Geological Society – Hong Kong Regional Group

Advances in Terrain Mapping for Landslide Hazard Assessment

Evolution of Natural Terrain Hazard Assessment Strategy in Hong Kong

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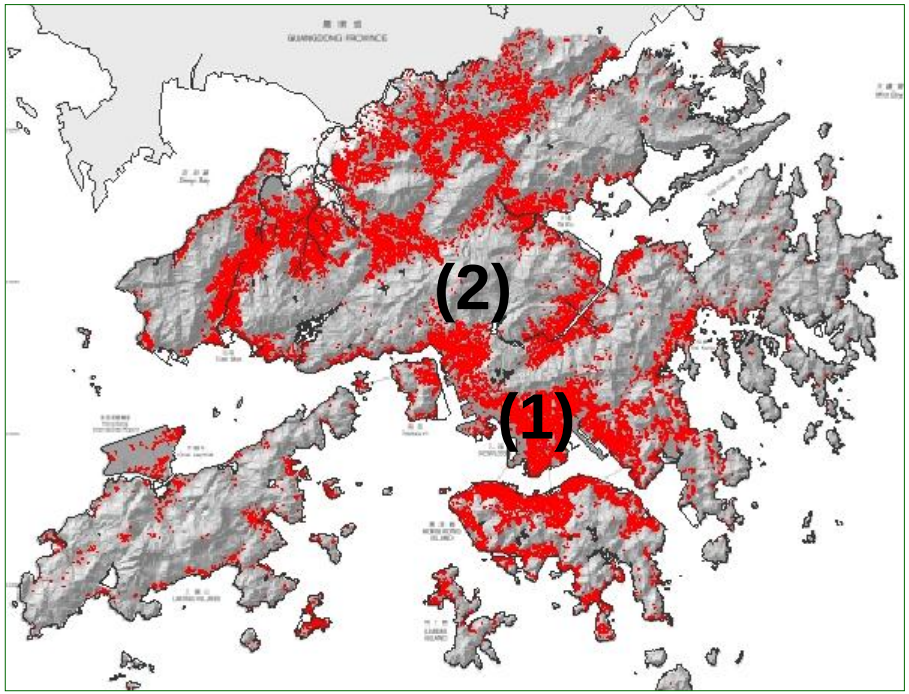
22.2.2014

Natural Hillside Plan Area 690 km^2

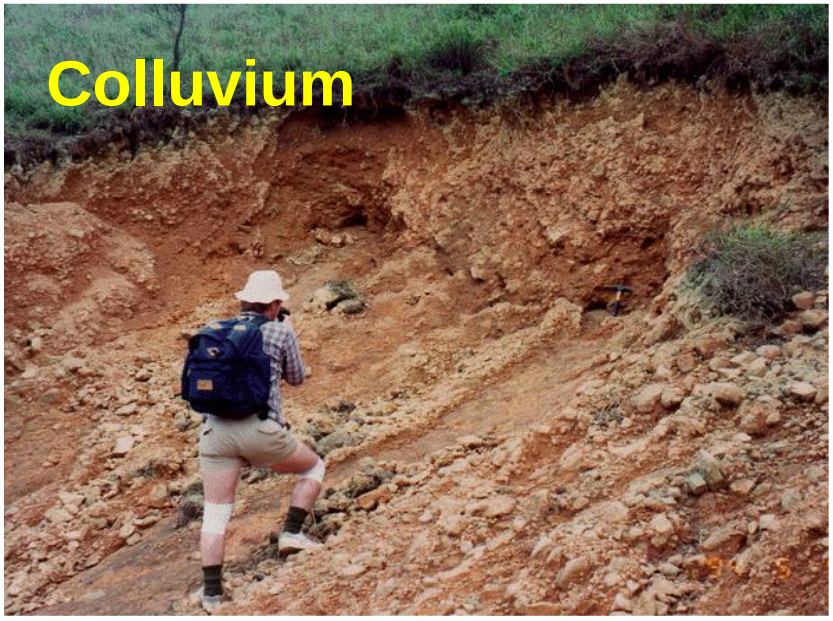
Total Land Area 1104 km^2

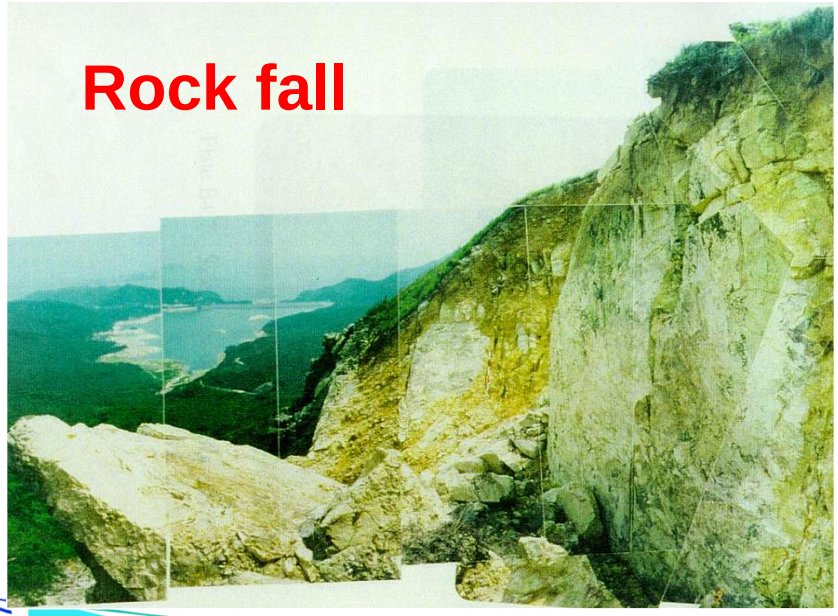


Key Issues with Natural Terrain

- Many landslides in an intense rainstorm
- Increasing risk due to developing closer to natural hillside
- Small failure can have serious consequence
- Low frequency, large magnitude event

