Guidelines for Natural Terrain Hazard Studies

GEO Report No. 138
(Second Edition)

H.Y. Ho & K.J. Roberts

Geotechnical Engineering Office
Civil Engineering and Development Department
The Government of the Hong Kong
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Preface

In keeping with our policy of releasing information which may be of general interest to the geotechnical profession and the public, we make available selected internal reports and other relevant technical materials in a series of publications termed the GEO Report series. The GEO Reports can be downloaded from the website of the Civil Engineering and Development Department (http://www.cedd.gov.hk) on the Internet. Printed copies are also available for some GEO Reports. For printed copies, a charge is made to cover the cost of printing.

The Geotechnical Engineering Office also produces documents specifically for publication in print. These include guidance documents and results of comprehensive reviews. They can also be downloaded from the above website.

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H.N. Wong
Head, Geotechnical Engineering Office
March 2016

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Foreword

This report describes the requirements for a natural terrain hazard study, and outlines the approaches to studying natural terrain hazards and the design requirements for appropriate mitigation measures.

Since the publication of the First Edition of GEO Report No. 138 (Ng *et al*., 2003), much experience has been gained in the study and mitigation of natural terrain hazards in Hong Kong, particularly from systematically dealing with natural hillside catchments under the Landslip Prevention and Mitigation Programme (LPMitP) since 2010. In 2012, the GEO undertook a review of the Design Event Approach (DEA) under the Agreement No. CE 12/2011 (GE). The review team comprised experienced engineering geologists in the industry including Messrs J.R. Hart, S. Parry, R.J. Sas, *Jr.*, K.A. Styles and S.J. Williamson, with Dr E.M. Lee providing an independent, international, peer review.

In 2013, the GEO undertook another review on the study and mitigation of natural terrain hazards in Hong Kong by consolidating the experience gained from the LPMitP, incorporating the findings from the DEA review and technical development work, and extensive consultation with geotechnical practitioners. Areas for enhancement to the DEA approach for dealing with natural terrain hazards were identified and promulgated in the GEO Technical Guidance Note (TGN) No. 36 which has been superseded by the publication of this report.

This report was prepared by Ms H.Y. Ho and Mr K.J. Roberts under the direction of Dr K.C. Ng. It updates the guidelines given in the First Edition of GEO Report No. 138, which was published in 2003, to reflect changes arising from the experience gained from landslide investigations and LPMitP studies, findings of the DEA review, the enhanced DEA approach and other relevant technical developments.

It is necessary to emphasize that this report is a guidance document and, as such, its recommendations are not mandatory. It is likely that situations will sometimes arise for which this report provides inadequate or inappropriate guidance, and the practitioner must use alternative methods or approach. Practitioners are encouraged to comment at any time to the GEO on the contents of this document so that improvements can be made to future editions. When needed, the GEO will issue Technical Guidance Notes for promulgation of further amendments to the report.

H.N. Wong
Head, Geotechnical Engineering Office

Abstract

Natural terrain covers about 60% of the land area of the Hong Kong Special Administrative Region. Urban expansion in Hong Kong is gradually encroaching further upon the steeper natural hillsides that fringe the urban area. Landsliding on these hillsides during intense rainfall is common and can be widespread, and has led to extensive studies of natural terrain landslide processes, the implementation of control procedures to ensure safe development, and systematic mitigation of the landslide risk through the Landslip Prevention and Mitigation Programme (LPMitP).

For existing development, the current strategy for study and mitigation of natural terrain landslide risk is founded on the 'react-to-known-hazard' principle. Natural terrain is now systematically dealt with under the LPMitP, which commenced in 2010.

For new development, the preferred technical approach for dealing with natural terrain hazards is to mitigate the risk through implementation of hazard mitigation measures, adjustments to the facility layout or providing buffer zones, in preference to carrying out stabilization works to large areas of natural terrain, which may be both impractical and environmentally damaging.

This report documents current recommended practice and procedures for studying natural terrain hazards. A Natural Terrain Hazard Study (NTHS) normally includes desk study, detailed aerial photograph interpretation and field mapping. The study should provide sufficient information to determine the hazard types, their respective design events and runout distances. If the risk posed by an identified hazard needs to be lowered, formulation of a mitigation strategy is required as part of the study.

As our understanding about the complex interplay between the various attributes contributing to natural terrain instability is evolving, judgement by experienced and competent professionals remains a key aspect in assessing hazards and in formulating appropriate mitigation strategies.

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1 Introduction

1.1 Purpose

Since the publication of GEO Report No. 138 (Ng *et al*., 2003), much experience has been gained in the study and mitigation of natural terrain hazards in Hong Kong, particularly under the Landslip Prevention and Mitigation Programme (LPMitP) since 2010 (e.g. Martin & Ng, 2011). In 2012, the Geotechnical Engineering Office (GEO) commissioned a study to undertake a review of the Design Event Approach (DEA) (FSWJV, 2014). In 2013, the GEO undertook another review on study and mitigation of natural terrain hazards in Hong Kong by consolidating the experience gained from the LPMitP and incorporating the findings from the DEA review and technical development work. An enhanced approach for dealing with natural terrain landslide hazard was developed and promulgated in the GEO Technical Guidance Note (TGN) No. 36 which has been superseded by the publication of this document.

This document outlines current recommended practice and procedures for studying natural terrain hazards that may affect land development in the Hong Kong Special Administrative Region (HKSAR), incorporating the latest findings of technical development works carried out in collaboration with geotechnical practitioners (e.g. GEO, 2004, 2016; Parry & Ng, 2010; FSWJV, 2014; Ng *et al*., 2014). This Second Edition of GEO Report No. 138 supersedes the version published in 2003.

This report is a guidance document, with emphasis on local conditions, practice and procedures, and is aimed at practitioners who have some familiarity with the subject. As such, the methodologies contained within are not mandatory. It is likely that situations will arise for which the report provides inadequate or inappropriate guidance, in which case practitioners should use alternative methods or approach. There will also be improvements in professional practice that will supersede specific recommendations of this report. For proper recognition to be made of advances in our knowledge, practitioners are encouraged to provide the GEO with suggestions for improvement to the report.

1.2 Natural and Quasi-natural Terrain

Natural terrain in this document is defined as “terrain that has not been modified substantially by human activity but includes areas where grazing, hill fires and deforestation may have occurred”. In Hong Kong, the term “quasi-natural terrain” is used to describe natural terrain which largely retains its original profile and regolith cover, but is partly modified by human activities.

Common anthropogenic features (e.g. Styles & Law, 2012) occurring on natural terrain in Hong Kong include the following:

(a) Hillsides that have previously been used for agriculture. Overgrown, abandoned agricultural terraces (Figures 1.1a & b) with small masonry walls at the front are found in many areas.

(b) Walking tracks, commonly along ridgelines, have in some cases developed into deep erosion gullies. Four-wheel drive vehicle tracks with minimal ground cutting have been used

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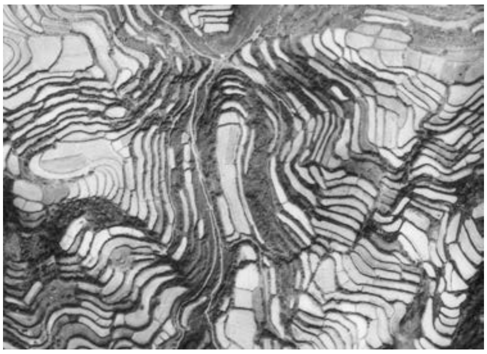
by the military to access remote areas in the past and remnants of other military artefacts such as dugouts, foxholes and fortifications (Figure 1.1c) also exist.

(c) Small dams, pipelines and catchwaters constructed on hillside streams used for water supply (Figure 1.1d), may be present.

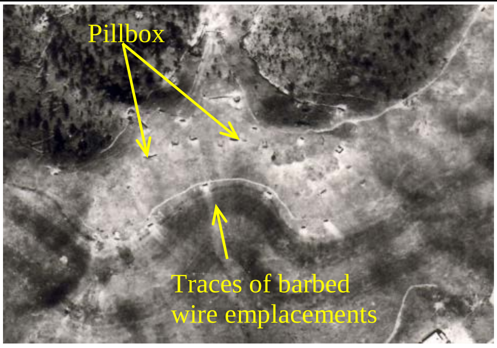
(d) Traditional village graves of various styles, some with a very similar arcuate shape to a landslide, occurring in groups, or as isolated features, on natural terrain (Figure 1.1e).

(e) Previous small scale prospecting and mines for various minerals. Overgrown pits, trenches, adits and spoil tips are the present day evidence of these and may be found on natural terrain in many parts of the HKSAR (Figure 1.1f). Areas where mining activities were common are provided in Fyfe *et al*. (2000) and Sewell *et al*. (2000).

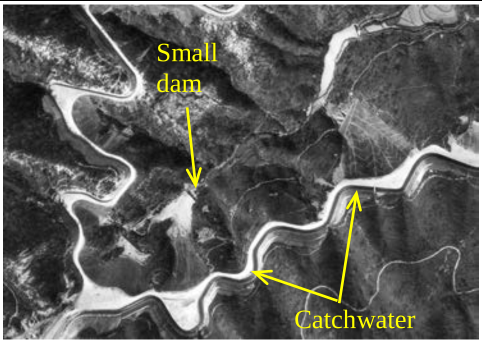


a. Agricultural terraces (Luk Keng, 1963)

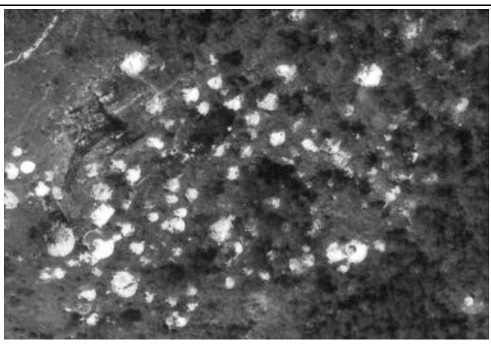
b. Abandoned tea terraces (Shek Kong, 1963)



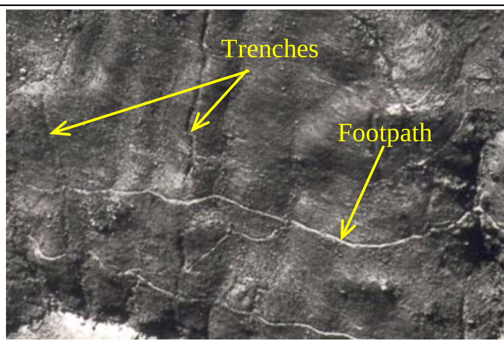
c. Military installations (Ying Pun, 1963)



d. Small dams and catchwaters (Ho Pui, 1963)



e. Graves (Tsing Shan, 1984)



f. Mineral exploration trenches (Lantau, 1963)

Figure 1.1 Examples of Anthropogenic Features on Natural Terrain

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In addition to the above anthropogenic influences, modification of the hillsides by cutting, filling and construction may have affected the surrounding ground and surface water conditions. The guidelines given in this document are generally also applicable to studying landslide hazards from quasi-natural terrain (Figure 1.2); however, the effects of relevant man-made features need to be taken into account.

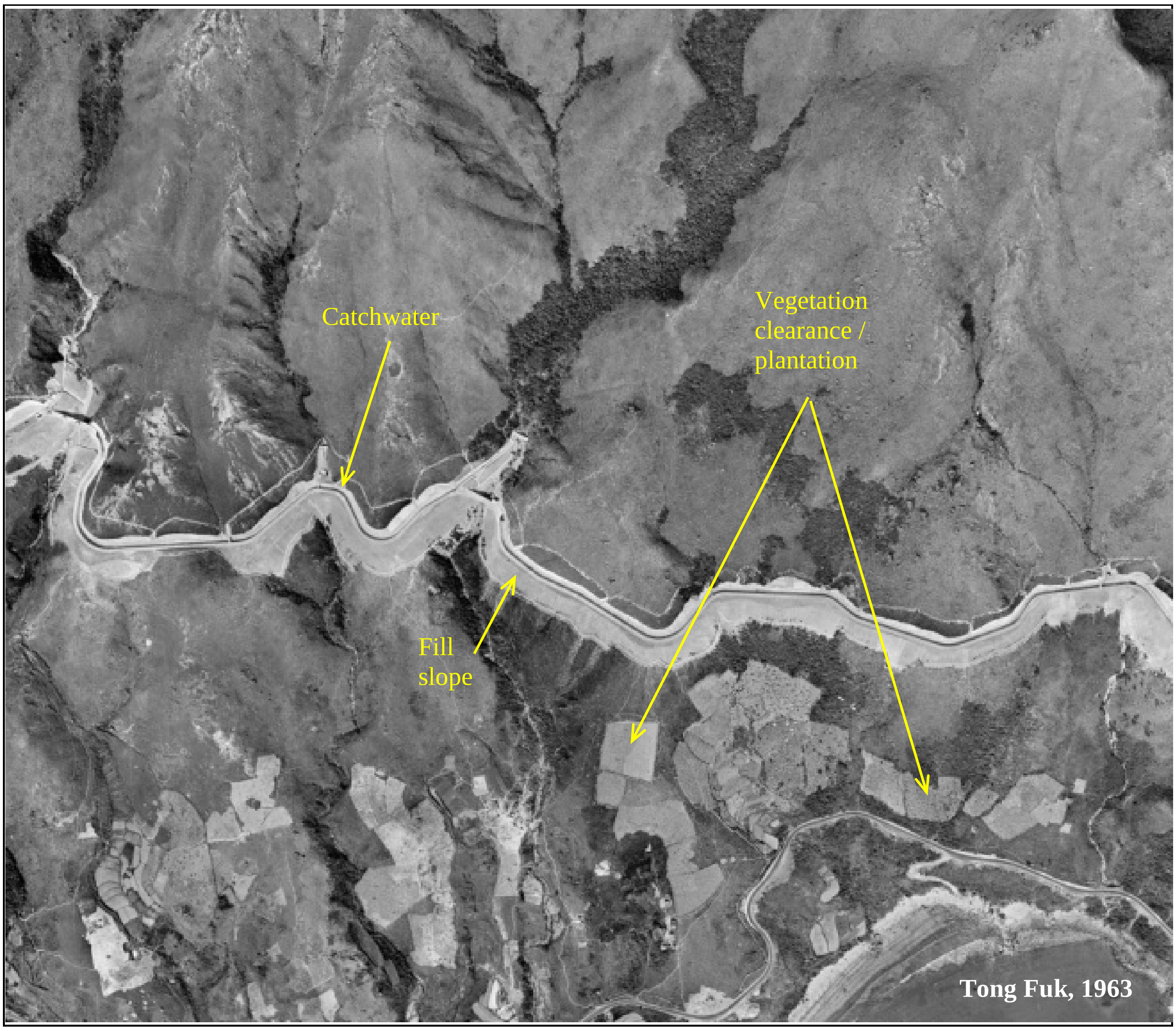

Figure 1.2 Examples of "Quasi-Natural Terrain"

1.3 Natural Terrain Landslides

Natural terrain covers over 60% of the total land area (about 1,105 km^2) of Hong Kong. About 35% of the natural terrain is sloping at 30° or more. Present-day landforms are the result of geological and climatic processes that may act at different spatial and temporal scales. Although landforms developed during the Pleistocene may persist in the modern landscape, it is the present day superficial and climatic processes that are of most relevance in modifying the natural hillsides, and hence of particular pertinence to Natural Terrain Hazard Studies (NTHS).

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From interpretation of both high and low altitude aerial photographs taken since 1924, about 20,000 recent (i.e. with determinable year of occurrence) and 90,000 relict landslides respectively on natural terrain were identified up to 2013 (see Section 2.2.2). The inventory is updated every 3 years or so. Between 1945 and 2013, on average, about 300 natural terrain landslides occurred in Hong Kong each year.

Several landslide-specific studies have been carried out in recent years. These well-documented natural and quasi-natural terrain landslides provide relevant information on the hazard model, probable cause and controlling factors of these failures. Some notable cases are summarised in Appendix C.

Whilst most natural terrain landslides occur in relatively remote areas, some of them do affect existing developments. Between 1982 and 2013, about 1,500 natural terrain landslide incidents affecting developed areas were reported to the GEO. Most of these landslides were small-scale failures affecting open spaces, minor roads and footpaths, and other less important facilities. Since 1980, natural terrain landslides have caused sixteen fatalities, thirteen of which were in squatter areas.

Although the natural terrain landslide data give an indication of the scale of the problem in Hong Kong, they do not fully reflect the inherent landslide risk to the community. Some landslides were “near-miss” incidents that could well have resulted in more serious consequences. This situation will be aggravated as more new developments take place on or close to steep natural hillsides. Wong & Mok (2009) found that there was an observed increase in the frequency of occurrence of heavy rain days in Hong Kong from the year 1885 to 2009. Pun *et al.* (2015) further illustrated the possible extreme landslide scenarios in Hong Kong under extreme rainfall events.

As is the case with other natural disasters, less frequent, larger scale natural terrain landslides, if they were to take place close to developed areas, could result in severe consequences. These “extreme” events are under-represented by the limited historical records available in Hong Kong. For example, the 20,000 m^3 debris flow in 1990 on the eastern hillslope of Tsing Shan, above Tuen Mun, reached the Area 19 platform below (King, 1996) and could have had more serious consequences if this area had been developed (Chan & Mak, 2007). This incident highlights the potential risk of natural terrain landslides in Hong Kong. Similarly, should the 7 June 2008 severe rainstorm, which resulted in widespread landslides on West Lantau Island (Millis & Parry, 2014), hit the more densely developed areas, the impact could be much more serious.

1.4 Objectives of Natural Terrain Hazard Study

The potential risk from landslides on natural hillsides, unless mitigated, will inevitably increase as the population of Hong Kong grows and as building and infrastructure developments continue to spread into areas adjacent to natural hillsides. The relative significance of the natural terrain hazards to any site will vary from non-existent in the middle of a flat plain to very high at a site below steeply sloping ground with a history of landslides.

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The objectives of an NTHS are to identify any natural terrain hazards that could affect an existing or a proposed development and to enable a decision to be reached as to whether the potential risk to the site warrants mitigation. In practice, there is the potential to curtail the NTHS during the study if there is sufficient information to conclude that no significant hazards exist. Alternatively, as more data are obtained about the site, it may become possible to establish that whilst hazards may exist, mitigation measures are unnecessary.

1.5 Personnel

Given the nature of the work involved, a multi-skilled team is normally required to undertake an NTHS. In general, the team should include professionals with suitable engineering geological and geotechnical engineering experience in NTHS. Engineering geological expertise is needed for aerial photograph interpretation (API), engineering geological mapping, interpretation of geological data, development of geological and geomorphological models, and hazard assessment. Geotechnical engineering expertise is required for analysis of engineering data, assessment of slope stability and debris mobility, and design of mitigation measures. Some tasks, such as determination of design events and development of mitigation strategy are best carried out jointly by engineering geologists and geotechnical engineers. In some cases, input from risk analysts may also be required in detailed quantitative risk assessment.

As an NTHS forms part of a geotechnical submission, it should be reviewed by a qualified professional with suitable knowledge and local experience in the assessment of natural terrain hazards.

2 Natural Terrain Risk Management

2.1 Government Strategy

The current practice for natural terrain landslide risk management is aimed at keeping the natural terrain landslide risk to the As Low As Reasonably Practicable (ALARP)[1] level. It entails the following general principles:

(a) For existing developments[2], the approach for study and mitigation of natural terrain landslide risk is founded on 'react-to-known-hazard' principle. Mitigation actions should be undertaken where there exists an 'immediate and obvious danger'. The natural terrain hazards should be studied where

[1] The GEO has adopted quantitative risk assessment methodology in the management of landslide risk in Hong Kong. The risk standards adopted are similar to those for managing the risk of Potentially Hazardous Installations (PHI). The principle of controlling landslide risk within the ALARP level is to attain a high level of slope safety that is practically achievable and at par with that required for PHI.

[2] Natural hillside catchments solely affecting squatter dwellings will not be selected for LPMit works. However, when upgrading works are to be implemented for man-made slopes affecting squatter dwellings, flexibility has been built into the LPMitP through exercising professional judgment to also deal with the natural terrain hazards affecting these dwellings from a cost-effectiveness viewpoint, pursuant to the 'react-to-known-hazard' principle.

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there is reason to believe that a dangerous situation could develop, such as persistent landslides affecting an existing development, and mitigation actions undertaken where considered necessary.

(b) For new developments, the approach is to contain undue increase in overall natural terrain landslide risk. This is implemented through screening of land disposal and development proposals, judicious land-use and project planning to avoid hazardous areas, and imposing requirements for study and mitigation of the hazards for sites that could be affected by natural terrain hazards.

For existing development, an 'immediate and obvious danger' situation typically refers to natural terrain that shows significant signs of distress, continuing hazardous movement or incipient instability, and which will involve a significant consequence to life or serious damage to property in the event of landsliding. A typical example in the category of 'there is reason to believe that a dangerous situation could develop' is where there have been in the past persistent landslides on natural terrain and where there is a significant consequence to life or where serious damage to property may occur in the event of further landsliding. These cases are normally identified by the GEO through inspections of landslides, review of documentary records, regional or site-specific studies, studies for safety clearance of squatters, etc.

Similar strategy has been adopted for dealing with risk of boulder falls from natural hillsides. For boulders affecting either existing or new developments, preventive or mitigation action should be taken urgently where there is an immediate and obvious danger. For cases where no immediate and obvious danger is involved, the need for evaluation of boulder stability to determine if preventive or mitigation action is necessary is stipulated as follows:

(a) For boulders affecting existing developments, evaluation of boulder stability should be undertaken only where there have been persistent boulder falls or where there is reason to believe that a dangerous situation could develop.

(b) For boulders affecting new developments, evaluation of boulder stability should be undertaken only when there would be a significant risk.

Otherwise, evaluation of boulder stability is not required. Further details on special considerations for dealing with boulder fall hazard are given in Sections 2.2.6 and 2.3.5 and supplementary guidelines on mapping of boulders are provided in Section 4.4.3.

2.2 Existing Development

2.2.1 Background

Given the current state of knowledge and available technology it is not possible to

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predict with confidence where and when natural terrain landslides will occur. For existing developments, given the vast number of sites involved, it is neither desirable nor realistic to deal with them all at the same time. However, for existing developments known to be subject to significant hazards, it is prudent and practical to mitigate the hazards. This 'react-to-known-hazard' strategy has been adopted initially in dealing with boulder fall hazard in Hong Kong, and has been extended to natural hillside landslide hazards.

2.2.2 Natural Terrain Landslide Inventory

The first inventory of natural terrain landslides in Hong Kong, namely the 'Natural Terrain Landslide Inventory (NTLI)', was compiled in the mid-1990s based on the interpretation of high altitude aerial photographs (see Section 4.2.4) taken between 1945 and 1994. Emery (1996) and King (1999) documented the methodology and procedures of compiling the inventory. The NTLI was updated regularly until 2003. The limitations of the NTLI (King, 1999) and discrepancies between site-specific landslide studies and the features contained within the NTLI have been discussed by practitioners, e.g. Parry (2001), Pinches *et al*. (2002) and MFJV (2003a). Many natural terrain landslides that are of small size or that occurred sometime before the aerial photographs were taken cannot be recognized from photographs taken at high altitude.

In early 2004, the GEO commenced compilation of an updated natural terrain landslide catalogue for Hong Kong, using both high and low altitude aerial photographs, in recognition of the limited resolution and temporal coverage of the high altitude aerial photographs. The improved inventory "Enhanced Natural Terrain Landslide Inventory (ENTLI)" (see Section 4.2.9), which supersedes the NTLI, was first prepared in March 2007 and is updated regularly to maintain its currency. The ENTLI is presented in a Geographic Information System (GIS) data format that contains the locations and attributes of more than 100,000 landslides identified on natural terrain (MFJV, 2007a; Dias *et al*., 2009).

Each ENTLI landslide has been classified as 'recent' or 'relict'. Recent landslides are those that occurred within the time scale of the available aerial photographs. The scars of which have a distinctive light tone on aerial photographs and are generally bare of vegetation. Relict landslides are those that occurred earlier than the time scale of the available aerial photographs. Relict landslides are generally covered in grass, shrubs or trees but the ground still shows some characteristics of a landslide scar. Relict landslide scars may be the result of multiple failures and were classified as A, B or C-Class features with an indicative degree of certainty in the aerial photograph interpretation (MFJV, 2007a).

2.2.3 Historical Landslide Catchments

With the compilation of the ENTLI, an exercise has been carried out to identify natural terrain catchments with known ENTLI landslides that occurred close to existing buildings and important transport corridors[3] (Figure 2.1). These vulnerable catchments, which pose a

[3] Important transport corridors refer to sensitive routes, including red routes, pink routes, routes to vulnerable areas, bus routes and bus depot routes as set out in Highways Department's strategic routes database; and mass transportation facilities, including Mass Transit Railway, Light Rail Transit, Tramway and Peak Tram.

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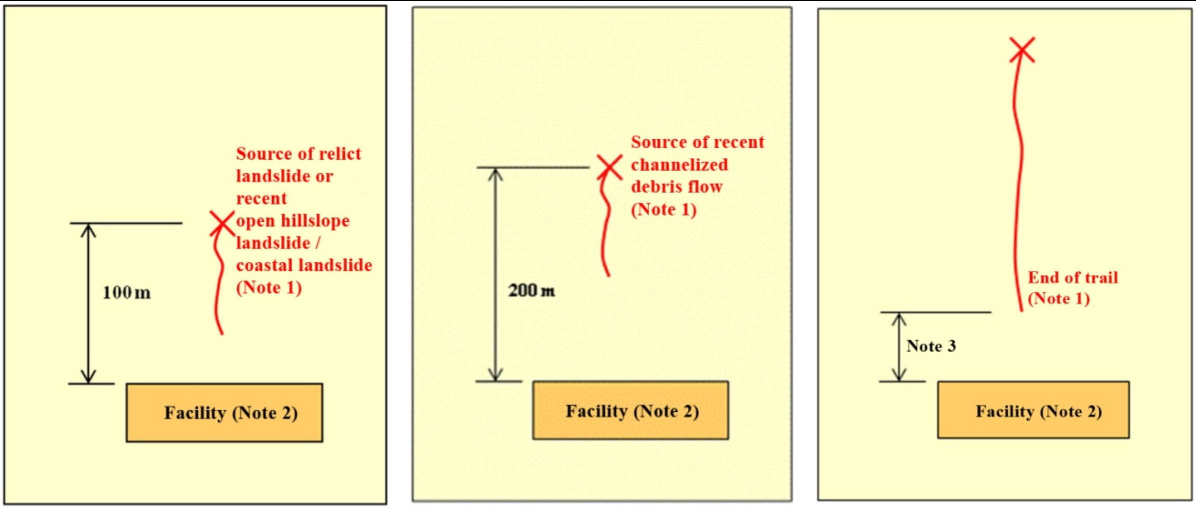
notable risk, are denoted as Historical Landslide Catchments (HLC). Currently, the inventory comprises about 2,700 HLC. The HLC inventory is updated in parallel with the ENTLI updates (see Section 4.2.8).



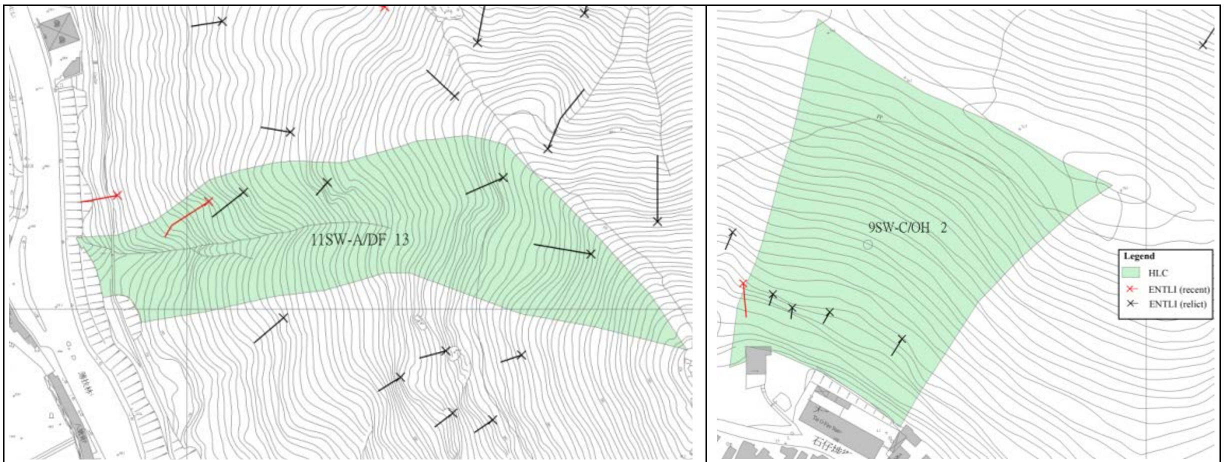
Notes:

(1) Landslide records based on ENTLI.

(2) Facility includes buildings and important transport corridors.

(3) Toe of the debris trail is within 40m, or 40% of the trail length, whichever is larger, of the upslope boundary of a facility.

Figure 2.1 HLC Selection Criteria



a. Example of Debris Flow Catchment

b. Example of Open Hillslope Catchment

Figure 2.2 Different Catchment Types of HLC

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HLC in the inventory were given unique identification numbers with indication of their catchment type (MFJV, 2003b). Debris flow (DF) catchments refer to those with definite flow path. This applies to catchments with the presence of a drainage line and/or pronounced topographic depression and for catchments with channelisation ratios less than 10 (Figure 2.2a). Open hillslope (OH) catchments refer to those where debris would travel downslope from the source of failure without entering a drainage line or pronounced topographic depression (Figure 2.2b).

Table 2.1 HLC Classification

HLC Class	Facility Type	Catchment Type
1	Multi-storey	Debris flow
2		Open Hillslope
3	Low-rise	Debris flow
4		Open Hillslope
5	Important transport corridors	Debris flow
6		Open Hillslope

The HLC were classified into six classes according to the facilities being affected and the catchment type (Table 2.1). The GEO has used quantitative risk assessment (QRA) to evaluate the risk levels of the HLC and to devise a risk-based priority ranking system (Wong *et al.*, 2006; Cheng & Ko, 2010) for systematic follow-up actions under the LPMitP. It is noted that more than 40% of the risk comes from HLC of Class 1, which contribute less than 10% of the total number of HLC.

2.2.4 Hillside Pockets

Given the history of infrastructure and building development on Hong Kong's foothills, small tracts of hillsides within developed areas are common. Hillside Pockets, which are a form of natural hillside catchment, are affected by human disturbance to varying degrees (e.g. construction of roads or building platforms).

Based on a review of previous landslides that have occurred within Hillside Pockets, the probable contributing factors to the landslides include presence of loose fill, inadequate drainage provision, presence of disturbed ground and poor slope surface protection. Given that the site setting of Hillside Pockets is different from typical natural hillsides, significant landslide risk may be posed by certain Hillside Pockets that do not meet the Historical Landslide Catchment (HLC) selection criteria.

GEO has recently compiled an inventory of Hillside Pockets for the whole of Hong Kong. Vulnerable Hillside Pockets refer to those affecting toe facilities of consequence-to-life (CTL) Category 1 (i.e. buildings, important transport corridors and infrastructure), with landslides (including landslides in the Enhanced Natural Terrain Landslide Inventory or the GEO landslide incident database) and/or those with known disturbance (i.e. registered

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Disturbed Terrain features). There are about 240 vulnerable Hillside Pockets identified and they have been included in a combined priority ranking list (i.e. HLC and Hillside Pockets) for action under LPMitP. Further details on special considerations for dealing with Hillside Pockets are given in Sections 4.10, 4.13.5 and 5.5 and supplementary guidelines on mapping of Hillside Pockets are provided in Section 4.4.3.

2.2.5 Area-based Approach

To overcome the limitations of the HLC selection framework, which is based on known failures, an area-based approach to natural terrain hazard studies is adopted under the LPMitP, whereby HLC are combined in study packages with adjoining hillside catchments that have similar topographical, geological and geomorphological settings, and affecting the same unit of development. Figure 2.3 shows an example of a study area. This arrangement takes account of some lower-ranked HLC and/or non-HLC hillside catchments flanking developed areas that may also be susceptible to failure. In addition, studying larger hillside areas is more amenable to systematic application of engineering geomorphology for hazard assessment.

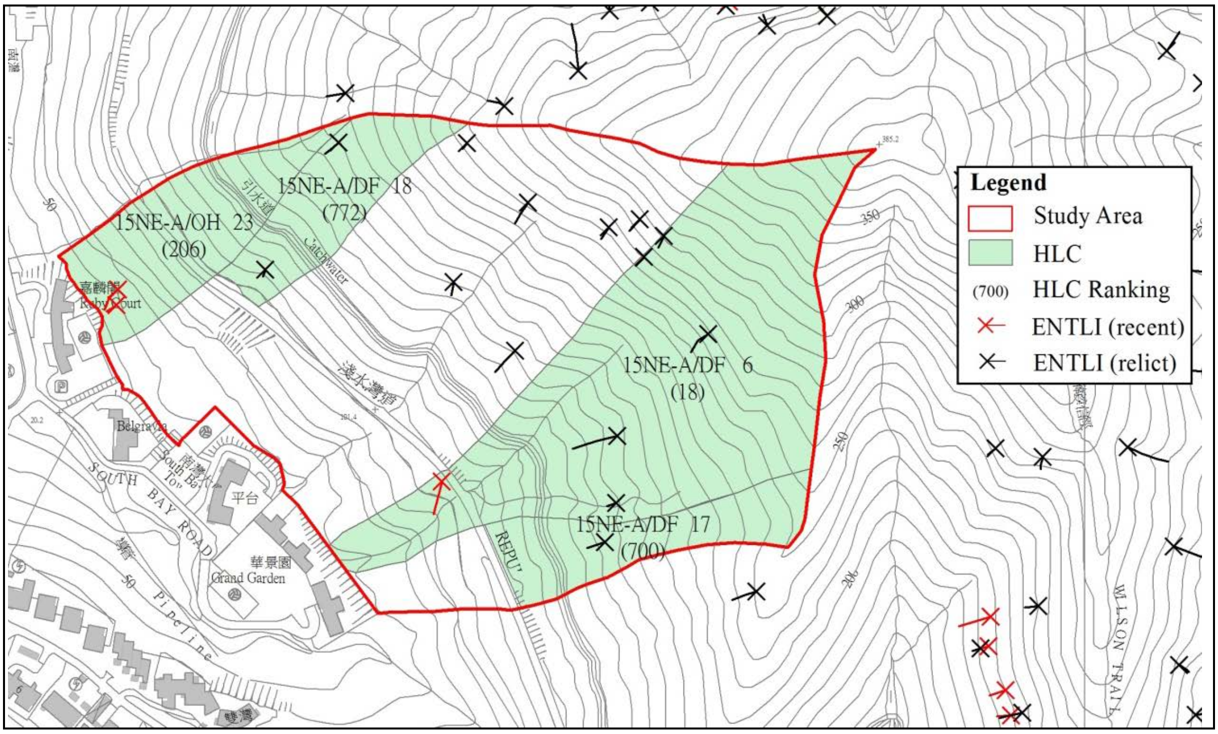

Figure 2.3 Example of a Study Area under the LPMitP

An area-based approach, similar to that for HLC, is also adopted for Hillside Pockets under the LPMitP, whereby adjoining lower-ranked and/or non-CTL Category 1 Hillside Pockets that have similar topographical, geological and geomorphological setting are combined into a study area. This approach allows Hillside Pockets that are of similar nature to be studied in one go and to assess any necessary preventive or mitigation works required based on the findings from the hazard assessment.

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2.2.6 Special Considerations for Dealing with Boulder Fall Hazard

For boulders which affect existing developments, follow-up action, including evaluation of boulder stability and implementation of preventive and mitigation measures, is only required for cases that comply with the following criteria:

(a) there have been persistent boulder falls; or

(b) there is reason to believe that a dangerous situation could develop.

In deliberating whether the requirement given in item (a) above is met, consideration should be given to the available evidence to demonstrate the occurrence of persistent boulder falls, such as reported incidents or the recent accumulation of boulders at the site boundary. However, the presence of boulders on the hillside alone should not be taken as evidence to confirm that there have been persistent boulder falls.

As regards item (b) above, the factors that should be considered in deliberating whether a dangerous situation could develop include:

(i) occurrence of new signs of distress or hazardous movement of boulders; or exacerbation of existing signs of distress or hazardous movement of boulders, particularly where there is concern of further deterioration leading to hazardous movement; or

(ii) presence of precarious boulders such as boulders overhanging on a steep slope, fractured boulders showing signs of detachment and instability, signs of erosion undermining the support of boulders, etc.

It should be noted that the results of boulder fall analysis based on generalized parameters without correlation with the nature and characteristics of the boulders specific to the hillside should not be accepted as evidence to demonstrate that a dangerous situation could develop. For instance, small tabular or angular boulders are unlikely to initiate movement and in the event of movement occurring would likely not travel far within a drainage line. Supplementary guidelines on mapping of boulders are provided in Section 4.4.3.

2.3 New Development

2.3.1 Background

The Geotechnical Manual for Slopes (GCO, 1984) noted that natural slopes are frequently close to limiting equilibrium over very large areas, that preventive works can be expensive and difficult, and that it is not advisable to undertake extensive trimming-back of natural slopes in order to achieve what may only be marginal improvement in stability. Therefore, it is considered that widespread disturbance to natural slopes and vegetation and the need for costly preventive or protective measures should be avoided where practicable.

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For new developments, the most effective means of risk mitigation is to avoid areas that are exposed to undue natural terrain hazards. Whilst this is the solution commonly adopted in many countries, it is sometimes not practical in Hong Kong where flat land is limited. However, if the potential natural terrain hazards are considered at an early stage of the development project, the hazards can be controlled in a cost-effective manner by such methods as siting of critical facilities away from the most vulnerable areas, providing buffer zones between the hillsides and the developments, delineating no-build zones for the most vulnerable parts of the sites, implementing drainage provisions to divert debris-laden stormwaters from important facilities, specifying minimum clearance of occupied floors from ground level, integrating debris-resisting structures as part of the building structures, constructing debris-resisting barriers, boulder fences, etc. It is much more practical, economical and safe to study and deal with the hazards at the time of development, than to attempt to address the problem later.

2.3.2 Screening of Sites Subject to Natural Terrain Hazards

Not all development sites are affected by natural terrain hazards. Whether a site will be affected depends on how close the site is to the hillside and how susceptible the hillside is to landsliding. To facilitate project planning and early identification of potential constraints, it is good practice to carry out, where necessary, an initial screening as early as possible to examine whether the site may be subject to natural terrain hazards. The screening is not demanding either in terms of skills or time.

Sites that are located beyond the influence zone where landslide debris may reach would not be subject to the natural terrain hazards even if landslides occur on the hillside. Such sites may be excluded from further screening and study of natural terrain hazards. For this reason, the GEO has established a set of simple guidelines to assist planners, land administrators, project managers, etc. in identifying whether a site may require screening in respect of natural terrain hazards. This set of "Inclusion" guidelines comprise the following two conditions:

(a) the proposed development involves Group 1, 2 or 3 facilities[4] (see Table 2.2), <u>and</u>

(b) there is a 'hillside' sloping at more than 15° within 100 m horizontally upslope of the site boundary. For the purpose of applying the "Inclusion" guidelines, the term 'hillside' refers to sloping natural or quasi-natural terrain that is undeveloped or largely undeveloped. It excludes built-up areas, such as terraces supported by retaining walls, and a series of paved platforms separated by man-made slopes. Where there are man-made slope features adjoining a sloping terrain that is undeveloped or largely undeveloped, the 'hillside' includes both the man-made slope features and the sloping terrain.

[4] Natural hillsides (including Hillside Pockets) affecting Group 4 and 5 facilities normally do not require natural terrain hazard study.

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Table 2.2 Grouping of Facilities (adapted from Wong, 1998)

Group No.	Facilities
1	(a) Buildings - any residential building, commercial office, store and shop, hotel, factory, school, power station, ambulance depot, market, hospital/polyclinic/ clinic, welfare centre
	(b) Others - bus shelter, railway platform and other sheltered public waiting area - cottage, licensed and squatter area - dangerous goods storage site (e.g. petrol station) - road with very heavy vehicular or pedestrian traffic density
2	(a) Buildings - built-up area (e.g. indoor car park, building within barracks, abattoir, incinerator, indoor games' sport hall, sewage treatment plant, refuse transfer station, church, temple, monastery, civic centre, manned substation)
	(b) Others - road with heavy vehicular or pedestrian traffic density - major infrastructure facility (e.g. railway, tramway, flyover, subway, tunnel portal, service reservoir)
3	- densely-used open space and public waiting area (e.g. densely-used playground, open car park, densely-used sitting out area, horticultural garden) - quarry - road with moderate vehicular or pedestrian traffic density
4	- lightly-used open-air recreation area (e.g. district open space, lightly-used playground, cemetery, columbarium) - non-dangerous goods storage site - road with low vehicular or pedestrian traffic density
5	- remote area (e.g. country park, undeveloped green belt, abandoned quarry) - road with very low vehicular or pedestrian traffic density

Note:

(1) For roads, the Facility Group should be based on Figure 4.1 of Highway Slope Manual (GEO, 2000) taking into account the actual Annual Average Daily Traffic and the number of road lanes[5].

(2) For footpaths alongside roads, it may be assumed that footpaths are within the same group as the adjoining roads, except for Expressways (EX), Urban Trunk Roads (UT) and Rural Trunk Roads (RT). Footpaths alongside EX, UT and RT roads may be taken, by default, as a Group 5 facility, unless dictated otherwise by site-specific conditions.

[5] When studying natural terrain hazards for existing roads under the LPMitP, sensitive routes (e.g. red routes, pink routes, routes to vulnerable areas, bus routes, bus depot routes) with traffic density lower than Group 3 may be considered as a Group 3 facility.

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Where a development site satisfies the “Inclusion” guidelines, arrangements should be made for a screening in respect of natural terrain hazards. The GEO has been adopting two sets of technical criteria for screening of sites in respect of natural terrain hazards. These two sets of criteria, viz. the “In-principle Objection Criteria” and the “Alert Criteria”.

The screening process is generally conducted at the land use planning stage when the case is referred to the GEO from the Planning Department, e.g. during planning application under the Town Planning Ordinance (Cap. 131), or at the land disposal or lease modification stage when Lands Department seeks GEO’s input. The screening should also be carried out as part of the technical feasibility of a proposed public works project (i.e. Technical Feasibility Statement or Feasibility Study report) and geotechnical preliminary study of Housing Department projects.

The screening will provide information on whether any parts of the site may be affected by natural terrain hazards, which will give an indication of likely scale of the problem, facilitate preliminary design of the site layout, and help to determine where further input on study of natural terrain hazards is required. It should normally come to a conclusion on the feasibility of the proposed development, any need to avoid areas exposed to severe hazards, and any provision to be made in the development for NTHS and mitigation.

2.3.3 In-principle Objection Criteria

In line with the current practice, the GEO would object in-principle to proposals for the zoning and disposal of a site that falls under either (a) or (b) of the following conditions, denoted as “In-principle Objection Criteria” (Figure 2.4):

(a) The site is faced with severe natural terrain hazards. A site falls within this category if any proposed Facility Groups 1(a), 1(b) and 2(a) (Table 2.2) is either:

(i) located within an angle of reach of 35° from any natural terrain at an elevation of 50 m or more above the proposed site formation level, or

(ii) located on, or immediately below, terrain that is known to be affected by active, large-scale movement (e.g. Tuen Mun Area 19).

(b) The site is proposed for small-scale New Territories Exempted House (NTEH) and is subject to potential natural terrain hazards. However, the required NTHS and mitigation works are disproportionate to the scale of the proposed development and could thereby render the proposed development not economically viable. A site falls within this category if it meets all of the following conditions:

(i) the site meets GEO’s requirement for study of natural terrain hazards (see Sections 2.3.4 to 2.3.6 below),

(ii) the site is not located in a cluster of existing developments of a comparable nature and affected by similar hazards, and

(iii) it is unlikely that the requirement for study and mitigation of natural terrain hazards can be lifted by alternative means, such as adjustment of the layout of the proposed development, delineation of no-build zone, simple drainage provisions, confirmation of no need for NTHS and mitigation by a brief review of the natural terrain hazards, etc.

