QUANTITATIVE RISK ASSESSMENT OF LANDSLIDE HAZARDS AT FU YUNG SHAN TSUEN, TSUEN WAN

GEO REPORT No. 224

H.N. Wong & F.W.Y. Ko

GEOTECHNICAL ENGINEERING OFFICE

CIVIL ENGINEERING AND DEVELOPMENT DEPARTMENT

THE GOVERNMENT OF THE HONG KONG SPECIAL ADMINISTRATIVE REGION

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This report is largely based on GEO Landslide Study Report No. LSR 3/2006 produced in June 2006

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First published, May 2008

Prepared by:

Geotechnical Engineering Office,
Civil Engineering and Development Department,
Civil Engineering and Development Building,
101 Princess Margaret Road,
Homantin, Kowloon,
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 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. These include guidance documents and results of comprehensive reviews. These publications and the printed GEO Reports may be obtained from the Government's Information Services Department. Information on how to purchase these documents is given on the last page of this report.

R.K.S. Chan
Head, Geotechnical Engineering Office
May 2008

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FOREWORD

This work presents the findings of a quantitative risk assessment (QRA) of landslide hazards on facilities, viz. habitable structures and footpath network, arising from man-made slopes, and natural and disturbed hillsides at Fu Yung Shan Tsuen, Tsuen Wan.

The study was commissioned by the Environment, Transport and Works Bureau in December 2005. The work was jointly led by H.N. Wong and K.K.S. Ho, with the former focusing on the technical aspect and the latter on the administrative aspect. Maunsell Geotechnical Services Ltd., the Landslide Investigation Consultants (LIC), undertook the tasks on hazard identification, and mapping of facilities and population at risk. F.W.Y. Ko carried out the risk quantification work under the supervision of H.N. Wong and H.W. Sun. T.M.F. Lau and S.M. Tam of the Landslip Preventive Measures Division 1 assisted in managing the LIC and handled related administrative matters.

H.N. Wong
Chief Geotechnical Engineer/Planning

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ABSTRACT

A major landslide (Incident No. 2005/08/0362) occurred on a disturbed hillside within Fu Yung Shan Tsuen, Tsuen Wan, on 20 August 2005 resulting in one fatality. In December 2005, the Environment, Transport and Works Bureau requested the Geotechnical Engineering Office to undertake a quantitative risk assessment (QRA) of landslide hazards arising from man-made slopes, and natural and disturbed hillsides for the squatter area at Fu Yung Shan Tsuen.

The key tasks that have been carried out comprise hazard identification, mapping of facilities and population at risk, development of frequency and consequence models, quantification of landslide risk on facilities arising from man-made slopes, and natural and disturbed hillsides in terms of Personal Individual Risk (PIR), Potential Loss of Life (PLL) and F-N curves, and assessment of risk on facilities affected by overtopping of the Shing Mun catchwater due to blockage by landslide debris.

The following are the key findings of the study:

(a) The calculated PLL is 0.24 per year, of which 99% is associated with structures and 1% with footpaths. With regard to the risk to structures, hillsides account for 65% of the risk and man-made slopes contribute the other 35%. More than 85% of the risk to structures from hillsides is associated with disturbed hillsides. Open hillslope failures constitute about 68% of the hillside risk to structures, whilst the remaining 32% is associated with channelized debris flows.

(b) A considerable portion of the F-N curve falls within the ‘unacceptable’ zone of the risk criteria given in GEO Report No. 75 for existing facilities at risk from natural terrain landslides.

(c) The spatial distribution of the calculated PIR at each of the structures subject to landslide risk has been assessed. The vast majority (about 95%) of the structures with Non-Development Clearance (NDC) recommendations not yet discharged have high individual risks ranging from $\geq 10^{-4}$ to $< 10^{-2}$ per year, which exceed the risk tolerability limit given in GEO Report No. 75 for existing facilities at risk from natural terrain landslides. Structures without NDC recommendations (38 nos.) have noticeably lower PIR, mostly from $\geq 10^{-6}$ to $< 10^{-3}$ per year. Those structures with PIR from $\geq 10^{-4}$ to $< 10^{-3}$ per year are either within private land (some with Dangerous Hillside Orders served to the owners) or are at risk principally from hillside failures, or both. The structures are mostly either relatively more substantial or used for religious activities.

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(d) With regard to registered squatter structures, structures with NDC recommendations not yet discharged constitute 93% of the overall risk of all registered squatter structures. The majority of the registered squatter structures without NDC recommendations are located on private land.

(e) The calculated maximum individual risk along the footpath network is $1.5x10^{-5}$ per year, which is below the risk tolerability limit given in GEO Report No. 75 for existing facilities at risk from natural terrain landslides.

The QRA can provide a benchmark for the NDC recommendations, which have been made principally on the basis of engineering judgment. It is concluded that the NDC recommendations are consistent with the findings of the QRA in that the vast majority of the existing structures with NDC recommendations are exposed to an unacceptably high landslide risk. Also, the NDC recommendations are not unduly conservative by reference to the risk tolerability criteria.

The landslide risk of the footpath network is much lower than that of the structures. The August 2005 landslide, which resulted in one fatality, was an improbable and unfortunate event, and should not be taken as indicating that the footpath network is of high risk.

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1. INTRODUCTION

Fu Yung Shan Tsuen is a squatter village developed adjacent to Chuk Lam Sim Yuen in Tsuen Wan. A major landslide (Incident No. 2005/08/0362) occurred on a disturbed hillside within Fu Yung Shan Tsuen on 20 August 2005 resulting in one fatality. The history of development of the area and the findings of the investigation of the August 2005 landslide are given in Maunsell Geotechnical Services Ltd. (2006).

Non-Development Clearance (NDC) recommendations were made by the Geotechnical Engineering Office (GEO) in 1985, 1992 and after the August 2005 fatal landslide respectively. In December 2005, the Environment, Transport and Works Bureau requested the GEO to undertake a quantitative risk assessment (QRA) of landslide hazards arising from man-made slopes, and natural and disturbed hillsides for the squatter area at Fu Yung Shan Tsuen (Figure 1; Plate 1).

Risk is a measure of potential damage. A formal QRA provides a structured framework for risk quantification, with due regard to nature of slopes, probabilities of landslides and likely consequences to affected facilities. It was adopted in the present study, which considers landslide hazards posed to the existing structures and footpaths by both man-made slopes and hillsides (natural terrain as well as disturbed hillsides).

A total of 100 structures in Fu Yung Shan Tsuen subject to landslide risk were assessed in the QRA, 62 of which with NDC recommendations. Risk tolerability was evaluated and NDC recommendations were benchmarked in terms of Personal Individual Risk (PIR), Potential Loss of Life (PLL) and F-N curves.

The QRA provides for a rigorous assessment of the landslide risk, and gives quantified estimates of the level of PLL and spatial distribution of PIR. It facilitates a more objective evaluation of the risk tolerability and benchmarking of the NDC recommendations, which have been made principally on the basis of engineering judgment.

The QRA was jointly undertaken by the Planning Division, the Landslip Preventive Measures Division 1 and the GEO's Landslide Investigation Consultants (LIC), Maunsell Geotechnical Services Limited.

The QRA included the following key areas of work:

(a) Review of historical landslides in the area, including those identified from reported landslide incidents, from interpretation of aerial photographs and from field mapping.

(b) Engineering geological mapping for assessment of the terrain conditions, geomorphology and landslide susceptibility.

(c) Calculation of base-line landslide frequencies for different types of man-made slopes, and natural and disturbed hillsides.

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(d) Identification of the existing squatter dwellings, other structures and footpath network at Fu Yung Shan Tsuen.

(e) Survey the degree of usage of the facilities.

(f) Delineation of slopes and hillside catchments that pose a potential risk to the existing facilities, and matching the slopes/catchments with their affected facilities.

(g) Development of landslide frequency and consequence models.

(h) Calibration of the models by comparing the QRA results with findings from qualitative risk assessment carried out independently by the LIC.

(i) Assessment of landslide frequencies for man-made slopes, with account taken of the slope type, size, topography, conditions, history of failure, etc.

(j) Assessment of landslide frequencies for natural and disturbed hillsides, with account taken of the slope size, topography, geomorphology, geological conditions, degree and type of man-made disturbance, history of failure, etc.

(k) Assessment of the likelihood of overtopping from the Shing Mun catchwater (the catchwater) due to blockage by landslide debris.

(l) Numerical modeling for assessment of lateral influence zones along the major drainage lines in the event of channelized debris flows and overtopping of the catchwater.

(m) Assessment of landslide consequence at each of the affected facilities.

(n) Calculation of landslide risk, in terms of PIR, PLL and F-N curves, for the structures and footpath network.

(o) Evaluation of the risk results.

2. METHODOLOGY FOR RISK ASSESSMENT

2.1 Hazard Identification

Relevant information on landslide hazards arising from the man-made slopes, and the natural and disturbed hillsides at Fu Yung Shan Tsuen was collated, examined and compiled for the development of hazard and frequency models in the QRA. The work mainly included:

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(a) A review of the historical landslide data which included Lo & Cheung (2004), records of reported landslide incidents within the village and aerial photographs over an observation period within which landslide information is available. Lo & Cheung (2004) provided the required landslide information for development of the frequency models for different types of the man-made slopes. With respect to hillside failures, six recent and eight relict hillside failures were identified over an observation period of 24 years and 70 years respectively. Five of the recent hillside failures have occurred on the disturbed portion while all the relict hillside failures have occurred on the natural portion. Information such as landslide types (i.e. natural hillside failures or disturbed hillside failures), landslide volumes and number of occurrences over the observation periods was considered in the assessment of landslide frequencies for different types of failures and their respective magnitude-frequency model. Details of the collation of the relevant historical landslide data are described in Appendix A.

(b) Engineering geological mapping of major geological and geomorphological features for assessment of landslide susceptibility of different units of the natural and disturbed hillsides. These features included topography, regolith, head of drainage line, oversteepen hillsides, incised gully and terrain surface conditions (i.e. paved, bared or eroded land with vegetation, cultivation, cut and fill platforms and refuse distribution). Details of the engineering geological mapping work are described in Appendix B.

2.2 Mapping of Facilities and Population at Risk

The facilities and population at risk of landslide hazards arising from the man-made slopes and the natural and disturbed hillsides at Fu Yung Shan Tsuen (Plate 2) were identified and mapped based on field inspection and population survey.

The facilities assessed in the QRA comprised: (i) a total of 100 nos. of existing structures that were in use at the time of the study (Plate 3) or considered to have a potential for occupation, irrespective of their land and squatter registration status, and (ii) the existing footpath network (Plate 4), with a total length of about 2.5 km. Structures that have already been demolished, or were in such a poor condition that were considered not habitable (Plate 5) were not included in the mapping exercise. Existing structures that were not in use at the time of the study but could be occupied (Plate 6) were included in the QRA.

The degree of usage (i.e. number of population at risk and its temporal distribution) of some of the mapped structures was assumed to be the same as that of typical squatter dwellings in Hong Kong. In this respect, the QRA results reflect the potential risk when the

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existing habitable structures are occupied. Some of the structures in the village were known to be used as hostels (Plate 7) or for religious purposes (Plate 8), and their usage is very different from typical squatter dwellings in Hong Kong. The degree of usage of these structures was surveyed and the findings used in the QRA. For the footpath network, field surveys were carried out in early 2006 to establish its degree of usage at each critical section in different time periods.

Details of the mapping of the facilities and population at risk are described in Appendix C.

2.3 Frequency Assessment

Based on the findings from Section 2.1 above, base-line frequencies for different types of man-made slopes, and natural and disturbed hillsides were calculated. Frequency models were developed to adjust, based on the actual conditions of a specific slope or hillside catchment, the base-line frequency to such a level that best reflects the likelihood of failure of the individual slope or hillside catchment. For man-made slopes, factors considered included geometry, past instability records and adverse attributes such as inadequate drainage provision and concentration of surface water. For natural and disturbed hillsides, a number of susceptibility attributes such as topography, regolith, geomorphology and terrain surface conditions (i.e. paved, bared or eroded land with vegetation, cultivation, cut and fill platforms and refuse distribution) were considered. Adjustment to magnitude-frequency relationships was also incorporated in the frequency models to account for the variation in the sizes of the man-made slopes and the hillside catchments. It was considered that very small slopes or catchments would have low, if not negligible, chance of having large-scale failures. Details of the frequency models are discussed in Appendix D.

2.4 Consequence Assessment

For man-made slopes, the consequence model developed by Wong et al (1997) and adopted in Lo & Cheung (2004) was applied for the assessment of proximity and vulnerability factors for each mapped facility with respect to different types of landslide hazards.

For natural and disturbed hillsides, the spatial distribution of the mapped facilities (see Section 2.2 above) was used as a guided reference to delineate the boundaries of hillside catchments and hillside units that pose potential risk to the facilities. These hillside catchments and hillside units were then matched to their affected facilities. Updated runout and vulnerability models based on those adopted in Wong et al (2004) were developed and applied for the assessment of proximity and vulnerability factors for each mapped facility with respect to different types of landslide hazards.

Details of the consequence models are discussed in Appendix E.

2.5 Risk Evaluation

Landslide frequencies for different types of man-made slopes and hillsides with respect

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to different types of landslide hazards, were calculated based on the frequency models developed (see Section 2.3 and Appendix D). The severity of different types of landslide hazards to each affected facility was estimated based on the consequence models described in Section 2.4 and Appendix E. The landslide risk on each affected facility combined via the frequency and the consequence models was calculated in terms of PIR, PLL and F-N curves. Details of the risk calculation are described in Appendix F.

2.6 Comparative Assessment of Results from Qualitative and Quantitative Risk Assessment

A qualitative risk assessment was carried out by the LIC to estimate qualitatively landslide risk arising from man-made slopes on structures in Fu Yung Shan Tsuen. The results from the qualitative risk assessment were compared with those obtained from the QRA described in Sections 2.1 to 2.5 above using a comparative framework. Details of the qualitative risk assessment and the calibration exercise are described in Appendix G.

2.7 Assessment of Risk due to Overtopping of Catchwater

In the event of sizeable landslides from the man-made slopes or the natural hillside overlooking the section of the catchwater uphill of Fu Yung Shan Tsuen, the catchwater may be blocked by landslide debris. The blockage of the catchwater could result in overtopping, despite the provision of a number of overflow weirs along its length. The overtopping of the catchwater would cause uncontrolled overland flow of surface water together with entrained debris in the form of debris floods downhill to Fu Yung Shan Tsuen. Depending on the lateral influence zones of the overland flow from different overtopping sections of the catchwater, structures could be adversely affected by debris floods possibly at high speed and considerable depths resulting in loss of life.

Frequency and consequence models were developed to estimate the likelihood of blockage of the catchwater in the event of landslide failures on the man-made slopes/ hillside catchment overlooking the catchwater, and the severity of damage by debris floods to the affected facilities in terms of PIR and PLL. For mapping of facilities affected by a blockage of the catchwater, a series of numerical modeling of flow (Julien et al, 1997) were carried out to estimate the lateral influence zones of the overland flow from different overtopping sections. Details of the analysis are discussed in Appendix H. The analysis focused on the habitable structures, as the risk to the footpath network was considered negligible for its relatively low degree of usage, especially during heavy rainfall.

3. KEY FINDINGS

Following the above methodology, the landslide risk arising from the man-made slopes and the hillsides for each affected facility was calculated in terms of PIR, PLL and F-N curves. The key findings are described below:

(a) Spatial Distribution of Personal Individual Risk

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(i) The spatial distribution of the calculated PIR at each of the structures (a total of 100 structures) at risk from landslides (combined man-made and hillside failures) is shown in Figure 2.

(ii) Structures with NDC recommendations (a total of 62 structures) have high PIR, with about 95% having PIR ranging from $\geq 10^{-4}$ to $< 10^{-2}$ per year. The remaining structures have PIR less than 10^{-4} per year. They are either within a cluster of registered squatter dwellings with high PIR and NDC recommendations, or located over the crest of a steep cut slope, or located near the outlet of a major drainage line which may also be subjected to some additional risks from surface water flows that have not been included in the current PIR figures.

(iii) Structures without NDC recommendations (a total of 38 structures) have noticeably lower PIR, mostly from $\geq 10^{-6}$ to $< 10^{-3}$ per year. Those structures with PIR from $\geq 10^{-4}$ to $< 10^{-3}$ per year are either within private land or are at risk principally from hillside failures, or both. Also, they are mostly either relatively more substantial or religion-related structures.

(iv) According to GEO Report No. 75 (ERM, 1998) for existing facilities at risk from natural terrain, PIR $\geq 10^{-4}$ per year is taken to be 'Unacceptable' for existing facilities at risk from natural terrain landslides. By reference to this criterion, the PIR in the vast majority of the structures with NDC recommendations is 'Unacceptable'. The PIR at some of the other structures (i.e. without NDC recommendations) also falls within the 'Unacceptable' category.

(v) The calculated maximum individual risk at the footpath network is 1.5×10^{-5} per year, which is tolerable according to the risk criterion given in GEO Report No. 75.

(b) Overall Distribution of Societal Risk

(i) Total calculated PLL = 0.2380 per year. This figure includes the landslide risk on both the structures and the footpath network. The figure, compared with the perceived overall landslide risk on the squatter population in Hong Kong (Lo & Cheung, 2004), suggests that the QRA model adopted in this study is likely to be conservative and the degree of

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conservatism is probably within one order of magnitude. The degree of conservatism is largely associated with the assumed degree of usage of the habitable structures, which is necessary to reflect the potential landslide risk.

(ii) A breakdown of the total calculated PLL according to the types of facilities is shown in Figure 3. The total risk on the structures affected by man-made slopes and hillsides = 0.2350 per year (i.e. 98.7% of the total risk) and that for the footpath network = 0.0030 per year (i.e. 1.3% of the total risk)

(iii) The F-N curves for the structures affected are shown in Figure 4. Multiple-fatalities (e.g. N exceeding 4) arise principally from landslides affecting structures used as hostels and for religious purposes, and structures that have more than one storey.

(iv) If the whole village is taken as a standard consultation zone for application of the risk criteria given in GEO Report No. 75, then a considerable portion of the calculated societal risk is within the 'Unacceptable' zone (Figure 4).

(v) The breakdown of the calculated PLL according to the structures affected by man-made slopes, and natural and disturbed hillsides is shown in Figure 3, and highlighted as follows:

- Risk from the registered and registerable man-made slopes affecting 68 structures = 0.0822 per year (i.e. about 35% of the total risk)

- Risk from the hillsides affecting 91 structures = 0.1528 per year (i.e. about 65%), in which the vast majority (PLL = 0.1312 per year) comes from the disturbed hillsides in the vicinity of the structures. The natural hillsides, which are at some distance from the structures, pose a PLL of about 0.0216 per year.

(vi) The breakdown of the calculated PLL according to the structures with and without NDC recommendations is shown in Figure 5, and highlighted as follows:

- Structures with NDC recommendations constitute the majority (PLL = 0.1734 per year, i.e. about 74%) of the total risk. They take up about 84%

(PLL = 0.0689 per year) of the risk from man-made slope failures and about 68% (PLL = 0.1045 per year) of that from hillside landslides.

– Structures without NDC recommendations constitute about 26% (PLL = 0.0616 per year) of the total risk. About 27% (PLL = 0.0167 per year) rests with 16 structures without NDC recommendations but affected by slopes that have been subjected to Dangerous Hillside (DH) Orders. The DH Orders were served principally on man-made slopes (involving PLL = 0.0057 per year), but a small portion of the hillside was also covered (involving PLL = 0.0024 per year). The 16 structures are also at risk from landslides arising from mand-made slopes and hillsides that are outside the boundaries of the DH Orders (involving PLL = 0.0086 per year). The remaining 73% (PLL = 0.0449 per year) of the risk rests with 22 structures without NDC recommendations and not affected by slopes that have been subjected to DH Orders. The vast majority of this risk (PLL = 0.0374 per year, i.e. about 83%) comes from hillside landslides.

(vii) If the consideration is confined to registered squatter dwellings, registered squatter dwellings with NDC recommendations (62 nos.) constitute about 93% of the risk on all registered squatter dwellings (77 nos. with PLL = 0.1861 per year, see Figure 6). This means that registered squatter dwellings without NDC recommendations (15 nos.) constitute about 7% of the risk on all registered squatter dwellings.

(c) Land Status and NDC Recommendations

(i) A majority of the structures without NDC recommendations are on private land (i.e. 34 out of the 38 structures). Among them, 13 structures are registered squatter dwellings.

(ii) Only 4 structures without NDC recommendations are on Government land:

– One of the structures is adjoining a major drainage line (Index No. 74, see Figure C5). It is a suspected unauthorized structure that has been built in recent years. It will likely be considered for clearance in the pre-clearance

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survey if conducted. Pre-clearance survey aims at defining the exact extent of the squatter clearance needed.

– The other structure (Index No. 29) appears to be part of a larger group of structures with NDC recommendations and it has been confirmed as a registered squatter dwelling.

– The remaining two structures are bordering private land and appear to be part of a larger group of structures that are located mostly on private land. One of them is a registered squatter dwelling (Index No. 70) while the other has unclear structure status (Index No. 82) (i.e. it has neither be confirmed to be registered squatter dwelling nor known planned development nor known unauthorized structure). It will likely be considered for clearance in the pre-clearance survey if conducted.

(d) Land Status and Squatter Registration Status

A breakdown of the risk distribution according the land/squatter registration status is given in Figure 6. Their spatial distribution is shown in Figure C8. Registered squatter dwellings constitute about 79% (PLL = 0.1861 per year) of the total risk. About 1/3 of the calculated PLL is from registered squatter dwellings on Government land and 2/3 from dwellings on private land. As for the remaining 21% (PLL = 0.0489 per year) of the total risk, about 37% (PLL = 0.0180 per year) comes from 16 structures that are known to be planned developments (e.g. private village houses). Another 15% (PLL = 0.0074 per year) comes from four known unauthorized structures. About 48% (PLL = 0.0235 per year) come from three other structures whose status is not clear.

4. <u>DISCUSSIONS</u>

For the purpose of benchmarking the NDC recommendations at Fu Yung Shan Tsuen, the QRA results give the following overall picture:

(a) The NDC recommendations that have been made are consistent with the findings of the QRA in that the vast majority of the existing structures with NDC recommendations have a high risk.

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(b) The NDC recommendations that have been made are not unduly conservative by reference to the risk tolerability criteria given in GEO Report No. 75.

The following observations are also noteworthy:

(a) Both man-made slopes and hillsides pose a significant risk to the structures.

(b) The risk of hillside landslides arises principally from failure of the disturbed hillside. This is consistent with the fact that the hillside in the vicinity of the structures has been highly disturbed by local cutting, filling, terracing and other man-made activities.

(c) Open slope failures constitute about 68% of the hillside landslide risk (PLL = 0.1036 per year). The remaining 32% are associated with channelized debris flows (PLL = 0.0492 per year). The relatively high portion of hillside landslide risk due to open slope failures reflects the situation that the existing structures are scattered on steep terrain, and risk mitigation would involve dealing with large areas of open hillsides and is hence likely to be more difficult and costly than dealing with channelized debris flows.

(d) Structures with NDC recommendations constitute about 74% of the overall societal risk. The remaining 26% of the risk rests with 38 structures without NDC recommendations. 34 of these 38 structures are on private land. Some of these structures on private land are subject to a moderate level of risk (PIR $\geq 10^{-4}$ per year). DH Orders have been served on some of the man-made slopes affecting the structures without NDC recommendations. However, some of the structures are also at risk from the hillsides, including hillsides within and outside the private lots. If the consideration is confined to registered squatter dwellings, then structures with NDC recommendations constitute about 93% of the risk on all registered squatter dwellings.

(e) The PIR and the societal risk of the footpath network is much lower than that at the structures, which is consistent with its low pedestrian density and the low temporal probability of presence of an individual person in the footpath network. The August 2005 landslide, which resulted in one fatality, was an improbable and unfortunate event, and should not be taken as indicating that the footpath network is of high risk.

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(f) In the absence of available risk criteria for combined man-made slope and hillside failures, the risk criteria given in GEO Report No. 75 were used as a reference in this QRA. Such criteria are developed for natural terrain landslides. It is arguable that the criteria for man-made slopes and hillsides involving man-made disturbance could be more stringent than those for natural terrain. However, as squatter population is, to some extent, ‘voluntary’ in their exposure to landslide risk, they could be willing to tolerate a higher risk level. The size of the consultation zone would also affect the evaluation of the tolerability of societal risk. For a village like this, which includes a fairly high density of vulnerable structures, the calculated societal risk would tend to be high if a large consultation zone (equivalent to a plan circular area 150 m in radius as suggested by GEO Report No. 75) is adopted.

(g) Three structures with NDC Category 2 have not been included in the QRA (see Figure 2). One of the structures has only potential downslope hillside failures and the risk is generally small compared with that due to landslides on hillsides overlooking structures. Another structure is largely affected by an overtopping of the Shing Mun catchwater when it is blocked by landslide debris. The landslide risk to the structure as arising from the man-made slopes and the hillsides is considered insignificant. The last structure is constructed right against a steep slope, which, in its present setting, is not accessible for inspection and assessment.

(h) The QRA is based on the site conditions at the time of the assessment, i.e. early 2006. It is noteworthy that the site conditions are changing with time, possibly leading to progressive increase in landslide risk. Apart from signs of deterioration at some of the man-made slope features (e.g. cracking and bulging at masonry walls), there is on-going human disturbance in the area, such as unauthorized cutting and filling (Plate 9), illegal cultivation (Plate 10), building of fish ponds (Plate 11), disposal of rubbish on sloping ground (Plate 12), etc.

(i) The QRA of Fu Yung Shan Tsuen, which was taken to be a test case, has provided insights in relation to the risk levels and their spatial distribution, together with risk tolerability. It has highlighted that disturbed hillsides deserve particular attention for this village. As the majority of the risk (68%) from hillsides is associated with open slope failures (which reflects the situation that the existing structures are scattered on steep terrain), risk mitigation works, if undertaken,

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would involve dealing with large areas of hillsides and are hence likely to be more difficult and costly than dealing with channelized debris flows.

(j) As illustrated by this study, a formal QRA provides for a rigorous assessment of the risk levels (delineation of the spatial distribution of individual risk as well as the overall risk), which facilitate an objective evaluation of risk tolerability. However, the assessment is resources-demanding, particularly for large village areas involving scattered squatter structures on steep terrain, such as Fu Yung Shan Tsuen.

(k) In this QRA, an attempt has been made to quantify the likely level of risk of debris floods arising from overtopping of the catchwater due to blockage by landslide debris. The assessment is preliminary in that it involved simplified assumptions made to facilitate the analysis of the performance of the catchwater system in the event of blockage and modeling of the debris floods. The results indicate that the risk of such debris flood scenarios is small compared with that due to landslides on the man-made slopes and the hillsides. The increases in PIR and PLL are both about 1%. In consideration of the relatively low risk level and the possibility that measures can be provided separately to protect the catchwater and mitigate the risk of the debris floods, the risk was not included as part of the landslide risks presented above and was not evaluated in this QRA exercise.

5. CONCLUSIONS

The level of landslide risk to facilities at the Fu Yung Shan Tsuen arising from man-made slopes and hillsides has been assessed, with the support of the Landslip Preventive Measures Division 1 and the LIC, using QRA methodology. The landslide risk has been estimated in terms of PIR, PLL and F-N curves. The risk to those affected facilities due to overtopping of the catchwater has also been calculated.

The QRA can provide a benchmark for the NDC recommendations, which have been made principally on the basis of engineering judgment. It is found that the NDC recommendations are consistent with the findings of the QRA in that the vast majority of the existing structures with NDC recommendations are exposed to an unacceptably high landslide risk. Also, the NDC recommendations are not unduly conservative by reference to the risk tolerability criteria.

The landslide risk of the footpath network is much lower than that of the structures. The August 2005 landslide, which resulted in one fatality, was an improbable and unfortunate event, and should not be taken as indicating that the footpath network is of high risk.

6. REFERENCES

ERM-Hong Kong Limited (1998). Landslides and Boulder Falls from Natural Terrain: Interim Risk Guidelines. GEO Report No. 75, Geotechnical Engineering Office, Hong Kong, 183 p.

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Wong, H.N., Shum, W.W.L. & Ko, F.W.Y. (2004). Assessment of Natural Terrain Landslide Risk on the Planned Development in Ling Pei, Lantau. Advisory Report No. ADR 4/2004, Geotechnical Engineering Office, Hong Kong, 173 p.

