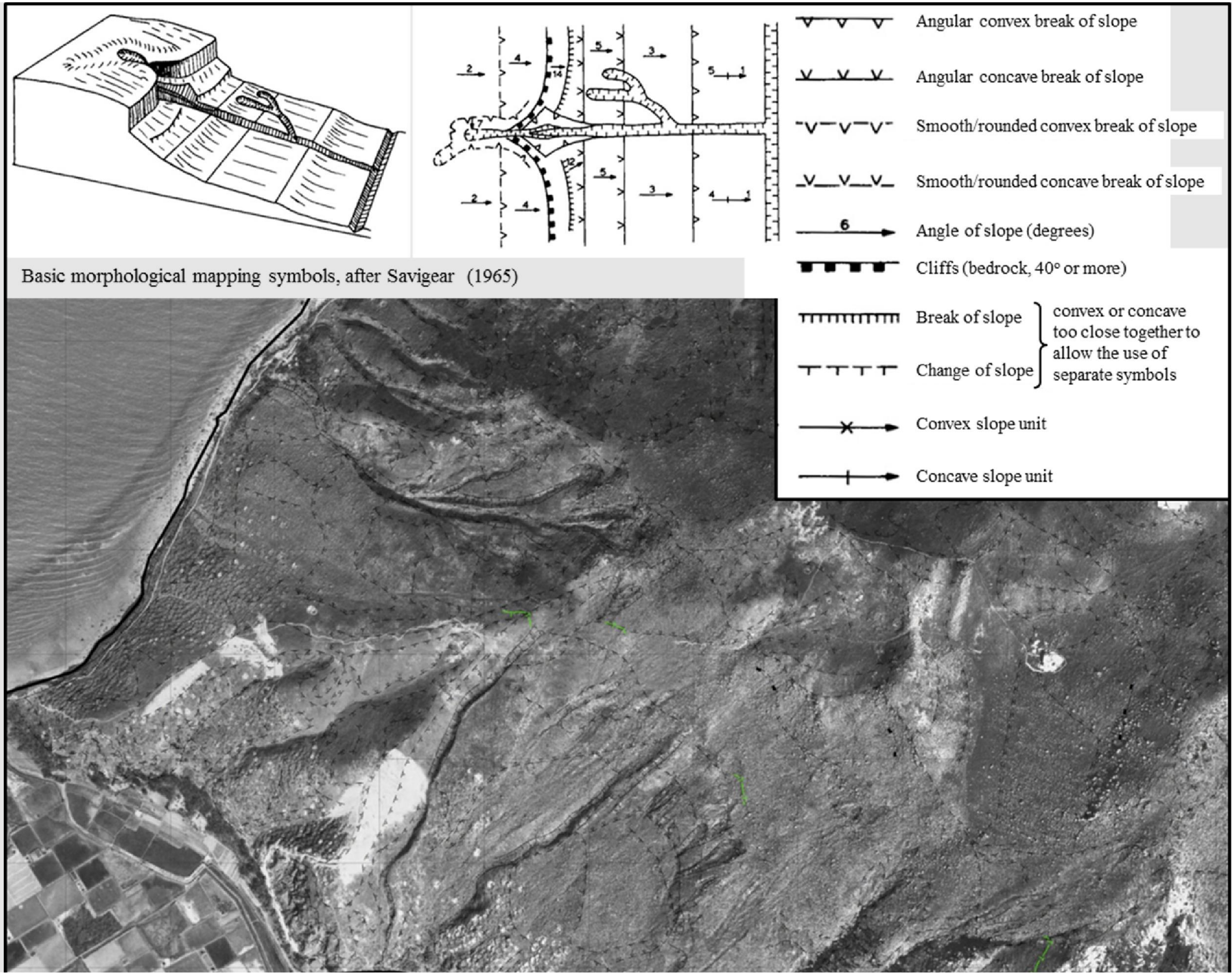
- morphological mapping
- superficial geological mapping
- drainage line mapping
- terrain unit mapping
- landform mapping



# Morphological mapping

“Every surface form, within reason, that can be recorded at the scale of the map should be represented, whether of natural or human origin. Although it does not appear significant at the time of the survey, the presence of a particular form may, when seen in the wider context of the rest of the features mapped, lead to comprehension of the character and origin of a landform that would otherwise defy understanding”.




Basic morphological mapping symbols, after Savigear (1965)

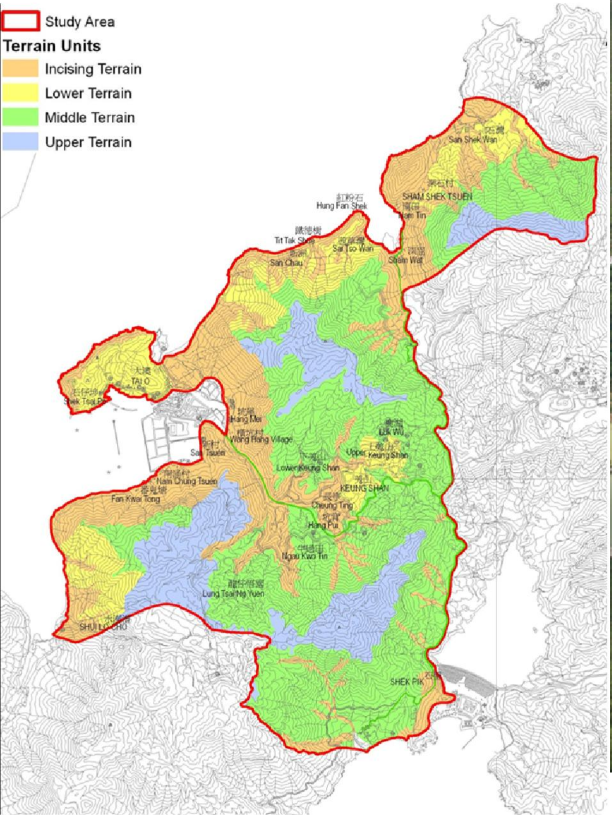
**Solid & Superficial Geology**
**Superficials (From API)**

