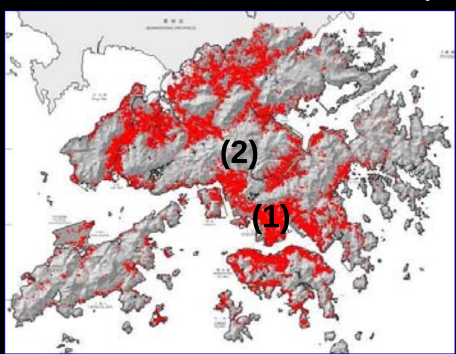
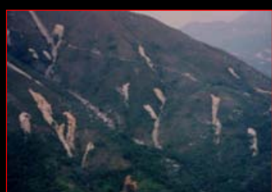
Natural Hillside in Hong Kong

Plan area ~690 km^2 (total land area 1100 km^2)



(1) Man-made slope failures



(2) Natural terrain landslides

Policy Agenda of Chief Executive's Policy Address

2005 - 2006

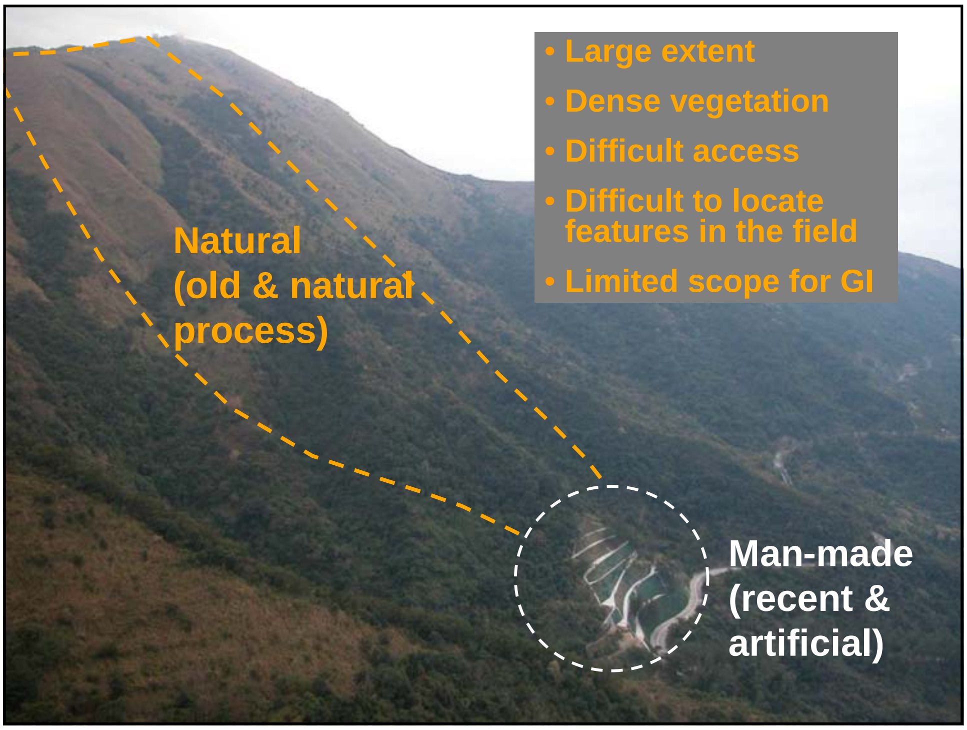
- Reviewing the Landslip Preventive Measures Programme….., managing the risk posed by natural terrain landslides on the dense population in Hong Kong, and according priority to dealing with natural slopes which are susceptible to potential landslip.

2006 - 2007

- Reviewing the Landslip Preventive Measures Programme….., as well as developing a risk-based priority ranking system for dealing with natural terrain susceptible to potential landslips,...

2007 - 2008

- To devise a strategy to deal with natural hillside catchments known to be susceptible to potential landslides and which are close to buildings and public facilities, based on a risk-based ranking system to set priority.



Topograhical Setting

- Steep topography in close proximity to high value / densely populated developments
- Natural terrain landslide poses a special concern

Geomorphological Setting

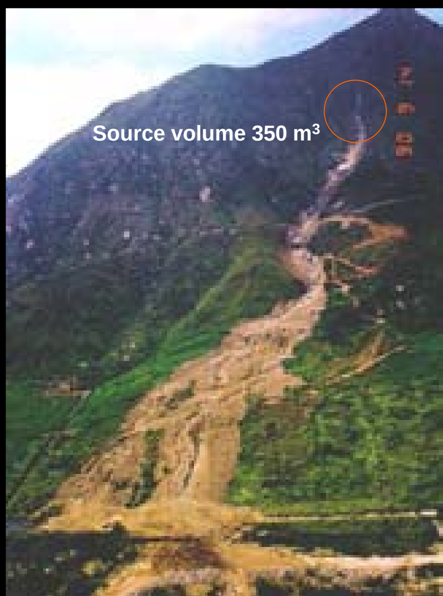
- Relatively mature landscape – rugged uplands & steep slopes
- 53% of land area <100 m; only 12% >300 m; highest peak 957 m
- No major rivers; low drainage order; most streams are ephemeral with short, steep courses

Configuration of present day landscape – hillside not susceptible to massive failures

Large-magnitude Events in Hong Kong

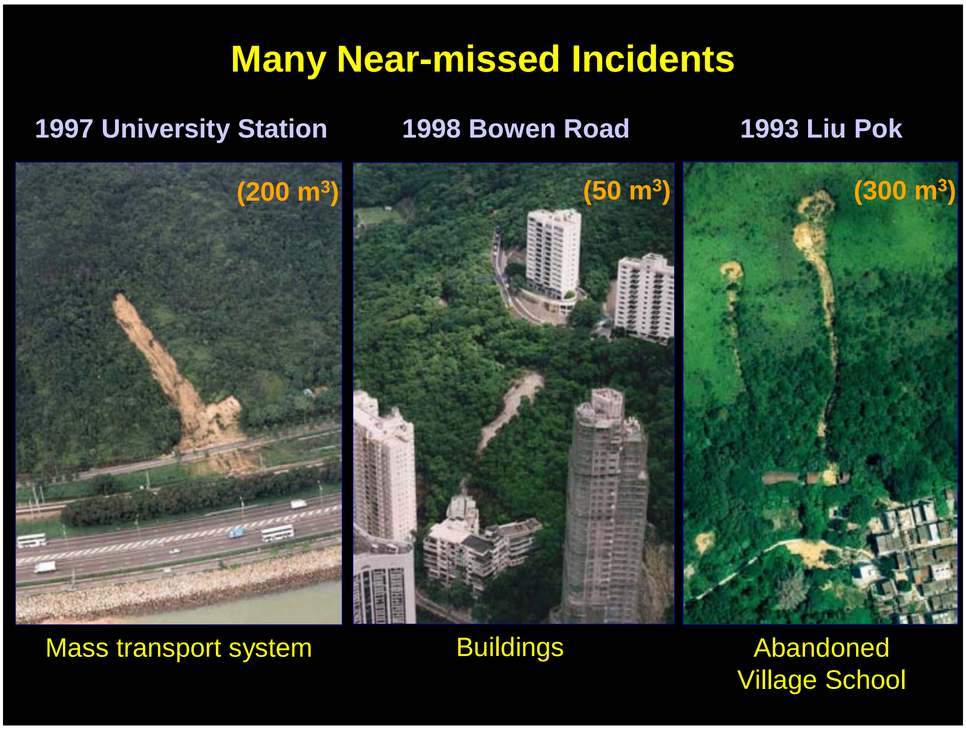
1995 Shum Wan Landslide (26,000 m^3)