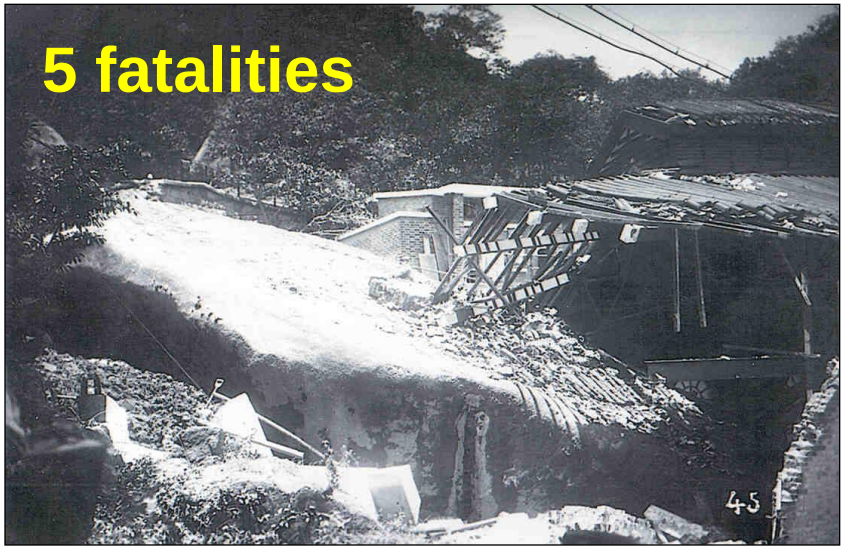
Principally Shallow Landslides



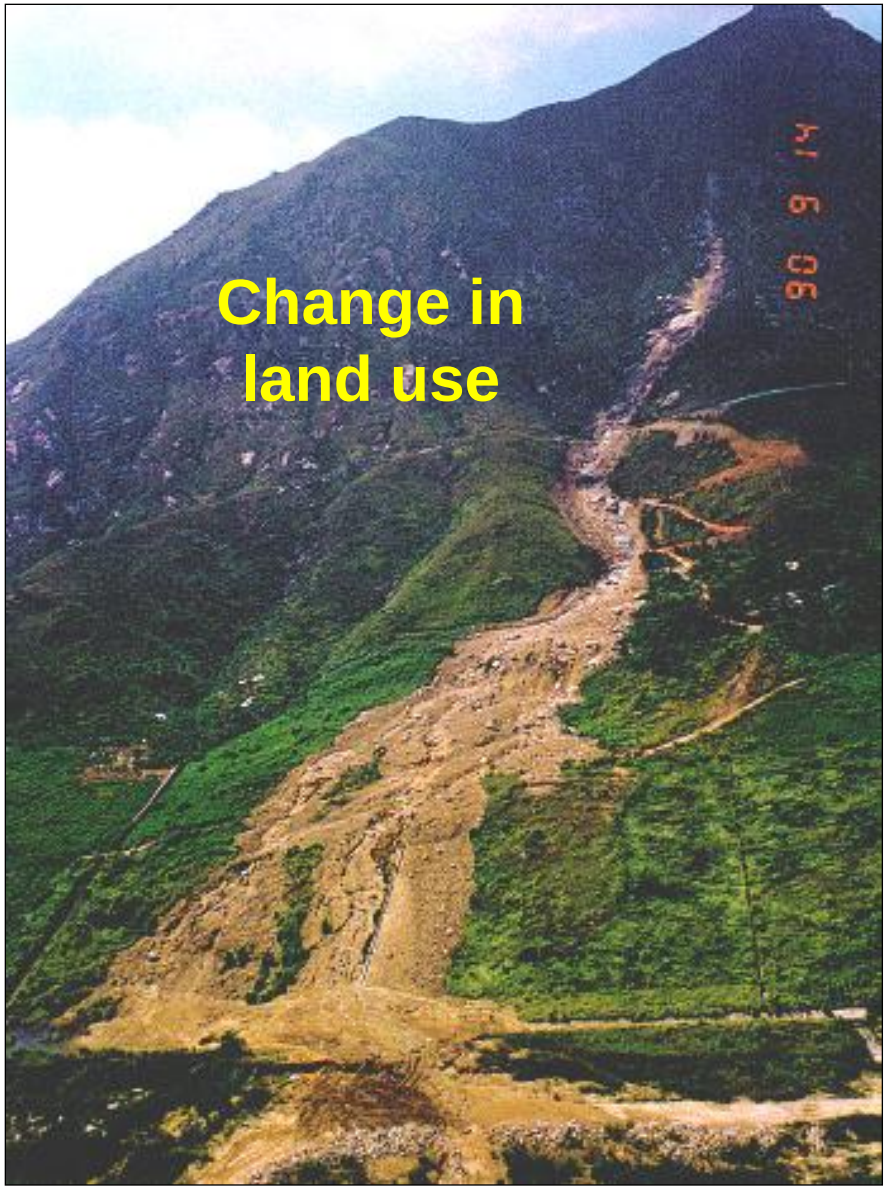


Some Large-magnitude Events

1995 Shum Wan Rd Landslide (26,000 m^3)

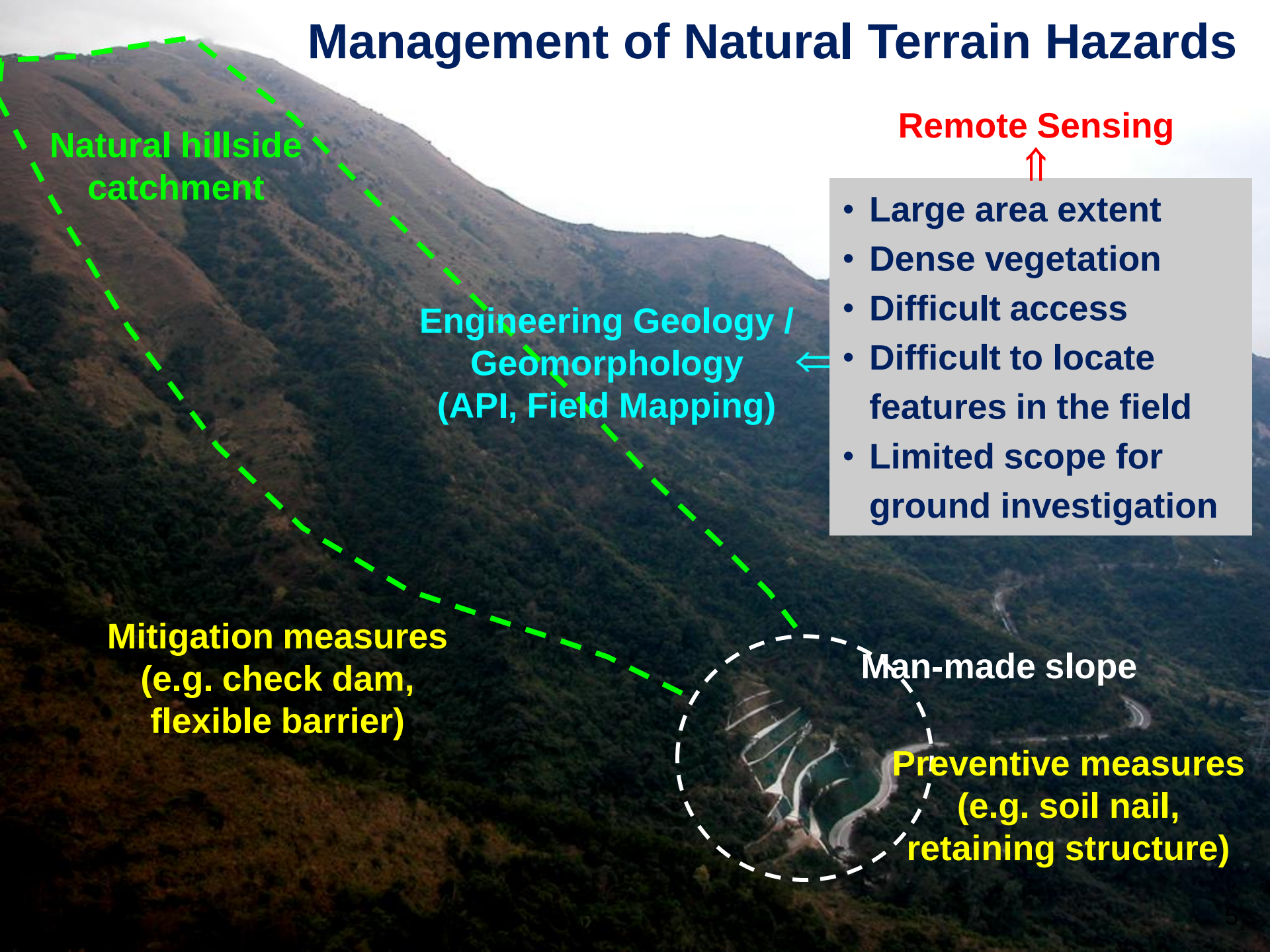


1924 Pokfulam Rock/Boulder Fall

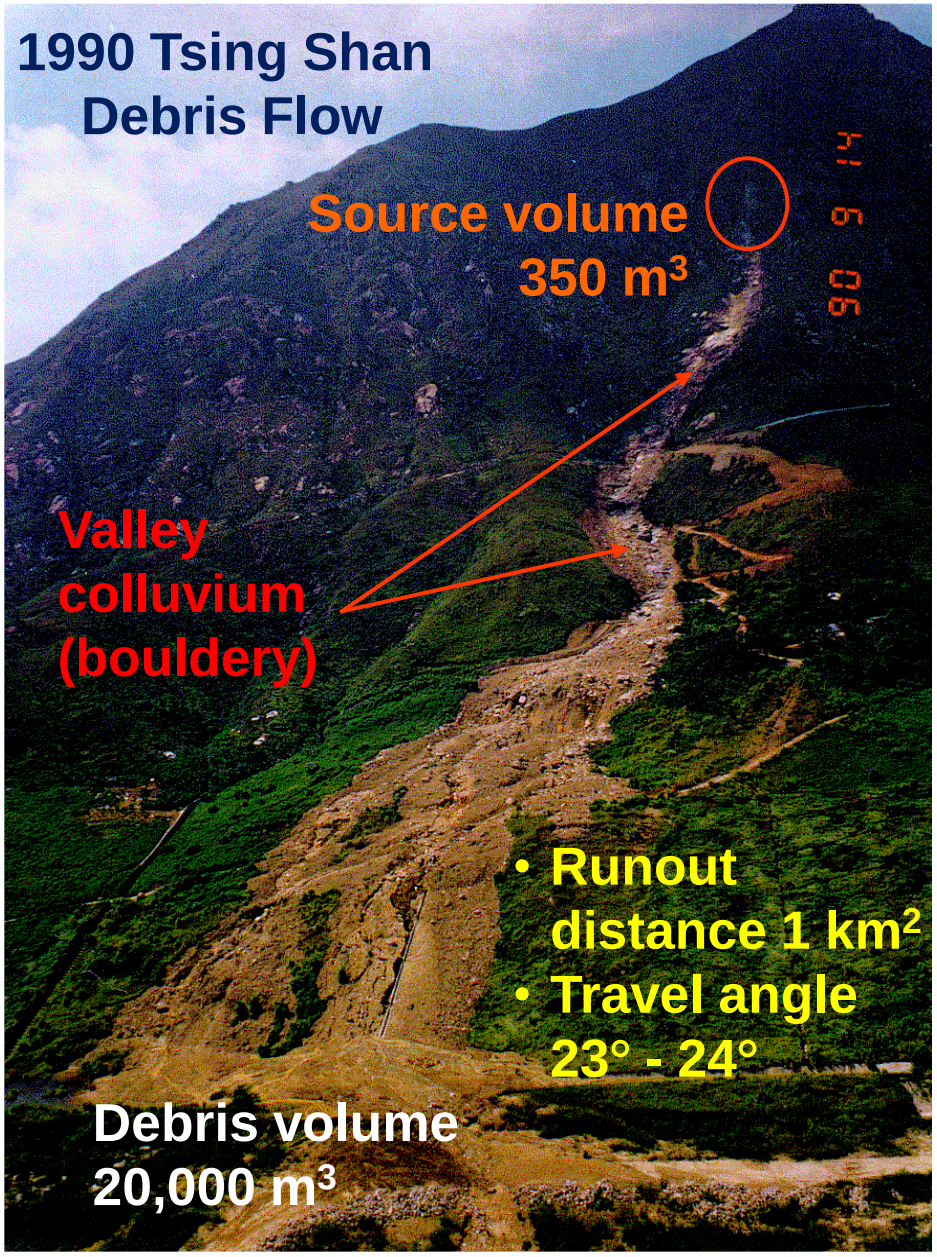


1990 Tsing Shan Debris Flow (20,000 m^3)

Management of Natural Terrain Hazards



(1) Early Phase of Landslide Studies



Ad hoc Studies – major landslide events

Nov 1993 on Lantau Island

- Over 800 landslides
- Shallow failures involving bouldery colluvium
- Terrain gradient 30˚ to 35˚
- Higher debris mobility for CDF than OHF

(2) Territory-wide Landslide Data Compilation & Analysis Phase

Scoping Programme –

Natural Terrain Landslide Study

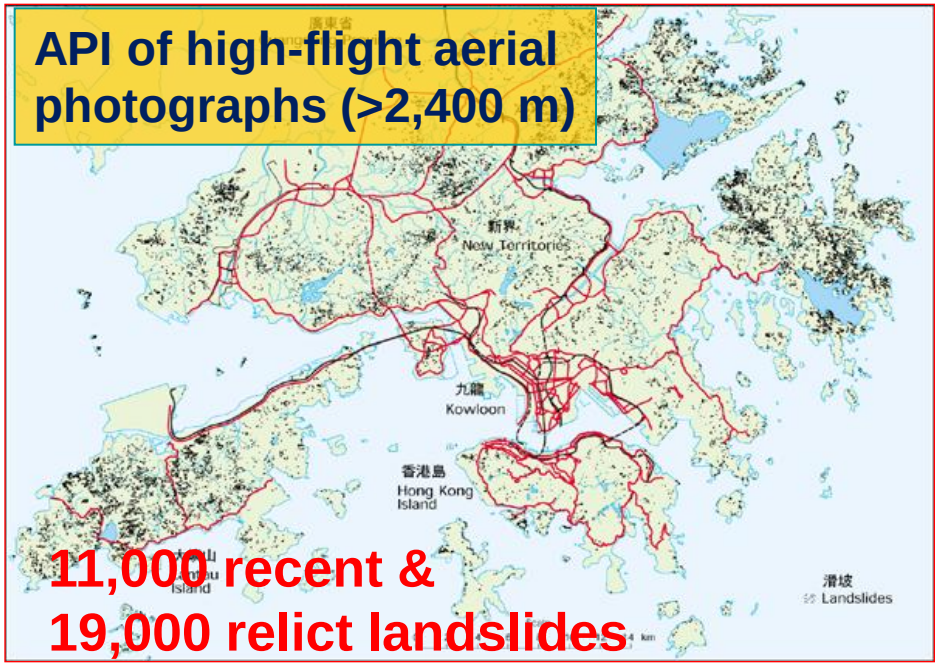
- Natural Terrain Landslide Inventory (1995)
- Large Landslide Dataset (1998)
- Natural Terrain Susceptibility Analysis (1998)

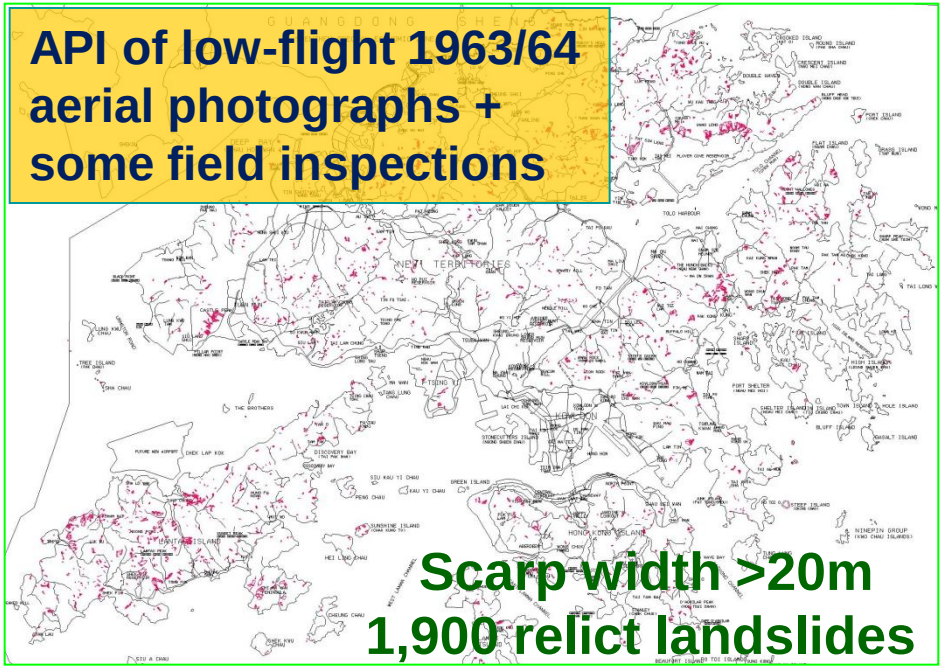
Systematic Landslide Investigation (since 1997) –

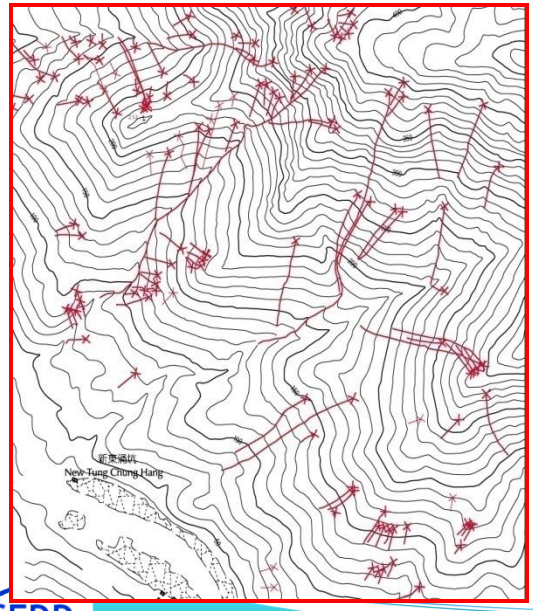
provides further insights into the causes, mechanisms and characteristics of notable natural terrain landslides