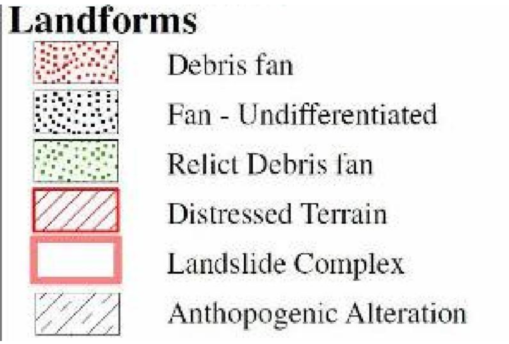
- Undifferentiated Colluvium
- Fluvially Reworked Colluvium
- Boulder Levees (Colluvial)
- Boulder Filled Depressions (Colluvial)
- Taluvium
- Alluvium

| Superficial Geology | Typical Characteristics |
|---|---|
| Alluvium | comprises sediments deposited by water in a non-marine environment. This has been used as an encompassing term and includes fluvial (river) and estuarine sediments. This material is likely to comprise both fine and coarse grained sediments. |
| Undifferentiated Colluvium | includes sediment moved predominantly by gravity, including landslides as well as fluvial processes such as channelised debris flows. |
| Fluvially Reworked Colluvium | comprises relict colluvial deposits that have been subject to notable fluvial reworking, typically resulting in areas with low slope angles and internal lobate features. **This material was probably formed in the geological past** and is often located immediately below large taluvium drapes. It forms a key identifier of landslide complexes**.** |
| Boulder Levees | comprise **positive sinuous features predominantly composed of boulders** and typically located adjacent to drainage lines or former drainage lines. |
| Taluvium | comprises colluvium with a high boulder content that is predominantly located below rock or intermittent rock and is deposited on steeper slope angles than other colluvial deposits. Boulders are typically angular and occasionally grade into talus, which has not been differentiated within this study. |
| Boulder Filled Depressions | comprises accumulations of boulders within relatively gentle and broad topographic depressions that are interpreted as being formed by a mix of gravitational down slope movement of exhumed corestones, with subsequent winnowing of fines by surface water flow. |
| Saprolite | the predominant material type within the hillside catchments in the study area. In aerial photographs it is typically smooth in texture, although occasional boulders may be evident indicating the presence of corestones. Saprolite may have a thin (<0.5m) mantle of colluvium or slope wash material above the in-situ strata. This however is not shown on the engineering geomorphological maps. |
| Rock | appears as light grey tones in aerial photographs. Joints often evident giving angular shape to outcrop and often controlling the orientation of individual outcrops. Where vegetation cover is low rock can be easily distinguished from colour photographs due to its light brown colour in contrast to the green vegetation. |
| Intermittent Rock | Comprises areas of intermixed small rock outcrops surrounded by thin layers of saprolite. It is best identified from colour aerial photographs. |

**Terrain Units**

- Incising Terrain
- Lower Terrain
- Middle Terrain
- Upper Terrain




Key identifiers

Fan morphology + colluvium + boulder levees
= Debris fan
Active

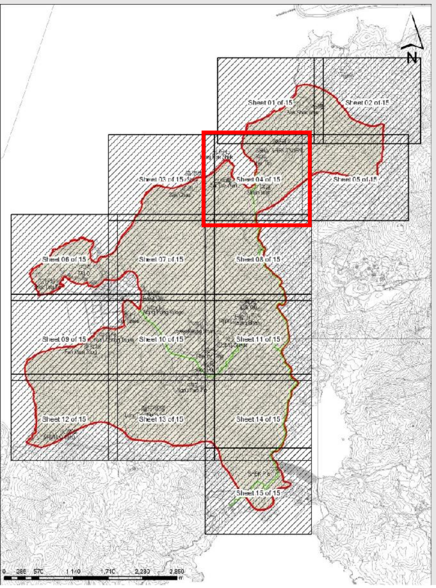
Fan morphology + colluvium
= Debris fan (undif)
Inactive or older

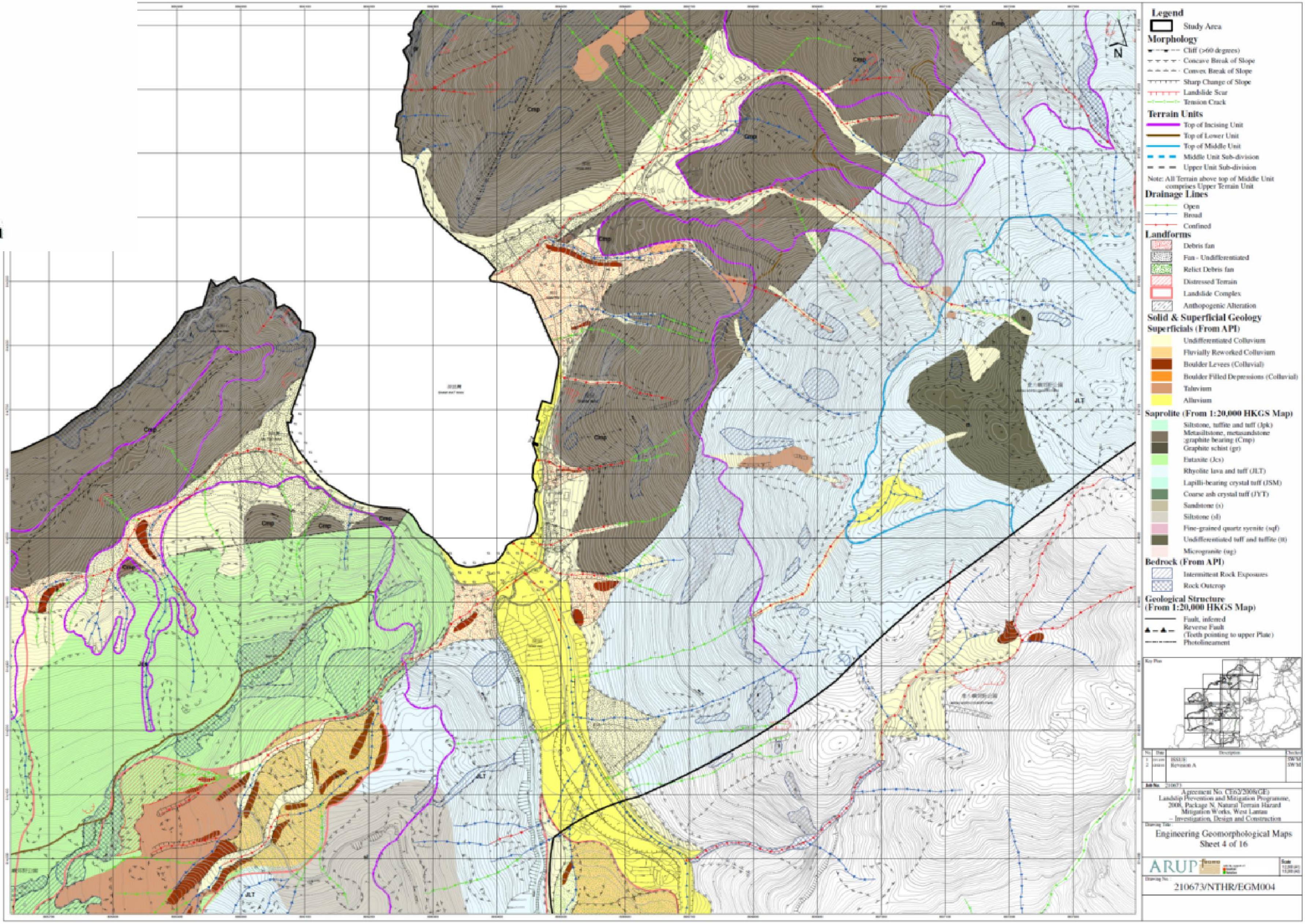
Fan morphology + fluvial reworked colluvium
= Relict Debris fan
Geological past