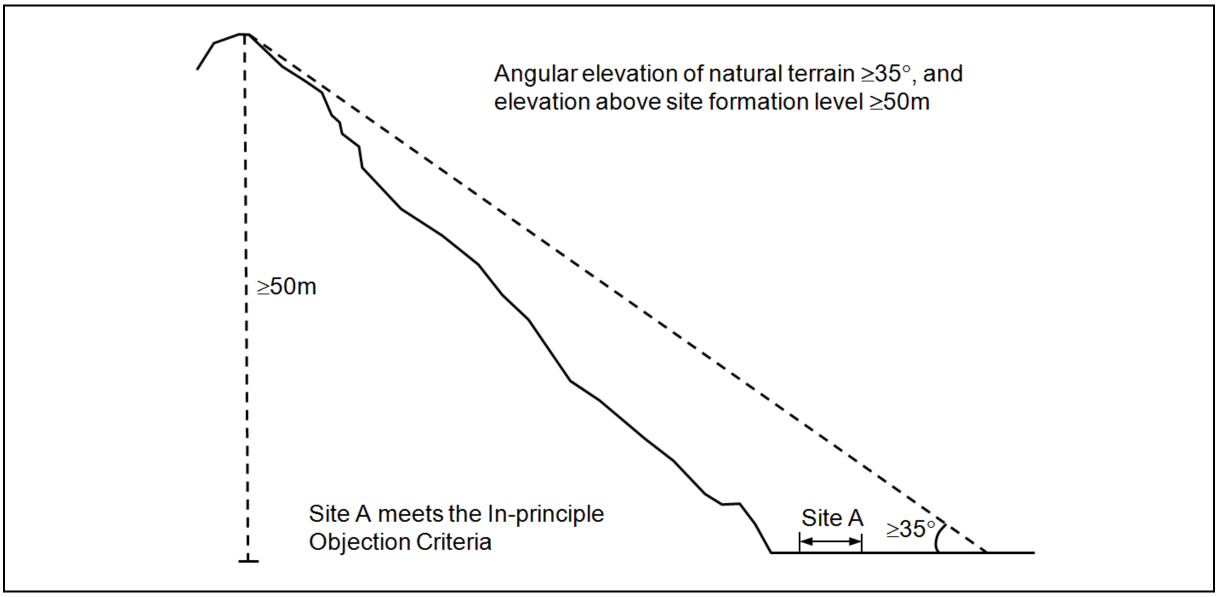

Figure 2.4 Application of In-principle Objection Criteria

Although the criteria are essentially applied to "habitable" facilities, Group 1(b) facilities (Table 2.2) are included because they are comparable in terms of consequence if affected by natural terrain landslides. Items 2.3.3(b)(i) to (b)(iii) above are to be assessed based on professional judgement on a case-by-case basis, with account taken of the nature of the proposed development, its proximity to the hillside, size and geometry of the site, and available information on the conditions and landslide history of the hillside. The above criteria are not applicable to sites after disposal.

2.3.4 Alert Criteria

For a site that may be affected by natural terrain hazards, but does not satisfy the "In-principle Objection Criteria", an NTHS is required to study the hazards and identify any mitigation measures required. The following criteria, denoted as "Alert Criteria" (Figure 2.5),

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are used by the GEO to help decide whether a site falls under this category:

(a) It is a new development site involving provision of Group 1 to 3 facilities (Table 2.2), or it is a redevelopment that requires modification of the lease conditions and involves either a significant population at risk or a significant increase in population at risk.

(b) Where there is natural terrain outside the site, but within the same catchment, that is at an angular elevation of 20° or more from the site and where there is ground sloping at more than 15° within 50 m horizontally upslope of the site boundary, provided that there is a credible debris flow path to the site.

Site	Angular elevation of natural terrain ≥20°	Within 50m of ground sloping at >15°	Alert Criteria met?
A	Yes	Yes	Yes
B	Yes	No	No

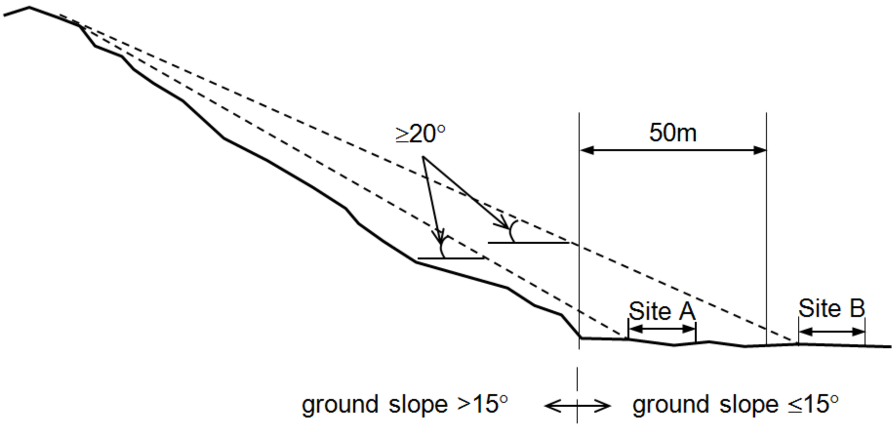

Figure 2.5 Application of Alert Criteria

An NTHS may be required for sites that lie beyond the area delineated by the above criteria, as for example for sites where there are historical landslides with long debris runout extending beyond these limits, and for sites that are either intersected by, or adjacent to, a natural drainage course.

A "credible debris flow path" is generally a downhill path followed by surface water. However, flow paths that debris could follow, but are deemed unlikely to do so would not be regarded as "credible". For example, a debris flow path down a ridge line, rather than descending into the catchment on either side of the ridge line, would not be "credible". Another example would be a site that is shielded from debris by a substantial structure such as a large building.

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In applying the "Alert Criteria" to help decide whether an NTHS is required for a site, professional judgement is exercised with account taken of the nature of the proposed development, its proximity to the hillside, size and geometry of the site, and available information on the conditions and landslide history of the hillside. In addition to recommending that an NTHS be carried out, consideration is also given to alternative means for dealing with natural terrain hazards. These include adjustment of the layout of the proposed development, delineation of no-build zones, simple drainage provisions, etc. (see Section 5.2).

2.3.5 Special Considerations for Dealing with Boulder Fall Hazard

For boulders affecting new developments, it is necessary to establish that there would be a significant risk before any further action is taken to deal with the boulders. In the context of boulder falls, the term "significant risk" should mean:

(a) the presence of potentially unstable boulders, as evidenced by any known signs of potential boulder falls from API or field inspection (e.g. accumulation of recent boulder falls at the hillslope toe), or boulder field with known instability, as evidenced by past boulder fall records, on the hillside close to the new development; and

(b) a significant population (i.e. Group 1, 2 or 3 facilities as shown in Table 2.2) would be at risk in the event of boulder falls.

Since an NTHS will be required for a new development site that meets the "Alert Criteria", and this includes an evaluation of boulder fall hazard, the "Alert Criteria" is a sufficient screening mechanism to ensure that new development sites subjected to a significant risk of boulder falls are not overlooked.

Where the new development does not meet the natural terrain "Alert Criteria", evaluation of boulder stability would not be required unless there is evidence to show that the site is subject to a significant risk of boulder falls. An example of this would be previous boulder falls with long runout distances around the site or on a similar adjoining hillside. However, long runout distance calculated from boulder fall analysis based on generalised parameters without correlation cannot be accepted as evidence that there is a significant risk of boulder falls affecting the site beyond the area delineated by the "Alert" area. Supplementary guidelines on mapping of boulders are provided in Section 4.4.3.

2.3.6 Special Considerations for Dealing with Planar Hillside Catchments

The requirement for NTHS would not be imposed on new development sites if all the following principles are met:

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(a) the hillside catchment(s) directly overlooking the site is planar in nature, i.e. devoid of topographic depressions or drainage lines;

(b) the natural hillside overlooking the subject site has an angular elevation of <25° (i.e. the first criterion regarding angular elevation of the Alert Criteria is relaxed from 20° to 25°; the second criterion regarding ground slope angle remains unchanged);

(c) there are no recent ENTLI records and reported landslide incidents within and in the immediate vicinity[6] of the hillside catchment(s);

(d) there are no Class A and B relict ENTLI records within and in the immediate vicinity of the hillside catchment(s);

(e) there are no obvious signs of distress (e.g. tension crack) within and in the immediate vicinity of the hillside catchment(s) from API or vantage point observations; and

(f) there are no obvious signs of boulder fall hazard or evidence of severe surface erosion within and in the immediate vicinity of the hillside from a review of aerial photographs. An example would be to see if there are any recent boulder falls on the hillslope by reviewing different years of aerial photos (e.g. year 1963 for baseline and recent years for latest conditions). This review also serves to supplement the landslide records of recent years not yet covered by the ENTLI. Supplementary guidelines on dealing with boulder fall hazard are given in Sections 2.3.5 and 4.4.3.

The principles given above should not be applied to Hillside Pockets (see Section 2.2.4) that are planar in nature. This is because the particular setting of planar Hillside Pockets may possess a combination of hazardous factors, such as presence of fill bodies, disturbed terrain and erratic surface runoff from roads and building platforms.

2.3.7 Site and Study Area

The study of any natural terrain close to a proposed development should be related to a well-defined site boundary, preferably recorded on a topographical map of scale 1:5,000 or larger. In the early stages of a project, there may be a number of possible uses and layouts for a site, which may be subject to changes. At this stage, the study may have to consider the entire area inside the site boundary as potentially habitable. Hence, any hazards would be evaluated in relation to the site boundary. The study should determine if any identified

[6] Determination of "immediate vicinity" shall be based on the geomorphological setting of the catchment of concern on a case-by-case basis.

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hazards could result in debris being deposited within the site boundary and if so, to establish the debris travel path, magnitude and nature of such materials.

The study area for any site is normally the entire upslope catchment of natural terrain above the site boundary. This may include natural terrain separated from the site by existing developments such as roads or buildings, unless these developments are judged to provide a barrier or buffer against debris reaching the site from the natural terrain. It may be possible during the early stage of a study to exclude parts of the catchment on the basis that simple topographical relationships show that the terrain could not affect any part of the site. However, in order to assess the potential natural terrain hazards in its regional context, catchments in the relevant vicinity may need to be considered.

3 Approaches to a Natural Terrain Hazard Study

3.1 Scope of a Natural Terrain Hazard Study

The scope of an NTHS comprises:

(a) the determination of the location, type, frequency and magnitude of any natural terrain hazards that may affect a site, and

(b) where an identified hazard is deemed to affect a site, to determine the design event for such a hazard and outline a mitigation strategy to reduce the risk it poses to the development.

The level of study required to determine if any hazards exist and to select suitable mitigation measures if required will vary according to the setting of a site. The resources required to study a site will also vary according to the size of the site and its proposed use. Siting critical facilities away from vulnerable areas, where possible, will often result in a substantial saving with respect to the input required to address the natural terrain hazards. It will also minimize exposure to risk associated with uncertainties or unforeseen conditions.

3.2 Approaches to the Study

3.2.1 Introduction

Three approaches, namely Factor of Safety, Quantitative Risk Assessment (QRA) and Design Event Approach (DEA), may be used, either individually or in combination, to evaluate natural terrain hazards.

3.2.2 Factor of Safety Approach

The Factor of Safety approach is set out in the Geotechnical Manual for Slopes (GCO, 1984). This approach requires the study of the stability of the natural terrain and design of

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any necessary slope stabilization measures to meet the requirements given in the Manual.

As stipulated in Section 5.2.3 of the Manual, natural terrain does not need to meet the factors of safety given in Table 5.1 of the Manual if it is "undisturbed" and "a careful examination is made to determine that there is no evidence of instability or severe surface erosion". The term "evidence of instability" used in the Manual refers to "evidence relevant to future instability".

By implication, if one chooses to adopt the Factor of Safety approach and if the natural terrain does not satisfy the two criteria given in Section 5.2.3 of the Manual, the natural terrain has to meet the factors of safety stipulated in Table 5.1 of the Manual. In practice, few natural hillsides satisfy both criteria.

The Factor of Safety approach can be used by practitioners who opt for prevention of natural terrain failures. In the past, the Factor of Safety approach was adopted in the study of natural terrain below development areas to check that they would not be adversely affected by failure of the natural hillside. It has also been used in assessing the stability of hillsides above development areas against large failures or deep-seated landslides. For a small hillside, it may sometimes be cost-effective and environmentally acceptable to carry out soil nailing rather than installation of debris-resisting barriers. Local soil nailing has also been used for stabilizing oversteepened landslide scarps.

3.2.3 Quantitative Risk Assessment Approach

The Quantitative Risk Assessment (QRA) approach entails detailed assessment of the probability and consequence of natural terrain hazards, and the consideration of risk management actions, e.g. implementation of landslide mitigation measures, to reduce the risk to a development to the ALARP level. The outcome of a QRA is an estimate of the probability of occurrence of different types of adverse consequences, such as the death of individuals (i.e. individual risk) and multiple deaths (i.e. societal risk). The tolerability of the outcome of a QRA is evaluated against a set of risk guidelines with a view to deciding the necessary risk management actions based on the ALARP principle.

A generic framework for landslide risk assessment and management is summarized in Fell *et al.* (2005). Ho *et al.* (2000) gave a detailed discussion of the concepts and misconceptions of QRA as applied to slope engineering, with special reference to landslide problems. Wong (2005) presented methodologies and good practice to assess landslide risk for individual facilities at site-specific level, based on recent application and case histories in Hong Kong. The interim risk guidelines currently adopted by the GEO are given in ERM (1998). As an attempt to standardize the QRA process and further improve practice of QRA on natural terrain landslides, 16 key modules of work were discussed (Wong, 2005).

QRA has been applied to some individual sites in Hong Kong to quantify and evaluate natural terrain landslide risk. Notable case histories include Atkins Haswell (1995), FMSWJV (2004), Halcrow (2005a, b), Arup (2003, 2005a, b) and Wong *et al*. (2004). QRA has also been carried out along with some NTHS under LPMitP, e.g. Fugro (2010), Arup (2011), Aecom (2012a), Halcrow (2012) and Jacobs (2014).

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It should be highlighted that the reliability of QRA results depends on the availability of good quality data, use of an appropriate methodology, techniques and procedures, rigour of the assessment, realistic calibration of the results, together with input by relevant experts exercising sound engineering judgement (Ho & Ko, 2007). The evaluation of landslide risk must be based on a good understanding of the landsliding processes, potential failure modes and likely landslide debris runout characteristics. Parry & Ng (2010) noted that sufficient geotechnical, engineering geological and geomorphological input for the purposes of hazard identification and classification of landslides is essential for risk quantification.

For construction of Potentially Hazardous Installations (PHI), e.g. liquefied petroleum gas station, a QRA is normally required as outlined in the Hong Kong Planning Standards and Guidelines (Planning Department, 2015). Natural terrain landslide hazard risk, being one of the risks that the facility would be exposed to, should be taken into account as part of the QRA.

3.2.4 Design Event Approach

The DEA is based on a qualitative risk framework, with account taken of both the potential hazards and failure consequence. Use of DEA is different from, and does not necessarily require, the adoption of analytical design. The design requirements for the Design Event approach are given in Section 4.9 below.

Like QRA, the DEA can be used by practitioners who opt for mitigation of landslide risk instead of prevention of natural terrain failures. The Design Event is relatively easy to apply as it does not demand formal and rigorous quantification of risk. Many practitioners in Hong Kong favour the use of the DEA where the required mitigation measures are not disproportionate to the scale of the development. However, as this approach does not explicitly consider the risk tolerability, it cannot evaluate mitigation actions based on the ALARP principle, or justify not taking actions on the grounds of a broadly acceptable risk level.

3.2.5 Other Approaches

Other risk-based approaches have been adopted for different scenarios. Figure 3.1 shows a 'bow-tie' diagram, with the two wings representing hazard assessment and consequence assessment. Hazard assessment is directed towards estimating the probability of the full range of credible threats that have the potential to cause adverse consequences; that is, their occurrence initiates a potential accident or damage scenario. Consequence assessment involves the identification and quantification of the full range of adverse consequences arising from the accident scenarios, including the estimation of the probabilities of these consequences. This approach enables simplified QRA to be undertaken (Lee, 2009). However, it must be acknowledged that there are uncertainties and difficulties in practice in extrapolating and evaluating the more extreme scenarios in terms of frequency and volume.

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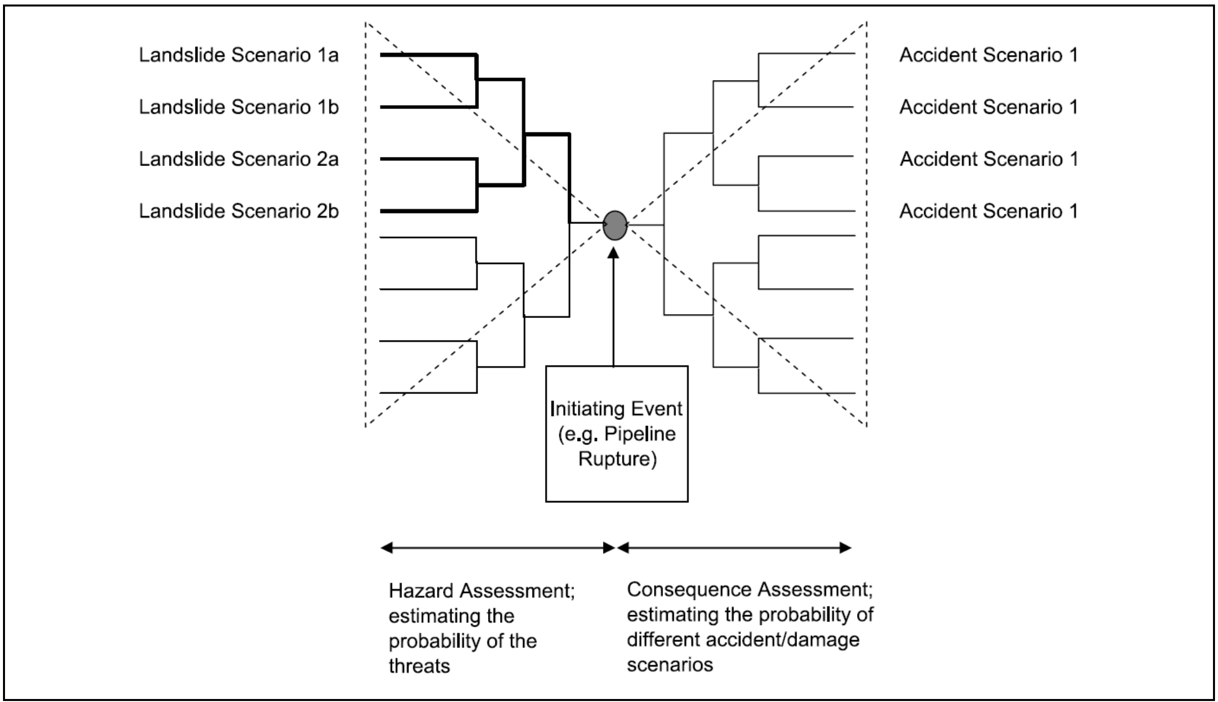

Figure 3.1 A Landslide Risk Assessment 'Bow-Tie' (Lee, 2009)

Another approach is the use of risk matrices (Figure 3.2) where measures of hazard frequency/probability are matched with consequence severity levels. This approach can be an effective tool in raising awareness and increasing visibility of risk for taking appropriate management decisions. The risk matrix approach has been adopted for the West Lantau Regional Study (Millis & Parry, 2014). By evaluating the relative landslide hazards in a given catchment against the corresponding landslide consequence, risk matrices of hazard versus consequence for villages and transportation routes have been produced to allow screening and ranking of the hillside catchments (Figure 3.3).

Likelihood		**Consequences to property (With indicative approximate cost of damage)** (1)				
	Indicative Value of Approximate Annual Probability	**1: CATASTROPHIC 200%**	**2: MAJOR 60%**	**3: MEDIUM 20%**	**4: MINOR 5%**	**5: INSIGNIFICANT 0.5%**
A ALMOST CERTAIN	10^{-1}	VH	VH	VH	H	M or **L** (2)
B LIKELY	10^{-2}	VH	VH	H	M	**L**
C -POSSIBLE	10^{-3}	VH	H	M	M	**VL**
D UNLIKELY	10^{-4}	H	M	**L**	**L**	**VL**
E RARE	10^{-5}	M	**L**	**L**	**VL**	**VL**
F BARELY CREDIBLE	10^{-6}	**L**	**VL**	**VL**	**VL**	**VL**

Qualitative Risk: L low, M medium, H high, VL very low, VH very high

Figure 3.2 Example of a Risk Matrix (AGS, 2007)

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	Hazard Class 1	Hazard Class 2	Hazard Class 3	Hazard Class 4
Primary Classifier	Debris Fan is present	within Incised Terrain Unit	within Middle or Lower Terrain Unit	within Upper Terrain Unit
Secondary Classifier	Undifferentiated Fan and Distressed Terrain Present	within Upper, Middle or Lower Terrain Unit and contains Distressed Terrain	Confined drainage line present within the Upper Terrain Unit	N/A
Tertiary Classifier	N/A	N/A	N/A	N/A

a. Landslide Hazard Assessment Matrix

	Consequence Class 1	Consequence Class 2	Consequence Class 3	Consequence Class 4
Primary Classifier	Building Density GFA >6,000 m^2/ha	Building Density GFA 3,000 to 6,000 m^2/ha	Building Density GFA 1,500 to 3,000 m^2/ha	Building Density GFA <1,500 m^2/ha
Secondary Classifier	>10 Buildings located on a Debris Fan	1 to 10 Buildings located on a Debris Fan; >10 Buildings located on an Undifferentiated Fan; Buildings with 100 m downslope of Distressed Terrain	1 to 10 Buildings located on an Undifferentiated Fan	N/A

b. Consequence Assessment Matrix for Buildings

Consequence Class (Buildings)	Landslide Hazard Class 1	2	3	4
1	1	1	2	3
2	1	2	3	4
3	2	3	4	4
4	3	4	4	4

Risk Level BR1
Risk Level BR2
Risk Level BR3
Risk Level BR4

Highest
Increasing Risk
Lowest

c. Risk Assessment Matrix for Buildings

Figure 3.3 Risk Matrices for Buildings Adopted in the West Lantau Regional Study (Millis & Parry, 2014)

Map-based computer modeling studies (e.g. GIS-enabled, gridded slope stability modeling), especially approaches that use a combination of high-resolution topographic data such as airborne Light Detection and Ranging (LiDAR) and morphological mapping automation, may assist in more rapid, regional assessment than conventional mapping techniques (Sas, 2014).

3.3 Hazard Types

3.3.1 Introduction

Natural terrain hazards can be grouped into hazard types on the basis of the topographical location, the nature of the displaced material and the transport mechanism of the debris. Five hazard types that are generally applicable to most sites in Hong Kong are presented below. These may not cover all possible situations and it may be useful to define other hazard types as appropriate to the prevailing conditions.

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The five hazard types described in the following sections should be considered in the study of each site. For certain sites it may be possible to discount some of them at an early stage. As a study progresses, the hazard types may need to be refined in the light of additional information.

3.3.2 Open Hillslope Landslide

This type of hazard results from a landslide that remains wholly on a planar hillslope and is not channelised along a stream course. Open Hillslope Landslide (OHL) may be classified as slumps, debris slides or debris avalanche (Figure 3.4).

		
a. Debris Slump (Burma Lines Camp, Fanling)	b. Debris Slide (South Lantau)	c. Debris Avalanche (North Tsing Shan Range)

Figure 3.4 Different Types of Open Hillslope Landslide

A <u>slump</u> is a form of slide in which the intact displaced mass partially overlies the surface of rupture. Slumps range considerably in size. Smaller examples of debris slumps are the relatively common shallow displacements of hillslope debris defined by tension cracks or small landslide scarps, such as the Burma Lines Camp failure (FSWJV, 1999). At the other end of the scale are the larger, deeper seated, rotational, inactive ancient failures that have been recognized at several localities, for example at Area 19 in Tuen Mun (Scott Wilson, 1999a).

A <u>debris slide</u> is the next stage of mobilisation where the displaced, but still intact, mass moves beyond the plane of rupture by sliding. When these occur on steep hillsides they typically form an elongate scar. True debris slides are seldom encountered due to the propensity of a coarse granular soil mass to break up when sliding over an irregular surface, although isolated rafts of intact displaced material are commonly found associated with remoulded landslide debris. These features probably represent a transitional stage between a debris slide and debris avalanche. Whilst rare, earth slides do occur in Hong Kong, e.g. the slow moving earth slide in Tuen Mun (Parry & Campbell, 2007).

<u>Debris avalanche</u> is the most common type of natural terrain landslides in Hong Kong (Figure 3.5a). Most of the displaced material breaks up and becomes remoulded, but no additional surface water is incorporated into the debris. The initial displacement of material at the source may be by sliding at the base of the displaced mass, although there are few examples with clear field evidence for this.

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Open hillslope landslides may occur on any part of a hillside. Depending upon the local topography, the debris below the scarp may be funneled into topographic depressions or drainage lines. This results in a trail that is narrower than the source and the avalanche is somewhat channelised (Figure 3.5b). Although the overall movement of the landslide debris has a flow-like morphology, a number of mechanisms may have been involved in addition to flow. If the material is saturated, then slurry flow may become the dominant mechanism and this part of the event could be classified as a debris flow. The upper section of the 1990 Tsing Shan Debris Flow was a debris avalanche, which developed into a debris flow further down the slope (King, 1996).

a. Debris Avalanche
(Tai O San Tsuen, Year 2008)

b. Debris Avalanche *(channelised to an extent at the lower section)*
(Mid Tsing Shan Range, Year 2000)

Figure 3.5 Examples of Debris Avalanche

3.3.3 Debris Flow

Debris flow refers to a landslide in which the landslide debris moves by the dominant mechanism of slurry flow. In Hong Kong, debris flows usually develop from debris slides or debris avalanches. If the moisture content of the displaced material is high enough then slurry flow may develop during movement without additional water. More commonly a debris flow develops when landslide debris mixes with surface runoff. A conspicuous and important trait of debris flows involves their tendency to move as a discrete surge or series of surges, with each surge typically exhibiting a coarse-grained head and a finer grained, more-liquefied tail (Jakob & Hungr, 2005).

Debris flows usually occur within topographic depressions (Figure 3.6a). Quite often, the debris enters a drainage line where it mixes with the surface runoff forming Channelised Debris Flows (CDF). Their debris path is controlled by the alignment and confinement of the drainage line. CDF generally have greater mobility than debris flows and debris flows generally have greater mobility than OHL. CDF commonly increase in volume due to erosion and entrainment of loose deposits from the stream bed and banks. It is noted that CDF could occur in drainage lines with different morphological characteristics and are somewhat related to the size of the debris flow. Therefore, field inspection coupled with professional judgment should be used to determine if the drainage line would likely facilitate development of CDF.

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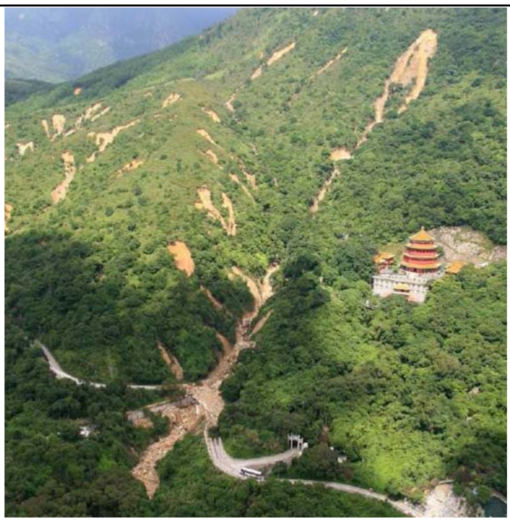
Some of the CDF in Hong Kong may have resulted from the coalescing of multiple debris avalanches to form a single CDF (Figure 3.6b). Examples of debris flow coalescence include the landslides that occurred above Keung Shan Road, Tai O and Mount Davis during the 7 June 2008 rainstorm (GEO, 2012d), north of Leung King Estate at Tuen Mun in 2000 (MFJV, 2004) as well as above Sham Tseng San Tsuen in 1999 (FMSWJV, 2005). Most of them have a main source area with significant failure volume and the other smaller source areas usually contributed a relatively small amount of failure material.

a. Debris Flow within a Topographic Depression (Mui Wo, Year 1993)



b. Channelised Debris Flow (Kwum Yum Temple, Lantau, Year 2008)

Figure 3.6 Examples of Debris Flow and Channelised Debris Flow

As dilution increases, the debris slurry will become progressively more mobile until slurry flow develops into hyper-concentrated stream flow. With further dilution the mechanism grades into stream flow, which is no longer a mass movement process but an alluvial process. At this stage the phenomenon is termed a Debris Flood. An example of this affected the North Lantau Highway during the severe 7 June 2008 rainstorm (Aecom, 2012b) where the debris flood brought a significant amount of sediment/debris downstream, resulting in flooding of a 400 m section of Cheung Tung Road and the adjoining North Lantau Highway (Figure 3.7). Further details of this incident are given in Appendix C.

A debris flood has a lower percentage of sediment by volume than a debris flow. It is believed that the flow velocity in a debris flood would be comparable to that of an ordinary storm water flow and it can move continuously in a channel with a shallow gradient while debris flows usually have peak discharges tens of times greater than debris floods. Debris floods typically produce relatively thin, wide sheets of material, whereas debris flows produce thicker, more hummocky and lobate deposits (Hungr *et al.*, 2001). However, it is usually difficult to assess whether a debris flood could occur on a drainage catchment, unless there is evidence to suggest that this has occurred previously.

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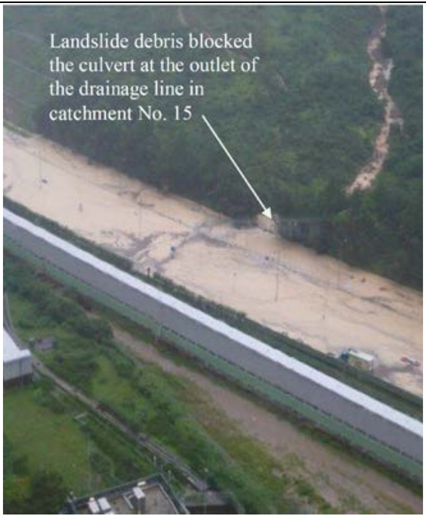
a. General View of the Site



b. Flooding of the Highway

Figure 3.7 Debris Flood at North Lantau Highway

3.3.4 Deep-seated Slide

This type of hazard involves displacement of an intact mass by sliding along a basal rupture surface, usually within saprolite and controlled by adverse geological features. Notable deep-seated slides in Hong Kong include the Shum Wan Road landslide of 1995 (GEO, 1996) where a maximum depth of the 12 m was recorded (Figure 3.8a) and the fault controlled debris slide that occurred above Shek Pik Reservoir in 2008 (McMackin *et al.*, 2009) (Figure 3.8b) where the basal rupture surface was estimated to be greater than 10 m below ground surface. Another example is the Fei Ngo Shan landslide of 2005 where the main scarp involved a 5 m deep failure situated beneath a truncated spurline (MGS, 2008).

a. 1995 Shum Wan Road Landslide

b. 2008 Fault Controlled Debris Slide above Shek Pik Reservoir

Figure 3.8 Examples of a Deep-seated Slide

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This landslide type does not include soil creep, which is not generally considered to be a hazard; however, evidence of soil creep may provide an indication of potential hazards. Deep-seated, intact sliding is not common in Hong Kong and in some cases the displaced material has not moved from the source area (slump) or where tension cracks and bulging are the sole surface expression of movement (Irfan, 1989; Ho & Evans, 1993).

The degraded scars of ancient, more deep-seated landslides in the Hong Kong landscape can be recognized on aerial photographs. However, the source areas are usually indistinct due to modification by more recent small landslides on the scarps. Also the displaced material commonly forms fans and aprons of colluvium which make it difficult to distinguish the deposits from individual events. The materials, mechanism of failure and age of these scars may be established if they have been investigated in the field.

3.3.5 Rock Fall

This type of hazard results from one, or several, typically angular rock fragments being transported initially by free fall but may include sliding, bouncing and rolling. Rock fragments are generally joint-bounded and displaced from a rock face by sliding, wedge failure or toppling. Initiation may often be related to transient high water pressure along joints and where smaller “key” blocks have been displaced. Rock fragments may also be displaced by root wedging. Locations where this hazard is present can be identified as it is limited to rock faces. The 2001 Lei Pui Street landslide initiated as a structurally controlled failure of a granite rock slab which subsequently developed into a CDF when the debris entered a drainage line (Williamson & Ho, 2009).

a. Rock Fall

b. Boulder Fall

Figure 3.9 Example of Rock Fall and Boulder Fall

The sudden failure of a large-scale rock mass with rapid and chaotic movement downslope in a relatively dry state may be referred to as a rock avalanche. They often override minor relief features and are unconfined. Possible relict rock avalanches were identified in Wang Hang (AFJV, 2014) based on the sharpness, steepness and irregularity of

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the degraded rock faces and presence of debris lobes below with a high rock block content. However, it should be noted that the interpretation of relict rock avalanches have a considerable degree of uncertainty (e.g. whether accumulation of rock debris is from a single or multiple events).

3.3.6 Boulder Fall

This type of hazard results from one, or several, typically rounded rock fragments being transported by rolling, bouncing and sliding. Boulders originate either as corestones in a weathered profile or are derived from colluvium or talus. They become exhumed during hillslope erosion, although in some instances they may have originated higher up the slope from rock outcrops and been displaced to their present position as a rock fall. They are usually dislodged from the natural hillside as a result of soil erosion or undercutting due to landsliding. Where vegetation growth is minimal, locations of boulders on steep slopes can be revealed from interpretation of aerial photographs if they are of high resolution. Once displaced, the rounded boulders could be expected to be more prone to downslope movement than would the angular rock blocks.

3.4 Approaches to Study Hazard Types

3.4.1 Introduction

The three approaches outlined in Section 3.2 above should not be considered as independent of one another. A site may be exposed to several types of natural terrain hazard and of varying scales. Some approaches may be more applicable to certain hazards than others. Therefore, the practitioners should choose the most suitable approach, or combination of approaches, for a study area.

3.4.2 Open Hillslope Landslide and Debris Flow

As large areas of natural terrain may be susceptible to OHL which may develop into debris flows, the Factor of Safety approach for determining any stabilization works required to prevent these hazards are usually impractical. Therefore, the QRA and DEA are usually more appropriate for addressing this type of hazard.

3.4.3 Deep-seated Slide

If the extent of the hillside that is susceptible to this type of hazard can be defined, the Factor of Safety approach may be applied to determine the need for any slope stabilization works. However, stabilization works on the hillside may be costly, particularly if a large volume of potentially unstable ground is involved.

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3.4.4 Rock Fall

The Factor of Safety approach is generally applicable to dealing with rock fall hazard especially for unstable rock faces where in-situ stabilization works are anticipated because potentially unstable blocks can commonly be identified from field mapping. However, implementation of some mitigation measures, such as rock ditches and meshing, is prescriptive or empirical in nature.

3.4.5 Boulder Fall

There is an established methodology in Hong Kong for studying boulder fall hazard (e.g. Au & Chan, 1991). Depending on the hillside conditions, all three approaches may be used to assess this type of hazard. However, it should be noted that engineering judgement based on available records and field observations often overrides rigorous analysis in the evaluation of boulder stability. The likelihood of boulder fall initiation and subsequent movement can generally be assessed by field mapping based on boulder location, embedded depth, boulder shape, local slope angle, vegetation density, etc.

4 Natural Terrain Hazard Study

4.1 Introduction

The purpose of an NTHS is to identify natural terrain hazards that may affect a particular site and to propose a mitigation strategy if required. The study of natural terrain hazards involves consideration of the site in the context of its regional geological and geomorphological settings, any man-made influences that may have modified this setting (e.g. Styles & Law, 2012) and the history of landsliding in the area. This information together with an engineering geological investigation allows a geological model of the catchment to be developed.

An NTHS generally comprises a desk study of available information about the study area, an examination of all available aerial photographs, collection of field data, identification of natural terrain hazard types and assessment of their hazards, and determination of the hazard events to be mitigated against. Ground investigation (GI), in the form of trial pits, trial trenches or drillholes, may also be required. Account may have to be taken of catchments in the relevant vicinity or other similar locations to identify all possible hazards.

The results of the study should allow a decision to be reached as to whether the potential risk can be contained by mitigation works or minimized by adjusting the development layout, or whether the risk is so severe that it would render a proposed development not feasible or relocation of facilities at risk. Where applicable, the study should include determination of the location, potential magnitude (i.e. the design events) and runout characteristics of specific hazard types that are likely to affect the site being studied.

The following sub-sections outline the key components and procedures of good practice recommended for an NTHS. The aspects on mitigation strategy of an NTHS are given in Section 5.

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4.2 Desk Study

4.2.1 General

The desk study should comprise a thorough review of geological and geotechnical information pertinent to the study area so as to identify those features that may be hazardous to the site.

4.2.2 Types of Information

Desk study information relevant to site investigation in Hong Kong is described in Geoguide 2 "Guide to Site Investigation" (GEO, 1987). Much of the information described in Sections 4, 5 and 6 and Appendices A, B and C in the Geoguide is relevant to the desk study. Appendix B of the Geoguide "Sources of Information" has been superseded by GEO Technical Guidance Note (TGN) No. 5 (GEO, 2009).

Published maps that provide information on natural terrain for the whole of Hong Kong include topographical maps, geological maps, and the Geotechnical Area Study Programme (GASP) series maps based on terrain classification (Styles & Hansen, 1989). Another map series based on interpretation of high and low altitude aerial photographs is the ENTLI. An inventory of boulder fields mapped from the 1963 low altitude aerial photographs is also available. Most of these data are available for consultation by the public in the Geotechnical Information Unit (GIU) of the Civil Engineering Library (CEL) maintained by the CEDD.

A considerable amount of slope safety-related information is contained in a computerized Slope Information System (SIS). The SIS displays the locations of registered man-made slopes, ENTLI features, HLC, past landslide incidents, GI records, etc., along with base maps. The SIS can be accessed via the Hong Kong Slope Safety website http://hkss.cedd.gov.hk. A web-based application "Geotechnical Information Infrastructure" (GInfo) is also available for retrieval of the datasets from dedicated terminals in GEO and conducting spatial analysis using predetermined geo-processing functions. The GInfo is also available to the practitioners via the Internet.

If the site or other parts of the study area have previously been investigated, or developed, then useful data may be available. This information may include previous GI records, building records, details of man-made slope and natural terrain hazard studies. Each Government Department retains its own files on projects that are carried out under its control. Copies of design reports and record drawings of completed projects are also kept. A digital Geotechnical Information Unit (DGIU) system is available for retrieval of existing GI records in the CEL and also for registered practitioners to retrieve information in their work place.

There is no single topographical dataset, remote sensing data, nor mapping technique that can be independently used for geomorphological assessment. Integrated approaches to API, field mapping, and LiDAR interpretation are essential for balancing the limitations of particular data and techniques.

4.2.3 Topographical Maps

Topographical maps of Hong Kong are available from the Survey & Mapping Office (SMO) of the Lands Department. Full coverage of Hong Kong is available at 1:20,000, 1:5,000 and 1:1,000-scales and each is appropriate for different aspects of NTHS.

The 1:20,000-scale maps have been used as base plans for various thematic maps that cover the whole of Hong Kong, including geology, GASP terrain classification and boulder field inventory. In general, this scale is too small to show details of a study area but can be used to place the study area in a regional context. The 1:5,000-scale maps are useful for delineating the study area, and for large catchments they can be useful base maps to present data and information. The 1:1,000-scale maps are a suitable base for API and field mapping.

4.2.4 Aerial Photographs

Aerial surveys in the HKSAR have been undertaken by the Government, or the British Royal Air Force (RAF). Since 1967, almost all aerial surveys have been undertaken in-house using fixed-wing aircraft and helicopters from the Government Flying Service (previously named the Royal Hong Kong Auxiliary Air Force). The Photogrammetric and Aerial Survey Section of the Survey and Mapping Office, Lands Department was set up in 1975 to organise regular aerial surveys, although one set of photographs was still produced by the RAF in 1975.

The earliest available aerial photographs of parts of Hong Kong were taken in 1924 with the next set of photographs taken in 1945. Other photographs of variable quality and coverage are available up to the first complete survey of Hong Kong undertaken in 1963. This is a set of high quality, low altitude[7] aerial photographs taken at a time when there was generally low vegetation cover in Hong Kong, which allows clear observations of ground features and consequently provides a useful "baseline" for comparison with subsequent observations.

Regular low altitude photography has been carried out since 1985, although these aerial surveys have concentrated on Hong Kong Island, Kowloon and the new towns. Between 1972 and 1985 there was at least partial low altitude coverage of Hong Kong Island and Kowloon each year; however, the remaining land area only has sporadic coverage. High altitude coverage of the HKSAR is more comprehensive from 1972 to date, with only the years 1972, 1977, 1980 and 1984 having very limited coverage. Since 1988, two sets of high altitude photography have been carried out for most years, at 8,000 and 20,000 feet. Examples of high altitude and low altitude aerial photographs are given in Figure 4.1.

The vertical aerial photographs have been utilized for the production of Digital Orthophotos (DOP) using digital photogrammetric technology. DOP produced from aerial photographs taken in 1963 and some recent years are available for sale in the Survey and Mapping Office of Lands Department.

[7] In Hong Kong aerial photographs taken with flying height less than 8,000 feet are referred to as 'low altitude' while 'high altitude' refers to photographs taken at altitude more than 8,000 feet.

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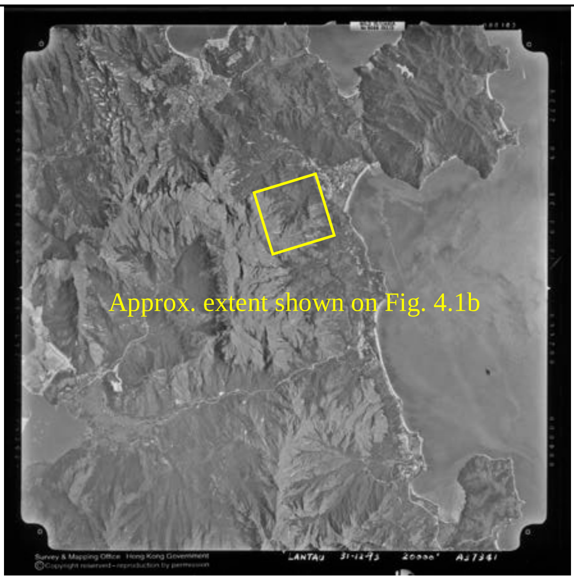
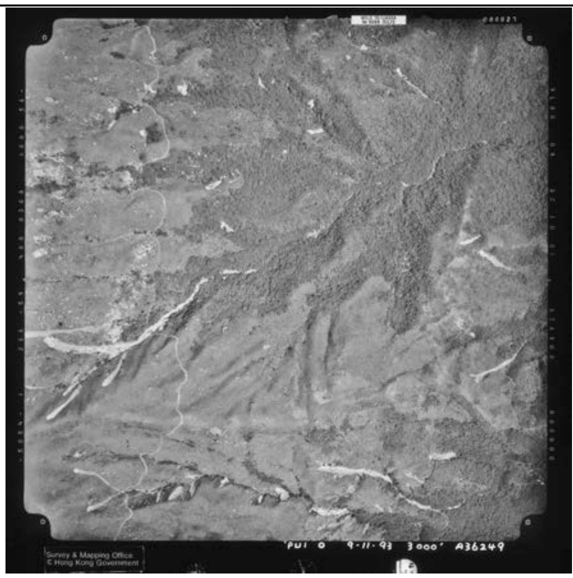


a. Example of a High Altitude Aerial Photograph taken in December 1993 at 20,000 feet



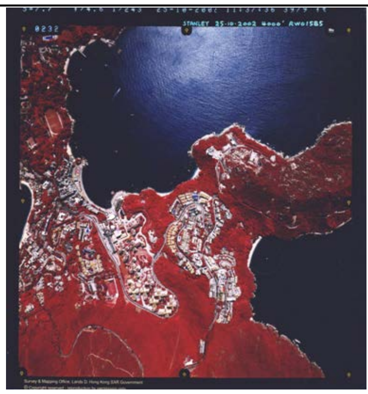
b. Example of a Low Altitude Aerial Photograph taken in November 1993 at 3,000 feet

Figure 4.1 Aerial Photographs Taken at Different Flight Height

Vertical aerial photography provides the most consistent coverage and is therefore obtained systematically for mapping purposes and to provide a historical record of development. Most (>95%) of the aerial photographs taken in Hong Kong are vertical whereas oblique photographs (Figure 4.2a) are taken in some areas. Oblique aerial photography is an extremely useful complement to vertical photography. A collection of oblique aerial photographs taken by GEO between 1974 and 1997 using helicopters is also held in the Planning Division of GEO and should be consulted where appropriate.

a. Black & White, Oblique

b. Colour, Vertical



c. Infra Red, Vertical

Figure 4.2 Different Types of Aerial Photographs Available in Hong Kong

Before 1972, all aerial photographs were black and white. From 1972 to 1980s, colour photography was only very occasionally taken. There was an increase of usage of colour up to 1993, both with improvements in colour film and processing. Since 1993, colour aerial photography has been carried out routinely, with both sets of high altitude photographs and at

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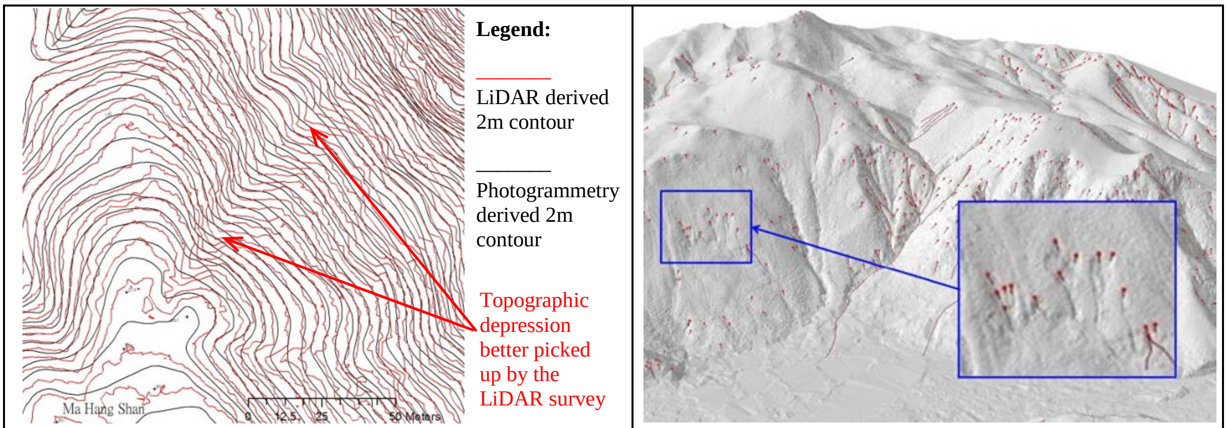
least one of the low altitude sets completed in colour (Figure 4.2b). Infra-red aerial photography has been taken for some areas in Hong Kong (Figure 4.2c), which may in some cases be useful for identifying areas of seepage and erosion. Some common applications of API in Hong Kong are given in Ho *et al*. (2006).