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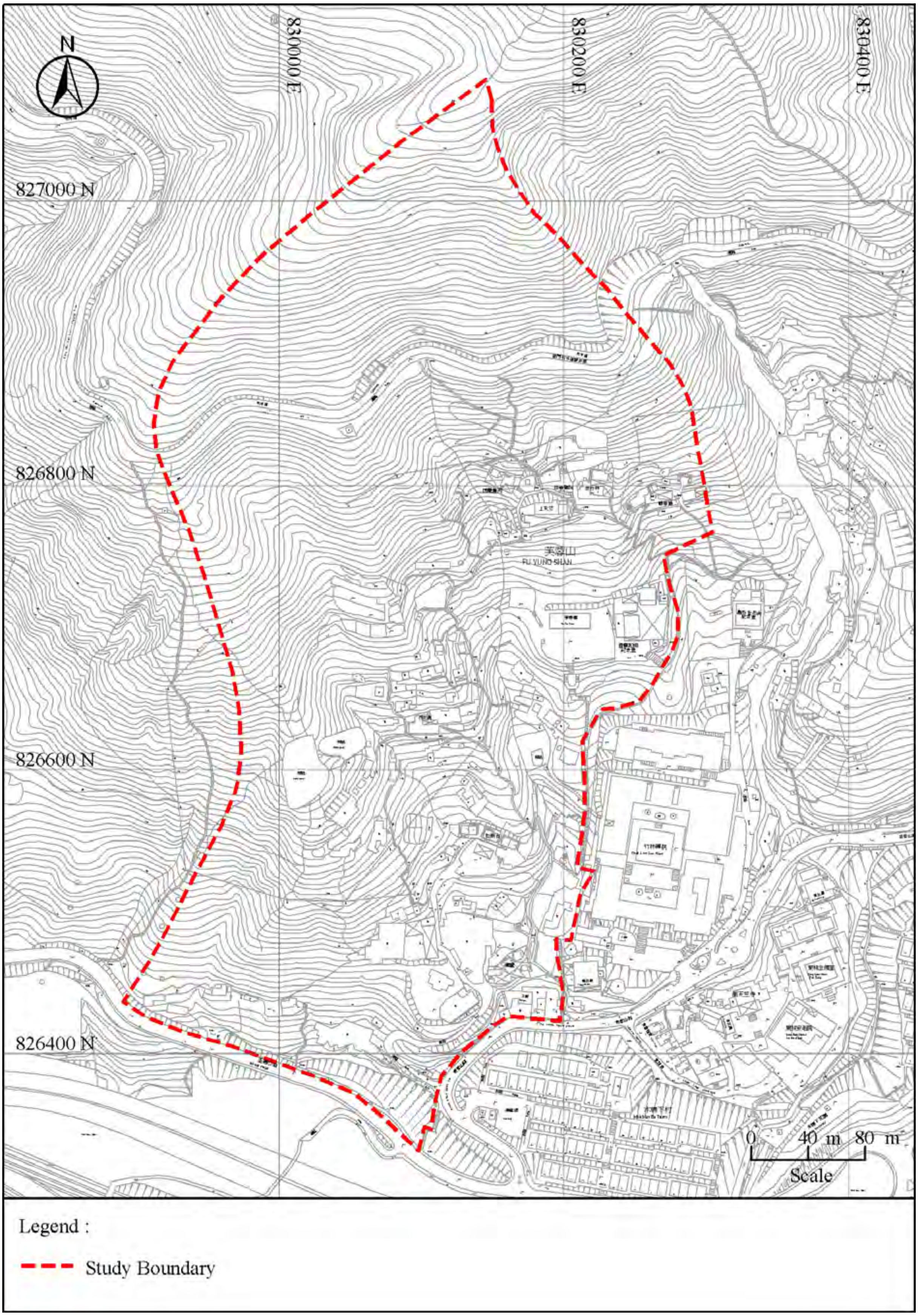

Figure 1 - Location Plan of Study Area

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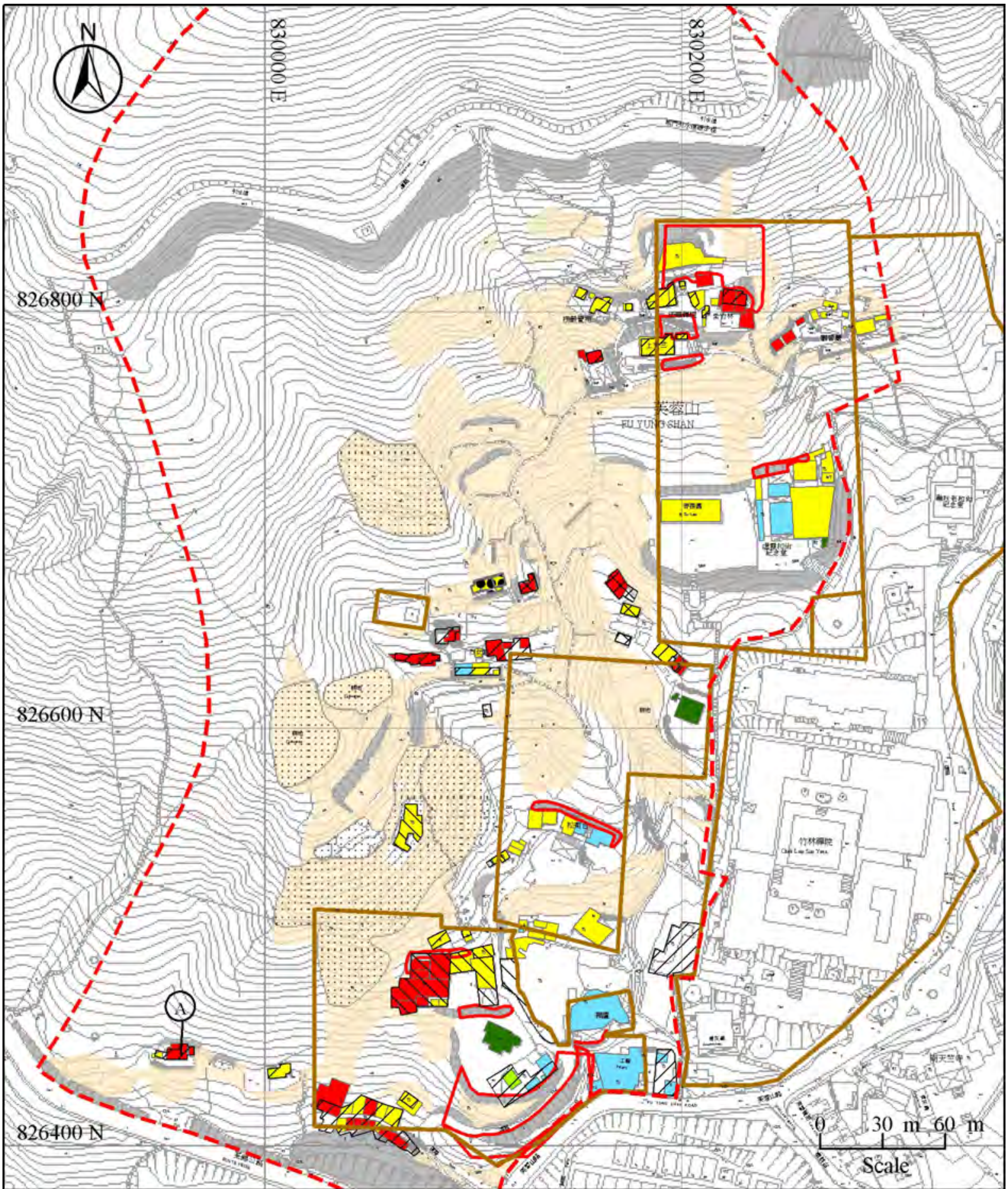

Legend :

- Study Boundary
- Man-made Slopes
- Disturbed Terrain
- Registered Disturbed Terrain
- Private Lot
- Cat 1 NDC Recommendation But Structure Not Yet Demolished
- Cat 2 NDC Recommendation Made Before August 2005 Rainstorm
- Cat 2 NDC Recommendation Made After August 2005 Rainstorm
- NDC Recommended by HD
- DH Orders

Individual Risk at Structures

- $< 10^{-6}$
- 10^{-6} to 10^{-5}
- 10^{-5} to 10^{-4}
- 10^{-4} to 10^{-3}
- 10^{-3} to 10^{-2}

Note: A landslide occurred in June 2006 on the man-made slope behind the structure (A), which has subsequently been upgraded from NDC Category 2 to NDC Category 1.

Figure 2 - Spatial Distribution of Personal Individual Risk

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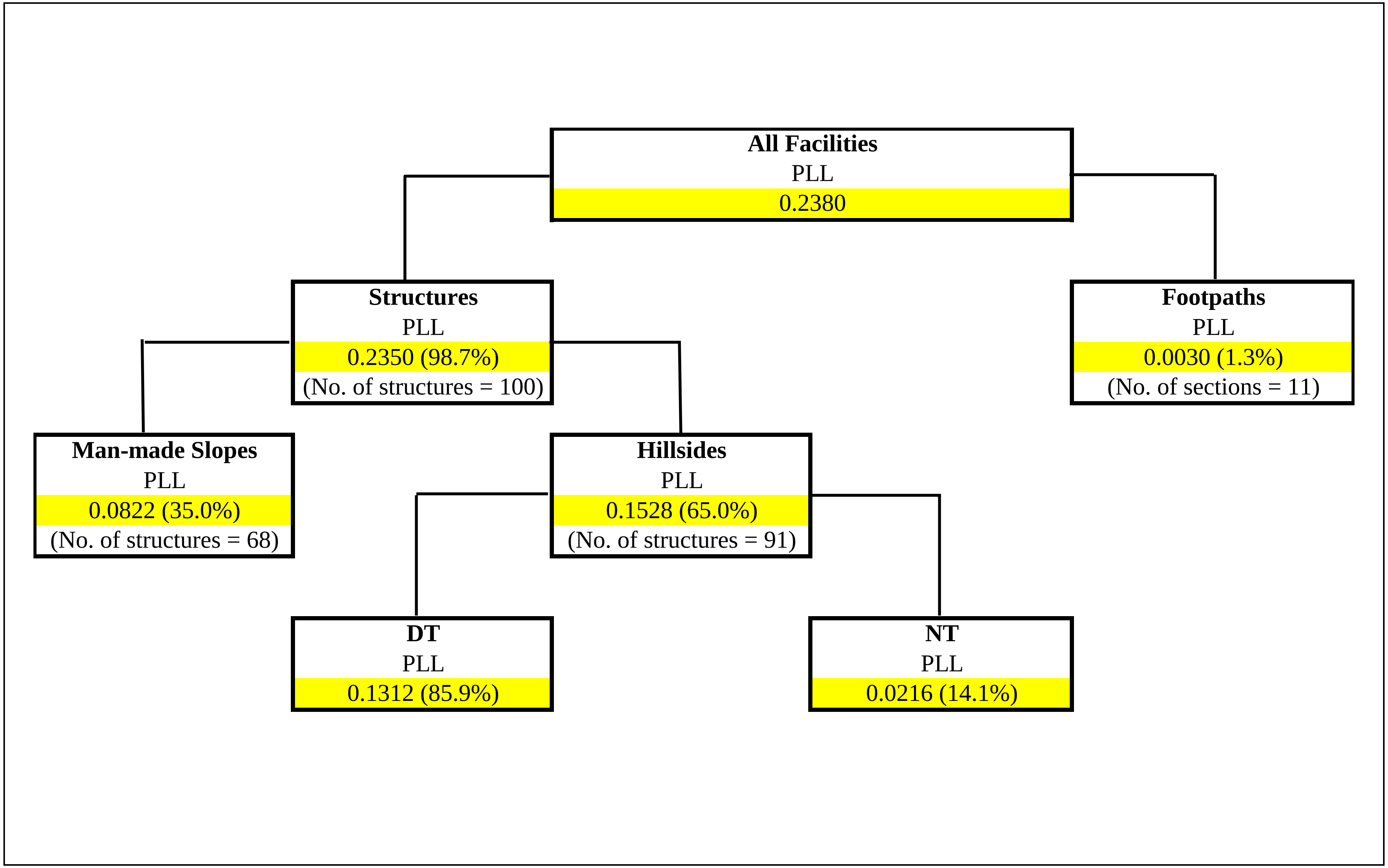

Figure 3 - Summary of PLL for Structures and Footpaths Affected by Man-made Slopes and Hillsides

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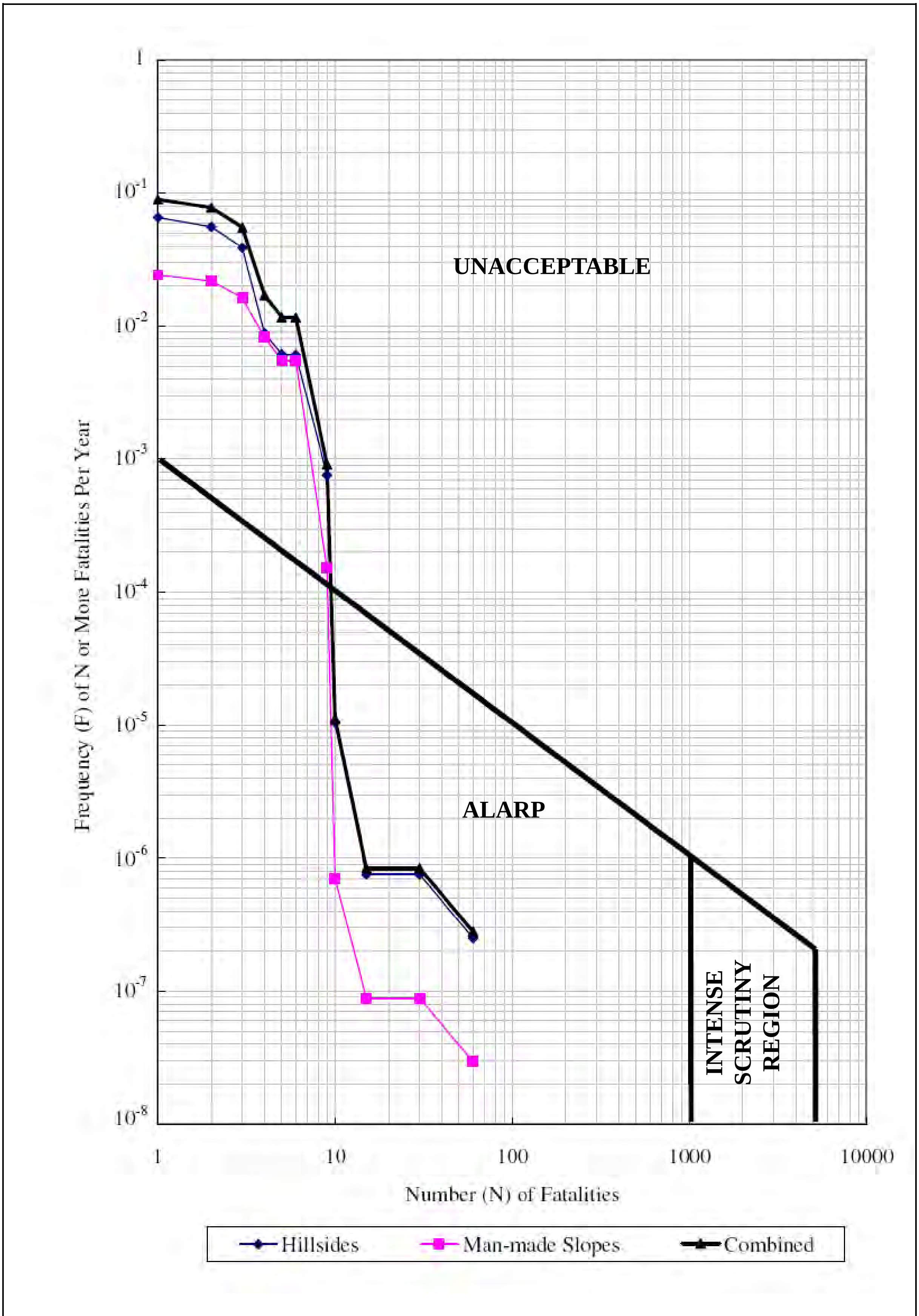

Figure 4 - F-N Curves

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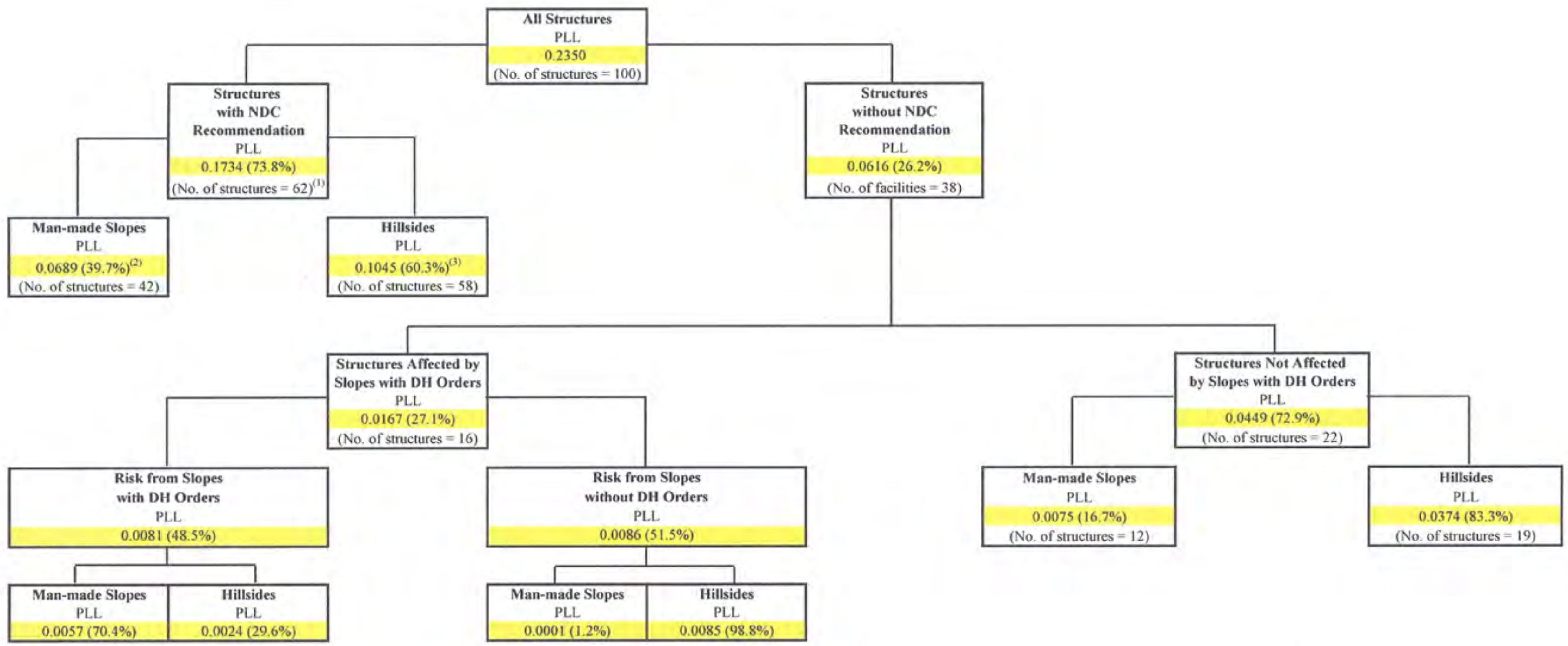

Notes: (1) Of the 62 structures with NDC recommendation, the recommendation was made on 49 structures before the August 2005 rainstorm.
(2) The percentage shown is with respect to the total PLL arising from man-made slopes.
(3) The percentage shown is with respect to the total PLL arising from hillsides.

Figure 5 - Summary of PLL for Structures with and without NDC Recommendation

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All Structures
PLL
0.2350
(No. of structures = 100)

Registered Squatter Structures
PLL
0.1861 (79.2%)
(No. of facilities = 77)

	Man-made Slopes	**Hillsides**	**All**
Structures on Government Land	0.0314 (16.9%)	0.0319 (17.1%)	0.0633 (34.0%)
Structures on Private Land	0.0434 (23.3%)	0.0794 (42.7%)	0.1228 (66.0%)
All	0.0748 (40.2%)	0.1113 (59.8%)	0.1861 (100%)

Others
PLL
0.0489 (20.8%)
(No. of facilities = 23)

	Man-made Slopes	**Hillsides**	**All**
Structures on Government Land	0.0001 (0.2%)	0.0210 (42.9%)	0.0211 (43.1%)
Structures on Private Land	0.0073 (14.9%)	0.0206 (42.0%)	0.0279 (56.9%)
All	0.0074 (15.1%)	0.0416 (84.9%)	0.0489 (100%)

Known Planned Development
PLL
0.0180 (36.8%)
(No. of facilities = 16)

Known Unauthorized Structures
PLL
0.0074 (15.1%)
(No. of facilities = 4)

Structures Status Not Clear
PLL
0.0235 (48.1%)
(No. of facilities = 3)

Figure 6 - Summary of PLL for Structures of Different Land/Squatter Registration Status

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Plate 1 - Overview of the Study Area

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(a) A Structure Affected by Man-made Slopes

(b) Clusters of Structures Affected by Man-made Slopes, and Natural and Disturbed Hillsides

Plate 2 - Illustrations of Structures Affected by Man-made Slopes, Natural and Disturbed Hillsides

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Plate 3 - An Illustration of Structures that were in Use at the Time of Study

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(a) Footpath Section No. 1

(b) Footpath Section No. 3

(c) Footpath Section No. 5

(d) Footpath Section No. 8

Plate 4 - Selected Examples of Footpath Sections

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Plate 5 - An Illustration of Structures that were Considered not Habitable

Plate 6 - An Illustration of Structures that were not in Use at the Time of Study but could be Occupied

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Plate 7 - An Illustration of Structures that are Used as Hostels

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Plate 9 - Area with Unauthorized Cutting and Filling

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Plate 11 - Area with Newly Built Fish Pond

Plate 12 - Area with Disposal of Rubbish on Sloping Ground

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APPENDIX A

REVIEW OF HISTORICAL LANDSLIDES

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CONTENTS

A1. INTRODUCTION

This Appendix describes the methodology adopted by the LIC for the compilation of historical landslide data in the study area for use in the QRA.

A2. METHODOLOGY

The compilation of the landslide data involved a review of historical landslides on man-made slopes, and disturbed and natural hillsides in the study area as identified from reported landslide incidents, Natural Terrain Landslide Inventory (NTLI)/ Enhanced NTLI (ENTLI) and aerial photograph interpretation.

A2.1 Reported Landslide Incidents

The reported landslide incidents within the study area were retrieved from the GEO landslide database, the annual rainfall and landslide reports between year 1982 and year 2003 and records of instability in desk study records. For every landslide incident, the following information was collated and compiled:

(a) Incident No.
(b) Type of feature involved, viz., man-made, disturbed and natural
(c) Slope No.
(d) Failure type
(e) Volume of failure
(f) Consequence

A2.2 NTLI and ENTLI

The NTLI was compiled by the GEO from the interpretation of high altitude aerial photographs (10,000 ft to 20,000 ft) taken from 1945 to 1994 (King, 1999). The locations of identified relict and recent landslides were recorded onto a 1:5000 scale plan and the year of occurrence, width, vegetation cover and slope angle across the landslide head recorded.

The compilation of the ENTLI database is currently undertaken by consultants managed by the Planning Division of the GEO. The ENTLI contains landslide information interpreted from low altitude aerial photographs taken from year 1945 to year 2004. The locations of identified relict and recent landslide are recorded onto a 1:2000 scale plan. The information available from the database at the time of this QRA study covered only the southeast portion of the study area (i.e. map sheet No. 7SW-C).

A2.3 Aerial Photograph Interpretation

A review of available low and high altitude aerial photographs taken from year 1924 to year 2004 was carried out to identify landslides, both recent and relict, that had previously occurred within the study area (Table A1). For every landslide, the following information was collated and compiled:

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(a) Landslide ID No.
(b) ENTLI class of slope
(c) Failure/ Instability type
(d) Estimated volume
(e) Solid geology
(f) Regolith type
(g) Morphology
(h) Geomorphological setting

A3. FINDINGS

A3.1 Landslides Identified from Existing Information

From the review of reported landslide incidents, a total of 32 landslide incidents within the study area have been reported to the GEO (Figure A1; Table A2). A total of 26 incidents have occurred on man-made slopes and one of them is a major landslide involving a failure volume of 80 m^3. Five incidents have occurred on disturbed terrain, one of which is the fatal landslide occurred in August 2005 and another is a major washout incident. The remaining one reported landslide incident was a minor landslide occurred on the natural hillside.

According to the NTLI database, no landslides were identified within the study area. The nearest NTLI landslide (Tag No. 6SED0065) has been recorded approximately 170 m west of the study area. It occurred in year 1973 and had a runout distance of about 44 m. Two ENTLI landslides (Tag Nos. 7SWC0035E and 7SWC0036E) were identified on the southern portion of the study area (Figure A1; Table A3).

A3.2 Landslides Identified from Aerial Photograph Interpretation

Based on API, there are in total eight relict landslides (No. R1 to R8) identified within the study area (Figure A1; Table A3). The two ENTLI landslides that have occurred on the southern portion of the study area coincide with the relict landslides No. R3 and R8. No recent landslides were observed in the period between year 1924 and year 2004 as occurring within and in the vicinity of the study area boundary.

The majority of the landslides have occurred near the head of ephemeral drainage lines, except landslides No. R1 and R2 which have occurred on the over-steepened east-facing flank of a spurline. The probable single landslide event (No. R1 to R4) involves an estimated source volume varying from 30 to 75 m^3, while the remaining are probable multiple landslide events (No. R5 to R7) or shows no evidence of instability (No. R8).

The solid geology of the source areas comprises approximately 50% of granodiorite and 50% of tuff. 75% of the landslides occurred on regolith type of relict colluvium/ non-corestone-bearing saprolite, while 25% of the landslides occurred on disturbed terrain or corestone bearing saprolite.

Based on ENTLI classes the reflect confidence of identification, the relict landslides have been classified into three classes with suggestions as to their relevance of inclusion into the QRA study: (a) Class A - 80 to 100% confidence; (b) Class B - 50 to 80% confidence and

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(c) Class C - 10 to 50% confidence. Five of the relict landslides were classified as Classes A and B and the remaining three were classified as Class C.

A4. REFERENCE

King, J.P. (1999). Natural Terrain Landslide Study - the Natural Terrain Landslide Inventory. GEO Report No. 74, Geotechnical Engineering Office, Hong Kong, 127 p.

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Table A1 - List of Aerial Photographs Reviewed (Sheet 1 of 5)

Date	Aerial Photograph No.	Flight Elevation (ft)
1924	Y120-21	11,100
10 Nov. 1945	Y689	20,000
17 Jun. 1949	Y2007	5,800
24 Apr. 1949	Y2055	5,800
18 Nov. 1954	Y2729-30	29,200
29 Jan. 1963	Y9036-38	3,900
26 Feb. 1963	Y9120-21	8,000
31 Dec. 1964	Y11149-51	1,800
22 Dec. 1964	Y11238-39	1,800
11 Dec. 1964	Y11276-77	2,700
31 Dec. 1964	Y11313-14	1,800
31 Dec. 1964	Y11322-23	2,300
11 Dec. 1964	Y11346-47	2,700
22 Dec. 1964	Y11383-84	1,800
13 Dec. 1964	Y12969	12,500
13 Dec. 1964	Y12971	12,500
14 Dec. 1964	Y12989-90	12,500
13 May. 1967	Y13483-85	3,900
1969	Y15380-82	4,000
1969	Y15402-04	3,000
1972	2279	13,000
1972	2281	13,000
20 Feb. 1973	3261-63	5,000
14 Jul. 1973	4504-05	1,700
20 Dec. 1973	7964	12,500
20 Nov. 1974	9578-79	12,500
19 Dec. 1975	11794-95	12,500
29 Jan. 1976	13270	4,000
29 Jan. 1976	13272	4,000
04 Oct. 1976	15463-64	4,000
04 Nov. 1976	15993	12,500
23 Nov. 1976	16520	12,500
23 Nov. 1976	16554	12,500
06 Dec. 1977	19734-35	4,000
12 Dec. 1977	20070-71	4,000
10 Jan. 1978	20705-06	12,500
10 Jan. 1978	20730-31	12,500
07 Dec. 1978	24061-62	4,000
01 Aug. 1979	26359	4,000
01 Aug. 1979	26426	4,000
10 Mar. 1979	27492	4,000
10 Mar. 1979	27494	4,000
28 Nov. 1979	28108	10,000
29 Nov. 1979	28169	10,000
13 Nov. 1980	32966-67	4,000

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Table A1 - List of Aerial Photographs Reviewed (Sheet 2 of 5)

Date	Aerial Photograph No.	Flight Elevation (ft)
13 Jan. 1981	35680	10,000
19 Jan. 1981	36310	4,000
19 Jan. 1981	36324	4,000
10 Feb. 1981	36577	5,500
26 Oct. 1981	39105-06	10,000
27 Oct. 1981	39184-85	10,000
27 Nov. 1981	40060	4,000
27 Nov. 1981	40077	4,000
28 Jul. 1982	43086-87	3,000
28 Jul. 1982	43123-26	3,000
20 Sep. 1982	43857-61	2,500
10 Oct. 1982	44593-95	10,000
24 Jan. 1983	47108-09	20,000
24 Jan. 1983	47112	20,000
24 Jan. 1983	47244	20,000
01 Dec. 1983	51541-42	20,000
01 Dec. 1983	51590-91	20,000
22 Dec. 1983	52149-50	10,000
22 Dec. 1983	52180	10,000
20 Oct. 1984	56514-15	4,000
20 Oct. 1984	56548-49	4,000
01 Oct. 1985	67209	10,000
02 Oct. 1985	67581-82	4,000
04 Oct. 1985	A2690-91	15,000
04 Oct. 1985	A2712-13	15,000
03 Mar. 1986	A4391-93	2,100
17 Sep. 1986	A5703	4,000
24 Sep. 1986	A6622	5,000
21 Dec. 1986	A8129	10,000
04 Oct. 1987	A10492-94	4,000
04 Oct. 1987	A10503-04	4,000
13 Jul. 1987	A9886-87	4,000
10 Oct. 1988	70322	4,000
10 Oct. 1988	70351-52	4,000
16 Jan. 1988	A12043	10,000
16 Jan. 1988	A12068-70	10,000
03 Jun. 1988	A13369	20,000
03 Jun. 1988	A13437-38	20,000
04 Jun. 1988	A13754	10,000
03 Nov. 1988	A15128	10,000
09 Sep. 1989	A18380	4,000
13 Nov. 1989	A19219	10,000
20 Nov. 1989	A19357	10,000
29 Nov. 1989	A19703	10,000
11 Dec. 1989	A20045-49	4,000
13 Nov. 1990	A23535	4,000

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Table A1 - List of Aerial Photographs Reviewed (Sheet 3 of 5)

Date	Aerial Photograph No.	Flight Elevation (ft)
04 Dec. 1990	A24504	20,000
04 Dec. 1990	A24606-07	20,000
01 Oct. 1991	A27540-43	4,000
01 Oct. 1991	A27555	4,000
29 Oct. 1991	A28809-10	10,000
16 Apr. 1992	A30482-83	5,000
13 May. 1992	A31165-67	4,000
13 May. 1992	A31185-88	4,000
14 Oct. 1992	A32345-46	8,000
14 Oct. 1992	A32370-71	8,000
20 Oct. 1992	A32637-38	4,000
20 Oct. 1992	A32652	4,000
11 Nov. 1992	A33255	10,000
11 Nov. 1992	A33304	10,000
17 Dec. 1992	A33627-28	20,000
09 Jan. 1992	CN2793	5,000
09 Jul. 1993	A35365	4,000
09 Jul. 1993	A35375	4,000
02 Nov. 1993	A35973-74	4,000
19 Aug. 1993	CN4256-57	10,000
04 Oct. 1993	CN4423-25	20,000
04 Oct. 1993	CN4518-19	20,000
01 Nov. 1993	CN4945	10,000
05 Dec. 1993	CN5409	10,000
06 Dec. 1993	CN5647-48	10,000
06 May. 1994	A38141	5,000
06 May. 1994	A38152	4,000
21 Oct. 1994	A39459	10,000
08 Nov. 1994	A39945	4,000
20 Mar. 1994	CN6181	10,000
25 Oct. 1994	CN8245	20,000
23 Nov. 1995	CN12320-21	10,000
24 Nov. 1995	CN12369-70	10,000
21 Dec. 1995	CN13228	20,000
12 Feb. 1995	CN9556	10,000
12 Jun. 1996	CN14206-07	4,000
12 Jun. 1996	CN14217-18	4,000
14 Nov. 1996	CN15764	4,000
14 Nov. 1996	CN15816-17	4,000
21 Nov. 1996	CN16171	10,000
21 Nov. 1996	CN16196-97	10,000
27 Dec. 1996	CN16402	10,000
29 Jan. 1997	CN16573-74	20,000
01 Nov. 1997	CN19031	10,000
25 Aug. 1998	A48357-58	4,000

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Table A1 - List of Aerial Photographs Reviewed (Sheet 4 of 5)

Date	Aerial Photograph No.	Flight Elevation (ft)
05 Mar. 1998	CN19464	4,000
11 Nov. 1998	CN21487	8,000
10 Nov. 1998	CN21882	8,000
03 Feb. 1999	CN22270	20,000
08 Feb. 1999	CN22681-82	4,000
03 Nov. 1999	CN24380	5,000
09 Dec. 1999	CN25102-03	8,000
09 Dec. 1999	CN25458-59	8,000
20 Jan. 2000	CN25783	4,000
16 Feb. 2000	CN26002-03	20,000
16 Feb. 2000	CN26064-65	20,000
14 Sep. 2000	CN28056-57	6,000
14 Sep. 2000	CN28065-66	5,500
14 Jan. 2001	CN29355-56	8,000
15 Feb. 2001	CN29822-23	8,000
15 Feb. 2001	CN29922	20,000
04 Jul. 2001	CS1064	8,000
04 Jul. 2001	CS1128-29	8,000
31 May. 2001	CW31301	4,000
18 Jun. 2001	CW31655	7,000
18 Jun. 2001	CW31688-89	7,000
13 Sep. 2001	CW32673-74	4,000
13 Sep. 2001	CW32753-55	4,000
25 Sep. 2001	CW34175-76	19,000
25 Sep. 2001	CW34205-06	19,000
20 Nov. 2001	CW35605-06	8,000
20 Nov. 2001	CW35672	8,000
21 Nov. 2001	CW36364-65	8,000
21 Nov. 2001	CW36405-06	8,000
27 Dec. 2001	RW460-61	4,000
18 Feb. 2002	CW38683-84	20,000
29 May. 2002	CW41958	4,000
15 Aug. 2002	CW42607-08	4,000
15 Aug. 2002	CW42645-47	4,000
09 Oct. 2002	CW44880	8,000
09 Oct. 2002	CW44932-33	8,000
09 Oct. 2002	CW44992-93	8,000
09 Oct. 2002	CW45027-28	8,000
25 Oct. 2002	RW1467-68	4,000
25 Oct. 2002	RW1544-45	4,000
21 Jan. 2002	RW823-24	16,000
21 Jan. 2002	RW846-48	16,000
11 May. 2003	CW47196-98	4,000
25 Nov. 2003	CW47259-60	4,000
25 Sep. 2003	CW49575	8,000