Natural Terrain Landslide Inventory

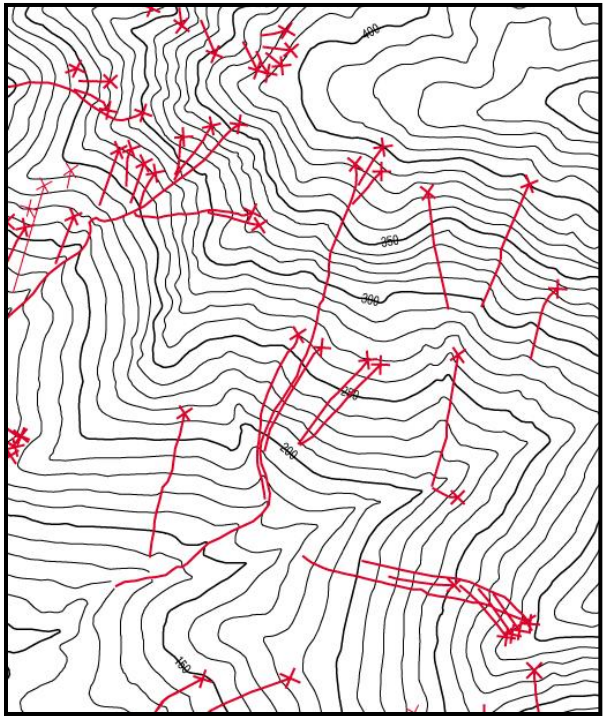
Large Landslide Dataset

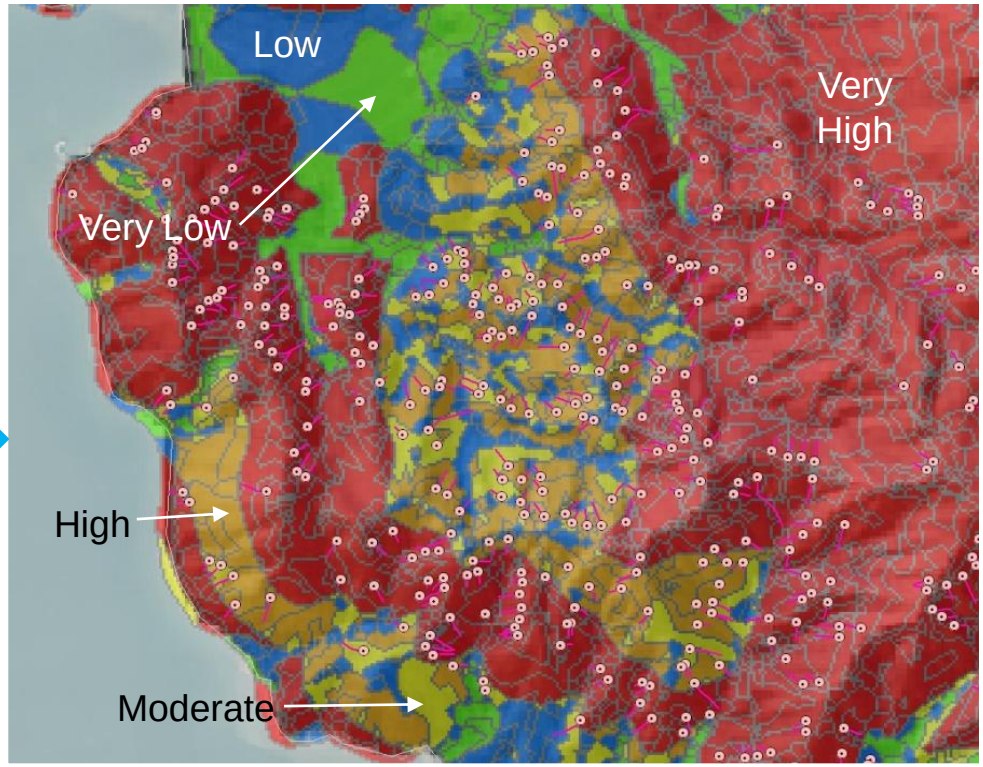


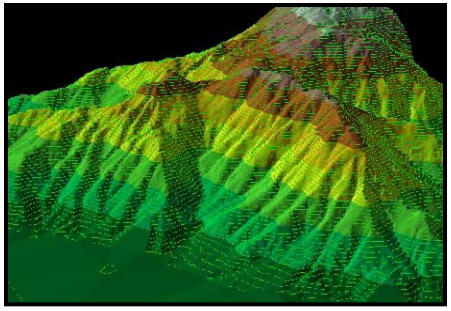




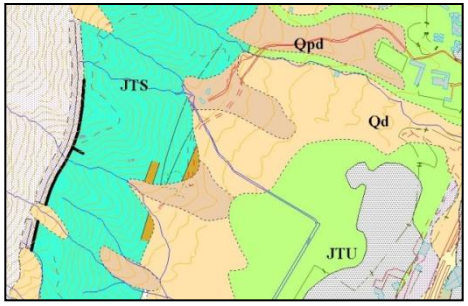
Natural Terrain Susceptibility Analyses
(Technical Note TN 1/98)







Gradient



Geology

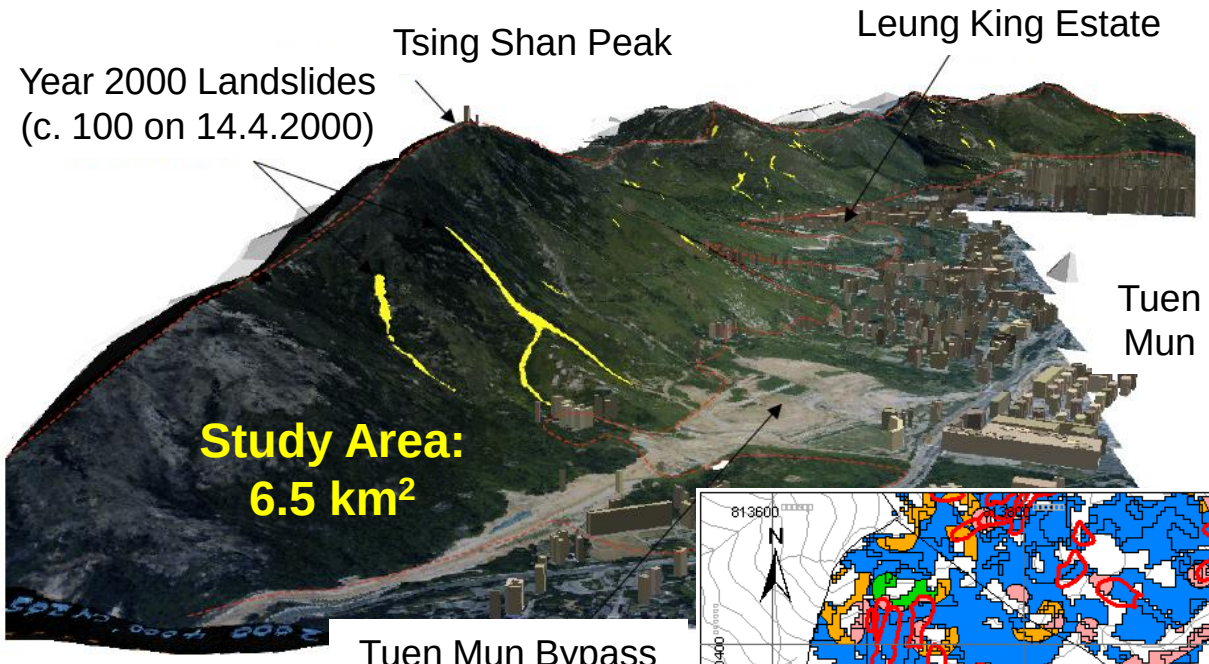
Very High	= landslide frequency >100 no./km^2
High	= landslide frequency 40 - 100 no./km^2
Moderate	= landslide frequency 20 - 40 no./km^2
Low	= landslide frequency 10 - 20 no./km^2
Very Low	= landslide frequency $\leq$ 10 no./km^2)

(3) Regional and Site Specific Studies Phase

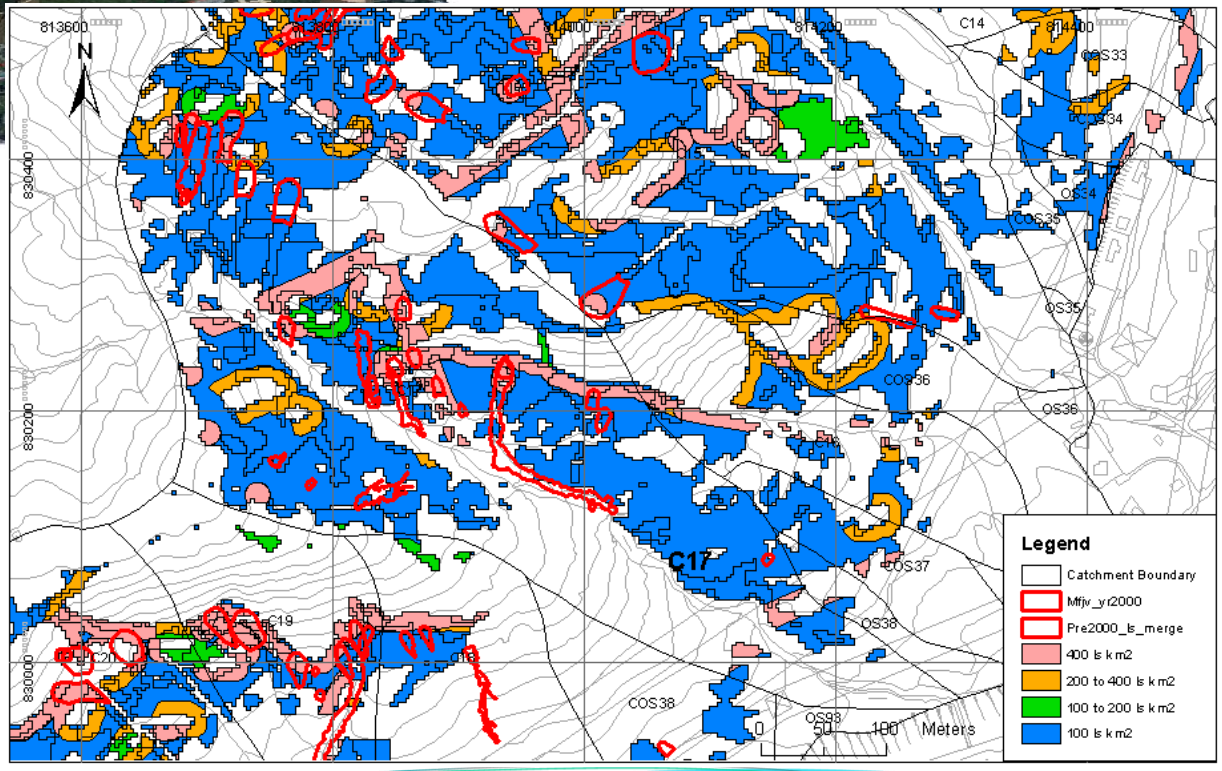
Development Programme –
Consolidation of Knowledge

- Regional Study – Tsing Shan Foothills (2000)
- Regional Hazard Review – North-eastern Hong Kong Island (2006)
- Guidelines for Natural Terrain Hazard Studies (2000, 2003)
- Guidelines for Geomorphological Mapping for Natural Terrain Hazard Studies (2004)
- Site Specific Studies (since 2001)