Aerial photographs (in paper or digital format) are available for sale from the SMO of the Lands Department. For public works projects, much of the Government collection can be borrowed from the GEO Aerial Photograph Library, housed in the Planning Division of the GEO. It should be noted that the aerial photographs purchased at Lands Department are currently produced by printing of scanned film while some old aerial photographs contained in the GEO Aerial Photograph Library were printed directly from the film and are of better quality.

4.2.5 Territory-wide Airborne LiDAR Data

LiDAR technology, with multi-return capability, can produce ‘bare-earth’ ground profiles or digital terrain models through a data processing technique known as ‘virtual deforestation’. In 2006, a pilot airborne LiDAR (Light Detection and Ranging) survey of Hong Kong Island demonstrated that LiDAR data would be beneficial in deciphering ground features under a thick vegetation cover (Ng & Chiu 2008). The LiDAR-derived contours in densely vegetated areas provide more details than those produced from conventional mapping method using the photogrammetric technique (Figure 4.3a). With the experience gained from the pilot survey in 2006, a territory-wide survey was conducted in 2010.

LiDAR data have proven to be useful in NTHS where much of the hillsides are covered with vegetation. The ‘bare-earth’ models facilitate identification of ground features, such as relict landslides and subtle terrain morphology that would not usually be discernible from aerial photographs due to the thick vegetation cover (Figure 4.3b). Recent developments in the application of the LiDAR data are outlined in Lai *et al*. (2012), Sas *et al*. (2012) and Sas (2014).



a. Comparison between LiDAR-derived Contours and Contours Derived from Photogrammetry

b. Landslide Scars and Trails Clearly Seen on Bare Earth Surface Model

Figure 4.3 LiDAR-derived Ground Model

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4.2.6 Digital and Remote Sensing Technologies

Apart from airborne LiDAR, GEO over the years has made significant efforts in exploring the application of digital and remote sensing technologies to enhance the capability and efficiency of undertaking NTHS. These include GIS, digital photogrammetry, Global Positioning System (GPS) and terrestrial LiDAR, which have provided promising results. Digital and remote sensing technologies are playing an increasingly important role in NTHS, ranging from data management, analysis and interpretation of geospatial data, to providing critical information for problem solving and decision making (Ng and Wong, 2007).

Due to the availability of high resolution aerial photography in Hong Kong, satellite imagery usually has limited use in the routine NTHS. However, due to the high frequency of data capture, satellite images could be useful in mapping of landslide events shortly after their occurrence. Nichol *et al*. (2006) documented the application of high-resolution stereo satellite images to landslide hazard assessment in Hong Kong. Potential applications of remote sensing techniques for identifying areas of seepage in Hong Kong and for geotechnical applications are discussed by Scott Wilson (1999b).

4.2.7 Geological Maps

Geological maps, covering the whole of Hong Kong at 1:20,000-scale, are available from Government Publications Centres. These maps are regional surveys, and should not be used to determine site-specific lithology. However, they are useful in forming an initial geological model as the basis for detailed field mapping and GI. Areas mapped as colluvium in the geological maps are those areas with a colluvial thickness of 2 m or more. These 1:20,000-scale maps are supported by a series of six memoirs describing the geology of Hong Kong. GEO is currently undertaking an updating programme of the 1:20,000-scale geological maps. Individual updated map sheets are released when published. The 1:10,000-scale field sheets that record the original field mapping observations can be viewed at the Hong Kong Geological Survey, which is part of the Planning Division of the GEO.

The geology of Hong Kong is comprehensively described in two memoirs, one of which focuses on the Quaternary geology, including aspects of weathering and geomorphology (Fyfe *et al*., 2000), and the other provides details on the solid geology (Sewell *et al*., 2000). These two memoirs and the accompanying 1:100,000-scale geological maps provide the latest information and interpretation of Hong Kong geology.

A limited number of 1:5,000-scale maps, supported by sheet reports, have also been published. They were prepared to support the new development areas, e.g. North Lantau, Ma On Shan and Yuen Long. These sheet reports can be downloaded from the CEDD website http://www.cedd.gov.hk. Some site-specific geological data are available in the Hong Kong Geological Survey Archive of Maps and Reports and can be viewed in the Planning Division of the GEO. Some of the geologically oriented data held by Planning Division of the GEO have been digitized and are stored in a GIS. These include the 1:20,000-scale geological maps and the locations of geophysical surveys.

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4.2.8 Terrain Classification Maps

A series of eleven 1:20,000-scale terrain classification maps (TCM) covering the whole of Hong Kong were produced by the GEO in the 1980s. Each map covers an irregular area based on catchment boundaries. Derivative maps and accompanying reports have been published for each area as the Geotechnical Area Studies Programme (GASP) series. The series contains 12 volumes, of which Volume XII is a summary report for the whole of Hong Kong (Styles & Hansen, 1989). They are available for consultation in the GIU.

The terrain classification system recorded three attributes, namely slope angle, landform, and instability and erosion. This information was derived from interpretation of pre-1980 aerial photographs. The slope angle information was derived from topographical maps and visual estimates and should now be replaced with slope angles derived from more updated large-scale maps and airborne LiDAR data. The landform data are still generally relevant although the erosion and instability characteristics may have changed due to erosion control measures, particularly revegetation. The terrain classification maps were used to create thematic maps that include a Physical Constraints Map and the Geotechnical Land Use Map (GLUM).

It should be noted that these maps were prepared for general planning and resource evaluation purposes. Whilst the information they contain provides a good basis for engineering feasibility studies they should not be used to interpret parcels of land smaller than 3 ha in size.

Nine catchments with extensive colluvial deposits were also identified for Geotechnical Area Study (GAS) mapping at 1:2,500-scale. These maps contain details of old landslide scars. In 1990, a 1:5,000-scale terrain classification mapping exercise was carried out for eleven 1:5,000-scale map sheets in North Lantau. These are available for consultation in the CEL and have been incorporated into three engineering geology reports on the North Lantau Area (Franks, 1991, 1992; Woods, 1992).

4.2.9 Enhanced Natural Terrain Landslide Inventory (ENTLI)

In early 2004, the GEO commenced compilation of the ENTLI, using both high and low altitude aerial photographs (see Section 2.2.2). The ENTLI is presented in a GIS data format that contains the locations and attributes of landslides identified on natural terrain (MFJV, 2007a; Dias *et al*., 2009). With several updates since the first inventory in 2007, it contains about 110,000 landslides by the year of 2013. Information includes the dates of the aerial photographs when the landslide was first observed, width and length of the landslide scar, slope gradient, and nature of vegetation cover across the landslide source. The following points should be noted when using the ENTLI.

(a) The landslides were identified solely from available aerial photographs. No field validation was undertaken.

(b) There are cases where natural terrain landslides have been mapped within areas which have subsequently been developed.

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(c) Identification of natural terrain landslides using the aerial photographs may have been hindered by poor image resolution, cloud cover, shadows or vegetation cover.

(d) Coverage, availability, scale and resolution of the aerial photographs impose certain limitations. Consequently, all landslides may not have been identified within certain time periods.

The ENTLI is available for inspection as 1:5,000-scale map sheet paper copies in the CEL and the digital copy of the data is available in the SIS. The ENTLI provides a general indication of the distribution of landslides on natural terrain but it should not be used as the sole basis for site-specific assessment. Parry and Ng (2010) stated the limitations of the ENTLI while Hart *et al*. (2009) discussed some limitations in the interpretation of vertical stereo photographic images for landslide investigation.

4.2.10 Large Landslide Dataset

In 1998, the Large Landslide Dataset, covering the whole of Hong Kong, was prepared under the Large Landslide Study. In this study, a geomorphological interpretation was conducted to identify features thought to be landslides with source areas greater than 20 m wide. The study examined the large landslides recorded in the NTLI, GASP maps and geological maps. Some 1,900 large natural terrain landslides were compiled based largely on the interpretation of the 1963/64 low altitude aerial photographs (Scott Wilson, 1999a, c). The 1:5,000-scale maps containing the features are available for viewing in the Planning Division of the GEO.

The features that were identified range from fully vegetated, degraded features of valley-side dimensions to single recent landslide scars. It should be noted that some features might be the result of multiple smaller landslides. Furthermore, old landslides might have occurred under environmental conditions different from the present day. The classifications of sliding, flowing or toppling/falling need to be confirmed by field observations.

4.2.11 Boulder Field Inventory

A series of fifteen 1:20,000-scale boulder field inventory maps covering the whole of Hong Kong was completed in 1998. These maps were derived mainly from interpretation of the low altitude aerial photographs taken in 1963/64. A multiple attribute mapping technique was adopted to present the results. An area of land considered to have a relatively uniform pattern of boulder deposits was delineated within a polygon and drawn onto the 1:20,000-sacle topographical maps (Emery, 1998). The polygons were defined to ensure that they were essentially homogeneous for the four attributes described, namely percentage area covered by boulder, boulder type, boulder size and boulder shape. These maps are available for reference in CEL and a digitised version is available in the SIS. For site-specific assessment, these maps should be superseded by detailed interpretation of aerial photographs and by field mapping.

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4.2.12 Rainfall Data

The GEO operates an extensive network of automatic rain gauges which provides real-time rainfall data to support the operation of the Landslip Warning System. This network has been continuously enhanced and upgraded, to improve coverage and reliability, since its establishment in 1984. The network now comprises 88 rain gauges located throughout Hong Kong. The data capture, control and processing system receives real-time rainfall data from the GEO rain gauges and from an additional 26 automatic rain gauges operated by the Hong Kong Observatory and 4 gauges operated by the Drainage Services Department. Since 1984, the GEO has compiled annual reports to document information on rainfall and landslides occurring in Hong Kong. Detailed reports on landslide investigations, prepared by the GEO, also analyse the relevant rainfall data.

4.2.13 Output from Desk Study

The information obtained through desk study (including detailed API) allows:

(a) the understanding of regional geomorphological setting;

(b) the development of an initial site-specific engineering geological/geomorphological map;

(c) the compilation of an initial landslide inventory;

(d) the identification of an uncertainty register;

(e) the design of an initial GI plan; and

(f) the planning of field mapping traverses.

Some examples of developing the initial engineering geological and geomorphological maps are given in Appendix D for reference.

An initial site-specific landslide inventory should be developed for every study area. For large study areas the site may be of sufficient size so that it is representative of landslide types, magnitudes and frequencies. For small study areas, a larger area than the study area should be considered in order that landslides in a similar setting to the study area can be evaluated. Where evident from API, landslide trails should be mapped with emphasis on separating out landslide runout from subsequent fluvial reworking. Given the limitations of API, key identified landslides will require field verification.

At the stage of the desk study there may be considerable uncertainty associated with the interpretation and to formalize this, an uncertainty register could be used. Table 4.1 shows an example of an uncertainty register following the desk study. This register ensures that the uncertainties are addressed at the subsequent stages and should be updated as the study progresses. Parry *et al*. (2009) illustrated how engineering geological input throughout

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the assessment process can reduce uncertainty with respect to critical issues such as hazard identification, magnitude, frequency and debris mobility.

Table 4.1 Example of Initial Uncertainty Register (modified from C M Wong, 2012)

Description	Significance	Justification of Significance	Proposed Action	Status
Is the large source area of relict landslide RL18 the result of multiple failures? Is the source volume of recent landslide RC25 correct?	Critical	Affect selection of design event volume	Detailed evaluation during field mapping & GI if necessary	Open
Conceptual engineering geological model suggests that the majority of landslides occur at convex breaks in slope associated with Terrain Unit boundaries. The exception to this is Terrain Unit TU3 where changes in slope angle appear to be the key control. Is the change in slope lithologically controlled?	Critical	Possibility of geological/structural control of landslides within the Study Area	Detailed evaluation during field mapping & GI if necessary	Open
Landslide inventory. Are the features landslide related and are the dimensions assumed correct?	High	Affect determination of design event volume	Detailed evaluation during field mapping & GI if necessary	Open
Although considered low possibility based on API and site reconnaissance there is a possibility of development of CDF in Terrain Unit TU 4.2.	High	Possibility of more mobile landslides	Detailed evaluation during field mapping & GI if necessary	Open
Failure of cut slope could destabilize the natural terrain above	High	Previous large-scale failures of a cut slope has occurred. However, the cut slopes are located within the barracks and access is problematic	Detailed evaluation during field mapping & GI if necessary	Open

4.3 Aerial Photograph Interpretation

4.3.1 Purpose

Aerial Photograph Interpretation (API) should be used as the first step in the development of the geological and geomorphological models as well as to examine the history of development and past instability in the study area. Being one of the most important parts of an NTHS, interpretation of aerial photographs should be undertaken by an experienced professional.

The objective of the API is to determine, in as much detail as possible, the terrain attributes of the study area and its surroundings that may influence hazards, as well as details

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of past events. These include the characteristics, magnitudes and observed consequences of past natural terrain hazards, the extent of any boulder fields, drainage characteristics, slope gradient, slope aspect and morphology, characteristics of vegetation cover, location and types of rock outcrops and superficial deposits, etc. Further guidance on terrain attributes that can be mapped from aerial photographs is given in RISC (1996). The API results can help to identify areas for field data collection and provides the basis for determining landslide susceptibility. The API should ideally be undertaken by the personnel who will undertake the field mapping to ensure that the photographs can be re-evaluated during the study as mapping progresses and, where necessary, reinterpreted.

4.3.2 Review of Existing Data

Many of the datasets available for an NTHS were derived from the interpretation of aerial photographs (e.g. Terrain Classification Maps, ENTLI, Large Landslide Dataset and Boulder Field Inventory). As described in their respective sections, these data were prepared under various constraints; some due to data quality whereas others due to method of mapping. Consequently, it is recommended that these datasets should be compared with the results of the site-specific API in order to evaluate the relevance of the desk study information. Account should be taken of the coverage and quality of the datasets, corresponding rainfall history at the site and any environmental changes (e.g. hill fires, human activities) that have occurred in the area.

4.3.3 Review of the Site Condition

The most recent aerial photographs provide information on the current condition of the study area. This is a useful check on the current status of the base map to be used for the API and may provide data to update it. Observations from these photographs can also be useful for planning the site reconnaissance by identifying suitable locations for an overview of the site and possible access points. The best access to the hillside is normally along well-worn footpaths and drainage lines as the vegetation cover in these locations is generally less. Vegetation cover can change rapidly in Hong Kong due to hill fires or clearance by man and regrowth of vegetation can make a cleared area difficult to access.

4.3.4 Interpretation

An important part of the API is mapping topographical, geological and geomorphological features to assist in the development of a geological/geomorphological model. The 1:1,000-scale topographical maps or LiDAR derived contours generally represent sufficient details of the topography to be used as the base maps for recording information. The observations need to be transferred onto a suitable base map, preferably at a scale similar to that of the photographs. The use of orthophotos is generally beneficial in that it allows the accurate location of ground features and enables scaled measurements to be made.

The mapping should be carried out using a well-defined legend that includes all the aspects of engineering geology and geomorphology covered by the mapping. A generally

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accepted system is described in Anon (1972). Important aspects to consider include the scale, flying height, year of photography, time of year and quality of the photographs. Both high and low altitude photographs should be included in any interpretation. Review of good quality oblique aerial photographs (see Section 4.2.4) and site photographs can provide useful information.

The interpretation should make use of as complete a history as possible, preferably using both dry season and wet season coverage as this may allow more precise age-bracketing of specific landslides, and/or determination of the effect of changed conditions such as hillside excavations or hill fires. It is important to review aerial photographs from as many consecutive wet seasons for a catchment as possible to build up a history on the likelihood of landslide initiation.

Relevant features that can be recorded from API are discussed below.

(a) Catchment Characteristics - Catchment boundaries can be delineated on the basis of the 1:1,000-scale topographic and/or LiDAR-derived maps but details should be confirmed by API. Topographic depressions and drainage lines should also be marked.

(b) Superficial Geology - The ground surface should, as far as possible, be divided into areas of rock outcrop and regolith. It may be possible to interpret structure or lithology from the rock outcrop and open joints and loose blocks may be observed. Regolith may be divided into saprolite and transported soils. Colluvium can often be recognized by distinct morphological features such as fans, lobes and valley infill. The colluvium may be further sub-divided depending on topographical position, morphology and material properties (MFJV, 2002). Areas of boulders should be mapped and if possible interpreted as rock outcrops, saprolite with corestones or as colluvial boulders. Colluvial boulders may form boulder trails or fans on the surface of distinct colluvial landforms.

(c) Bedrock Geology - With the assistance of geological maps, it may be possible to define rock outcrop, rock type, geological structures and orientation of strata. Photo-lineaments that are typically geologically related should be recorded. These lineaments could be major joints, dykes, lithological contacts or faults.

(d) Landslide Scars - As the past instability of terrain can provide information for the assessment of future events, it is critical to record the location and dimensions of all landslide scars and to estimate their date of occurrence. The terminology used to describe landslide scars and the

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parameters recorded should be clear and unambiguous. A useful reference for landslide description is given by Cruden & Varnes (1996) with a recent update by Hungr *et al*. (2014).

A landslide scar is defined as the land surface affected by a landslide and includes the source, the displaced material and any trail. Care should be taken in the identification of recent landslide scars, particularly on high altitude aerial photographs, because some features, such as gully erosion and graves, can easily be confused with landslides. Parameters such as source dimensions and runout extent can be recorded from API.

The identification of relict landslide scars is much more interpretative. Although it may be possible to estimate source dimensions, it is seldom possible to record runout information with confidence. Vegetated concave features with colluvial deposits downslope are common in the Hong Kong landscape and may be interpreted as relict landslide sources. However, such landscape features could result from a large single past event, a number of smaller landslide events, protracted surface erosion, or any combinations of these processes. As such interpretation of landscape features can be crucial to an understanding of the largest events that may have affected the site. Consideration should also be given to the likely age of these landslides and their relevance to the current climatic and site conditions. Great care should therefore be taken with their interpretation, and it should always be backed up by thorough field observations or age dating techniques (Sewell *et al.*, 2015) wherever possible.

(e) Landslide Deposits - Locations of landslide deposits such as colluvial lobes and fans, talus deposits, boulder fields or trails, and scree slopes should be recorded.

(f) Slope Features - Breaks in slope, ridges, knolls, topographic depressions and other small slope features that may not be reflected on the contour map should also be mapped. In particular, attention should be paid to locally steep slopes that could be the source of landslides, and for topographic depressions that could focus flowing landslide debris or surface runoff.

Areas of hummocky ground, reverse scarps, tension cracks, and impeded drainage should also be recorded. These may offer clues to areas where sliding movements have occurred.

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(g) Channel/Stream Features - Where possible, particular attention should be paid to streams that could act as channels for channelised debris flows. The roughness of the stream bed, as represented by the presence or absence of vegetation, bedrock or boulders, should be recorded. Local steep reaches and waterfalls should be noted. The steepness and character of the channel banks and their potential to contribute debris from bank failures and channelise debris should be established if possible.

(h) Boulders - Signs of boulder fall hazard (e.g. recent accumulation of boulders at site boundary) or evidence of severe erosion in the immediate vicinity of the area of concern shall be identified.

(i) Rock Outcrops - Evidence of recent rock fall (e.g. recent detachment of rock blocks or slabs often leave a high reflective colour from joint infill) shall be identified.

(j) Anthropogenic Features - They may include walking tracks, abandoned agricultural terraces, fill bodies, traditional village graves, military fortifications, and trenches and adits left from previous small-scale prospecting and mining (see Section 1.2).

(k) Erosion - Unvegetated areas where sheet or gully/rill erosion occurs are present in some parts of Hong Kong, mainly on granite bedrock. Eroded areas, bare of vegetation, were more common in the past and because much revegetation has occurred in recent years, the relevance of historical information should not be discounted. Where erosion has resulted in steep scarps or undercutting of boulders, these may form landslide sources and should be mapped as such, even if the surface has become revegetated.

(l) Vegetation - Vegetation patterns should be mapped and may provide information on surface or ground water flow, and past erosion and instability. High lush vegetation cover may indicate areas of shallow groundwater table or groundwater discharge; linear strips of low vegetation oriented down slope may indicate overgrown landslide trails. As hill fires are common in Hong Kong, care should always be taken to relate the current vegetation pattern to past conditions.

4.3.5 Limitations

The limitations of API are well documented both in Hong Kong (e.g. Ho *et al*., 2006; Parry & Ng, 2010) and elsewhere (e.g. Fookes *et al*., 1991; Hart *et al*., 2009). Fookes *et al.*

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(1991) observed that "All aerial photographic interpretation must be used with caution. When well done and supported by ground truth exercises they can be a valuable aid to site investigation, depending on the quality and scale of the aerial photographs and the skill and background of the interpreter."

4.4 Collection of Field Data

4.4.1 Introduction

Both engineering geological and engineering geomorphological mapping should normally be carried out by the engineering geologist who undertook the API. The field work, anticipated to be predominantly mapping and site measurements, should be of sufficient detail to verify the findings of the API and to enable a well reasoned assessment of any natural terrain hazards in the catchment. It should contain significantly more detail than that obtained from API given its larger scale. GI, including vegetation clearance, excavation of trial pits and trial trenches as well as drillholes, may be required to supplement the field mapping.

4.4.2 Site Overview

It is beneficial to take an overview of the site, and preferably the whole study area, from some vantage points. This is generally from a hill or tall building close by. In some cases, oblique photographs or stereo pairs taken by helicopters or unmanned aerial vehicles can help to illustrate site conditions for field mapping in the next stage and for further analysis in the office.

As part of the overview, the upslope site boundary of the site should be traversed, as this is the location where any landslide debris would impinge upon it. Any materials along the boundary, such as colluvium or boulder deposits, that could be debris from past landslides or boulder falls should be noted. Careful observation of the local topography along the site boundary should also be made. This can be one of the most important aspects in identifying any possible hazards to a site.

If the proposed development platform is located higher than the adjacent ground or potential debris transport paths such as streams and channels, then the hazard from any postulated event is likely to be relatively low. The final proposed site formation level needs to be considered when making these judgements.

4.4.3 Field Mapping and Site Measurements

<u>General</u>

Although the API will have determined the range of features associated with any natural terrain hazards in the study area, most of the critical and other key features should be confirmed, as much as possible, and quantified further during the field mapping. Full engineering geological descriptions should be recorded for all key rock and superficial exposures. Further reference to natural terrain features that should be recorded during field

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mapping is given in RISC (1996). The field mapping may be required to extend outside the catchment of concern in order that the geological and geomorphological setting is fully understood.

The contour interval of 1:1,000-scale topographical maps is 2 m and the topography shown usually bears a closer resemblance to the ground conditions than that on smaller-scale maps; therefore, this scale is the most useful for field work where reliable positioning is essential. However, locating specific features on a broad, vegetated catchment can be difficult. A contour map derived from airborne LiDAR data may provide a better base plan for mapping purposes (see Section 4.2.5). Furthermore, mobile GIS mapping technology could be considered to improve the capability, efficiency and quality of geotechnical fieldwork (Ng *et al*., 2004).

Where access is restricted by dense vegetation, emphasis should be placed on examining features relevant to the potential magnitude of natural terrain hazards. Specific features to target for detailed field examination will come from the detailed API of the study area and its environs.

The field work should enable relevant information to be collected on all accessible landslide scars, topographic depressions and drainage lines, regolith (e.g. rock outcrops, boulders and boulder fields, colluvium, etc.), seepages and stream flows, open slope and drainage line morphologies, and vegetation types and densities. Traverses should be made both across the open hillside and along important drainage lines, to examine the nature and extent of superficial materials, and to determine areas that may be susceptible to failure during heavy rainfall. Superficial deposits should be subdivided as far as practical. A knowledge and understanding of geomorphology is essential to assist in their subdivisions, particularly in terms of age and processes. Full descriptions of each material type should be provided. Streamlines, landslide scars and anthropogenic cuts can provide exposures of such materials.

It is recommended to include copies of all field sheets in the NTHS report. Field observations, field sketches and field cross sections should be included where appropriate. In addition to the field sheets, all traverses (e.g. GPS track plots) should be included in the report to demonstrate the field coverage with explanations provided where certain areas were not inspected. All non-standard terms used should be clearly defined in the report.

Mapping of Landslides

Landslides contained in the ENTLI and identified during the site-specific API shall be verified by field mapping as far as possible, especially for landslides which will be used to determine the Design Event. Details of each landslide should be collected, including their depth, length and width of the main scarps for volume estimates. Where possible for recent landslides, materials displaced from the source areas and their degree of disaggregation should be described. In addition, characteristics of debris trails should be determined, including their length, width and processes of transport and deposition, and related erosion.

Other significant observations should be made, if possible, to determine the cause and mechanisms of recent landslides and their implications for future landslide hazards. These may include:

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(a) super-elevation of debris trails, based on vegetation flattening, erosion scars, marks on trees, and/or characteristics of materials deposited in levees (including thickness and volume of materials) for estimating velocity of debris flows (Johnson & Rodine, 1984; Prochaska *et al.*, 2008),

(b) Evidence of scour within stream beds or scars on channel sides to determine whether entrainment of additional debris from within the debris trail has occurred, and

(c) the location and character of tension cracks above the main scarp to establish the possibility of future landslide hazards.

<u>Mapping of Drainage Lines</u>

Traverses along drainage lines should examine their characteristics, such as channel width and height, slope gradient, and channel bed materials. The character of the weathering profile in stream sections, landslide scarps or rock outcrops should also be recorded, as should descriptions of colluvial materials if present. Estimation should be made of any material in the stream bed and on the banks that could be eroded and entrained in a debris flow. Hungr *et al*. (1984) suggested using the yield rate approach for quantifying the potential of entrainment during debris flow. The level of detail should be sufficient to assess the likely travel paths, velocities, depths and transport distances of any failure debris and entrained materials that enter the drainage line.

<u>Mapping of Rock Outcrops</u>

An examination of rock mass characteristics should be made at all accessible rock outcrops. Where pertinent, rock type, material weathering grade, joint properties and spacing, geological features that could affect stability (e.g. bedding, eutaxitic fabric, clay layers, metamorphic texture), and seepage locations and flow rates should be recorded.

<u>Mapping of Boulders</u>

Where boulder falls are considered to be a hazard, evaluation of boulder fields should be at sufficient detail to allow an assessment of the processes and the identification of potentially unstable boulders that are considered to pose a significant risk to the site under consideration. Potentially unstable boulders should be identified on site, particularly if in-situ stabilization is to be adopted for hazard mitigation. The likely travel path of such boulders in the event of failure should, where possible, also be assessed in the field. The field work should also attempt to distinguish between rock outcrops and individual corestones/boulders. In order to estimate the likelihood of boulder fall initiation and subsequent movement, information on boulder shape, boulder volume, boulder location, slope gradient, exposure conditions, embedding material, surface drainage and vegetation cover of the hillside are useful.

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It is not necessary to map each and every boulder on the hillside catchment under study as such indiscriminate inspection is out of proportion to the risk that boulders may pose judging from the records of boulder falls in the past 50 years and previous QRA studies. In addition, such inspection could entail extensive removal of vegetation/deforestation which can in itself exacerbate the risk of boulder falls, as well as causing adverse environmental impacts. The mapping of boulders should normally be conducted over those areas of the hillside catchment where access has already been made available for GI and site reconnaissance for the NTHS. Mapping of boulders over any other area should be conducted only where there are strong justifications to do so, such as the occurrence of hazardous movement or incipient instability of sizeable boulders identified from API or vantage point observations. The mere presence of a cluster of boulders should not be considered sufficient grounds for requiring boulder mapping.

Special considerations for dealing with boulder fall hazard for existing developments and new developments are given in Sections 2.2.6 and 2.3.5 respectively.

Mapping of Hillside Pockets

When carrying out mapping of Hillside Pockets, the following hazard factors associated with Hillside Pocket settings should be duly considered:

(a) presence of recognizable fill bodies (plan area >10 m^2) with adverse site setting (e.g. a fill body located at the upper portion of a catchment on steep terrain with a slope gradient >30°, and with a credible flow path reaching the facility at risk);

(b) adequacy of drainage provisions at the crest and within the Hillside Pocket, specifically the likelihood of any possible concentration of surface water onto the Hillside Pocket; and

(c) condition of surface protection (e.g. cracks on the hard surfacing).

Special considerations for dealing with Hillside Pockets are given in Sections 4.10, 4.13.5 and 5.5.

4.5 Geological and Geomorphological Model

Based on the information collected and interpreted, a geological and geomorphological model of current and past processes in the study area should be developed. This will form a basis for assessing the likely sources, nature and volume of any instability that could affect the site. It is generally beneficial to look beyond the catchment boundary so as to observe processes and events in adjacent or similar catchments that may be relevant for determining possible hazards to the site. Fookes (1997) noted that “The strength of the geological model is in providing an understanding of the geological processes which made the site. This enables predictions to be made or situations anticipated for which explorations need to be

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sought in the geological materials, geological structure and the ancient and active geological processes in the area".

Mass movements have displaced much of the weathered mantle on hillslopes, forming extensive colluvial deposits on the shallower slopes, and large debris sheets and lobes on the slopes and in the tributary valleys. Recent scars can be identified either in the field or on aerial photographs, a record that covers most of the territory from 1945 to the present (see Section 4.2.4). On the other end of the spectrum, large relict scars, which have a degraded morphology, probably extend the historical record to thousands of years.

Engineering geological mapping is typically concerned with the identification of materials, their geotechnical properties and the immediate or relatively short-term engineering implications. In comparison, engineering geomorphological mapping is concerned with recording surface form, materials and processes and is specifically directed towards engineering applications. Much of the focus is on inferring past processes as well as current and future rates of change in the landscape. Consequently, the integration of engineering geology and engineering geomorphology combines the short-term static with the longer term dynamism of the landscape (Hearn, 2002). Such an approach facilitates the development of comprehensive landslide hazard models, in particular for assessing the nature, magnitude and frequency of the various hazard types.

Details with respect to engineering geological mapping for natural terrain hazard studies are contained in Sections 4.2 to 4.4. According to Anon (1982), geomorphological mapping can be broadly divided into morphological (shape), morphographical (type), morphogenetic (origin) and morphochronological (age) components. While a single component could be used, a combination of components is usually more beneficial when assessing natural terrain hazards and these combinations will vary depending upon the lithology, elevation variation, size of study area and geomorphological history (GEO, 2004). Parry (2011) provided some useful guidelines on the application of geomorphological mapping in the assessment of landslide hazards in Hong Kong. Some examples of geological and geomorphological mapping techniques adopted in some recent NTHS are given in Appendix D for reference.

It should be stressed that there is no single methodology or series of techniques that should be automatically adopted for an NTHS or even a particular component of an NTHS. Instead each study area should be evaluated on a case-by-case basis and the most appropriate engineering geological techniques adopted.

4.6 Classification of Hillside Catchments

In landslide studies and field mapping, it is observed that some hillside catchments have a topographic depression where convergence of surface water and debris may occur, and that debris flows or avalanches may develop, with possible entrainment in the process. On the one hand, a failure involving a topographic depression (TD) catchment is different from that in an open hillslope (OH) catchment in terms of the mechanism and mobility of debris movement as well as in terms of the cost-effectiveness aspect of hazard mitigation. On the other hand, a TD catchment is also different from a channelised (CD) catchment, in that there

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will be a lesser degree of drainage and debris concentration, and that failure within a TD catchment will tend to result in less watery and hence less mobile debris.

As part of the hazard identification process, hillside catchments (and sub-catchments where appropriate) should be classified, according to the type of hazard, viz. CDF, debris flow, or debris slide/avalanche, etc., that may develop at the catchment. Where field evidence of potential confinement is present, the discharge point, together with the drainage area upstream, should be identified. For CD catchments, the discharge point is usually located at the toe of the catchment (Figure 4.4) whereas for TD catchments, the discharge point could be located somewhere within the catchment where the depression is no longer confined (Figures 4.4 and 4.5).

Both CD and TD catchments may also contain ancillary open hillslopes, i.e. OH sub-catchments (see Figure 4.5). Apart from the CD and TD discharge points where debris flow hazard from the upstream drainage areas should be considered, the rest of the 'mitigation line' is deemed to be subject to OHL hazard. Guidelines for classification of natural terrain hillside catchments are given in Table 4.2.

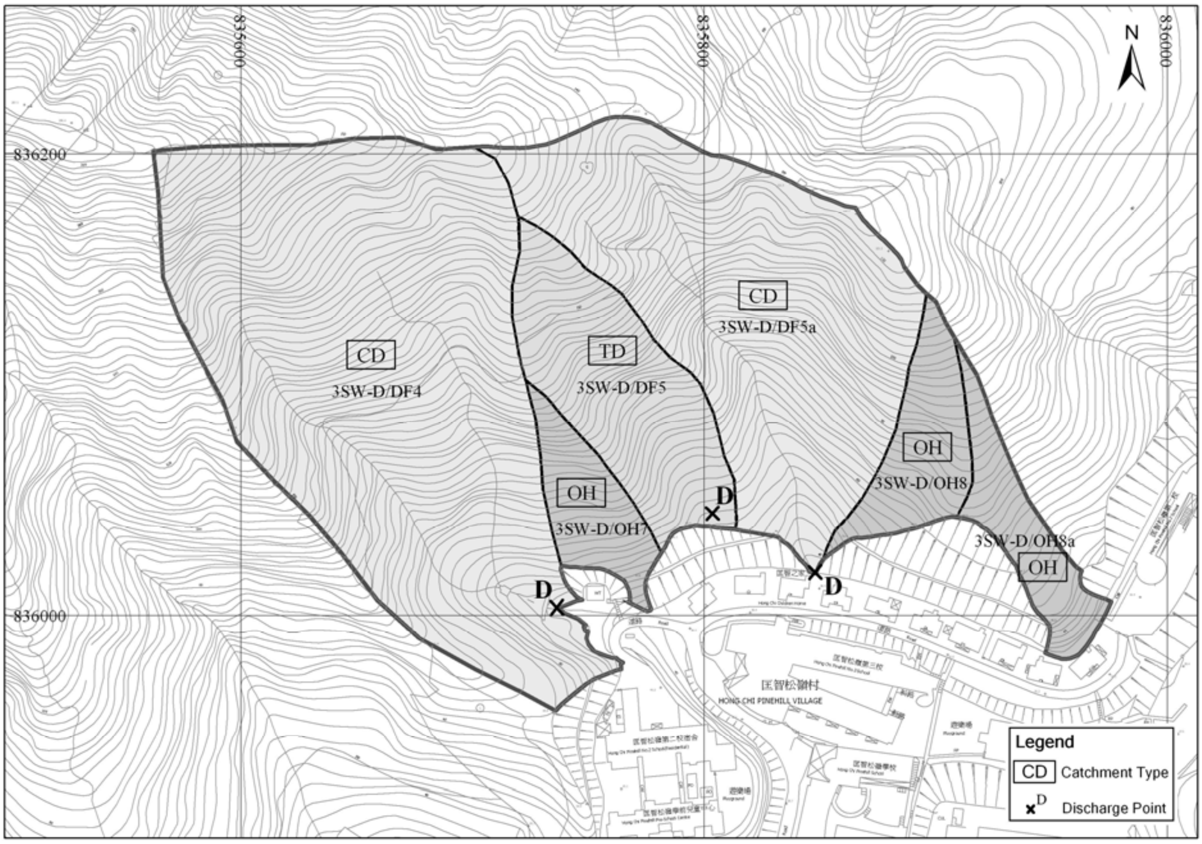

Figure 4.4 Example of Different Types of Catchment

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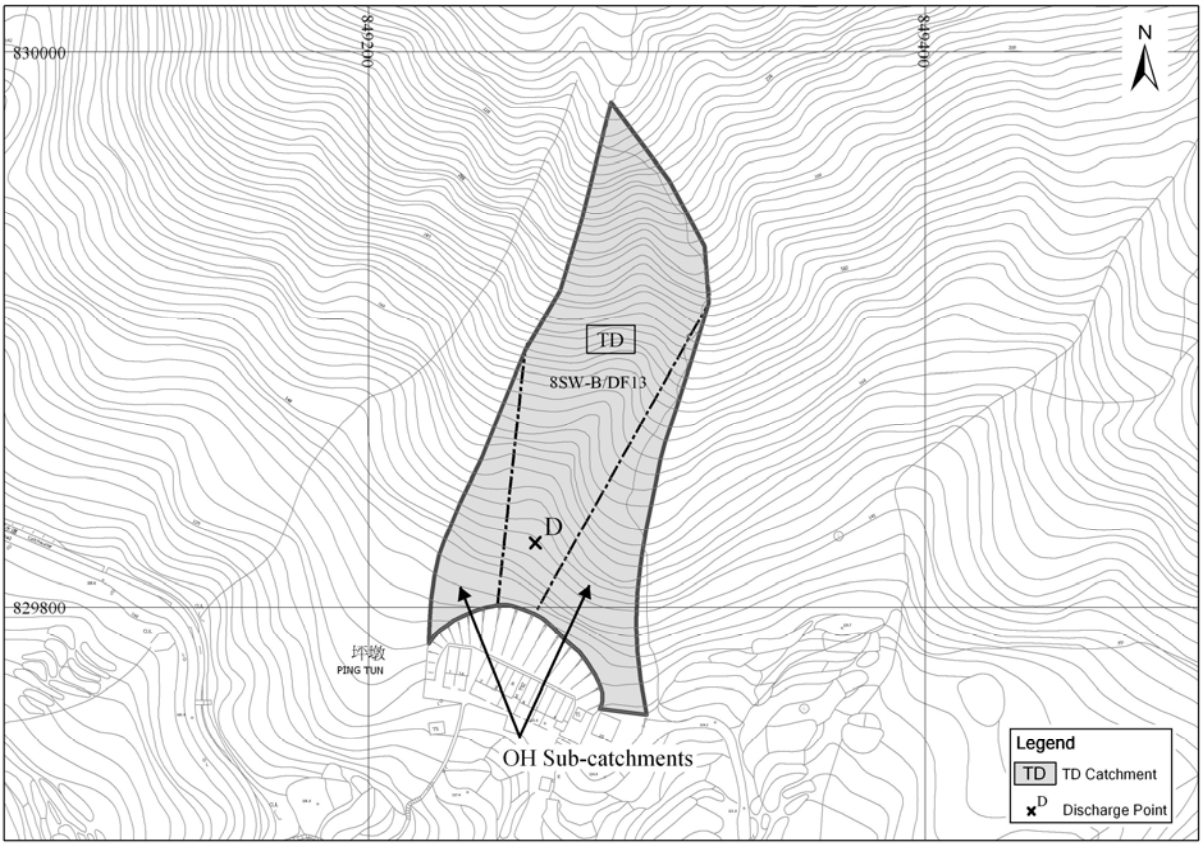

Figure 4.5 Example of Topographic Depression (TD) Catchment

Table 4.2 Classification of Hillside Catchments

Catchment Characteristics	Channelised (CD) Catchment	Topographic Depression (TD) Catchment	Open Hillslope (OH) Catchment
Topography	• Presence of an incised drainage channel. • In practice, this applies to catchments with the presence of a well-defined drainage channel based on the contours or a hydro-line feature shown in the Land Information Centre (LIC) 1:1,000-scale topographical map, unless otherwise invalidated by API, airborne LiDAR data, information from historical landslides, and / or field mapping. • The degree of confinement provided by the drainage line should be considered in relation to the design event being considered.	• Presence of a pronounced topographic depression but without a well-defined drainage channel. • In practice, this applies to catchments without the presence of a hydro-line feature in the LIC 1:1,000-scale topographical map but where a certain degree of confinement can be observed based on the contours of the LIC 1:1,000-scale topographical map, and where debris would converge and travel downslope. This should be verified by API, airborne LiDAR data, information from historical landslides, and / or field mapping. • The topographic depression can vary from well defined valleys of limited extent to linear depressions on otherwise planar	• Generally planar slope as observed from the LIC 1:1,000-scale topographical map, with neither a conspicuous drainage channel nor pronounced topographic depression. This should be verified by API, airborne LiDAR data, information from historical landslides, and / or field mapping.

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Catchment Characteristics	Channelised (CD) Catchment	Topographic Depression (TD) Catchment	Open Hillslope (OH) Catchment
		slopes. · In general, the plan distance between the downslope end of the topographic depression and the facilities at risk would normally be less than 100 m.	
Drainage / Debris Concentration	· Has a high drainage concentration in general, i.e. the section through which debris would be discharged is significantly small compared with that of its upstream catchment.	· Has some drainage concentration in general, i.e. the section through which debris would be discharged is relatively small compared with that of its upstream catchment. There is evidence of only limited surface water flow occurring and only in significant rainstorms.	· Has insignificant drainage concentration, i.e. the width of the section through which debris would be discharged is comparable to (or even greater than) that of its source area width or upstream catchment.
Discharge Outlet	· Debris from different sources within the catchment would travel downstream, given sufficient mobility, to a predictable discharge point.	· Debris would likely converge, given sufficient mobility, to a likely discharge point, i.e. debris would continue to travel along a preferential pathway exiting the topographic depression.	· Debris from different sources within the catchment could travel downslope, given sufficient mobility, to different discharge points and may involve the lateral spreading of debris.
Debris Path	· Debris path is controlled by the alignment and confinement of the drainage line. · 'Overshooting' of debris laterally from the drainage line is very unlikely within the main drainage line. However, near the exit point or where a debris fan is present this may occur.	· Debris path is somewhat confined by topography and may either be curved or relatively straight. · Possibility of 'overshooting' of debris laterally from the topographic depression is unlikely but cannot be excluded entirely, depending on the size of the potential failure event relative to the dimensions of the depression.	· Debris path is relatively unconfined, straight, and tends to follow the line of greatest slope which has insignificant change in its dip direction. · Actual debris path may be different from that assessed based on the line of greatest slope, e.g. due to uncertainty in the strike of the failure plane at source and resolution of the available data.
Potential Hazard to Consider	· Channelised debris flow (CDF) hazards. · High entrainment potential in general, dependent on presence of entrainable materials within the stream bed, the steepness and / or stability of channel sides.	· Debris flow (DF) hazards. · Lower entrainment potential than CDF in general, largely dependent on the steepness and presence of entrainable materials within the topographic depression.	· Open hillslope landslide (OHL) hazards (i.e. debris slide or debris avalanche on a relatively planar slope). · No entrainment potential in general.

Notes:

(1) It should be noted that the potential hazard of a small CD catchment may be more akin to a TD catchment and hence in such cases a small CD catchment may be treated as a TD catchment. Similarly, the potential hazard of a small TD catchment may be more akin to an OH catchment and hence in such cases a small TD catchment may be treated as an OH catchment. In these cases, judgement needs to be exercised and justifications should be provided.

(2) The possibility of presence of localised topographic depression on an OH catchment and affecting debris movement mechanism cannot be excluded, e.g. due to the hillslope being not entirely planar, resolution of the available data, and local concavity due to gully erosion and landsliding.

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4.7 Design Event

4.7.1 Overview

A design event refers to the magnitude of the hazard type selected for mitigation. It can be derived in several ways, largely dependent on the nature of the natural terrain hazards. It requires the development of an appropriate geological and geomorphological model to aid making professional judgement. Historical data, such as from landslide records, API and field mapping might help to determine the design event of more frequent shallow failures. For the large infrequent events such as deep-seated slides, a more detailed understanding of the geological and geomorphological conditions of the hillside, coupled with necessary GI would normally be required.

The design event needs to be defined in terms of the volume, velocity (or impact load) and nature of the landslide debris at the site boundary, or any other location where construction of mitigation measures might be proposed.

4.7.2 Determining the Design Event Source Volume

The DEA is stated in the First Edition of GEO Report No. 138 (Ng *et al*., 2003) as an acceptable approach for design of natural terrain hazard mitigation works, with the design requirements for 'Worst Credible Event' and 'Conservative Event' stipulated. It noted that the "*Worst credible event is a very conservative estimate such that the occurrence of a more severe event is sufficiently unlikely. Its notional return period is in the order of 1,000 years*", and that the return periods quoted for the design events "*are notional, and are intended to reflect the design principles. They should not be taken as accurate values derived from detailed statistical analysis*". A 'Conservative Event', as referred to in the First Edition of GEO Report No. 138, is intended as a less severe design event than a 'Worst Credible Event' for hazard mitigation for circumstances with a lesser risk concern, "*with a notional return period in the order of 100 years*".

Under the DEA, the hazard event to be mitigated involves consideration of both the failure volume and debris mobility. There is a concern that a combination of very conservatively assessed failure volume and mobile runout scenario could result in overly conservative design, which exceeds the intended notional return period. In analytical design based on the DEA, given that debris mobility has been conservatively assessed based on the use of back-analyzed rheological parameters for mobile failures, it would offer at least a factor of ten in terms of likelihood of occurrence (i.e. a conditional probability of occurrence of 0.1). Hence, it would suffice for the failure volume to be adopted in design to align with a notional return period of 100 years, which when combined with the use of the recommended rheological parameters in runout modeling, would correspond to a notional 1,000-year event, i.e. as per the 'Worst Credible Event' referred to in the First Edition of GEO Report No. 138.

In principle, other scenarios of failure volume and debris mobility, such as a notional 1,000-year failure volume combined with mean debris mobility, may constitute the design event. In practice, consideration of these alternative scenarios is generally unwarranted. This is because the use of mean debris mobility could result in less robust design and assessment of 1,000-year failure volume is subject to significant uncertainty, and their combination would

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not result in a more coherent and suitable design event.