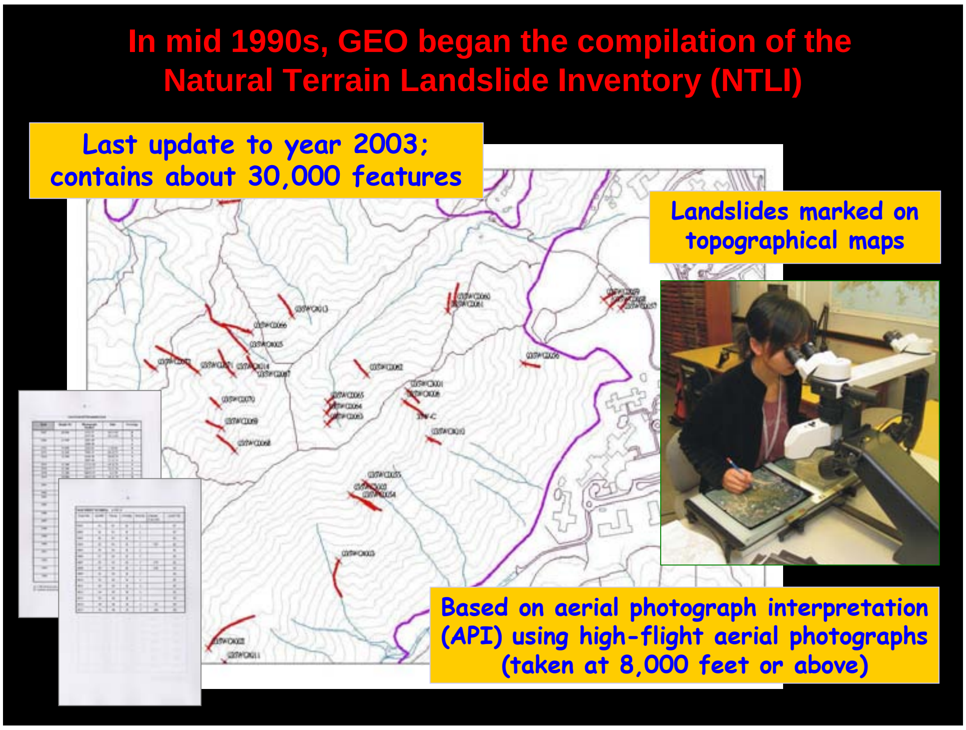
1924 Pokfulam Rock/Boulder Fall

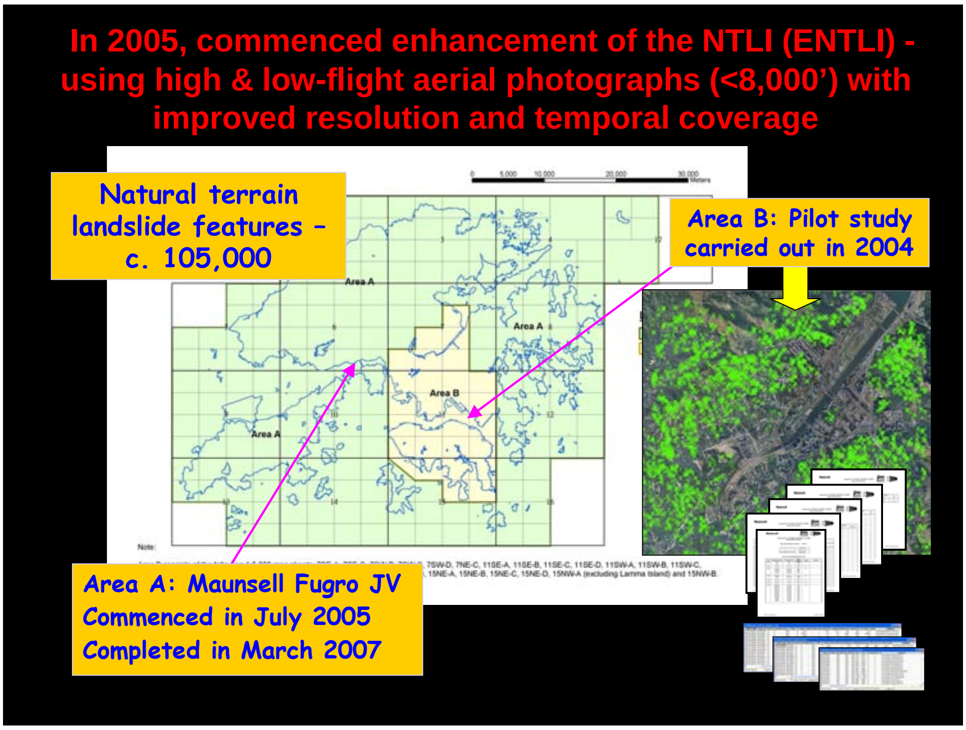


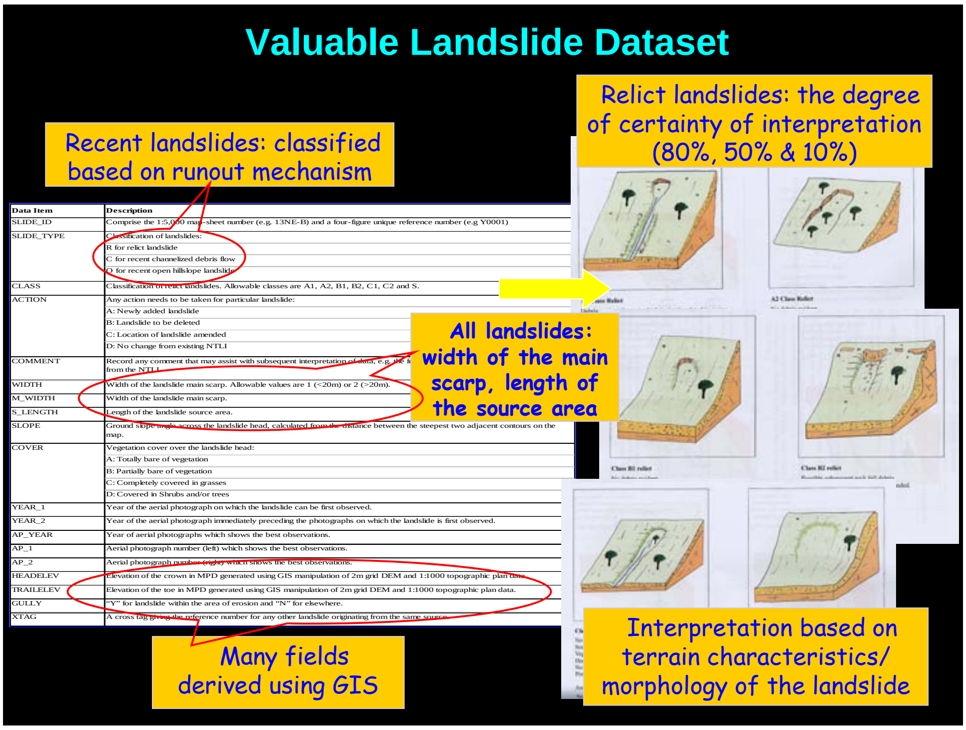
1990 Tsing Shan Debris Flow (20,000 m^3)


1999 Sham Tseng San Tsuen (600 m³)
1 fatality &
13 injuries

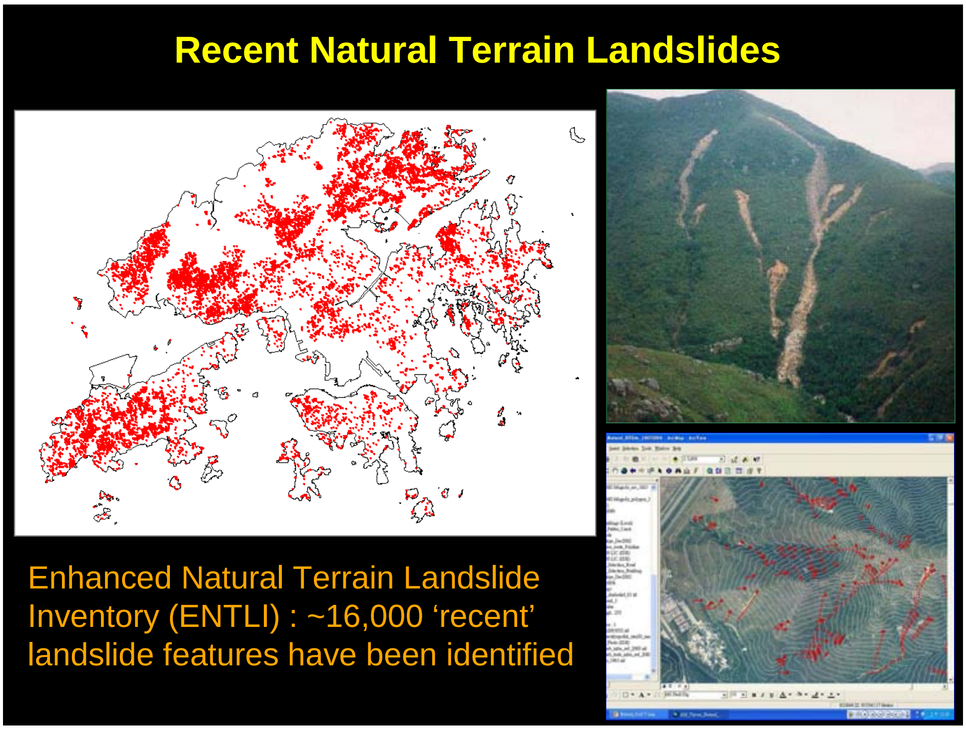

Many Near-missed Incidents
1997 University Station
1998 Bowen Road
1993 Liu Pok
(200 m³)
(50 m³)
(300 m³)
Mass transport system
Buildings
Abandoned
Village School