Table 2. Summary of Landform Units presented in the Engineering Geomorphological Map

| Landform Unit | Typical Characteristics |
|---|---|
| Anthropogenic Terrain | comprises large-scale areas in which significant human disturbance and modification of the natural hillsides has occurred. The most common types of anthropogenic terrain observed within the hillside catchments comprised the presence of abandoned agricultural terraces, hillside grave yards and disturbance associated with the development of catchwaters. |
| Debris Fan | comprises fans within which boulder levees, interpreted to represent deposits from channelised debris flows, are present. Debris fans have been interpreted as being potentially younger and more active than undifferentiated debris fans and relict debris fans (see below) given that boulder levees can be identified within them |
| Debris Fan (Undifferentiated) | comprises fans of predominantly undifferentiated colluvium. They commonly form the outer parts of fan complexes. Given their field relationships, they may represent inactive parts of fan complexes or may represent older, more degraded, fans. |
| Relict Debris Fan | similar to debris fans but are considerably larger in plan area and commonly extend much higher into catchments. These fans commonly include notable areas of fluvial reworked colluvium and comprise parts of larger landslide complexes that have been tentatively identified. They possibly represent the remnants of coalescing debris fans, associated with large landslide complexes typically extending from Middle to Lower Terrain.<br>It is considered that relict fans were probably formed in the geological past, possibly in during different climatic regime. Subsequent erosion has resulted in the removal of many of the landforms associated with original landslide complex. |
| Landslide Complex | comprise large scale features occasionally crossing landscape assemblage boundaries. Often involving multiple processes and materials e.g. talus, fluvially reworked colluvium, debris fans, boulder levees. Typically these features are located in the Middle Terrain with their heads located at the boundary of the Upper Terrain.<br>It is considered that these landslide complexes were probably formed in the geological past, possibly in during different climatic regime. Subsequent erosion has resulted in the removal of many of the landforms associated with original landslide complex. |
| Distressed Terrain | these areas are associated with active fluvial undercutting and incision into saprolite resulting in significant concentrations of landslide features.<br>This terrain is typically located at the head of the erosion fronts, typically at the upper boundary of Incising Terrain. However, it does occasionally occur in the Middle Terrain particularly at Keung Shan. |


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


N


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)
Talus/ium
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
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
Drawing No.:
210673/NTHR/EGM004
N
Cmp
JLT

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

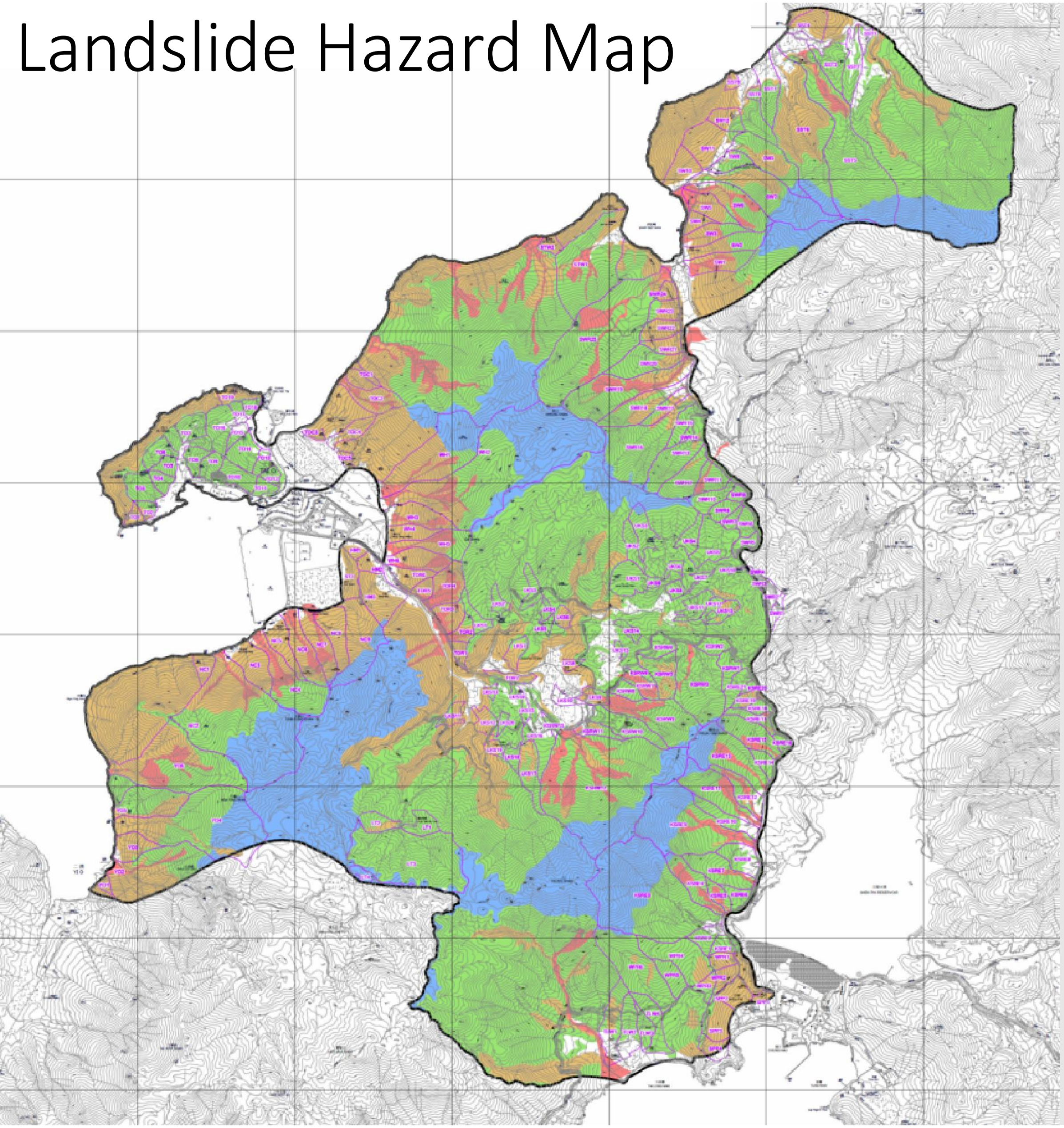
Consequently, fan areas were used as surrogates for relatively high magnitude, low frequency channelised debris flows.