Given the current state of knowledge and limited available data, it is more realistic to assess a credible failure volume without excessive extrapolation as compared to the failure volume of an ‘extreme’ event. As the term ‘Worst Credible Event’ may lead to a misunderstanding that it should be interpreted as pertaining to an ‘extreme’ event, the term ‘Design Event’ is now used. The design principle is that the mitigation measures to be provided are not aimed at dealing with an ‘extreme’ failure volume, but with a sufficiently realistic estimate of the credible failure volume (e.g. based on recent landslides as well as relict landslides with a high degree of certainty) that may be encountered during the design life of the affected facilities. When it is used in combination with a conservative assessment of debris mobility, the Design Event is adequately robust for the purpose of hazard mitigation based on analytical design.

It should be noted that the derivation of a design event for a notional return period of 1 in 100-years (P = 0.01 event) is complex. The largest landslide recorded over a 100-year period is not necessarily the P = 0.01 event, because the relationship between annual probability and the probability of occurrence over a particular time period is not straightforward, as indicated below for 50 and 70 year periods (Table 4.3), using the binomial model as suggested by Lee & Jones (2004).

Table 4.3 Probability of a 1 in 100-year Event Occurring in a Particular Time Period

Year of Earliest Aerial Photograph Available for a Study Area	Approx. Time Period (*n*) (Year)	Probability (P) of 1/100 Year Event in *n* years $P = 1 - (1 - 0.01)^n$
1945	70	51%
1963	50	39%

Thus, the largest recent landslide identified in the last 50 years (i.e. the typical length of API records with reference to the 1963 territory-wide coverage) has only a 39% chance of being the 1/100 year event. Even for a study area with the 1945 aerial photographs available, the largest recent landslide identified has only a 51% chance of being the 1/100 year event, irrespective of a few missing years of photographs between 1945 and 1963 which may lead to missing of landslide events. To achieve 95% reliability on the return period of a 100-year event would require 300 years of continuous records. Therefore, the design events should be determined based on the scale of recent landslides as well as relevant relict landslides with a high degree of certainty. In general it is considered that past events in the hillside catchment and its relevant vicinity will give a reasonable indication of the potential scale for future events. A combination of desk study, API and detailed field mapping should provide a good basis for developing a realistic geological/geomorphological model of the study area and defining the nature and magnitude of the design event.

Records of the date and source dimensions of past landslides in the study area can also be used to construct local frequency-magnitude relationships that may provide a useful

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reference for assessing the likely source volume for a design event (e.g. Tse *et al*., 1999; Arup, 2003; Tattersall *et al*., 2009). However, it is essential that any extrapolation is compatible with the geological and geomorphological setting of the catchment concerned.

A territory-wide rainfall-based landslide susceptibility analysis was carried out in Hong Kong that correlates rainfall and landslide occurrence, together with the consideration of effects of slope angle and solid geology (Lo *et al*., 2015). For the time being, the new susceptibility model would be applied in predicting the number of natural terrain landslides in a rainstorm and undertaking global analysis. The resolution and reliability of the model are not yet sufficient to support direct application for site-specific hazard assessments at this stage.

4.7.3 Considerations for Deep-seated Slides

Deep-seated slides or large scale (area extent) shallow failures are relatively infrequent, and may not be well represented by historical landslides at the site. Hence, correlation by reference to historical landslide data could be of limited use. Consideration of the geological and geomorphological model, as well as any geomorphological evidence of relict events such as the large relict landslides (see Section 4.2.10), is essential to assessing the likelihood of occurrence of such failures. Historical landslides in the vicinity of the site, and in other places with a similar geological/geomorphological setting, could also give insight into evaluating whether factors contributing to development of such failures are present at the site. For example, large deep-seated debris slides in Hong Kong include the quasi-natural terrain Shum Wan Road landslide with a thick weathering profile related to presence of persistent clay seams (GEO, 1996) and the fault controlled debris slide that occurred above Shek Pik Reservoir in 2008 (McMackin *et al*., 2009). Fugro (2015) provided an approach to assessing the potential for deep-seated failures at Ap Lei Chau which is within proximity to several notable cases of deeper landslides of various ages. The practitioner should be aware of the geological environments in which these events have occurred, and make a comparison with that of the study area.

4.7.4 Considerations for Channelised Debris Flows

If the study has determined that the catchment contains drainage lines that have the characteristics to develop debris flows, then the possibility of multiple landslide sources, the potential entrainment of eroded debris along the travel path, and the possible development of a dam-break scenario need to be considered. These phenomena can result in a significant increase in the total volume of the landslide debris and/or a significant increase in the debris mobility. Concurrent occurrence of failures at different landslide source locations should be considered, where there is evidence of such occurrence in the catchment in past rainstorm(s) within the aerial photograph record or based on obvious field evidence.

For drainage lines that are considered susceptible to channelised debris flows, the debris yield rate (volume of eroded material per linear metre, expressed in m^3/m) for each section of the drainage line should be determined. This will typically be carried out by reference to the thickness, characteristics and distribution of the materials present within the sections of the drainage line susceptible to erosion and entrainment of debris. Debris yield

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rate is affected by the characteristics of the stream course such as slope gradient, confinement, tributary drainage area as well as bank slope geometry and stability. Even for the same stream course, debris yield rate can be affected by the volume and mechanism of the source failure. Some guidelines on estimation of entrainment potential by debris flows are provided in Hungr *et al*. (1984) and Jakob & Hungr (2005). Entrainment for debris flows occurring within topographic depressions would be expected to be relatively minor compared to those occurring within well defined drainage lines.

After the 7 June 2008 black rainstorm, some fifty CDF with long debirs runout were systematically mapped. The yield rates recorded along the CDF paths for most of the channel sections are lower than 2 m^3/m while exceptional high yield rates (>20 m^3/m) have been recorded in some channel sections.

In Hong Kong, some very high entrainment rates were recorded in some CDF events. For example, King (1996) reported a debris yield rate of up to 57 m^3/m for the Tsing Shan debris flow in 1990, with an initial source volume of about 350 m^3. Debris yield rates for landslides that occurred during two heavy rainstorms in 1992 and 1993 in the vicinity of Tung Chung New Town were estimated to be 2.3 m^3/m to 3.7 m^3/m, for landslide source volumes of about 450 m^3 to 1,500 m^3 and where the average stream bed gradients were in the range of 20° to 30°, respectively (Franks, 1998). From the field mapping records of some relatively large scale 2008 CDF at West Lantau, average debris yield rates were estimated to be 0.2 m^3/m to 12.7 m^3/m with a rather high debris yield rate of 42 m^3/m estimated for a 20 m long section of a drainage line above Shek Pik Reservoir.

Based on a review of aerial photographs, most locations with exceptional high entrainment rates appeared to be related to accumulation of valley colluvium and/or old landslide debris. It should be noted that presence of anthropogenic features (e.g. loose fill below footpath or abandoned terraces) could also contribute to the debris yield rate. For example, a recent review by GEO suggested that the exceptionally high entrainment rates along certain channel sections of the 1990 Tsing Shan debris flow appeared to be related to anthropogenic influence. For those sections of a drainage line that have exposed bedrock in the stream bed, debris yield rates are likely to be much lower. For example, the debris yield rate of the Sham Tseng San Tsuen debris flow was estimated to be negligible (FMSWJV, 2005).

For channel sections with steep gradients, e.g. greater than 40°, the entrainment rates are usually low as those areas are typically rocky with limited debris accumulation. On the other hand, the high debris energy in steep channel locations may trigger detachment of rock outcrops contributing to the debris yield rates. Such circumstances were observed in the 1990 Tsing Shan debris flow (King, 1996), the 2001 debris flow above Lei Pui Street (MGS, 2002) and a debris flow at Yi O in 2008. For channel sections with gentle gradients, e.g. less than 15°, entrainment rates could also be high under extreme rainfall as those areas may have accumulation of debris from previous landslide events.

Halcrow (2001) documented the formation of a debris dam along a drainage line, some 30 m below the source area of a landslide above Leung King Estate, Tuen Mun. The dam, represents the initial debris lobe resulting from the failure, which had a travel angle of about 27°. Subsequently breaching of the dam, presumably due to damming of water behind the debris lobe,

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resulted in the formation of a wet channelised debris flow with a travel angle of about 17°. This case demonstrates that debris mobility can be significantly increased in a dam break scenario.

4.7.5 Regional Landslide Data

Sources of regional data on natural terrain landslides in Hong Kong include the ENTLI, which is a database of some 110,000 landslides and the Large Landslide Dataset which contains some 1,900 features. Compilations of field data from landslide area studies are reported in Franks (1998), Wong *et al*. (1998), MFJV (2003b) and AFJV (2010). A number of individual natural terrain landslide case studies have also been carried out (see Appendix C).

The regional data sets are useful for regional studies or for determining the event magnitude where catchment-specific landslide records and data are insufficient or not available for NTHS using the QRA approach. It may be possible to extend relationships established from catchment-specific data by incorporating regional data. However, care should be taken to ensure that the datasets used are from similar geological/geomorphological settings. When appropriate, it may be useful for practitioners to review the published case study interpretations when there are advances in the state-of-knowledge or methods.

4.8 Runout Assessment

Where the probable sources for future landsliding have been identified, the potential runout of landslide debris from them should be estimated in respect of the design event. Determination of the debris travel distance is an important component in assessing if the hazards may affect the site.

A reliable runout assessment requires information on the likely failure volume, characteristics of the travel path (e.g. potential sources of entrainment, channel geometry and gradient, etc.) and the momentum or energy of the moving debris which is related to the velocity and density of the debris. It should be assessed either with respect to the site boundary, or other suitable reference point critical to the consideration or mitigation of the hazards (e.g. the location of a debris-resisting barrier).

Catchment-specific data on the extent of debris trails of past landslides can be used if available. However, it is often difficult to map the extent of past landslide debris from aerial photographs because such debris may be difficult to recognize on the ground after several years. Even conducting field mapping soon after the landslide event, it may not be straight forward as subsequent washout may have occurred. Colluvial deposits provide some guidance as to the possible reach of past landslide debris but the possibility that they were deposited under a different climatic and geomorphological regime than today must be considered.

Lo (2000) presented a comprehensive review of various approaches for debris runout assessment and suggestions for assessing debris impact loads in the design of landslide debris-resisting barriers. Mobility of landslide debris in different types of natural hillside catchment

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was discussed by Kwan *et al*. (2013), Lo *et al*. (2013) and Yam & Hui (2014). Guidelines on assessment of debris mobility are available for channelised debris flows (GEO, 2011a), open hillslope landslides (GEO, 2012a) and failures involving topographic depressions (GEO, 2013). Adverse site settings that are prone to the development of sizeable CDF with watery debris of high mobility have been diagnosed by Wong (2009) and the recommended rheological parameters for channelized catchments that are deemed to be prone to watery debris are given in GEO (2011a). Some additional factors that should be considered in undertaking the debris mobility analysis are also given in GEO (2015).

4.9 Design Requirements for Natural Terrain Landslide Hazards

The DEA framework allows for the use of both analytical design and empirical design as appropriate. Two levels of hazard mitigation, viz. Primary Protection and Enhanced Protection, are denoted. In essence, for CDF affecting Group 1 and 2 facilities, analytical design is called for. This is denoted as Level 2 hazard mitigation, i.e. Enhanced Protection. Failure within TD catchment is to be dealt with in a similar manner to CDF, except that the recommended rheological parameters given in GEO (2013) should be adopted in the assessment of debris mobility for analytical design. For OHL, empirical design is adopted to provide Level 1 hazard mitigation, i.e. Primary Protection. The relevant considerations and corresponding design details are given in GEO (2014). Tables 4.4 and 4.5 illustrate the DEA framework and design requirements.

Table 4.4 DEA Framework

Facility affected (Note (a))	Level of mitigation required	
	Hazards from CD and TD Catchments	Hazards from OH Catchment (Note (b))
Groups 1 & 2	2	1
Group 3	2 (Note (c))	1

Notes:

(a) The framework stipulates Level 1 mitigation for hazards from OH catchments, while Level 2 mitigation is required for hazards from CD and TD catchments affecting Groups 1 and 2 facilities. This provides a more coherent risk management strategy given that the risk of debris slide/avalanche is lower than debris flow or channelised debris flow, and enhances cost-effectiveness of the mitigation works under the project.

(b) Presence of OHL hazard in general calls for Level 1 hazard mitigation if the OH catchment satisfies the qualifying criteria as set out in GEO (2014). Where the empirical design approach is not applicable because the qualifying criteria are not met, the mitigation works for the OH catchment should be designed by other means, with account taken of the site-specific circumstances. Possible mitigation schemes that may be considered include soil nailing, the use of flexible or rigid barrier designed by analysis, or the provision of a hybrid system consisting of flexible barriers prescribed by the empirical method and other engineering measures (e.g. local soil nailing) determined via analytical design.

(c) For hazard from CD and TD catchments affecting Group 3 facilities, the possibility of developing suitable Level 1 hazard mitigation, which may involve prescribed barriers or measures based on analytical design but with the use of less mobile rheological parameters, will be kept under review. In the interim, Level 2 hazard mitigation shall be applied.

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Table 4.5 Design Requirements

Level of hazard mitigation	Description	Design requirements (Note (i))
1	Primary Protection, based on empirical provisions	For OH Catchments: Empirical design based on use of prescribed barriers where the qualifying criteria are satisfied. (Note ii)
2	Enhanced Protection, with enhanced measures designed by analysis	Analytical design of mitigation measures to cater for the Design Event based on the DEA.

Notes:

(i) Apart from the DEA, the Factor of Safety Approach and QRA Approach may also be adopted. Where the Factor of Safety Approach is adopted in designing the mitigation measures by analysis, it is deemed to have met the design requirements for Level 2 hazard mitigation. Use of QRA Approach may result in either Level 1 or Level 2 hazard mitigation, depending on the nature of the mitigation measures found necessary from risk evaluation.

(ii) Where the empirical design approach is not applicable because the qualifying criteria are not met or for other considerations such as cost-effectiveness and environmental concern, the mitigation works for the OH catchment should be designed by other means, with account taken of the site-specific circumstances. For details, refer to GEO (2014).

When using soil nails as structural support, the design should aim to reduce the likelihood of OHL on the hillside. In this regard, it is noted that the natural hillsides in Hong Kong are susceptible to rain-induced, shallow failures. Field observations have revealed that failures typically occur within 0.5 m to 2 m of the hillside surface. For example, more than 99% of the natural terrain landslides that occurred in Lantau during the 7 June 2008 rainstorm had a maximum depth of failure not greater than 2 m at the source areas. Therefore, unless there are concerns about known significant hazards involving deeper failures, the following generalized design objectives may be adopted in the hillslope stability analysis or analytical design of soil nails for mitigation of OHL hazards:

(a) demonstrate or provide an adequate factor of safety against failure of the top 2 m of the regolith, in accordance with the design standards given in the Geotechnical Manual for Slopes (GEO, 1984); or

(b) in the absence of reliable information on the soil and groundwater conditions for the stability analysis, provide soil nails to increase the margin of safety against failure of the top 2 m of the regolith by 20% and 40% for circumstances that call for a minimum design factor of safety of 1.2 and 1.4 respectively.

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4.10 Design Considerations for Hillside Pockets

Given site constraints for Hillside Pockets (presence of developments at both crest and toe within developed areas), it is often not practicable to provide substantial mitigation works, e.g. rigid barriers, for dealing with OHL hazards. Adopting empirical design based on the use of prescribed flexible barriers can be a practicable approach for mitigation of OHL hazard in general. Guidelines on empirical design of flexible barriers for mitigating natural terrain OHL have been set out in GEO TGN 37 (GEO, 2014). Adoption of these guidelines should be evaluated on a case-by-case basis.

Apart from DEA, the Factor of Safety approach can also be considered in the study of Hillside Pockets especially for a small planar hillside where it may sometimes be cost-effective and environmentally acceptable to carry out soil nailing rather than installation of debris-resisting barriers. Most landslides that have occurred within Hillside Pockets are shallow in nature (i.e. 0.5 to 2 m deep). When adopting the soil nailing option to provide an adequate factor of safety against failure of the regolith, an appropriate geological model should be developed in determining the credible slip surface. Furthermore, overly conservative groundwater conditions should be avoided. Some useful guidelines on this aspect are given in GEO TGN 37 (GEO, 2014).

Some Hillside Pockets may have been extensively modified by anthropogenic activities, e.g. fill platforms. Detailed API and field inspection should be carried out to delineate the extent and where possible depth of these fill bodies, and confirmed by GI as necessary. Suitable preventive or mitigation measures should be implemented based on analytical design.

For Hillside Pockets affecting Group 2(b) and Group 3 facilities (refer to Table 2.2), the following approaches should be adopted:

(a) GI would normally be considered only if presence of fill bodies is suspected from API or field inspection; and

(b) mitigation works are generally not required for these Hillside Pockets if the Natural Terrain Hazard Assessment (see Section 4.13.4) confirms all of the hazard factors stated under the paragraph “Mapping of Hillside Pockets” of Section 4.4.3 do not exist, unless there is evidence of persistent landslides and/or significant signs of distress.

With respect to the above paragraph, a holistic approach could be considered to protect the facilities at risk if mitigation actions are required at the adjacent catchments. In considering whether the holistic risk mitigation strategy should be adopted, judgement needs to be exercised taking into account the types of facility affected and their proximity from the catchment, and sound justifications should be provided. Mitigation strategy for Hillside Pockets is given in Section 5.5.

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4.11 Design Considerations for Boulder Fall Hazard

Engineering judgement should be exercised in the inspection and identification of unstable boulders as well as the need for corresponding mitigation works with due regard to the exposure conditions, surface drainage, embedment condition, slope gradient and vegetation cover of the hillside and also the factors described in Section 2.2.6. As there are considerable limitations and uncertainties in the use of numerical models for the evaluation of boulder stability, the results derived from such numerical model should be carefully calibrated and should not take precedence over experience and judgement. In particular, the need for mitigation works should not be justified or confirmed solely by the results of numerical modeling.

4.12 Presentation of Results

The NTHS should establish the following:

(a) Geological/geomorphological model for the study area with particular reference to existing and potential landslide locations.

(b) Hazard types and their respective design requirements based on the detailed assessment.

(c) The location, magnitude, and runout distance of each specific hazard type that may affect the site or other relevant facilities.

(d) Whether measures are required to mitigate against the specific hazards that may affect the site.

In the NTHS report, the study area should be described in the context of its regional setting with specific regard to the site and its topography, geomorphology, geology, drainage and rainfall characteristics. The limitations of the study (e.g. access problems, limited aerial photograph coverage) should be stated. The uncertainties in different stages of the study should be highlighted and discussion provided on how they are addressed.

The report should include the scope and methodology adopted and assumptions used to establish items (a) to (d) above. Adequate photographs, tables, figures and drawings, including cross-sections, should be used. The following illustrations are suggested as part of the report:

(a) Geological cross-sections along each potential debris travel path from identified natural terrain hazard source locations to the site boundary.

(b) An engineering geological/engineering geomorphological map (or in separate maps for presenting different information as appropriate) of the study area at an

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appropriate scale (e.g. 1:1,000) showing:

(i) solid geology and regolith,

(ii) geomorphological setting,

(iii) locations of rock exposures, annotated where necessary with key information about the nature of the rock mass (e.g. stereonet analyses for rock outcrops),

(iv) locations of past instability (e.g. landslide scars, boulder fall locations), annotated with key information about the nature of the instability,

(v) locations of relevant GI stations,

(vi) catchment boundary and drainage courses with comments regarding any areas of concentrated surface water flow or seepage, and

(vii) location of field traverses and field descriptions.

(c) A Natural Terrain Hazard Map of the study area at an appropriate scale (e.g. 1:1,000) showing:

(i) potential landslide sources and potential areas of entrainment,

(ii) potential boulder fall and/or rock fall locations,

(iii) open hillslope landslide paths from identified potential landslide sources with the likely distance that debris will travel,

(iv) debris flow paths with their likely maximum extent, and

(v) boulder/rock fall trajectories with the estimated distance that boulders and/or rock blocks will travel, where numerical modelling has been carried out.

Where mitigation measures are required, the report should clearly present the rationale for the mitigation strategy formulated to reduce the risk to the development. The general types and layout of the measures should be shown on a Mitigation Measures Strategy Map at an appropriate scale (e.g. 1:1,000 or 1:5,000). If in-situ stabilization measures at the source area are recommended, their locations should be marked on the map. This is particularly applicable to boulder and rock falls hazards where the exact location of the hazards should be indicated on a map of 1:1,000 scale or better. Some examples on presentation of results in various stages of NTHS are given in Appendix D for reference.

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4.13 Stages of the Natural Terrain Hazard Study for LPMitP Projects

4.13.1 Introduction

The study shall be divided into sequential stages (review and assessment) of increasing detail, that meets the requirements for different phases of the projects.

4.13.2 Natural Terrain Hazard Review

At the Natural Terrain Hazard Review (NTHR) stage, site-specific API and field mapping are carried out. This will facilitate classification of catchment type and deliberation of whether or not the catchments meet the 'react-to-known-hazard' principle, such as validating the ENTLI records, and identifying other landslides that are not in the ENTLI.

An NTHR should include the following aspects:

(a) desk study of available information (Section 4.2),

(b) detailed interpretation of all available aerial photographs (Section 4.3), and

(c) field mapping involving overview of the catchments, inspection at the catchment boundary and field verification of specific hillside features identified from API (e.g. landslide scars, tension cracks, major gully erosion, etc.).

For item (c) above, it may be necessary to arrange access (e.g. vegetation clearance and provision of safety ropes) so as to allow inspection of the specific hillside features.

At the end of the review stage, the study should conclude the following:

(a) Classification of catchment types following the methodology given in Section 4.6.

(b) Determination on catchments that meet the 'react-to-known-hazard' principle following the guidelines given in Section 4.13.3.

Consideration should be given to the overall geomorphological setting of the hillside in the catchment subdivision process especially in deliberating if individual catchments meet the 'react-to-known-hazard' principle. For example, a continuous OH catchment should not be subdivided into smaller OH catchments unless the sub-catchments contain distinct geomorphological characteristics.

The results of the review should be presented in a report that summarises all the geological and geotechnical information about the study area. Sufficient documentation should be given to explain the reasoning and the methodology adopted for the review and to justify the conclusions made. The report should be supported by relevant photographs, preliminary engineering geological/geomorphological map and representative cross-sections.

4.13.3 'React-to-Known-Hazard' Principle

Background

HLC contain ENTLI records (i.e. historical landslides) that occurred close to important facilities (see Section 2.2.3). As such, HLC are taken as meeting the screen-in criterion of the 'react-to-known-hazard' principle for NTHS under the LPMitP. This is based on the consideration that HLC are likely candidates under the category of '*there is reason to believe that a dangerous situation could develop*' with the concern that HLC could be '*where there have been in the past persistent landslides on natural terrain and where a significant consequence to life or serious damage to property may occur in the event of further landsliding*'.

Under the LPMitP, an area-based approach is adopted (see Section 2.2.5). A Study Area typically includes an HLC and may consist of other lower ranked HLC. The Study Area may also contain other natural hillside catchments adjoining the HLC, which are denoted as Related Catchments (RC). However, it is noted that some of the catchments, especially the RC, may not meet the 'react-to-known-hazard' principle based on the updated information obtained from the site-specific assessment. Such catchments may be excluded from the LPMit works after sufficient confirmatory work has been carried out in the assessment.

In deliberating whether or not a hillside catchment, or part of the catchment, assessed under LPMitP meets the 'react-to-known-hazard' principle in the NTHR stage, consideration should be given to the following factors:

(a) past persistent landslides indicating an active catchment,

(b) strong geological/geomorphological evidence of a hazardous catchment, and

(c) newly emerged hazardous situation as a result of occurrence of new landslide(s), development of new signs of distress (e.g. tension cracks) and hazardous movement, or exacerbation of existing signs of distress and hazardous movement, particularly where there is a concern of further deterioration leading to instability.

Where any of the above factors are evident and where a significant consequence to life or serious damage to property may occur in the event of future landsliding, the 'react-to-known-hazard' principle is deemed to have been met.

Past Persistent Landslides

In respect of (a) above, this refers to a catchment with many (with respect to the size of the catchment, e.g. no. of landslides per km^2) small (typically <50 m^3) landslides, or with fewer but more sizeable or long runout recent landslides. Account may be taken of relict landslides, provided due consideration is given to:

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(i) the degree of certainty with respect to the landslides (e.g. evidence of sharp scarp or debris clearly related to a landslide source),

(ii) the likely age of the landslide,

(iii) the degree of certainty with respect to landslide volume and mobility,

(iv) the longer observation period as compared with that of recent landslides, and

(v) the relevance of the relict landslide activity to the present site setting.

Strong Geological / Geomorphological Evidence

In respect of (b) above, the following considerations should be given:

(i) 'strong geological/geomorphological evidence of a hazardous catchment' refers to clear evidence that the catchment poses a significant landslide hazard, such as field evidence of debris flow deposits suggesting that such hazards are credible, or where the geomorphological setting suggests CDF could occur.

(ii) for an OH catchment without past persistent landslides but which only comprises mapped terrain units classified as the same as those in its adjacent catchments where landslides have occurred, this may be indicative of the potential that similar landslides could occur on the hillside. However, in general, this alone should not be taken as 'strong geological/geomorphological evidence of a hazardous catchment', based on which the 'react-to-known-hazard' principle is deemed to have been met.

(iii) the presence of coastal landslides in the vicinity of the study area alone should in general not be taken as 'strong geological/geomorphological evidence of a hazardous catchment' where the previous trigger (e.g. active wave undercutting) for such landslides no longer exists. However, it is recommended to further assess if the oversteepened slope poses a significant landslide hazard and whether any mitigation works are required.

4.13.4 Natural Terrain Hazard Assessment

The necessity for Natural Terrain Hazard Assessment (NTHA) and mitigation actions for the catchments should be decided on an individual catchment basis. The area-based assessment should be of sufficient detail to determine the location, type, frequency and

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magnitude of any hazards. Cost effectiveness should be considered in both the GI as well as the formulation of the mitigation strategy, to ensure that the cost of which is not disproportionate to the level of landslide risk posed by the natural hillsides (including Hillside Pockets) to the development.

OH catchments not meeting the ‘react-to-known-hazard’ principle will be studied as part of the area-based assessment in the NTHA undertaken after NTHR for the whole study area, albeit GI would normally not be carried out. Where significant signs of distress are revealed during the area-based assessment, the associated hazards should be assessed with mitigation measures designed as appropriate if the catchment is confirmed to have OHL hazards.

CD/TD catchments are taken forward to the NTHA stage regardless of whether or not they are deemed to meet the ‘react-to-known-hazard’ principle at the NTHR stage. This is due to the consideration that the site setting of these catchments would either have known landslides close to existing developments, or tend to exhibit geological and geomorphological evidence of channelised debris flow or debris flow hazards. The findings of the NTHR for CD/TD catchments in this aspect should be regarded as preliminary and these catchments should be evaluated in detail at the NTHA stage with respect to their potential hazards.

An NTHA should include the following aspects:

(a) all items covered in an NTHR (Section 4.13.2),

(b) detailed field mapping (Section 4.4.3),

(c) GI (where necessary) to obtain data for detailed evaluation of the hillsides including stability assessment or to determine the location, type and magnitude (i.e. Design Event) of any hazard,

(d) debris runout assessment (Section 4.8), and

(e) strategy formulated for mitigating the risk to the development.

At the end of the assessment stage, the study report should cover all the items given in Section 4.12 above.

4.13.5 Special Considerations for Dealing with Hillside Pockets

In dealing with Hillside Pockets, guidelines on the NTHS as given in Section 4 are generally applicable except that any OH catchment not meeting the ‘react-to-known-hazard’ principle must still proceed to the NTHA stage with detailed evaluation of these catchments, including GI, if necessary, given that the contributing factors to the landslides are different to that of natural hillsides (see Section 2.2.4).

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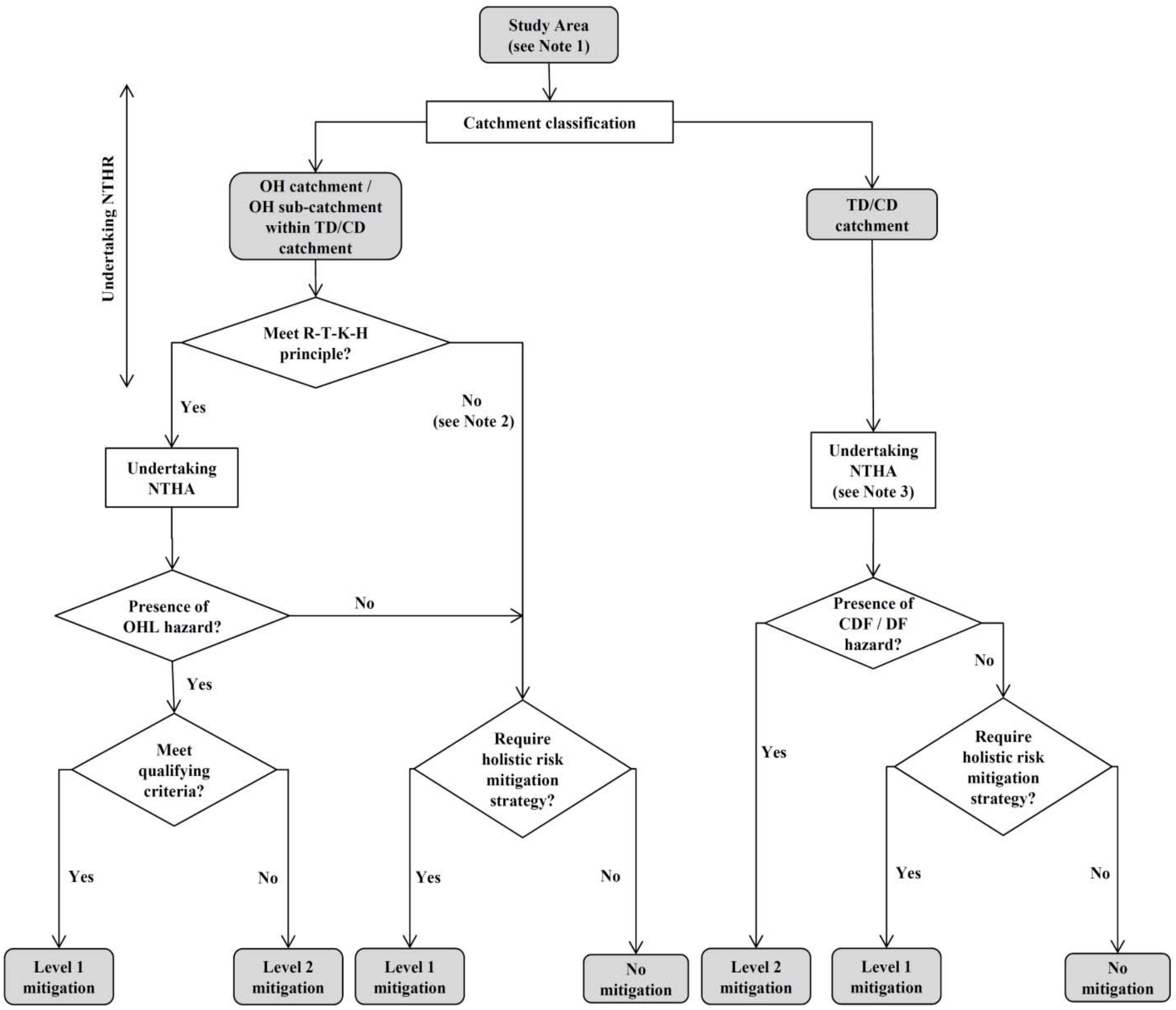
4.13.6 Overall Workflow

The overall workflow on the DEA for LPMitP is given in Figure 4.6.



<u>Notes :</u>

(1) A Study Area typically includes an HLC and may consist of other lower-ranked HLC and other adjoining natural hillside catchments known as Related Catchments (RC). For Hillside Pockets, the Study Area typically includes a vulnerable Hillside Pocket and may consist of other lower-ranked and/or non-CTL Category 1 Hillside Pockets.

(2) OH catchments not meeting the 'react-to-known-hazard' principle should be included as part of the area-based assessment in the NTHA undertaken for the whole study area. However, GI would normally not be carried out for these OH catchments (see Section 4.13.4). Such catchments may be excluded from the LPMit works if the assessment confirms that there are no OHL hazards. For a Study Area comprising Hillside Pockets, any OH catchment not meeting the 'react-to-known-hazard' principle must still proceed to the NTHA stage with detailed evaluation of these catchments, including GI (if necessary).

(3) CD/TD catchments are taken forward to the NTHA stage regardless of whether or not they are deemed to meet the 'react-to-known-hazard' principle at the NTHR stage.

Figure 4.6 Workflow on the DEA for LPMitP Projects

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4.14 Stages of the Natural Terrain Hazard Study for Non-LPMitP Projects

4.14.1 Introduction

Non-LPMitP projects refer to public works projects, Housing Department projects and private developments/re-developments. Project sites meeting the ‘Alert Criteria’ will be required to carry out NTHS. Apart from the ‘react-to-known-hazard’ principle which is not applicable to non-LPMitP projects, the overall workflow on the DEA essentially follows that of the LPMitP projects.

For large scale projects, it may be beneficial to divide the study into sequential stages, (e.g. preliminary review and detailed assessment) of increasing detail, that meet the requirements for different phases of the projects from land use planning through engineering feasibility study to design stage.

4.14.2 Preliminary Review

The preliminary review is to decide whether further assessment will be necessary, and also to identify whether the hazards are so significant that the site is deemed uneconomical to develop. If the preliminary review identifies significant hazards, the study should progress to the assessment stage. Consideration should also be given at this stage of the order of cost that may be involved for future financial estimates. The preliminary review should include the aspects as stated in Section 4.13.2.

At the end of the preliminary review stage, the study should conclude the following:

(a) Whether further study is required or whether the proposed development is considered not feasible.

(b) If further study is required, the recommended design approach should be provided (Section 3.2).

If the DEA is to be followed (Section 3.2.4), the probable scale of the natural terrain hazards posed to the proposed development and relative to the site boundary should be provided. This would give the practitioner the opportunity to consider reducing the hazards through adjusting the internal layout of the critical facilities at an early stage of the development.

The results of the review should be presented in a report that summarises all the geological and geotechnical information about the study area. Sufficient text should be given to explain the reasoning and the methodology adopted for the review and to justify the conclusions made. The report should be supported by relevant photographs, preliminary engineering geological/geomorphological map, and representative cross-sections.

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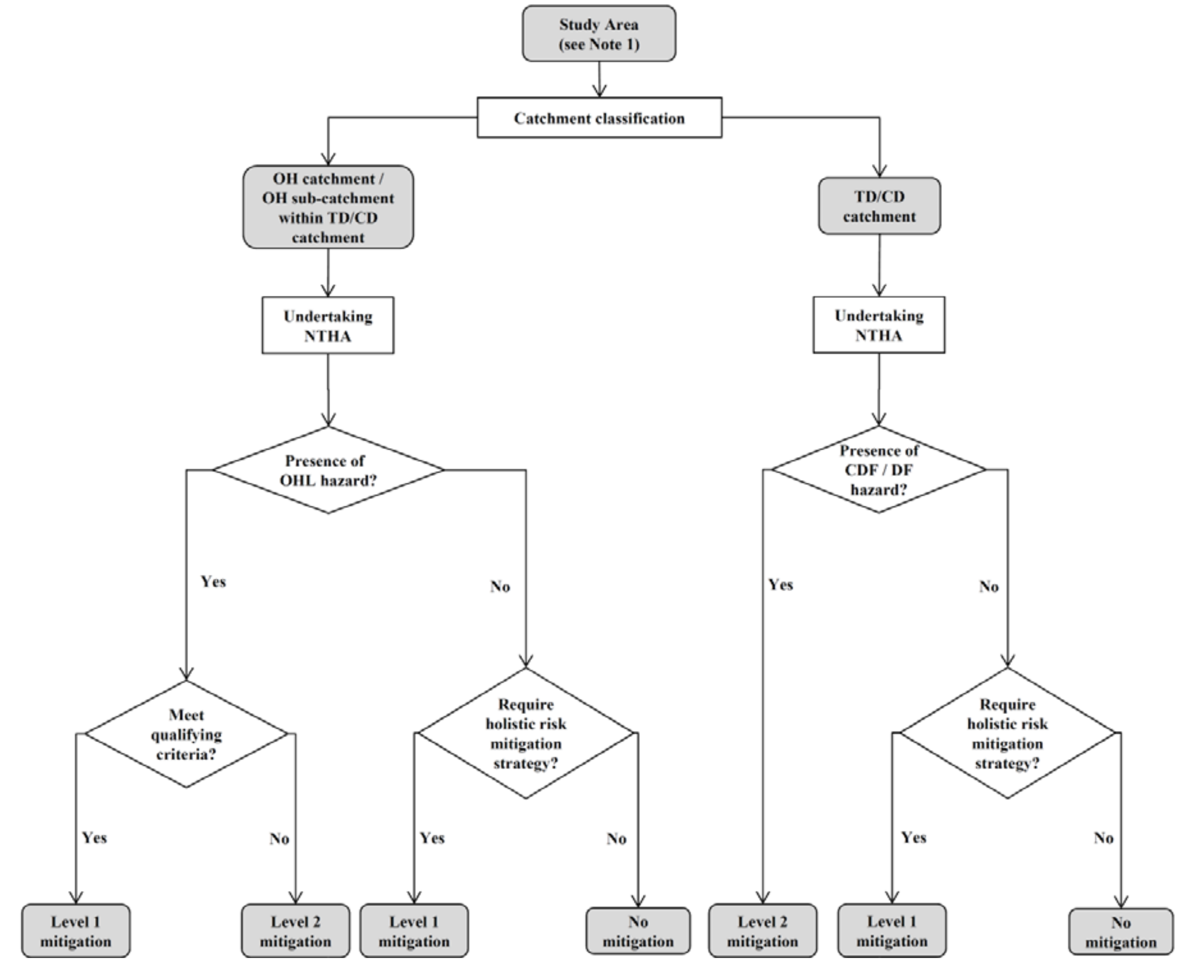
4.14.3 Natural Terrain Hazard Assessment

The assessment requires a detailed field study of the natural terrain, sufficient to determine the location, type, frequency and magnitude of any hazards. Quantifying the design event from the catchment above the site can be carried out when the detailed design and layout of the development have been decided. The assessment will establish whether the risk necessitates mitigation measures. This process is generally carried out at the design stage for both private and public works projects. As noted in Section 4.13.4, cost effectiveness should be considered in both the GI and the formulation of the mitigation strategy. An NTHA should include the aspects as stated in Section 4.13.4. At the end of the assessment stage, the study report should cover all the items given in Section 4.12.

4.14.4 Overall Workflow

The overall workflow on the design event approach for non-LPMitP projects including public works projects, Housing Department projects and private developments/re-developments is given in Figure 4.7.



Notes :

(1) Study Area refers to hillside catchment(s) that meets the 'Alert Criteria' and therefore may pose natural terrain hazards to the proposed project.

Figure 4.7 Workflow on the DEA for Non-LPMitP Projects

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5 Natural Terrain Hazard Mitigation Strategy

5.1 Introduction

Upon determination of the design event, the risk to the development can be assessed and an appropriate mitigation strategy formulated if the risk has to be reduced. Mitigation measures can either be "passive", for example by re-locating a development site beyond the area considered at risk and so avoiding the hazard, or "active", involving the construction of measures to reduce the effect of the anticipated hazard and therefore the risk to the development. Active mitigation measures can be further subdivided into preventive and protective. The former may include in-situ stabilization (at source areas) and the latter commonly involves defensive mitigation works in the travel path or within the site to retard, store or deflect failure debris.

The conventional approach to stabilization works on man-made slopes is generally not suitable for natural terrain. Given the possible large areas of potentially unstable natural terrain involved, such works are likely to be exceedingly expensive, and may not be justified. Also, widespread stabilization works on natural terrain could cause considerable environmental impact, and are difficult to carry out safely. Franks and Woods (1997), Greg Wong & Associates (1999), Lo (2000) and Shum & Lam (2011) have reviewed typical mitigation measures and their applicability to Hong Kong conditions.

Natural hillsides do not require maintenance, and hazard mitigation measures do not normally result in substantial modification to the geometry and condition of the natural hillsides. The purpose of maintenance for hazard mitigation measures is confined to ensuring their physical integrity and satisfactory performance. Maintenance requirements for natural terrain hazard mitigation measures are given in Geoguide 5 (GEO, 2003). It should be noted that with proper design, detailing and construction quality control including effective re-instatement of the ground around soil nail heads, natural hillside stabilized solely by soil nailing are essentially maintenance free. The Routine Maintenance Inspection (RMI) stipulated in Geoguide 5 for soil-nailed hillsides is thus not required.

5.2 Passive Mitigation Strategies

Passive mitigation strategies involve precluding development in areas that may be affected by severe natural terrain hazards. This may be accomplished by land use planning, statutory regulations and development moratoria. A temporary statutory restriction on building development in the Mid-Levels was imposed in May 1979 to safeguard the stability of slopes in the district and to facilitate a regional stability assessment for formulating appropriate geotechnical controls for this area. The temporary restriction expired in July 1982 upon the introduction, in August 1982, of more stringent statutory geotechnical controls on development in the Mid-Levels as compared to other areas.

Examples of some passive mitigation measures are given below for reference:

(a) Closure or relocation of facilities at risk.

(b) Adjusting facility layout. This can be an effective action for

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a large site. It is generally possible to avoid or reduce the exposure to natural terrain hazards by siting the critical facilities (e.g. residential blocks) away from the hillside.

(c) Provision of suitable buffer areas on the upslope side of the development site or adjacent to drainage lines.

(d) Delineating non-building area. In some cases, it may be possible to delineate the most hazardous part of the site as no-build zone.

(e) Making use of natural barrier. During site formation planning stage, the possibility of making use of natural features (e.g. existing ridge) as a barrier for landslide debris should be considered.

(f) Elevated platform. For a narrow site, there may be little room to accommodate debris barriers. A possible option is to have the superstructure built on an elevated platform so as to allow debris to pass underneath the building.

(g) Erection of warning signs.

To deal with the landslide risk posed to minor facilities, it is sometimes more cost-effective to erect landslip warning signs at appropriate locations to alert the public of the landslide hazards identified under the LPMitP projects. In some cases, it may be appropriate to install warning signs for sites with potential boulder fall hazard. Defensive mitigation measures are commonly used for mitigation of debris flow hazard. Warning signs should also be erected at/or in the vicinity of the completed defensive mitigation measures so as to guard against inadvertent entry of the public to the area which could be affected by debris flow in the event of failure.

For new development, the option of adopting passive mitigation measures should be considered at an early stage of the project so as to ensure that any necessary arrangements can be accommodated.

5.3 Active Mitigation Strategies

Active mitigation generally involves the construction of engineering measures to reduce the likelihood of failure (i.e. prevention) by stabilizing the landslide source, or the implementation of energy dissipation, deflection or containment measures along the travel path or in the deposition zone to mitigate the consequences (i.e. mitigation). Shum & Lam (2011) discussed various types of preventive and mitigation measures in details. A brief summary for each measure is given in Sections 5.3.1 and 5.3.2 below.

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5.3.1 Preventive Measures

Landslide preventive works can be effective for potential hazards associated with clearly defined source areas (e.g. landslide scars and overhanging boulders), including potential deep-seated slides (e.g. areas with signs of distress and evidence of deep-seated movement). However, it would not be practical to stabilize the entire hillside catchment in order to prevent the occurrence of open hillslope landslides and channelised debris flows.

Landslide preventive techniques generally include the following:

(a) Structural support - structural support in the form of soil nailing has been used to stabilize recent landslide scars (e.g. Yu Tung Road, Tung Chung) and severely distressed hillside (e.g. Kwun Yam Shan, Sha Tin). Rock bolts, concrete buttresses and steel wire mesh have been used to prevent boulder and rock fall.

(b) Drainage provisions - Surface drainage channels can be used to reduce the amount of direct infiltration and minimize uncontrolled overland flow. Sub-surface drainage, such as raking drains and drainage tunnels (Ho *et al*., 2008), can be used to control groundwater flow to avoid a significant rise in the main groundwater table or build-up of perched water table.

(c) Erosion control - Surface erosion control measures such as shotcreting can be applied, in particular under landslide emergency situations where further deterioration of the landslide scars is to be prevented. However, the visual impact of shotcreted slopes on the surrounding environment is a major concern. In order to blend in with the surrounding hillsides, erosion control mats (with wire mesh if needed) can be utilised to act as protection, as an alternative to shotcreting.

(d) Soil bio-engineering techniques - soil bio-engineering may be defined variously as "the use of living vegetation, either alone or in conjunction with non-living plant material and civil engineering structures, to stabilize slopes and/or reduce erosion", and "the use of any form of vegetation, whether a single plant or collection of plants, as an engineering material, i.e. one that has quantifiable characteristics and behaviour" (Morgan & Rickson, 1995) (see also Section 5.6.2). Guidelines for application of soil bio-engineering measures on natural terrain landslide scars to reduce the rate of deterioration are described by Campbell *et al*. (2008).

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Preventive works to boulders usually comprise various combinations of the following measures:

(a) break up and removal;

(b) in-situ stabilization by buttressing, dowelling, anchoring or by tying back with steel cables or other structural members;

(c) provision of surface water drainage and erosion protection and in some cases groundwater drainage; and

(d) defensive works utilizing rock traps, boulder fencing/barriers and wire mesh covers.

Access for such boulder stabilization works with construction plant is often difficult and this can have an important bearing on the choice of suitable stabilization measures.

5.3.2 Mitigation Measures

According to Shum & Lam (2011), mitigation techniques can be divided into three principal functions, namely flow control, erosion control and deposition control, as indicated in Table 5.1.