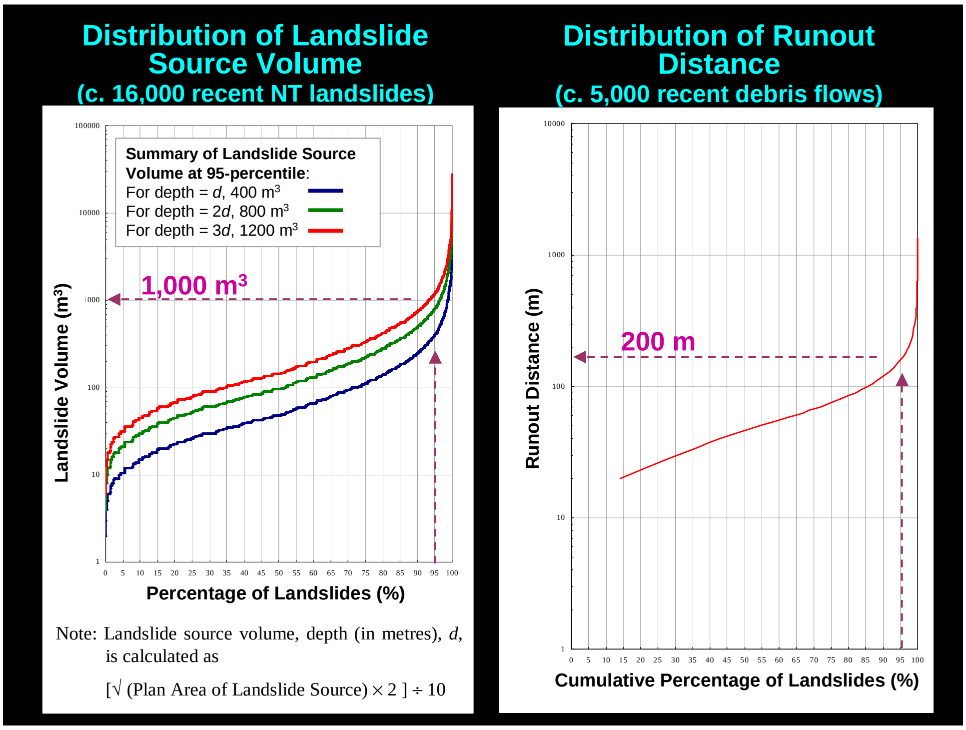

In mid 1990s, GEO began the compilation of the Natural Terrain Landslide Inventory (NTLI)
Last update to year 2003; contains about 30,000 features
Landslides marked on topographical maps
Based on aerial photograph interpretation (API) using high-flight aerial photographs (taken at 8,000 feet or above)


In 2005, commenced enhancement of the NTLI (ENTLI) - using high & low-flight aerial photographs (<8,000') with improved resolution and temporal coverage
Natural terrain landslide features – c. 105,000
Area B: Pilot study carried out in 2004
Area A
Area B
Area A: Maunsell Fugro JV
Commenced in July 2005
Completed in March 2007

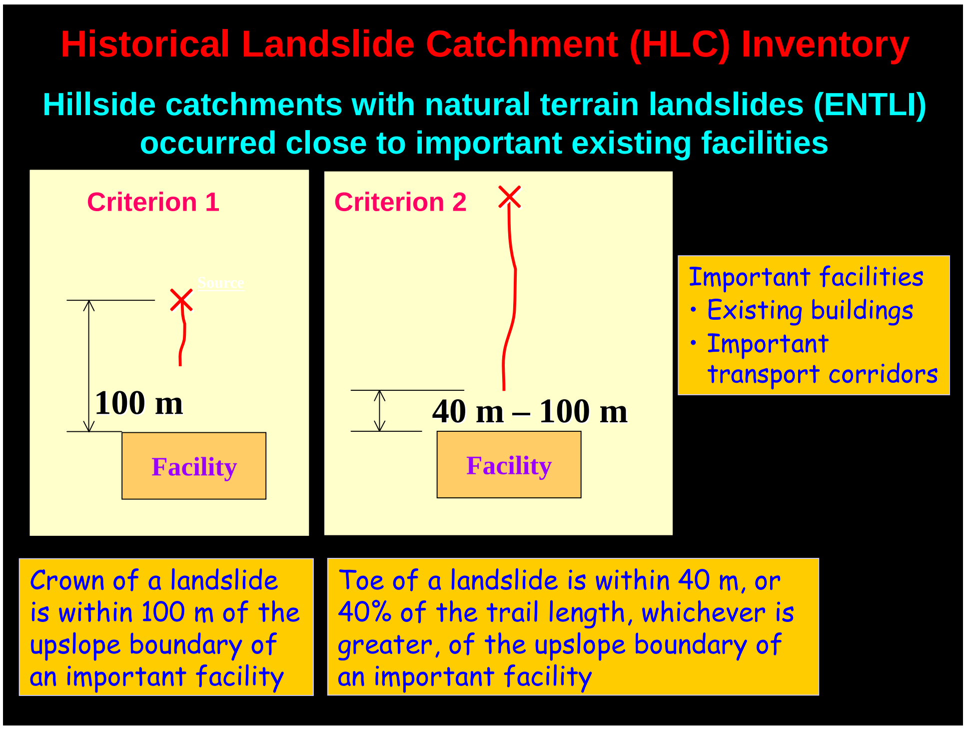


Data Item	Description
SLIDE_ID	Comprise the 1:5,000 map-sheet number (e.g. 13NE-B) and a four-figure unique reference number (e.g Y0001)
SLIDE_TYPE	Classification of landslides: R for relict landslide C for recent channelized debris flow O for recent open hillslope landslide
CLASS	Classification of relict landslides. Allowable classes are A1, A2, B1, B2, C1, C2 and S.
ACTION	Any action needs to be taken for particular landslide: A: Newly added landslide B: Landslide to be deleted C: Location of landslide amended D: No change from existing NTLI
COMMENT	Record any comment that may assist with subsequent interpretation of data, e.g. the fe… from the NTLI
WIDTH	Width of the landslide main scarp. Allowable values are 1 (<20m) or 2 (>20m).
M_WIDTH	Width of the landslide main scarp.
S_LENGTH	Length of the landslide source area.
SLOPE	Ground slope angle across the landslide head, calculated from the distance between the steepest two adjacent contours on the map.
COVER	Vegetation cover over the landslide head: A: Totally bare of vegetation B: Partially bare of vegetation C: Completely covered in grasses D: Covered in Shrubs and/or trees
YEAR_1	Year of the aerial photograph on which the landslide can be first observed.
YEAR_2	Year of the aerial photograph immediately preceding the photographs on which the landslide is first observed.
AP_YEAR	Year of aerial photographs which shows the best observations.
AP_1	Aerial photograph number (left) which shows the best observations.
AP_2	Aerial photograph number (right) which shows the best observations.
HEADELEV	Elevation of the crown in MPD generated using GIS manipulation of 2m grid DEM and 1:1000 topographic plan data.
TRAILELEV	Elevation of the toe in MPD generated using GIS manipulation of 2m grid DEM and 1:1000 topographic plan data.
GULLY	“Y” for landslide within the area of erosion and “N” for elsewhere.
XTAG	A cross tag giving the reference number for any other landslide originating from the same source.





Distribution of Landslide Source Volume
(c. 16,000 recent NT landslides)
Summary of Landslide Source Volume at 95-percentile:
For depth = d, 400 m3
For depth = 2d, 800 m3
For depth = 3d, 1200 m3
1,000 m3
Landslide Volume (m3)
Percentage of Landslides (%)
Note: Landslide source volume, depth (in metres), d, is calculated as
[√ (Plan Area of Landslide Source) × 2] ÷ 10
Distribution of Runout Distance
(c. 5,000 recent debris flows)
200 m
Runout Distance (m)
Cumulative Percentage of Landslides (%)



Historical Landslide Catchment (HLC) Inventory
Hillside catchments with natural terrain landslides (ENTLI) occurred close to important existing facilities
Criterion 1
100 m
Facility
Criterion 2
40 m – 100 m
Facility
Important facilities
• Existing buildings
• Important transport corridors
Crown of a landslide is within 100 m of the upslope boundary of an important facility
Toe of a landslide is within 40 m, or 40% of the trail length, whichever is greater, of the upslope boundary of an important facility

HLC Inventory

Each HLC:

- contains at least one validated landslide
- is classified according to the runount mechanism (open hillslope or debris flow)

Historical Landslide Catchments – c. 2,700

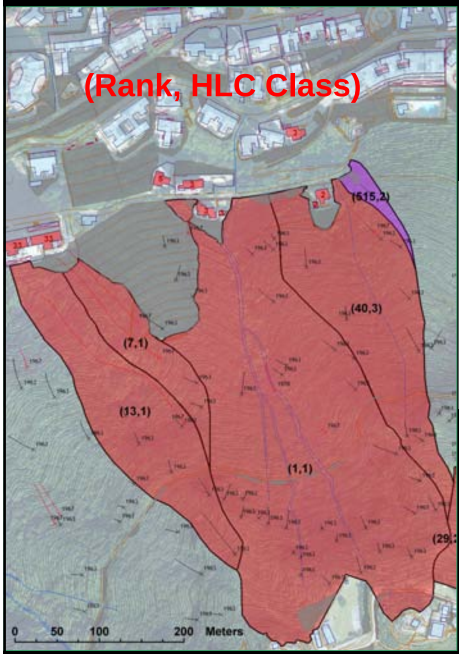
Field Inspection Records

Risk-based Ranking System –

rank the most deserving HLC and related catchments for action

based on:

- Societal risk of the HLC, in terms of PLL per year, assessed by the Global QRA model
- Adjustment Factor to cater for multiple fatalities and individual risk, based on types of facility
- Adjustment Factor to reflect the special risk concern at debris flow catchments



Priority Ranking of HLC

Classes of HLC

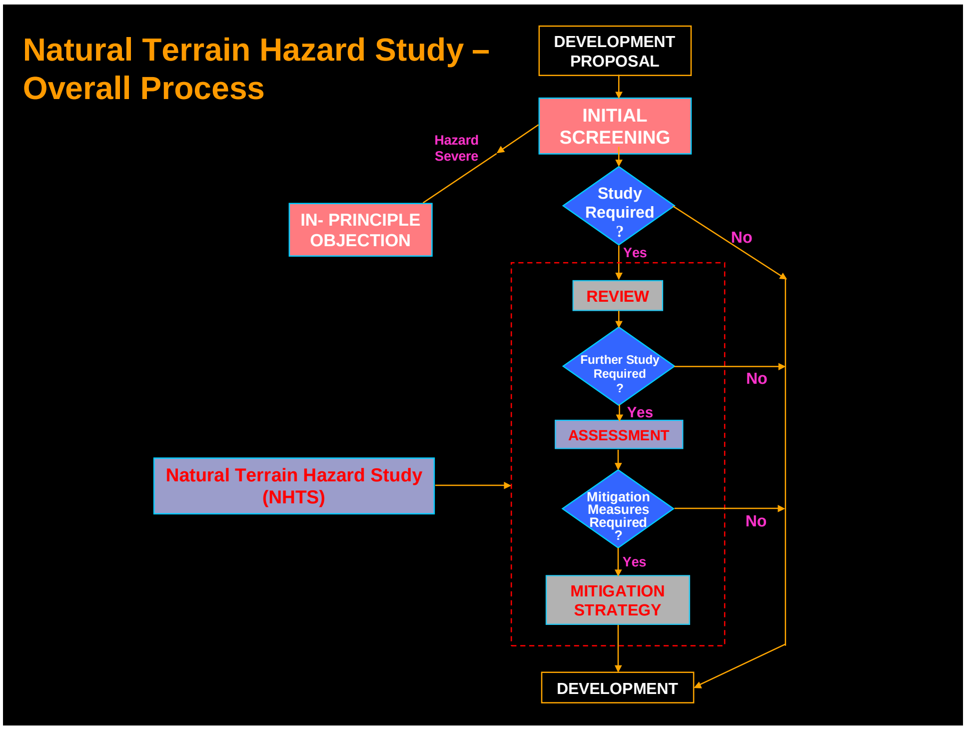
Type of Catchment / Type of Facility Affected	Debris Flow	Open Hillslope
Multi-storey Building	Class 1	Class 2
Low-rise Building	Class 3	Class 4
Important Transport Corridor	Class 5	Class 6

Rank No. 1, 7 and 13 HLC: Debris flow catchments affecting multi-storey building in Po Shan, Mid-levels

Post-2010 Landslip Prevention and Mitigation Programme (LPMitP)

with respect to natural terrain landslide hazards

- About 2,700 natural hillside catchments with known hazards to existing buildings and important transport corridors
- Expanded effort to systematically deal with the natural terrain landslide risk
- Risk mitigation works to be implemented for 30 natural hillside catchments each year
- Annual expenditure about $300 million

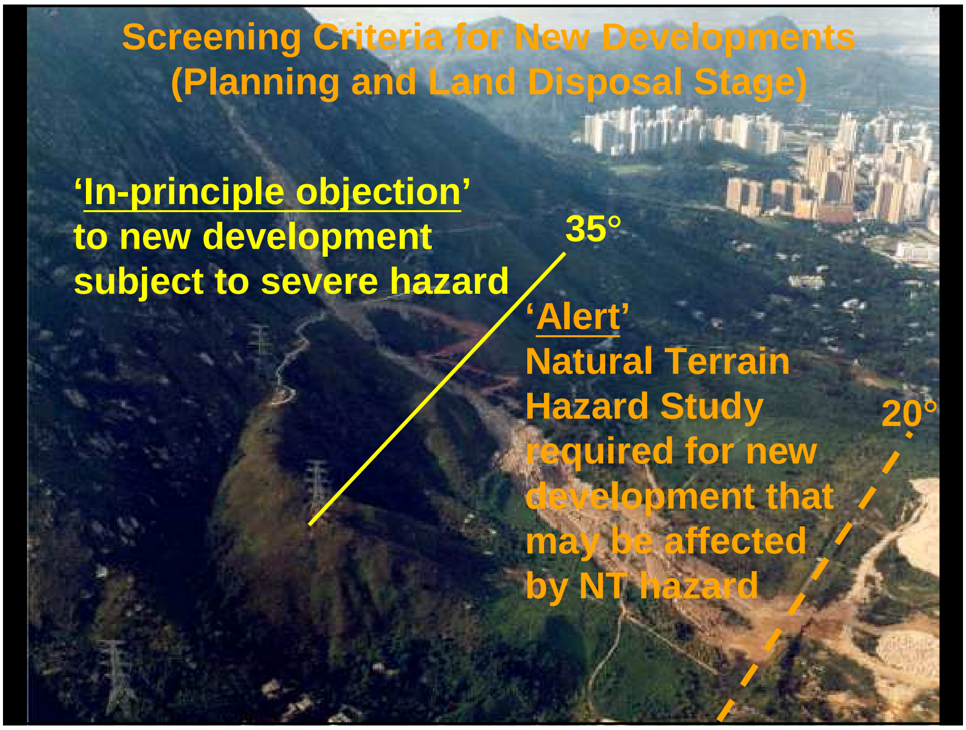


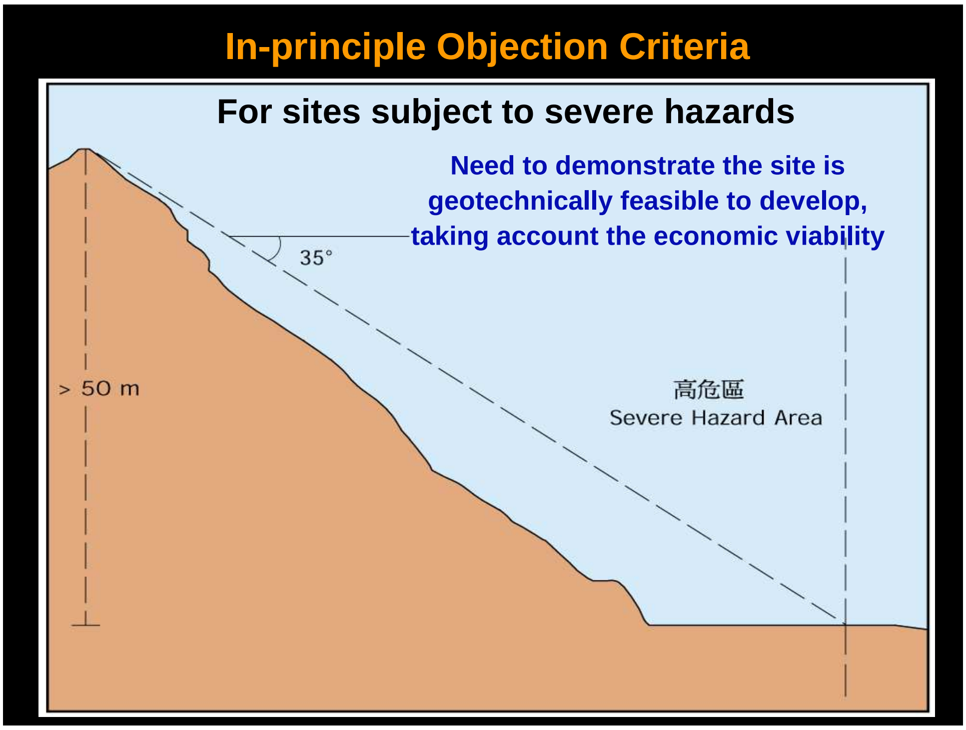
Natural Terrain Landslide Risk Management - keep risk to as low as practically achievable level

Type	Strategy
New Development	Contain risk increase, through study and mitigation action as part of the new development
Existing Development	Undertake action where subject to an immediate and obvious danger or where a dangerous situation could develop ‘react-to-known-hazard’ principle