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Table A1 - List of Aerial Photographs Reviewed (Sheet 5 of 5)

Date	Aerial Photograph No.	Flight Elevation (ft)
25 Sep. 2003	CW49673-74	8,000
25 Sep. 2003	CW49880-81	8,000
25 Sep. 2003	CW49906-07	8,000
30 Oct. 2003	CW51461	4,000
30 Oct. 2003	CW51532	4,000
25 Nov. 2003	CW52801	4,000
26 Nov. 2003	CW53671-72	4,000
12 Dec. 2003	CW54455	20,000
12 Nov. 2003	RW3223-24	8,000
12 Nov. 2003	RW3279-80	8,000
29 Nov. 2003	RW3443	2,500
29 Nov. 2003	RW3446	2,500
25 Jan. 2004	CW54579-80	20,000
10 Feb. 2004	CW55411-12	8,000
10 Feb. 2004	CW55443-44	8,000
10 Feb. 2004	CW55478-79	8,000
20 Apr. 2004	CW57022-23	4,000
27 Sep. 2004	CW59194	4,000
05 Oct. 2004	CW60174-75	4,000
05 Oct. 2004	CW61026-27	8,000
05 Oct. 2004	CW61059-60	8,000
05 Oct. 2004	CW61116-17	8,000
10 Dec. 2004	CW62633-34	20,000
12 Feb. 2004	RW3681-82	16,000
12 Feb. 2004	RW3702-03	16,000
15 Feb. 2004	RW3862-63	17,000
15 Feb. 2004	RW3884-85	17,000
05 Dec. 2004	RW4007-08	16,000
05 Dec. 2004	RW4017-18	16,000

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Table A2 - Summary of Reported Landslide Incidents

Incident No	Type of feature Involved (Man-made/Natural/Disturbed)			Type of Feature	Slope Involved	Height (m)		Type of Failure	Volume (m³)	Consequence	Remarks
	GEO Incident Reports	Annual Rainfall and Landslide Report	Interpretation			Slope	Wall				
NT82/55	Man-made (inferred from section)	Man-made	Man-made	Soil cut slope	Inferred at 7SW-C/C572 (location in SIS appeared incorrect)	4	-	Landslide	Unknown (~40)	1 squatter dwelling permanently evacuated and 3 dwelling temp. evacuated	
NT82/238	Man-made (inferred from section)	Man-made	Man-made	Soil cut slope	Uncertain (location in SIS appeared incorrect)	-	-	Boulder threaten	Unknown (minor)	1 squatter dwelling permanently evacuated	
				Retaining wall	Uncertain (location in SIS appeared incorrect)	-	-	Wall Distress	Unknown (minor)	Part of the dwelling temporarily closed	
NT82/240	Man-made	Man-made	Man-made	Soil/Rock cut slope	7SW-C/C561	10	-	Landslide	Unknown (~40)	Catchwater blocked	
NT82/8/36	Disturbed terrain (inferred from text)	Flooding	**Disturbed terrain**	Retaining wall/Weir, streamcourse	-	-	-	Retaining wall failure, washout along streamcourse	Major (>50)	1person injured, 20 squatter dwellings permanently evacuated	Incident report mentioned a rubble wall at the boundary of a cultivation area failed
NT82/9/5	Man-made (in section)	Man-made	Man-made	Soil cut slope	7SW-C/R123 (uncertain)	-	4	Landslide	Unknown	2 squatter dwellings affected	
MW87/8/28	Man-made	Man-made	Man-made	Soil/Rock cut slope	7SW-C/C1331	3	-	Landslide	3	1 squatter dwelling temporarily evacuated	
MW87/8/29	Natural terrain	Natural terrain	**Disturbed terrain**	Hillside immediate below footpath	-	-	-	Landslide	3	Footpath affected	From the photo in the incident report, the landslide occurred just below a footpath and was located within disturbed area around squatter structures
MW88/7/1	Subsidence	Subsidence	Man-made	Fill slope	Not registerable fill slope	-	-	Subsidence	N/A	1 squatter dwelling permanently evacuated	
MW89/5/61A	Man-made	Man-made	Man-made	Soil/Rock cut slope	7SW-C/C1332	8	-	Landslide	2	1 lane of road blocked	
MW89/5/61B	Man-made	Man-made	Man-made	Soil/Rock cut slope	7SW-C/C1332	8	-	Landslide	1	1 lane of road blocked	
MW89/5/66	Man-made	Man-made	Man-made	Soil cut slope	Not registerable soil cut slope	-	-	Landslide	~0.5	1 squatter dwelling permanently evacuated	
MW92/5/63	Man-made	Man-made	**Disturbed terrain**	Soil cut slope	small cut slope currently within 7SW-C/DT11	11	-	Landslide, boulder fall	2	1 squatter dwelling affected	
MW92/5/69	Man-made	Man-made	Man-made	Soil cut slope	7SW-C/C607	2.3	-	Landslide	2.5	2 squatter dwellings permanently evacuated	
MW93/6/15	Man-made	Man-made	Man-made	Retaining wall	Not registerable masonry wall	-	-	Retaining wall failure	2	1 squatter dwelling temporarily evacuated, footpath closed	
MW93/6/16	Man-made	Man-made	Man-made	Soil cut slope	7SW-C/C364	14	-	Landslide	1-2	1 footpath closed	
MW93/6/17	Natural terrain	Natural terrain	**Disturbed terrain**	Hillside immediate below footpath	-	7	-	Landslide	45	1 footpath closed	From the photo and section in the incident report, fill was likely present below footpath at crest and domestic refuse in the debris was also observed. As such, the slope was intrepreted as DT.
MW93/9/6	Natural terrain	Natural terrain	**Natural hillside**	Natural Hillside	-	-	-	Landslide	1	2 squatter dwellings permanently evacuated	
MW94/7/33	Man-made	Natural terrain	Man-made	Soil/Rock cut slope	7SW-C/C1332	8	-	Landslide	10-20	1 road closed, 1 pedestrian pavement closed	From the photo in the incident report and present review on site, the landslide occurred on a man-made cut slope.
MW94/8/44	Man-made	Man-made	Man-made	Soil cut slope	3 m high soil cut slope	-	-	Landslide	2	1 squatter dwelling permanently evacuated	
MW97/5/9	Man-made	Man-made	Man-made	Soil cut slope	6SE-D/C48	7	-	Landslide	3	Road affected	
MW97/5/34	Man-made	Man-made	Man-made	Soil cut slope	7SW-C/C1319	6	-	Landslide	35-40	1 road closed	
MW97/7/102	Man-made	Man-made	Man-made	Retaining wall	7SW-C/R465	-	5.5	Landslide	10	2 squatter dwellings permanently evacuated	
MW97/7/103	Man-made	Man-made	Man-made	Fill slope	7SW-C/F487	5	-	Landslide	4	1 squatter dwellings permanently evacuated	
MW97/8/15	Man-made	Man-made	Man-made	Soil cut slope	6SE-D/C48	7	-	Landslide	10	1 road closed, 1 pedestrian pavement closed	
MW2001/06/045	Man-made	Natural terrain	Man-made	Soil cut slope	Registered as 7SW-C/DT106 after landslide	-	7	Landslide	2	1 footpath affected	The LI consultant (MGSL) suggested the landslide occurred on a man-made slope. For some reason, it was reported as natural terrain in the Annual report.
2002/06/038	Man-made	Man-made	Man-made	Soil cut slope	Registered as 7SW-C/R499 after landslide	-	-	Landslide	1	1 footpath affected	
2003/10/0198	Man-made	Man-made	Man-made	Soil cut slope	Registered as 7SW-C/C1426 after landslide	4.6	-	Landslide	0.5	1 footpath affected	
2005/06/0181	Man-made	-	Man-made	Soil/Rock cut slope and toe wall	7SW-C/CR564	5	2	Landslide	45	1 squatter dwelling permanently closed	
2005/07/0251	Man-made	-	Man-made	Fill slope/wall	4 m high fill slope/wall	6	-	Landslide	8	1 footpath affected	
2005/08/0362	Natural terrain	-	**Disturbed terrain**	Hillside with significant domestic refuse dumping	-	3.1	-	Landslide	400	1 person killed, 4 squatter structure temporary evacuated	It was interpreted as DT due to the presence of the domestic refuse dump.
2005/08/0481	Man-made	-	Man-made	Soil cut slope	7SW-C/C1319	6	-	Landslide	80	Access road blocked	
No Incident No.	Man-made	-	Man-made	Soil/Rock cut slope and toe wall	7SW-C/CR567	4	2.8	Unknown	2	unknown	Instability recorded in GEO slope files

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Table A3 - Summary of Natural Terrain Landslides Identified from ENTLI and Aerial Photograph Interpretation

ID No.	Slope Class#	Failure / Instability Type	Estimated Volume (m^3)	Solid Geology	Regolith	Morphology	Geomorphological Setting
R1	A	Probable single landslide event	30 - 50	Granodiorite	Relict colluvium / Non corestone bearing saprolite	Vegetated scar	Over-steepened east-facing flank of spurline
R2	A	Probable single landslide event	30 - 50	Granodiorite	Relict colluvium / Non corestone bearing saprolite	Vegetated scar	Over-steepened east-facing flank of spurline
R3*	B	Probable single landslide event	50	Granodiorite	Disturbed terrain / Relict colluvium / Non corestone bearing saprolite	Rounded depression	Head of minor ephemeral drainage line
R4	B	Probable single landslide event	75	Tuff	Relict colluvium / Non corestone bearing saprolite	Rounded depression	Head of major ephemeral drainage line
R5	B	Probable multiple landslide events	N/A	Tuff	Relict colluvium / Non corestone bearing saprolite	Degraded rounded depression	Head of minor ephemeral drainage line
R6	C	Probable multiple landslide events	N/A	Tuff	Corestone bearing saprolite	Degraded rounded depression	Head of major ephemeral drainage line
R7	C	Probable multiple landslide events	N/A	Tuff	Relict colluvium / Non corestone bearing saprolite	Degraded rounded depression	Head of major ephemeral drainage line
R8*	C	No evidence of instability	N/A	Granodiorite	Disturbed terrain	Generally open slope	Head of minor ephemeral drainage line

Notes:
(1) * denotes landslide identified in ENTLI with following ENTLI ID Nos.: R3 - 07SWC0035E and R8 - 07SWC0036E.
(2) # Class A = 80 - 100% confidence; Class B = 50 - 80% confidence; Class C = 10 - 50% confidence.

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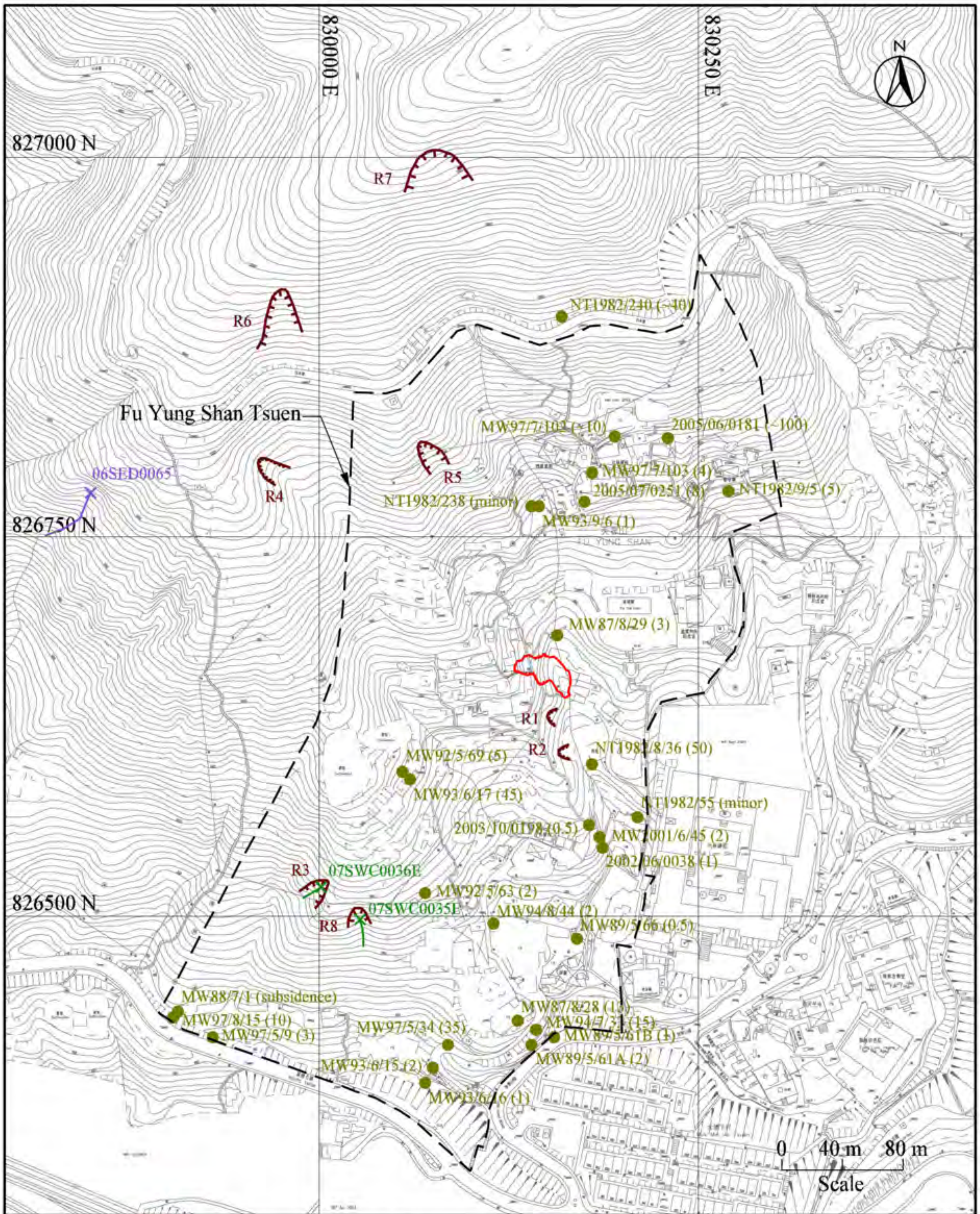

Legend :

	The August 2005 landslide	06SED0065	NTLI landslide with reference No.
R8	Relict landslide identified from API	07SWC0035E	ENTLI landslide with reference No.
MW92/5/63 (2)	Landslide incident No. MW92/5/63 with a failure volume of 2 m^3		

Note : Base plan is extracted from 1 : 1000 survey sheets No. 6SE-15D, 6SE20B, 7SW-11C and 7SW-16A dated March 2004.

Figure A1 - Historical Landslides within and in the vicinity of Fu Yung Shan Tsuen

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APPENDIX B

ENGINEERING GEOLOGICAL MAPPING

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B1. INTRODUCTION

This Appendix describes the engineering geological mapping of the study area carried out by the LIC to identify landslide susceptibility attributes for the QRA.

B2. METHODOLOGY AND FINDINGS

The engineering geological mapping was undertaken in March 2006. It was primarily based on aerial photograph interpretation (API) and field mapping in relation to the landslide inventory and instability history as described in Appendix A.

The study area has a plan area of about 18 hectares. Geological and geomorphological features that were considered to be susceptible to landslides were identified and mapped at a scale of 1:2000. In certain areas, the scale of the mapping was zoomed to 1:500 to incorporate additional important details.

B2.1 Delineation of Natural and Disturbed Hillsides

The terrain within the study area is complex in terms of delineation of natural and disturbed hillsides. It was observed that, for example, much of the apparently ‘natural’ terrain had some old footpaths or small steps of degraded terraces. As such, expert judgment was applied to delineate areas of terrain as predominantly natural or disturbed based on API and field mapping (Figure B1). Disturbed terrain is usually characterized by previous anthropogenic activities, in particular terracing on the hillsides, recognized from either API or field mapping or both.

B2.2 Mapping of Geological Features

Based on API and the historical landslide records, it was found that different types of regolith units of the natural hillside have different susceptibility to landslides. Regolith of the natural hillside was thus included as one of the susceptibility attributes for the QRA study. There are four main regolith units on the natural hillside affecting mapped structures (see Appendix C for the location of mapped structures), which were mapped in Figure B1:

(a) Predominantly corestone-bearing saprolite: This material was located mainly in the upper part of the study area and along ridgelines. It is the source of much of the bouldery colluvial deposits along the adjacent drainage lines.

(b) Recent colluvium: This material is typically located within the drainage lines and comprises small amounts (< 15%) of slightly decomposed sub-angular boulders within a fine soil matrix.

(c) Recent bouldery colluvium: This material is also typically located within the drainage lines and comprises variable

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amounts (15% - 50%) of slightly decomposed sub-angular boulders within a fine soil matrix.

(d) Relict Colluvium/ Non-corestone bearing saprolite: This material forms the remaining area and is distinguished by the absence of boulders, and its relatively smooth and even morphology. It was not possible to differentiate between the two classes of materials because of their similar morphology and it is considered that older colluvium and saprolite have similar properties.

B2.3 Mapping of Geomorphological Features

The stereo pairs of aerial photographs from year 1963 and year 1964 (Nos. Y9036-37 and Y11149-50) were used to establish major geomorphological features that were considered as key contributory factors of landslide activities on the natural and disturbed hillsides affecting mapped structures (see Appendix C for the location of mapped structures). In addition, field mapping was conducted at certain areas to confirm features identified from the API and to add on any fine details that were difficult to identify from aerial photographs.

In the previous development work on natural terrain landslide hazards in Hong Kong where large historical landslide databases have been compiled (MFJV, 2004), it was found that certain geomorphological characteristics are commonly susceptible to landslide initiation, notwithstanding the diverse nature of natural hillsides in Hong Kong. When these were applied to the study area, the most relevant features are steep terrain topology and head of drainage lines. In addition, site-specific geomorphological features that appeared to be favourable to landslide initiation on the natural hillside were compiled based on the site-specific landslide data using API and field mapping, if necessary. It was found that the over-steepened east-facing flanks of the natural stream courses on which several landslides had occurred and the incised gullies are the key site-specific susceptibility attributes for landslide activities on the natural hillside. Their spatial distributions are shown in Figures B2 and B3.

Similar work was carried out to identify site-specific terrain features that were considered contributory to landslide activities on the disturbed hillside within the study area. It was found that steep terrain topology and unfavourable terrain surface conditions are the key site-specific susceptibility attributes for landslide activities on the disturbed hillside. Their spatial distribution are shown in Figure B5.

B3. REFERENCE

Maunsell-Fugro Joint Venture (2004). Natural Terrain Hazard Study for Tsing Shan Foothill Area. Report to Geotechnical Engineering Office, Hong Kong, 145 p.

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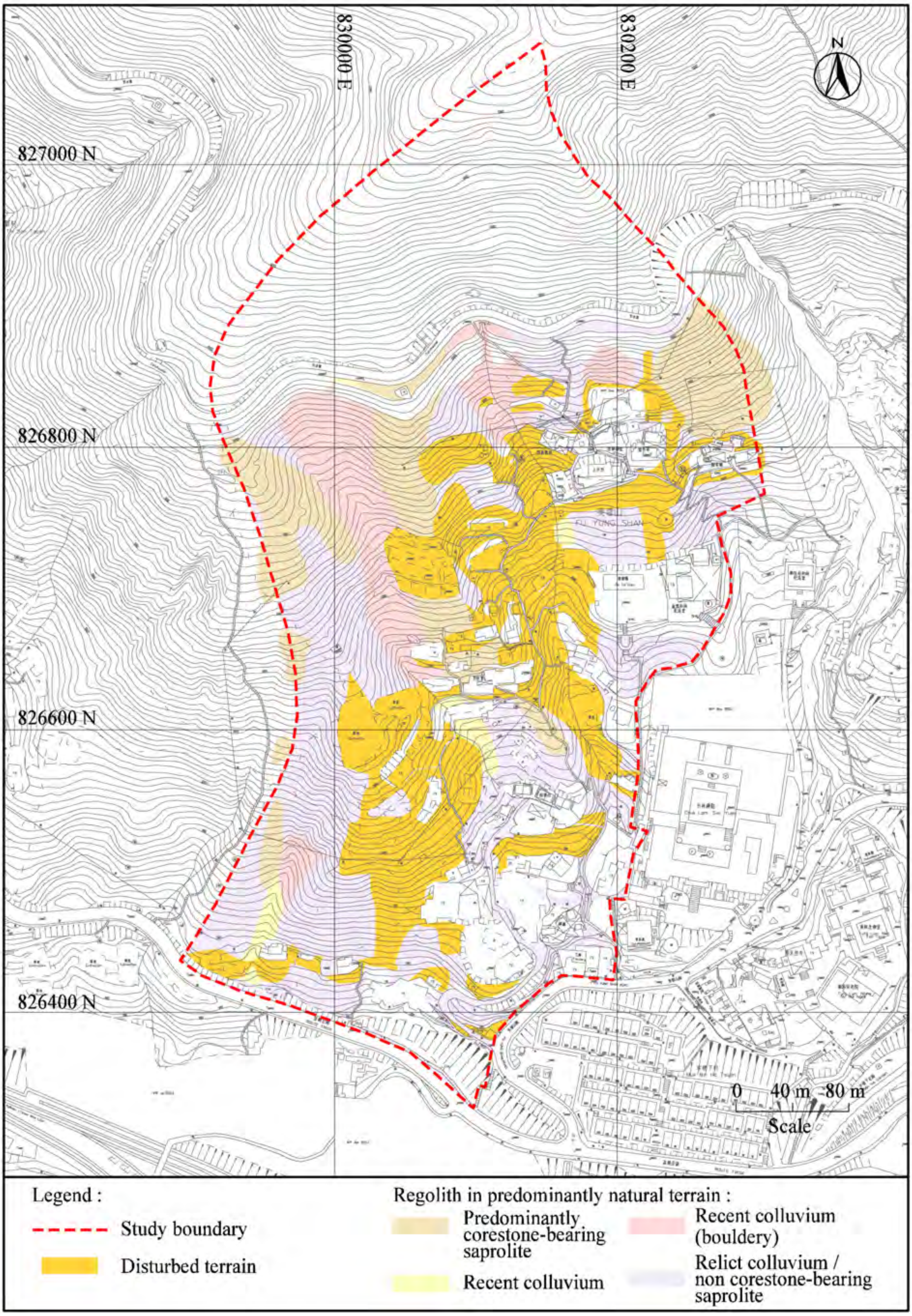

Figure B1 - Identified Regolith Units

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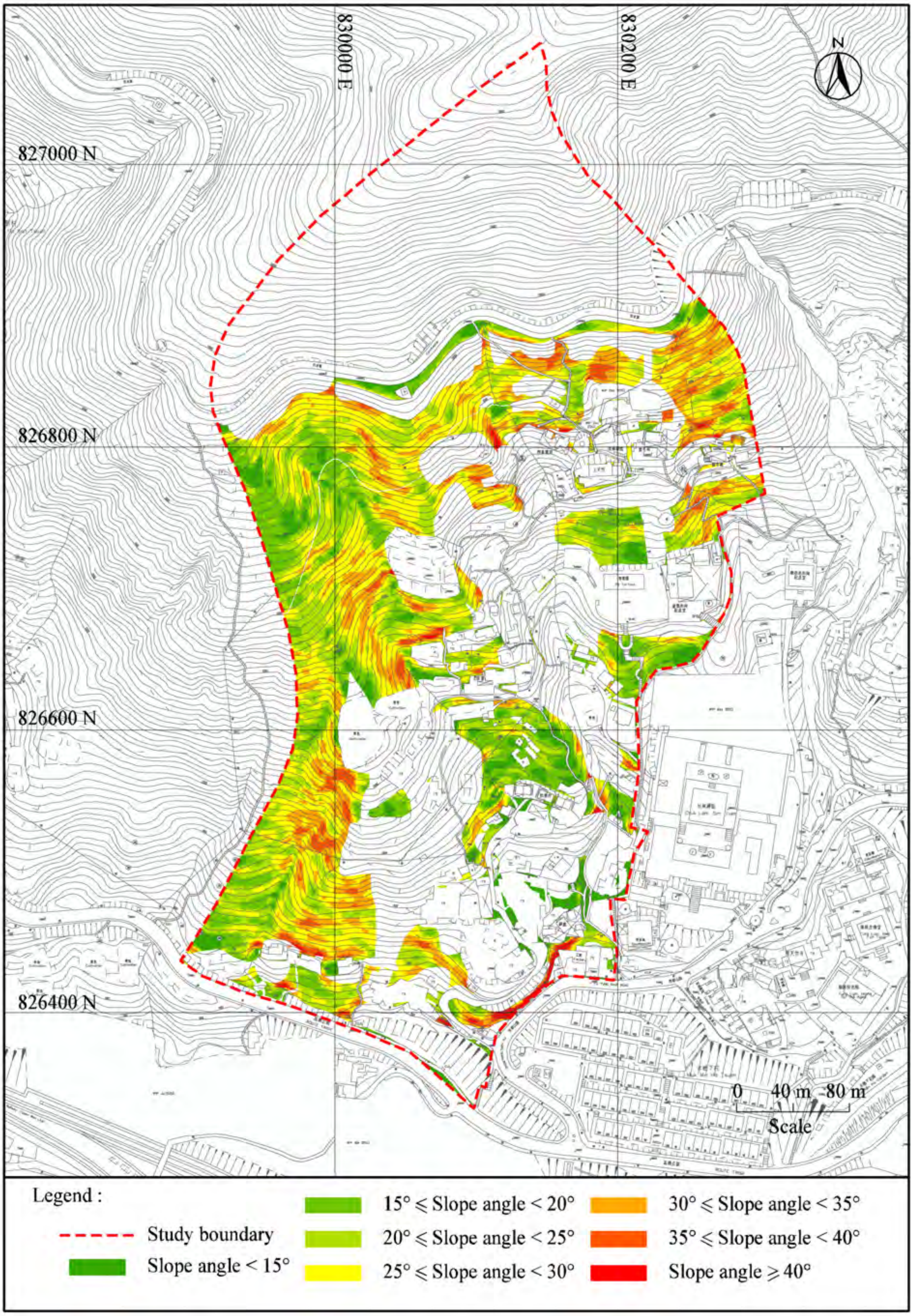

Figure B2 - Spatial Distribution of Different Classes of Terrain Topology on Natural Hillside

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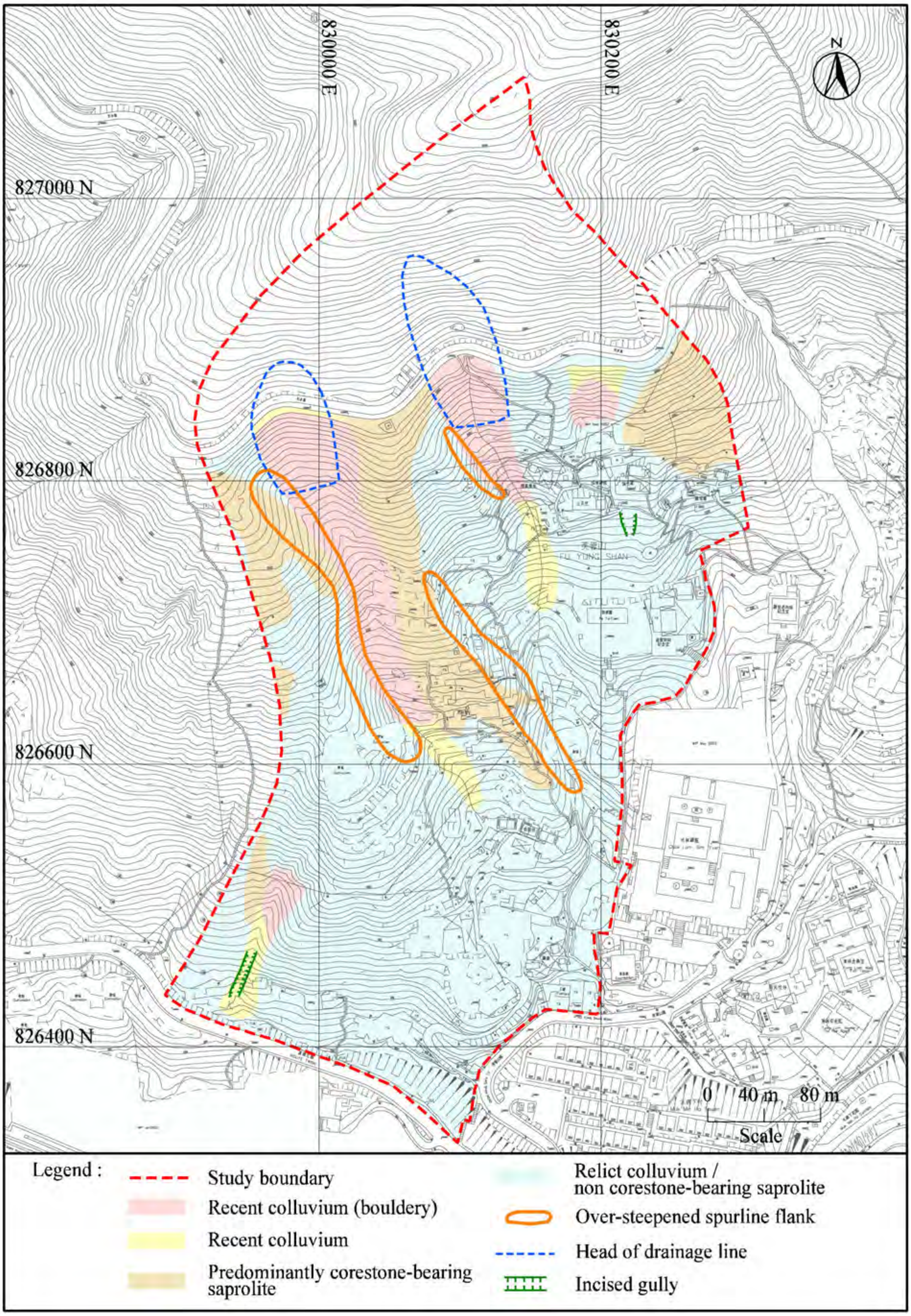

Figure B3 - Spatial Distribution of Other Key Susceptibility Attributes on Natural Hillside