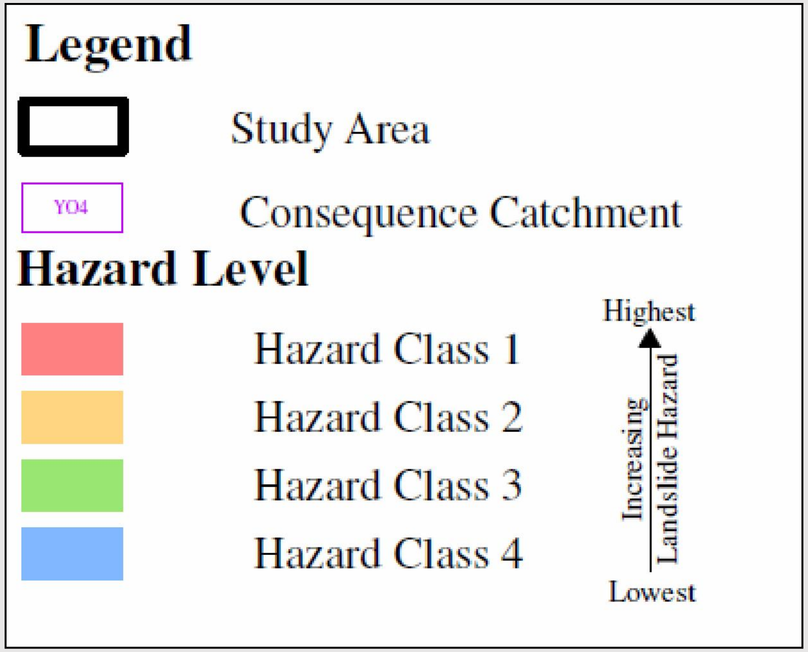
Such hazards are under-represented in the existing landslide datasets in Hong Kong

| | VERY HIGH | HIGH | MODERATE | LOW |
|---|---|---|---|---|
| **Primary Classifier** | Debris Fan is present | Within the Incised Terrain Unit | Within the Middle or Lower Terrain Units | Within the Upper Terrain Unit |
| **Secondary Classifier** | Undifferentiated Fan and Distressed Terrain are present | Within Upper, Middle or Lower Terrain Units and contains Distressed Terrain | Confined Drainage Line within the Upper Terrain Unit | N/A |
| **Tertiary Classifier** | N/A | Undifferentiated Fan present but no upslope areas 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