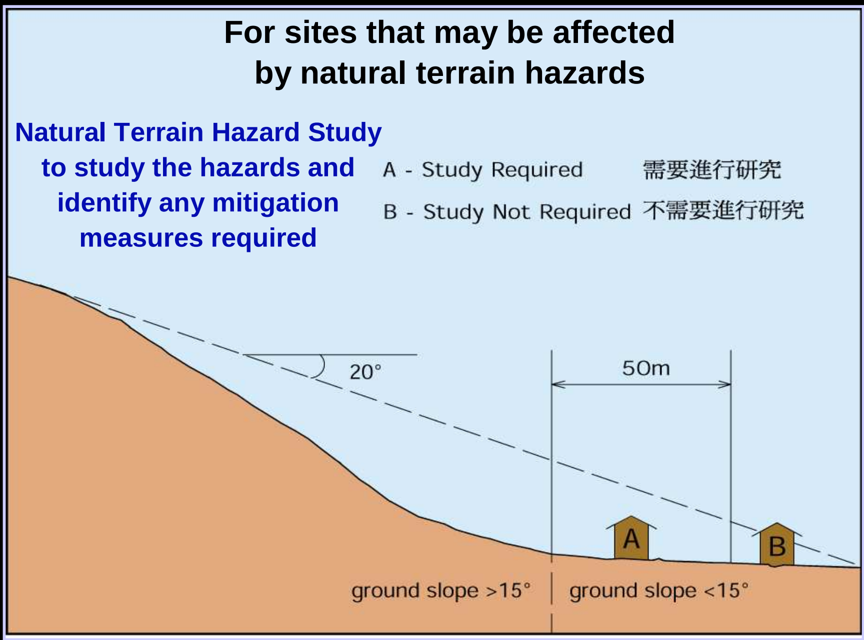

Fanling Area 49A – New Development
Developer carried out natural terrain hazard study and provided debris barriers


Sham Tseng San Tsuen - Existing Developments
'React-to-known-hazard'
1 fatality & 13 injuries
Potential landslide source
Check dam
(1400 m³)


Screening Criteria for New Developments
(Planning and Land Disposal Stage)
'In-principle objection'
to new development
subject to severe hazard
35°
'Alert'
Natural Terrain
Hazard Study
required for new
development that
may be affected
by NT hazard
20°

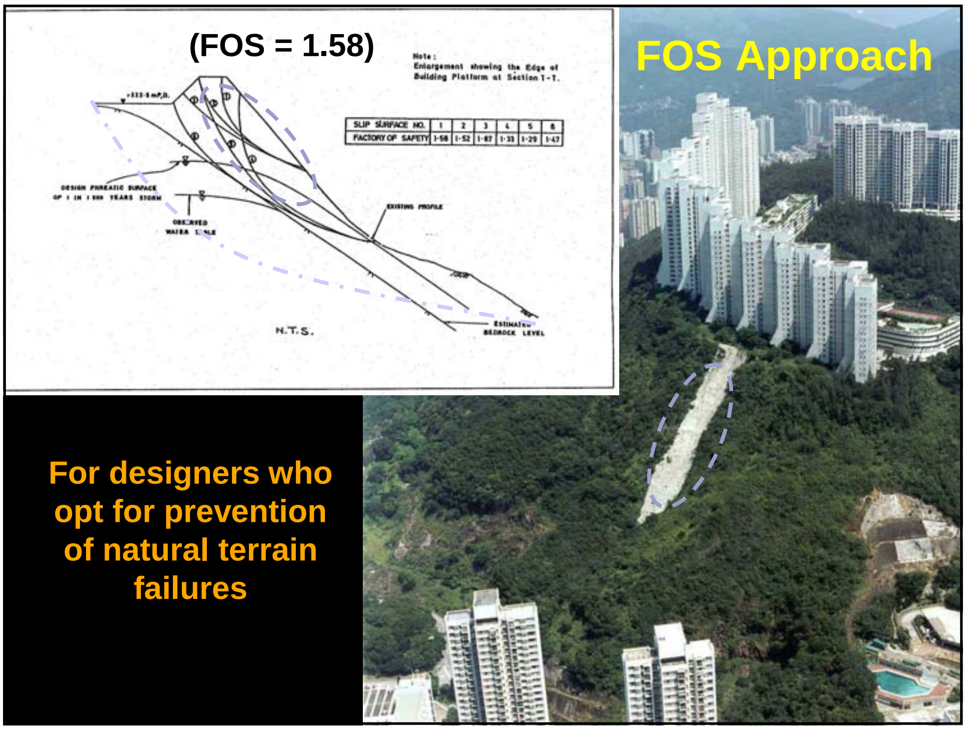

In-principle Objection Criteria
For sites subject to severe hazards
Need to demonstrate the site is
geotechnically feasible to develop,
taking account the economic viability
35°
> 50 m
高危區
Severe Hazard Area

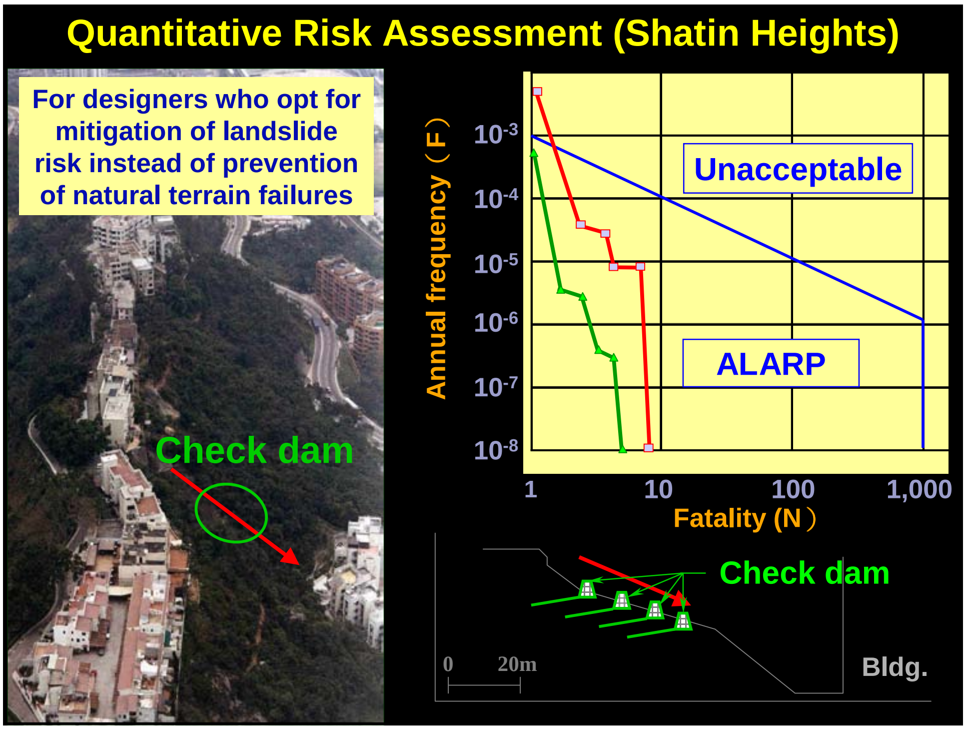
Alert Criteria



Approaches of Natural Terrain Hazard Studies

Approach	Design Concept	Guidance
Factor of Safety (FOS)	Study stability of hillside and design any slope stabilization measures to meet the required FOS (prevent failure)	Geotechnical Manual for Slopes
Quantitative Risk Assess-ment (QRA)	Assess risk to development site and determine any risk mitigation measures based on risk guidelines (control risk)	GEO Report No. 75
Design Event Approach (DEA)	Study landslide hazards and determine the design event and any mitigation measures (control risk)	GEO Report No. 138


(FOS = 1.58)
FOS Approach
For designers who opt for prevention of natural terrain failures


Quantitative Risk Assessment (Shatin Heights)
For designers who opt for mitigation of landslide risk instead of prevention of natural terrain failures
Check dam
Annual frequency (F)
10-3
10-4
10-5
10-6
10-7
10-8
Unacceptable
ALARP
1
10
100
1,000
Fatality (N)
Check dam
0
20m
Bldg.