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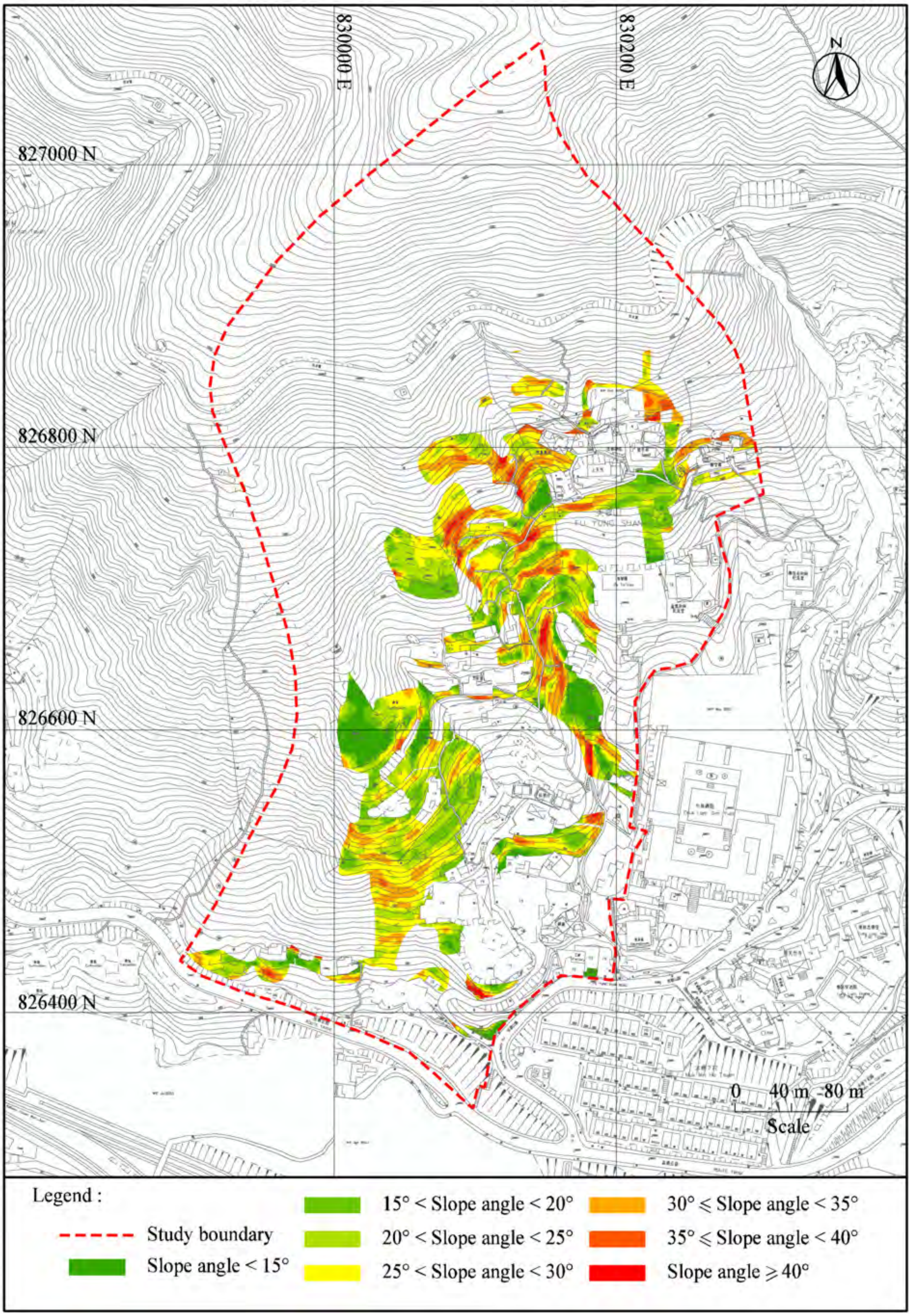

Figure B4 - Spatial Distribution of Different Classes of Terrain Topology on Disturbed Hillside

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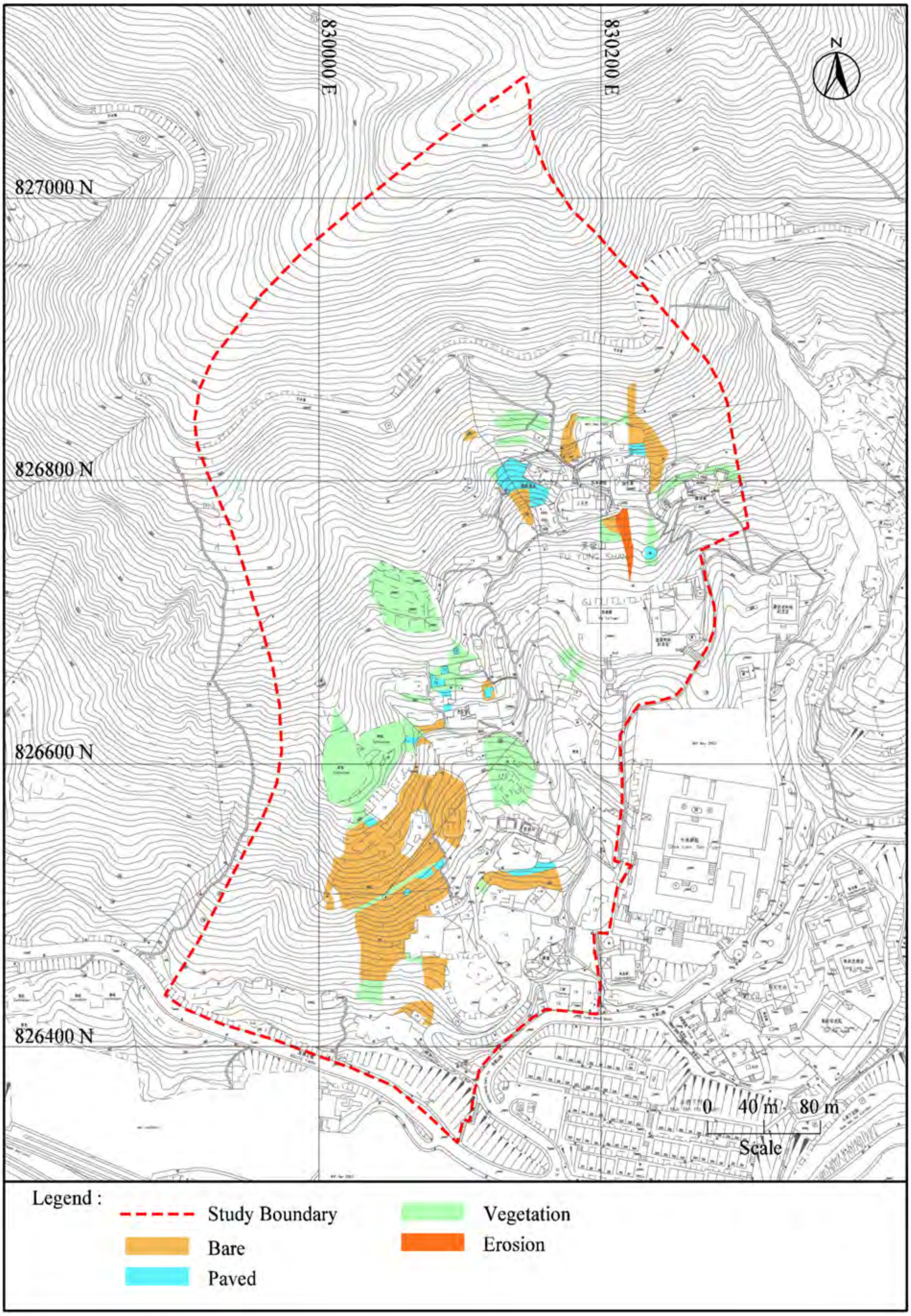

Figure B5 - Spatial Distribution of Different Surface Conditions on Disturbed Hillside (Sheet 1 of 3)

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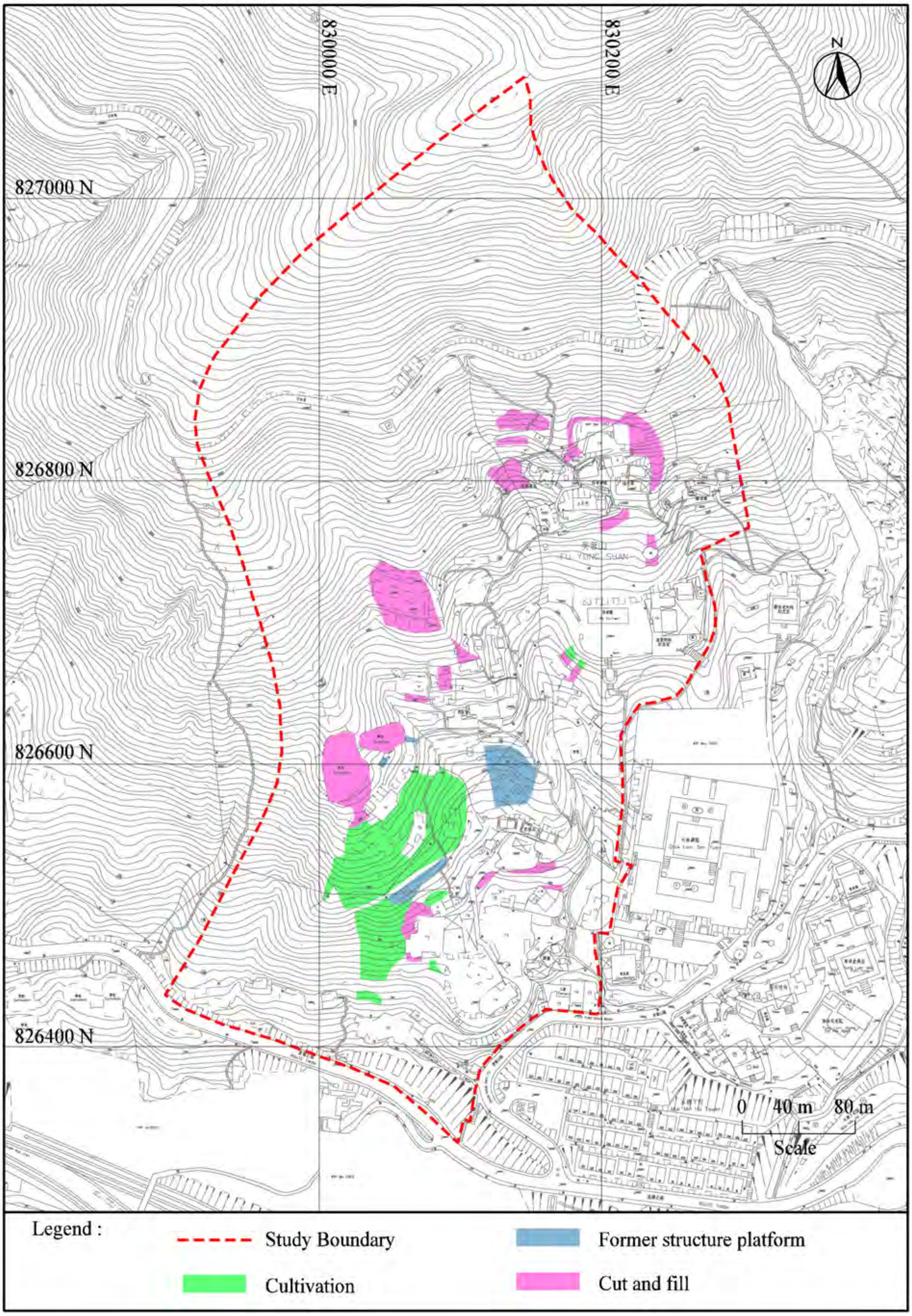

Figure B5 - Spatial Distribution of Different Surface Conditions on Disturbed Hillside (Sheet 2 of 3)

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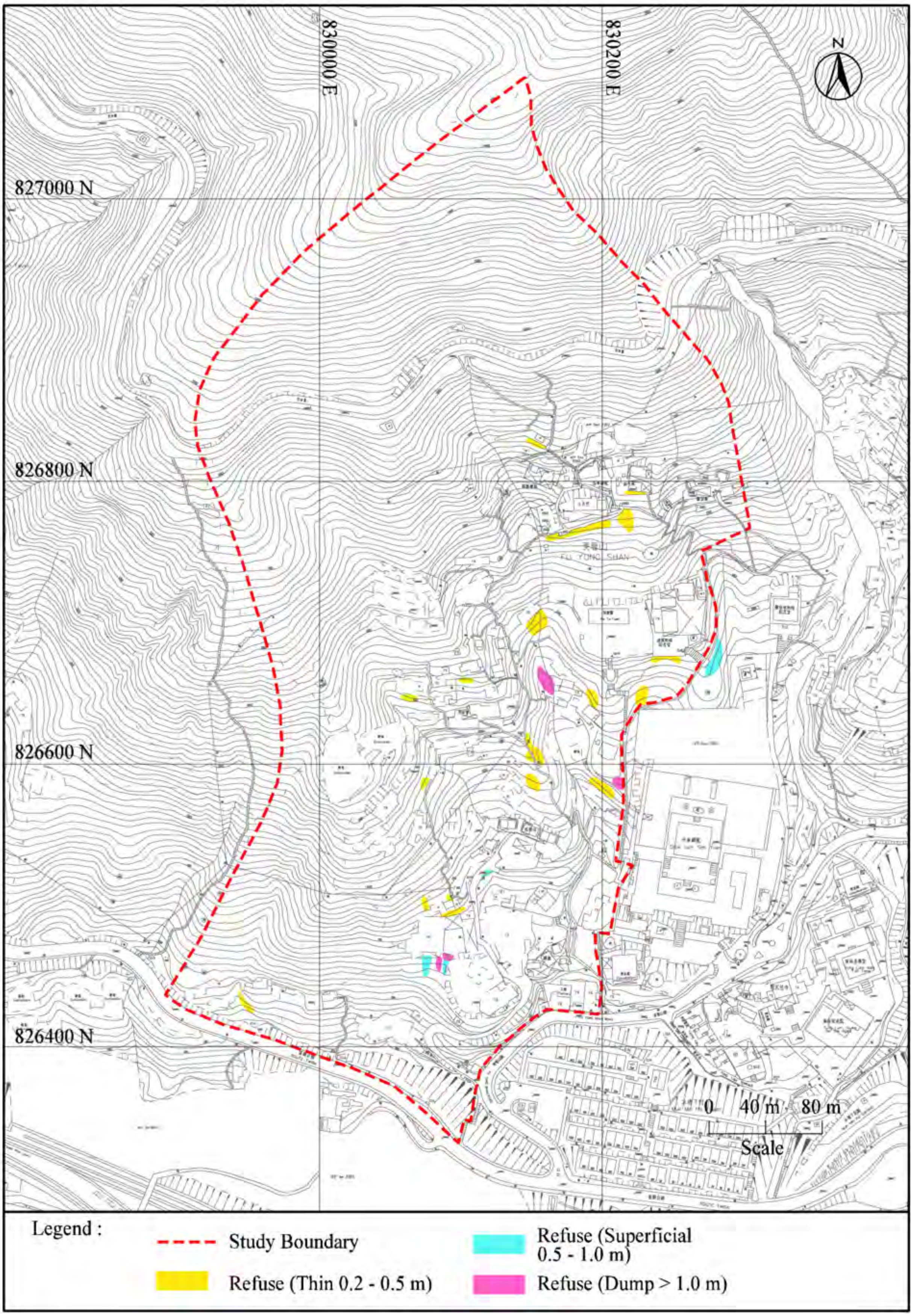

Figure B5 - Spatial Distribution of Different Surface Conditions on Disturbed Hillside (Sheet 3 of 3)

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APPENDIX C

MAPPING OF FACILITIES AND POPULATION AT RISK

CONTENTS

C1. INTRODUCTION

This Appendix describes the methodology adopted by the LIC in, and the findings of, the mapping exercise for facilities subject to potential landslide risk in Fu Yung Shan Tsuen.

C2. METHODOLOGY

The mapping exercise was carried out in early 2006 by the LIC. It comprised field survey and mapping of facilities. Existing structures that were in use at the time of the study or were not in use at the time of the study but could be occupied, irrespective of their land and squatter registration status, were included in the mapping exercise. Structures that have already been demolished, or were in such a poor condition that was considered not habitable were excluded. The scope of the mapping exercise also encompassed the existing footpath network, which is the sole access to the structures.

C2.1 Field Surveys

For structures, the field surveys collated information via field inspection and/ or personal interviews with the local community on, inter alia:

(a) type of structures, viz., flimsy and substantial;

(b) type of usages, viz., typical squatter dwellings, large religious facilities/ small religious facilities, quarters and factories; and

(c) degree of usage, i.e. number of population at risk and its temporal distribution.

A field survey form has been developed to facilitate data collation in the field (Figure C1). Parts 1 and 2 contain general information of a given structure. Information collected in Part 3 was used to determine its structural type. Part 4 recorded the type of usages and Part 5 contained information from personal interviews on the number of population at risk and its temporal distribution. A recent image of the structure was annexed to the field survey form (Figure C1) and its layout or layouts for its individual living units were recorded on a plan (Figure C1).

For the footpath network, eleven critical sections, each of about 10 m long, were first identified (Figure C2). They were selected for their sensitive locations with respect to potential landslide risk arising from man-made slopes and hillsides. Field surveys of the number of population at risk were conducted on five individual days. One of the field surveys were deliberately set on the 1st of March in the Chinese calendar, which were believed to be one of the most popular days for worship in the month, to measure the probable maximum usage of the footpath network. Normal usage of the footpath network was measured via the other field surveys. Two were scheduled during the peak hours of the weekdays and the other two during the day-time of two Sundays. In each field survey, hourly head counts for pedestrians moving uphill and downhill using the survey form in Figure C3 were conducted at nine stations (Figure C4) leading to the eleven critical sections.

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C2.2 Field Mapping

The layouts of the structures were approximately mapped in the field and were later reproduced in plans (see Figure C1). The layout of a given structure might include layouts for its individual living units such as kitchen and toilet, and some restricted religious facilities, if there is any. The field mapping was carried out by simple measurement on site using mainly tapes. The outcomes serve as an up-to-date reference to the information given in the 1:1000-scale topographic base map.

C3. FINDINGS

A total of 100 nos. of existing structures were mapped (Figure C5). The breakdown according to their structural types and type of usages are tabulated in Table C1. Their spatial distributions are shown in Figures C6 and C7 respectively.

Information on the number of population and its temporal distribution could not been collected for each of the mapped structures. There were no responses from some of the structures during the course of the field surveys and therefore personal interviews could not be conducted. In addition, nearby residents could not provide a reliable account on the information required. It was noted that these structures were mainly used for residential purpose. Because of the incompleteness of the information, the number of population and its temporal distribution of the structures were taken to be the same as that of typical squatter dwellings in Hong Kong (Table C2). The figures might be slightly on the conservative side given the general condition of the Fu Yung Shan Tsuen. For structures used for other purposes, i.e. large religious facilities/ small religious facilities, quarters and factories, their number of population and temporal distribution were successfully surveyed based on field observation and personal interviews with either the owners or the nearby residents. Their respective population events and temporal distributions are tabulated in Table C2.

The results of the head count surveys for the eleven critical sections of the footpath network is shown in Table C3. It is also considered appropriate to include here the spatial distribution of the structures according to their squatter registration status as shown in Figure C8 (see Section 3(d)).

C4. DISCUSSION

In this study, the structures were mapped and classified for risk assessment based on the application of the QRA models. Such classification may not be the same as that adopted by the GEO and other government departments in administering squatter matters. Some notable issues are highlighted below:

(a) Living units of a squatter dwelling were not mapped individually. They were grouped together as one structure for risk assessment in the QRA. Should the living units have different properties, classification of the structure followed that of the main living unit.

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(b) A cluster of structures, which might be recorded as one large squatter dwelling by the GEO and other government departments, might have been delineated into individual squatter structures for risk assessment in the QRA.

(c) Some religious-related structures, which have also been used for residential purpose, were classified as typical squatter dwelling.

Given the above, the Squatter Section of the GEO should be consulted on any squatter matters concerning the classification of the structures in relation to the NDC Programmes, such as their usage, type and squatter registration status.

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Table C1 - Summary of Structural and Usage Types for Structures Affected by Man-made Slopes and Hillsides

(a) Structural Types

Structural Type	Number of Structures
Substantial	50
Flimsy	50
All	100

(b) Usage Types

<table>
<tr><th colspan="2">Usage Types</th><th>Number of Structures</th></tr>
<tr><td rowspan="3">Typical squatter Dwelling</td><td>1-storey</td><td>62</td></tr>
<tr><td>2-storey</td><td>17</td></tr>
<tr><td>3-storey</td><td>5</td></tr>
<tr><td colspan="2">Quarter</td><td>5</td></tr>
<tr><td colspan="2">Small Religious Facility</td><td>3</td></tr>
<tr><td colspan="2">Large Religious Facility</td><td>3</td></tr>
<tr><td colspan="2">Factory/ Workshop</td><td>5</td></tr>
<tr><td colspan="2">All</td><td>100</td></tr>
</table>

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Table C2 - Temporal Distribution of Population at Different Types of Structures

Typical Squatter Dwelling		Quarter		Others					
				Small Religious Facility		Large Religious Facility		Factory/ Workshop	
Time	People[1]	Time	People	Time	People	Time	People	Time	People
50%	3	1%	10	0.2%	10	0.2%	60	2%	5
25%	2	2%	5	0.4%	5	0.4%	30	7%	4
15%	1	3%	2	2.2%	2	3.0%	6	15%	2
10%	0	4%	1	11.6%	1	6.0%	3	12%	1
		90%	0	85.6%	0	90.4%	0	64%	0
Total									
100%	-	100	-	100%	-	100%	-	100%	-
Average Number of Person in a Structure									
2.15		0.3		0.2		0.6		0.8	

Note: (1) The numbers in this column represent the respective number of population for one-storey structures at different time proportion of a day. At a given duration, two- and three-storey structures have number of population two times and three times of that for one-storey structures respectively.

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Table C3 - Result of Head Count Survey

Critical Footpath Section	1st of March		Sunday (02/04/06 or 09/04/06)		Tuesday/Thursday		Maximum of Average Head Count per Hour	Estimated Head Count per Day(4)
	Total Head Count in 12 hours	Average Head Count per Hour	Total Head Count in 12 Hours	Average Head Count per Hour	Total Head Count in 4 Hours	Average Head Count per Hour		
1	64	5	644 (2)	53*	39	10	53	700
2	63	5	626 (2)	52*	36	9	52	690
3	63	5	626 (2)	52*	36	9	52	690
4	75	6	212	18*	37	9	18	240
5	157	13	195 (3)	15*	47	12	15	200
6	9	1	25	2	20	5*	5	70
7	41	3*	27	2	9	2	3	40
8	32	3	33	3	20	5*	5	70
9	9	1	25	2	20	5*	5	70
10	41	3*	27	2	9	2	3	40
11	120	10	85	7	59	15*	15	200

Notes:
(1) All head counts include pedestrian in both directions (uphill and downhill).
(2) Estimated value based on the head count stations 3 and 4.
(3) Estimated value based on the head count stations 6 and 9.
(4) Estimated head count/day
= maximum average head count/hour (taken during day time) × 12 × 1.1 (round off to the nearest ten)
(5) * - maximum of the average head count per hour.

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Agreement No. CE 15/2004 (GE)
Study of Landslides Occurring in Kowloon and the New Territories in 2005 - Feasibility Study
QRA of Landslide Hazards at Fu Yung Shan Tsuen
Site Reconnaissance of Structures and Other Facilities

Inspection Team Members: **Inspection Date:**

1. General

Facility Type: (Abbreviation in bracket)
☐ Hut/Cottage (SS) * ☐ Village House (VH) * ☐ Building (BG) *
☐ Shelter (SH) ☐ Footpath (FP) ☐ Sitting Out Area (SO)
☐ Open Space (OS) ☐ Former Structure Platform (FS) ☐ Others (OR): ________

* defined as 'Structure' including registered squatter dwelling and other building structure.

Zone No.: __________ Cluster No.: __________ Land Status: ______________ (private/government)

Facility Ref. No.: ______________________

Address: ____ (applicable only to Hut / Cottage / Village House / Building)

Squatter Status: ______________________ Squatter Control Survey No.: ______________________

2. Accessibility

☐ Accessible ☐ Others: ____________________
☐ Accessible with difficulties, blocked by *vegetation / refuse / others*: ____________________

3. Form of Construction

Material of Hut / Cottage / Village House / Building / Shelter:
☐ Wood ☐ Brick ☐ Concrete ☐ Corrugated Metal
☐ Stone ☐ Container ☐ Others: ________________

Strength of Hut / Cottage / Village House / Building / Shelter:
☐ Flimsy ☐ Solid ☐ Massive

No. of Storey: ____________ Remarks: ______________________________

Paving of Footpath / Sitting Out Area / Open Space Surface:
☐ Concrete ☐ Bare ☐ Others: ____________________

Furniture of Footpath / Sitting Out Area / Open Space Surface:
☐ Chair ☐ Lighting ☐ Recreation ☐ Others: ____________________

Open Space / Former Structure Platform : ☐ Cut ☐ Fill ☐ Front Wall (e.g. masonry) ☐ Elevated

Remarks: ______________________________

Form of Construction for Others: ______________________________

Remarks: ______________________________

4. Usage

Hut / Cottage / Village House / Building :
☐ Occupied (residential, storage, etc.) ☐ Signs of occupation (residential, storage, etc.)
☐ Unoccupied (no sign of occupation) ☐ Ruined (not suitable for occupation unless with substantiation renovation)

Field Observations: ______________________________

Percentage Coverage:	Residential	Storage	Religion	Commercial	Industrial	Factory	Others	Total
								100%

Shelter / Former Structure Platform / Others:
Current Usage (if no usage, go to item 5): ______________________________

Shelter / Footpath / Sitting Out Area / Open Space / Former Structure Platform / Others:
☐ Frequently Used ☐ Moderately Used ☐ Lightly Used ☐ Disused

Condition for Use: ☐ Good ☐ Fair ☐ Poor

5. Population/Degree of Usage

☐ Interviewed ☐ Estimation No. of resident/No. of people working: _______/_______

Details: ______________________________

(To provide information on population and degree of usage - e.g. no. of seat and frequency of events in a religious facility)

Reviewed By: **Date:**

Figure C1 - Sample of Field Inspection Proforma (Sheet 1 of 3)

View 3: Facility No.: B-22-SS-1

Figure C1 - Sample of Field Inspection Proforma (Sheet 2 of 3)

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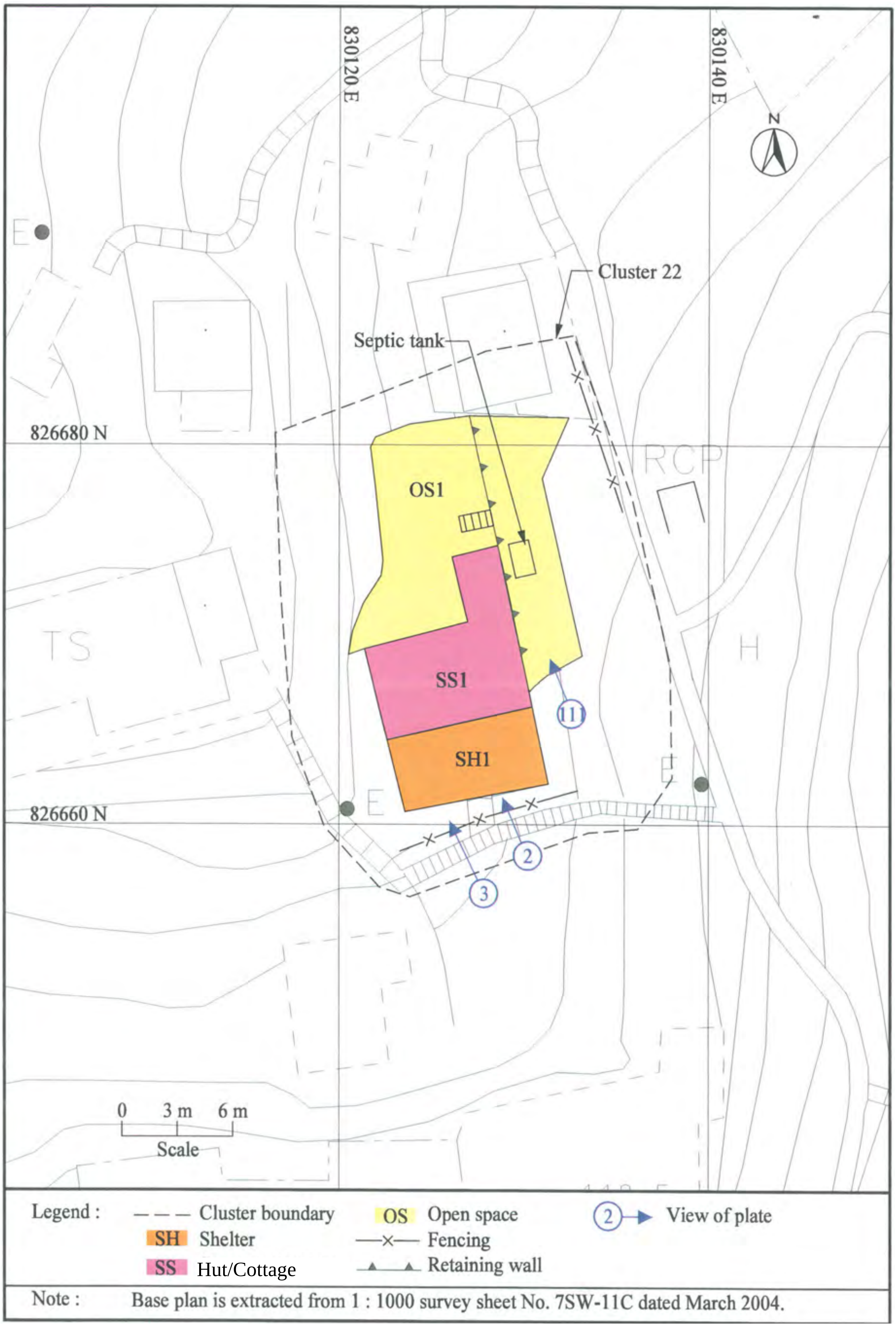

Figure C1 - Sample of Field Inspection Proforma (Sheet 3 of 3)

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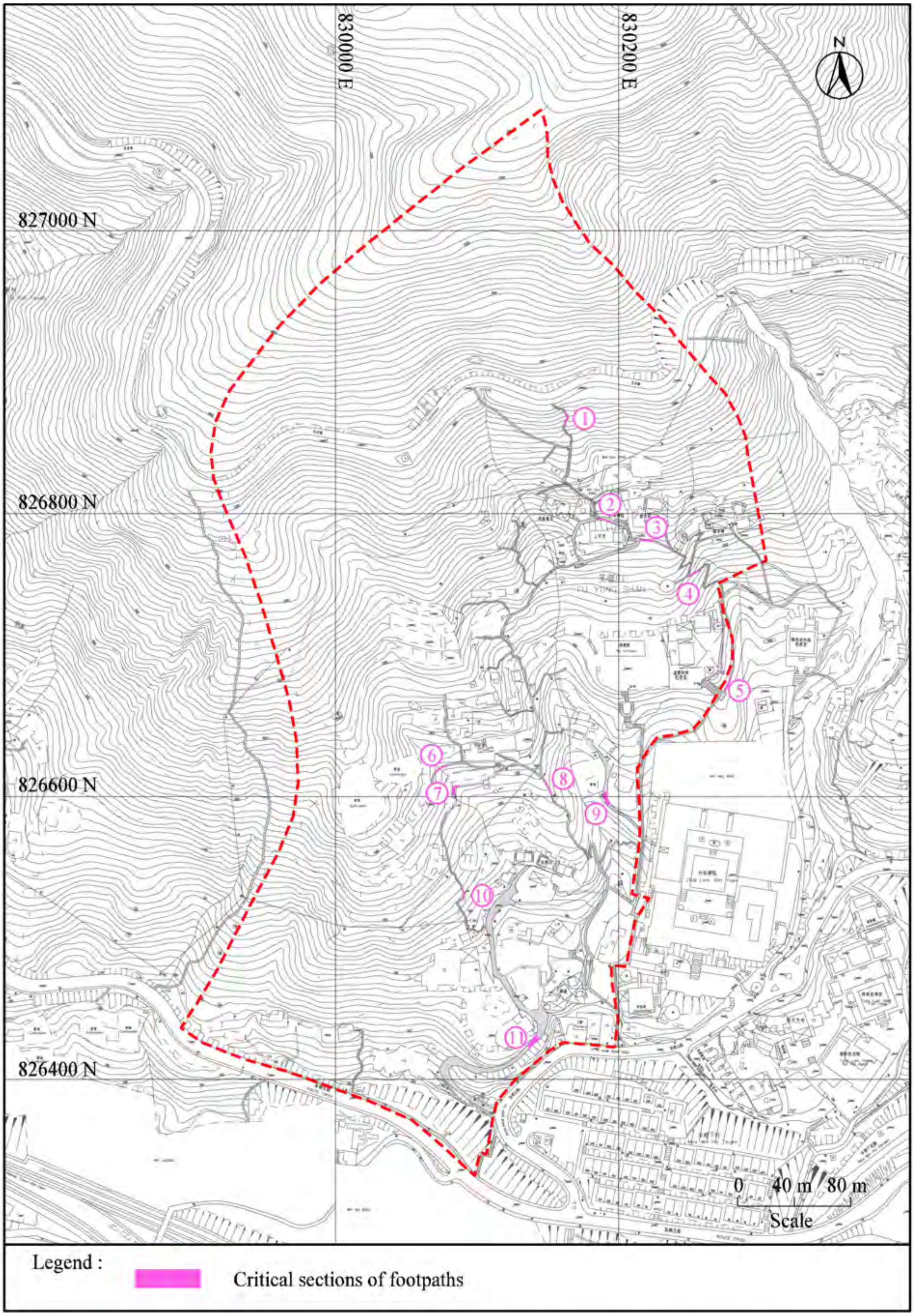