Regional Study – Tsing Shan Foothills



Main Focus:
key factors controlling NT landslides in Tsing Shan foothills

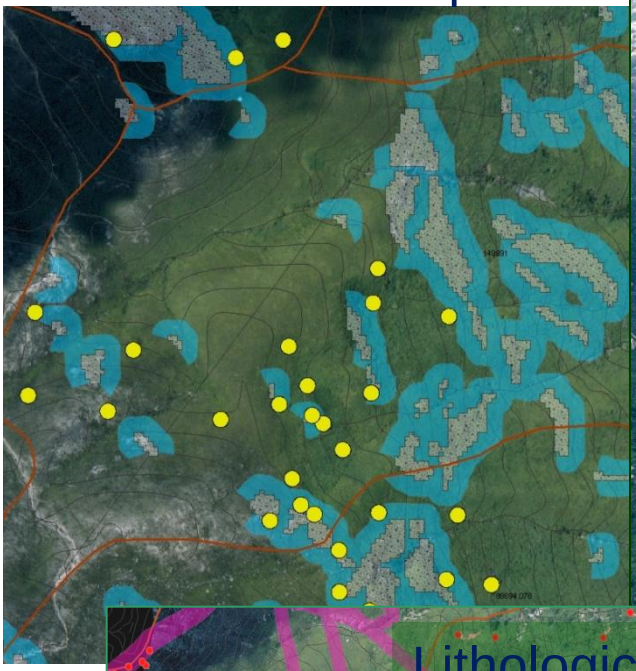


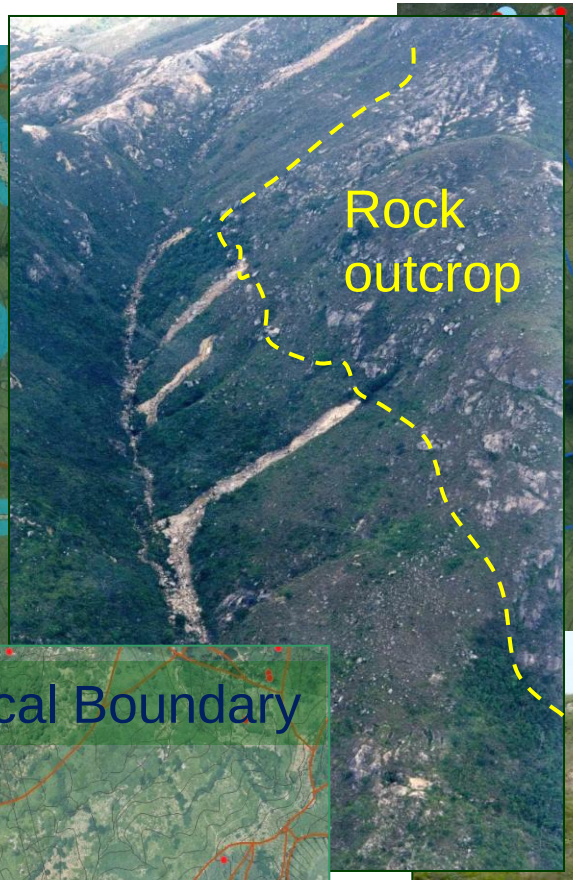
- Area-based susceptibility analysis 1;2,000 scale
- Landslides/km²: <100 to 400

MFJV, 2003

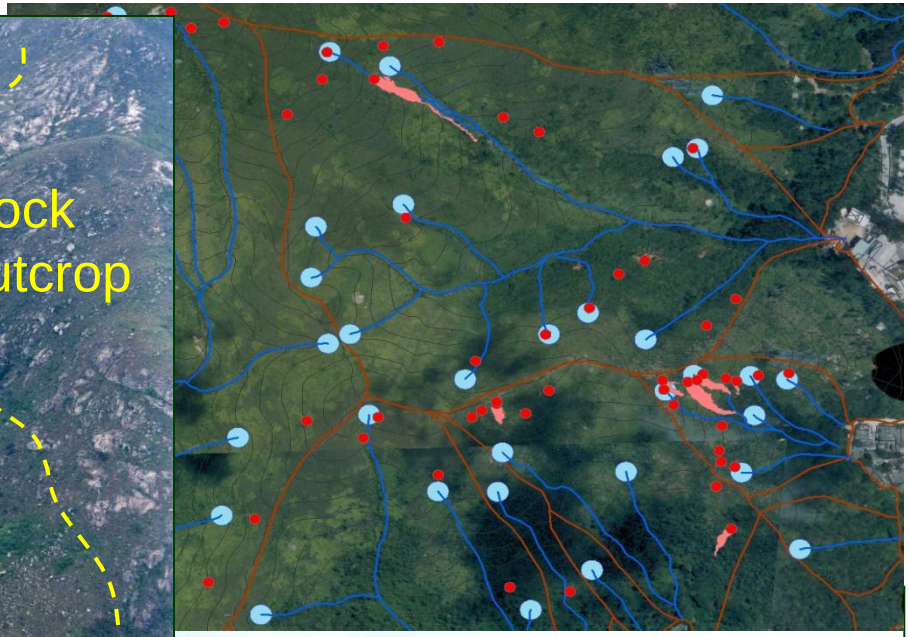
Key Controlling Factors for NT Landslides

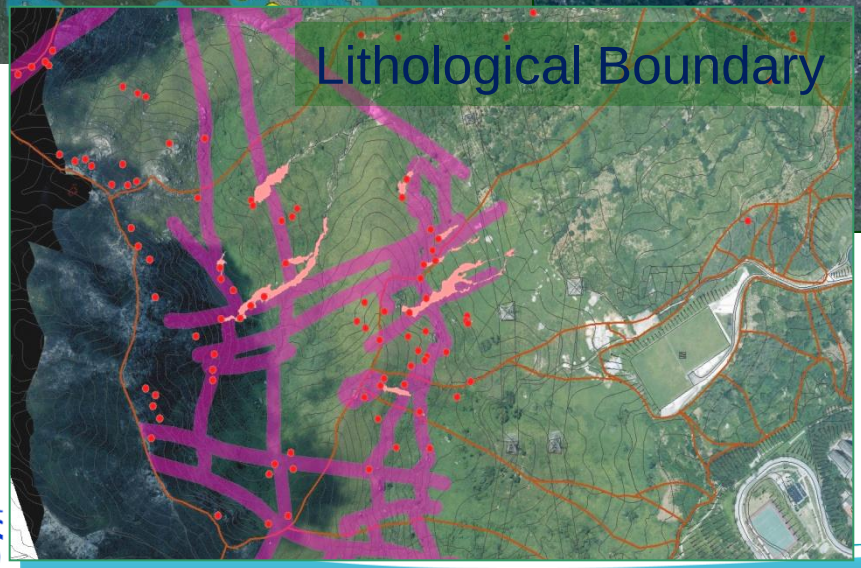
Regolith Downslope of Rock Outcrop



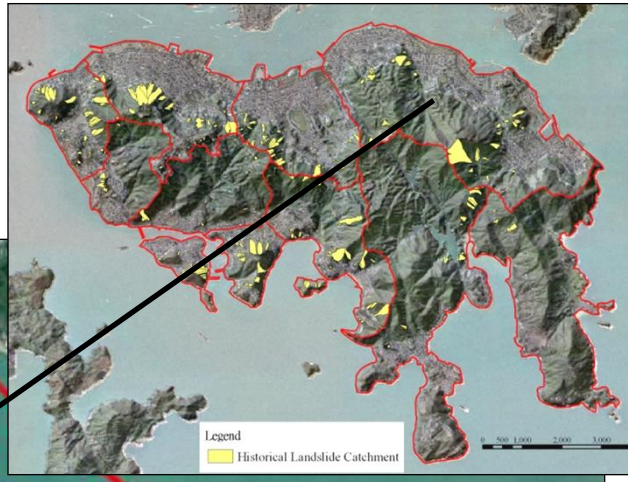


Head of Drainage Line





Regional Hazard Review – North-eastern Hong Kong Island



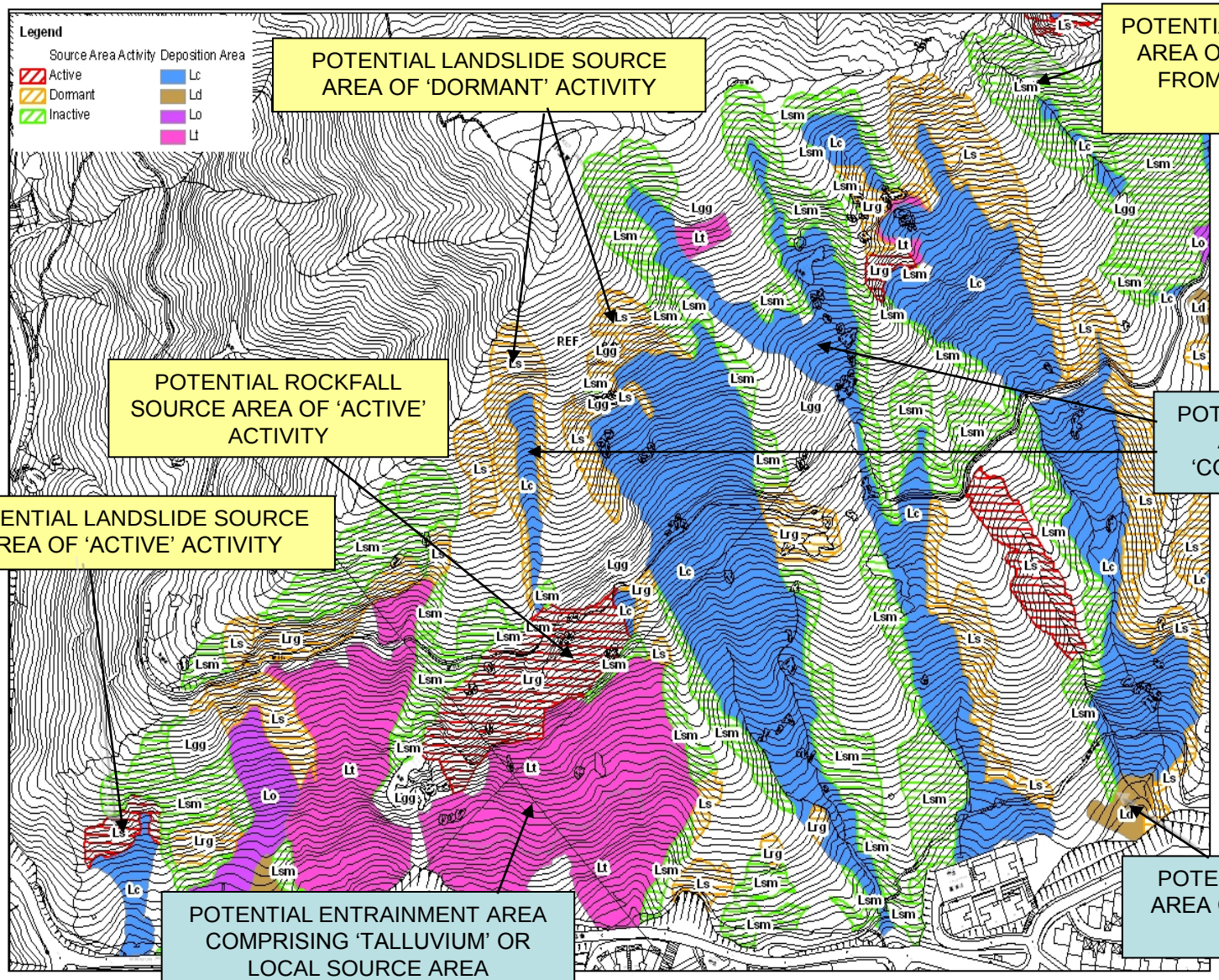
Study Area – 19 km²

Legend
Study Area
Regional Catchments
Trial Area

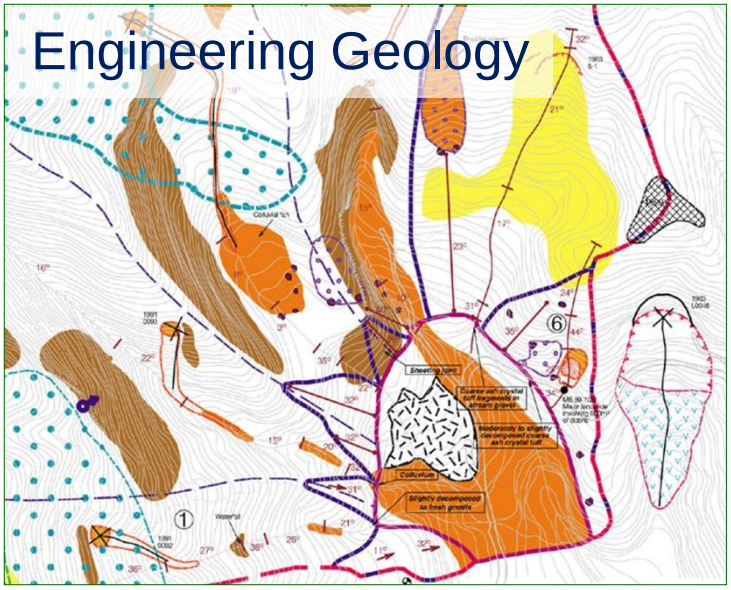
Main Focus: To develop a geomorphological based approach to supplement the landslide based approach