Design Event Approach

For designers who opt for mitigation of landslide risk instead of prevention of natural terrain failures

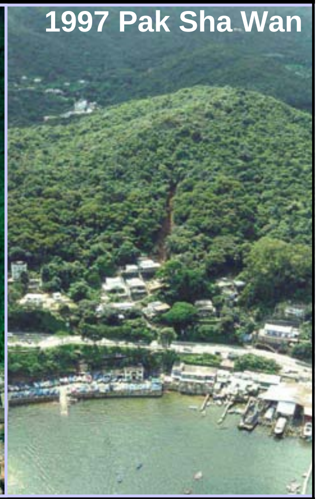
- study the natural terrain hazards
- establish the relevant design events
- determine any necessary mitigation measures

Design Requirements for Design Event Approach

Susceptibility	Consequence Class I	Consequence Class II	Consequence Class III	Consequence Class IV
A (extremely susceptible)	WCE	WCE	WCE	CE
B (highly susceptible)	WCE	WCE	CE	CE
C (moderately susceptible)	WCE	CE	CE	N
D (low susceptibility)	N	N	N	N

WCE = adopt 'worst credible event' as design event
CE = adopt 'conservative event' as design event
N = further study not required

Examples of Susceptibility Class



A (extremely) :
Distressed hillside

B (highly) :
Records of occasional failures

C (moderately) :
Few records of failure, other evidence

Consequence Classes

Proximity	Facility Group (GEO Report No. 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

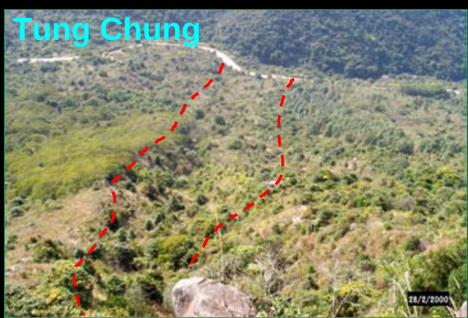
AE = Angular elevation from the site to the hillside

Group 1 - Buildings (densely use) & Roads (very high traffic density)
Group 2 - Buildings (lightly used) & Roads (High Traffic Density)
Group 3 - Open Space (densely used) & Roads (moderate traffic density)

Susceptibility Classes	Examples *	Notional Probability
A (extremely)	Signs of instability, continued movement and records of repeated failures (API)	1/10 yrs
B (highly)	Records of occasional failures (API)	1/100 yrs
C (moderately)	Few records of failures (API), but with indications of relict failures or geomorphological evidence or other evidence from similar terrain	1/1,000 yrs
D (low)	No records of recent and relict failures, little geomorphological evidence and other evidence from similar terrain	

* In the catchment and relevant vicinity
Consider potential effects of changes in environmental factors and relevance of data

Age Dating of Relict Landslides



~10,000 years

Probably different climatic conditions compared to the present day

Multiple events
1,000s to 10,000s years

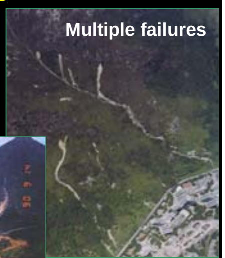
Geomorphological Controls of Large-magnitude Open Hillside Failures

- **Topographical setting**
  - Steep terrain above the main scarp
  - Steep/sharp convex break in slope

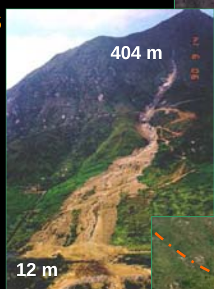
- **Evidence of instability**
  - Extensive signs of distress
  - Previous sizable failures
  - Large relict instability
  - Adversely discontinuities
  - Old coastal slope

- **Man-made influence**
  - Large cut-slope at toe
  - Discharge of large surface runoff
  - Large tract of disturbed terrain

Geomorphological Controls of Large-magnitude Debris Flows



- **Large source area**
  - Large initial source volume
  - Coalescence of multiple landsides



- **Large entrainment**
  - Availability of entrainable material
  - Damming of natural debris

- **High mobility**
  - Steep, incised and straight DL
  - Sharp convex break in slope
  - Large catchment upstream
  - Large elevation difference
  - Past record of long debris runout
  - Dam-break with release of mobile debris