Figure C2 - Location of Eleven Critical Sections of Footpaths

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Study of Landslides Occurring in Kowloon and the New Territories in 2005
- Feasibility Study
QRA of Landslide Hazards at Fu Yung Shan Tsuen
Head Count for Fu Yung Shan Footpath

Station ________________

Surveyor ________________

Date ________________ **Weather** ________________

PM			**Movement**	**Movement**
TIME			***up***	***down***
07:00	-	07:30		
07:30	-	08:00		
08:00	-	08:30		
08:30	-	09:00		
09:00	-	09:30		
09:30	-	10:00		
10:00	-	10:30		
10:30	-	11:00		
11:00	-	11:30		
11:30	-	12:00		
12:00	-	12:30		
12:30	-	13:00		
13:00	-	13:30		
13:30	-	14:00		
14:00	-	14:30		
14:30	-	15:00		
15:00	-	15:30		
15:30	-	16:00		
16:00	-	16:30		
16:30	-	17:00		
17:00	-	17:30		
17:30	-	18:00		
18:00	-	18:30		
18:30	-	19:00		
19:00	-	19:30		
19:30	-	20:00		

Figure C3 - Sample of Head Count Survey Form

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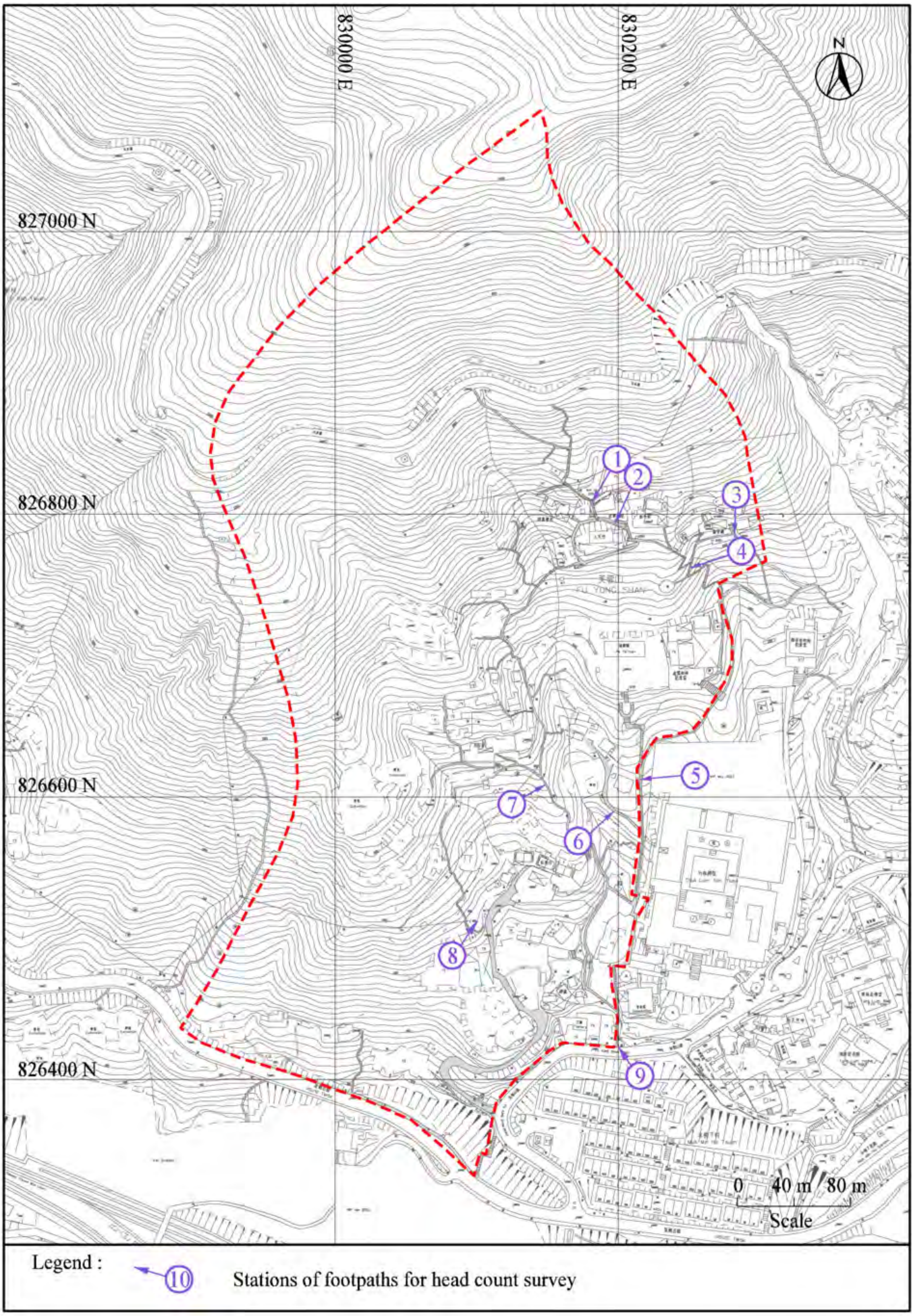

Figure C4 - Stations of Footpaths for Head Count Survey

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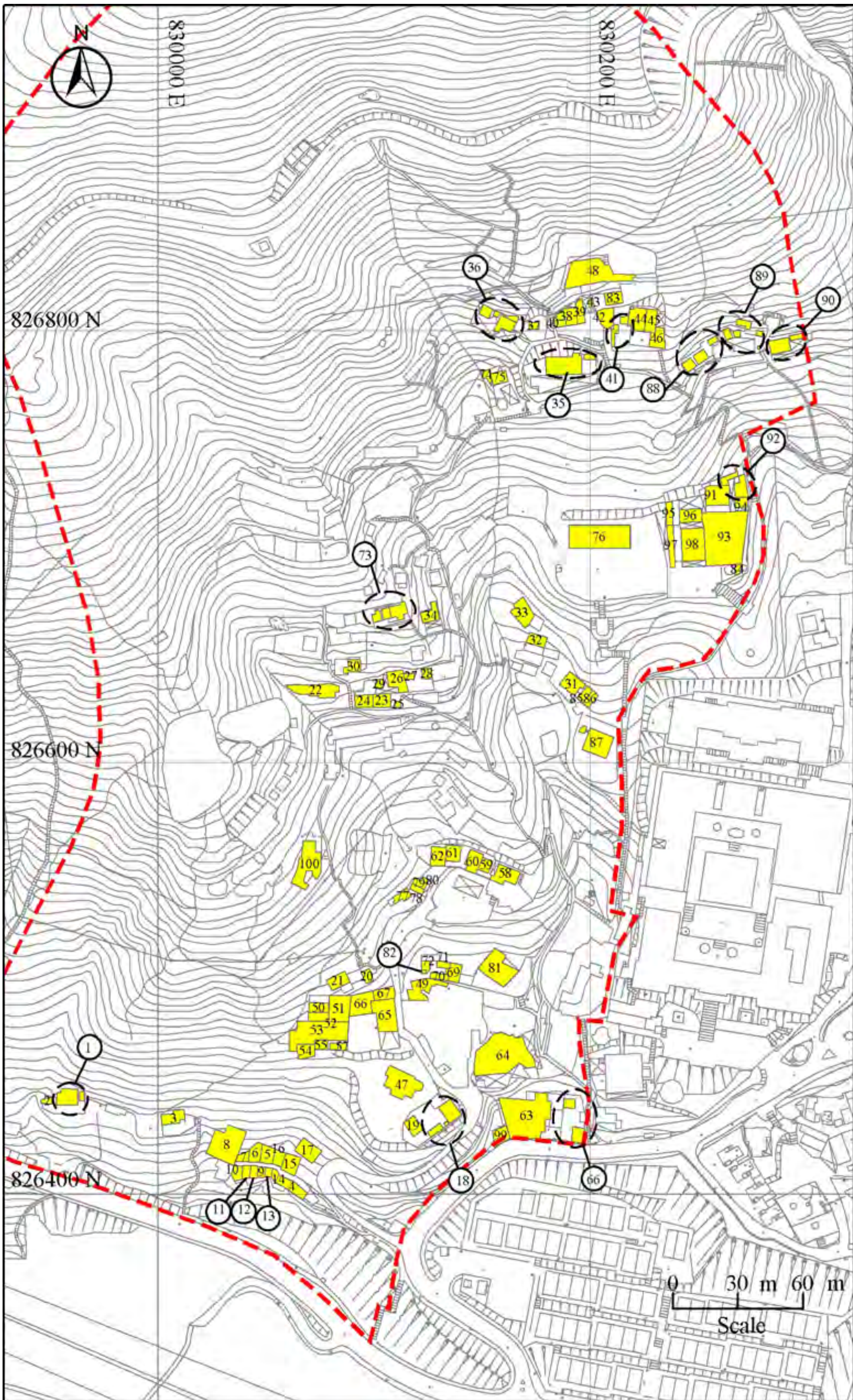

Index	Structure No.
1	1992039_003_1
2	1992039_003_2
3	1992039_005_0
4	1992039_006_1
5	1992039_006_10
6	1992039_006_11
7	1992039_006_12
8	1992039_006_13
9	1992039_006_2
10	1992039_006_3
11	1992039_006_4
12	1992039_006_5
13	1992039_006_6
14	1992039_006_7
15	1992039_006_8
16	1992039_006_9
17	1992039_007_0
18	1992039_008_1
19	1992039_008_2
20	1992039_011_0
21	1992039_012_0
22	1992039_019_0
23	1992039_020_1
24	1992039_020_2
25	1992039_020_3
26	1992039_021_1
27	1992039_021_2
28	1992039_021_3
29	1992039_021_4
30	1992039_022_0
31	1992039_025_0
32	1992039_026_0
33	1992039_027_0
34	1992039_030_0
35	1992039_047_0
36	1992039_049_0
37	1992039_051_0
38	1992039_052_1
39	1992039_052_2
40	1992039_052_3
41	1992039_053_0
42	1992039_054_0
43	1992039_055_0
44	1992039_056_1
45	1992039_056_2
46	1992039_056_3
47	1992039_S001_0
48	1992039_S005_0
49	1992039_S008_0
50	1992039_S010_1
51	1992039_S010_2
52	1992039_S010_3
53	1992039_S010_4
54	1992039_S010_5
55	1992039_S010_6
56	1992039_S010_7
57	1992039_S010_8
58	CKT_001_0
59	CKT_002_0
60	CKT_003_0
61	CKT_004_0
62	CKT_005_0
63	FYS_002_0
64	FYS_006_0
65	FYS_007_1
66	FYS_007_2
67	FYS_008_0
68	FYS_009_0
69	FYS_009_1
70	FYS_009_2
71	FYS_010_3
72	FYS_011_0
73	FYS_031_0
74	TS1_1
75	TS1_2
76	TS10
77	TS11
78	TS12_1
79	TS12_2
80	TS12_3
81	TS13
82	TS14
83	TS2
84	TS3
85	TS4
86	TS5
87	TS6
88	TS7
89	TS8
90	TS9
91	TW30_007_1
92	TW30_007_2
93	TW30_007_3
94	TW30_007_4
95	TW30_008_1
96	TW30_008_2
97	TW30_008_3
98	TW30_008_4
99	TW30_025_0
100	TW30_028_0

Legend: Study Boundary Mapped Structure

Note: See Section C4 for further explanation of the classification of the structures in this QRA.

Figure C5 - Spatial Distribution of Mapped Structures

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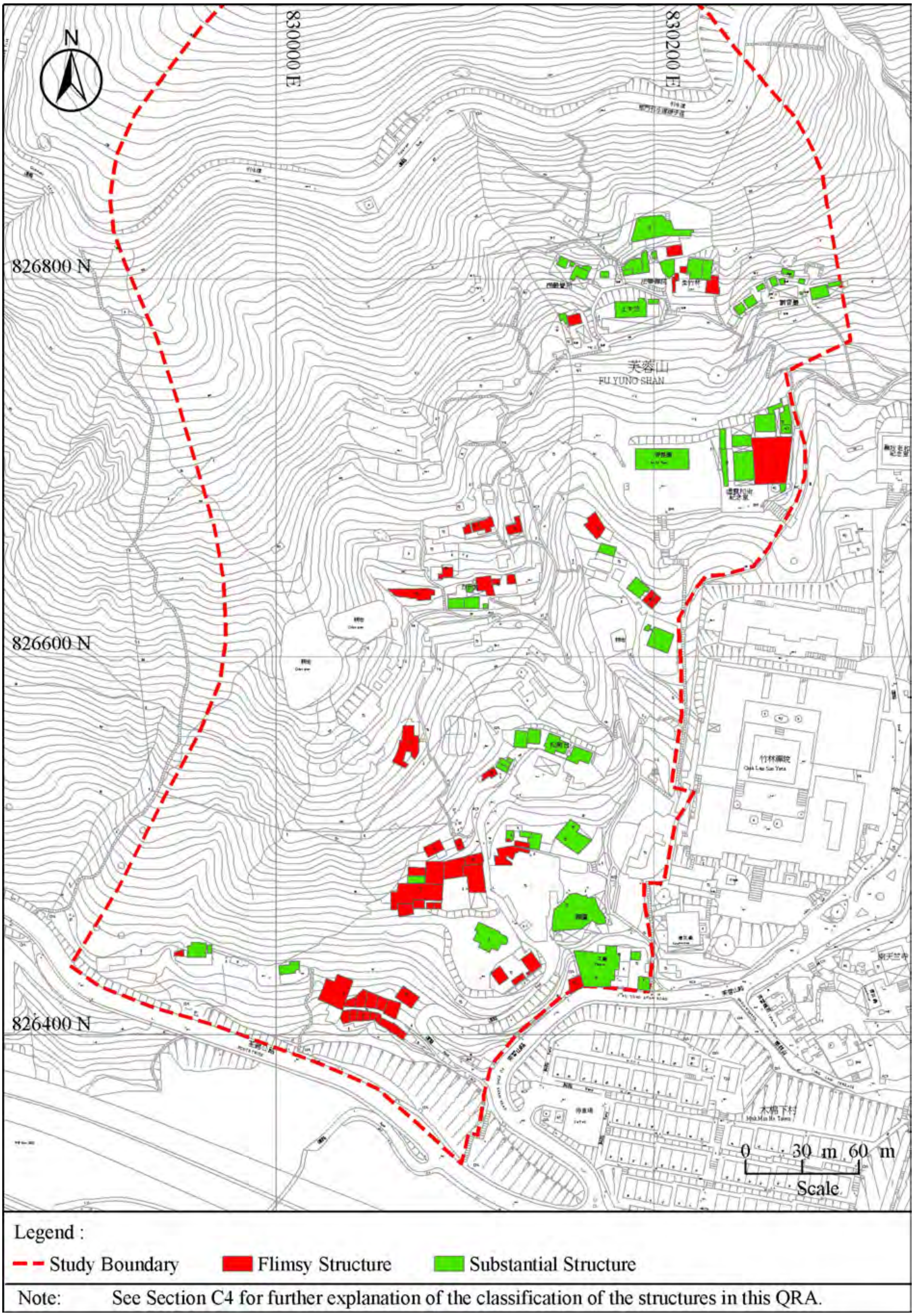

Figure C6 - Spatial Distribution of Structures According to Structural Types

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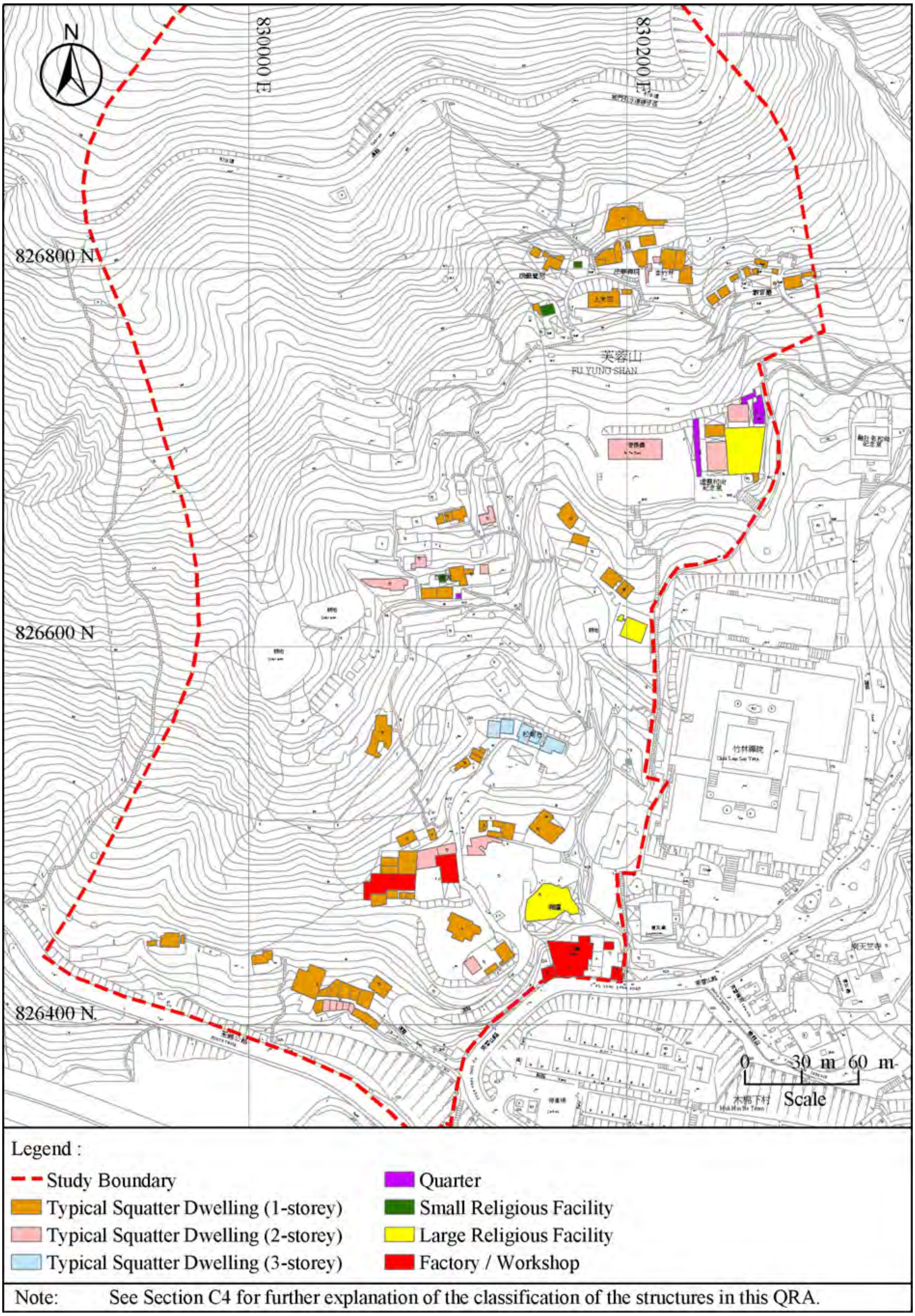

Figure C7 - Spatial Distribution of Structures According to Type of Usages

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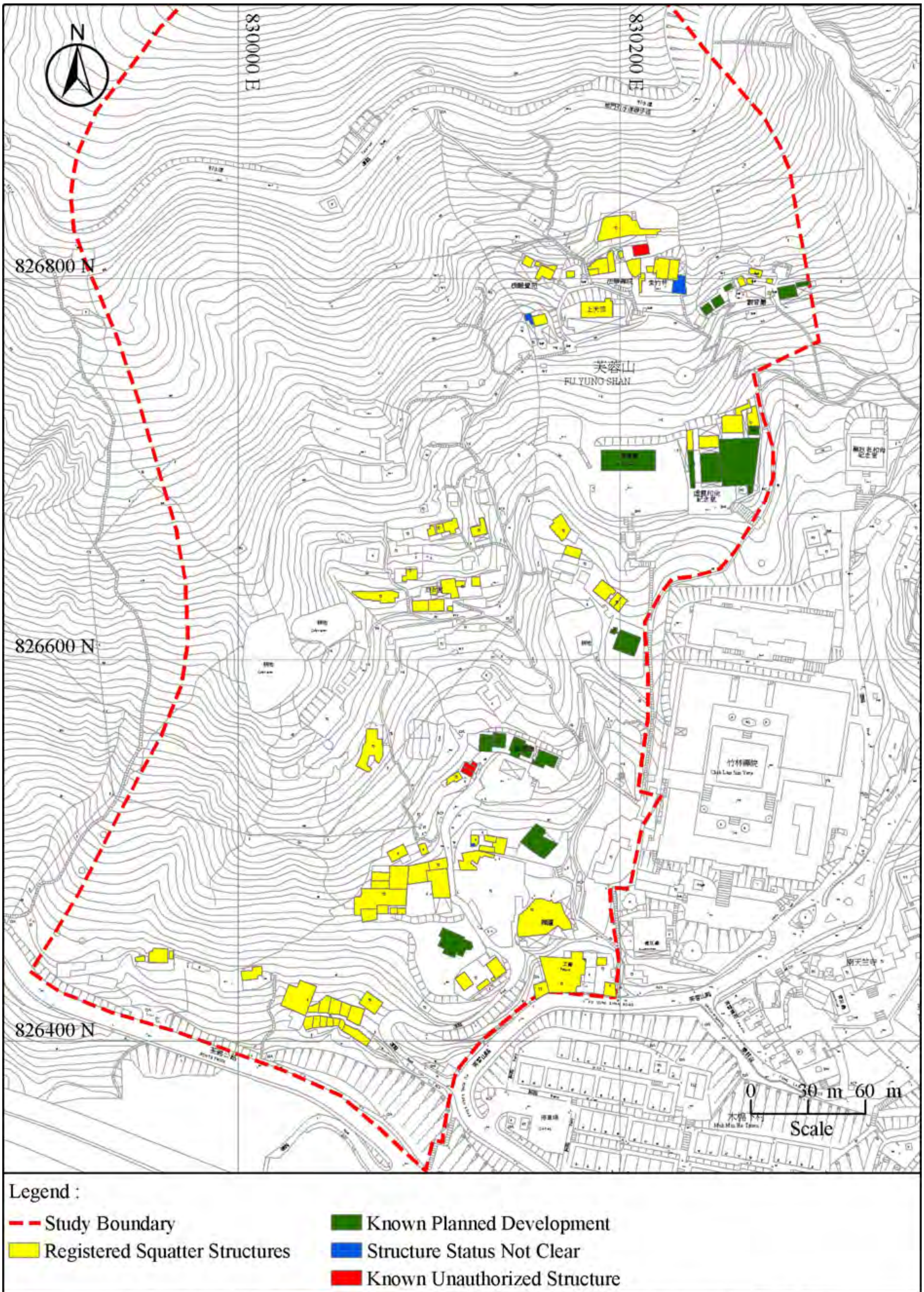

Note: See Section C4 for further explanation of the classification of the structures in this QRA.

Figure C8 - Spatial Distribution of Structures According to Squatter Registration Status

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APPENDIX D

FREQUENCY MODELS

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D1. INTRODUCTION

This Appendix describes the landslide frequency models that have been developed and adopted in the QRA for assessing landslide frequencies for the man-made slopes, and the natural and disturbed hillsides that affect the facilities, viz. the structures and the footpaths. The model for assessing the risk of overtopping of the Shing Mun catchwater is described separately in Appendix H.

D2. CALCULATION OF BASE-LINE LANDSLIDE FREQUENCY

D2.1 Man-made Slopes

There were in general three types of man-made slopes: cut slopes, fill slopes and retaining walls. The spatial distribution of the man-made slopes affecting the facilities is shown in Figure D1. For each type of the slopes, the features were further categorized into groups of different heights: <= 10 m, > 10 m to <= 20 m and > 20 m. The base-line landslide frequency for each type and category of the slopes was determined based on the average annual landslide frequency for that type and category of the slopes affecting registered squatter structures between year 1984 and year 2003 (Lo & Cheung, 2004).

D2.1.1 Cut Slopes

The cut slopes affecting facilities are generally less than 10 m high, therefore, the average annual landslide frequency for cut slopes <= 10 m high was adopted.

- Average annual landslide frequency = 2.2×10^{-5} no./ year/ m^2
- Average slope area = $576 \times 10^3 / 2193 \approx 250$ m^2
- Average annual landslide frequency $\approx 5 \times 10^{-3}$ no./ year

D2.1.2 Fill Slopes

Taking into consideration the general size of the fill slopes affecting facilities, the average annual landside frequency for fill slopes <= 10 m and > 10 m to <= 20 m high were adopted, the values of which are comparable.

- Average annual landslide frequency = 2.0×10^{-6} no./ year/ m^2
- Average slope area = $276 \times 10^3 / 266 \approx 1000$ m^2
- Average annual landslide frequency $\approx 2 \times 10^{-3}$ no./ year

D2.1.3 Retaining Walls

The retaining walls affecting facilities are less than 10 m high, therefore, the average annual landslide frequency for retaining walls <= 10 m high was adopted.

- Average annual landslide frequency = 1.6×10^{-5} no./ year/ m^2

- Average slope area = $95 \times 10^3 / 804 \approx 100$ m^2
- Average annual landslide frequency $\approx 2 \times 10^{-3}$ no./ year

D2.2 Natural and Disturbed Hillsides

The study area was divided into two main portions: the hillside below the Shing Mun Catchwater and that above. Structures and footpaths in Fu Yung Shan Tsuen are located at the hillside below the Shing Mun catchwater.

Catchments directly overlooking facilities were delineated, which comes to a total of 52 catchments (Figure D2). A given catchment comprises either entirely natural or disturbed terrain or a spread of both.

The base-line landslide frequencies for the natural and disturbed hillsides were calculated from historical landslide data collated from recorded landslide incidents and aerial photograph interpretation (API), as follows:

(a) Natural Hillside

- Area of natural hillside within the study area = 0.105 km^2
- Total catchment area affecting facilities = 0.048 km^2
- No. of validated historical natural terrain landslides within the study area = 4.5 (Note: This includes 1 recent landslide that occurred in the past 24 years and 3.5 relict landslides that were expected to have occurred in the past 70 years. This number of relict landslides does not equal to the number of relict landslides identified. It was adjusted based on the number of relict landslides identified with account taken of the uncertainties involved in the recognition of relict landslides from API due to poor coverage and presence of thick vegetation. There were in total 8 relict landslides identified. Two are of 85% confidence, three are of 50% and three are of 10%, making general reference to the levels of confidence recorded in Table A3. The product sum is 3.5.)
- Base-line natural hillside landslide frequency for the entire study area = (1/24 + 3.5/70) = 0.092 no./ yr
- Base-line natural hillside landslide frequency, $(f_b)_{NT}$, for the catchments affecting facilities
  = $(1/24 + 3.5/70) \times (0.048/0.105) = 0.042$ no./ yr

(b) Disturbed Hillside

- Area of disturbed hillside within the study area = 0.038 km^2
- Total catchment area affecting facilities = 0.019 km^2

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- No. of validated historical landslides on the disturbed hillside within the study area in the past 24 years = 5
- The patches of hillsides disturbed by human activities within the study area have changed with times. Those parts of the hillsides that appear to be natural now might once be extensively disturbed by human activities sometime in the past. To avoid underestimation of the number of validated historical landslides on the disturbed hillside, 50% of the base-line natural hillside landslide frequency within the study area was considered to have occurred partly on the disturbed hillside.
- Base-line landslide frequency for the disturbed hillside within the study area
  = (5/24) + 0.5 × (1/24 + 3.5/70) = 0.254 no./ yr
- Base-line landslide frequency for the disturbed hillside within catchments affecting facilities, $(f_b)_{DT}$,
  = [(5/24) + 0.5 × (1/24 + 3.5/70)] × (0.019/0.038)
  = 0.127 no./ yr

D3. ADJUSTMENT FOR BASE-LINE LANDSLIDE FREQUENCY

D3.1 Man-made Slopes

For each type of the man-made slopes (viz, cut slopes, fill slopes and retaining walls), a grade module was set up to adjust the respective base-line landslide frequency for each slope based on field assessments of three key attributes. The details of the attributes for different types of the man-made slopes are described in Table D1.

The grade module operated on each key attribute using a simple adjustment scale. There are three grades involved in the grade module; upgrade (+1), downgrade (-1) and unchange (0). ‘Upgrade (+1)’ represents the case when a given key attribute of an inspected slope is in a condition worse than the average condition of all the inspected slopes within the study area, which is considered comparable to the global average (Lo & Cheung, 2004). ‘Downgrade (-1)’ represents the case when a given key attribute is in a condition better than the average. Similarly, ‘unchange (0)’ represents the case when a given key attribute is in a condition alike the average.

Applying the grade module on all three key attributes, a given slope can be rated between the total maximum upgrade of +3 and the total maximum downgrade of –3, i.e. +3, +2, +1, 0, -1, -2 and -3. As the rating ‘unchange (0)’ represents the case when the overall conditions of a slope are comparable to the average conditions, a slope with the rating ‘unchange (0)’ follows the base-line landslide frequency with no adjustment. The corresponding landslide frequency for the other ratings is shown in Table D2. With this rating matrix, the base-line landslide frequency is adjusted up/down or remained unchanged, based on the actual conditions of a slope itself.

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D3.2 Natural and Disturbed Hillsides

The 52 catchments affecting facilities were sub-divided into a number of hillside units. Details on how the hillside units were sub-divided are described in Appendix E.

Each hillside unit, *i*, has a weighted percentage share of the base-line landslide frequency, $(f_b)_{NT}$ and $(f_b)_{DT}$, that depends on the plan area of the hillside unit, *Ai*, and its overall susceptibility factor (N_i). The adjustment for the base-line landslide frequency for the natural and disturbed hillsides using susceptibility factors is described below.