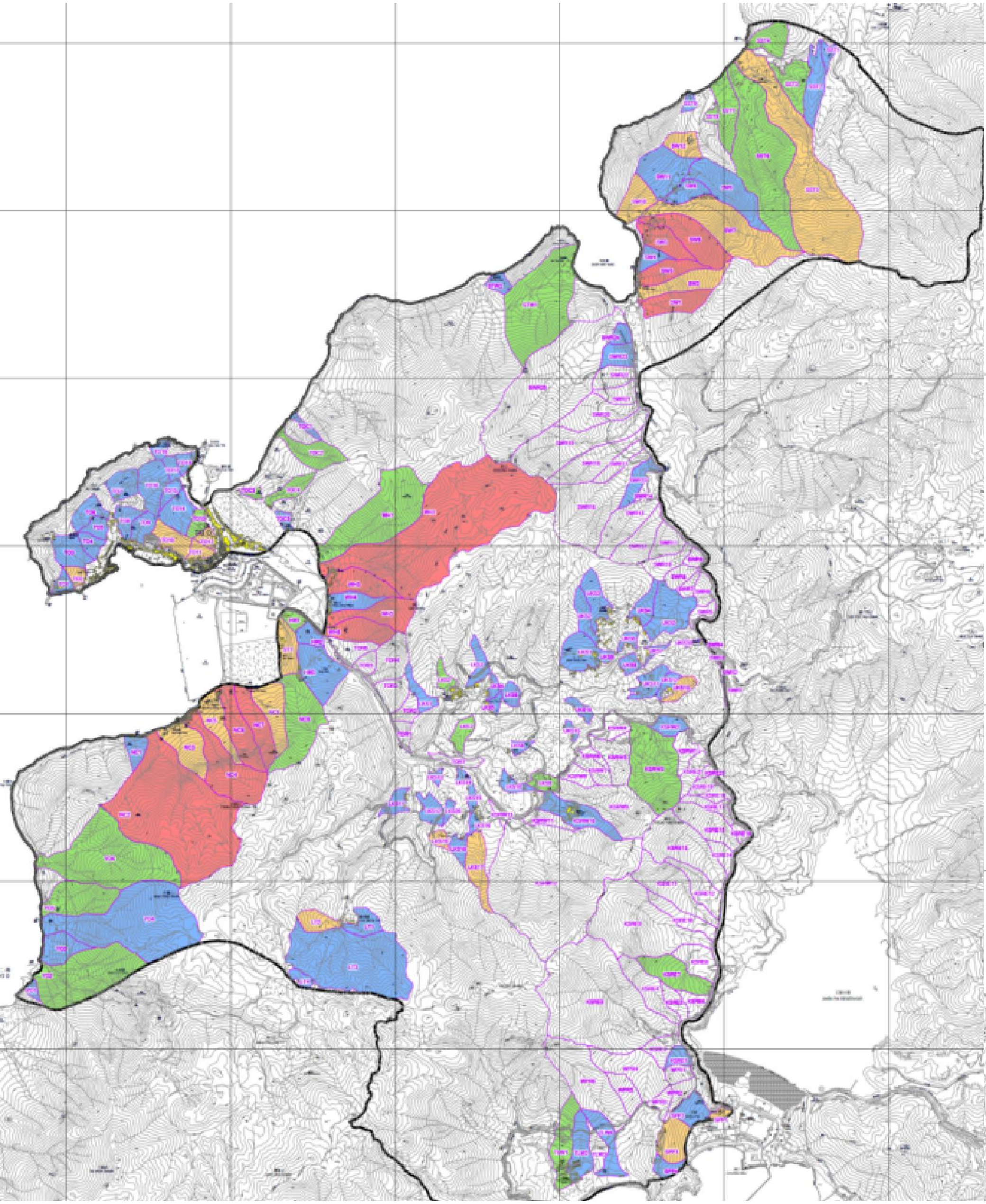


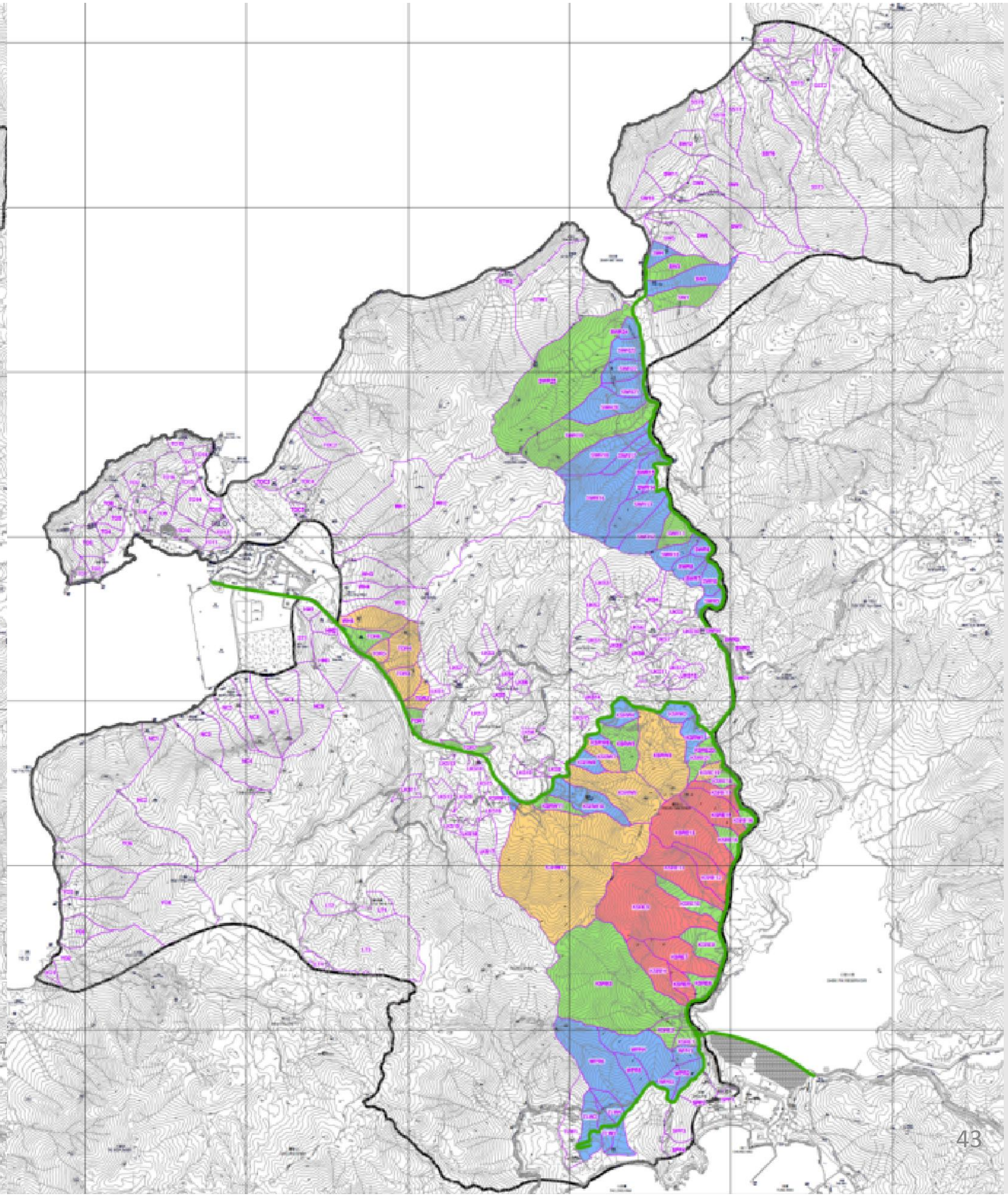


# Catchment Risk Screening Matrix

| 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<br>Schools<br>Hospital | VERY HIGH | VERY HIGH | HIGH | MODERATE | |
| High | 30-70 bldgs per ha<br>Tai O Road<br>Shek Pik Road<br>Keung Shan Road | VERY HIGH | HIGH | MODERATE | LOW | |
| Moderate | <30 bldgs per ha<br>Sham Wat Road<br>Wang Pui Road | HIGH | MODERATE | LOW | LOW | |
| Low | Other non-designated<br>Roads<br>Uninhabited Structures<br>(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