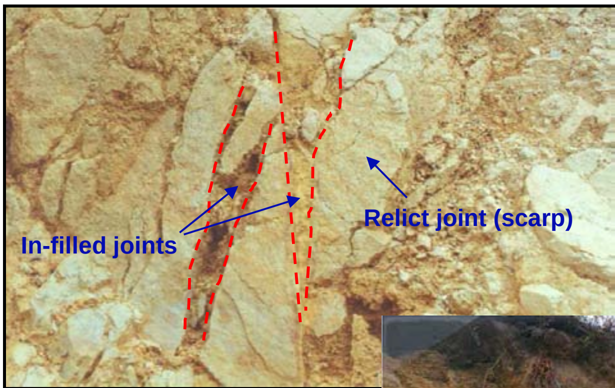
Landslide Source Area

Exhaustion of source

Far from Exhaustion

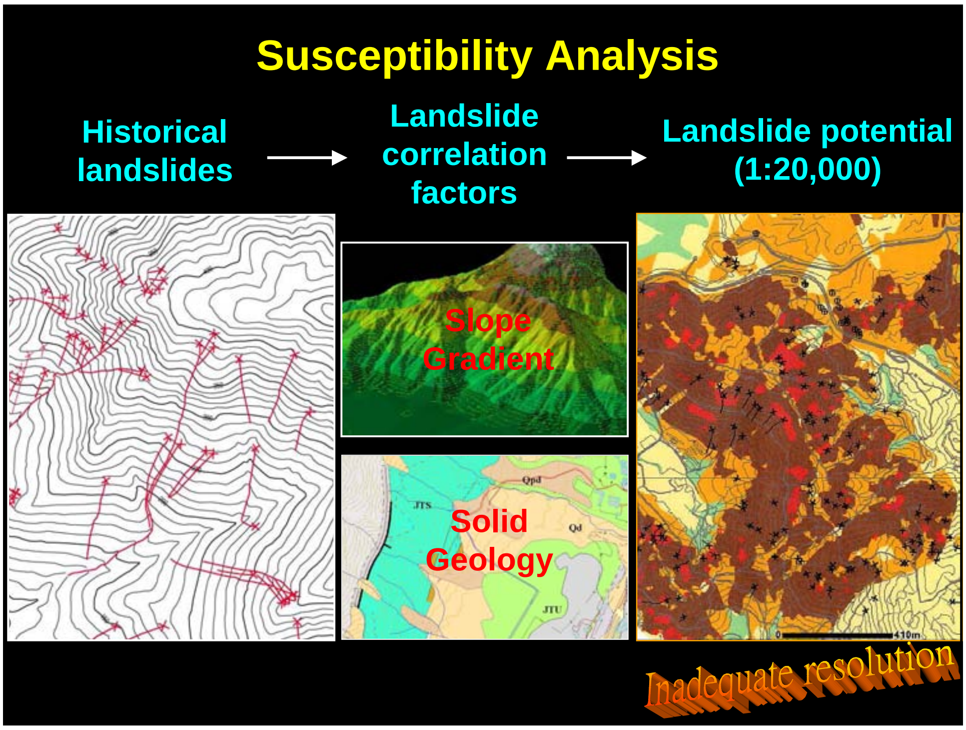
Lamma relict landslide

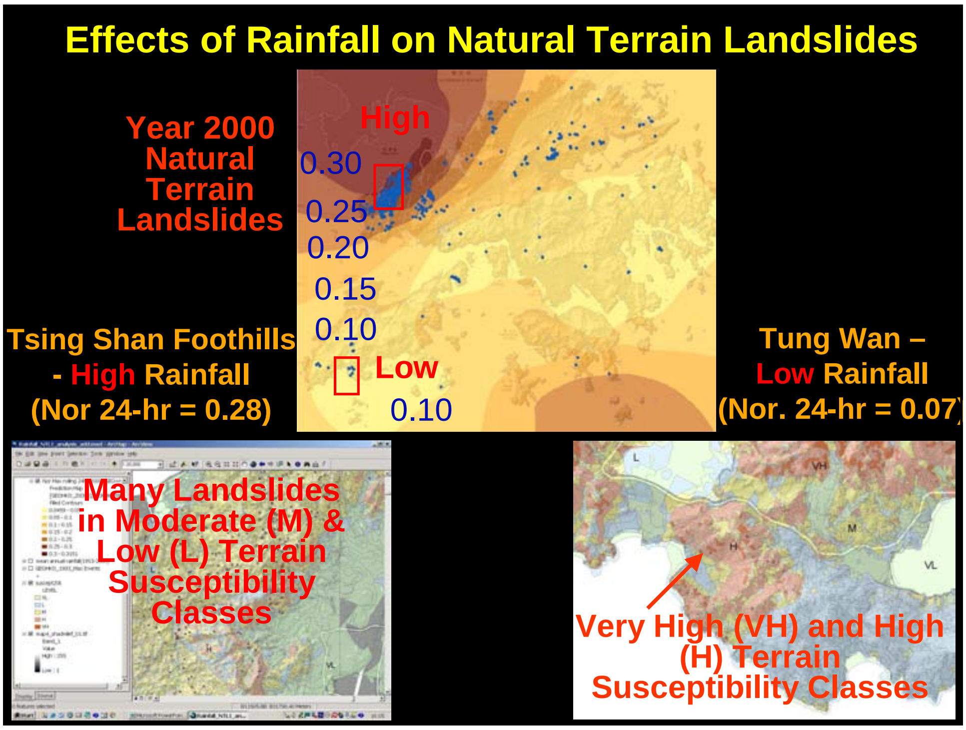
1999 Sham Tseng
San Tsuen debris flow

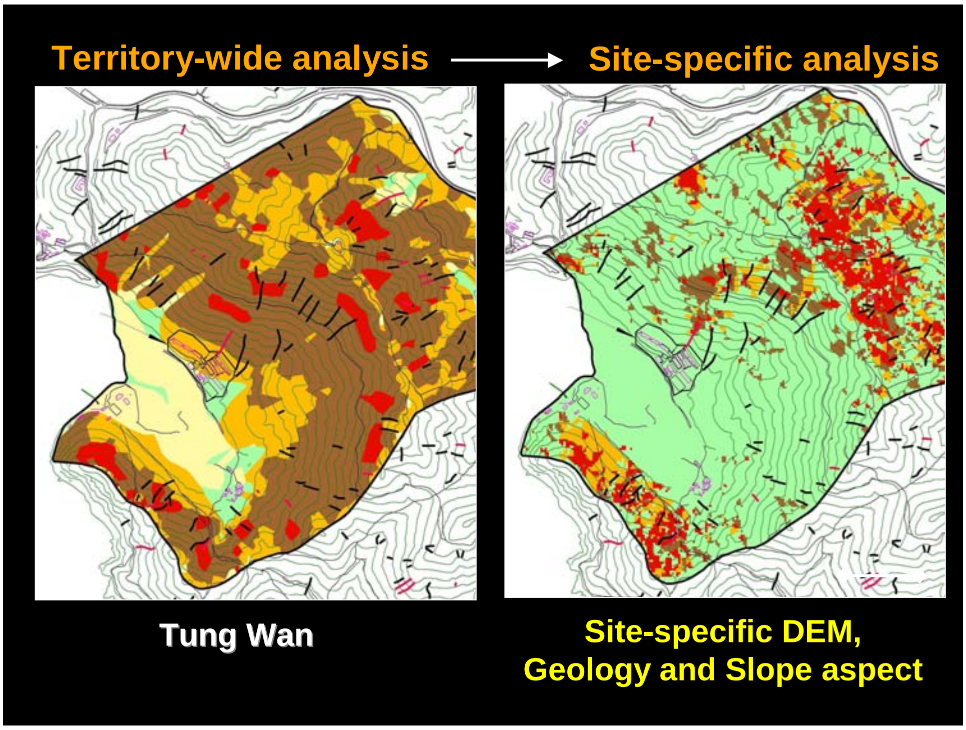


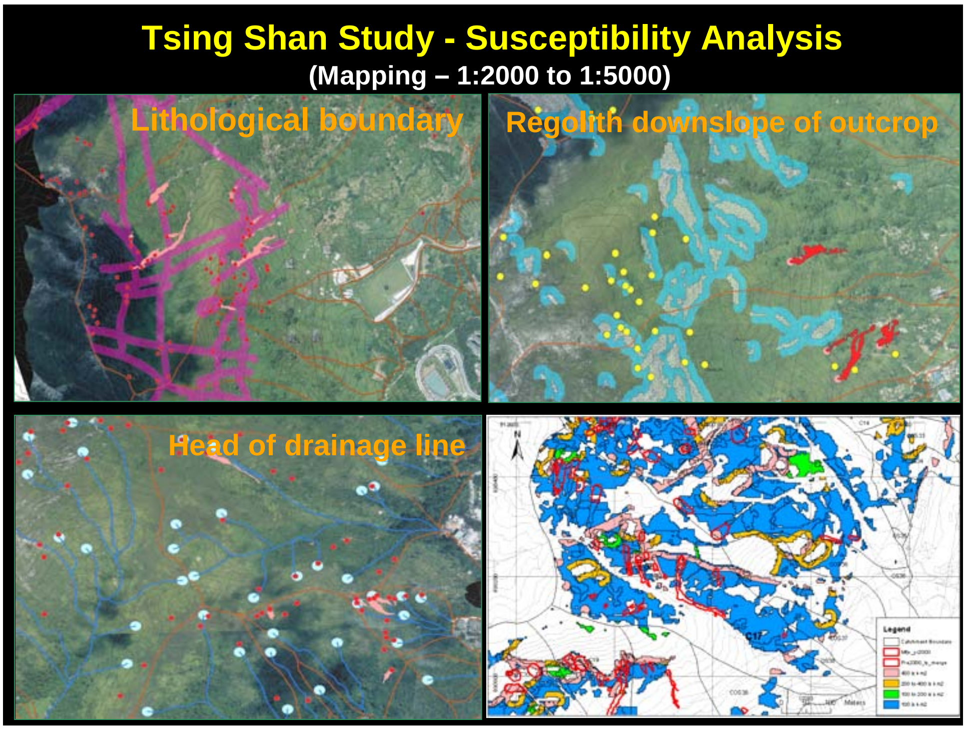
'Disturbed' Weathered Volcanic Rock

Natural Degradation of Hillside

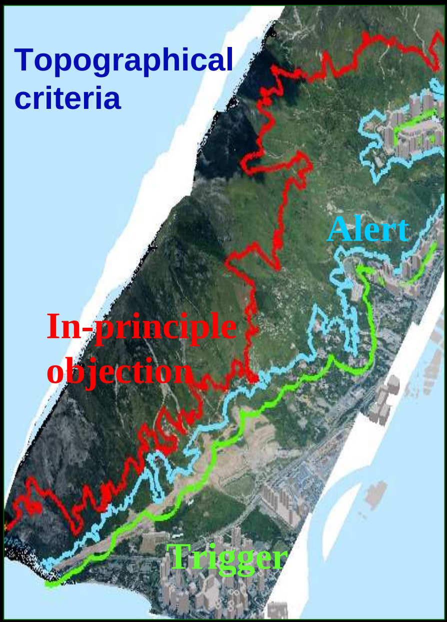

Susceptibility Analysis
Historical landslides
Landslide correlation factors
Landslide potential (1:20,000)
Slope Gradient
Solid Geology
Inadequate resolution

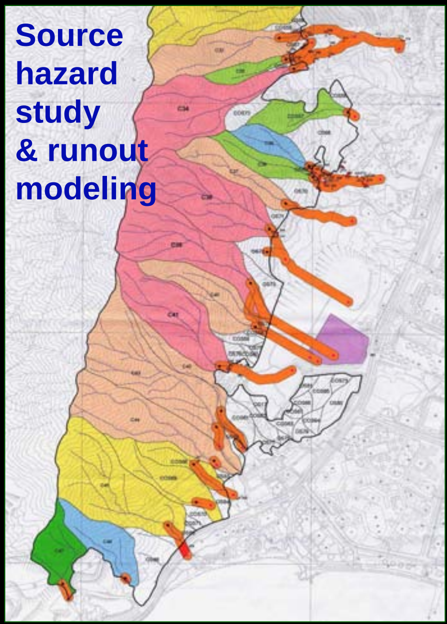

Effects of Rainfall on Natural Terrain Landslides
Year 2000 Natural Terrain Landslides
High
0.30
0.25
0.20
0.15
0.10
Low
0.10
Tsing Shan Foothills - High Rainfall (Nor 24-hr = 0.28)
Tung Wan – Low Rainfall (Nor. 24-hr = 0.07)
Many Landslides in Moderate (M) & Low (L) Terrain Susceptibility Classes
Very High (VH) and High (H) Terrain Susceptibility Classes


Territory-wide analysis
Site-specific analysis
Tung Wan
Site-specific DEM,
Geology and Slope aspect


Tsing Shan Study - Susceptibility Analysis
(Mapping – 1:2000 to 1:5000)
Lithological boundary
Regolith downslope of outcrop
Head of drainage line

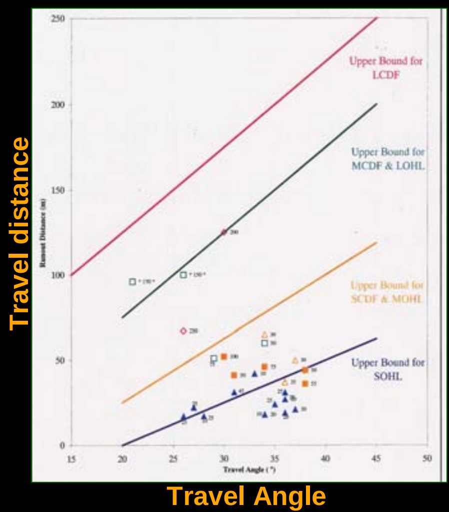
Landslide Hazard Map – Area-based Study (Tsing Shan)