Table 5.1 Classification of Mitigation Techniques (from Shum & Lam, 2011)

Function	Objective	Mitigation Technique
Flow control	Flow path diversion	Deflection structure
		Transport channel
		Debris flow shed
	Energy dissipation	Drop structure
		Debris flow impediment
		Debris-straining structure
Erosion control	Reduce erosion potential of channel bed	Check dam
Deposition control	Arrest / contain debris	Debris-resisting barrier
		Debris retention basin
		Boulder fence

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a. Deflection Structure (Tseng Tau Sheung Tsuen)

b. Transport Channels (Tuen Mun Area 19)

c. Drop Structure (Wang Hang Village)

d. Debris Flow Impediment (Lung Wah Street)

e. Debris-straining Structure (Tuen Mun Area 19)

f. Concrete Barrier (Tsing Yi)

g. Gabion Barrier (Leung King Estate)

h. Flexible Barrier (Sha Tin Hospital)

i. Closed Basin (Sham Tseng)

j. Boulder Fence (Mid-Levels)

Figure 5.1 Examples of Mitigation Measures Used in Hong Kong

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A brief discussion on the principles and applicability of different mitigation techniques in Hong Kong is given in the following paragraphs:

(a) Deflection structure - Deflection structures can be used to divert debris flows away from highly vulnerable areas towards areas with low vulnerability. In Hong Kong, deflection structures have been used to divert debris flows (Figure 5.1a) and prevent overspilling at the bends of drainage lines.

(b) Transport channels - The main purpose of transport channels is to ensure the passage of debris surges down a pre-determined path, without blockage or overflowing (Figure 5.1b).

(c) Debris flow sheds - Debris flow sheds are constructed to protect roads, railways and sometimes structures by allowing debris to pass over the facilities. They are rarely used in Hong Kong to date as they may not be favourable for mitigating natural terrain landslides in the urban setting given that a fairly large area has to be sterilized for debris or boulder fall deposition.

(d) Drop structure - Drop structures are normally built in series along the drainage line where the gradient is relatively steep so that the velocity and energy of debris flows are reduced and dissipated respectively (Figure 5.1c).

(e) Debris flow impediment - Debris flow impediments, also known as baffles, are used primarily to slow down a debris flow and encourage the debris to deposit (Figure 5.1d).

(f) Debris-straining structure - Debris-straining structures are measures with openings designed to trap coarse fractions of landslide debris, including boulders, from a debris flow (Figure 5.1e), to impede the debris flow. There are numerous types of structural forms such as grid structures, sectional structures and net structures. These structures reap the advantage of providing good drainage to the debris retained behind.

(g) Check dam - Check dams have been widely used in the mountainous regions of Japan and Europe, for the mitigation of debris flows by allowing landslide debris to accumulate behind the dams to form platforms. As compared to debris-resisting barrier, check dams are typically constructed at the upper reaches of a drainage channel where the potential volume for landslide source and erosion is high. Usually a

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series of check dams are built in order to modify the longitudinal channel bed profile when the check dams are filled, hence the overall gradient of the channel is reduced and the energy of debris flows would be dissipated. Although check dams have not been used in Hong Kong, there is potential for their application in mitigating sizeable debris flows, particularly for drainage lines with high entrainment potential.

(h) Debris-resisting barrier - Debris-resisting barriers can be broadly divided into rigid barriers (Figures 5.1f and 5.1g) and flexible barriers (Figure 5.1h). Typical forms of rigid debris-resisting barriers are concrete barriers, earthfill barriers and gabion barriers. Concrete barriers in the form of gravity structures are the most commonly used debris-resisting barriers. In Hong Kong, a terminal concrete barrier is a popular option for debris flow mitigation because of its ability to resist high impact loading from debris flows and boulders. Technical guidance on design of rigid debris-resisting barriers is given in GEO (2012b, c).

(i) Debris retention basin - Debris retention basins are usually constructed at the deposition zone where the ground profile is relatively gentle and a sufficient area is available for the debris flow to slow down and deposit (Figure 5.1i). Debris retention basins can be broadly divided into open basins and closed basins. In Hong Kong, closed retention basins are more commonly used because of the scarcity of land in the urban areas.

(j) Boulder fence - In Hong Kong, the first attempt to utilize flexible steel fences to mitigate boulder and rock-fall hazards on a large scale was carried out in the Mid-Levels Area in the early-1980s (Chan *et al.*, 1986) (Figure 5.1j). Since then, numerous flexible steel fences have been installed to protect developments from boulder fall and rock fall hazards.

5.4 Holistic Risk Mitigation Strategy

Where mitigation actions are required at the CD or TD discharge points but the adjacent ancillary OH sub-catchments do not meet the ‘react-to-known-hazard’ principle, a holistic risk mitigation strategy may include the OH sub-catchments to protect the facilities at risk. This arrangement may also be applied to OH catchments that do not meet the ‘react-to-known-hazard’ principle but adjoining a catchment that requires mitigation actions. For CD and TD catchments where CDF and DF hazards are considered unlikely, Level 1 hazard mitigation may also be adopted, as a prudent provision for more holistic risk mitigation.

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In considering whether the holistic risk mitigation strategy should be adopted, judgement needs to be exercised taking into account the types of facility affected, their proximity from the catchment and the level of uncertainties involved. Strong justifications for significant additional expenditure should be provided.

5.5 Mitigation Strategy for Hillside Pockets

The typical setting of a Hillside Pocket within the densely developed urban area means that a number of constraints will require careful review and consideration when determining the most appropriate mitigation scheme. These include, but are not limited to, the following items:

(a) presence of private lots;

(b) access for GI and mitigation works;

(c) presence of steep man-made slopes at the toe and issues associated with surcharge loading onto these slopes;

(d) discharge of surface water run-off from the developed area above onto the Hillside Pocket;

(e) visual impact to nearby residents and the public in general;

(f) buildability of the measures proposed; and

(g) landscaping treatment.

Preventive and mitigation measures have been successfully implemented in some LPMit projects involving Hillside Pockets. These include:

(a) local soil nails to stabilize landslide source areas or local steep terrain;

(b) removal / re-compaction of loose fill bodies;

(c) improved drainage provisions;

(d) in-situ stabilization or removal of boulders;

(e) soil bioengineering techniques for surface erosion protection; and

(f) debris resisting barrier along the toe.

5.6 Landslide Monitoring

As geotechnical instrumentation techniques continue to improve and practitioners gain a better understanding of the possible influence of progressive slope deterioration, slope instrumentation for long-term performance monitoring of hillsides can provide valuable

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information on the understanding of ground and groundwater behaviour during rainstorms. The GEO has undertaken some technical development work to study the performance of various instruments and arrange pilot instrumentation schemes to set up prototype real-time instrumentation networks in Hong Kong (Millis *et al*., 2008). Given the developmental nature of field instrumentation for landslide monitoring purposes, this approach has only been applied for potentially slow moving landslides or sites with signs of distress at some distance from major development.

A wide range of conventional and state-of-the-art geotechnical sensors, e.g. multi-antenna type differential global positioning system (DGPS), ground movement Time Domain Reflectometry (TDR), in-place inclinometers, real-time data communication and geotechnical data processing system were installed in selected sites (Millis *et al*., 2008). Collaborative studies were also carried out with local tertiary institutions (e.g. Leung *et al*., 2011).

For sites with signs of distress, e.g. presence of tension cracks or active deformation, suitable field instruments could be considered to investigate the type, rate and frequency of ground movement, the role of hydrogeology and its effects on slope instability. The instrumentation works may include sensors to monitor surface and sub-surface ground movement, rainfall, groundwater levels, fluvial activity along the drainage lines and potential debris flow behavior.

5.7 Environmental Considerations

5.7.1 Introduction

The majority of natural terrain landslides occur in areas where substantial urban/ suburban development has not occurred. As a result both mitigation and remedial works as applied to natural terrain should consider landscape aesthetics in that the measures should blend with their surroundings as far as practicable (GEO, 2011b). Although both Works Bureau Technical Circular (WBTC) No. 25/93 and 17/2000 specifically apply to the design and maintenance of man-made slopes, their principle of minimizing visual impact is also relevant to natural terrain. Emergency landslide repairs are however exempt from both circulars.

For any mitigation works carried out within the Country Parks or in environmentally sensitive areas, or for any works classified as designated projects under the Environmental Impact Assessment (EIA) Ordinance, the potential environmental impacts of these works should be assessed. If found necessary, appropriate monitoring and/or measures should be implemented to ensure that the impacts to the environment are kept to an acceptable level.

5.7.2 Soil Bio-engineering

Natural terrain landslides occur as part of the on-going, natural processes of erosion and landform evolution. Therefore, aesthetic reasons alone may not be sufficient to qualify a natural terrain landslide scar for revegetation. However, where landslide reactivation is likely, or where the landslide debris may be remobilized, or deterioration of the conditions of the hillsides needs to be minimized, revegetation may form an integral, cost-effective part of any

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mitigation proposals. Soil bio-engineering may be adopted in reparation of hillsides affected by landslides or hill fires so as to control surface erosion and soil loss, and to prevent further deterioration of the hillsides. There is also scope for application of soil bio-engineering as mitigation measures to reduce the consequence of natural terrain landslides by partial retention of coarse debris or to reduce entrainment by stabilizing loose deposits.

Most natural terrain landslides in Hong Kong are relatively shallow and commonly occur along geological/hydrogeological boundaries such as the colluvium/saprolite interface. The topsoil and other suitable growth media are commonly removed and natural revegetation can be slow. Furthermore, natural terrain landslides can take many forms and hence they result in a wide range of soil damage. Therefore, each location needs to be carefully studied to determine the objective of the bio-engineering application and the most appropriate techniques for that site.

Characteristics of various plant species commonly used in Hong Kong as surface protection are summarized in the Geotechnical Manual for Slopes (GCO, 1984). The General Specification for Civil Engineering Works provides specifications and guidance on landscaping works and establishment. Campbell *et al*. (2008) provided useful commentary on and evaluation of soil bioengineering techniques, both generally and specifically for landslide repairs. Cheung *et al*. (2011) gave information on bioengineering trials. GEO (2011b) provided guidance on good practice of landscape treatments for engineering works on natural terrain.

5.7.3 Visual Impact of Mitigation Measures

In addition to the soil bio-engineering approach, the visual impacts of any hard mitigation measures, such as rigid debris-resisting barriers, should be considered. Where possible visual intrusion should be reduced, for example, through plantation of vegetation screens to hide the facilities or blending of the measures with the natural environment.

As natural hillsides are generally remote, consideration should be given to future access requirements for maintenance of the mitigation works. If planting of vegetation is to be used, special consideration should be given to use of maintenance free plant species.

Although flexible barriers are generally less visually intrusive than rigid barriers, they may still be considered undesirable where extensive flexible barriers are to be located in close proximity to residential buildings. This aspect should be carefully considered in the formulation of suitable mitigation options.

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Appendix A

Acronyms

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A.1 Acronyms

API	Aerial Photograph Interpretation
CDF	Channelised Debris Flow
CEDD	Civil Engineering and Development Department
CEL	Civil Engineering Library
DEA	Design Event Approach
DGIU	Digital Geotechnical Information Unit
DOP	Digital OrthoPhoto
ENTLI	Enhanced Natural Terrain Landslide Inventory
GASP	Geotechnical Area Studies Programme
GCO	Geotechnical Control Office
GEO	Geotechnical Engineering Office
GI	Ground Investigation
GInfo	Geotechnical Information Infrastructure
GIS	Geographic Information System
GIU	Geotechnical Information Unit
GPS	Global Positioning System
HLC	Historical Landslide Catchment
LIC	Land Information Centre
LiDAR	Light Detection and Ranging
LPMitP	Landslip Prevention and Mitigation Programme
NTHA	Natural Terrain Hazard Assessment
NTHR	Natural Terrain Hazard Review
NTHS	Natural Terrain Hazard Study
NTLI	Natural Terrain Landslide Inventory
OHL	Open Hillslope Landslide
QRA	Quantitative Risk Assessment
RMI	Routine Maintenance Inspection
SIS	Slope Information System
TD	Topographic Depression
TGN	Technical Guidance Note

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Appendix B

Glossary of Terms

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B.1 Introduction

This glossary of terms has been compiled to help promote a consistent use of terms in the study of natural terrain hazards in Hong Kong. Much of it is extracted from Cruden and Varnes (1996) which is a widely accepted reference on landslide types and processes. A review on the landslide terminology is given by Hungr *et al*. (2001).

For many Hong Kong natural terrain landslides, it is difficult to establish the mechanism of initial displacement and transport and use of the wider definitions proposed below may be more practical. The terminology is primarily prepared for study of natural terrain landslides in Hong Kong. As such, it is biased towards terms used for describing elongate, relatively shallow natural terrain landslides which are dominated by flow and alluvial processes. The glossary includes some additional and more detailed terms than those of Cruden and Varnes (1996), and some new definitions. Additional definitions of landslide types are based on Hutchinson (1988) and for the description of sediment-water flows, on Pierson and Costa (1987). Users of the terminology may define and use their own terms for any specific project although consistency is recommended wherever possible. Figure B.1.1 illustrates the main features of a typical natural terrain landslide scar.

B.2 Glossary of Terms

<u>Angle of Reach</u>
The arc-tangent of the height of a landslide (H) divided by its length (L) where; H = elevation difference between the crown and the toe and L = the horizontal distance from the crown to the toe. Note that this is similar to the apparent angle of friction (Sassa, 1987), equivalent coefficient of friction (Hsu, 1975) and average coefficient of friction (Scheidegger, 1973). However, these terms have in some cases been used when H and L are defined on the basis of the centre of gravity of the displaced material. The term reach angle is proposed in conformity with its use by Corominas (1996) as this reference may be used to help estimate run out distance. The same angle is termed Travel Angle by Cruden and Varnes (1996).

<u>Blocky Landslide Debris</u>
Landslide debris comprising loose blocks of intact displaced material, commonly rock and/or soil.

<u>Block</u>
A discrete boulder-sized fragment of rock significantly detached from its outcrop source and characterized by an angular shape of tabular or blocky form. It may lie on or adjacent to the source or have travelled downslope.

<u>Boulder</u>
A rock fragment greater than 200 mm diameter that is not part of a rock mass.

<u>Boulder Fall</u>
The displacement of a boulder where the movement may include free fall through the air, sliding, leaping and rolling. Note that in Hong Kong boulder falls commonly result from undercutting by erosion, or landsliding of exhumed corestones or colluvial boulders on steep natural hillsides.

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Boulder Field
An area covered by a veneer of boulders.

Catchment
An area of a hillside with a relatively uniform geomorphology from which one or several well-defined hazard models could affect the site.

Channel
A linear depression of the ground surface in which water may flow.

Channelize
To convey in a channel. A landslide is considered to be channelized when the moving landslide debris converges into a channel that confines its lateral extent. Note that this commonly results in a longer travel distance than for an open slope landslide of the same volume.

Channelized Debris Flow
A debris flow that has become channelized in a drainage line with significant amounts of surface water mixed into the debris. Note that while debris flows may occasionally develop on hillslopes and become confined in hollows, these are difficult to distinguish from debris avalanches on the basis of mobility or by API, or even by field observations soon after the failure. Therefore, for the purposes of hazard recognition and data collection, the term is best used for debris flows that are coincident with a streambed.

Channelization Ratio
The width to depth ratio of the cross section area in a channel occupied by a pulse of landslide debris. Channelization may be defined in relation to this ratio.

Cliff
Any steep to sub-vertical or over-hanging face of rock.

Colluvium
A general term applied to generally structureless and commonly heterogeneous mass of soil and/or rock material and sometimes organic matter, deposited on, and at the base of, natural slopes predominantly by mass-wasting processes (after Bates & Jackson, 1987). It is usually landslide debris.

Colluvial Fan
A colluvial deposit shaped like a fan or cone, usually with the apex at a point where a drainage line ends. Such a feature is usually the result of deposition from a number of debris flows over a period of time.

Colluvial Lobe
A colluvial deposit with convex sides that forms a positive landscape feature. Often located along the bottom of a valley. Such a feature is usually interpreted as a landslide debris deposit from a single landslide.

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Confined Scar
A landslide scar in which the surface of rupture comprises a distinct main scarp and floor and may include a rising downslope part. The source material cannot be displaced until it is transformed into a kinematically feasible geometry by internal displacements or shears (Hutchinson, 1988). A confined scar has no trail.

Crown
The practically undisplaced material still in place and adjacent to the highest parts of the main scarp (IAEG, 1990).

Debris
Predominantly coarse soil. In Hong Kong such material is usually the weathered profile and/or colluvium and may be referred to as regolith. Landslide displaced material that has disintegrated is commonly called “debris”. To retain conformity with international practice the term landslide debris is used for this in the terminology (see Landslide Debris).

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Debris Avalanche
A landslide comprising a rapid to extremely rapid, shallow movement of partially or fully saturated mainly granular debris on steep slopes with only minimal water mixed into the displaced material after failure. Movement is by sliding and/or liquefaction and/or rolling and/or bouncing and/or saturated or inertial granular flow (Pierson and Costa, 1987; Varnes, 1978).

In most cases the surface of rupture is rough, comprising in-situ weathered rock with embedded corestones or colluvium containing large clasts. Thin layers of remoulded debris and rafts of intact soil may locally overlie the surface of rupture, which suggests that other processes may be involved such as the localized flow of the displaced material due to elevated pore water pressure. This could be caused by perched water tables from infiltration and soil pipes, seepage pressures, and the collapse of soil structure in undrained conditions. As movement continues, and the intact material breaks up into landslide debris, components of undrained loading, rolling, bouncing and inertial granular or slurry flow (Pierson & Costa, 1987) may also be important. Where the landslide debris is mobile, but the slope below the source is planar or convex, the debris usually spreads out over the ground with lobes and fingers extending downslope as an open slope debris avalanche.

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Debris Flood
The transport of significant load of sediment by the dominant mechanisms of stream flow or hyperconcentrated stream flow. The load can range in grain size from clay to boulders. A debris flood may originate from outwash of landslide debris or gully erosion.

Debris Flow
A landslide in which the landslide debris moves by the dominant mechanism of slurry flow. Note that the presence of remoulded landslide debris is a good indication that slurry flow has occurred. If the moisture content of the displaced material is high enough then slurry flow may develop during movement without additional water. More commonly a debris flow develops when landslide debris mixes with surface runoff.

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Debris Slide

A landslide in which an intact displaced mass moves by the dominant mechanism of sliding. Note that when these occur on steep hillsides they typically form an elongate scar.

Debris Torrent

A term used in Canada by D.F. VanDine (1985) to mean the same as “channelized debris flow” and defined by him as “a mass movement that involves water-charged, predominantly coarse grained inorganic and organic material flowing rapidly down a steep confined pre-existing channel”. Torrent is used by Aulitzky (1989) to describe steep mountain streams.

Debris Runout

The travel distance of landslide debris beyond a specified point. The “landslide run-out” may be the horizontal length of the scar. Run-out may also be considered beyond a point with a limiting angle where deposition starts (deposition point) or the “slope toe”.

Deposition Point

A notional point on a landslide trail beyond which most landslide debris is assumed to be deposited.

Design Event

The particular size specification for a hazard model that is selected to be mitigated against as part of a development.

Displaced Material

The material moved from its original position on the slope by a landslide (IAEG, 1990). Note that an accumulation of displaced material forms a deposit.

Drainage Line

A channel with a stream bed in which water flows for at least part of the year.

Drainage Line Order

A first order drainage line has no confluences (i.e. no other contributing drainage lines), two first order drainage lines make a second order, and two second orders drainage lines make a third order (a second and first order confluence remains a second order) (after Strahler, A.N., 1952).

Elongate Scar

A landslide scar in which some or all of the displaced material has mobilized from the surface of rupture forming landslide debris. Note that an elongate scar has a trail and the source is often a spoon shaped or tabular depression.

Elongate Channelized Scar

An elongate scar in which the landslide debris has been channelized in a drainage line or depression and the trail has a low channelization ratio.

Engineering Geology

Engineering geology has methods at its disposal to quantify or express geological data in a way which allows them to be integrated into numerical modelling and into decision-making

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processes during planning and construction. Interpreting geology from the perspective of engineering geology allows the behaviour of ground to be defined and predicted (Vallejo & Ferrer, 2011). Engineering geologists have training and experience in ground problems that arise in civil engineering and in the investigation, classification and performance of soils and rocks related to civil engineering situations; and a working knowledge of basic soil mechanics, rock mechanics and hydrogeology (Fookes, 1997).

Engineering Geomorphology
Engineering geomorphology complements engineering geology in providing a spatial context for explaining the nature and distribution of particular ground-related problems and resources (Fookes, *et al*., 2005). Engineering geomorphology is directed towards understanding the way landforms or earth surface systems respond to relatively short to medium-term (<1 to 1000 years) changes in energy inputs (e.g. resulting from climatic variability, changes in sediment supply, land use change, neotectonics, the effects of man) rather than long-term landscape denudation and evolution (Fookes *et al*., 2007). The implications for engineering geomorphology include landscape elements of different ages and stabilities; a legacy of pre-existing geohazards; the presence of inherited near surface materials and inherited resources (Fookes, *et al*., 2005).

Entrainment Factor
The volume of additional material that has been entrained by a landslide expressed as a proportion of the source volume.

Entrained Material
The displaced material from any location other than the source.

Floor
Any exposed shallow part of the surface of rupture.

Flow
A spatially continuous movement in which surfaces of shear are short-lived, closely-spaced, and usually not preserved. The distribution of velocities in the displacing mass resembles that in a viscous liquid (Cruden and Varnes, 1996).

Frequency
The number of events that occur in a specific period of time.

Geological Model
A representation of the geology of a particular location. The form of the model can vary widely and may include written descriptions, two-dimensional sections or plans, block diagrams, or be slanted towards some particular aspect such as groundwater or geomorphological processes, rock structure and so on (Fookes, 1997).

Gully Erosion
The incision of ground along flow lines by surface water.

Hazard
A physical situation with a potential for human injury, damage to property, damage to the environment or some combination of these (ERM, 1998).

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Hazard Types
Types of landslide that will result in a well-defined risk to a development site. It is described in terms of volume, nature and velocity of material passing the site boundary at a specified location.

Hazard Intensity
A relative measure of the potential for harm from a hazard. High intensity has a greater potential for injury and loss than low intensity.

Head
The upper parts of a landslide along the contact between the displaced material and the main scarp (IAEG, 1990). Note that an elongate landslide may not have a definable head.

Hollow
A depression, commonly linear, on hillside.

Hyperconcentrated Stream Flow
The flow of a mixture of water and sediment that possesses a small but measurable yield strength but that still appears to flow like a liquid. Particles settling out of a hyperconcentrated stream flow suspension settle independently, giving deposits sorted by grain size (Pierson and Costa 1987).

Inertial Granular Flow
A flow in which the full weight of the flowing granular mass is borne by grain-to-grain contact or collisions in which grain inertial effects dominate but frictional effects are still significant (Pierson and Costa, 1987).

Intact Displaced Mass
The full mass of displaced material (soil, colluvium or rock) from a landslide when it largely retains its original morphology.

Intact Displaced Material
A displaced block of soil, colluvium or rock that retains its original structure. Note that intact displaced material may occur as clasts, blocks or slabs within landslide debris.

Intermediate Deposit
The landslide debris accumulation at some point along the trail between the source and the toe.

Landslide
A general, all-encompassing term used to describe an event comprising the relatively rapid downslope movement of a discrete mass of soil and/or rock. Note that the term makes no inference to process, i.e. true sliding may not be involved. It is proposed that extremely slow slope movements such as soil creep and gravitational sagging are not included under the general term landslide.

Landslide Cause
An environmental factor that gradually brings a slope to failure such as the chemical or physical weathering of slope materials (Weiczorek, 1996).

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Landslide Debris

The displaced material from a specific landslide that has disintegrated and lost its original morphology. Landslide debris may include clasts of intact displaced material. Note that landslide debris is very young colluvium and it is proposed that the term is used to distinguish the landslide debris of a specific landslide from pre-existing in-situ colluvium in the regolith which may have the same composition. The term landslide debris may be shortened to "debris" for convenience where this will not be ambiguous or confused with regolith debris.

Landslide Erosion Feature

A relatively large depression defined by scarps or a sharp break in slope. This is assumed to be landslide related. Smaller recent landslides may occur along the perimeter scarp but there is no debris deposit that can be unambiguously interpreted as the result of a single failure. This feature could be the source of a single very large landslide, or the result of a number of smaller landslides over time, or an erosion scarp (possibly landslide generated) cutting back into an older landscape.

Landslide Trigger

An external stimulus that causes a near-immediate response in the form of a landslide by rapidly increasing the stresses or by reducing the strength of slope materials. Typical triggers are intense rainfall, collapse of a soil erosion pipe, earthquake shaking, storm waves or rapid stream erosion (Weiczorek 1996).

Lateral Deposit

A landslide debris deposit comprising ridges aligned along the trail at or near its lateral margins.

Liquefaction

The generation of high positive excess pore water pressures during shearing and hence a substantial reduction of the effective stress and the shearing resistance. Note that in Hong Kong liquefaction is known to have occurred in the rain-induced failure of loose fill slopes.

Liquefaction Slide

A slide in which liquefaction occurs within a zone at the sliding surface and the landslide debris is not saturated (Casagrande, 1971; Hutchinson, 1988).

Main Scarp

The exposed steep part of the surface of rupture (IAEG, 1990).

Mass Transport

The carrying of soil and rock material in a moving medium such as water, air, or ice (after Bates & Jackson, 1987).

Mass Movements

A general term for the dislodgement and downslope transport of soil and rock material under the direct application of gravitational body stresses. In contrast to other erosion processes, the debris removed by mass movement processes is not carried within, on, or under another medium. The mass properties of the material being transported depend on the interaction of the soil and rock particles and on the moisture content. Mass movements include slow displacements, such as creep, and rapid processes such as rock falls, rock slides, and debris flows (Syn. mass wasting) (after Bates & Jackson, 1987).

Mobilization
The movement of displaced material from the source. Usually expressed as the proportion of the material that is displaced.

Mud Flow
A landslide with the same characteristics as a debris flow in which the displaced material is predominantly fine-grained.

Natural Terrain
Terrain that has not been modified substantially by human activity such as site formation works, agricultural terracing, cemetery platforms or squatter habitation. Note that in most of Hong Kong natural terrain has been influenced by deforestation and fire and locally may have been influenced by prehistoric agriculture. Natural terrain and natural hillside are synonyms

Natural Terrain Landslide
A landslide in which the source is located entirely within natural terrain. Note that a landslide involving both natural terrain and terrain that has been modified substantially by human activity is not considered to be a natural terrain landslide, e.g. failure immediately above and extending into an excavation or immediately below fill.

Open Hillslope Landslide
A landslide with its scar entirely on the hillside and is not channelized along a stream course. It is initiated on a hillside slope and transported by the mechanism of debris avalanche or debris slide.

Outcrop
An exposed area underlain by a specific material or rock unit.

Outwash
The redistribution of landslide debris by stream flow and hyper-concentrated stream flow.

Parent Landslide
A discrete initial landslide, the landslide debris from which increases in volume through erosion and entrainment of the downslope substrate to become a debris flow.

Quasi-natural Terrain
Predominantly natural terrain which is partly modified by human activities but largely retains its original profile and regolith cover. Minor surface features such as agricultural terracing, grave sites or squatter platforms may be present. Modification of the slopes above and below by cutting, filling and construction may have affected the surrounding ground and surface water conditions.

Quasi-natural Terrain Landslide
A failure in predominantly natural terrain triggered by, or possibly triggered by, a relatively small human activity. Landslides for which there is an element of doubt with respect to the importance of human activity are placed in this category.

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Recent Landslide

A landslide that occurred within the aerial photograph coverage. The time period in which they occurred can be determined by reference to timing of aerial photography. In the ENTLI recent landslides are defined as those with a light tone on aerial photographs and are generally bare of vegetation, being in vegetation cover Classes A or B (i.e. completely or partially bare of vegetation).

Regolith

A general term for the layer or mantle of fragmental and unconsolidated rock material (engineering soil), whether residual or transported and of highly varied character, that nearly everywhere forms the surface of the land and overlies or covers the bedrock. It includes rock debris of all kinds (after Bates & Jackson, 1987).

Relict Landslide

A landslide that occurred earlier than the time scale of the available aerial photographs. In the NTLI, relict landslides are defined in relation to landslides first observed on the earliest available photographs and with vegetation class C or D (i.e. completely covered by grasses or by shrubs and trees). As part of the ENTLI, the relict landslide definition has included an expression of the relative certainty behind the interpretation.

Remoulded Landslide Debris

Landslide debris that has largely lost its original structure and comprises a remoulded matrix that supports particles of gravel size or larger. Note that remoulded landslide debris may occur as steep-sided deposits such as lobate fronts, levees, and accumulations on the uphill side of, or capping, obstructions in the trail.

Risk

The likelihood of a specified undesired event occurring within a specified period or in specified circumstances. It may be viewed in terms of either a frequency (the number of specified events occurring in unit time) or a probability (the likelihood of a specified event following a prior event) depending upon the circumstances (ERM, 1998). It commonly refers to as the product of frequency (or probability) and consequence.

Rock Fall

The displacement of a piece of rock from a rock face chiefly by free fall through the air but may include sliding, leaping and rolling. Note that this is a simple landslide if the initial displacement does not involve another mechanism such as sliding or toppling.

Rotational Scar

A scar in which the surface of rupture is curved and concave upwards and imparts a degree of backward rotation or tilt to the surface of the displaced ground. Note this was termed a slump by Varnes (1978) and a slip by Hutchinson (1988).

Runout

The process of transport of displaced material beyond the source. If expressed as a distance it will be length less the horizontal extent of the source.

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<u>Scar</u>
The land surface affected by a landslide. This includes the source, the displaced material and any trail.

<u>Sheet Erosion</u>
The uniform removal of soil or decomposed rock by the surface flow of water or a mixture of water and sediment.

<u>Side/Head wall</u>
The area of a catchment or sub-catchment that could contribute debris to a stream channel.

<u>Site Catchment</u>
The area from which surface runoff would intersect the site boundary or flow into a drainage line adjacent to the site, effectively the water catchment to a site.

<u>Slide</u>
A landslide in which the movement of debris is sliding. Note that this may be further qualified by a prefix describing the morphology of the scar and specifying the material involved, e.g. slides may result in translational, rotational, compound or confined scars from failures of colluvium, saprolite or rock.

<u>Sliding</u>
Downslope movement occurring dominantly on surfaces of rupture or on relatively thin zones of intense shear strain (Cruden and Varnes, 1996).

<u>Slump</u>
A scar with an intact displaced mass which partially overlies the surface of rupture.

<u>Slurry Flow</u>
The movement of a saturated sediment/water mixture having sufficient yield strength to exhibit plastic flow behaviour in the field. When movement ceases, fine and coarse particles settle together with no inter-particle movement (Pierson and Costa 1987).

<u>Sorted Landslide Debris</u>
Landslide debris in which grain size sorting and/or layering is present and that has little or no fines.

<u>Source</u>
The space between the surface of rupture and the original ground level.

<u>Stream Bed</u>
The bottom of a relatively narrow but clearly defined channel, where surface water flows or may flow over bedrock and/or loose granular deposits.

<u>Stream Flow</u>
The flow of water with insufficient sediment concentration to affect the flow behaviour (Pierson and Costa 1987).

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Study Area
The area from which natural terrain landslide hazards could affect the site. In most cases this should include both the site and its catchment.

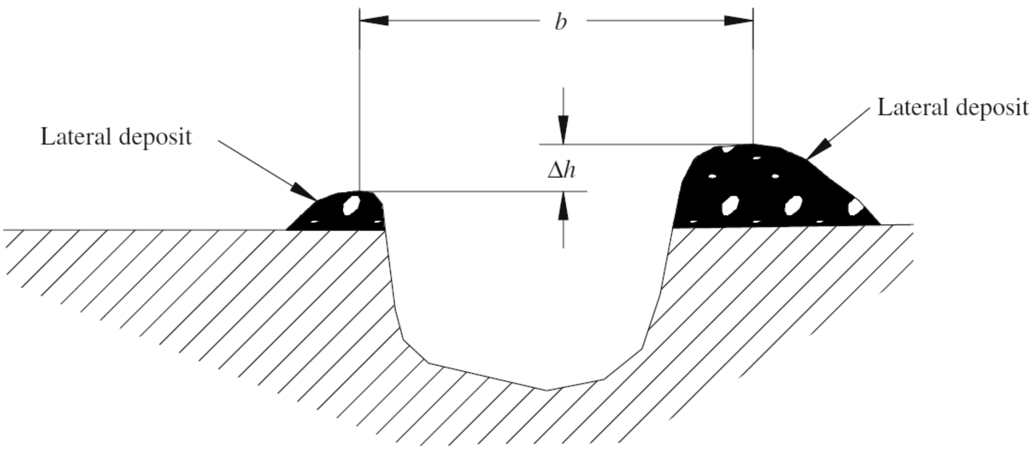
Substrate
In-situ material over which landslide debris is transported.

Super-elevation
Super-elevation refers to the difference in surface elevation, or banking, of a debris flow as it travels around a bend. Higher velocities result in increased banking. If the bend geometry is known, flow velocity can be estimated from super-elevation or vice versa. The most commonly referenced method for making this estimation is the forced vortex equation (Hungr *et al*., 1984; Johnson & Rodine, 1984) as shown below. Prochaska *et al.* (2008) noted several difficulties with the use of the forced vortex equation and the uncertainties involved.

$$v = \sqrt{\frac{R_c g}{k} \frac{\Delta h}{b}}$$

where

v	mean flow velocity
Rc	the channel's radius of curvature
g	acceleration due to gravity
Δh	super-elevation height
k	correction factor for viscosity and vertical sorting
b	the flow width



Surface of Entrainment
A surface on undisturbed ground that was originally below ground level and from which material has been picked up and moved away during the landslide. This is separate, and downslope from the source.

Surface of Rupture
A surface on undisturbed ground that was originally below ground level and from which a discrete mass of displaced material has moved away (IAEG, 1990).

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<u>Terminal Deposit</u>
A landslide debris deposit at the toe of the trail. It is commonly lobate or fan shaped.

<u>Toe</u>
The lower margin of the displaced material of a landslide. It is the most distant part of the scar from the main scarp IAEG (1990). Note that for a landslide with a trail this will be the distal part of the trail.

<u>Topple</u>
Movement of a detached rock mass by overturning about a pivot point below the centre of gravity of the unit (Varnes, 1978). Note that topples are often multiple.

<u>Trail</u>
The part of a scar downslope from the source. This may include displaced material, ground over which displaced material has passed and any surface of entrainment.

<u>Translational Scar</u>
A scar in which the surface of rupture is relatively planar or gently undulating in downslope section and often broadly channel-shaped in cross section (Cruden and Varnes 1996).

<u>Uniform Deposit</u>
A landslide debris deposit comprises a sheet of landslide debris of uniform thickness within the trail.

<u>Weathered Mantle</u>
A regionally widespread and usually deep zone of weathered rock materials, formed in situ over a geologically long interval by relatively uniform chemical weathering (Syn. weathered profile, weathering crust) (after Bates & Jackson, 1987).

<u>Yield Rate</u>
The yield rate is defined as the volume eroded per metre of channel length (Hungr *et al*., 1984; Jakob & Hungr, 2005).

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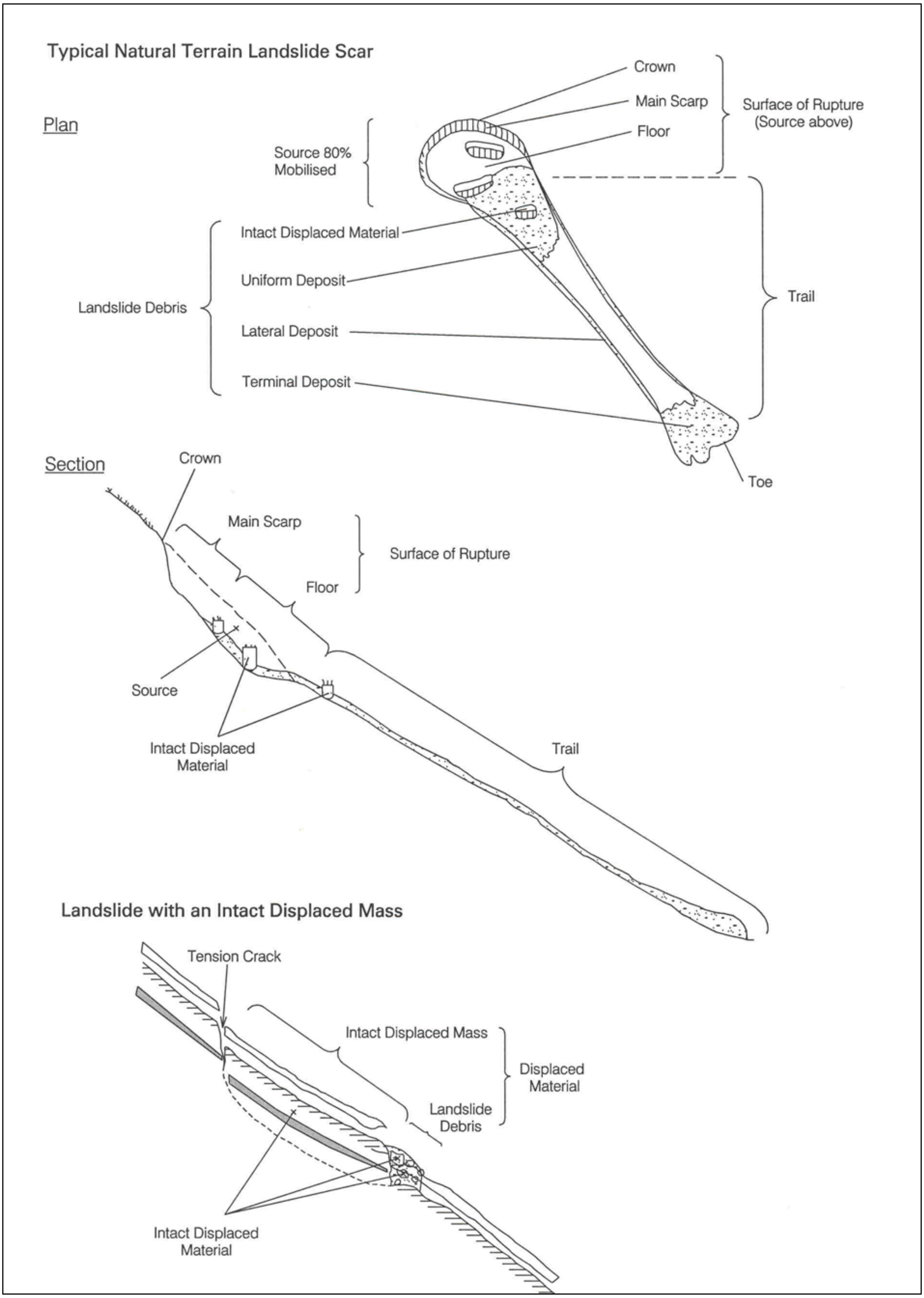

Figure B.1.1 Schematic Diagram of a Typical Natural Terrain Landslide Scar

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Appendix C

Notable Natural Terrain Landslides in Hong Kong

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C.1 Notable Natural Terrain Landslides in Hong Kong

Some notable recent natural terrain landslides that have been studied and documented in a systematic manner are summarised in Figures C.1.1 to C.1.7. In addition to the study reports, the main findings of some of these landslides are available on the GEO Hong Kong Slope Safety Website, http://hkss.cedd.gov.hk under "Summary of Findings of Landslide Investigation".

Natural terrain landslides tend to become widespread when rain is very heavy, say the normalized 24-hour rainfall (defined as the maximum rolling 24-hour rainfall divided by the mean annual rainfall, as an indicator of rainfall intensity) being greater than 20%. Such heavy rainstorms had caused widespread failure and increased failure scale and mobility. Some examples are given in Figures C.1.8 to C.1.11.

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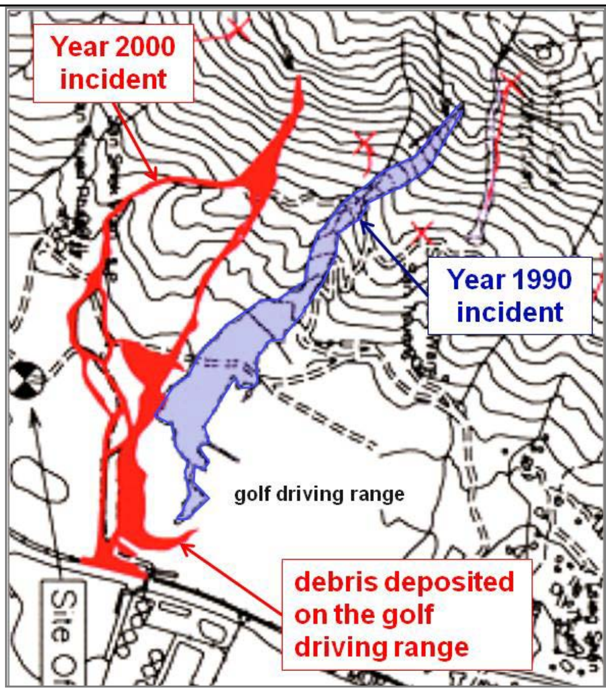
General View



Location Plan

Date	11 September 1990
Landslide Type	Debris flow
Volume of Landslide Debris Involved	20,000 m^3
Consequence	Planned land use of the site below the landslide was amended from residential development to a golf driving range.
Key Observations	The debris flow started as a debris slide of about 350 m^3 at the landslide source. After significant erosion and entrainment, the total volume of debris involved became 20,000 m^3, with a runout distance of about 1 km. *(A recent review by GEO suggested that the exceptionally high entrainment rates along certain channel sections appeared to be related to anthropogenic influence.)* This event demonstrated the risk of debris flows due to the potential for high material entrainment along their flow path. After the debris flow, the originally planned residential development at the Tsing Shan foothills was changed to a golf driving range to minimize the risk exposure to debris flows. In 2000, another debris flow of about 1,600 m^3 occurred at an adjacent drainage line, and resulted in debris deposited on the golf driving range. This is a vivid illustration of the role of land-use and development planning in controlling undue increase in the risk of natural terrain landslides.
Reference	King, J.P. (2013). Tsing Shan Debris Flow and Debris Flood. GEO Report No. 281, Geotechnical Engineering Office, Hong Kong.

Figure C.1.1 1990 Tsing Shan Landslide

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General View

Date	13 August 1995
Landslide Type	Deep-seated slide *(Note: the Shum Wan Road landslide was partially triggered by anthropogenic influences)*
Volume of Landslide Debris Involved	26,000 m^3
Consequence	Severely damaged three shipyards and a factory on the sea front. 2 fatalities and 5 injured.
Key Observations	The landslide occurred in a slope which had moved in the past as identified by the GASP studies and confirmed by the site specific aerial photograph studies. It was initiated by a small fill failure at the top of the slope which then permitted the discharge of water from Nam Long Shan Road directly onto the slope. The landslide was controlled by structures within the weathered volcanic rock which were not bedding-related, and not obviously related to local joint and fault patterns. The presence of kaolinitic clay seams and clay-filled joints at shallow depth within the weathered rock mass was a major contributory factor to the relatively low shear strength as well as to controls on shallow groundwater flow.
Reference	GEO (1996). Report on the Shum Wan Road Landslide of 13 August 1995. Geotechnical Engineering Office, Hong Kong.

Figure C.1.2 1995 Shum Wan Road Landslide

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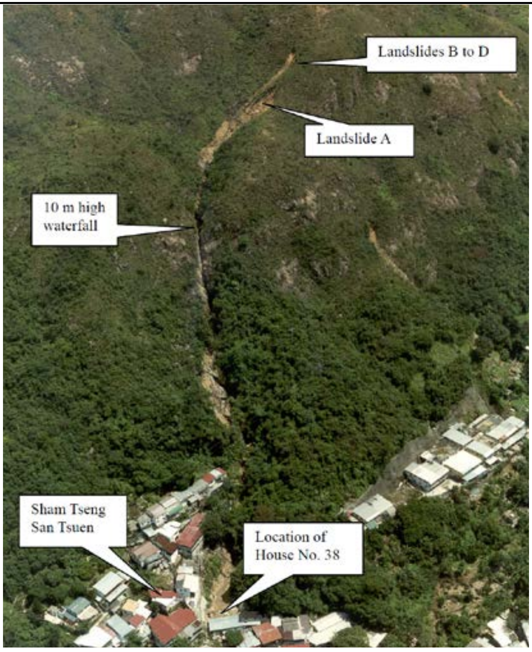

General View

Remains of House No. 38

Date	23 August 1999
Landslide Type	Channelised debris flow
Volume of Landslide Debris Involved	600 m^3
Consequence	Demolished several dwellings. 1 fatality and 13 injured.
Key Observations	The debris flow occurred during a severe rainstorm which was the most severe in the area in terms of short to medium-duration rainfall since 1984 when the nearest automatic raingauge was installed. The affected hillside was vulnerable to rain-induced shallow failures due to the following unfavourable factors: (i) thin mantle of bouldery colluvium overlying weathered rock, which is favourable to the build-up of perched water tables; (ii) the presence of relict failures at the landslide sites which would probably have disturbed and weakened the rock mass and adversely affected the local hydrogeology by promoting direct infiltration through the open or partially infilled joints; (iii) the occurrence of a major hillfire in the 1995/1996 dry season which removed much of the vegetation cover; and (iv) progressive deterioration of the hillside involving opening up of discontinuities with time, probably associated with intermittent slope movement, during heavy rain.
Reference	FMSWJV (2005). Report on the Debris Flow at Sham Tseng San Tsuen of 23 August 1999. GEO Report No. 169, Geotechnical Engineering Office, Hong Kong.