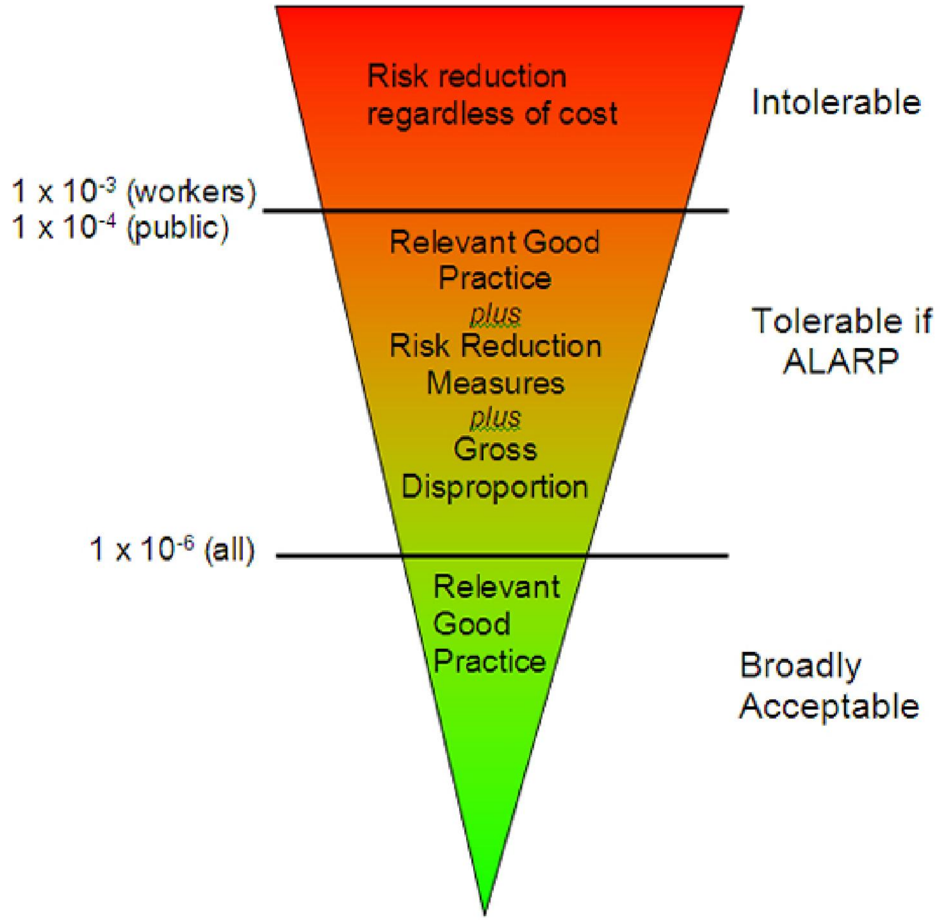


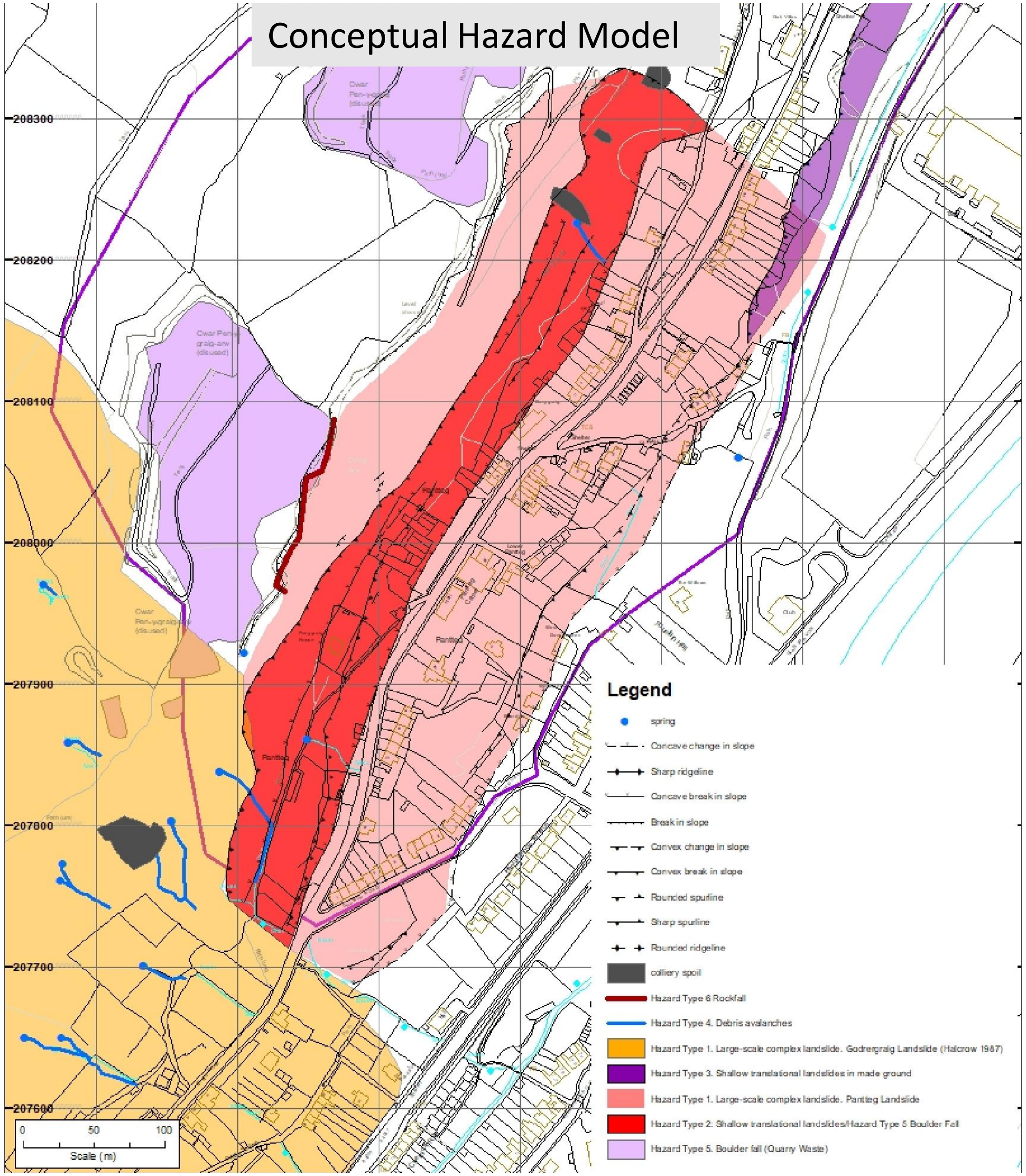
# Case 2 – Site Quantitative Risk Assessment

– calculated values.

- 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

Pantteg, South Wales - 2012 Landslide






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

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 (Red)

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

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 (Blue line)

Hazard Type 5. Boulder Fall, possible structural damage, impact on people/vehicles (Red/Lilac)

Hazard Type 6 Rockfall, possible structural damage, impact on people/vehicles (Brown line)

## **Quantitative** – calculated values.

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

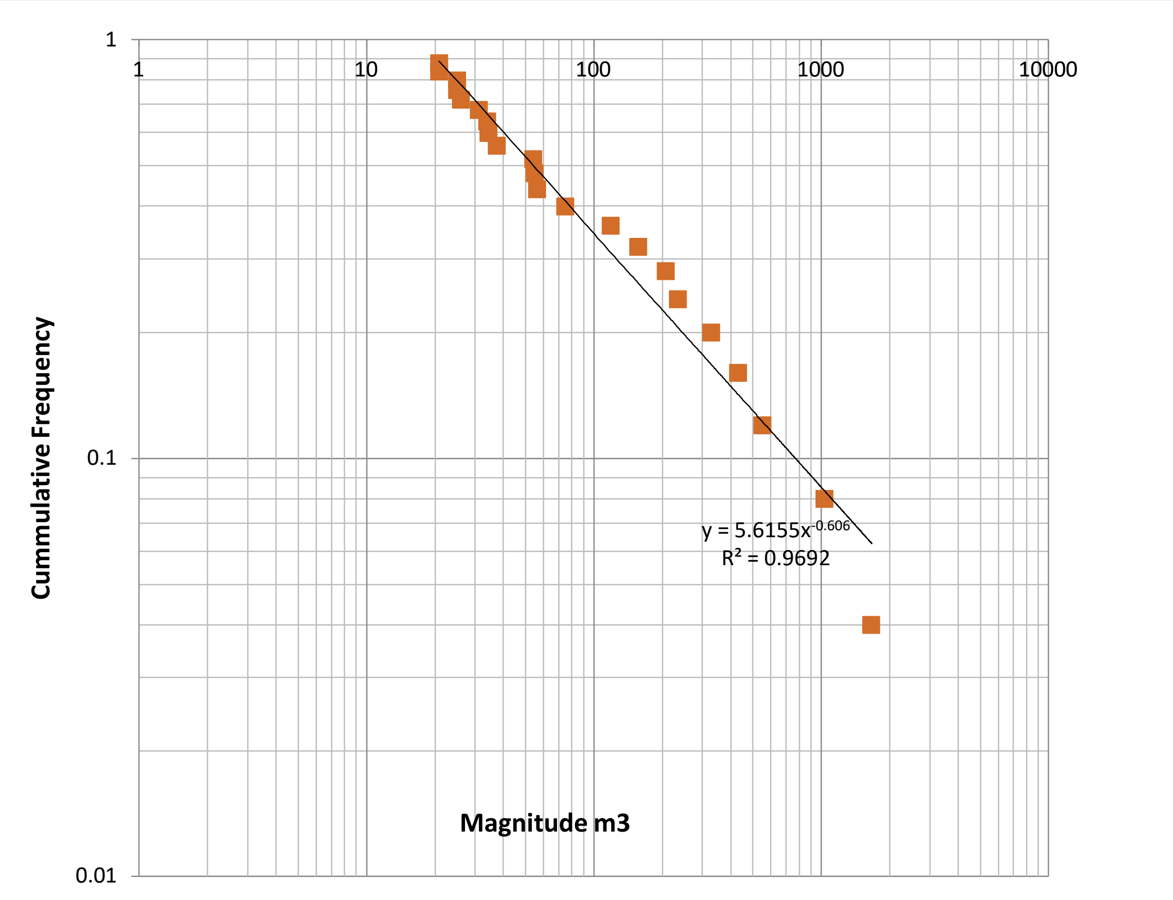
Evaluation of magnitude and frequency of each hazard type
Evaluation of run out for each hazard type