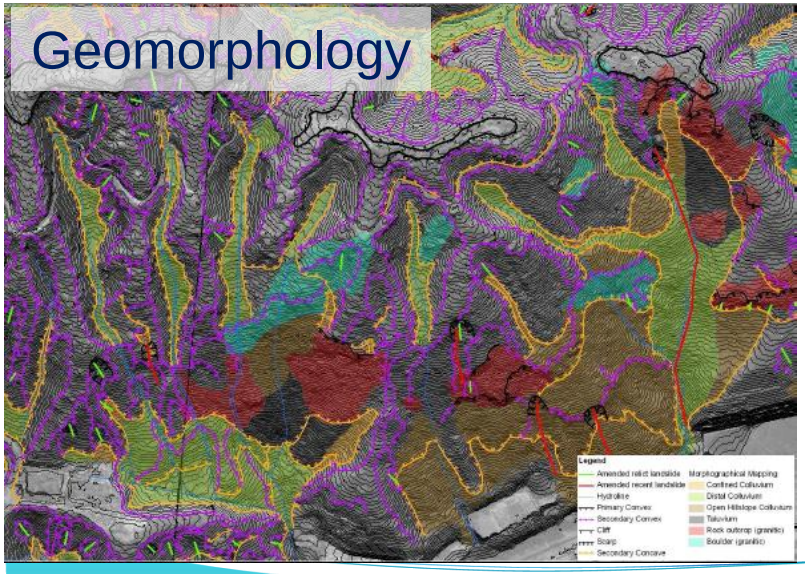
MFJV, 2003

Derivation of Hazards from Engineering Geological Maps



Guidelines for Natural Terrain Hazard Studies
(GEO Report No. 138; TGN 22)





Design Event Approach

Consequence Class

Proximity	Facility Group (GEO Report 68)	
	1 & 2	3
Very Close (e.g. AE ≥ 30°)	I	II
Moderately Close (e.g. AE ≥ 25°)	II	III
Far (e.g. AE < 25°)	III	IV

Design Requirements

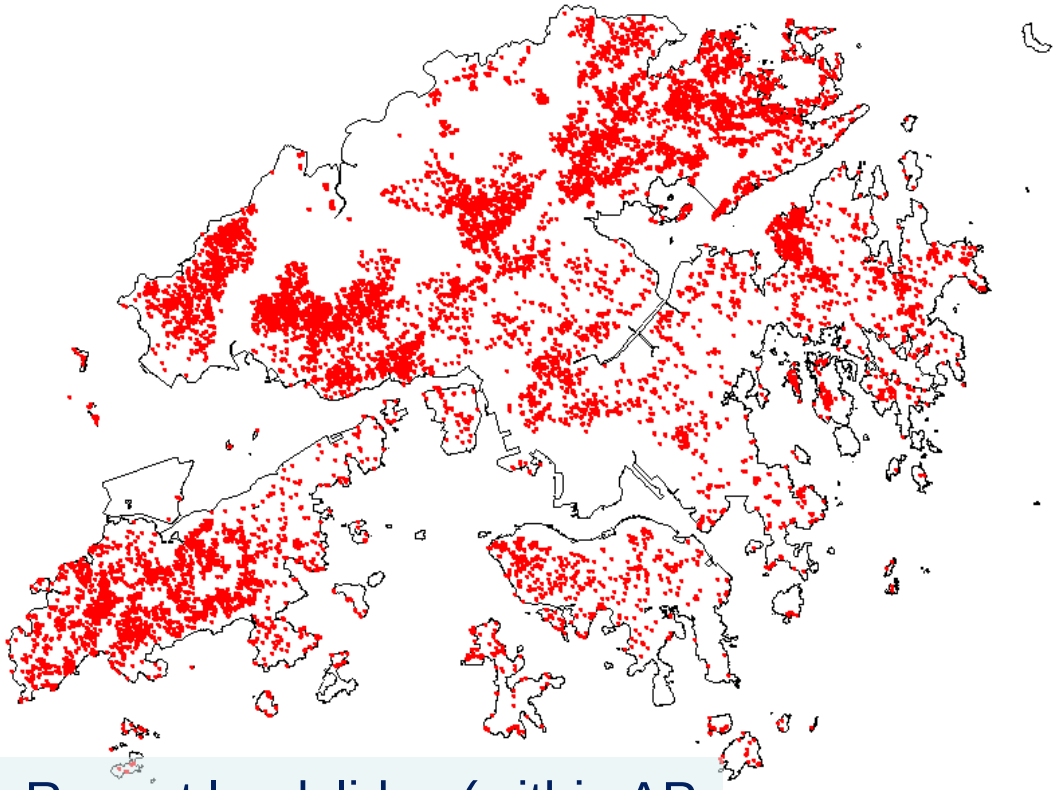
Susceptibility	Consequence Class			
	I	II	III	IV
extremely susceptible	Worst Credible Event (notional return period 1:1,000)			
highly susceptible			Conservative Event	
moderately susceptible		(notional return period 1:100)		
low susceptibility	Further study not required			

(4) NT Risk Management Phase
(Landslip Prevention and Mitigation Programme, LPMitP)

Systematic Studies and Mitigation Programme –

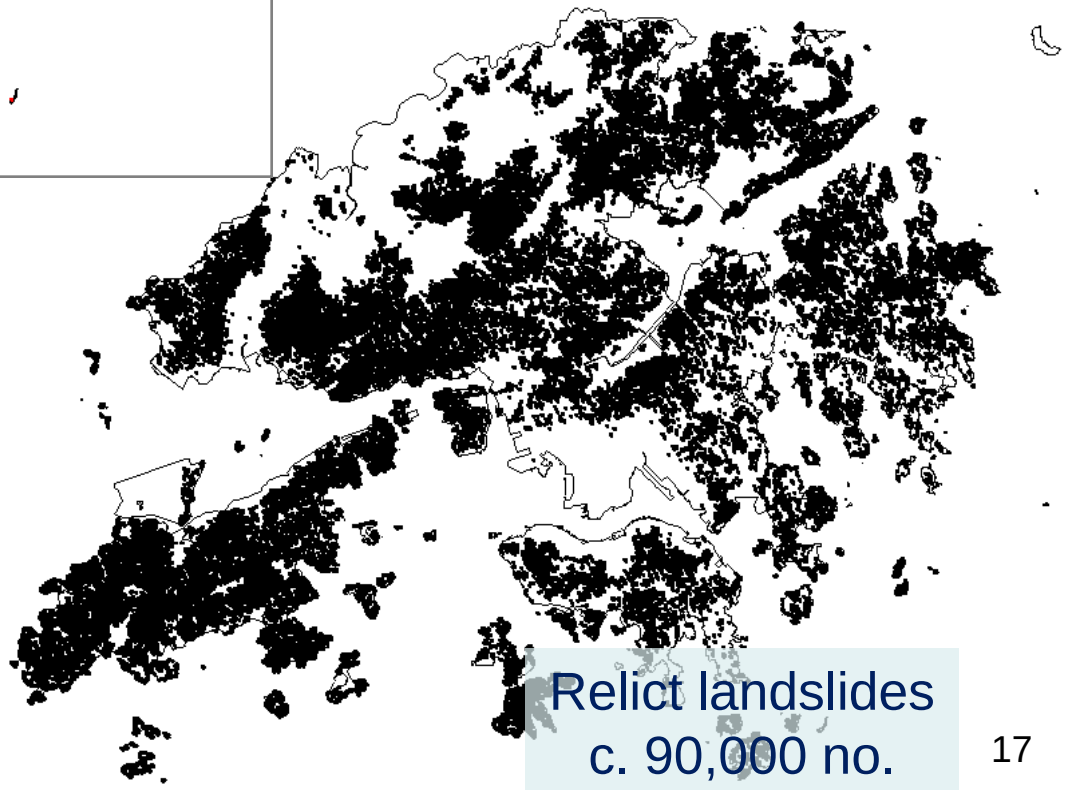
50% of the resources under LPMitP (since 2010) for natural terrain vs. 5% on average pre-2010

- **Enhanced Natural Terrain Landslide Inventory (2005)**
- **Inventory of Historical Landslide Catchments (2007)**
- **Area-based Approach to Natural Terrain Hazard Studies (since 2008)**
- **Regional Hazard Assessment – West Lantau Island (Out-of-turn LPMit Action, 2009)**



Recent landslides (within AP coverage;<100 years)
c. 19,000 no.

In 2005, commenced **enhancement of the NTLI (ENTLI)** - using high & low-flight AP (<2,400 m) with improved resolution and temporal coverage

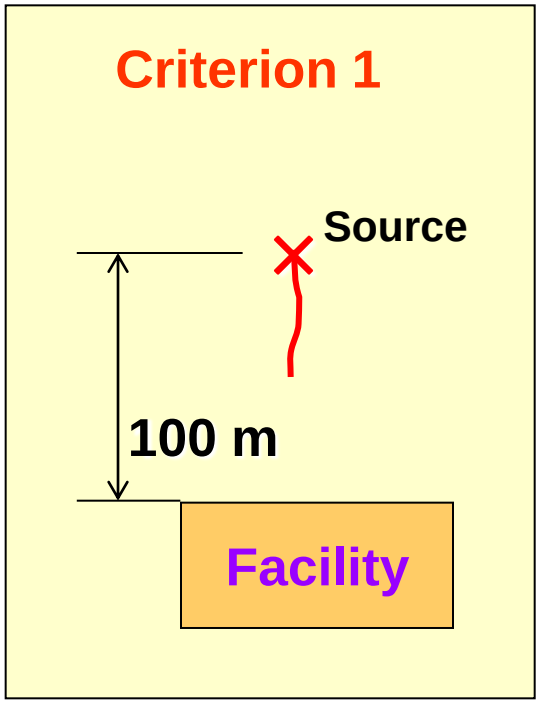


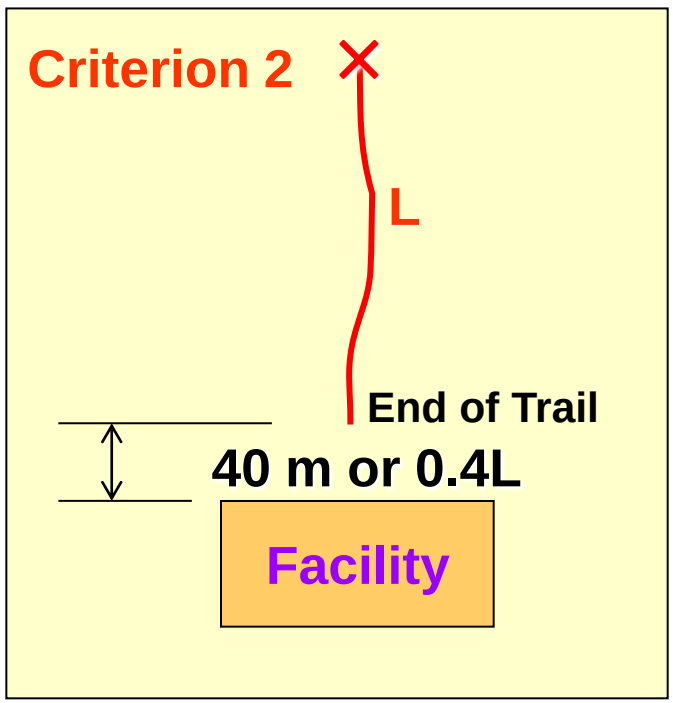
Relict landslides
c. 90,000 no.