D3.2.1 Natural Hillside

The overall susceptibility factor (N_i) for each hillside unit, *i*, is a product of the average susceptibility factor ($avg(n_{ij})$) of each of the three susceptibility attributes, *j*: topography, regolith and geomorphology. The division of classes in each susceptibility attribute and the relative factors for the various classes are tabulated in Table D3. Adjustment for gradient effects was based on Wong & Lam (1998). Engineering geological mapping was carried out to identify key geological and geomorphological features influencing landslide initiation and to determine their relative significance. The average susceptibility factor of each susceptibility attribute for each hillside unit depends on the terrain characteristics of the hillside unit and was calculated as below:

$$avg(n_{ij}) = \frac{1}{A_i}\sum_{k=1}^{k}(a_k)_j(r_k)_j \text{ , i = 1 to i; j = 1, 2 and 3} \quad \text{.........................(D1)}$$

where
- i = hillside unit number i
- j = type of susceptibility attributes, viz. 1 = topography, 2 = regolith and 3 = geomorphology
- k = division of classes in the susceptibility attribute j
- $avg(n_{ij})$ = average susceptibility factor of the susceptibility attribute j for hillside unit number i
- A_i = total hillside area of the hillside unit
- $(r_k)_j$ = relative factor in the kth class of the susceptibility attribute j
- $(a_k)_j$ = natural hillside area with respect to the kth classes of the susceptibility attribute j

For each hillside unit, *i*, the overall susceptibility factor (N_i) was calculated as below:

$$N_i = Product\ [avg(n_{i1}), avg(n_{i2}), avg(n_{i3})] \quad \text{..............................(D2)}$$

D3.2.2 Disturbed Hillside

Adjustment for the base-line landslide frequency for the disturbed hillside was similar to that for the natural hillside. But the different natures of the two terrain types required the use of a separate set of susceptibility attributes for adjustment of the base-line landslide frequency for the disturbed hillside. The susceptibility attributes adopted were topography and terrain surface conditions (i.e. paved, bared or eroded land with vegetation, cultivation,

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cut and fill platforms and refuse distribution). The division of classes in each susceptibility attribute and the relative factors for the various classes are tabulated in Table D4. The average susceptibility factor of each susceptibility attribute for each hillside unit was calculated according to Equation (D1). For each hillside unit, *i*, the overall susceptibility factor (N_i) was calculated based on Equation (D2).

D3.2.3 Landslide Frequency for Hillside Unit

Based on Sections D3.2.1 and D3.2.2 above, the landslide frequency for each hillside unit, *i*, was calculated as below:

$$f_i = (f_b)_{NT} \times \frac{(A_{NT})_i \times N_i}{\sum_{i=1}^{i}\left[(A_{NT})_i \times N_i\right]} + (f_b)_{DT} \times \frac{(A_{DT})_i \times N_i}{\sum_{i=1}^{i}\left[(A_{DT})_i \times N_i\right]}$$

where

i	=	hillside unit number i
f_i	=	landslide frequency for hillside unit number i
$(f_b)_{NT}$	=	base-line natural hillside landslide frequency for catchments affecting facilities
$(f_b)_{DT}$	=	base-line landslide frequency for the disturbed hillside within catchments affecting facilities
$(A_{NT})_i$	=	natural hillside area in hillside unit number i
$(A_{DT})_i$	=	disturbed hillside area in hillside unit number i

D4. MAGNITUDE-FREQUENCY MODEL

D4.1 Man-made Slopes

Applying the magnitude model adopted in Lo & Cheung (2004), there were four types of landslide hazard, each with a notional range of landslide volume:

(a) H1: notionally < 20 m^3
(b) H2: notionally 20 m^3 to 50 m^3
(c) H3: notionally 50 m^3 to 500 m^3
(d) H4: notionally >= 500 m^3

The volume distribution for the above four types of landslide hazard was obtained from the global analysis (Lo & Cheung, 2004) and the magnitude-frequency relationship was shown in Table D5.

From field observation, it was noted that the sizes of the man-made slopes varied widely. With this site setting, the conventional magnitude-frequency model in Table D5 with a single volume distribution for all the man-made slopes assessed in the QRA was considered not sufficiently robust, in particular to account for the likelihood of failure of medium to large scales, like H3 and H4, in small man-made slopes. This may result in unrealistic outcome. Because of this, adjustment to the magnitude-frequency distribution for medium to large-scale failures, H3 and H4, was included in the QRA (see Table D6).

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D4.2 Natural and Disturbed Hillsides

D4.2.1 Catchments with Open Hillside Failures

Four types of landslide hazard from the hillsides, each with a notional range of landslide volume, were adopted for the natural and disturbed hillsides:

(a) H1: notionally < 60 m^3
(b) H2: notionally 60 m^3 to 200 m^3
(c) H3: notionally 200 m^3 to 600 m^3
(d) H4: notionally 600 m^3 to 2000 m^3

The volume distributions of the historical landslides identified from recorded landslide incidents and API are shown in Table D7. Based on the distributions, the magnitude-frequency relationship in Table D8 was adopted in the QRA. As there is no historical data for the landslide hazard H4, a nominal distribution of 1/30 of the share for the landslide hazard H3 was assumed.

Since some of the catchments overlooking the facilities are small in nature, their likelihood of having hillside failures in the volume range of H3 or H4 is relatively low. The magnitude-frequency distribution for landslide hazards H3 and H4 was therefore capped by height limit as shown in Table D8.

D4.2.2 Catchments with Channelized Debris Flows

There are four major drainage lines in catchments No. C10, C22, C30 and C48 within the study area where debris flows may occur. The magnitude-frequency relationship for open hillside failures is also applicable to channelized debris flows. Nevertheless, the entrainment effect along the potential flow paths needs to be additionally accounted for. The likelihood of having an entrainment ratio of 3, i.e. moving up from H1 to H2, H2 to H3 and H3 to H4, for the four drainage lines are shown in Table D9. With this adjustment for the entrainment effects, the magnitude-frequency relationship for catchments No. C10, C22, C30 and C48 are shown in Table D10.

As catchments No. C10, C22, C30 and C48 are large catchments, capping by height limit for landslide hazards H3 and H4 was not necessary.

D5. REFERENCES

Lo, D.O.K. & Cheung, W.M. (2004). Assessment of Landslide Risk of Man-made Slopes in Hong Kong. Special Project Report No. SPR 4/2004, Geotechnical Engineering Office, Hong Kong, 82 p.

Wong, H.N. & Lam, K.C. (1998). The November 1993 natural terrain landslides on Lantau Island, Hong Kong. Proceedings of Seminar on Slope Engineering in Hong Kong, Hong Kong, A.A. Balkema Publisher, pp 51-57.

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Table D1 - Key Attributes for Different Type of Slopes

Key Attribute	Cut Slopes	Fill Slopes	Retaining Walls
1	Slope geometry	Slope geometry	Wall types(2)
2	Presence of past failures	Presence of past failures	Evidence of wall movement
3	Presence of adverse factors contributing to failures(1)	Presence of adverse factors contributing to failures(1)	Presence of adverse factors contributing to failures(1)

Notes: (1) This includes unfavourable surface condition, sign of seepage, insufficient drainage provision and potential concentration of flow.
(2) There are basically three wall types; dry packed random rubber wall, pointed random rubble wall and dressed concrete block wall.

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Table D2 - Adjustment Mechanism for Base-line Landslide Frequency

(a) For Cut Slopes		
Landslide Frequency	Grade Adjustment	Likelihood Description(1)
1/6	+3	Very Likely
1/20	+2	Likely
1/60	+1	Quite Likely
1/200 (Base-line)	0	Possible
1/600	-1	Less Likely
1/2000	-2	Low Chance
1/20000	-3	Very Low Chance
(b) For Fill Slopes		
Landslide Frequency	Grade Adjustment	Likelihood Description(1)
1/20	+3	Very Likely
1/50	+2	Likely
1/200	+1	Quite Likely
1/500 (Base-line)	0	Possible
1/2000	-1	Less Likely
1/5000	-2	Low Chance
1/50000	-3	Very Low Chance
(c) For Retaining Walls		
Landslide Frequency	Grade Adjustment	Likelihood Description(1)
1/20	+3	Very Likely
1/50	+2	Likely
1/200	+1	Quite Likely
1/500 (Base-line)	0	Possible
1/2000	-1	Less Likely
1/5000	-2	Low Chance
1/50000	-3	Very Low Chance

Notes:
(1) Very likely = May occur in near future. Very likely would occur in the service life.
(2) Likely = May occur in foreseeable future. Very high chance of occurrence in the service life.
(3) Quite likely = May occur some time in the future. High chance of occurrence in the service life.
(4) Possible = May occur in the service life.
(5) Less likely = Lower chance of occurrence in the service life.
(6) Low chance = Low chance of occurrence in the service life.
(7) Very low chance = Very low chance of occurrence in the service life.

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Table D3 - Susceptibility Attributes for Natural Hillside

(a) Topography		
Class	Description	Relative Factors
G1	Gradient within 15º	0
G2	Gradient between 15º to 20º	1
G3	Gradient between 20º to 25º	5
G4	Gradient between 25º to 30º	10
G5	Gradient between 30º to 35º	20
G6	Gradient between 35º to 40º	20
G7	Gradient exceeding 40º	10
(b) Regolith		
Class	Description	Relative Factors
R1	Tuff/ rhyolite with corestone bearing saprolite	0.5
R2	Granodiorite with corestone bearing saprolite	0.75
R3	Recent colluvium without boulders	1.5
R4	Recent colluvium with boulders	1
R5	Relict colluvium and non-corestone bearing	1
(c) Geomorphology		
GD1	Head of drainage line	1.5
GD2	Incised gully	2
GD3	Over-steepened flank	2
GD4	Others	1

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Table D4 - Susceptibility Attributes for Disturbed Hillside

(a) Topography		
Class	Description	Relative Factors
G1	Gradient within 15º	0
G2	Gradient between 15º to 20º	1
G3	Gradient between 20º to 25º	5
G4	Gradient between 25º to 30º	10
G5	Gradient between 30º to 35º	20
G6	Gradient between 35º to 40º	20
G7	Gradient exceeding 40º	10
(b) Surface Condition		
Class	Description	Relative Factors
S1	Paved land or vegetated land, with no modification by human activities	0.5
S2	Bared land, with no modification by human activities	1.5
S3	Land other than bared, paved or eroded, with cultivation, platform or cut & fill	1.5
S4	Bared land with cultivation, platform or cut & fill	2
S5	Eroded land, with no modification by human activities	2
S6	Eroded land with platform or cut & fill	2
S7	Eroded land with cultivation	3
S8	Paved land or vegetated land, with cultivation, platform or cut & fill	1
S9	Land other than bared, paved or eroded, with no modification by human activities	1
(c) Refuse		
RD1	Thin	1.5
RD2	Superficial	2
RD3	Dump	4
RD4	Others	1

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Table D5 - Magnitude-frequency Relationship for Man-made Slopes

(a) For Cut Slopes

Landslide Hazard	Relative Frequency
H1: notionally < 20 m^3	80%
H2: notionally 20 m^3 to 50 m^3	20%
H3: notionally 50 m^3 to 500 m^3	see Table D6
H4: notionally > 500 m^3	see Table D6

(b) For Fill Slopes

Landslide Hazard	Height of Slopes	Relative Frequency
H1: notionally < 20 m^3	<= 10 m	95%
	10 m - 20 m	5%
H2: notionally 20 m^3 to 50 m^3	<= 10 m	90%
	10 m - 20 m	10%
H3: notionally 50 m^3 to 500 m^3	-	see Table D6
H4: notionally > 500 m^3	-	see Table D6

(c) For Retaining Walls

Landslide Hazard	Height of Slopes	Relative Frequency
H1: notionally < 20 m^3	<= 5 m	90%
	5 m - 10 m	10%
H2: notionally 20 m^3 to 50 m^3	<= 5 m	80%
	5 m - 10 m	20%
H3: notionally 50 m^3 to 500 m^3	-	see Table D6
H4: notionally > 500 m^3	-	see Table D6

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Table D6 - Adjustment Model for Magnitude-frequency Relationship for Large-volume Failures on Man-made Slopes

(a) Medium-scale failure (50 m^3 to 500 m^3)		
Category	Likelihood Description	Relative Frequency
1	Quite possible	10.0%
2	Possible	3.0%
3	Less possible	1.0%
4	Quite unlikely	0.3%
5	Very Unlikely	0%
(b) Large-scale failure (> 500 m^3)		
Category	Likelihood Description	Relative Frequency
1	Noticeable chance (for cases where signs of mechanism of large-scale, mobile failure is evident)	Indicate chance of failure being large-scaled and mobile (e.g. 3%, 10% or 30%)
2	There is a relatively high possibility	1.5%
3	There is a possibility	0.5%
4	Low possibility but still credible	0.1%
5	In practice not credible	0%

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Table D7 - Volume Distribution of Historical Landslides on Natural and Disturbed Hillsides

	Landslide Hazard	Recent	Relict
No. of Landslides	H1: notionally 20 m^3 to 60 m^3	4	2.8 (1)
	H2: notionally 60 m^3 to 200 m^3	1	0.7 (2)
	H3: notionally 200 m^3 to 600 m^3	1	0
	H4: notionally 600 m^3 to 2000 m^3	0	0
Observation Periods (Years)		24	70
Volume Frequency (3) (No./ Year)	H1: notionally 20 m^3 to 60 m^3	0.207	
	H2: notionally 60 m^3 to 200 m^3	0.052	
	H3: notionally 200 m^3 to 600 m^3	0.042	
	H4: notionally 600 m^3 to 2000 m^3	0	

Notes:
(1) The number of landslides is calculated from $3.5 \times 0.8 = 2.8$ (see Table A3 for the exact number of landslides in this volume range).
(2) The number of landslides is calculated from $3.5 \times 0.2 = 0.7$ (see Table A3 for the exact number of landslides in this volume range).
(3) Taking the volume range of 20 m^3 - 60 m^3 as an example, the volume frequency is calculated from $(4/24) + (2.8/70) = 0.207$.

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Table D8 - Magnitude-frequency Relationship for Open Hillside Failures on Natural and Disturbed Hillsides

Landslide Hazard	Relative Frequency [(1)]	Likelihood	
		Overall Height of Catchment	Likelihood
H1: notionally 20 m^3 to 60 m^3	68.89%	-	100%
H2: notionally 60 m^3 to 200 m^3	17.22%	-	100%
H3: notionally 200 m^3 to 600 m^3	13.89%	<= 10 m	50%
		10 m to 15 m	100%
		> 15 m	100%
H4: notionally 600 m^3 to 2000 m^3	0.46%	<= 10 m	0%
		10 m to 15 m	30%
		> 15 m	100%

Note: (1) The relative frequencies are calculated based on the volume frequencies shown in Table D7, except for landslide hazard H4, which is equal to (1/30) × 13.89% = 0.46%.

Table D9 - Likelihood of Channelized Debris Flows Having Entrainment Ratio of 3

Catchment	20 m^3 - 60 m^3	60 m^3 - 200 m^3	200 m^3 - 600 m^3
C10, C21 and C30	5%	10%	10%
C48	10%	20%	20%

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Table D10 - Magnitude-frequency Relationship for Channelized Debris Flows on Natural and Disturbed Hillsides

	Relative Frequency for Open Hillside Failures	Allowance for Entrainment Effect (1)	Relative Frequency for Channelized Debris Flows (2)
(a) Landslide Hazard for C48			
H1: notionally 20 m^3 to 60 m^3	68.89%	-	62.00%
H2: notionally 60 m^3 to 200 m^3	17.22%	0.1 × 68.89%	20.67%
H3: notionally 200 m^3 to 600 m^3	13.89%	0.2 × 17.22%	14.56%
H4: notionally 600 m^3 to 2000 m^3	0.46%	0.2 × 13.89%	3.24%
(b) Landslide Hazard for C10, C21 and C30			
H1: notionally 20 m^3 to 60 m^3	68.89%		65.44%
H2: notionally 60 m^3 to 200 m^3	17.22%	0.05 × 68.89%	18.94%
H3: notionally 200 m^3 to 600 m^3	13.89%	0.1 × 17.22%	14.22%
H4: notionally 600 m^3 to 2000 m^3	0.46%	0.1 × 13.89%	1.85%

Notes: (1) The likelihood of channelized debris flows having entrainment ratio of 3 is based on Table D9.

(2) Taking landslide hazard H2 for C48 as an example, the relative frequency for channelized debris flows is calculated from:
17.22% + (0.1 × 68.89%) – (0.2 × 17.22%) = 20.67%

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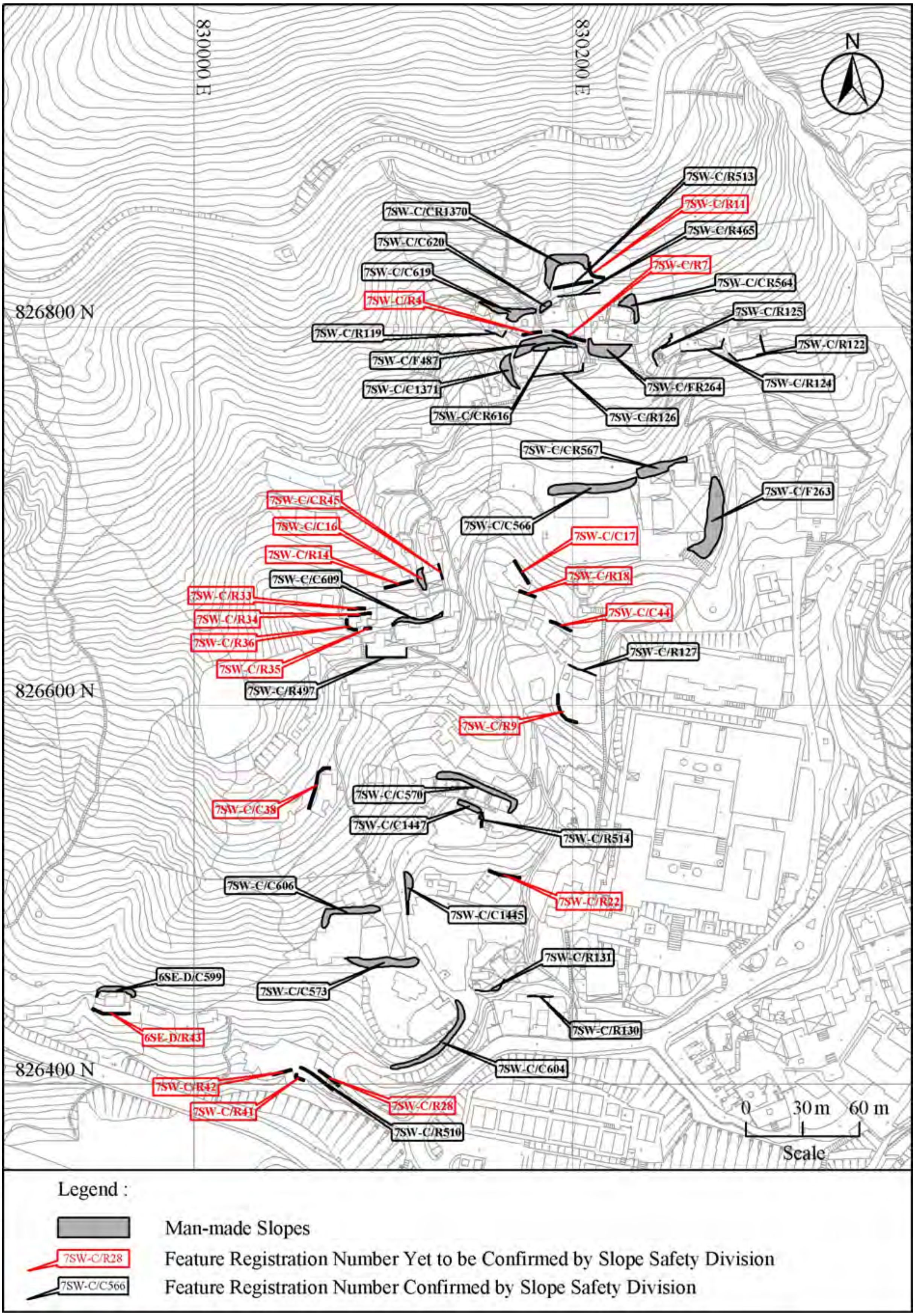

Figure D1 - Spatial Distribution of Man-made Slopes Affecting Facilities

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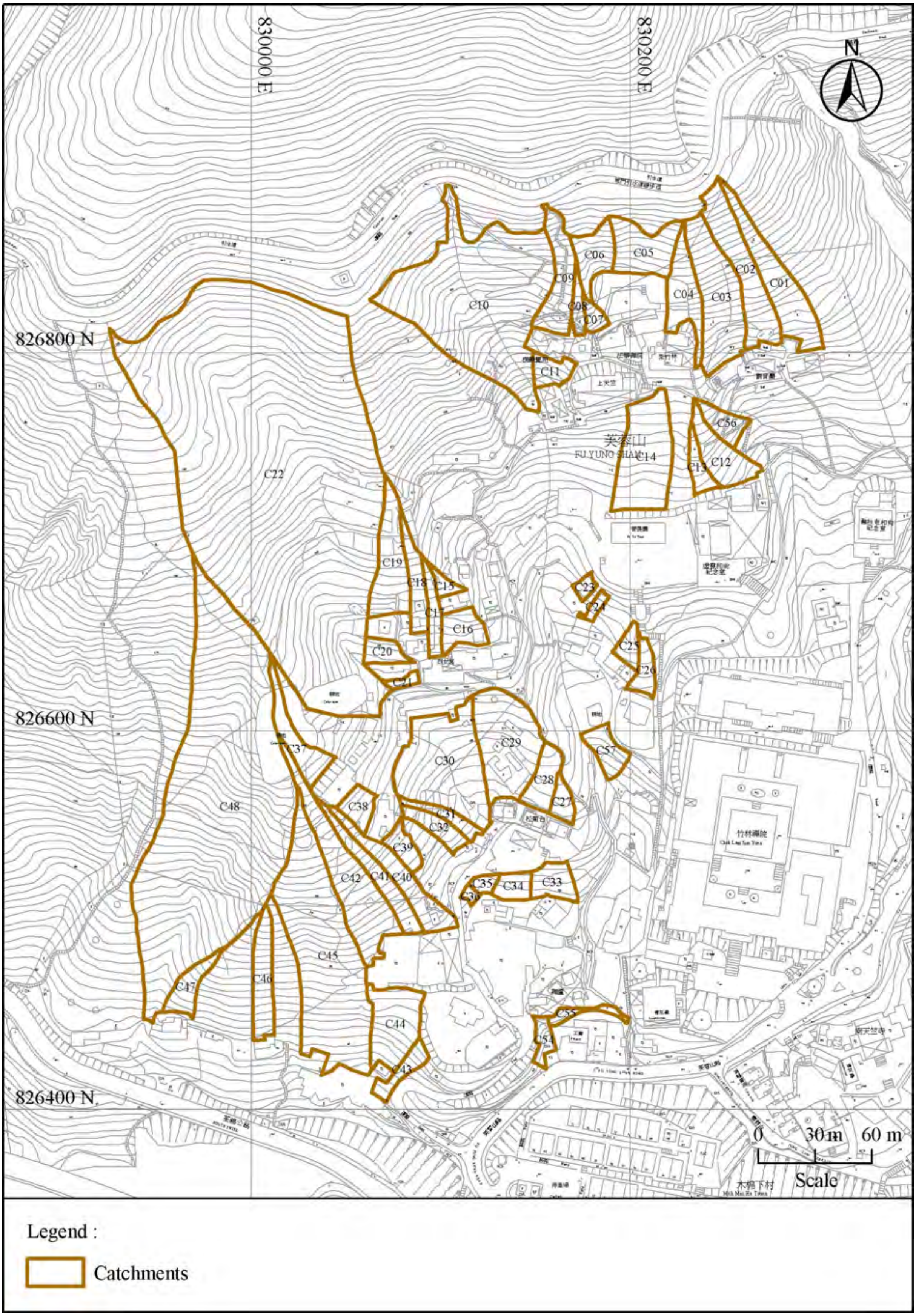

Figure D2 - Spatial Distribution of Hillside Catchments Directly Overlooking Facilities

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APPENDIX E

CONSEQUENCE MODELS

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E1. INTRODUCTION

This Appendix describes the consequence models that have been developed and adopted in the QRA for the man-made slopes, and the natural and disturbed hillsides that affect facilities, viz. structures and footpaths, in Fu Yung Shan Tsuen. The consequence model for assessing risk of overtopping of the Shing Mun catchwater is described separately in Appendix H.

E2. ASSESSMENT OF PROXIMITY AND VULNERABILITY FACTORS FOR MAN-MADE SLOPES

The landslide consequence models developed by Wong et al (1997) and adopted in Lo & Cheung (2004) were used in this study.

E2.1 Assessment of Proximity

For failures of man-made slopes affecting facilities at the toe, shadow angle is used as an indicator of debris mobility, which is a key parameter for assessing the proximity of a man-made slope to the facility under consideration. Facilities are usually developed close to man-made slopes. This close proximity renders other key parameters that have been adopted to assess the likelihood and the severity of damage brought by hillside failures to facilities, such as debris runout path and debris runout distance, not applicable.

For cut slopes and retaining walls affecting facilities behind slope crests, the ratio of the distance between the crest of a slope and the facility under consideration to the height of the slope is used as a measurement of proximity to the facility. For fill slopes, proximity is gauged by the distance between the crest of a slope and the facility. These indicators take into consideration the likelihood of undermining of a given facility in the event of a downslope failure.

E2.2 Assessment of Vulnerability Factors

The vulnerability factors have been determined with due consideration of (i) the nature, proximity and spatial distribution of the facilities, (ii) mobility of debris and likely extent of the upslope influence zone, (iii) scale of failure, and (iv) degree of protection offered to persons by the facility. The vulnerability factors adopted are given in Table E1.

E3. ASSESSMENT OF PROXIMITY AND VULNERABILITY FACTORS FOR NATURAL AND DISTURBED HILLSIDES

E3.1 Division of Hillside Units

Each of the 52 catchments affecting facilities was divided into a number of hillside units, which generally aligned with the toe boundary between a given catchment and its facilities (Figure E1). For each catchment, the width of the hillside units is typically about 5 m. Their length depends on the length of the facilities affected and the topographic

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conditions of the catchment, such that all parts within each unit might in practice be taken as sufficient uniform in their possible runout paths and proximity to the facilities.

E3.2 Assessment of Possible Debris Runout Paths

The possible debris runout paths of each hillside unit depend on the hillside topographic conditions. Having taken this into consideration, the hillside units were matched with the facilities. The outcome of the matching is summarized in Table E2.

E3.3 Assessment of Debris Mobility

The debris mobility model adopted in Wong et al (2004) was refined in this study, with the inclusion of an additional parameter, travel angle, as an indicator of debris mobility.

In the updated debris mobility model, the worst credible travel distances for different types of landslide hazard arising from each hillside unit were adjusted using the travel angle from the landslide source at the hillside unit to the facility affected. The adjustment mechanism is shown in Table E3. The mean travel distance was taken as half of the adjusted worst credible travel distance. A triangular probability distribution of travel distance from the mean value to the worst credible value, and to zero runout distance, was adopted (Wong et al, 2004).

E3.4 Assessment of Vulnerability Factors

The model adopted in Wong et al (2004) that indicates the levels of damage to the occupied ground floor of substantial structures located at different degrees of proximity to a landslide source was used. The model was expanded to include the levels of damage to flimsy structures or unprotected facilities, like footpaths. The complete model is shown in Figure E2.

For a given type of landslide hazard, the vulnerability factors on a structure at different proximity zones, as defined by the plan distance from the relevant hillside unit to the structure, were calculated by combining the triangular probability distribution of travel distance described in Section E3.3 above and the levels of damage shown in Figure E2. An example of the calculation is shown in Figure E3.

E4. POPULATION AT RISK

For assessment of PIR, the presence of an individual in the ground floor of a structure, or on a section of the footpaths, was considered for the calculation of the frequency of harm per year to an actual individual who is exposed to the landslide hazards, both from the man-made slopes and the hillsides, with account taken of the probability of escape or protection from the hazards.

For assessment of Societal Risk, the degree of usage of the structures was in general assumed to be the same as that of the typical squatter dwellings in Hong Kong. Some of the

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structures were known to be used as hostels or for religious purposes, and their usage was very different from the typical squatter dwellings in Hong Kong. The degree of usage of these structures has been surveyed and the findings used in the QRA. For the footpath network, the assessed risk is based on the current degree of usage, as established from field surveys carried out in early 2006.

The temporal distribution of the population at risk adopted in assessing the Societal Risk in terms of F-N distribution is described in Appendix F.

E5. APPLICATION OF CONSEQUENCE MODELS

In applying the consequence model for risk quantification, the consequence to each facility was calculated. This reflects the likelihood and the severity of damage to a facility (i.e. expressed in terms of PLL to an individual that is present at the facility), assuming that the facility was located along the runout path of all the debris that may cross the toe boundary of the catchment concerned.

E5.1 Catchments with Open Hillside Failures

In practice, the length of the toe boundary of a given catchment may be greater than the dimension of the facility affected and in such a case, the likelihood of damage calculated should be adjusted to account for the hit chance of the facility. The adjustment required is described below:

(a) Step 1: If the width of the toe boundary of the catchment (L) is greater than the dimension of the facility fronting the catchment (l), the probability that the facility would be located in the debris runout path is given by $(l+2w)/L$, where w is the width of the landslide (see Table E4 for the width of the landslide of different volumes) and $(l+2w)/L$ is capped at 1.

(b) Step 2: Given that the debris would hit the facility at a probability of $(l+2w)/L$, which is capped at 1, 100% of the debris would be impacted on the facility if the dimension of the facility fronting the catchment (l) is less than or equal to $2w$. Otherwise, the debris would be impacted on the facility at the probability of $2w/l$. The product of the calculated value from Steps 1 and 2 must not be greater than 1.

E5.2 Catchments with Channelized Debris Flows

The above is not applicable to catchments with channelized debris flows because of different topographic conditions. Well-defined drainage lines in the catchments are reflected by laterally-restrained terrain that confines the runout path of channelized debris flows. Unless a given structure is located at a drainage line, which would be hit directly by

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channelized debris flows, the degree of damage to the structure diminishes as it locates laterally further away from the drainage line. The rate of reduction depends on the extent of the lateral influence zone covered by landslide debris.

In the QRA, the lateral influence zones arising from different types of landslide hazard of channelized debris flows from the four catchments were estimated using numerical modeling. Three sub-divisions were defined within the influence zones:

(a) A given structure within the width (*w* in m) of flow boundary: 100% of the consequence would be direct on the structure.

(b) A given structure at a distance *w/2* away from the flow boundary: 70% of the consequence would be direct on the structure.

(c) A given structure at a distance *(w/2)+5* away from the flow boundary: 20% of the consequence would be direct on the structure.

E6. REFERENCES

Lo, D.O.K. & Cheung, W.M. (2004). Assessment of Landslide Risk of Man-made Slopes in Hong Kong. Special Project Report No. SPR 4/2004, Geotechnical Engineering Office, Hong Kong, 82 p.

Wong, H.N., Ho, K.K.S. & Chan, Y.C. (1997). Assessment of consequence of landslides. Proceedings of the International Workshop on Landslide Risk Assessment, Honolulu, Hawaii, USA, pp 111-149.

Wong, H.N., Shum, W.W.L. & Ko, F.W.Y. (2004). Assessment of Natural Terrain Landslide Risk on the Planned Development in Ling Pei, Lantau. Advisory Report No. ADR 4/2004, Geotechnical Engineering Office, Hong Kong, 173 p.