Figure C.1.3 1999 Sham Tseng San Tsuen Landslide

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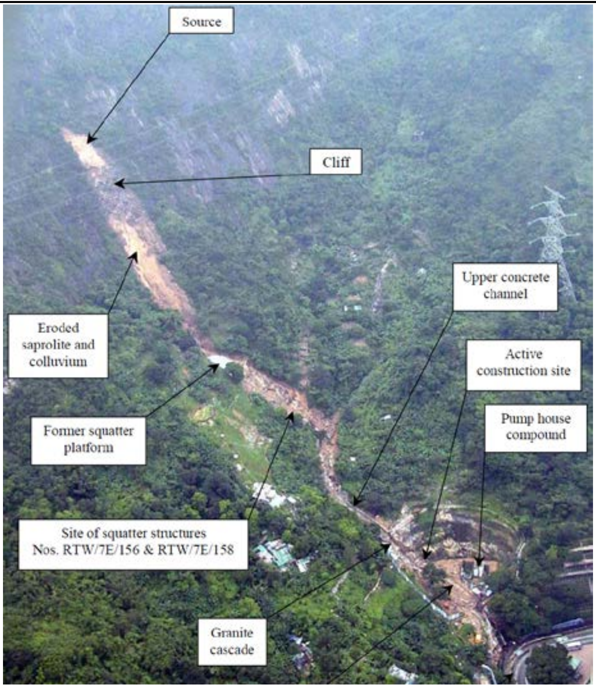

General View

Destroyed Squatter Structures

Date	1 September 2001
Landslide Type	Channelised debris flow
Volume of Landslide Debris Involved	780 m^3
Consequence	Demolished two squatter structures (the occupants of the squatter structures were evacuated from their dwellings about two hours before the event). Lei Pui Street was closed for 3 days.
Key Observations	The rainstorm preceding the landslide was not exceptionally heavy. This suggests that progressive deterioration of the marginally stable hillside at this location probably played a significant role in this incident. The hillside had a history of both soil and rock failures. In particular, structurally controlled rock slabs are vulnerable to rain-induced failures owing to the unfavourable orientation of the sheeting joints and a steeply dipping major joint set that strikes across the hillside to form potential release surfaces and tension cracks. Progressive weathering, dilation, infilling of joints and rotation of the 'key blocks' probably reached the critical point, where the reduction in effective shear strength was sufficient to trigger the failure of rock slabs in the source area of the landslide.
Reference	MGS (2004). Detailed Study of the 1 September 2001 Debris Flow on the Natural Hillside Above Lei Pui Street. GEO Report No. 154, Geotechnical Engineering Office, Hong Kong.

Figure C.1.4 2001 Lei Pui Street Landslide

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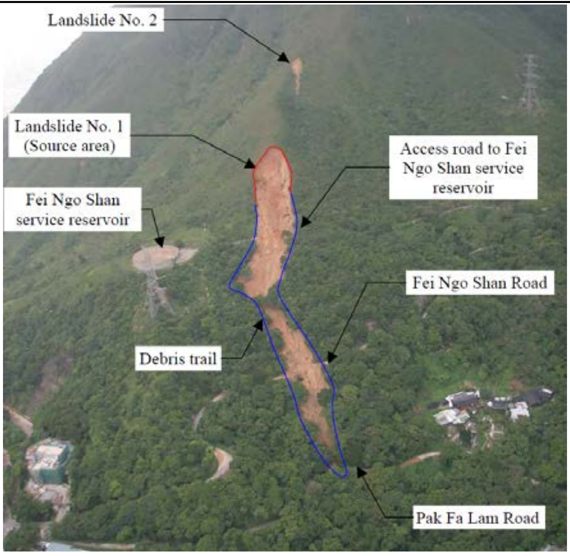
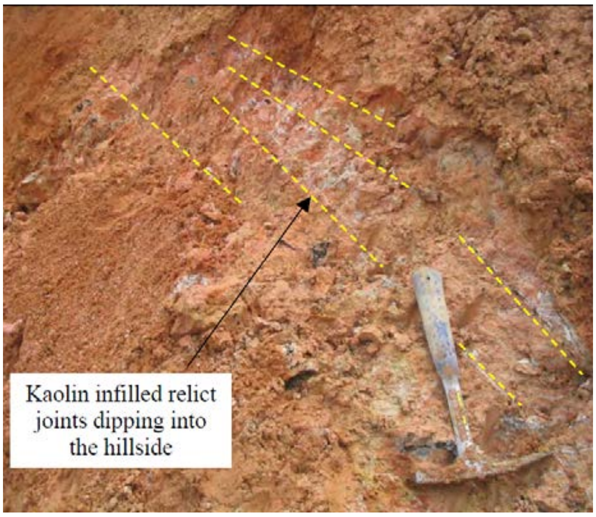


General View



Kaolin Infilled Relict Joints in the Basal Release Surface

Date	21 August 2005
Landslide Type	Channelised debris flow (with deep-seated slide at source)
Volume of Landslide Debris Involved	3,350 m^3
Consequence	Complete blockage of the access road to Fei Ngo Shan service reservoir and Fei Ngo Shan Road and a large boulder deposited on Pak Fa Lam Road.
Key Observations	The main scarp principally involved a 5m deep failure within a small drainage sub-catchment situated beneath a truncated spurline. It occurred first as an open hillside failure that developed along adverse geological structures, in particular the clay infilled relict joints. The landslide subsequently developed into a debris flow which travelled about 290 m. Based on API and field observations, the main scarp is located within a degraded relict landslide scar. The relatively degraded nature of this scar indicates that this site has experienced less frequent detachments of material than the other, fresher-looking landslide scars in the vicinity. The relatively low frequency of detachments at the landslide site may indicate a progressive deterioration in stability and intermittent, small slope movements over a long period of time which allowed a relatively large volume of potentially unstable material to develop without noticeable detachment. The presence of thick clay infillings along both shallow dipping and steeply dipping discontinuities provides supporting evidence of previous slope movements.
Reference	MGS (2008). Detailed Study of the 21 August 2005 Debris Flow on the Natural Hillside Near Fei Ngo Shan Service Reservoir. GEO Report No. 233, Geotechnical Engineering Office, Hong Kong.

Figure C.1.5 2005 Fei Ngo Shan Landslide

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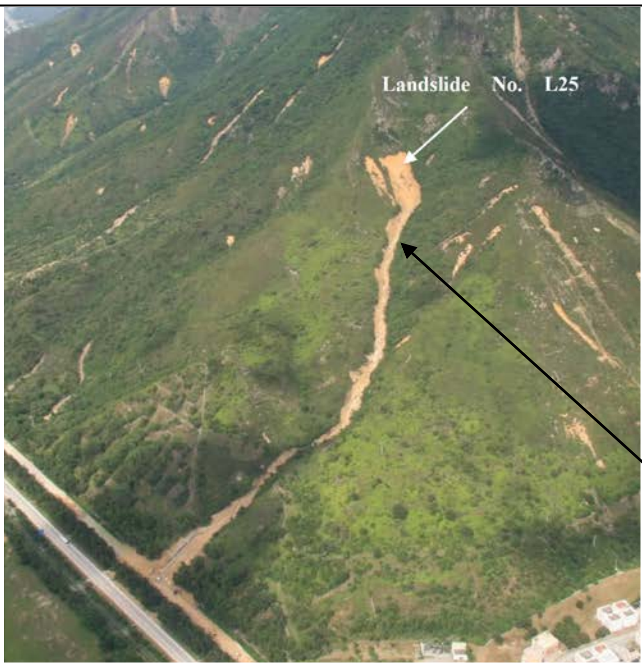

General View of Landslide No. L25

View down Drainage Line below the Landslide Source

Date	7 June 2008
Landslide Type	Channelised debris flow
Volume of Landslide Debris Involved	3,500 m^3
Consequence	The debris blocked the westbound lanes of Yu Tung Road.
Key Observations	The severe 7 June 2008 rainstorm triggered 19 landslides on the hillside above Yu Tung Road. The largest landslide was Landslide No. L25 (see the plates above). This landslide scar was spatially extensive (32m wide by 50m long). The failure involved a large area of bouldery deposits within a topographical depression. This may have influenced the extent of the landslide. The debris flow was very mobile and appeared to be more "watery" than those commonly observed in Hong Kong, probably due to the large catchment size and presence of tributaries. Field observations from the debris flow indicated that the entrainment mainly involved loose materials previously perched on the drainage line. The amount of perched material present along a drainage line is dynamic and may change significantly after a rainstorm.
Reference	Aecom (2012). Detailed Study of the 7 June 2008 Landslides on the Hillside Above Yu Tung Road, Tung Chung. GEO Report No. 271, Geotechnical Engineering Office, Hong Kong.

Figure C.1.6 2008 Yu Tung Road Landslide

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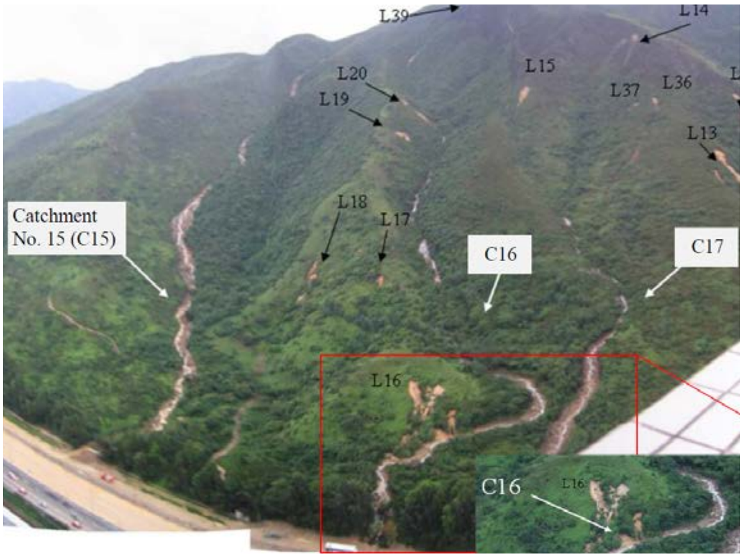
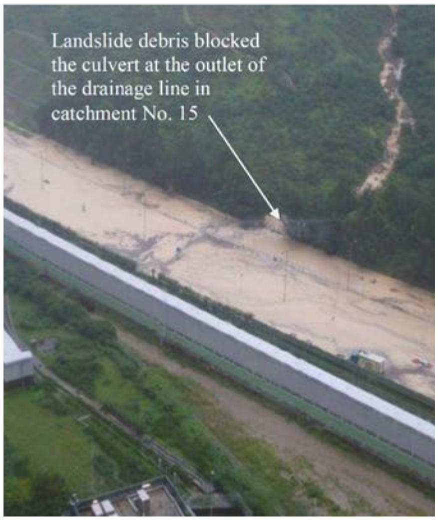


General View of the Site



Flooding of the Highway

Date	7 June 2008
Landslide Type	Debris flood
Volume of Landslide Debris Involved	400 m^3
Consequence	The affected Cheung Tung Road and North Lantau Highway (NLH), which are the sole vehicular access to the Hong Kong International Airport, were temporarily closed for 27 and 16 hours respectively.
Key Observations	A total of 38 landslides occurred on the hillside above NLH, four of them developed into channelized debris flows (CDF), with a runout distance ranging from 200 m to 735 m. None of the four CDF reached the facilities at the toe of the hillside. However, debris flood may have occurred in three hillside catchments (C15, C16 and C17) bringing a significant amount of sediment/debris further downstream. The sediment/debris containing small boulders blocked the toe drainage systems, resulting in flooding of a 400m section of Cheung Tung Road and adjoining NLH. Temporary closure of NLH, which is the sole vehicular access to the Hong Kong International Airport, caused significant impact and economic loss to the community.
Reference	Aecom (2012). Detailed Study of the 7 June 2008 Landslides on the Hillside Above the North Lantau Highway and Cheung Tung Road, North Lantau. GEO Report No. 272, Geotechnical Engineering Office, Hong Kong.

Figure C.1.7 2008 North Lantau Highway Landslide

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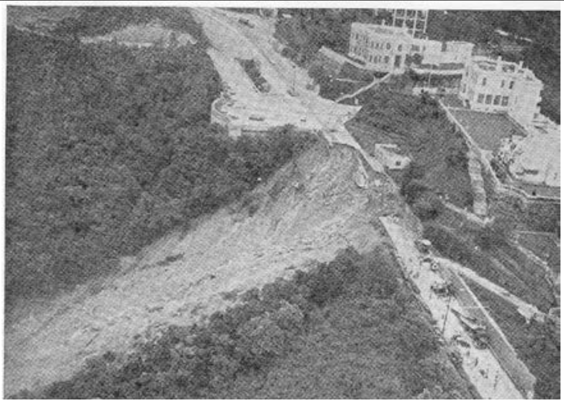
Victoria Road



Peak Road

Glenealy

Magazine Gap Road

Year	1966
Location	Hong Kong Island
Normalized 24-hour rainfall	10-25%
Number of Natural Terrain Landslide	A total of 180 ENTLI landslides over 45 km^2 of natural terrain.
Consequence	The available records suggest that the rainstorm resulted in 64 fatalities, 29 people injured, 2,672 people homeless, 8,561 people temporarily evacuated and 407 houses damaged. (Exact figures for consequence solely related to natural terrain landslides are not clear.)
Key Observations	It can be envisaged that more serious consequences can be caused by a similar rainfall event as the area affected is now more densely developed than in 1966.
Reference	Chen, T.Y. (1969). Supplement to Meteorological Results 1966 - The Severe Rainstorms in Hong Kong during June 1966. Royal Observatory, Hong Kong.

Figure C.1.8 Widespread Natural Terrain Landslides in 1966

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(a) Landslide in Kau Wah Keng

(b) Landslides in Sham Tseng San Tsuen

Year	1982
Location	Hong Kong
Normalized 24-hour rainfall	5-25%
Number of Natural Terrain Landslide	A total of 1,800 ENTLI landslides over the natural terrain of Hong Kong.
Consequence	Nine natural terrain landslide related fatalities were reported and most of which were in squatter areas.
Key Observations	In May and August 1982, Hong Kong was hit by two heavy rainstorms. Plate (a) shows a 200 m^3 natural terrain landslide, which killed two people in Kau Wah Keng, Lai Chi Kok. Plate (b) shows a cluster of 1982 natural terrain landslides on the hillside overlooking Sham Tseng San Tsuen, where further cluster of landslides occurred in 1999. One of the 1999 landslides developed into a debris flow and resulted in one fatality and injury to 13 people (see Figure C.1.3). Hong Kong was less densely developed in 1982 and since then more developments have taken place closer to steep hillsides.
Reference	Tang, M.C. (1995). Report on the Rainstorm of May 1982. GEO Report No. 25, Geotechnical Engineering Office, Hong Kong. Hudson, R.R. (1995). Report on the Rainstorm of August 1982. GEO Report No. 26, Geotechnical Engineering Office, Hong Kong.

Figure C.1.9 Widespread Natural Terrain Landslides in 1982

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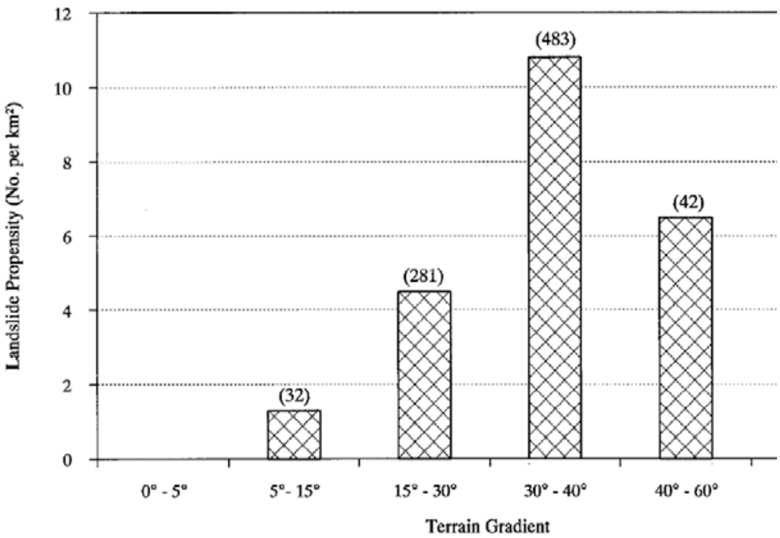
Clusters of Landslides



Correlation of Landslide Propensity with Terrain Gradient

Year	1993
Location	Lantau Island
Normalized 24-hour rainfall	10-35%
Number of Natural Terrain Landslide	Over 800 landslides on the natural terrain of Lantau Island.
Consequence	As Lantau Island was largely undeveloped, there were no serious consequences apart from blockage of roads and catchwaters.
Key Observations	A study on the natural terrain landslides in Lantau Island established that a high density of natural terrain landslides could be triggered in a severe rainstorm, and that terrain at a gradient of 30^{o} to 40^{o} underlain by volcanic rocks appeared to be particularly susceptible to failure. The field inspections have shown that the majority of the landslides inspected were shallow failures involving loose bouldery colluvium. Empirical assessment of landslide debris runout data showed that debris mobility was affected by the mechanism of debris movement, with channelized debris flows being more mobile than open hillslope failures.
Reference	Wong, H.N., Chen, Y.M. & Lam, K.C. (1996). Factual Report on the November 1993 Natural Terrain Landslides in Three Study Areas on Lantau Island. GEO Report No. 61, Geotechnical Engineering Office, Hong Kong. Wong, H.N., Lam, K.C. & Ho, K.K.S. (1998). Diagnostic Report on the November 1993 Natural Terrain Landslides on Lantau Island. GEO Report No. 69, Geotechnical Engineering Office, Hong Kong.

Figure C.1.10 Widespread Natural Terrain Landslides in 1993

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Landslides Occurring in Lantau Island during the 7 June 2008 Rainstorm

Year	2008
Location	Lantau Island
Normalized 24-hour rainfall	20-30%
Number of Natural Terrain Landslide	Over 2,400 landslides on the natural terrain of Lantau Island.
Consequence	These failures blocked several key road links that provided the sole access to rural communities and resulted in emergency evacuation of over 25 village houses. The highway to the airport was also closed for about 16 hours (see Figure C.1.7).
Key Observations	The intense rainfall on the 7 June 2008 was one of the most notable storms to have occurred in Hong Kong for several decades. The most intense portion of the storm was focused over the western part of Lantau Island and resulted in over 1,000 landslides in that area, including numerous debris flows. Had the rainstorm hit other more densely populated parts of Hong Kong, it is anticipated that the subsequent landslides could have resulted in much more significant consequences. A regional-scale Natural Terrain Hazard Review for an area of some 18.5 km^2 was undertaken in response to this widespread landslide event with the purpose of identifying landslide risk within natural hillside catchments and prioritising the implementation of more detailed hazard studies and mitigation works.
Reference	Li, A.C.O., Lau, J.W.C., Cheung, L.L.K. & Lam, C.L.H. (2012). Review of Landslides in 2008. GEO Report No. 274, Geotechnical Engineering Office, Hong Kong. Arup (2010). Natural Terrain Hazard Review Report. Prepared under Agreement No. CE 62/2008 (GE) Natural Terrain Hazard Mitigation Works, West Lantau. Geotechnical Engineering Office, Hong Kong.

Figure C.1.11 Widespread Natural Terrain Landslides in 2008

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Appendix D

Some Examples of Engineering Geological/Geomorphological Mapping Techniques to the Assessment of Natural Terrain Hazards

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D.1 Introduction

This Appendix provides illustrations of engineering geology and engineering geomorphology practice in NTHS.

It should be stressed that there is no single methodology or series of techniques that should be automatically adopted for an NTHS or even a particular component of an NTHS. Instead each study area should be evaluated on a case-by-case basis and the most appropriate engineering geological techniques adopted.

Most of the examples were extracted from Working Paper No. 3 prepared under Agreement No. CE 12/2011 (GE) "Review of the Design Event Approach to Natural Terrain Hazard Study" (FSWJV, 2012a)[1]. These case examples were extracted from various NTHS reports to illustrate different aspects for preparing mapping records for regional/site-specific purposes. Readers should refer to the full NTHS reports for detailed explanations/interpretations.

D.2 Desk Study and Aerial Photograph Interpretation

D.2.1 Regional Geomorphological Setting

The regional geomorphology should place the study area in context with respect to the surrounding area. The terrain is subdivided on geomorphological principles which allows for: the evaluation of the relative age of the various components of the landscape, their susceptibility to landslides, consideration of geological controls, the geomorphological processes that have taken place in the past, the processes which are currently active/inactive, and which could be reactivated, variations in regolith, the location, type, size and frequency of landslides, and the likely engineering geological controls on landslides. The use of such maps allows the consideration of issues such as the presence of large magnitude landslides in the vicinity of the study area and the possible effects of geological control such as lithology or structure, on landslide initiation. Whilst the size of the terrain which should be evaluated to assess a site regional setting cannot be simply defined, and is dependent upon the location and setting of each particular study area, it should be sufficiently large to encompass the fundamental processes which have controlled geomorphological variations (e.g. coastline, significant rivers, etc.), should extend upslope to the highest terrain and should include significant nearby large landslides if present.

[1] Other Working Papers prepared under Agreement No. CE 12/2011 (GE) "Review of the Design Event Approach to Natural Terrain Hazard Study" are listed in Section D.7.

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Case Study 1

(Main Consultant: Jacobs China Ltd., Sub-Consultant: GeoRisk Solutions Ltd.)

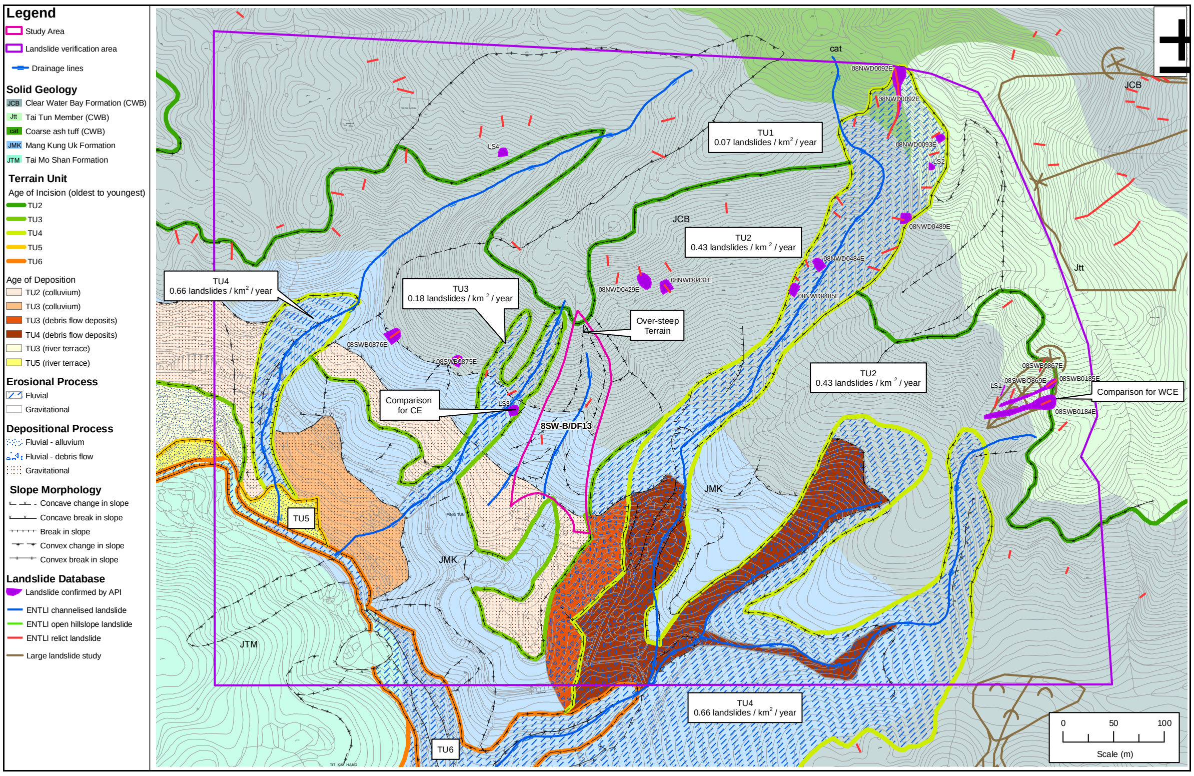

Figure D.2.1 Initial Regional Engineering Geomorphological Map from API (Jacobs, 2011)

The regional setting for this study area extends from the main drainage line, situated below the study area, up to the highest nearby terrain. It also includes the large debris lobes which were identified from API in the vicinity of the study area. Such features are not necessarily included in the ENTLI and the Large Landslide dataset. The study area is relatively small (10,000 m^2) and the regional area evaluated was ~550,000 m^2.

Based on this regional assessment, the conceptual hazard model suggested that the study area is located within a relatively old landscape which is likely to have been formed within the Pleistocene or earlier, probably as a response to sea level change. The key processes forming this landscape were considered to be associated with different environments to the present day. Furthermore, due to subsequent incision this terrain is now largely decoupled from responses to more recent sea level changes, e.g. incision possibly related to sea level fall approximately 6000 years BP. This is evident from the fact that a relatively well-defined valley comprises the majority of the study area but there is no main drainage line now associated with it, i.e. the present day ephemeral drainage line is a “misfit” stream. This provided a logical argument for assuming that the lobes were developed in the “geological past”, i.e. they probably occurred in the Late Pleistocene under different climatic conditions to the present day and therefore could be excluded from the design event evaluation.

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Case Study 2

(Main Consultant: C M Wong and Associates Ltd., Sub-Consultant: GeoRisk Solutions Ltd.)

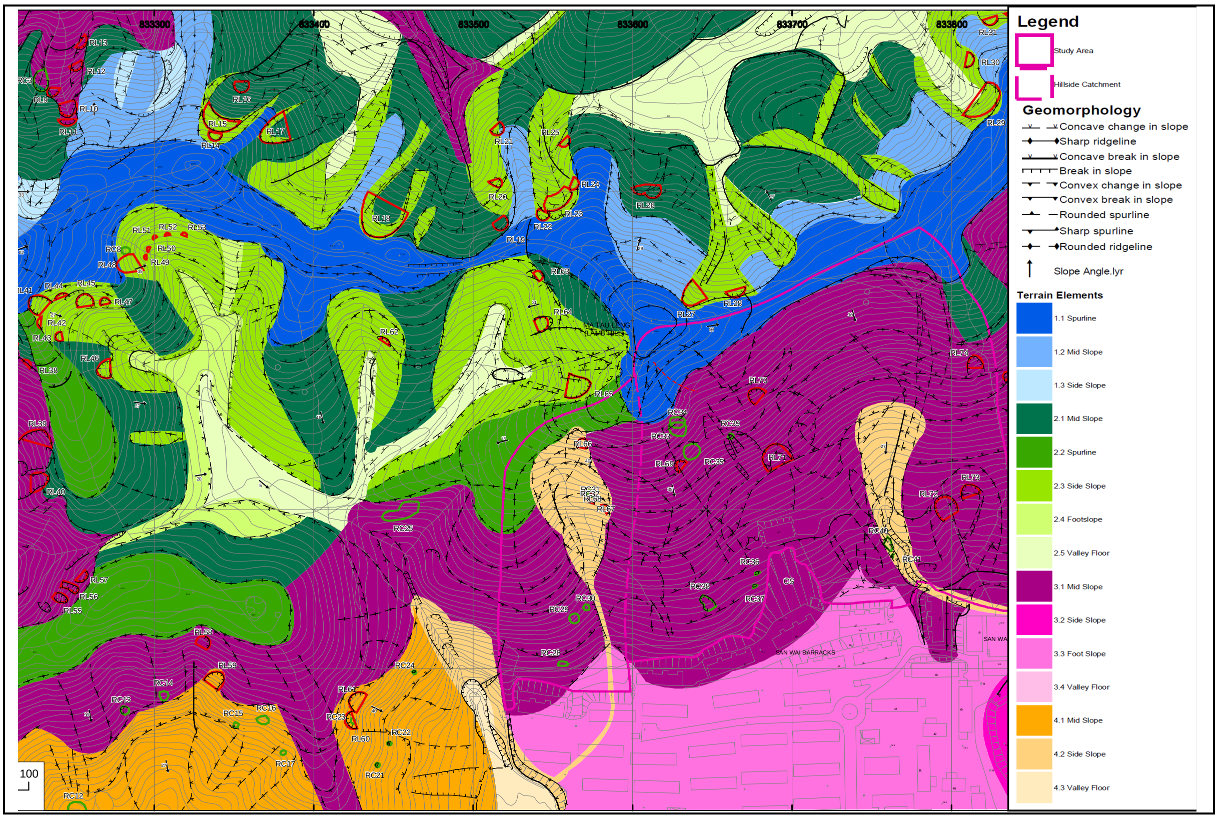

Figure D.2.2 Initial Geomorphological Map from API (C M Wong, 2012a)

The combination of both engineering geological (solid and superficial geology) and engineering geomorphological mapping on a single figure can be problematic depending on the complexity of the site. Case Study 2 shows a study area (~60,000 m^2) where a separate regional (~400,000 m^2) geomorphological figure was prepared. Whilst the regional map provided a broad framework to place the study area in its regional context and allowed discussion of the evolution of the landscape, its scale was insufficient to enable the identification of site-specific geomorphological processes and individual land elements that are likely to control landslide initiation locally. Consequently, a site-specific engineering geomorphological map based on API was prepared subdividing the terrain units into terrain elements.

Case Study 3

(Main Consultant: Arup-Fugro Joint Venture, Sub-Consultant: GeoRisk Solutions Ltd.)

Case Study 3 in comparison shows an example of initial engineering geomorphological mapping for a regional landslide assessment of West Lantau almost entirely from API given that the study area was 18.5 km^2. The mapping consisted of fifteen A1 sheets at 1:2500-scale. This mapping formed the basis for subsequent identification of landslide catchments for follow up actions.

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Mapping undertaken consisted of:

(i) Morphological mapping;

(ii) Morphographical mapping to reflect the key regolith/superficial materials present. These included colluvium (with several sub-types based on composition and depositional environment), taluvium and alluvium. In addition, areas of saprolite, intermittent rock outcrops and rock outcrops were also interpreted;

(iii) Morphochronological mapping to sub-divide the landscape into a series of terrain units based on their relative age of formation; and

(iv) Classification of drainage lines qualitatively according to their potential to constrain and channelise debris flows.

Landslide hazard within the study area was classified based on the unique components recorded within the engineering geomorphological maps, including morphology, superficial geology, landforms, drainage line characteristics and terrain units (Figure D.2.3).

Hazard classes for the different catchments were initially assessed based on the various Terrain Units defined by the geomorphological mapping, within which notable distinction in landslide density had been observed (Primary Classifier). Additional criteria were then used to delineate catchments in which potentially more hazardous channelised debris flows (CDF) could occur, primarily through the presence of distressed terrain within the catchment area and debris fans at the catchment toe (Secondary Classifier). These fans provided an indirect estimate of the potential travel distance of CDFs. Furthermore, by subdividing the fans into “Debris Fans” and “Undifferentiated Fans” based on their perceived age / activity (related to the presence of debris lobes or other signs of recent activity/debris accumulation) a relative level of hazard within the drainage line could be approximated. The assessment criteria used to define landslide hazards are presented in the landslide hazard assessment matrix in Table D.2.1, with graphical examples shown in Figure D.2.4.

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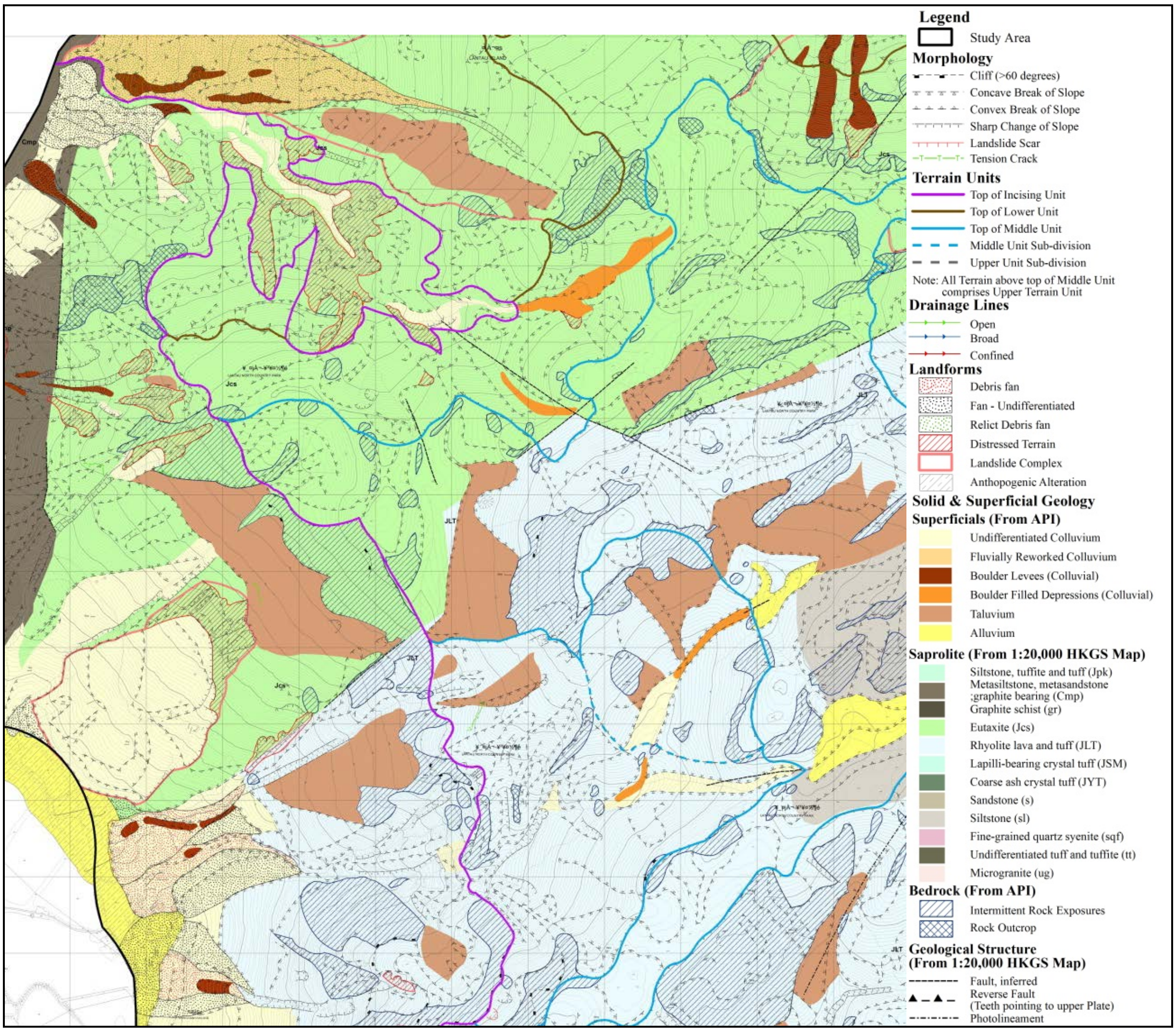

Figure D.2.3 Example of the Composite Engineering Geomorphological Map (Millis & Parry, 2014)

Table D.2.1 Landslide Hazard Assessment Matrix (Millis & Parry, 2014)

	Hazard Class 1	Hazard Class 2	Hazard Class 3	Hazard Class 4
Primary Classifier	Debris Fan is present	within Incised Terrain Unit	within Middle or Lower Terrain Unit	within Upper Terrain Unit
Secondary Classifier	Undifferentiated Fan and Distressed Terrain Present	within Upper, Middle or Lower Terrain Unit and contains Distressed Terrain	Confined drainage line present within the Upper Terrain Unit	N/A
Tertiary Classifier	N/A	N/A	N/A	N/A

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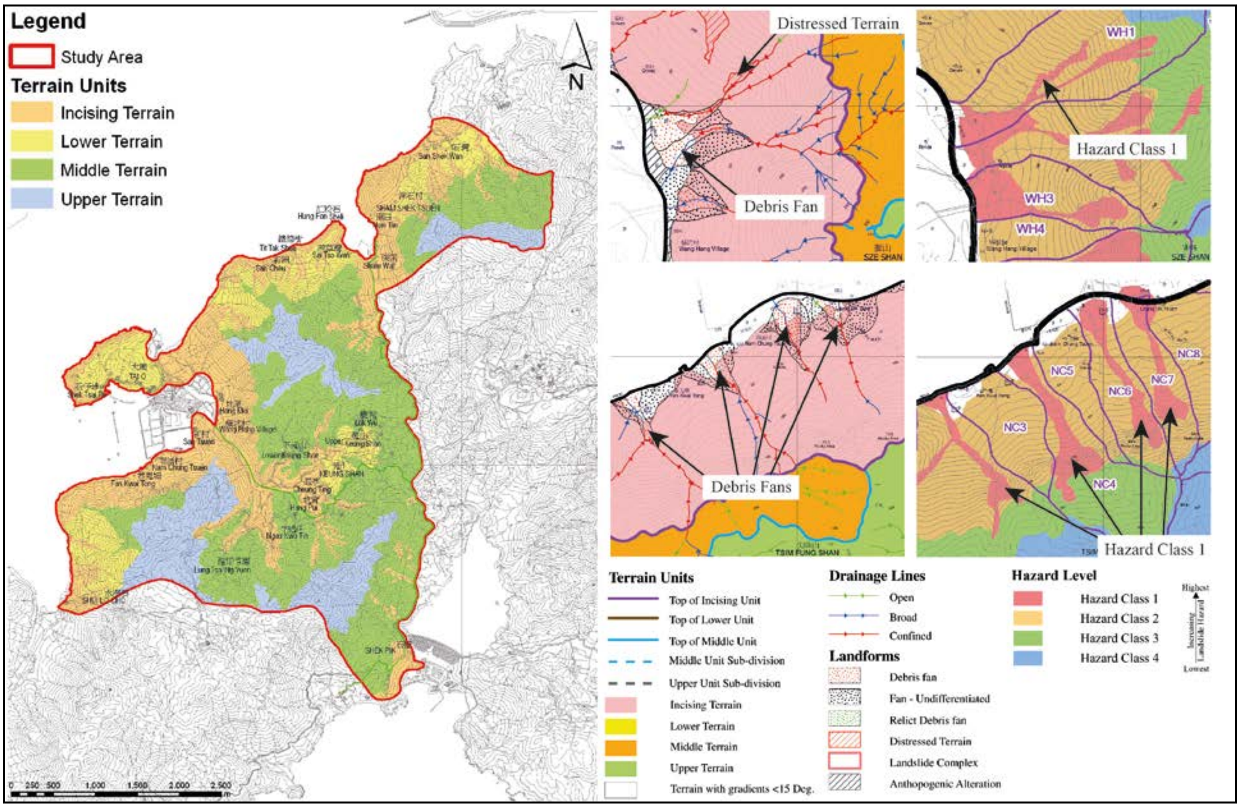

Figure D.2.4 Graphical Examples of Landslide Hazard Assessment Approach (Millis & Parry, 2014)

D.2.2 Site Specific Initial Engineering Geological/Engineering Geomorphological Map

In addition to a regional evaluation, interpretation of low level aerial photographs, in particular the 1963 territory-wide aerial photographs, allows preliminary engineering geological and engineering geomorphological maps to be generated. As with the regional map, the interpretation should extend beyond the boundaries of the study area to ensure that a sufficient area of terrain is evaluated. The scale and complexity of the mapping will vary depending on the size and geological and geomorphological setting of the study area.

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Case Study 4
(Main Consultant: Fugro Hong Kong Ltd., Sub-Consultant: GeoRisk Solutions Ltd.)

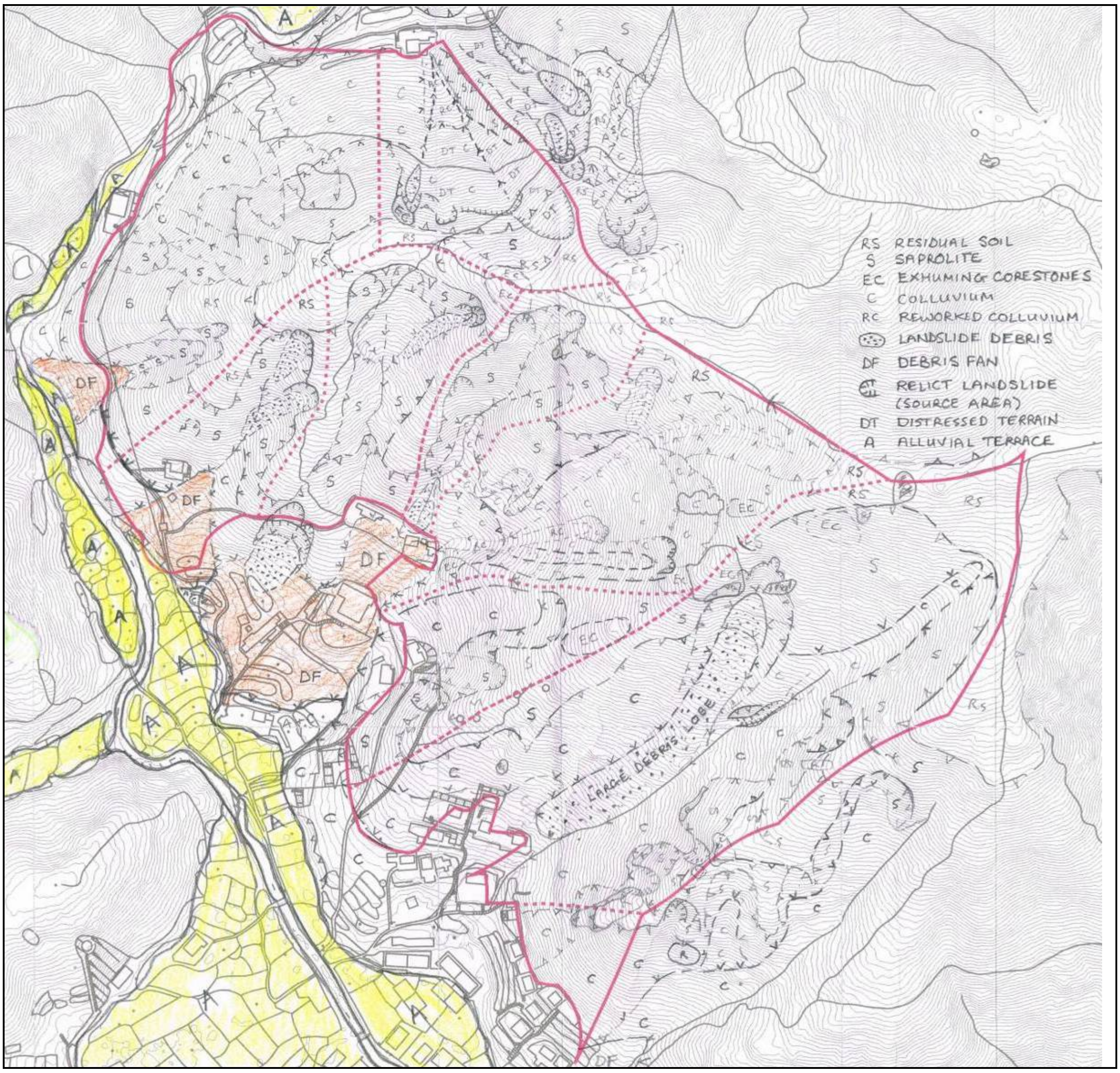

Figure D.2.5 API Interpretation (Fugro, 2015)

Case Study 4 shows the API and derivation of engineering geological and engineering geomorphological maps (Figures D.2.6 & D.2.7). The use of hand drawn API interpretation as shown in Figure D.2.5 demonstrates the interpreter's skills.