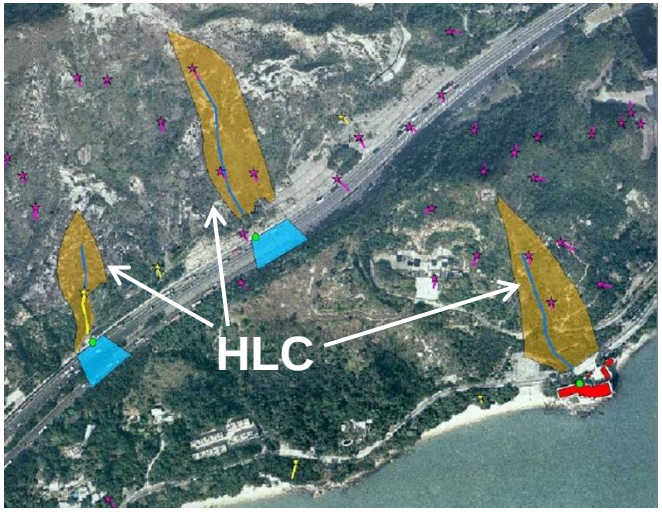
Enhanced Natural Terrain Landslide Inventory (ENTLI) is updated about every 3 years

Inventory of Historical Landslide Catchments (HLC)

– catchments with ENTLI features that occurred close to important existing facilities







A landslide crown is within 100 m of the upslope boundary of an important facility

A landslide toe is within 40 m, or 40% of the trail length, whichever is greater, of the upslope boundary of an important facility

Important existing facilities

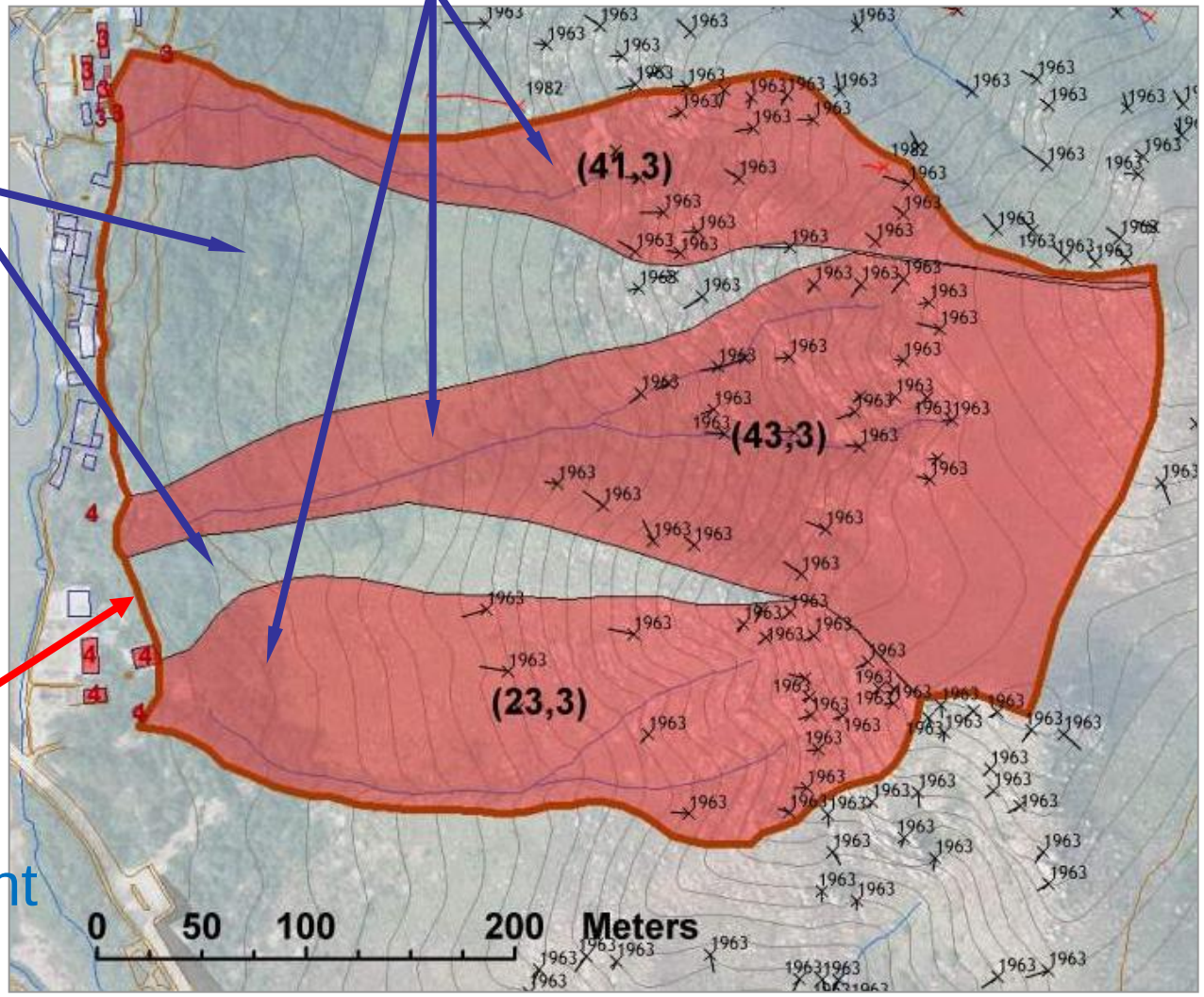
- Buildings
- Major transport corridors

Area-based Approach to NTHS

Historical Landslide Catchment (HLC)

Related Catchment (RC) – hillside catchment of similar geological & geomorphological settings to HLC

Study Area – A group of HLC (and RC) affecting an individual unit of existing development



Village House Evacuations

Wang Hang Village

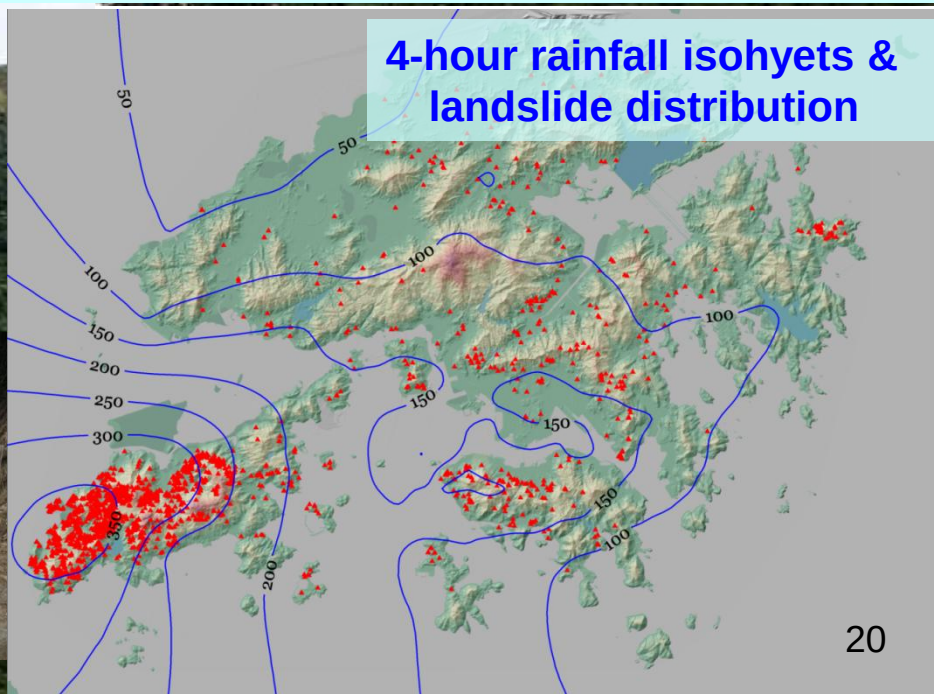
San Tsuen

Nam Chung Tsuen

7.6.2008 : Lantau Island c. 2600 landslides

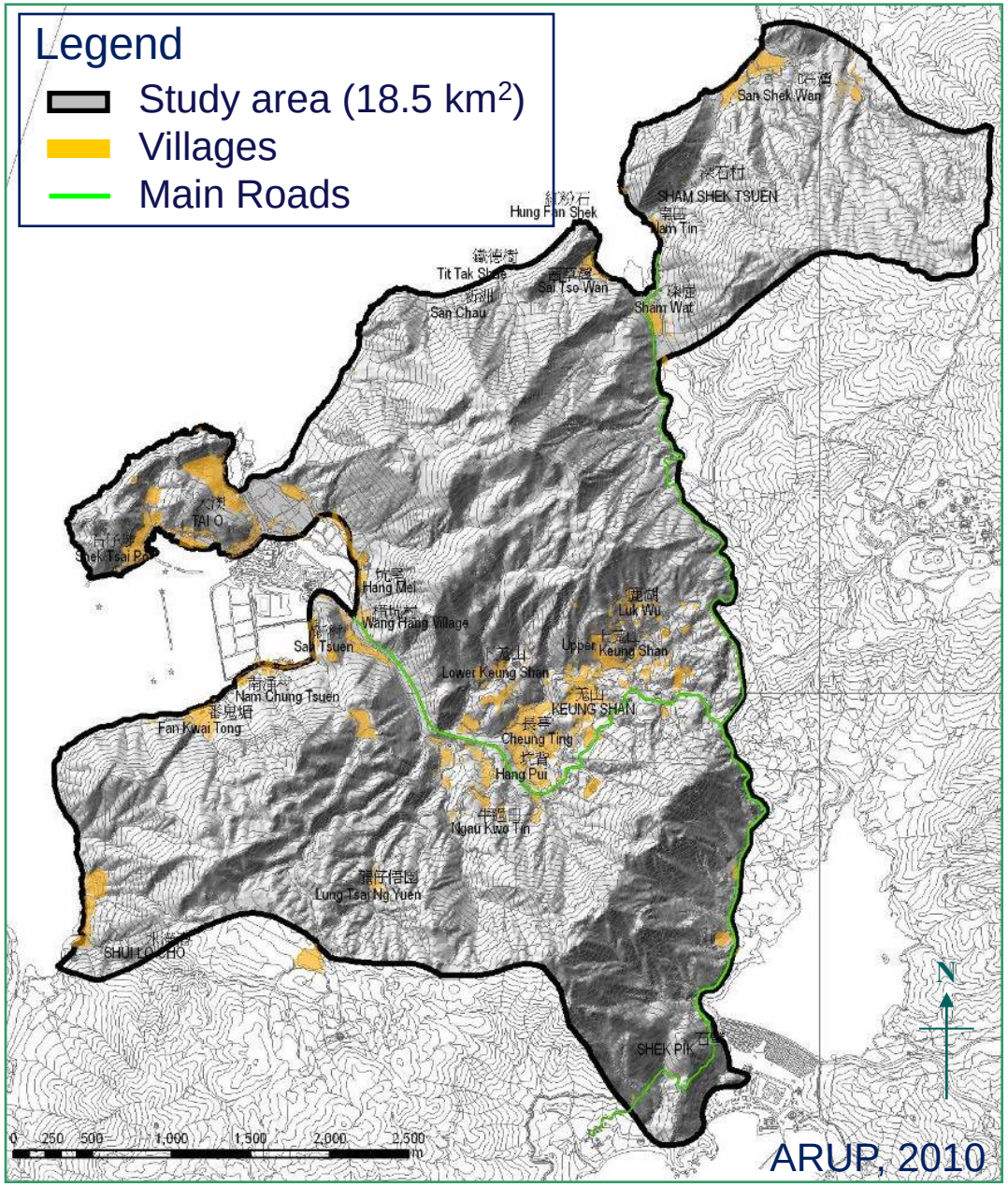
Road Closures

Keung Shan Road



Regional Hazard Assessment
(West Lantau Island)

- Develop a methodology for prioritisation and selection of hillsides requiring hazard mitigation works
- Ranking of hillside catchments and selection of catchments for follow up mitigation works



(5) Technical Development

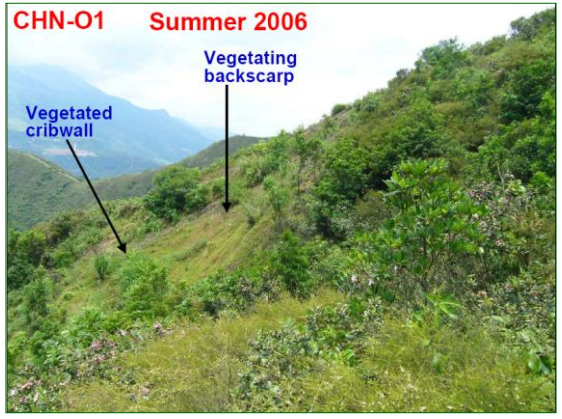
In support of natural terrain studies

- Soil Bioengineering
- Geotechnical Instrumentation & Monitoring
- Age Determination of NT Landslides
- Remote Sensing Technology