| 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

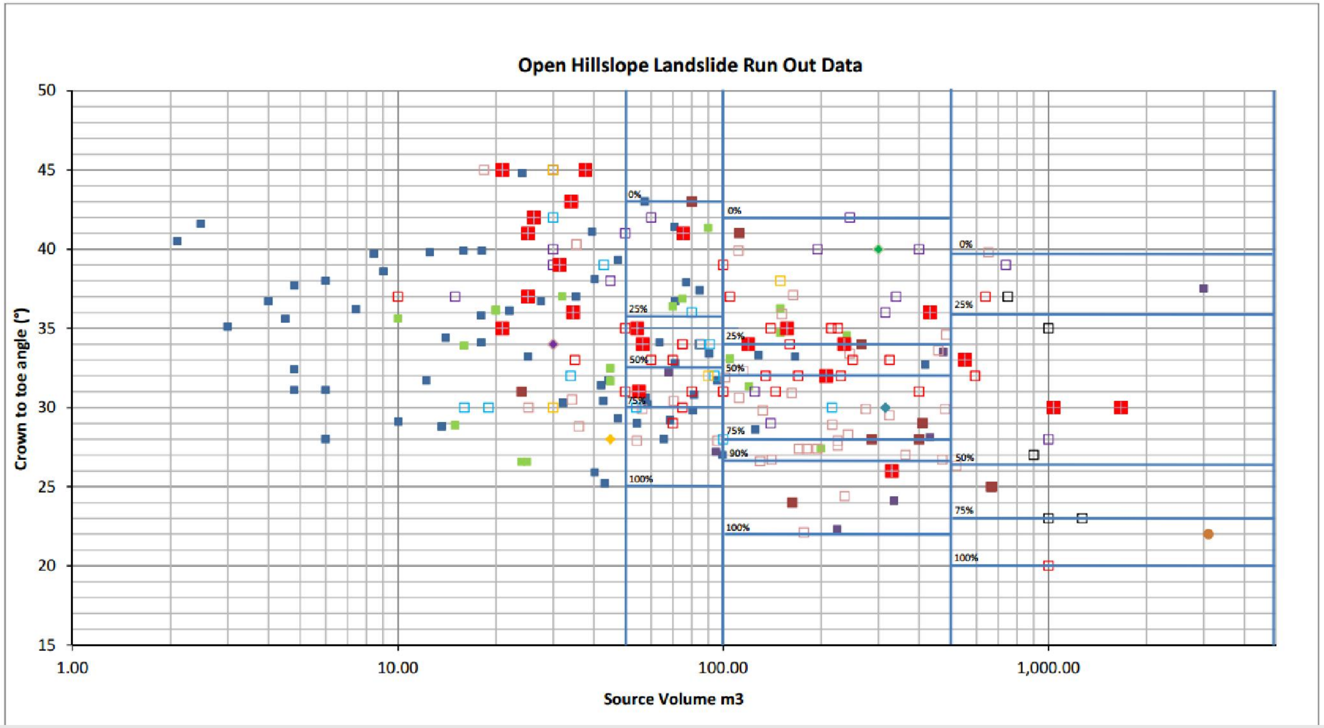



Landslide magnitude-frequency distributions can be described by an inverse power-law equation (Lee & Jones, 2014).

As the event magnitude increases, so the frequency of occurrence decreases i.e. there should be far fewer of the largest events than the smaller ones.

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

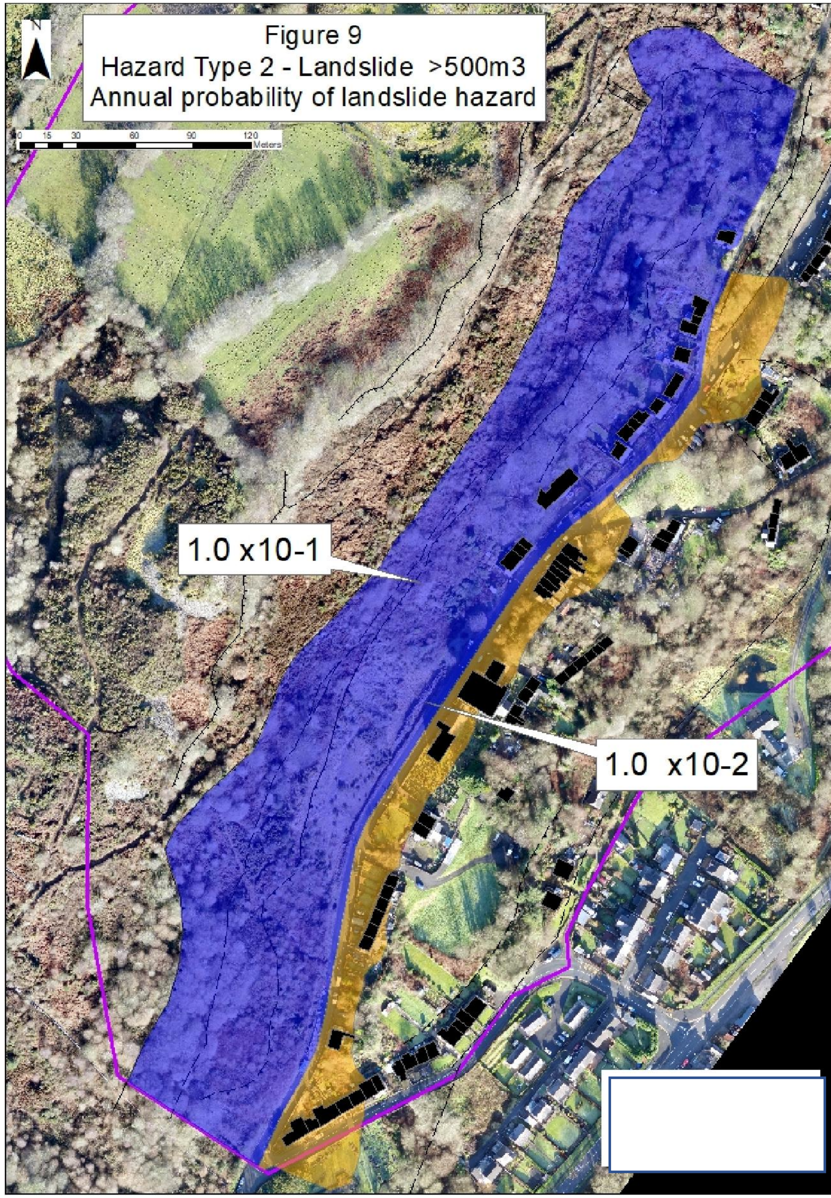
| Landslide Volume Range | Adopted Volume | Annual Probability |
|---|---|---|
| $0\text{-}100m^3$ | $50m^3$ | 0.524 |
| $100\text{-}500m^3$ | $300m^3$ | 0.177 |
| $>500m^3$ | $750m^3$ | 0.102 |