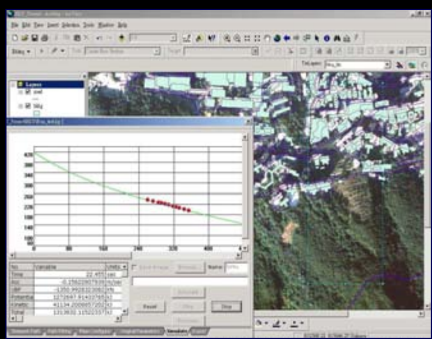


Assessment of Debris Mobility

- Improved empirical correlation



- Numerical & GIS modeling

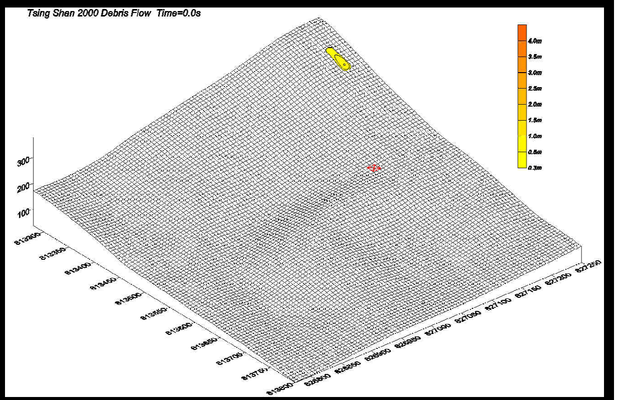


Dynamic Modeling in GIS

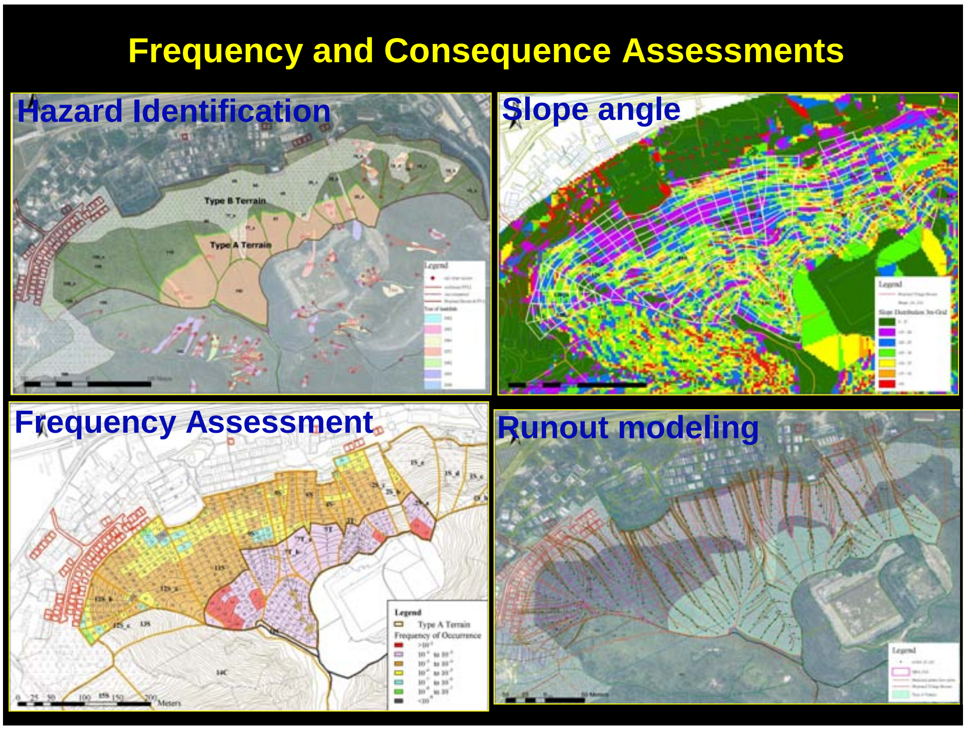
- Debris 3-D runout path
- Runout distance & velocity

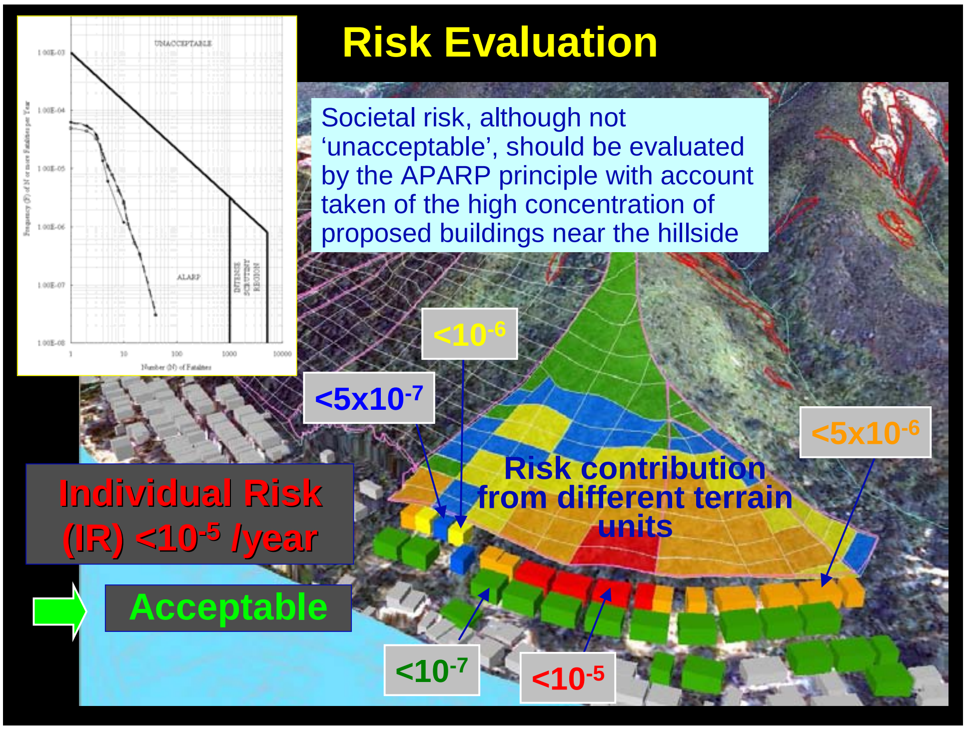
Debris Mobility Modeling

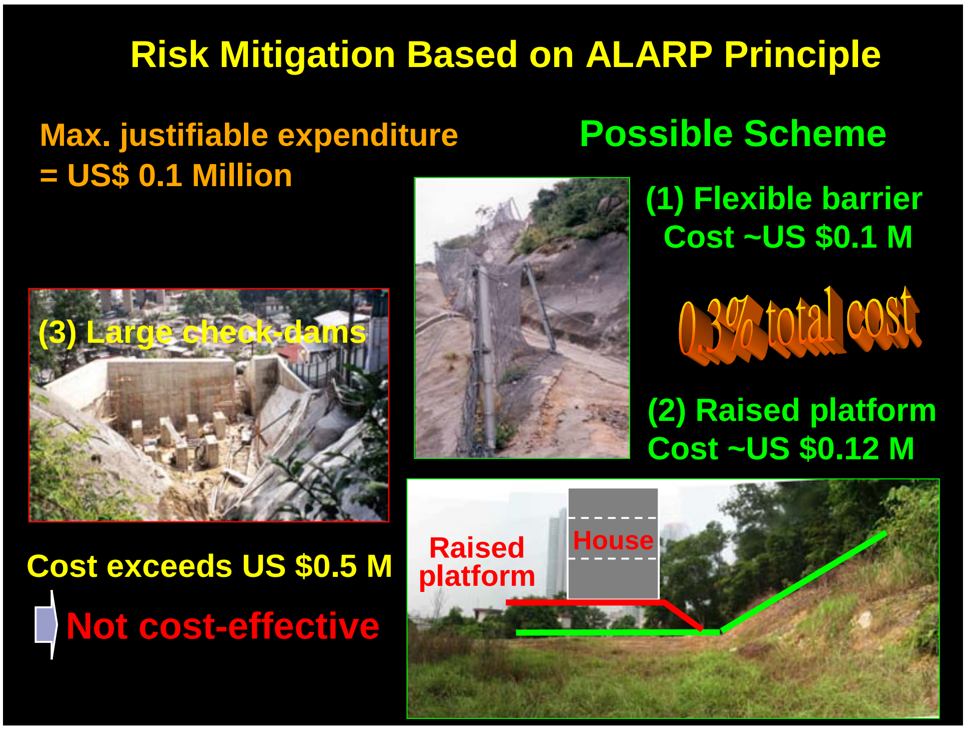
- 2000 Tsing Shan Debris Flow



Site-specific QRA on Planned Development at Ling Pei


Frequency and Consequence Assessments
Hazard Identification
Type B Terrain
Type A Terrain
Slope angle
Frequency Assessment
Runout modeling


Risk Evaluation
UNACCEPTABLE
ALARP
INTENSE SCRUTINY REGION
Societal risk, although not 'unacceptable', should be evaluated by the APARP principle with account taken of the high concentration of proposed buildings near the hillside
<10-6
<5x10-7
<5x10-6
Risk contribution from different terrain units
Individual Risk (IR) <10-5 /year
Acceptable
<10-7
<10-5


Risk Mitigation Based on ALARP Principle
Max. justifiable expenditure
= US$ 0.1 Million
Possible Scheme
(1) Flexible barrier
Cost ~US $0.1 M
0.3% total cost
(2) Raised platform
Cost ~US $0.12 M
(3) Large check-dams
Cost exceeds US $0.5 M
Not cost-effective
Raised platform
House


Thank You
15/03/2003