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Table E1 - Vulnerability Factors for Man-made Slopes (Sheet 1 of 3)

(a) Cut slopes

(i) Distribution of vulnerability factors for a cut slope affecting substantial facilities at the toe

Volume Class	Failure Volume (m^3)	Shadow Angle (^{o})									
		0 - 20	20 - 25	25 - 30	30 - 35	35 - 40	40 - 45	45 - 50	50 - 55	55 - 60	> 60
		1	2	3	4	5	6	7	8	9	10
1	< 20	0.000000	0.000000	0.000000	0.000001	0.000014	0.000070	0.000255	0.000750	0.001300	0.002000
2	20 - 50	0.000000	0.000000	0.000000	0.000050	0.000600	0.002150	0.005700	0.011000	0.016000	0.020000
3	50 - 500	0.000000	0.000000	0.003000	0.019000	0.048500	0.097000	0.157500	0.200000	0.232500	0.250000
4	500 - 2000	0.000000	0.015000	0.045000	0.135000	0.305000	0.520000	0.735000	0.870000	0.935000	0.950000

(ii) Distribution of vulnerability factors for a cut slope affecting flimsy facilities at the toe

Volume Class	Failure Volume (m^3)	Shadow Angle (^{o})									
		0 - 20	20 - 25	25 - 30	30 - 35	35 - 40	40 - 45	45 - 50	50 - 55	55 - 60	> 60
		1	2	3	4	5	6	7	8	9	10
1	< 20	0.000000	0.000000	0.000000	0.000200	0.001200	0.004600	0.017000	0.034000	0.065000	0.100000
2	20 - 50	0.000000	0.000000	0.000000	0.010000	0.040000	0.110000	0.230000	0.350000	0.460000	0.500000
3	50 - 500	0.000000	0.000000	0.022500	0.090000	0.215000	0.382500	0.545000	0.635000	0.665000	0.700000
4	500 - 2000	0.000000	0.060000	0.240000	0.480000	0.725000	0.870000	0.935000	0.950000	0.950000	0.950000

(iii) Distribution of vulnerability factors for a cut slope affecting substantial facilities at the crest

Volume Class	Failure Volume (m^3)	L/H						
		<= 0.25	0.25 - 0.50	0.50 - 0.75	0.75 - 1.00	1.00 - 1.25	1.25 - 1.50	> 1.50
		1	2	3	4	5	6	7
1	< 20	0.000150	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
2	20 - 50	0.003000	0.000500	0.000000	0.000000	0.000000	0.000000	0.000000
3	50 - 500	0.034000	0.009000	0.002000	0.000000	0.000000	0.000000	0.000000
4	500 - 2000	0.230000	0.110000	0.040000	0.007500	0.000000	0.000000	0.000000

(iv) Distribution of vulnerability factors for a cut slope affecting flimsy facilities at the crest

Volume Class	Failure Volume (m^3)	L/H						
		<= 0.25	0.25 - 0.50	0.50 - 0.75	0.75 - 1.00	1.00 - 1.25	1.25 - 1.50	> 1.50
		1	2	3	4	5	6	7
1	< 20	0.006000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
2	20 - 50	0.080000	0.010000	0.000000	0.000000	0.000000	0.000000	0.000000
3	50 - 500	0.450000	0.140000	0.020000	0.000000	0.000000	0.000000	0.000000
4	500 - 2000	0.630000	0.285000	0.080000	0.015000	0.000000	0.000000	0.000000

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Table E1 - Vulnerability Factors for Man-made Slopes (Sheet 2 of 3)

(b) Fill slopes

(i) Distribution of vulnerability factors for a fill slope affecting substantial facilities at the toe

Volume Class	Failure Volume (m^3)	Shadow Angle (^{o})									
		0 - 20	20 - 25	25 - 30	30 - 35	35 - 40	40 - 45	45 - 50	50 - 55	55 - 60	> 60
		1	2	3	4	5	6	7	8	9	10
1	< 20	0.000000	0.000000	0.000000	0.000001	0.000140	0.000800	0.002000	0.002000	0.002000	0.002000
2	20 - 50	0.000000	0.000000	0.000000	0.000250	0.002750	0.012500	0.020000	0.020000	0.020000	0.020000
3	50 - 500	0.000000	0.000000	0.002000	0.020000	0.103000	0.310000	0.450000	0.450000	0.450000	0.450000
4	500 - 2000	0.000000	0.015000	0.020000	0.105000	0.345000	0.700000	0.915000	0.950000	0.950000	0.950000

(ii) Distribution of vulnerability factors for a fill slope affecting flimsy facilities at the toe

Volume Class	Failure Volume (m^3)	Shadow Angle (^{o})									
		0 - 20	20 - 25	25 - 30	30 - 35	35 - 40	40 - 45	45 - 50	50 - 55	55 - 60	> 60
		1	2	3	4	5	6	7	8	9	10
1	< 20	0.000000	0.000000	0.000000	0.002000	0.012000	0.026000	0.050000	0.050000	0.050000	0.050000
2	20 - 50	0.000000	0.000000	0.000000	0.050000	0.150000	0.300000	0.400000	0.400000	0.400000	0.400000
3	50 - 500	0.000000	0.000000	0.015000	0.115000	0.320000	0.520000	0.600000	0.600000	0.600000	0.600000
4	500 - 2000	0.000000	0.000000	0.080000	0.340000	0.700000	0.915000	0.950000	0.950000	0.950000	0.950000

(iii) Distribution of vulnerability factors for a fill slope affecting substantial facilities at the crest

Volume Class	Failure Volume (m^3)	Crest Distance (m)			
		<= 3	3-6	6-10	> 10
		1	2	3	4
1	< 20	0.000000	0.000000	0.000000	0.000000
2	20 - 50	0.004000	0.000001	0.000000	0.000000
3	50 - 500	0.005800	0.000250	0.000000	0.000000
4	500 - 2000	0.020000	0.003300	0.000200	0.000000

(iv) Distribution of vulnerability factors for a fill slope affecting flimsy facilities at the crest

Volume Class	Failure Volume (m^3)	Crest Distance (m)			
		<= 3	3-6	6-10	> 10
		1	2	3	4
1	< 20	0.001000	0.000000	0.000000	0.000000
2	20 - 50	0.030000	0.000100	0.000000	0.000000
3	50 - 500	0.145000	0.005000	0.000000	0.000000
4	500 - 2000	0.400000	0.040500	0.002000	0.000000

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Table E1 - Vulnerability Factors for Man-made Slopes (Sheet 3 of 3)

(c) Retaining walls

(i) Distribution of vulnerability factors for a retaining wall affecting substantial facilities at the toe

Volume Class	Failure Volume (m^3)	Shadow Angle (^{o})									
		0 - 20	20 - 25	25 - 30	30 - 35	35 - 40	40 - 45	45 - 50	50 - 55	55 - 60	> 60
		1	2	3	4	5	6	7	8	9	10
1	< 20	0.000000	0.000000	0.000000	0.000001	0.000014	0.000070	0.000255	0.000750	0.001300	0.002000
2	20 - 50	0.000000	0.000000	0.000000	0.000050	0.000600	0.002150	0.005700	0.011000	0.016000	0.020000
3	50 - 500	0.000000	0.000000	0.003000	0.019000	0.048500	0.097000	0.157500	0.200000	0.232500	0.250000
4	500 - 2000	0.000000	0.015000	0.045000	0.135000	0.305000	0.520000	0.735000	0.870000	0.935000	0.950000

(ii) Distribution of vulnerability factors for a retaining wall affecting flimsy facilities at the toe

Volume Class	Failure Volume (m^3)	Shadow Angle (^{o})									
		0 - 20	20 - 25	25 - 30	30 - 35	35 - 40	40 - 45	45 - 50	50 - 55	55 - 60	> 60
		1	2	3	4	5	6	7	8	9	10
1	< 20	0.000000	0.000000	0.000000	0.000200	0.001200	0.004600	0.017000	0.034000	0.065000	0.100000
2	20 - 50	0.000000	0.000000	0.000000	0.010000	0.040000	0.110000	0.230000	0.350000	0.460000	0.500000
3	50 - 500	0.000000	0.000000	0.022500	0.090000	0.215000	0.382500	0.545000	0.635000	0.665000	0.700000
4	500 - 2000	0.000000	0.060000	0.240000	0.480000	0.725000	0.870000	0.935000	0.950000	0.950000	0.950000

(iii) Distribution of vulnerability factors for a retaining wall affecting substantial facilities at the crest

Volume Class	Failure Volume (m^3)	L/H						
		<= 0.25	0.25 - 0.50	0.50 - 0.75	0.75 - 1.00	1.00 - 1.25	1.25 - 1.50	> 1.50
		1	2	3	4	5	6	7
1	< 20	0.000575	0.006250	0.000000	0.000000	0.000000	0.000000	0.000000
2	20 - 50	0.035000	0.009000	0.002000	0.000000	0.000000	0.000000	0.000000
3	50 - 500	0.231250	0.111250	0.040000	0.007500	0.000000	0.000000	0.000000
4	500 - 2000	0.282500	0.153750	0.066250	0.020000	0.002500	0.000000	0.000000

(iv) Distribution of vulnerability factors for a retaining wall affecting flimsy facilities at the crest

Volume Class	Failure Volume (m^3)	L/H						
		<= 0.25	0.25 - 0.50	0.50 - 0.75	0.75 - 1.00	1.00 - 1.25	1.25 - 1.50	> 1.50
		1	2	3	4	5	6	7
1	< 20	0.025500	0.002500	0.000000	0.000000	0.000000	0.000000	0.000000
2	20 - 50	0.500000	0.140000	0.020000	0.000000	0.000000	0.000000	0.000000
3	50 - 500	0.630000	0.285000	0.080000	0.015000	0.000000	0.000000	0.000000
4	500 - 2000	0.737500	0.375000	0.145000	0.040000	0.005000	0.000000	0.000000

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Table E2 - Matching of Hillside Units and Facilities (Sheet 1 of 5)

Catchment No.	Structures Matched	Footpaths Matched
C01	TS9	-
C02	TS8	-
C03	TS7	-
C04	1992/039_056_1 1992/039_056_2 1992/039_056_3	-
C05	1992/039_052_1 1992/039_052_2 1992/039_053_0 1992/039_054_0 1992/039_055_0 1992/039_S005_0 TS2	-
C06	1992/039_052_2 1992/039_053_0 1992/039_054_0 1992/039_055_0 1992/039_S005_0 TS2	-
C07	1992/039_052_1 1992/039_052_3	-
C08	1992/039_051_0	-
C09	1992/039_049_0	-
C10	TS1_1	F1
C11	TS1_1 TS1_2	-
C12	TW30_007_1 TW30_007_2 TW30_007_3 TW30_007_4	-

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Table E2 - Matching of Hillside Units and Facilities (Sheet 2 of 5)

Catchment No.	Structures Matched	Footpaths Matched
C13	TW30_007_3 TW30_008_1 TW30_008_2 TW30_008_3 TW30_008_4	-
C14	TS10	F3
C15	1992/039_020_1 1992/039_020_3 1992/039_021_1 1992/039_021_2 1992/039_021_3 1992/039_021_4 FYS_031_0	-
C16	1992/039_020_1 1992/039_020_3 1992/039_021_1 1992/039_021_2 1992/039_021_3 1992/039_021_4	-
C17	1992/039_020_1 1992/039_020_2	-
C18	1992/039_022_0	-
C19	1992/039_019_0	F6 F7
C20	1992/039_019_0	F6 F7
C21		F6 F7

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Table E2 - Matching of Hillside Units and Facilities (Sheet 3 of 5)

Catchment No.	Structures Matched	Footpaths Matched
C22	1992/039_019_0 CKT_003_0 CKT_004_0 CKT_005_0 TS11 TS12_1 TS12_2 TS12_3	-
C23	1992/039_027_0	-
C24	1992/039_026_0	-
C25	1992/039_025_0 TS4 TS5	-
C26	TS6	-
C27	CKT_001_0	-
C28	CKT_002_0 CKT_003_0	-
C29	CKT_004_0 CKT_005_0	F8
C30	CKT_003_0 CKT_004_0 CKT_005_0 TS11 TS12_1 TS12_2 TS12_3	-
C31	TS12_1 TS12_2 TS12_3	-
C32	TS11	-
C33	TS13	-

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Table E2 - Matching of Hillside Units and Facilities (Sheet 4 of 5)

Catchment No.	Structures Matched	Footpaths Matched
C34	FYS_009_1 FYS_009_2 FYS_010_2 FYS_011_0	-
C35	FYS_011_0	-
C36	FYS_009_1 FYS_009_2 FYS_010_2 FYS_011_0	-
C37	TW30_028_0	-
C38	TW30_028_0	-
C39	-	F10
C40	1992/039_011_0 FYS_007_1 FYS_007_2 FYS_008_0	-
C41	1992/039_012_0 1992/039_S010_2 FYS_007_2	-
C42	1992/039_S010_1 1992/039_S010_2 1992/039_S010_3 1992/039_S010_4 1992/039_S010_5 1992/039_S010_6 1992/039_S010_7 1992/039_S010_8	-
C43	1992/039_006_1	-
C44	1992/039_006_1 1992/039_006_8 1992/039_007_0	-

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Table E2 - Matching of Hillside Units and Facilities (Sheet 5 of 5)

Catchment No.	Structures Matched	Footpaths Matched
C45	1992/039_006_1 1992/039_006_10 1992/039_006_11 1992/039_006_12 1992/039_006_13 1992/039_006_2 1992/039_006_3 1992/039_006_4 1992/039_006_5 1992/039_006_6 1992/039_006_7 1992/039_006_8 1992/039_006_9	-
C46	1992/039_005_0	-
C47	1992/039_003_1	-
C48	1992/039_003_2	-
C54	TW30_025_0	-
C55	FYS_002_0 FYS_009_0	-
C56	-	F4
C57	-	F9

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Table E3 - Adjustment for Worst Credible Travel Distance

Travel Angle from Landslide Sources to Facilities (°)	Adjustment Factor to Worst Credible Travel Distance	
	Open Hillslope Failures	Channelized Debris Flows
15 - 20	0.6	0.8
20 - 25	0.8	1.0
25 - 30	1.0	1.2
30 - 35	1.2	1.4
35 - 40	1.4	1.6
> 40	1.6	1.8

Table E4 - Distribution of Width of Landslide

	Landslide Debris Volume (m^3)			
Expected Width of Landslide (m)	<= 20	20 - 50	50 - 500	> 500
	4	7	15	20

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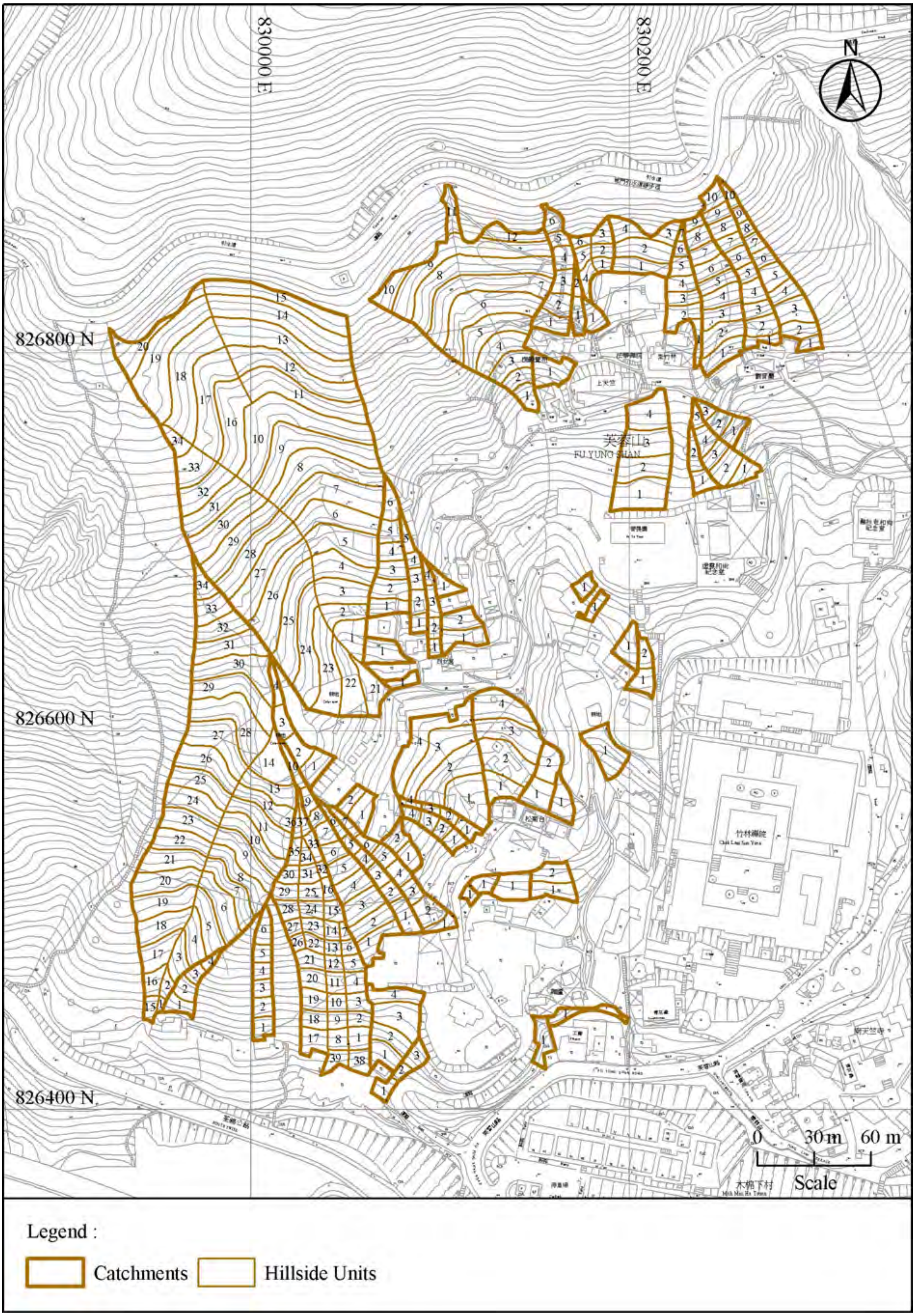

Figure E1 - Layout of Hillside Units

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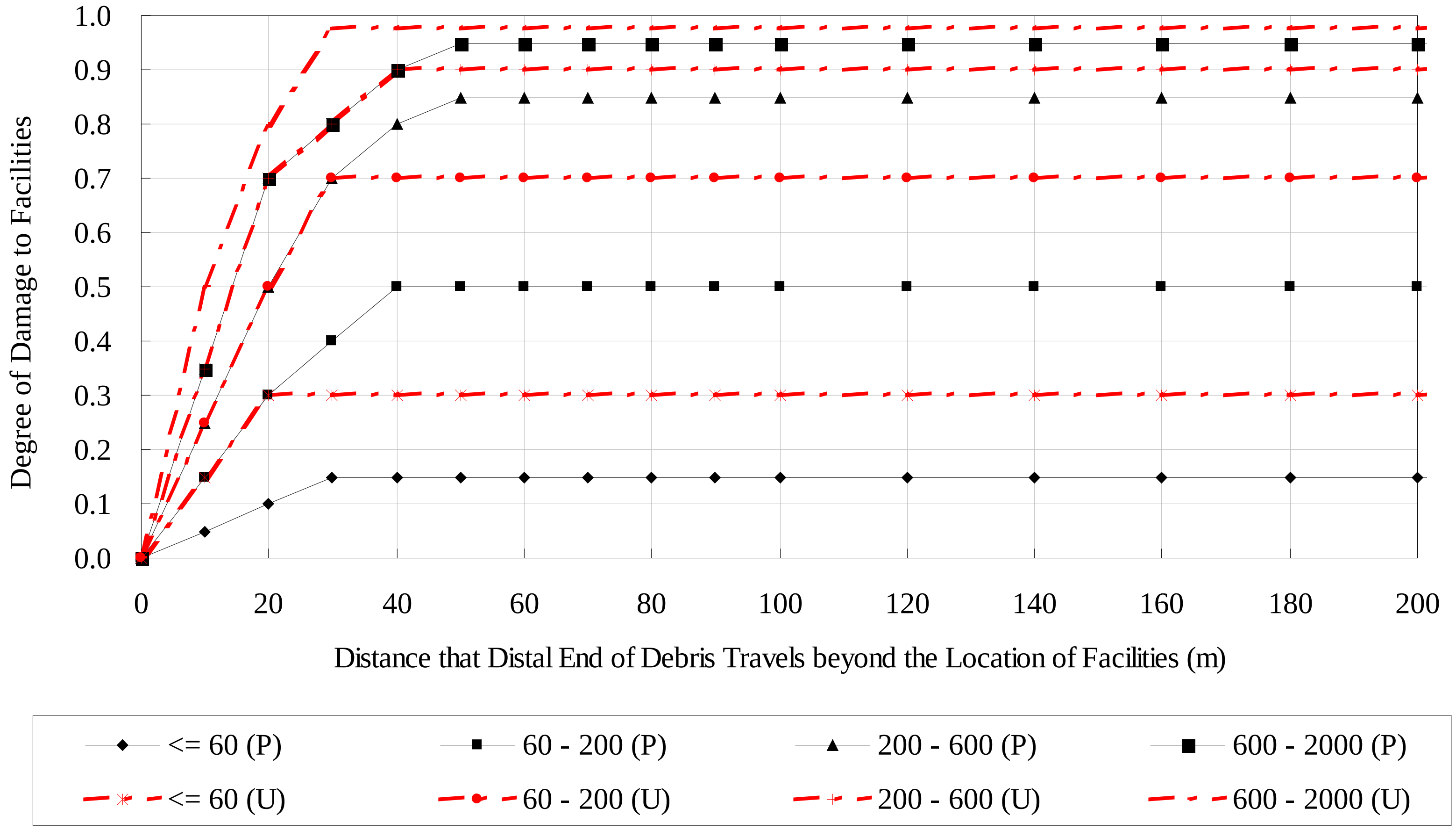

Note: Prepresents substantial structures while U represents flimsy structures or unprotected facilities.

Figure E2 - Degree of Damage to Facilities Affected by Different Types of Landslide Hazards

EXAMPLE:

(A) Sample data:

Type of failures: Open hillslope failure

Landslide volume: <= 60 m^3

Type of structure: Substantial structure

Travel angle from landslide source to structure: 50°

(B) Adjusted worst credible travel distance:

The worst credible travel distance = 40 m

The adjusted worst credible travel distance

$= 1.6 \times 40 \approx 65$ m

(C) Probability distribution of probable travel distance:

The probability distribution of the travel distance, based on a double triangular distribution, is as below:

Travel Distance (m)	Probability of Occurrence
5	0.011834
10	0.035503
15	0.059172
20	0.082840
25	0.106509
30	0.130178
35	0.147929
40	0.130178
45	0.106509
50	0.082840
55	0.059172
60	0.035503
65	0.011834

Figure E3 - Example for Calculation of Vulnerability Factors (Sheet 1 of 2)

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(D) Calculation of vulnerability factors

The following matrix is set up to combine the probability of occurrence of different debris travel distances with its corresponding degree of damage to the facility at different proximity from the landslide source (ref. Figure E2)

Debris Travel Distance	Probability of Occurrence	Plan Distance (m) of Facility from Source of Landslide / Degree of Damage to Facility												
		5	10	15	20	25	30	35	40	45	50	55	60	65
5	0.011834	0.0125	0	0	0	0	0	0	0	0	0	0	0	0
10	0.035503	0.0375	0.0125	0	0	0	0	0	0	0	0	0	0	0
15	0.059172	0.0625	0.0375	0.0125	0	0	0	0	0	0	0	0	0	0
20	0.082840	0.0875	0.0625	0.0375	0.0125	0	0	0	0	0	0	0	0	0
25	0.106509	0.1125	0.0875	0.0625	0.0375	0.0125	0	0	0	0	0	0	0	0
30	0.130178	0.1375	0.1125	0.0875	0.0625	0.0375	0.0125	0	0	0	0	0	0	0
35	0.147929	0.15	0.1375	0.1125	0.0875	0.0625	0.0375	0.0125	0	0	0	0	0	0
40	0.130178	0.15	0.15	0.1375	0.1125	0.0875	0.0625	0.0375	0.0125	0	0	0	0	0
45	0.106509	0.15	0.15	0.15	0.1375	0.1125	0.0875	0.0625	0.0375	0.0125	0	0	0	0
50	0.082840	0.15	0.15	0.15	0.15	0.1375	0.1125	0.0875	0.0625	0.0375	0.0125	0	0	0
55	0.059172	0.15	0.15	0.15	0.15	0.15	0.1375	0.1125	0.0875	0.0625	0.0375	0.0125	0	0
60	0.035503	0.15	0.15	0.15	0.15	0.15	0.15	0.1375	0.1125	0.0875	0.0625	0.0375	0.0125	0
65	0.011834	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.1375	0.1125	0.0875	0.0625	0.0375	0.0125
	P_i	**D_{i1}**	**D_{i2}**	**D_{i3}**	**D_{i4}**	**D_{i5}**	**D_{i6}**	**D_{i7}**	**D_{i8}**	**D_{i9}**	**D_{i10}**	**D_{i11}**	**D_{i12}**	**D_{i13}**
	V_j	**0.128402**	**0.116050**	**0.100814**	**0.083802**	**0.066198**	**0.049186**	**0.033950**	**0.021598**	**0.012574**	**0.006509**	**0.002811**	**0.000888**	**0.000148**

If P_i = Probability of occurrence of different debris travel distances, i = 1 to 13

D_{ij} = At a given debris travel distance, i, the degree of damage to facility at different proximity from landslide source, j = 1 to 13

$$V_j = \sum_{i=1}^{13} P_i \times D_{ij}$$

Figure E3 - Example for Calculation of Vulnerability Factors (Sheet 2 of 2)

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APPENDIX F

RISK CALCULATION

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F1. INTRODUCTION

This Appendix describes the combination of the hazard models and the consequence models described in Appendices D and E to calculate landslide risk at each of the affected facilities in terms of PIR, PLL and F-N curves. The risk calculation for overtopping of the Shing Mun catchwater is described separately in Appendix H.

F2. LANDSLIDE RISK IN TERMS OF PERSONAL INDIVIDUAL RISK

Landslide risk in terms of PIR at each affected facility was calculated as the product of the landslide frequency of the slopes/ hillsides affecting the facility and the consequence to the facility.

F2.1 Man-made Slopes

The spatial distribution of the PIR for the 68 structures affected by the man-made slopes is shown in Figure F1. The PIR for the four footpath sections affected by man-made slopes are tabulated in Table F1.

F2.2 Natural and Disturbed Hillsides

The spatial distribution of the PIR for the 91 structures affected by the natural and disturbed hillsides is shown in Figure F2. The PIR for the eight footpath sections affected by the hillsides are tabulated in Table F1.

F2.3 Combined Risk

The spatial distribution of the combined PIR for the 100 structures is shown in Figure 2. The combined PIR for the eleven footpath sections and the maximum individual risk at the footpath network are illustrated in Table F1.

F3. LANDSLIDE RISK IN TERMS OF POTENTIAL LOSS OF LIFE

Landslide risk in terms of PLL was calculated as the summation of the product of PIR and its average population at risk for all structures.

Table C2 shows the temporal distribution of population at risk of each type of the structures. Using Table C2, the landslide risk in terms of PLL for all structures was calculated as equal to 0.2350 per year. 35% of it comes from landslide risk due to the man-made slopes while the remaining 65% comes from the hillsides.

For the footpath sections, the total calculated PLL for the footpath network is 0.0030 per year. The calculation is shown in Table F2.

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F4. LANDSLIDE RISK IN TERMS OF F-N CURVES

Based on Table C2, the temporal probability of different numbers of people at landslide risk is given in Table F3. The shape of the F-N curve is governed by the cumulative temporal distribution/ probability given in Table F4. The results for landslide risk due to the man-made slopes and the hillsides are shown in Figures F3 and F4 respectively.

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Table F1 - Personal Individual Risk for Different Footpath Sections

Footpath Section	Personal Individual Risk			Estimated Head Count per Day [(1)]
	Man-made Slopes	Hillsides	Combined	
F1	-	1.50×10^{-4}	1.50×10^{-4}	700
F2	5.51×10^{-4}	-	5.51×10^{-4}	690
F3	5.42×10^{-3}	6.63×10^{-5}	5.49×10^{-3}	690
F4	-	3.00×10^{-4}	3.00×10^{-4}	240
F5	2.00×10^{-5}	-	2.00×10^{-5}	200
F6	-	2.16×10^{-4}	2.16×10^{-4}	70
F7	-	5.53×10^{-5}	5.53×10^{-5}	40
F8	-	1.39×10^{-4}	1.39×10^{-4}	70
F9	-	4.89×10^{-5}	4.89×10^{-5}	70
F10	-	2.19×10^{-4}	2.19×10^{-4}	40
F11	8.31×10^{-4}	-	8.31×10^{-4}	200

Notes:
(1) The data is based on Table C3.
(2) The maximum individual risk at the footpath network is equal to the weighted average of the combined PIR with due account of the temporal presence of the population, i.e.:
$[(1.50 \times 10^{-4} \times 700) + \ldots + (8.31 \times 10^{-4} \times 200)]/3010/100 = 1.5 \text{ x } 10^{-5}$

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Table F2 - Societal Risk for Footpath Network

Population Event (1)	Time Proportion (2)	Personal Individual Risk (3)	Potential Loss of Life (4)
93	1/100	1.51×10^{-5}	1.40×10^{-3}
281	1/300	5.04×10^{-6}	1.42×10^{-3}
93	1/1000	1.51×10^{-6}	1.40×10^{-4}
		Societal Risk =	0.003

Notes:

(1) The maximum estimated head count per day, i.e. 700 (see Table C3), was assumed to be the population on the footpath network. It was also assumed that 50% of the population spends 2 trips per day and the remaining population spends 1 trip per day. The net population on the footpath network therefore equals to 700/1.5 = 467. Three population events were considered for calculating the Societal Risk.

(2) This column shows the respective time proportion assumed for the three population events.

(3) This column shows the respective PIR calculated for the three population events. For example, the PIR for the first population events equals to $1.51 \times 10^{-3} \times 1/100 = 1.51 \times 10^{-5}$.

(4) This column calculates the Societal Risk in terms of Potential Loss of Life, which is the product sum of the population events and the respective Personal Individual Risk.