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 500m3 (100m wide)

| Scenario | P (Landslide) | P (Run-out) | P (spatial) | P (temporal) | Vulnerability | P (Fatality) |
|---|---|---|---|---|---|---|
| **Buried by debris** | 0.102 | 1 | 0.2 | 0.67 | 0.1 | $1.4 \times 10^{-3}$ |
| **Collapse of building** | 0.102 | 1 | 0.2 | 0.67 | 0.01 | $1.4 \times 10^{-4}$ |

Vulnerability Note

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.

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

Requires
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 type – buried vs collapse
Evaluation of vulnerability –see note

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 – pedestrians

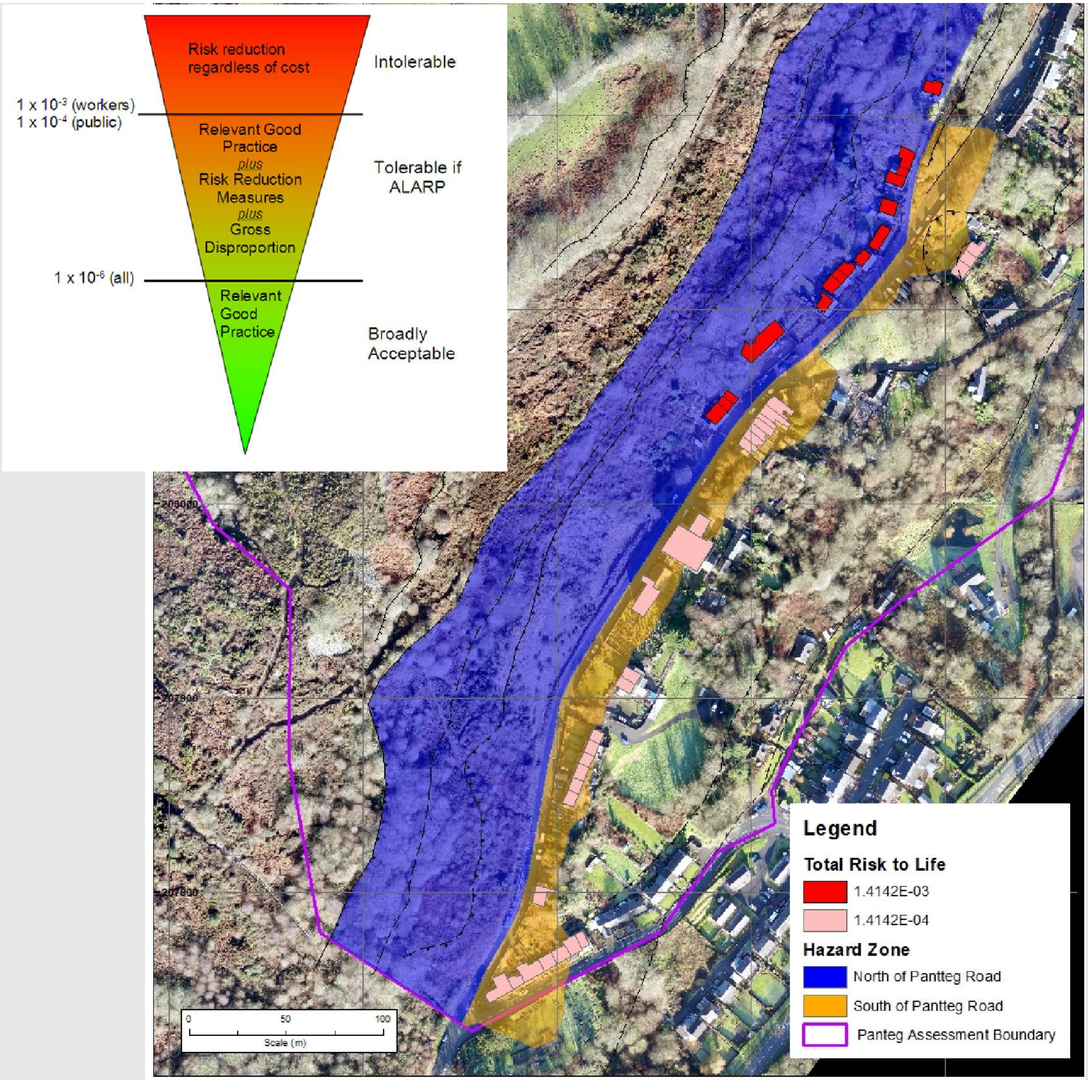
| Landslide Volume | N of Pantteg Road | South of Pantteg Road |
|---|---|---|
| <100m³ | $5.6x10^{-8}$ | $4.7x10^{-8}$ |
| 100-500m³ | $1.3x10^{-7}$ | $8.5x10^{-7}$ |
| >500m³ | $3.9x10^{-7}$ | $6.7x10^{-6}$ |
| TOTAL | $5.5x10^{-7}$ | $7.6x10^{-6}$ |

## 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

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)

Commenced 2010. Team comprises: Atkins, Bill Murphy (Uni of Leeds) and myself.
End 2021

**Final Observations**

Terminology is commonly misused

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 – i.e. not understanding the landscape

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 transparent and defensible (their assumptions are explicit), they allow a justifiable expenditure to be calculated

Thank You