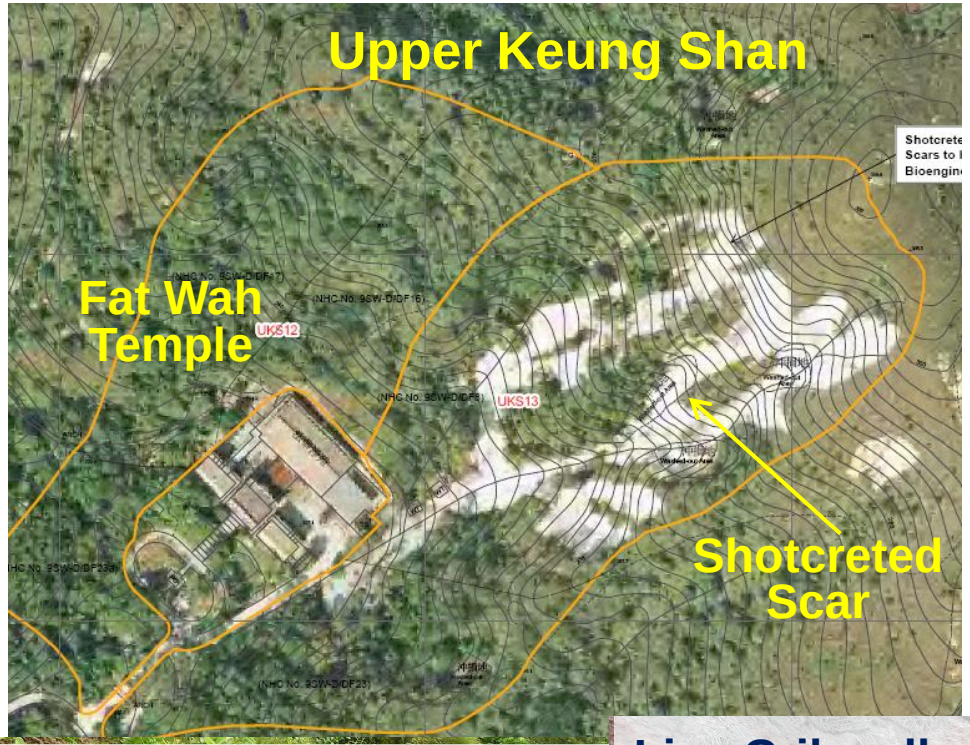
Soil Bioengineering

- Live cut branches &/or rooted woody plant materials
- Native vegetation around installation areas
- Specifically select & arrange to assist in controlling: shallow mass movement, water collection & transport, and surface erosion

Guidelines for Soil Bioengineering Applications on Natural Terrain Landslide Scars (GEO Report No. 227)

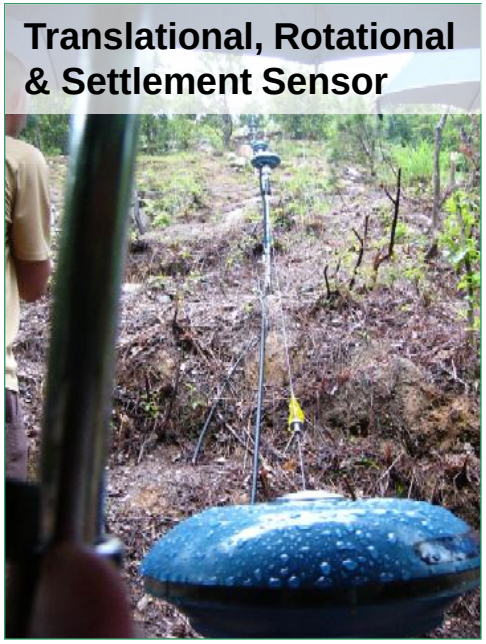


Rehabilitation of Shotcreted Landslide Scars
(to be implemented in 2014/15)



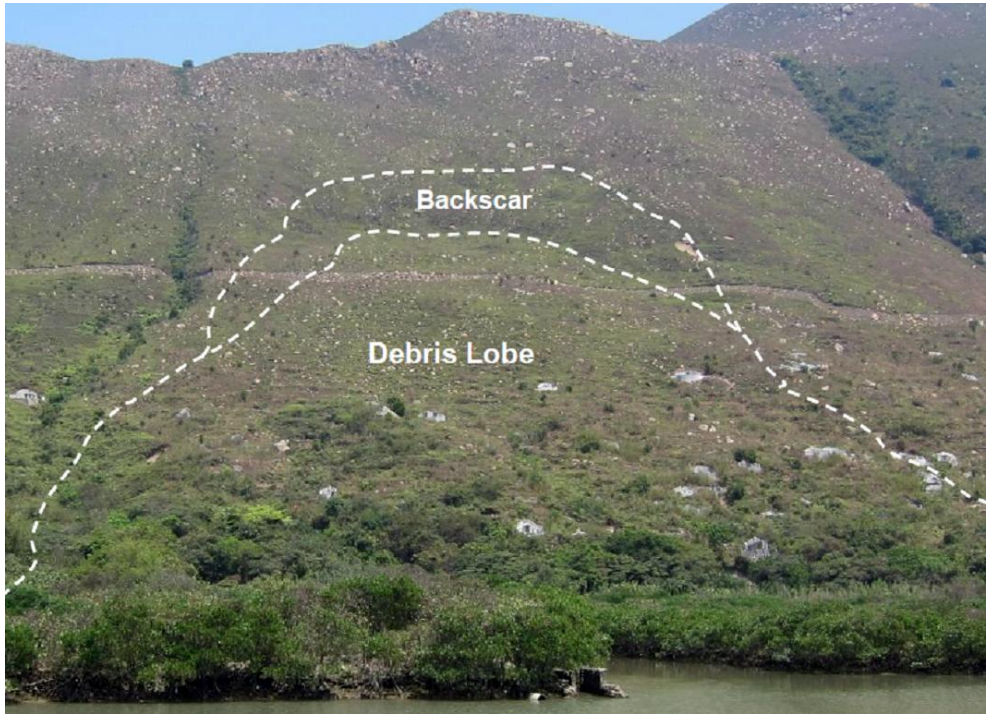
Geotechnical Instrumentation & Monitoring

– for improved understanding of ground & groundwater behaviour



ARUP, 2008 – 2011

Geotechnical Monitoring of Distressed Hillsides
(to be installed in 2014/15)



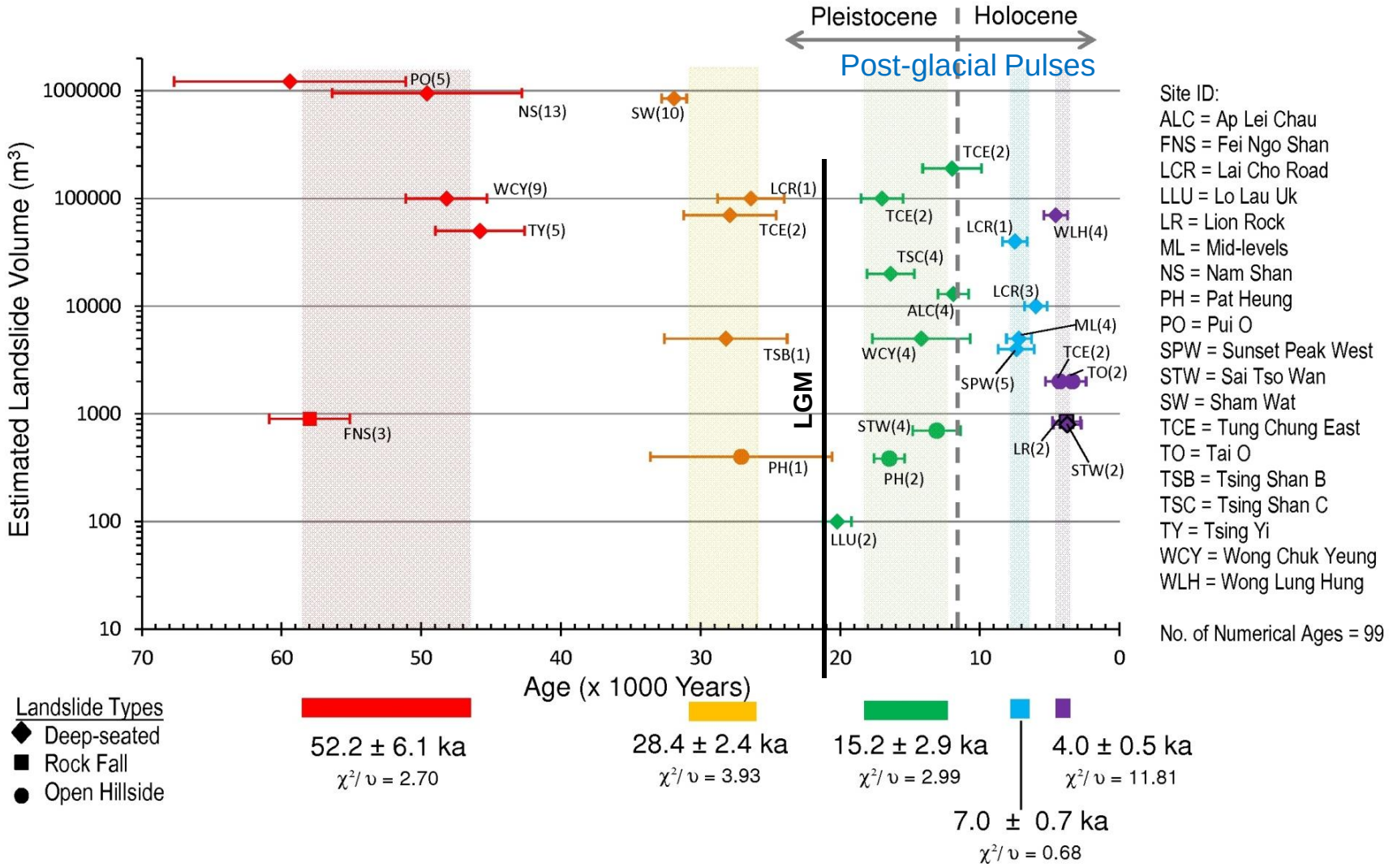
Landslide Complex
at Tai O Cemetery

Keung Shan Road

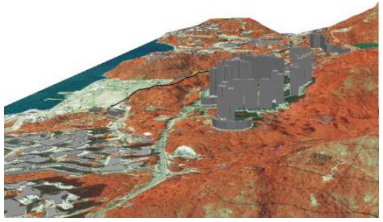
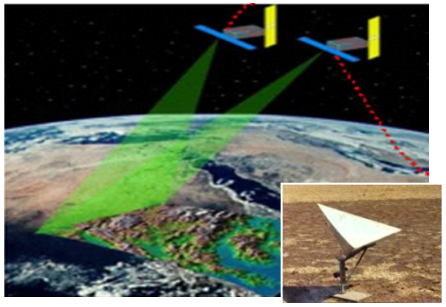
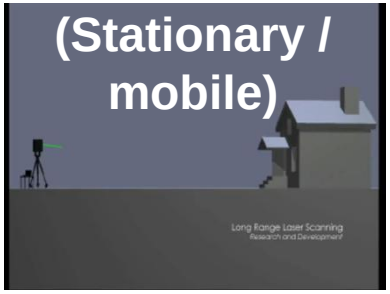
Age Determination of NT Landslides

- Direct dating of relict NT landslides (GEO Report No. 170):
  - Radiocarbon (^{14}C) – c. 200 to c. 50,000 years BP
  - Optically Stimulated Luminescence (OSL) – c. 100s to 100s of thousands years BP
  - Cosmogenic nuclide (Be^{10}, Al^{26}) – c. 2,000 to c. 1 million years BP
- Quantitative framework for improvements to design events – relevance of large relict landslides to present day climatic conditions
- Relationships between climate change and large landslides