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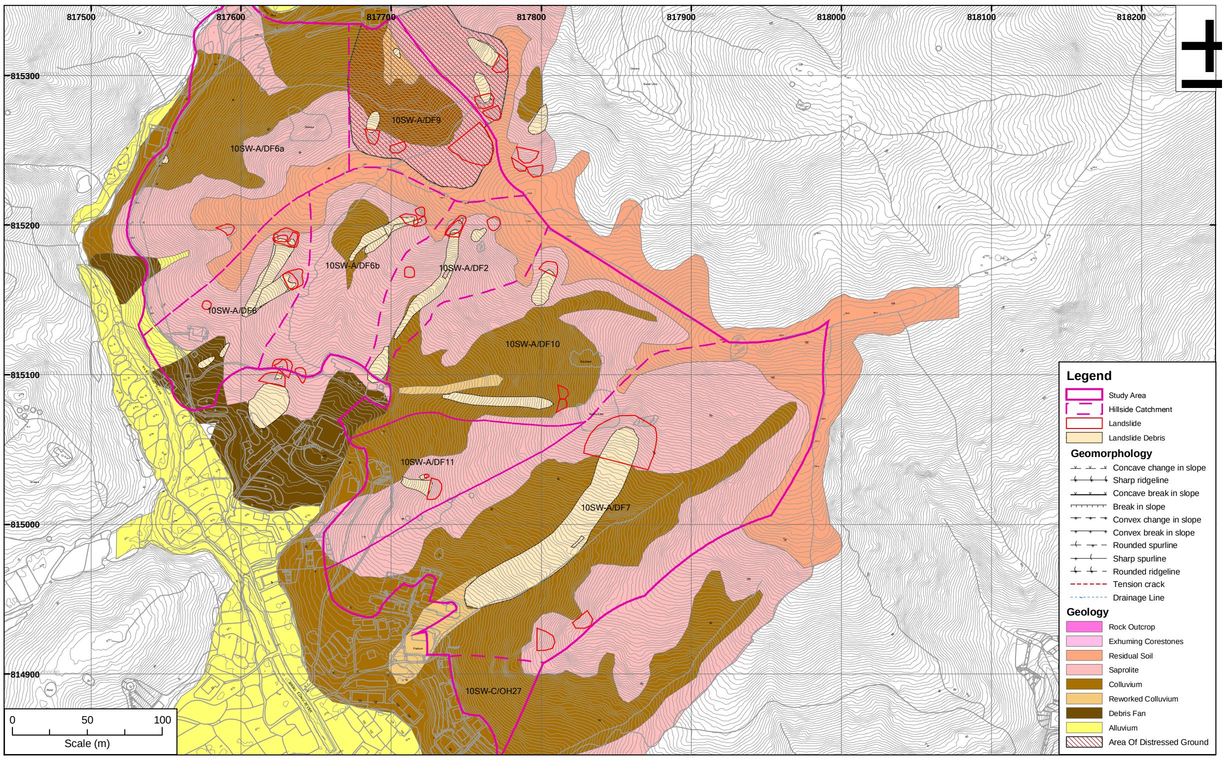

Figure D.2.6 Preliminary Engineering Geological Map Derived from API (Fugro, 2015)

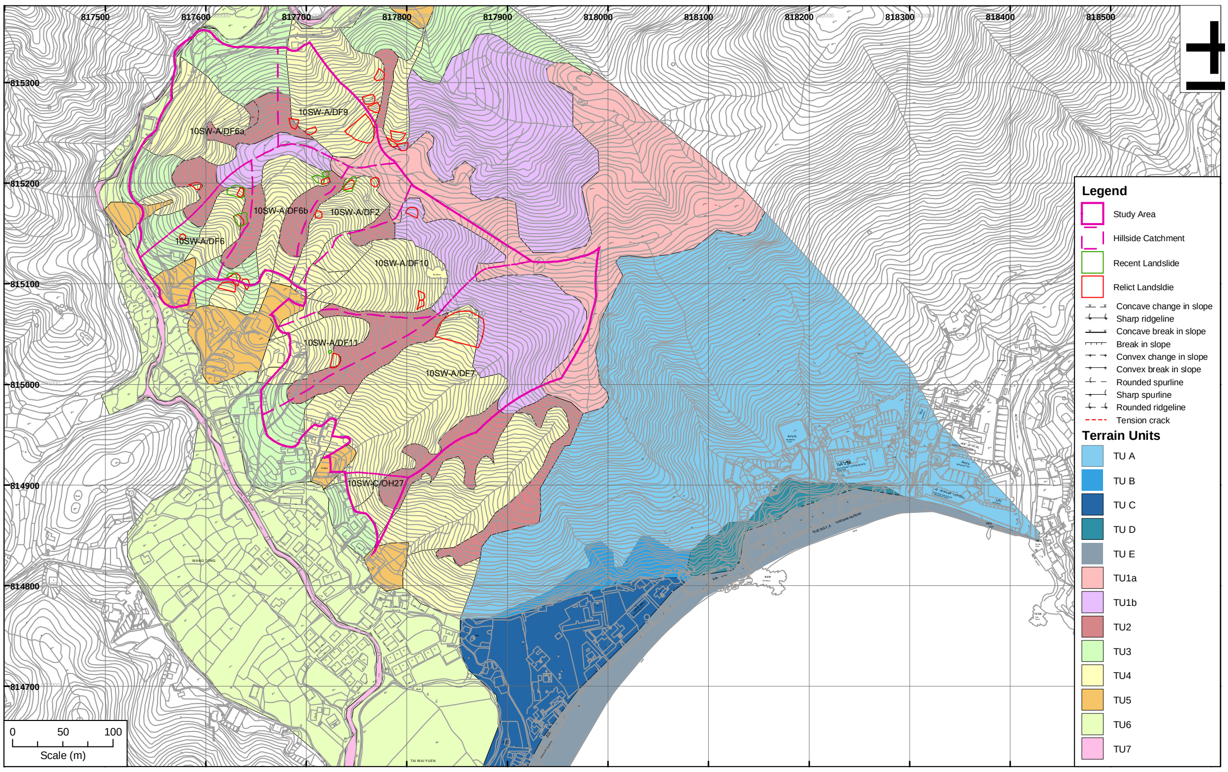

Figure D.2.7 Preliminary Engineering Geomorphological Map Derived from API (Fugro, 2015)

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Case Study 5

(Main Consultant: Jacobs China Ltd., Sub-Consultant: GeoRisk Solutions Ltd.)

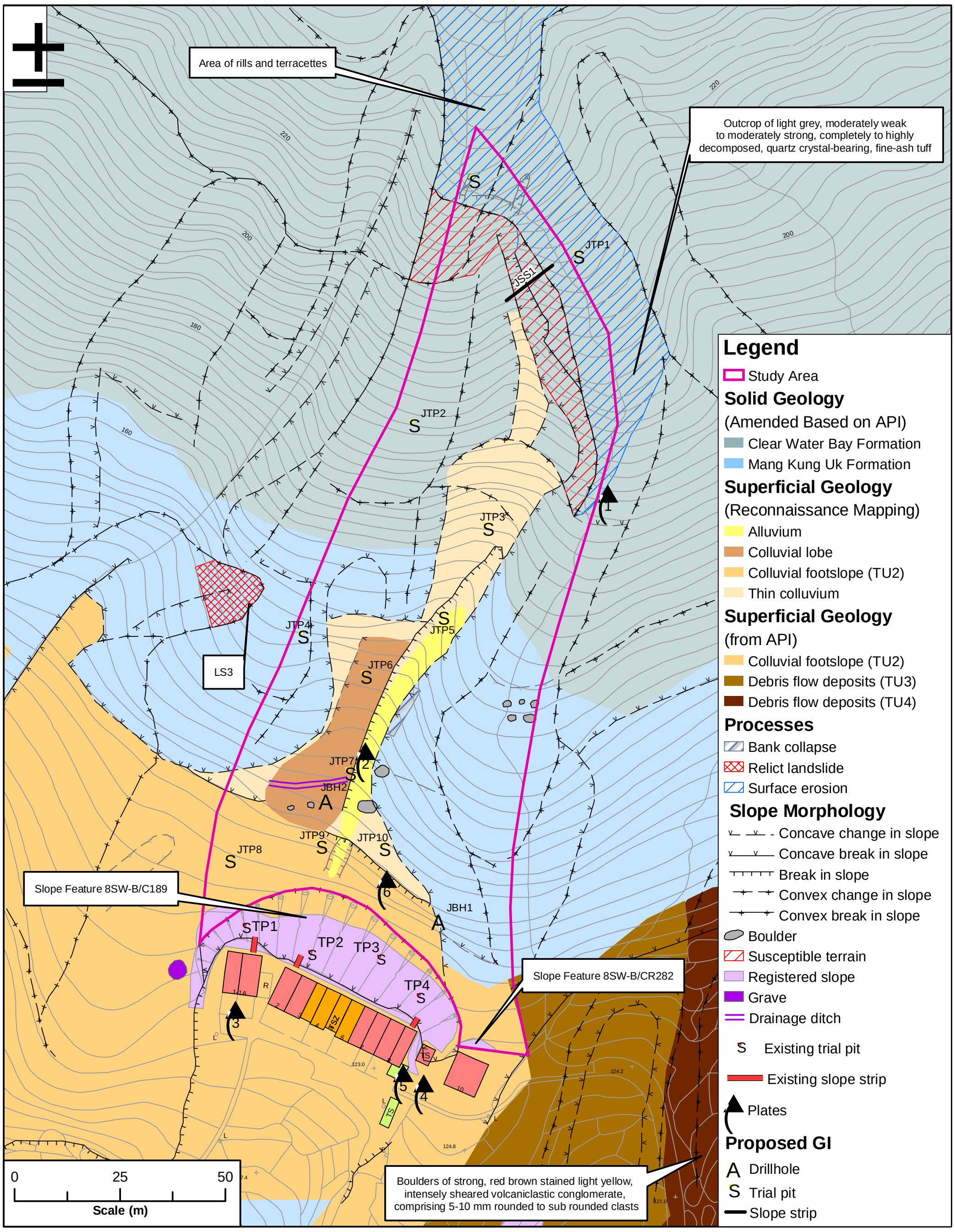

Figure D.2.8 Preliminary Engineering Geological Map Derived from API (Jacobs, 2011)

Case Study 5 shows the preliminary site-specific engineering geological map of the study area shown in Case Study 1. In addition to the API, a site reconnaissance was undertaken. Because of the relatively small size of the site (~10,000 m^2) the reconnaissance was able to cover a considerable portion of the site and a reasonably detailed initial field mapping was undertaken. Obviously for larger sites the ground that can be covered in a

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reconnaissance may be considerably restricted. However, the reconnaissance allows the re-evaluation and if necessary the reinterpretation of the initial API, significantly improving the interpretation. The map also shows the preliminary ground investigation (GI) plan for cost estimation purposes.

D.2.3 Use of Conceptual Models

For some sites, conceptual engineering geological models are useful to illustrate complex geological processes or ideas. Case Study 6 shows the use of a conceptual model to illustrate landscape evolution for the West Lantau Study Area.

Case Study 6
(Main Consultant: Arup-Fugro Joint Venture, Sub-Consultant: GeoRisk Solutions Ltd.)

A schematic evolutionary terrain model is shown in Figure D.2.9. The terrain units developed for this study comprise Upper, Middle, Lower and Incised Terrain Units. Whilst four distinct terrain units have been identified within the Study Area, the terrain evolution is more complex than this. For example, at least three phases of Upper Terrain evolution are evident in parts and three distinct river terrace levels are present in the main valley within the Incising Terrain unit. Furthermore, whilst some boundaries between terrain units are very distinctive, e.g. rock cliffs, other boundaries are defined by subtle convex changes in slope which are subtle and open to alternative interpretations.

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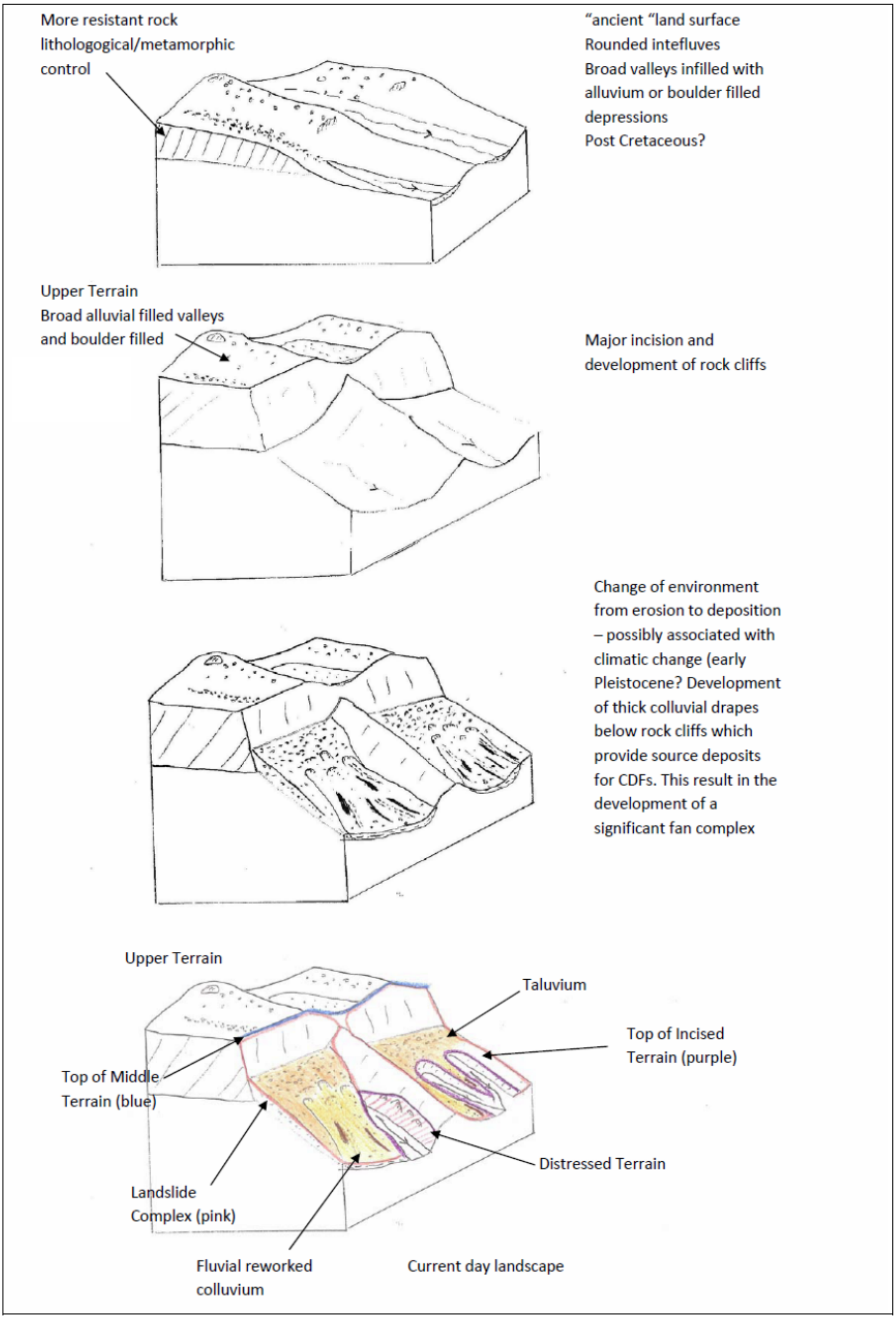

Figure D.2.9 **Schematic Landscape Evolution Model of the West Lantau Study Area (Parry *et al.*, 2010)**

D.3 Field Mapping

D.3.1 Solid Geological Mapping

Rock descriptions, not simply rock types, should be recorded with full engineering geological descriptions. In some areas of Hong Kong the geology can be complex and unless this complexity is observed and interpreted, geological controls on landslide hazard may be overlooked. For example, Case Study 7 shows detailed solid geological mapping undertaken as part of an NTHS in an area of West Lantau where the published geological map simply shows as Lantau Formation "undifferentiated". The geological variations controlled the engineering geological properties and hence influenced landslide magnitude, frequency and type.

Case Study 7

(Main Consultant: Arup-Fugro Joint Venture, Sub-Consultant: GeoRisk Solutions Ltd.)

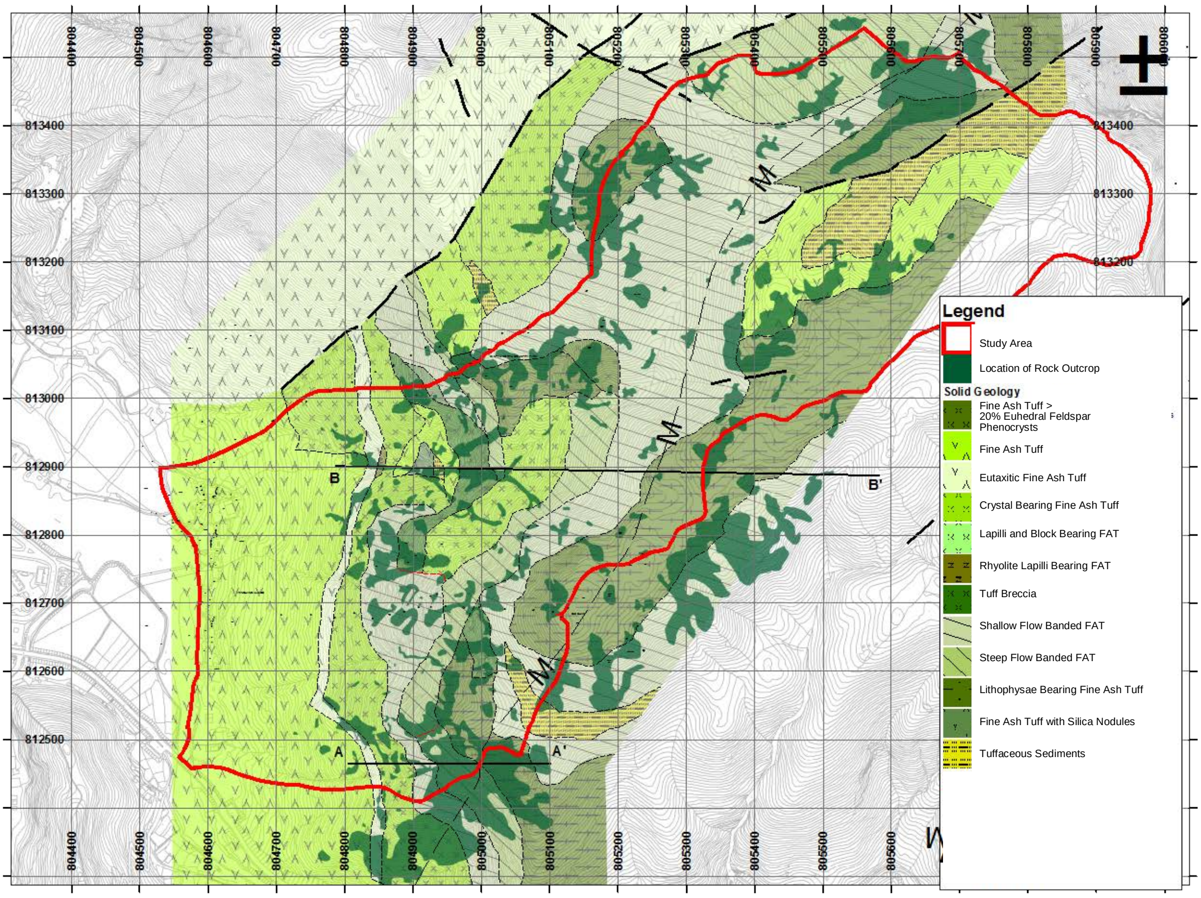

Figure D.3.1 Solid Geology Map (AFJV, 2014)

Figure D.3.1 formed a key input to the Engineering Geological Map of the study area which differentiated between rock outcrop, intermittent rock outcrop and saprolite and showed the influence of lithology on erosion and catchment development. The depositional foot slope is underlain by fine ash tuff but outcrops are limited and where they are present the rock has decomposed to a saprolite. This weathering may be associated with a zone of fracturing associated with the inferred north-east trending fault, which is supported by the

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sharp drop in rock head recorded in the existing drillholes and the presence of fault breccia in some of these drillholes.

The proportion of rock outcrop increases upslope and this may be related to the band of weathering resistant eutaxitic fine ash tuff. This rock type also corresponds with the development of broad catchments associated with drainage line incision into areas of predominately rock outcrop. The extent of this incision also appears to be lithologically controlled, with the boundaries of incision corresponding to outcrops of lithophysae bearing fine ash tuff suggesting that this lithology is also more resistant to weathering.

D.3.2 Engineering Geological Mapping

Case Study 8 is from a relatively small (~10,000 m^2) study area with no evidence of landslide activity (two ENTLI features were not confirmed by either API or field mapping). Figure D.3.2 shows an extract of the field map with the associated observations (this is the same site as discussed in Case Studies 1 and 5). Information recorded includes: individual boulders as well as their composition and size, anthropogenic modification, material descriptions and engineering geological implications, slope angles, morphology, vegetation changes, landslides (outside the study area), and tension cracks.

Case Study 8

(Main Consultant: Jacobs China Ltd., Sub-Consultant: GeoRisk Solutions Ltd.)

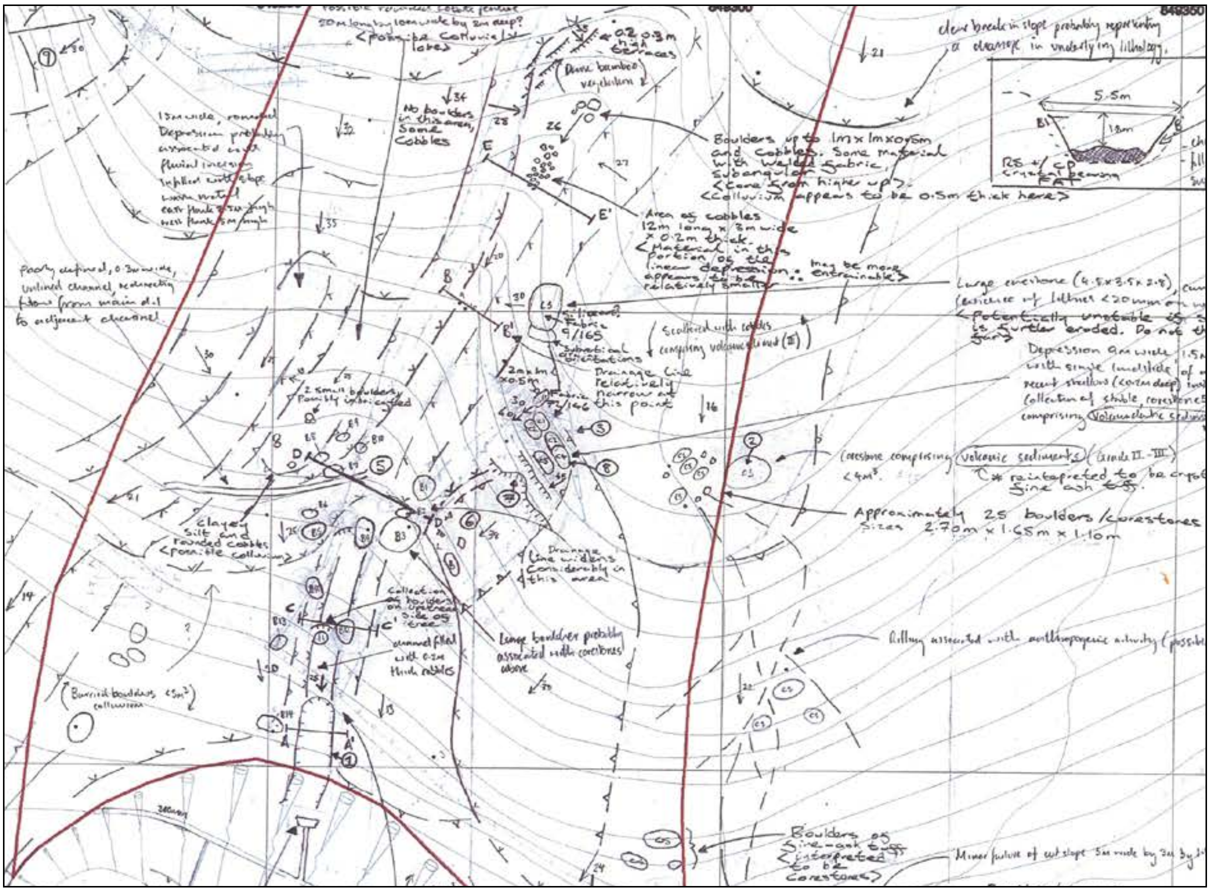

Figure D.3.2 Engineering Geological Field Sheet (Jacobs, 2011)

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The inclusion of the field sheets in the final report allows readers to easily distinguish between areas that have been mapped and areas where the mapping is inferred. The field sheets are prepared in pencil to allow modifications where necessary following subsequent mapping, e.g. during the later GI when additional vegetation clearance may be available.

Case Study 9 shows a more complex site of significant size (60,000 m^2) where the final field map (one of ten sheets) had colour applied which greatly improves the visualisation and hence interpretation of the field map and the generation of the final engineering geological map. It also allows hazards to be interpreted more readily.

Case Study 9

(Main Consultant: Ove Arup & Partners Hong Kong Ltd., Sub-Consultant: GeoRisk Solutions Ltd.)

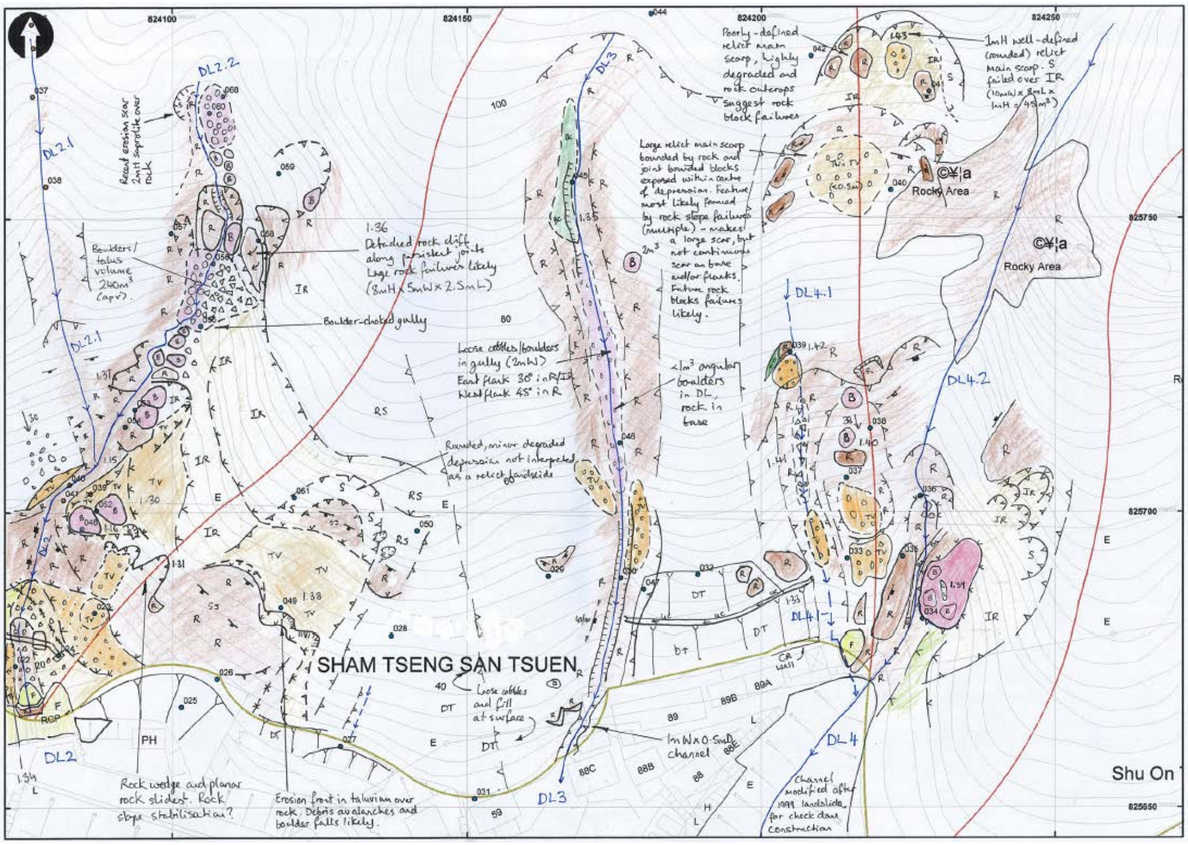

Figure D.3.3 Engineering Geological Field Map (Arup, 2010)

D.3.3 Landslide Mapping

Where practical, all possible landslides identified from API should be inspected, but the emphasis should be on critical landslides either in terms of location or magnitude. Additional detailed mapping of these landslides at a larger scale should be undertaken where necessary (Case Study 10). This mapping should evaluate landslide magnitude, type, age and engineering geological controls. Landslide dimensions should be based on field measurements rather than estimated from volumetric equations (e.g. IAEG, 1990) which are only recommended for API estimations.

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Landslide type should be based on internationally recognised terminology (e.g. NRC, 1996). Terminology such as “open hillslope” or “channelised landslide” should not be used to describe individual landslides, but should be restricted to hazard types. Recent landslides, where debris is still evident, should be carefully mapped and described in detail and the various processes recorded. Age of relict features is problematic but an estimate, in years, should be made if possible based on an evaluation of size, processes, vegetation cover and degradation of the scarp. Uncertainty of the age estimation should be discussed.

Case Study 10
(Main Consultant: C M Wong and Associates Ltd., Sub-Consultant: GeoRisk Solutions Ltd.)

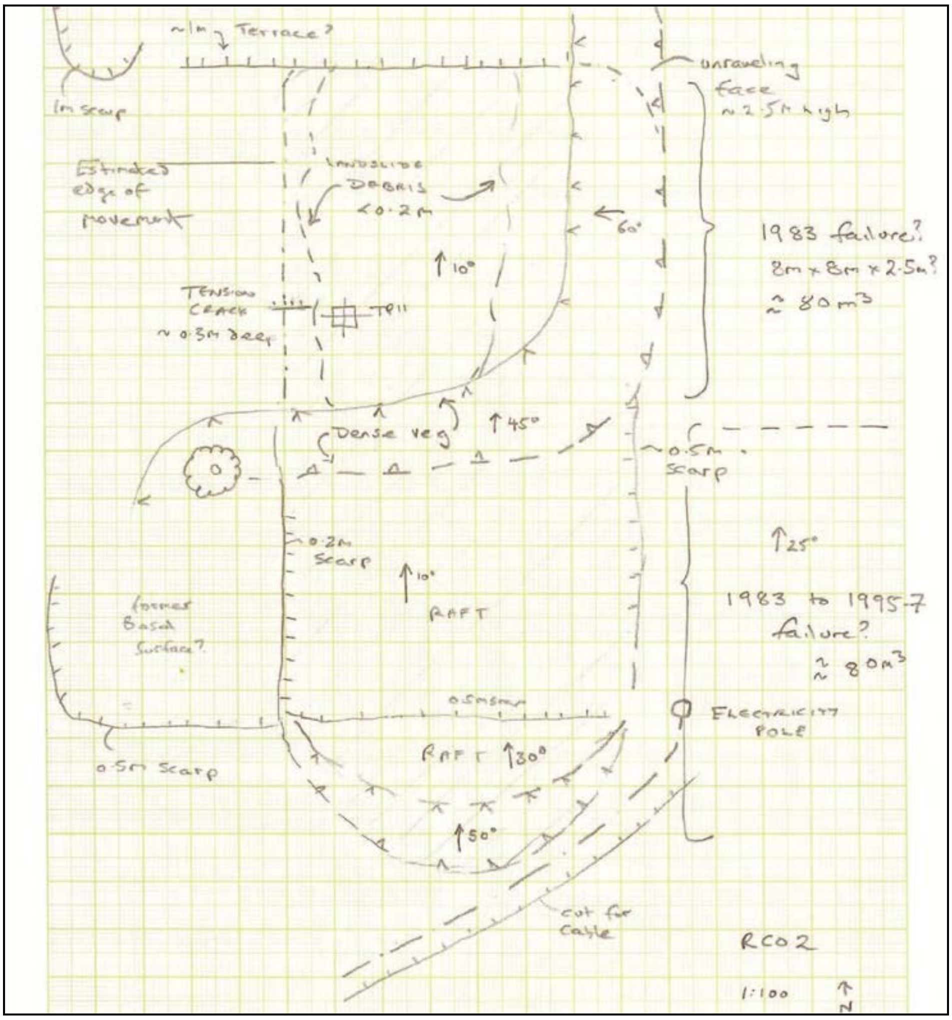

Figure D.3.4 Field Sketch of a Recent Landslide (original in 1:100-scale) (C M Wong, 2012b)

Figure D.3.4 shows the field map of the largest recent landslide within a study area. API indicated a single failure in 1983. However, field mapping identified a second failure which had affected an area of erosion protection matting which was installed between 1983 and 1995 (based on API). Based on the field mapping the volume of each landslide was estimated at ~80 m^3. Whilst the first landslide detached and had a run out of 85 m plan distance and a travel angle of 27°, the second landslide did not fully detach. The sketch also shows the location of the planned ground investigation station to evaluate the depth of failure.

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Based on the findings from landslide mapping, the landslide inventory should be updated, with geomorphological features identified as landslides from API reclassified but retained in both the landslide inventory and the engineering geological map, to enable ease of verification of the amended data set.

Case Study 11

(Main Consultant: C M Wong and Associates Ltd., Sub-Consultant: GeoRisk Solutions Ltd.)

Table D.3.1 Landslide Inventory Following Field Verification (Extract) (C M Wong, 2012a)

Landslide No.	ENTLI No.	AP Year	API Volume (m^3)	Estimated Age (years)	Field Inspection	Field Volume (m^3)	Adopted Volume (m^3)	Notes
RC28		1963	5	50	Y	na	na	No evidence during field mapping, from re-evaluation of AP it appears to be anthropogenic disturbance
RC29	03SWA0144E	1994	40	50	Y	45	45	Scar merges with RC30. Failure of colluvium over completely decomposed fine ash tuff. Just one failure
RC30	03SWA0143E	1994	15	50	Y	na	na	Re-evaluation of AP shows this is one scar formed by RC29 (see above)
RC31	03SWA0159E	2001	20	50	Y	30	30	Single failure
RC32		2003	15	50	Y	na	na	No evidence on re-evaluation of API
RC33	03SWA0160E	2001	100	50	Y	300	300	Translational failure within corestone bearing CDT
RC34		2004	80	50	Y	na	na	Re-evaluation of AP indicates this is minor erosion of RC33
RC35a	03SWA0142E	1994	110	50	Y	?	?	
RC35b		1995	NA	50	Y	315?	315?	Reactivation of 1994 landslide RC35a. 315m^3 is the volume for both landslides, therefore not CE
RC36		1963	5	50	Y	na	na	Not found, within area of registered slope, anthropogenic
RC37		1963	5	50	Y	na	na	Not found, within area of registered slope, anthropogenic
RC38		1963	75	50	Y	na	na	No evidence during field mapping, re-evaluation of AP appears to be anthropogenic disturbance
RC39		1975	40	50	Y	na	<10	No clear evidence on site, re-evaluation of AP appears to be small regression of gully
RC40		1963	45	50	Y	na	45?	Not observed during field mapping, possibly anthropogenic?
RC41		1963	5	50	Y	na	na	Not observed during field mapping, re-evaluation of AP seems to be anthropogenic
RL33a & b	03SWB0255E		105	100	Y	100 & 50	100 & 50	Appears to be two separate scars, both failures of Residual Soil (RS) with colluvium veneer.
RL34			33	100	Y	15	15	Small failure of colluvium over RS
RL66	03SWA0107E		50	100	Y	25	25	Gradual spalling of slope in small events
RL67			21	100	Y	na	na	Head of drainage line
RL68	03SWA0106E		20	100	Y	na	20	Not seen due to dense vegetation possibly reactivated forming RC31
RL69			50	100	Y	na	na	Not evident following field mapping
RL70	03SWA0109E		100	100	Y	460	460	Failure within corestone bearing CDT. Assumed to be translational based on joint controlled main scarp and recent landslides in same setting

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Table D.3.1 contains an extract of a site-specific landslide inventory initially developed from API followed by field verification. Grey colour highlighted features that were interpreted as landslides from the site-specific API but deleted following field inspection. Orange colour highlight indicates the largest recent landslide and the red colour highlight the largest relict landslide.

D.3.4 Drainage Line Mapping

Where channelised debris flows are considered a hazard, detailed cross sections should be generated for the potential transport corridors showing slope angle changes, material types and evidence of previous landslide events. The detailed field mapping of drainage lines is also critical to the evaluation of potentially entrainable materials during debris flows. An example of drainage line mapping is shown in Case Study 12.

Case Study 12

(Main Consultant: Arup-Fugro Joint Venture, Sub-Consultant: GeoRisk Solutions Ltd.)

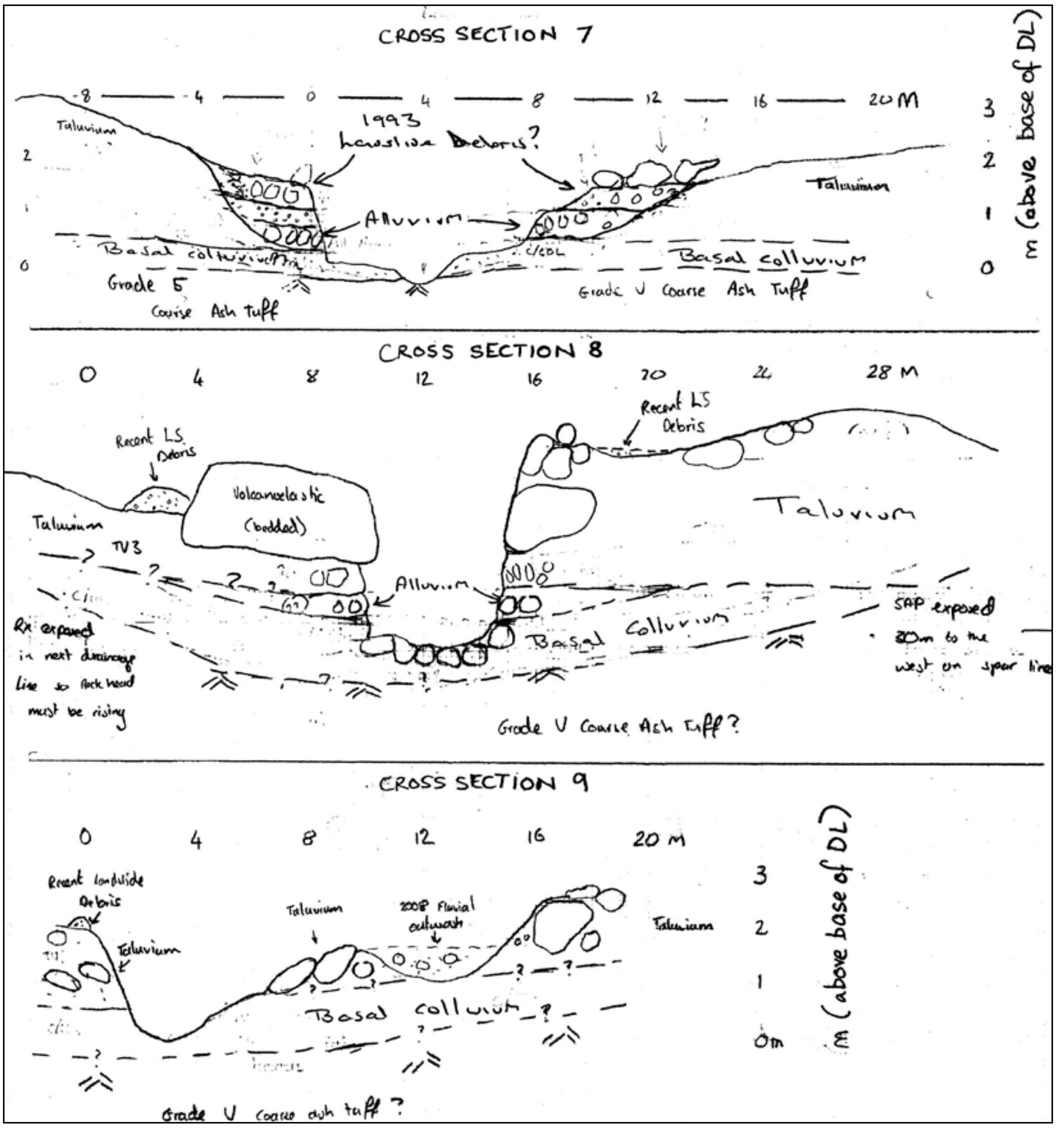

Figure D.3.5 Cross Sections of a Drainage Line at Different Reaches (AFJV, 2012)

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Case Study 13

(Main Consultant: Fugro Hong Kong Ltd., Sub-Consultant: GeoRisk Solutions Ltd.)

Figure D.3.6 shows the relevant extract of a field map of a drainage line assessed to be susceptible to channelised debris flows. Entrainment potential was based on the findings of the detailed field mapping of the channels and associated superficial deposits, including alluvium, colluvium (from bank collapse processes) and talus (where present below rock cliffs), assessed to be potentially entrainable during channelized debris flows. The attached debris mobility analysis plan is derived from the field maps and cross sections (refer to Case Study 12 for examples of cross sections).

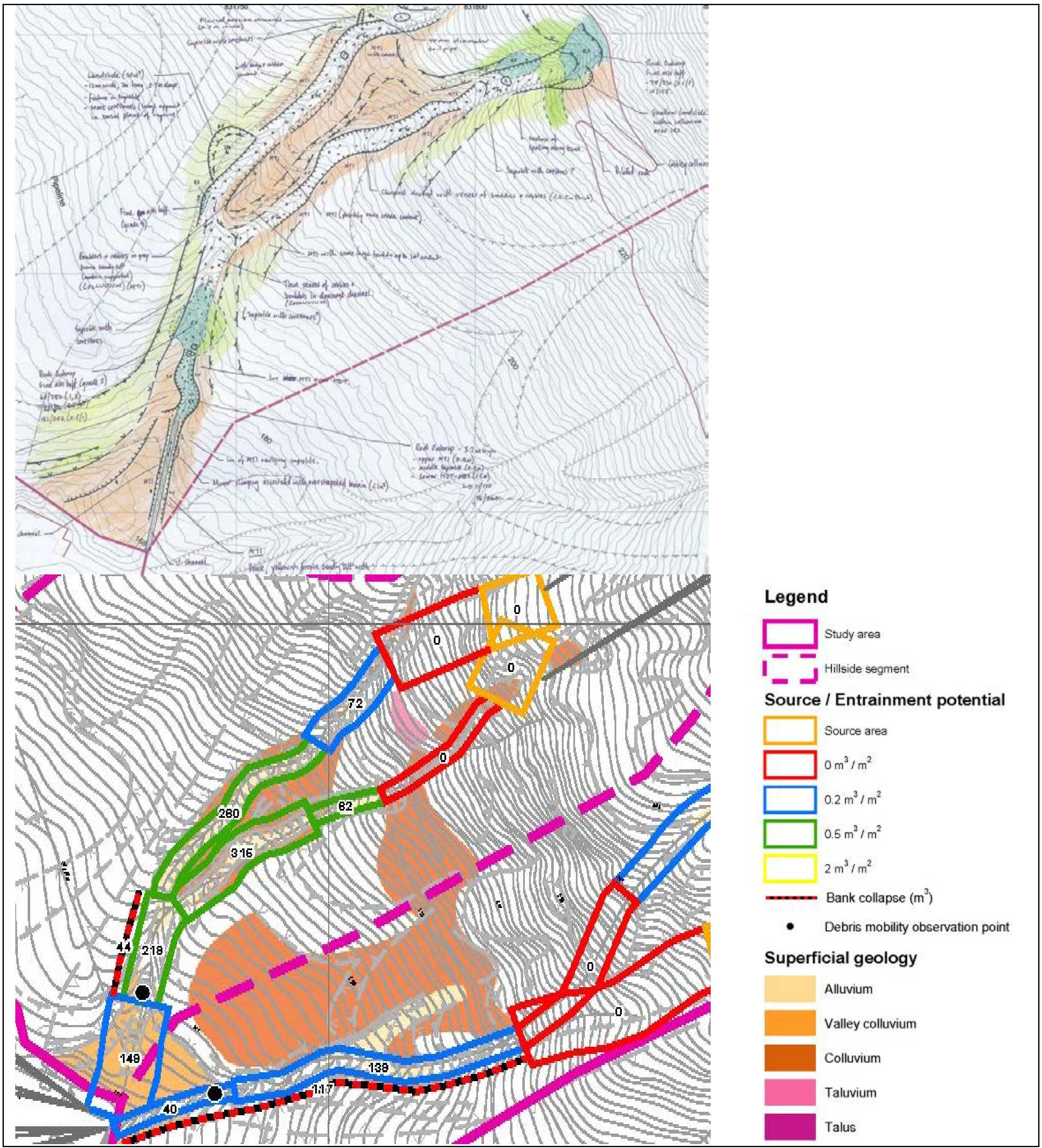

Figure D.3.6 Field Map (Top) and Derivative Entrainment Potential (Bottom) (Fugro, 2010)

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D.4 Ground Investigation

The scope of the ground investigation (GI) is often required to be estimated very early in the project in order that a GI contract can be let. A detailed desk study allows an initial estimation of the GI requirements to be made. However, it is critical that this is re-evaluated during the field mapping and additional GI provided, as required. In addition, vegetation clearance should be undertaken to allow access to critical areas obscured by dense vegetation during the NTHR stage.

GI for NTHS may be expensive depending on the requirement for steel access ladders to the majority of GI stations. Consequently all proposed GI stations and GI requirements should be critically assessed. GI techniques are typically limited to drillholes and trial pits. Where extensive debris lobes are present, trial trenches are recommended where possible.

GI is particularly important for assessing depths to failure surfaces in areas of distress where full detachment has not occurred. Continuous triple tube coring with foam flush is recommended and the resulting samples subject to detailed logging in order to ensure that the engineering geological controls of failure are understood and the depths of future failure surfaces predicted.

D.4.1 Mazier Sample Logging

When a mazier sample has been taken for investigating special hillside features, it should be split, carefully examined and properly logged by the project engineering geologist, especially for those samples not being used for laboratory testing. An example of mazier log is shown in Case Study 14.

Case Study 14
(Main Consultant: Ove Arup & Partners Hong Kong Ltd., Sub-Consultant: GeoRisk Solutions Ltd.)