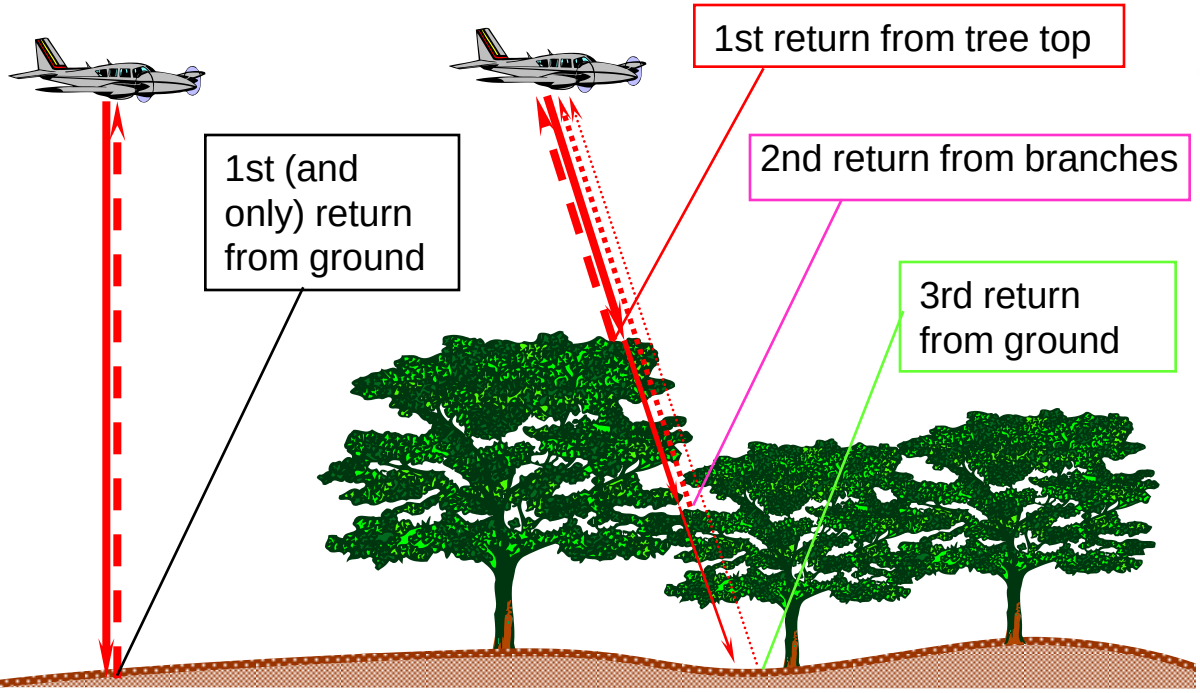
Landslide Age/Volume Relationships of Large Landslides and Rockfalls (OSL & Cosmogenic Nuclide methods)

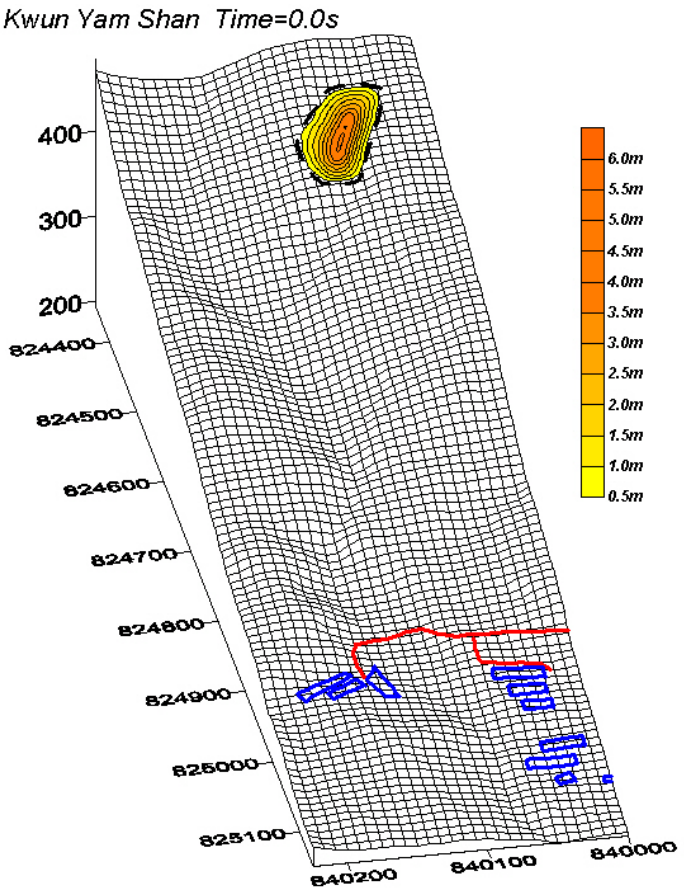


Remote Sensing Technology for NT Studies

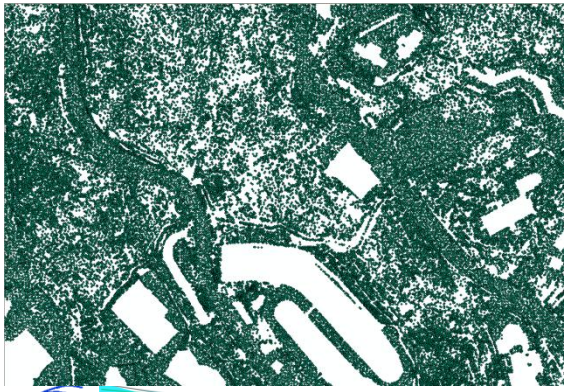
Position / Data (Status)	Terrestrial	Air-borne	Space-borne (satellite)
Image (Photogrammetry) (Routine)			
Radar (InSAR) (Development)			
Laser (LiDAR) (Mainstream)			

Digital Technology - Airborne LiDAR survey
(Virtual Deforestation)

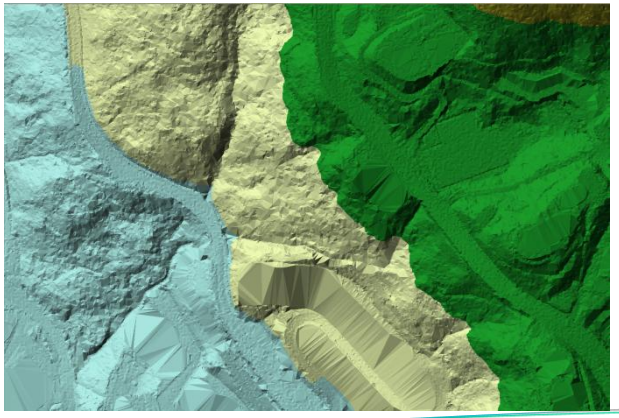




LiDAR point cloud



3D terrain (feature mapping)



Digital Elevation Model – Debris Mobility Modeling

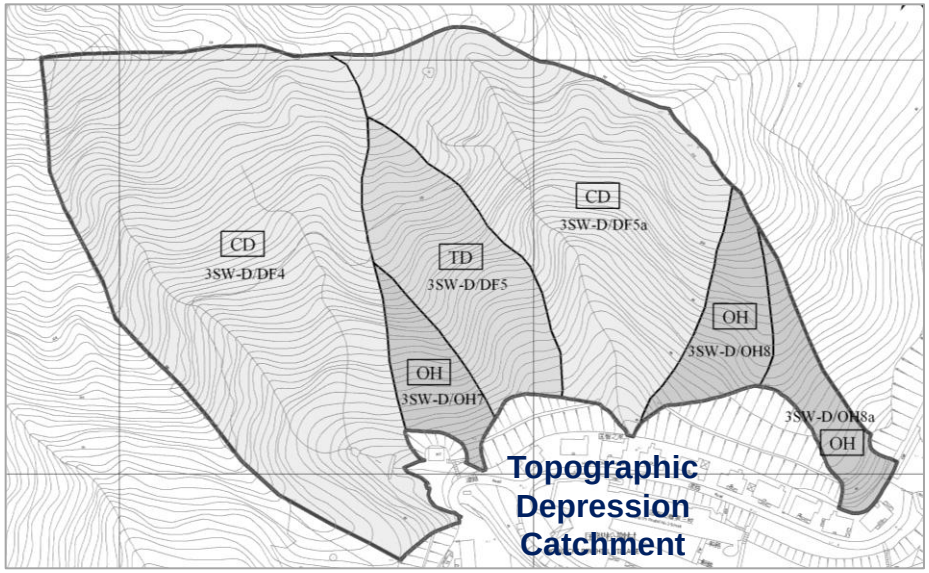
(6) Refinement to Current Practice

Enhance current practice and address lessons learnt

- Enhanced Approach for Dealing with NTHS
- HLC Selection Criteria
- Potentially Problematic Hillside Pockets
- Sizeable Catchments with Major Drainage Lines

Enhanced Approach for NTHS
(TGN 36, TGN 37 & TGN 38)

- Introduce Topographic Depression (TD) Catchments
- Application of R-t-K-H principle to individual catchments
- Streamline the Design Event Approach (replace 'Worst Credible Event' and 'Conservative Event' by a 'Design Event')



- Clarify the intended level of hazard mitigation
- Adopt a new set of rheological parameters for analytical design of mitigation measures for TD Catchments
- Enhance and extend the application of prescriptive barriers to mitigation of open hillslope landslides affecting buildings

Design Event Approach Framework (TGN 36)

Facility affected	Level of Hazard Mitigation Required	
	Hazards from CD/TD catchments	Hazards from OH catchments
Group 1 & 2 (high consequence)	2	1
Group 3 (moderate consequence)	*2*	1

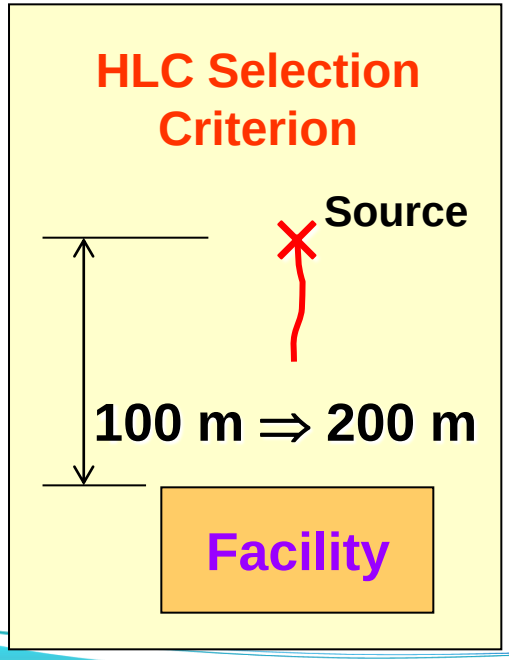
Design Requirements

Level of Hazard Mitigation	Description	Design Requirements
1	Primary Protection (based on empirical provisions)	For OH Catchments: Empirical design based on use of prescriptive barriers where the qualifying criteria are satisfied (TGN 37) (Note: if not, designed by analysis)
2	Enhanced Protection (enhanced measures designed by analysis)	Analytical design of mitigation measures to cater for Design Event

HLC Selection Criteria

Runout distance of debris flows that occurred in June 2008 vs. those recorded in the ENTLI

Runout distance of debris flow	No. of cases recorded in the ENTLI (up to 2006)	No. of cases identified in Lantau Island (June 2008)
Runout ≥200 m	162	105
Runout >200-500 m	149	87
Runout >500-1000 m	12	14
Runout > 1000 m	1	4



- For DF catchments, extend the plan distance between the landslide crown and the upslope boundary of the facility from 100 m to 200 m

Potentially Problematic Hillside Pockets

small tracts of hillsides flanking developed areas

Sizeable Catchments with Major Drainage Lines

potential locations of low-frequency, large-magnitude debris flows affecting high consequence facilities

– both types of hillside may deserve LPMit actions

Concluding Remarks

- Natural terrain landslides occur as part of the natural landform evolution ⇒ involves considerable uncertainties
- Our technical knowledge and capability in tackling natural terrain hazards are still fairly limited
- Some circumstances, such as climate change, are not entirely within our comprehension or control
- There will be a need to review and enhance the current practice as knowledge and experience develops