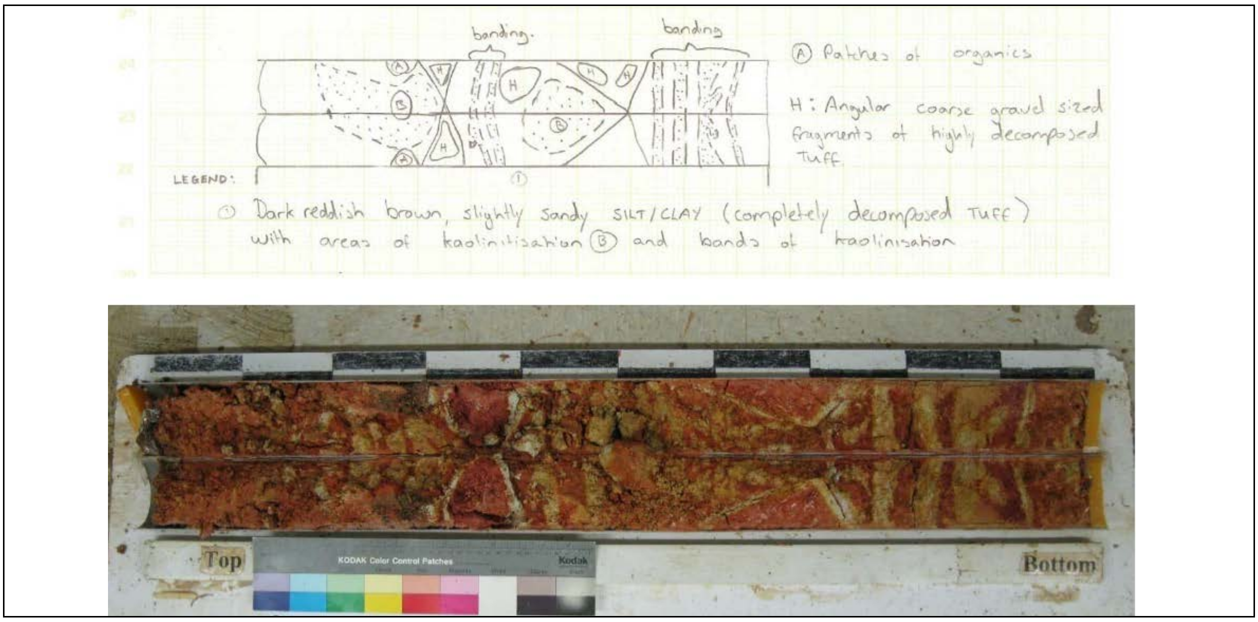

Figure D.4.1 Mazier Log Prepared by the Project Engineering Geologist (Arup, 2012)

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D.4.2 Trial Pit Logging

Logging is typically carried out in accordance with Geoguide 3 by the GI Contractor. However, the level of detail provided in the contractor's logs is often inadequate for the purpose of NTHS and simple "check logging" by the consultants may not be an appropriate method of rectifying this in many cases. A comparison between a contactor's log and the project engineering geologist's log is shown in Case Study 15. It illustrates the significant disparity between a basic contractor's log and the project engineering geologist's log.

The project engineering geologist has the advantage of having undertaken a detailed API and engineering geological mapping of the entire site. Consequently, it is recommended that consultants consider undertaking the logging of GI stations for NTHS.

Case Study 15

(Main Consultant: Halcrow China Ltd., Sub-Consultant: GeoRisk Solutions Ltd.)

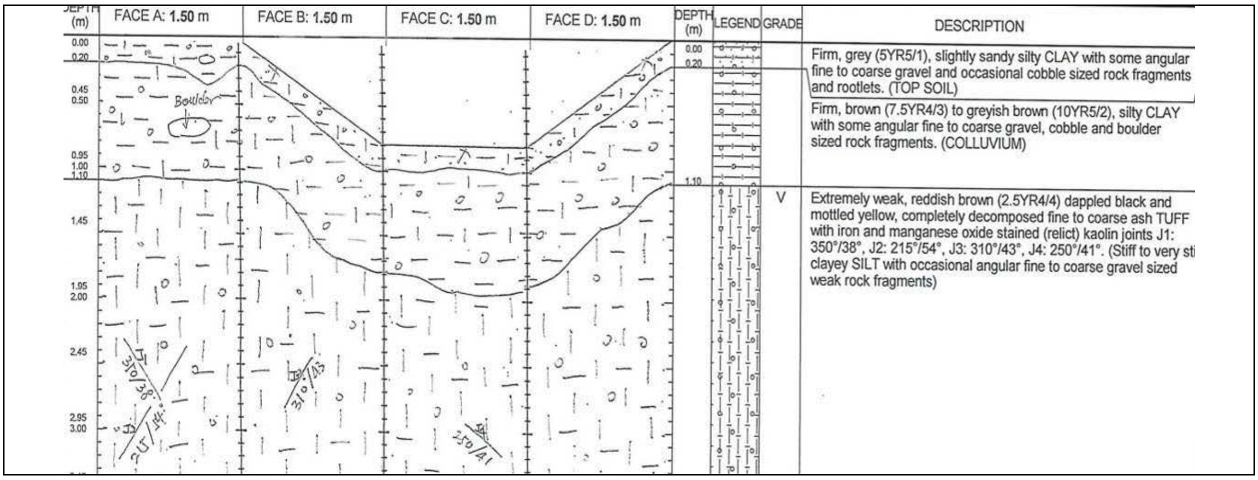

Figure D.4.2 Trial Pit Log Prepared by the GI Contractor (Halcrow, 2012)

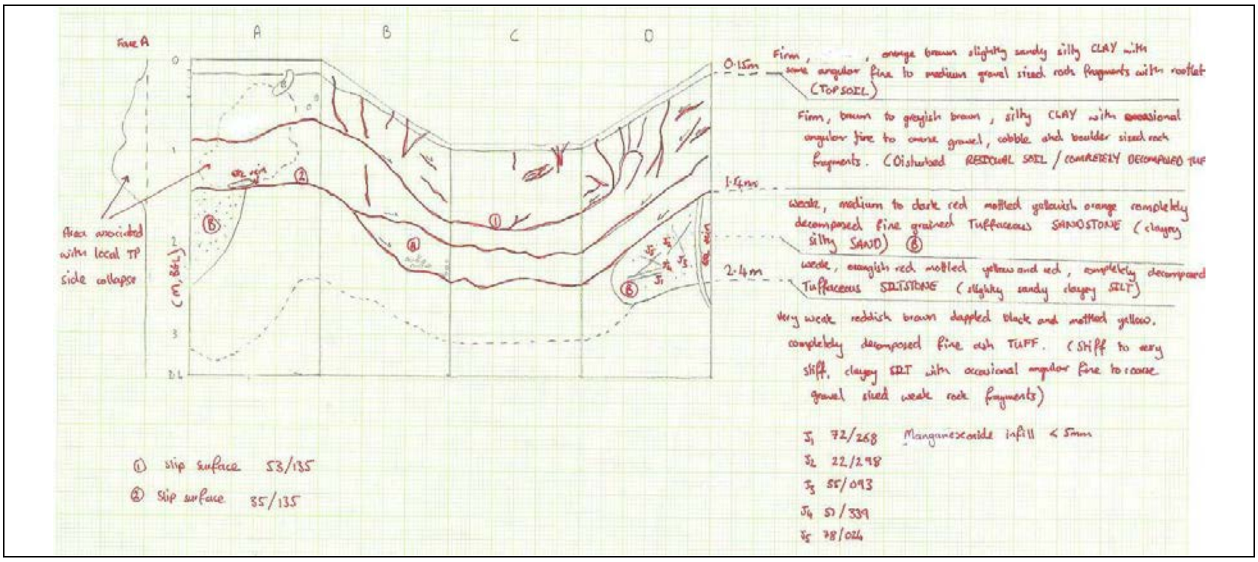

Figure D.4.3 Trial Pit Log Prepared by the Project Engineering Geologist (Halcrow, 2012)

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D.4.3 Sedimentological Logging

The use of undifferentiated "colluvium" should be avoided as far as possible and superficial deposits should be interpreted as far as practical to identify differing geomorphological processes, e.g. debris flows, debris flood, undifferentiated debris, rock fall, landslide rafts, remoulded debris, etc. Case Study 16 shows the use of graphical sedimentary logging to assist in the subdivision of deposits within debris lobes. The focus of this approach is on identifying compositional variations to interpret likely processes, e.g. debris flows as opposed to debris floods.

Case Study 16

(Main Consultant: Arup-Fugro Joint Venture, Sub-Consultant: GeoRisk Solutions Ltd.)

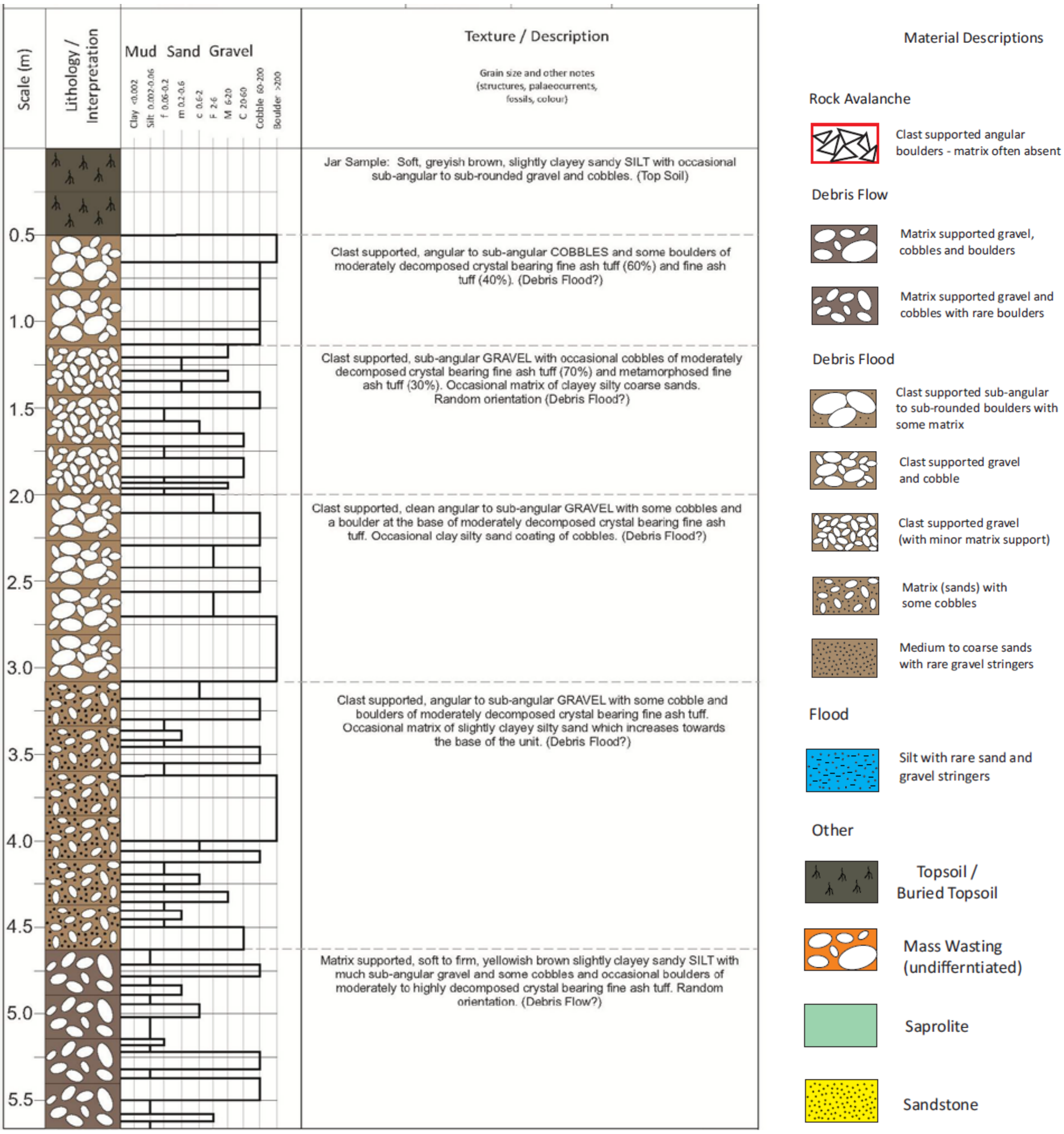

Figure D.4.4 Example of a Graphical Sedimentary Log (AFJV, 2012)

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D.5 Specific Hazards and their Evaluation

D.5.1 Large Debris Lobes

In addition to the identification of landslide scars, the NTHS should look for the presence of debris lobes. Significant debris lobes have been identified in Hong Kong, for example on Lantau Island (Case Study 17). These may be single lobes resulting from large single landslide events or multiple lobes developed over time and are predominantly associated with "relict" landslides. Statements such as "it is assumed that these occurred in the geological past" should not be made without supporting evidence such as presence of recognizable source area, layering in the debris lobe or dating result. These lobes can provide valuable information for the assessment of landslide magnitude and frequency.

Whilst such lobes may or may not be apparent from the LIC 1:1000-scale maps or even LiDAR derived maps depending on vegetation cover, they can usually be identified from API. Case Study 17 shows the assessment and interpretation of a large debris fan, comprised multiple events, based on detailed field mapping and targeted GI, including age dating, to allow the assessment of magnitude and frequency.

Case Study 17

(Main Consultant: Arup-Fugro Joint Venture, Sub-Consultant: GeoRisk Solutions Ltd.)

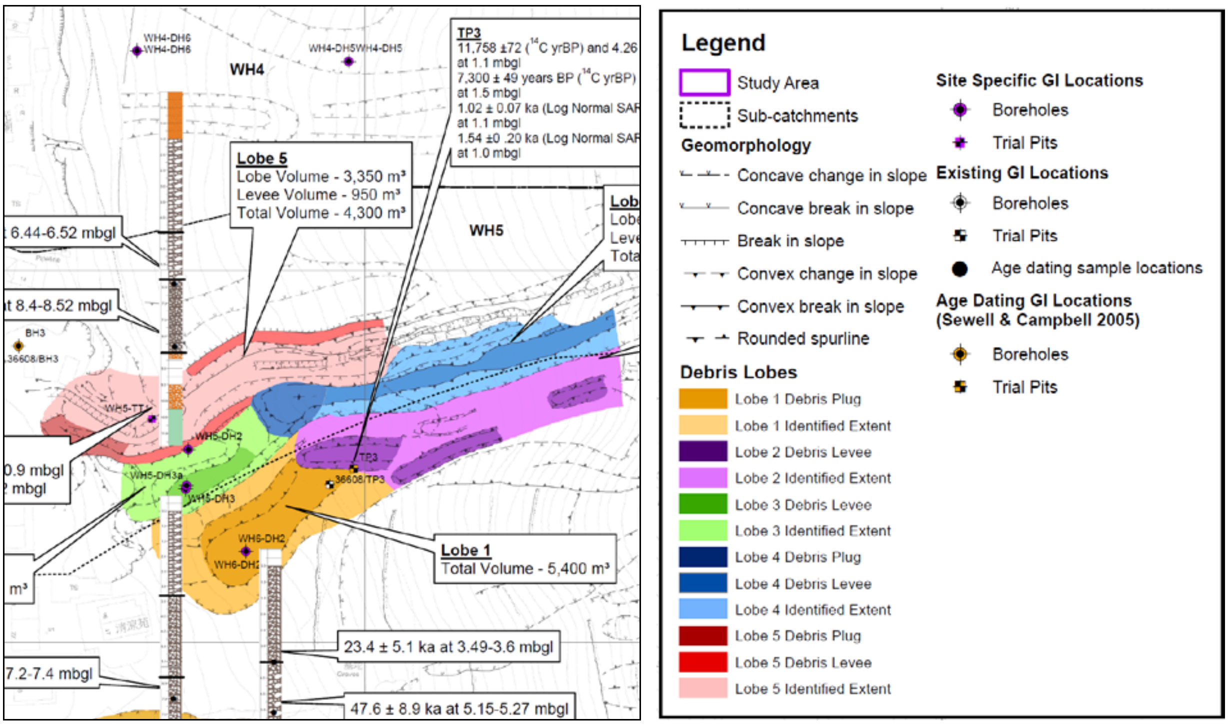

Figure D.5.1 Map of Debris Lobes (Extract) (AFJV, 2014)

The fan shown in Figure D.5.1 was sub-divided into 5 lobes or part-lobes based on surface mapping with plan areas varying from 100 m^2 to 1,200 m^2. Given the restricted size and relatively well defined morphology of the fan, drillholes were located in this fan.

Based on the field mapping and GI, a schematic cross section illustrates that the debris fan complex contains at least 12 separate debris flow events (see Figure D.5.2).

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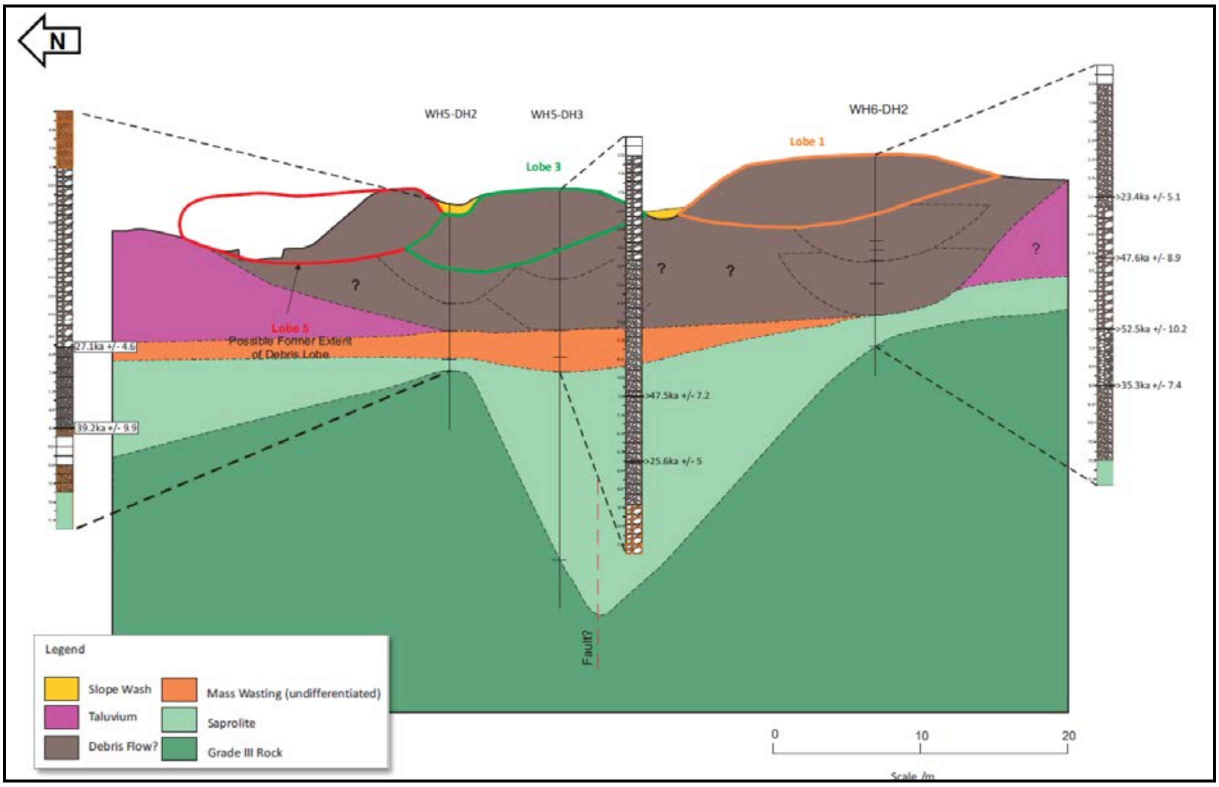

Figure D.5.2 Cross Section through Debris Lobes (AFJV, 2014)

The case study demonstrates the importance of detailed field mapping. Based on the API alone the largest relict landslide was 800 m^3. In comparison, the volumes of the debris lobe are an order of magnitude larger. An evaluation of the debris lobes and potential source areas was undertaken and tentative relationships between the two were evaluated. With the results of the age dating, an estimation of the possible age of the events was generated. This suggested that there have been three events in the last 1000 years (lobe volumes of 1,000 m^3, 2,000 m^3 and an unknown volume), four events in 3000 years (an additional lobe volume 3,000 m^3) and seven events in 4000 years (additional lobe volumes of 2,500 m^3, 10,000 m^3 and an unknown lobe volume).

D.5.2 Potentially Unstable Boulders and Exhumed Corestones

Field mapping should evaluate rock exposures and subdivide them into rock outcrops, corestones (in-situ) and boulders (displaced). They in turn should be placed in their geomorphological context and their relationships evaluated to understand processes and hazards. The emphasis should be on evaluating potentially unstable features resulting from either future erosion (corestones and boulders) or kinematically feasible instability (rock outcrops).

For more complex settings, detailed engineering geological maps may be required. Case Study 18 shows the mapping undertaken for a large unstable corestone complex immediately upslope of a facility. The mapping comprised an engineering geological map (Figure D.5.3), an evaluation of individual corestones within the complex that were

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considered potentially unstable (Figure D.5.4) and kinematic analysis to evaluate the potential for larger structurally-controlled failure mechanisms (Figure D.5.5).

Case Study 18
(Main Consultant: GeoRisk Solutions Ltd.)

Note: Mapping carried out for a natural terrain assessment above Intake C on the DSD Lai Chi Kok Drainage Transfer Scheme

Figure D.5.3 Engineering Geological Map of Corestone Complex (FSWJV, 2012a)

Figure D.5.4 Identification of Potentially Unstable Corestones (FSWJV, 2012a)

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Figure D.5.5 Evaluation of Larger Scale Instability of Corestone Complex (FSWJV, 2012a)

D.5.3 Extensive Hillside Distress

Whilst the API can greatly assist with the evaluation of the potential landslide hazard at a site, its resolution is restricted by vegetation cover and the scale and quality of the aerial photographs. Furthermore, where complete detachment of a landslide does not occur this may not be evident from API. Consequently, the use of targeted vegetation clearance is important where the assessment suggests that there is extensive hillside distress.

Case Study 19 shows the staged approach adopted during the investigation of such an area, where the initial mapping indicated limited distress but vegetation cover was dense. Consequently, GI and additional access was undertaken. The additional mapping, associated with targeted vegetation clearance, indicated more extensive distress and a second phase of GI was therefore undertaken. Very detailed logging of the GI stations and an understanding of weathering processes as well as structural geology are required to determine the likely type, extent and age of the movement, emphasising the importance of extensive engineering geological knowledge required by those undertaking an NTHS. The injection of significant amounts of additional GI during a study does have financial implications, but if such uncertainties are not addressed this could potentially result in significant errors in the recommended design event.

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Case Study 19
(Main Consultant: Halcrow China Ltd., Sub-Consultant: GeoRisk Solutions Ltd.)

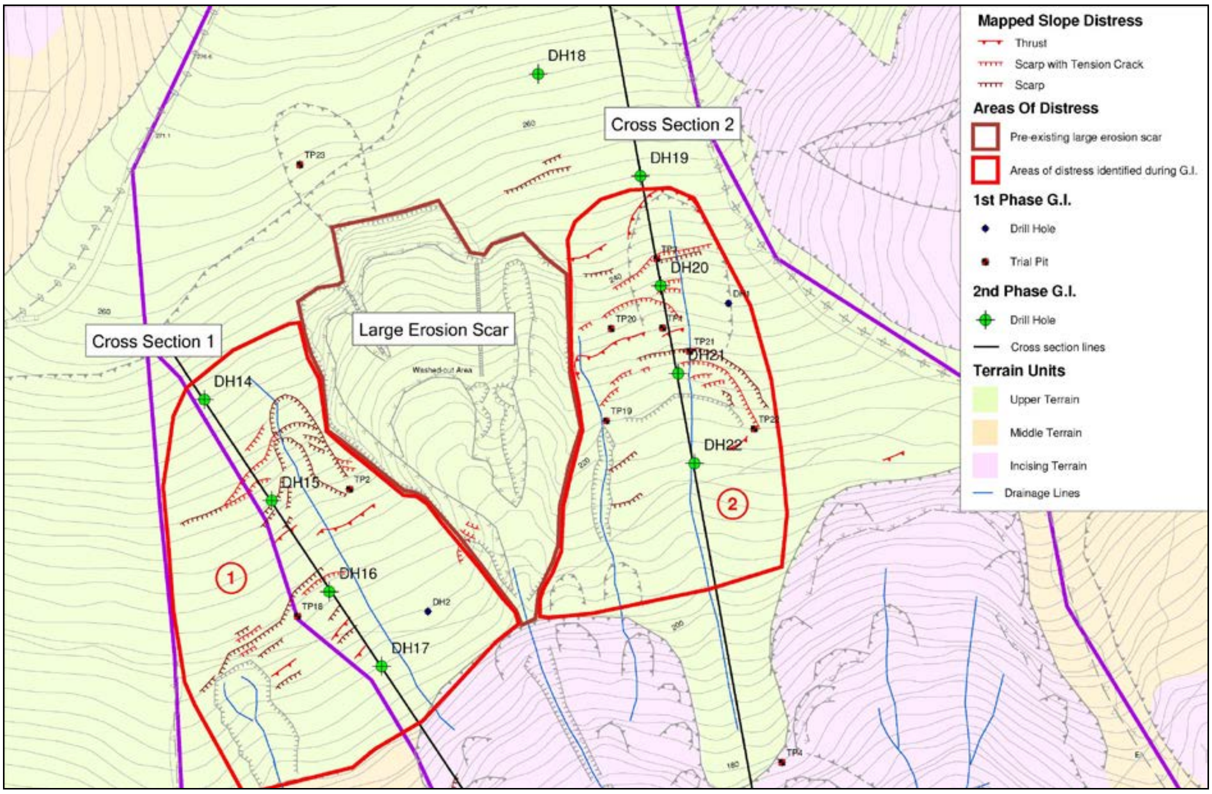

Figure D.5.6 Mapped Extent of Distress Following Vegetation Clearance (Halcrow, 2012)

Prior to GI, the field mapping had been significantly restricted in the Upper Terrain due to dense vegetation. The original GI design included 2 trial pits and 2 drillholes in the upper terrain as well as vegetation clearance. Once the additional access was available additional field mapping was undertaken and a large area of hillside distress was identified and mapped, and consequently additional trial pits were undertaken within the original GI scope of work. However, given the limitations with the original GI scope, together with the large extent of distress and uncertainties regarding depth of failure, a second phase GI was undertaken and included 9 drillholes (up to 40m depth), installation of slope inclinometers and piezometers. The additional expenditure of the second phase GI was well-justified given the need to evaluate the potential for a much larger scale of failure in the Upper Terrain.

The large area of slope distress consisted of two distinct areas of slope deformation (i.e. Areas 1 & 2 as shown in Figure D.5.6), which are located on either side of a pre-existing, large erosion scar. Area 1 is 3,600 m^2 and Area 2 is 2,800 m^2. The slope distress includes open tension cracks, minor scarps and small thrusts. Individual tension cracks and scarps were up to 30 m long. Recent movements in the form of a new tension crack and re-activation of an existing tension crack were noted. Much of the distress at the slope surface was associated with movement along slip surfaces within clayey colluvium, along the colluvium/saprolite boundary and/or within the near surface saprolite. In addition, there was localised evidence of small-scale internal movement/deformation at depth within saprolite interpreted from detailed examinations of split mazier samples (Figures D.5.7 and D.5.8).

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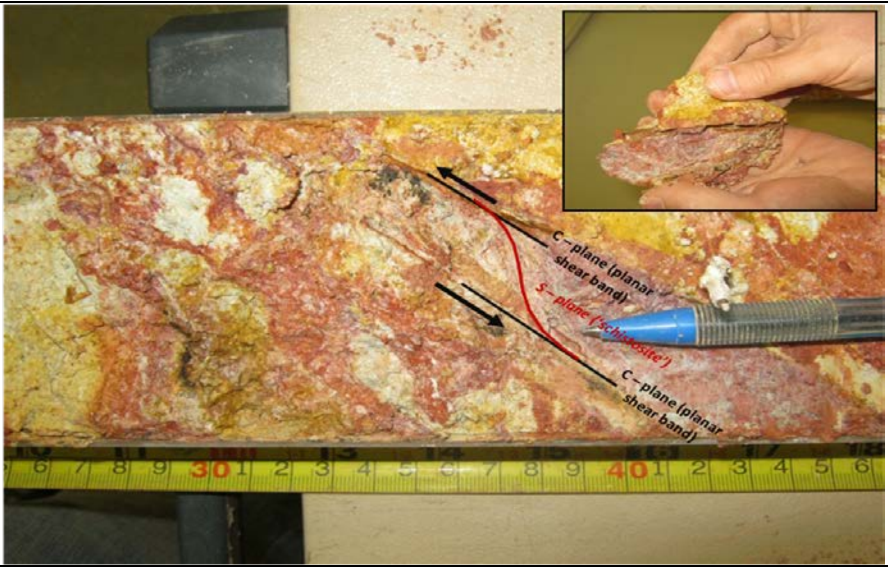

Figure D.5.7 Slip Surfaces and Soil Deformation (S-C fabrics) within a Shear Zone (Halcrow, 2012)

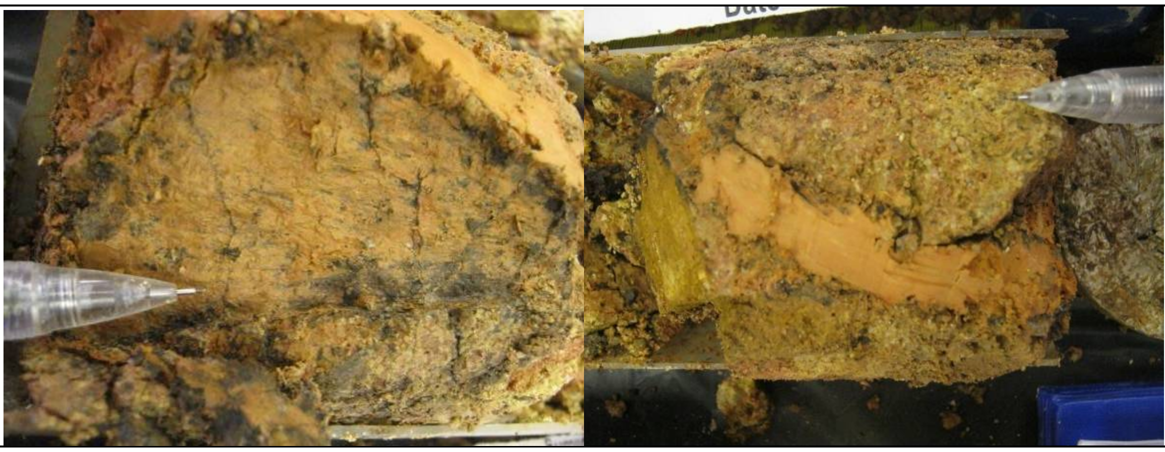

Figure D.5.8 Intensely Sheared and Deformed Kaolin Infilling a Relict Joint (Halcrow, 2012)

The age of formation of the slip planes, shear surfaces and deformation fabrics identified at depth within the saprolite are unknown. In some cases, the slip surfaces have offset discontinuities and weathered bands, which indicate that the movements occurred during or after weathering. Kaolin is often associated with surfaces of rupture and buff kaolin clay probably develops progressively and over long periods of time as kaolin-infilled discontinuities are subject to intermittent shear, dilation, and infilling as a response to and during intermittent slope movements. Such infilling probably requires considerable time, perhaps over time scales of hundreds to thousands of years.

Based on the evidence it was suggested that small-scale internal movements (possibly associated with extremely slow creep-type ductile deformation) were occurring at depth

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within saprolite, possibly in relation to the development of oversteepening due to incision in adjacent terrain. The commencement of the deformation is likely to be in the order of 1,000s to 10,000s of years before present. As such, based on the current information, there was no evidence to support the hypothesis of imminent, deep-seated and large-scale brittle detachment. However, this movement appears to result in localised failures at the colluvium-saprolite interface (i.e. 2 m to 3 m deep), with a likely return period of 10s to 100s of years.

D.6 Final Maps

Once the GI has been completed, the data should be incorporated into the field mapping results and final maps prepared. It is recommended that a simplified GI log is shown on the final engineering geological map to enable the thicknesses of the engineering geological units to be displayed (Figure D.6.3).

GI allows geological cross sections to be drawn with a higher degree of confidence than from mapping alone and for certain sites this can be very useful. However, geological cross sections should focus on evaluating the engineering geological conditions controlling landslide initiation. As such, they will be project-specific, depending on the type and magnitude of the landslide hazard. They may need to take into account factors such as lithology, structure, landscape evolution, geomorphological processes, superficial deposits and potential failure modes.

Case Study 20 shows a final engineering geological map (Figure D.6.1) supported by a series of cross sections (Figure D.6.2), illustrating the depth of weathering, geological structure and superficial materials. They were developed to demonstrate failure processes and their subsequent control on the location and magnitude of landslides.

Case Study 20

(Main Consultant: C M Wong and Associates Ltd., Sub-Consultant: GeoRisk Solutions Ltd.)

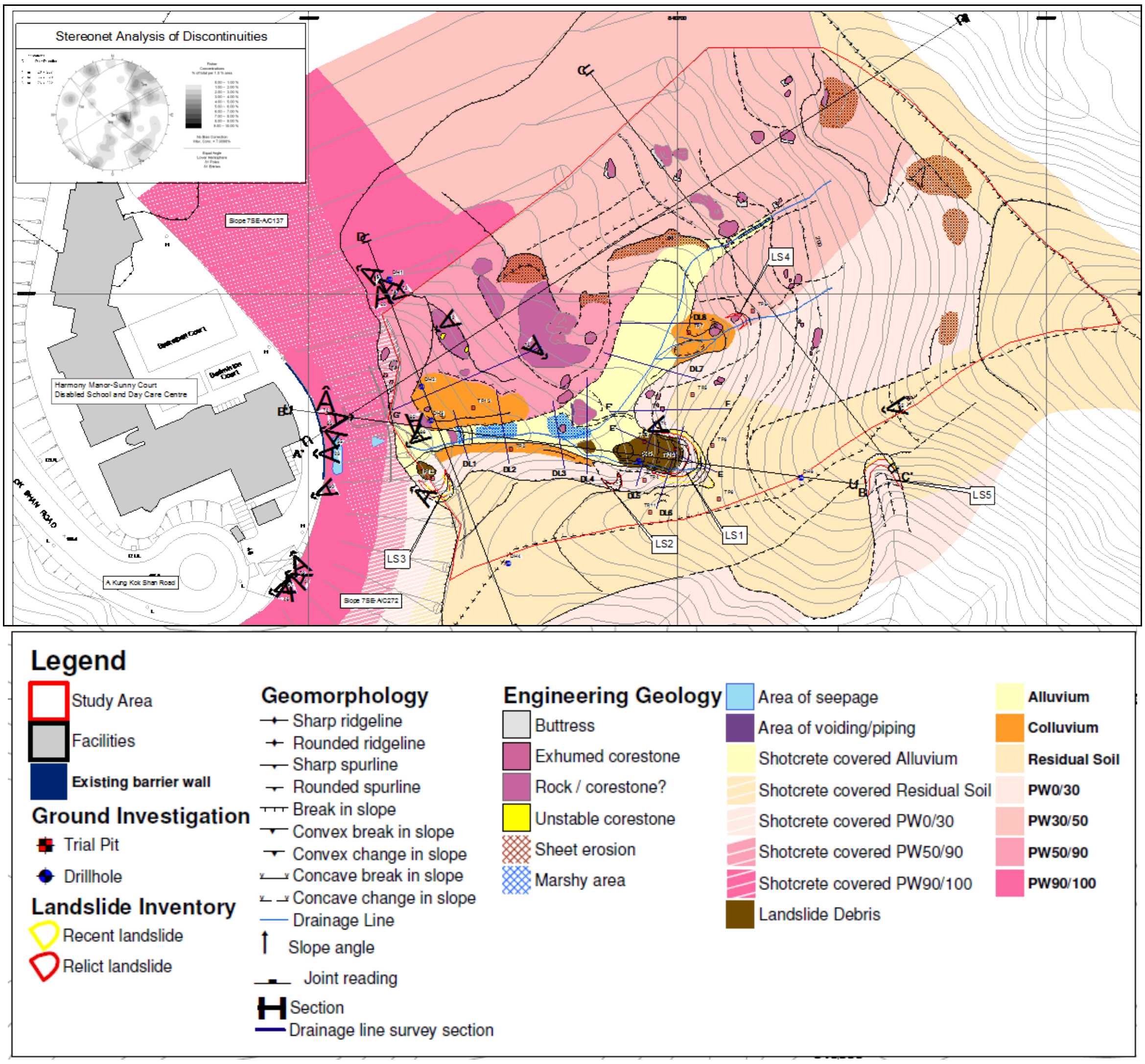

Figure D.6.1 Final Engineering Geological Map (C M Wong, 2011)

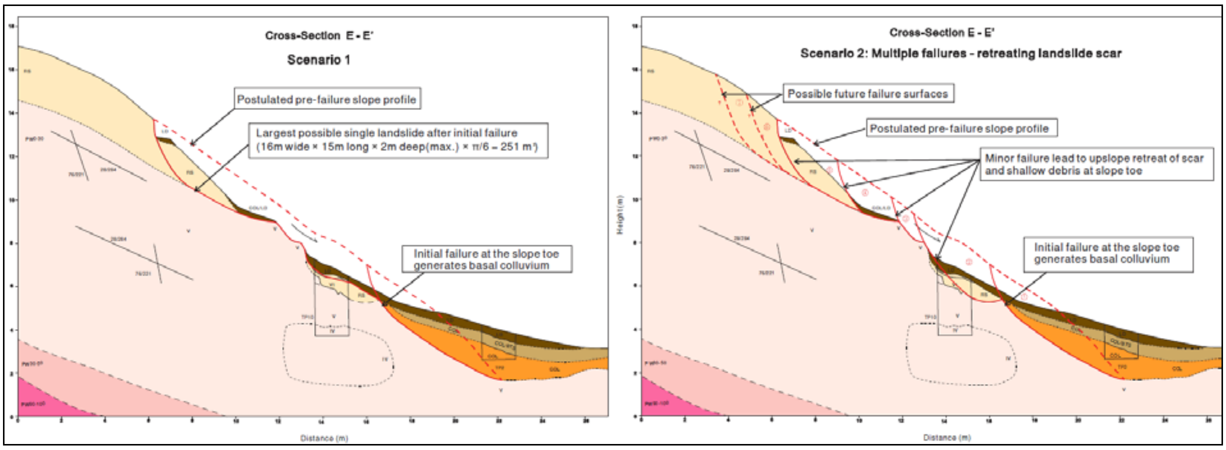

Figure D.6.2 Cross Section Indicating Landslide Mechanisms (C M Wong, 2011)

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The incorporation of both engineering geological mapping and engineering geomorphological maps into a single figure can be problematic for large or complex sites. Consequently, as with the desk study stage, it is sometimes beneficial to prepare the two maps separately (Figures D.6.3 & D.6.4).

Case Study 21

(Main Consultant: C M Wong and Associates Ltd., Sub-Consultant: GeoRisk Solutions Ltd.)

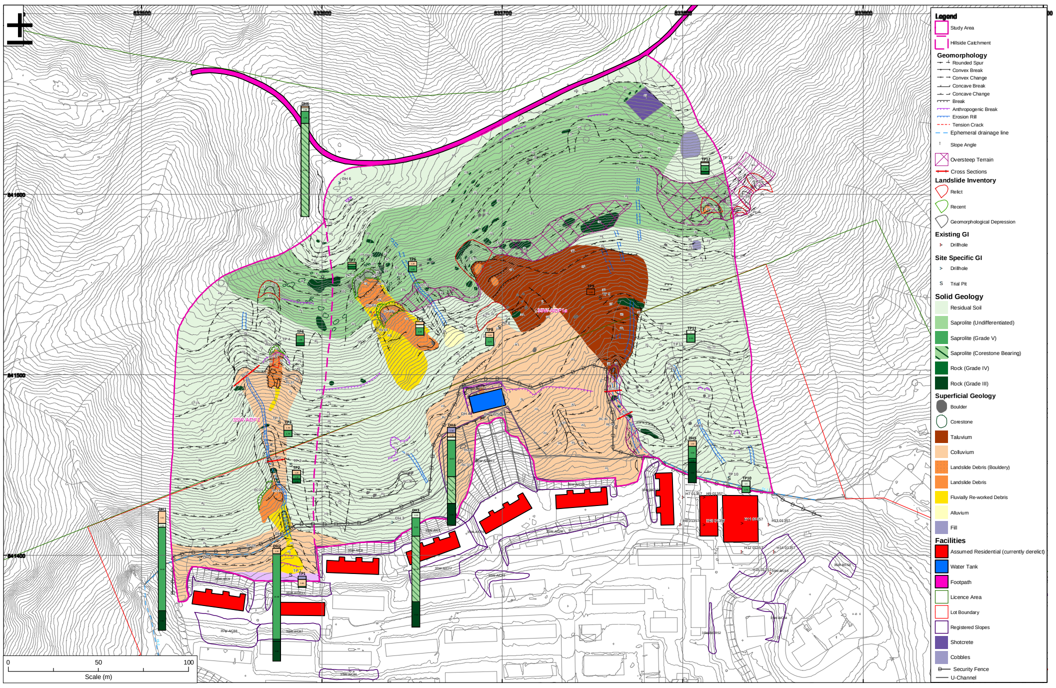

Figure D.6.3 Final Engineering Geological Map (C M Wong, 2012a)

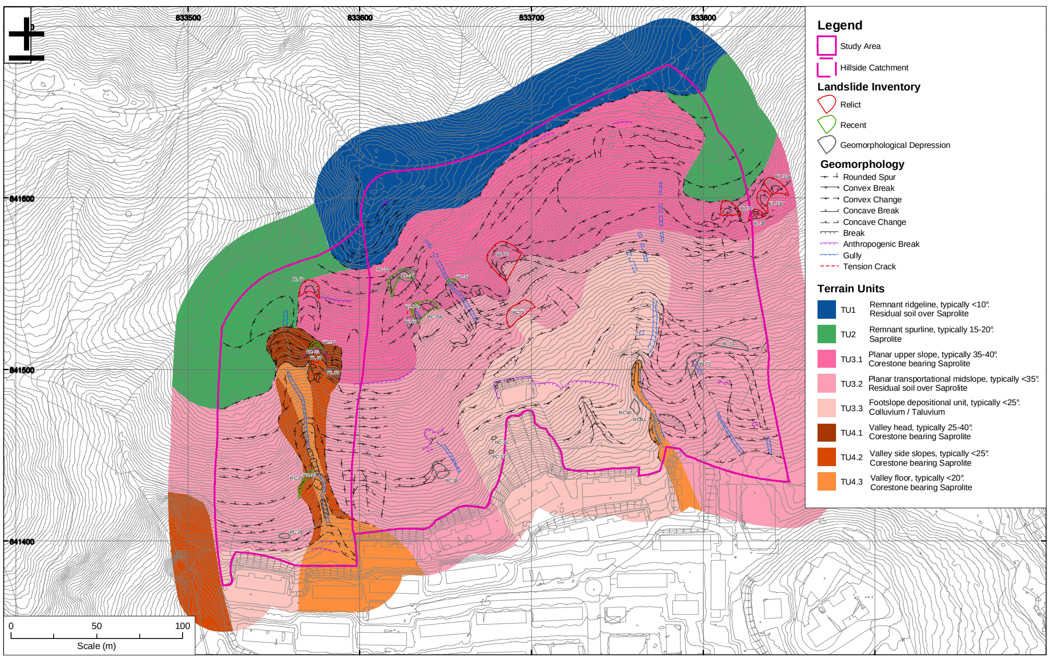

Figure D.6.4 Final Engineering Geomorphological Map (C M Wong, 2012a)

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FSWJV (2012b). Literature Review (Working Paper No. 1). Agreement No. CE12/2011(GE) Review of the Design Event Apporach to Natural Terrain Hazard Study. Geotechnical Engineering Office, Hong Kong.

FSWJV (2012c). Review of Endorsed NTHS Reports (Working Paper No. 2). Agreement No. CE12/2011(GE) Review of the Design Event Apporach to Natural Terrain Hazard Study. Geotechnical Engineering Office, Hong Kong.

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土力工程處刊物及訂購資料

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土力工程處之主要刊物

GEOTECHNICAL MANUALS

Geotechnical Manual for Slopes, 2nd Edition (1984), 302 p. (English Version), (Reprinted, 2011).

斜坡岩土工程手冊(1998)，308頁(1984年英文版的中文譯本)。

Highway Slope Manual (2000), 114 p.

GEOGUIDES

Geoguide 1	Guide to Retaining Wall Design, 2nd Edition (1993), 258 p. (Reprinted, 2007).
Geoguide 2	Guide to Site Investigation (1987), 359 p. (Reprinted, 2000).
Geoguide 3	Guide to Rock and Soil Descriptions (1988), 186 p. (Reprinted, 2000).
Geoguide 4	Guide to Cavern Engineering (1992), 148 p. (Reprinted, 1998).
Geoguide 5	Guide to Slope Maintenance, 3rd Edition (2003), 132 p. (English Version).
岩土指南第五冊	斜坡維修指南，第三版(2003)，120頁(中文版)。
Geoguide 6	Guide to Reinforced Fill Structure and Slope Design (2002), 236 p.
Geoguide 7	Guide to Soil Nail Design and Construction (2008), 97 p.

GEOSPECS

Geospec 1	Model Specification for Prestressed Ground Anchors, 2nd Edition (1989), 164 p. (Reprinted, 1997).
Geospec 3	Model Specification for Soil Testing (2001), 340 p.

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GCO Publication No. 1/90	Review of Design Methods for Excavations (1990), 187 p. (Reprinted, 2002).
GEO Publication No. 1/93	Review of Granular and Geotextile Filters (1993), 141 p.
GEO Publication No. 1/2006	Foundation Design and Construction (2006), 376 p.
GEO Publication No. 1/2007	Engineering Geological Practice in Hong Kong (2007), 278 p.
GEO Publication No. 1/2009	Prescriptive Measures for Man-Made Slopes and Retaining Walls (2009), 76 p.
GEO Publication No. 1/2011	Technical Guidelines on Landscape Treatment for Slopes (2011), 217 p.

GEOLOGICAL PUBLICATIONS

The Quaternary Geology of Hong Kong, by J.A. Fyfe, R. Shaw, S.D.G. Campbell, K.W. Lai & P.A. Kirk (2000), 210 p. plus 6 maps.

The Pre-Quaternary Geology of Hong Kong, by R.J. Sewell, S.D.G. Campbell, C.J.N. Fletcher, K.W. Lai & P.A. Kirk (2000), 181 p. plus 4 maps.

TECHNICAL GUIDANCE NOTES

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