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Table F3 - Temporal Probability of Different Numbers of People at Landslide Risk

Number of People Present (N)	Temporal Probability of Landslide Risk for People = N		
	Man-made Slopes	Hillsides	Combined
0	2.83×10^{-3}	1.08×10^{-2}	1.36×10^{-2}
1	2.42×10^{-3}	7.85×10^{-3}	1.03×10^{-2}
2	5.60×10^{-3}	1.38×10^{-2}	1.94×10^{-2}
3	8.04×10^{-3}	2.41×10^{-2}	3.21×10^{-2}
4	2.66×10^{-3}	2.46×10^{-3}	5.12×10^{-3}
5	1.57×10^{-6}	7.24×10^{-5}	7.40×10^{-5}
6	5.40×10^{-3}	4.86×10^{-3}	1.03×10^{-2}
9	1.51×10^{-4}	6.21×10^{-4}	7.72×10^{-4}
10	6.09×10^{-7}	9.18×10^{-6}	9.79×10^{-6}
30	5.91×10^{-8}	5.30×10^{-7}	5.89×10^{-7}
60	2.96×10^{-8}	2.65×10^{-7}	2.95×10^{-7}

Table F4 - Cumulative Temporal Probability of Different Numbers of People at Landslide Risk

Number of People Present (N)	Cumulative Temporal Probability of Landslide Risk for People ≥ N		
	Man-made Slopes	Hillsides	Combined
0	2.71×10^{-2}	6.45×10^{-2}	9.16×10^{-2}
1	2.43×10^{-2}	5.38×10^{-2}	7.81×10^{-2}
2	2.19×10^{-2}	4.59×10^{-2}	6.78×10^{-2}
3	1.63×10^{-2}	3.21×10^{-2}	4.84×10^{-2}
4	8.22×10^{-3}	8.02×10^{-3}	1.62×10^{-2}
5	5.56×10^{-3}	5.56×10^{-3}	1.11×10^{-2}
6	5.55×10^{-3}	5.49×10^{-3}	1.10×10^{-2}
9	1.52×10^{-4}	6.31×10^{-4}	7.83×10^{-4}
10	6.97×10^{-7}	9.98×10^{-6}	1.07×10^{-5}
30	8.87×10^{-8}	7.95×10^{-7}	8.84×10^{-7}
60	2.96×10^{-8}	2.65×10^{-7}	2.95×10^{-7}

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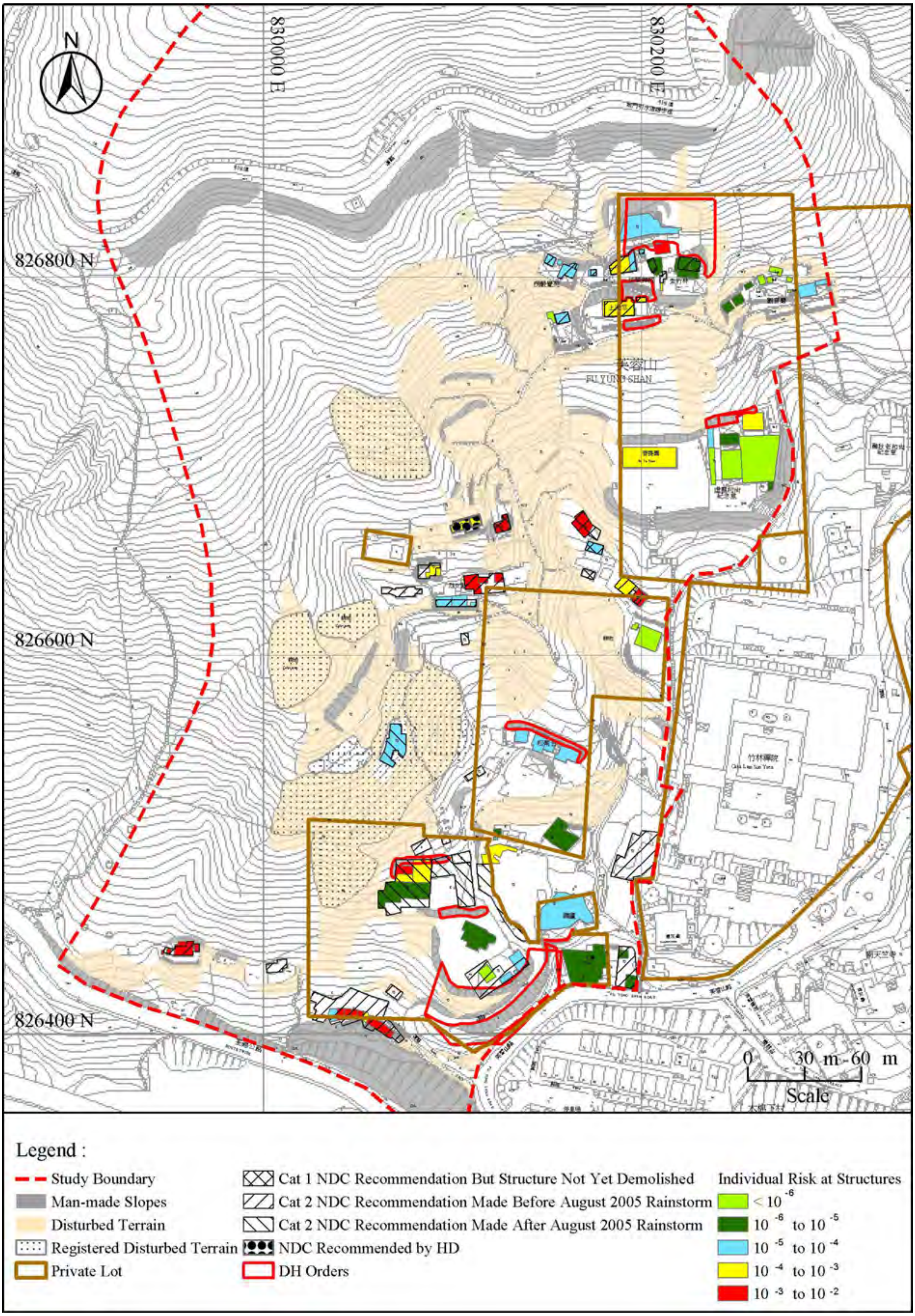

Figure F1 - Spatial Distribution of PIR of Structures Affected by Man-made Slopes

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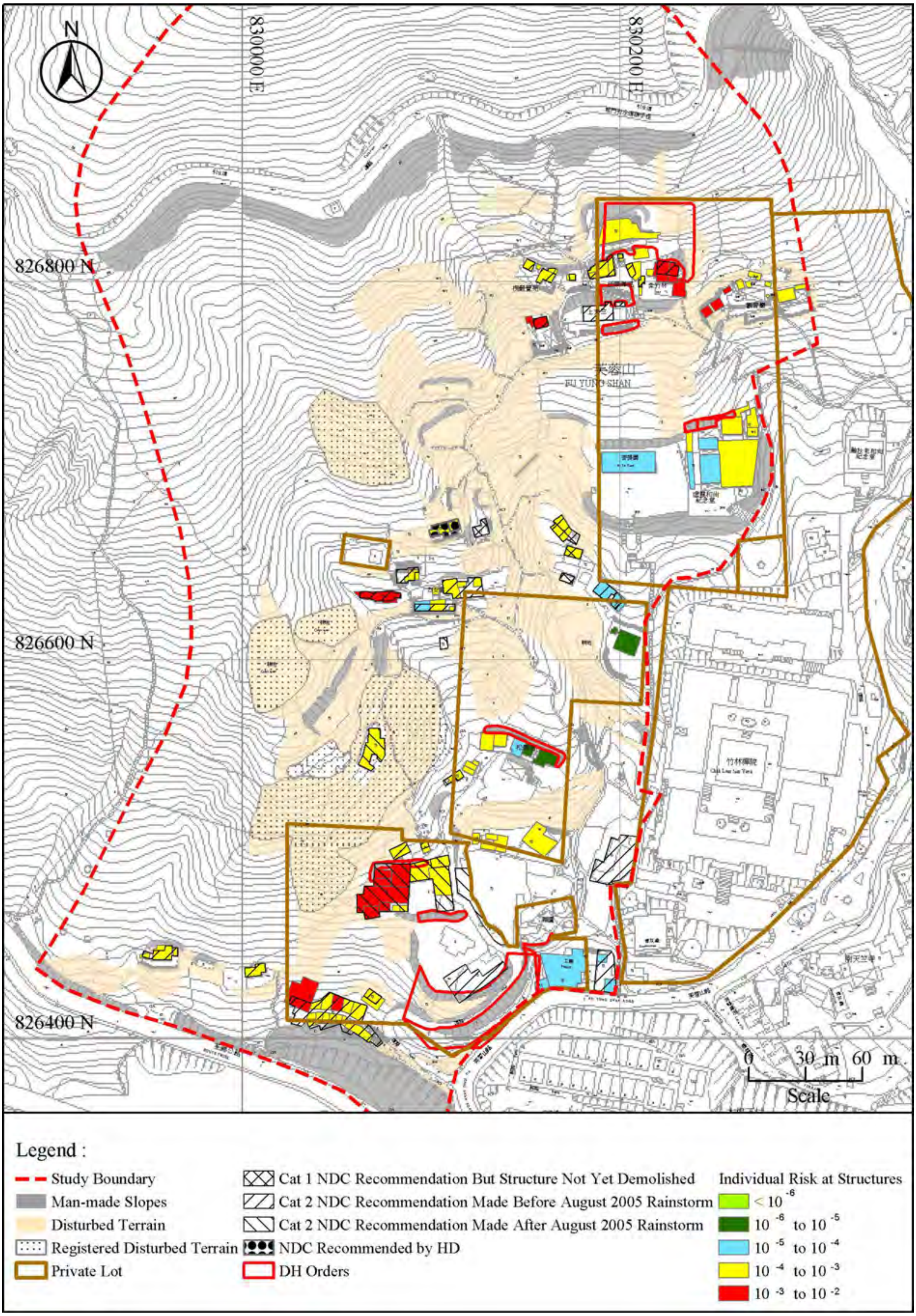

Figure F2 - Spatial Distribution of PIR of Structures Affected by Hillsides

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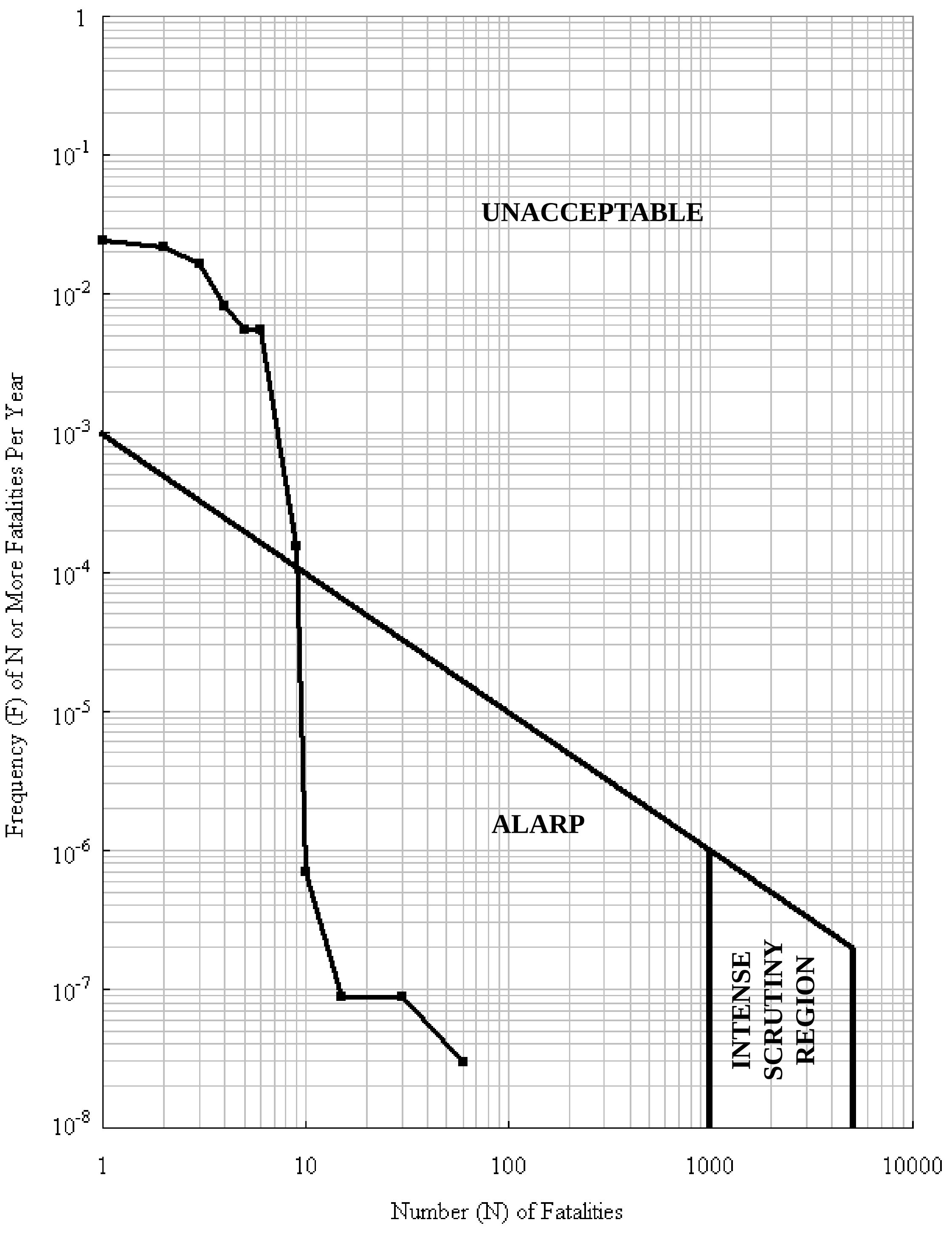

Figure F3 - F-N Curve for Structures Affected by Man-made Slopes

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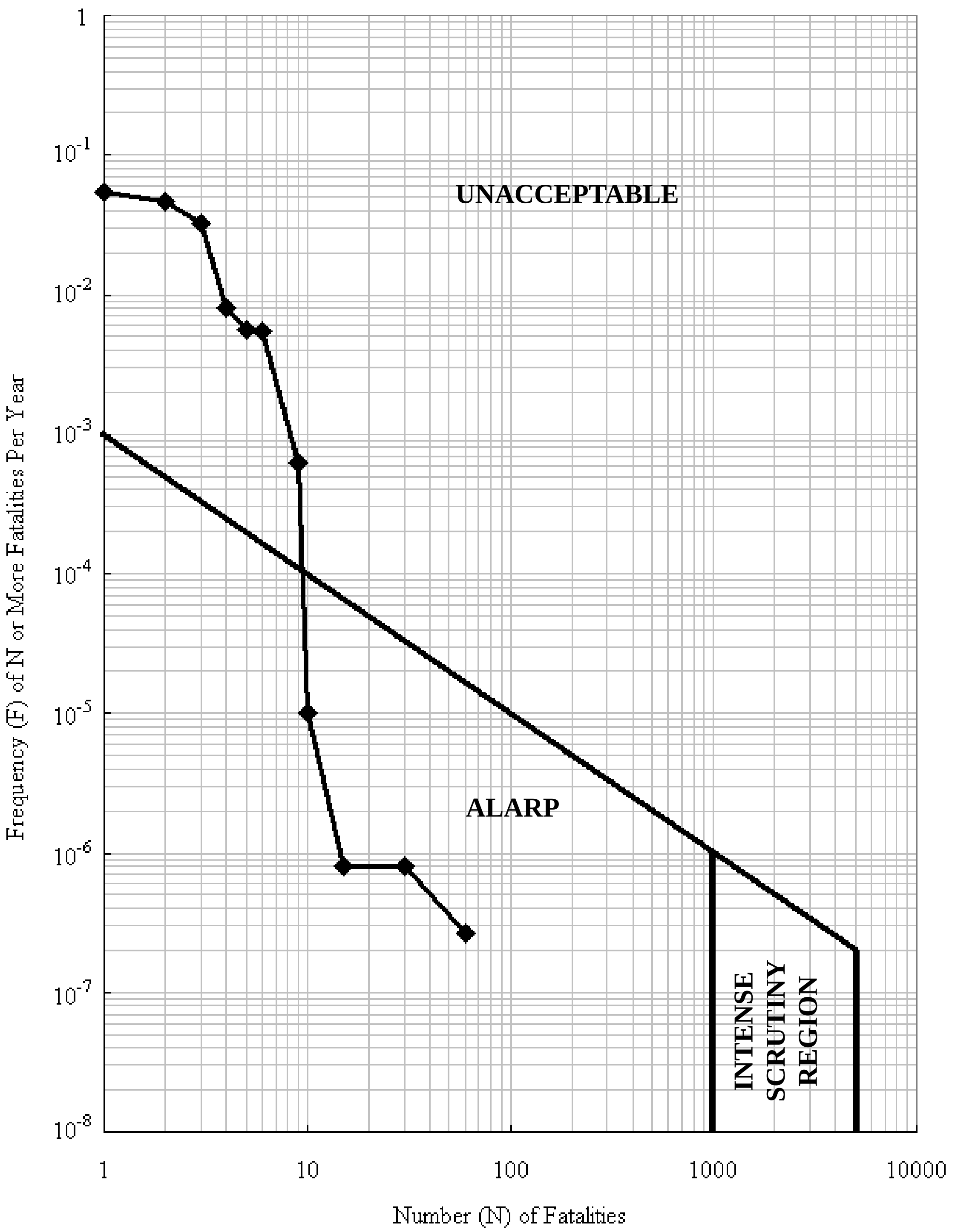

Figure F4 - F-N Curve for Structures Affected by Hillsides

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APPENDIX G

COMPARATIVE ASSESSMENT USING A QUALITATIVE APPROACH

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G1. INTRODUCTION

This Appendix describes a qualitative risk assessment carried out by the LIC to estimate qualitatively the level of risk arising from the man-made slopes on the mapped structures in Fu Yung Shan Tsuen, and a comparative assessment undertaken to calibrate the QRA results described in Appendix F using the results from the qualitative risk assessment.

G2. QUALITATIVE RISK ASSESSMENT

G2.1 Methodology

The qualitative risk assessment was carried out based on a qualitative risk rating framework. This involved assigning qualitative rating of the relative likelihood of the following three events with respect to each structure based on expert judgment:

(a) Likelihood of occurrence of landslides - factors considered included type, geometry (angle and height), conditions, surface drainage provision/potential infiltration and any history of past instability of a given man-made slope.

(b) Likelihood of landslide debris reaching a given structure - factors considered included the distance between the slope crest/toe and the structure, and the expected travel angle of the landslide.

(c) Likelihood of the structure being substantially damaged by the landslide debris - factors considered included the expected landslide volume, the extent of debris, which would be restrained by the structure and the form of the structure. The term ‘substantially affected’ means partial or complete collapse of the structure causing death to the occupants inside.

The qualitative rating comprises three levels of relative likelihood: ‘High’, ‘Moderate’ and ‘Low’. Expert judgment was applied to determine qualitative rating for each of the events based on basic desk study and field assessments.

For each structure, the qualitative ratings of the three events were combined through a risk matrix to derive the qualitative risk category, as shown in Table G1. The qualitative risk category reflects the relative landslide risk in a given structure.

While the qualitative risk category is an indication of the relative landslide risk based on expert judgment, the judgment has been made with subjective consideration of the possible tolerability of the landslide risk. In general, in the qualitative risk assessment process, qualitative risk category 1 was intended for circumstances that the landslide risk would not be tolerated. Qualitative risk category 2 was intended for circumstances that the landslide risk is significant but may be tolerable. Qualitative risk category 3 refers to circumstances that the landslide risk is not significant.

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G2.2 Calibration of Expert Judgment

The qualitative risk assessment was conducted by two senior professionals of the LIC between January and April 2006 following the framework described above.

One of the senior professional first completed the qualitative assessment for 47 structures which are all affected by man-made slopes. The 47 structures are made up of 70 individual units, some of which are used as kitchens and toilets. Qualitative risk ratings were assigned on each individual unit. Qualitative risk categories of all the individual units of a given structure were later integrated to form one qualitative risk category for the structure.

To calibrate the assessment carried out by the first senior professional, another senior professional selected randomly about 50% of the 47 structures for an independent assessment using the same framework. It was found that about 90% of the structures in the independent assessment have matched outcome with the first assessment. As such, the framework was considered reasonably robust and no particular adjustment to the framework or to the guidelines for exercising expert judgment would be needed.

G2.3 Findings

In total 70 nos. of individual units affected by the man-made slopes were assessed. 9 out of 70 individual units assessed did not have any man-made slope being close enough to the structure to be of a concern. The summary of qualitative risk rating of each event for the remaining 61 individual units is given in Table G2. More than a half of the 61 individual units (i.e. 34 nos.) have 'Moderate' likelihood of occurrence of landslide. 57 out of the 61 individual units have 'High' to 'Moderate' likelihood of landslide reaching the individual units, reflecting the fact that a significant portion of the structures in Fu Yung Shan Tsuen are built close to man-made slopes. Based on these qualitative risk ratings, qualitative risk categories were assigned on all individual units of a given structure, which were subsequently integrated to form one combined risk category for the structure. Table G3 summarizes the outcome of the qualitative risk assessment. 44, 3 and 1 nos. of structures were assessed to have qualitative risk category 1, 2 and 3 respectively. Figure G1 shows the spatial distribution of the structures according to their qualitative risk categories.

G3. COMPARATIVE ASSESSMENT

G3.1 Methodology

The QRA result of each of the 47 structures assessed in the qualitative risk assessment are tabulated in Table G4 against their counterpart results from the qualitative risk assessment.

To compare the results from the two different assessments, the following equalities were assumed:

(a) QRA results $>= 10^{-4} \equiv$ Type 1 action
(b) QRA results $>= 10^{-5}$ and $< 10^{-4} \equiv$ Type 2 action
(c) QRA results $< 10^{-5} \equiv$ Type 3 action

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In the absence of available risk criteria for man-made slopes, the risk tolerability limits given in GEO Report No. 75 were adopted. Such criteria were developed for natural terrain landslides. It is arguable that the criteria for man-made slopes could be more stringent than those for natural terrain. However, as squatter population is, to some extent, 'voluntary' in their exposure to landslide risk, they could be willing to tolerate a higher risk level. Therefore, GEO Report No. 75 was used as a reference.

It should be noted that the equalities above were assumed in a convenient manner using the available information in hand. The results from the two assessments have not been rigorously benchmarked and calibrated. At the moment, there are no fixed methods as to how to compare the results. The equalities were assumed and applied to provide a preliminary means for calibration of the QRA results. Other means of comparison may be employed which would likely lead to different outcomes.

Based on the equalities assumed above, a rating matrix was developed for the comparative assessment, which was shown in Table G5.

G3.2 Findings

27 out of 47 structures score 0, i.e. have matched risk results. 15 structures have score -1 and another five structures have score -2. There were no structures with positive scores. The results are tabulated in Table G4 and plotted in Figure G2. Their spatial distribution is shown in Figure G3.

There were five structures with a score of -2. The discrepancy for two of them is due to the omission in the consideration of the spatial relationship between the extent of a given slope and the size of the structure affected in the qualitative risk assessment. This was duly taken into account in the QRA (see Section E5.1 of Appendix E). The difference for the remaining three structures with a score of -2 is due to the low resolution of the qualitative risk rating framework in assessing proximity between a given slope and the structure affected. The low resolution of the model resulted in a more conservative assessment.

Notwithstanding, the results from the two risk assessments are in general comparable with the qualitative risk assessment slightly more conservative than the QRA. This outcome follows the general observations on the differences between qualitative and quantitative risk assessments carried out elsewhere (Wong and Ko, 2005).

G4. REFERENCE

Wong, H.N. & Ko, F.W.Y. (2005). Landslide Risk Assessment - Application and Practice. Special Project Report No. SPR 4/2005, Geotechnical Engineering Office, Hong Kong, 311 p.

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Table G1 - Qualitative Risk Rating Framework
(Note: Qualitative risk categories 1, 2 or 3 reflect the relative level of landslide risk)

Likelihood of occurrence of landslide = HIGH

Likelihood of landslide reaching the structure / Likelihood of squatter being substantially affected by the impact of landslide	High	Moderate	Low
High	1	1	1
Moderate	1	1	1
Low	1	1	2

Likelihood of occurrence of landslide = MODERATE

Likelihood of landslide reaching the structure / Likelihood of squatter being substantially affected by the impact of landslide	High	Moderate	Low
High	1	1	1
Moderate	1	1	2
Low	1	2	2

Likelihood of occurrence of landslide = LOW

Likelihood of landslide reaching the structure / Likelihood of squatter being substantially affected by the impact of landslide	High	Moderate	Low
High	1	1	2
Moderate	1	2	2
Low	2	2	3

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Table G2 - Measured Number of Individual Units in Different Groups of Qualitative Risk Ratings

Likelihood of occurrence of landslide = HIGH

Likelihood of squatter being substantially affected by the impact of landslide \ Likelihood of landslide reaching the structure	High	Moderate	Low
High	11	3	0
Moderate	5	0	0
Low	0	0	0

Likelihood of occurrence of landslide = MODERATE

Likelihood of squatter being substantially affected by the impact of landslide \ Likelihood of landslide reaching the structure	High	Moderate	Low
High	9	7	2
Moderate	10	5	1
Low	0	0	0

Likelihood of occurrence of landslide = LOW

Likelihood of squatter being substantially affected by the impact of landslide \ Likelihood of landslide reaching the structure	High	Moderate	Low
High	0	2	2
Moderate	2	2	0
Low	0	0	0

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Table G3 - Summary of Results of Qualitative Risk Assessment (Sheet 1 of 2)

Structure No.	Individual Unit No.	Qualitative Risk Rating			Qualitative Risk Category	
		Likelihood of Hazard to Occur	Likelihood of Hazard Reaching	Likelihood of being Substantially Affected	Individual Units	Structure
1992/039_003_1	C - 53 - SS - 1	High	High	Moderate	1	1
	C - 53 - SS - 2	High	High	Moderate	1	
1992/039_006_1	C - 51 - SS - 1	High	Moderate	High	1	1
1992/039_006_2	C - 51 - SS - 15	High	High	High	1	1
1992/039_006_3	C - 51 - SS - 12	Low	Low	High	2	2
1992/039_006_4	C - 51 - SS - 13	High	High	High	1	1
1992/039_006_5	C - 51 - SS - 14	High	High	High	1	1
1992/039_006_6	C - 51 - SS - 16	High	High	High	1	1
1992/039_006_7	C - 51 - SS - 2	High	High	High	1	1
1992/039_008_1	D - 48 - SS - 1	High	High	High	1	1
	D - 48 - SS - 2	High	High	High	1	
	D - 48 - SS - 5	High	High	High	1	
1992/039_008_2	D - 48 - SS - 4	High	Low	High	1	1
1992/039_020_1	B - 27 - SS - 2	Moderate	High	High	1	1
1992/039_020_2	B - 27 - SS - 3	Moderate	High	High	1	1
1992/039_020_3	B - 27 - SS - 4	Moderate	High	High	1	1
1992/039_021_1	B - 27 - SS - 1	High	High	Moderate	1	1
1992/039_021_2	B - 28 - SS - 1	High	High	High	1	1
1992/039_021_3	B - 28 - SS - 2	High	High	High	1	1
1992/039_022_0	B - 24 - SS - 1	High	High	High	1	1
	B - 24 - SS - 2	Moderate	High	High	1	
1992/039_025_0	B - 29 - SS - 3	Moderate	High	Moderate	1	1
1992/039_026_0	B - 23 - SS - 2	Moderate	High	Moderate	1	1
1992/039_027_0	B - 23 - SS - 3	Moderate	High	High	1	1
1992/039_030_0	B - 22 - SS - 1	High	High	High	1	1
1992/039_047_0	A - 10 - SS - 1	Moderate	High	Moderate	1	1
	A - 10 - SS - 2	Moderate	High	Moderate	1	
1992/039_049_0	A - 4 - SS - 1	Moderate	High	Moderate	1	1
	A - 4 - SS - 2	Moderate	Moderate	High	1	
	A - 4 - SS - 3	Moderate	High	Moderate	1	
	A - 4 - SS - 4	Moderate	Moderate	Moderate	1	
	A - 4 - SS - 5	Moderate	High	Moderate	1	
1992/039_051_0	A - 5 - SS - 1	Moderate	Moderate	Moderate	1	1
	A - 5 - SS - 2	Moderate	Moderate	Moderate	1	
1992/039_052_1	A - 6 - SS - 2	High	High	Moderate	1	1
1992/039_052_2	A - 6 - SS - 3	Moderate	High	Moderate	1	1

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Table G3 - Summary of Results of Qualitative Risk Assessment (Sheet 2 of 2)

Structure No.	Individual Unit No.	Qualitative Risk Rating			Qualitative Risk Category	
		Likelihood of Hazard to Occur	Likelihood of Hazard Reaching	Likelihood of being Substantially Affected	Individual Units	Structure
1992/039_053_0	A - 7 - SS - 8	Moderate	High	High	1	1
1992/039_054_0	A - 7 - SS - 9	Moderate	Low	Moderate	2	2
1992/039_055_0	A - 6 - SS - 4	Moderate	Moderate	Moderate	1	1
1992/039_056_1	A - 7 - SS - 3	Low	High	Moderate	1	1
1992/039_056_2	A - 7 - SS - 4	Low	High	Moderate	1	1
1992/039_S005_0	A - 2 - SS - 1	High	High	High	1	1
1992/039_S008_0	D - 42 - SS - 12	High	Moderate	High	1	1
1992/039_S010_1	D - 46 - SS - 16	Moderate	High	High	1	1
	D - 46 - SS - 17	Moderate	Low	High	1	
1992/039_S010_3	D - 46 - SS - 18	Moderate	Moderate	High	1	1
FYS_031_0	B - 21 - SS - 1	Moderate	Moderate	High	1	1
	B - 21 - SS - 2	Moderate	Moderate	High	1	
	B - 21 - SS - 3	Moderate	Moderate	High	1	
	B - 21 - SS - 4	Moderate	Moderate	High	1	
	B - 21 - SS - 6	Moderate	High	High	1	
TS1_1	A - 11 - SS - 1	Moderate	Moderate	Moderate	1	1
TS2	A - 2 - SS - 2	High	High	Moderate	1	1
TS3	B - 18 - SS - 2	High	High	High	1	1
TS4	B - 29 - SS - 2	Moderate	Moderate	High	1	1
TS5	B - 29 - SS - 1	Moderate	Low	High	1	1
TS8	A - 8 - SS - 4	Low	Low	Low	3	3
	A - 8 - SS - 5	Low	Low	Low	3	
	A - 8 - SS - 6	Low	Moderate	High	1	
	A - 8 - SS - 7	Low	Low	Low	3	
	A - 8 - SS - 8	Low	Low	Low	3	
	A - 8 - SS - 13	Moderate	High	High	1	
TS9	A - 8 - SS - 1	Low	Low	High	2	1
	A - 8 - SS - 2	Low	Moderate	High	1	
TW30_007_1	B - 18 - SS - 3	Moderate	High	Moderate	1	1
TW30_008_1	B - 18 - SS - 5	Moderate	High	Moderate	1	1
TW30_008_2	B - 18 - VH - 2	Low	Moderate	Moderate	2	2
TW30_028_0	D - 37 - SS - 1	Moderate	High	Moderate	1	1

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Table G4 - Comparison of Results from the Qualitative Risk Assessment and the QRA (Sheet 1 of 2)

Structure No.	Qualitative Risk Category from Qualitative Risk Assessment	Landslide Risk in terms of PIR from QRA	Rating based on Comparative Assessment
1992/039_003_1	1	1.97×10^{-3}	0
1992/039_006_1	1	1.01×10^{-3}	0
1992/039_006_2	1	1.14×10^{-3}	0
1992/039_006_3	2	7.30×10^{-5}	0
1992/039_006_4	1	1.14×10^{-3}	0
1992/039_006_5	1	1.14×10^{-3}	0
1992/039_006_6	1	1.13×10^{-3}	0
1992/039_006_7	1	3.17×10^{-4}	0
1992/039_008_1	1	1.78×10^{-5}	-1
1992/039_008_2	1	0.00	-2
1992/039_020_1	1	2.27×10^{-5}	-1
1992/039_020_2	1	2.27×10^{-5}	-1
1992/039_020_3	1	2.36×10^{-5}	-1
1992/039_021_1	1	2.03×10^{-3}	0
1992/039_021_2	1	1.84×10^{-3}	0
1992/039_021_3	1	1.78×10^{-3}	0
1992/039_022_0	1	7.85×10^{-4}	0
1992/039_025_0	1	1.38×10^{-4}	0
1992/039_026_0	1	2.13×10^{-5}	-1
1992/039_027_0	1	1.20×10^{-3}	0
1992/039_030_0	1	1.06×10^{-3}	0
1992/039_047_0	1	1.10×10^{-4}	0
1992/039_049_0	1	5.41×10^{-5}	-1
1992/039_051_0	1	2.62×10^{-5}	-1
1992/039_052_1	1	1.76×10^{-4}	0
1992/039_052_2	1	4.20×10^{-5}	-1
1992/039_053_0	1	1.06×10^{-4}	0
1992/039_054_0	2	3.95×10^{-6}	-1
1992/039_055_0	1	3.96×10^{-5}	-1
1992/039_056_1	1	7.89×10^{-6}	-2
1992/039_056_2	1	7.89×10^{-6}	-2
1992/039_S005_0	1	1.87×10^{-5}	-1
1992/039_S008_0	1	9.95×10^{-4}	0
1992/039_S010_1	1	1.45×10^{-3}	0
1992/039_S010_3	1	1.19×10^{-4}	0
FYS_031_0	1	1.12×10^{-4}	0
TS1_1	1	4.27×10^{-7}	-2
TS2	1	1.03×10^{-3}	0
TS3	1	1.11×10^{-6}	-2
TS4	1	1.74×10^{-3}	0

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Table G4 - Comparison of Results from the Qualitative Risk Assessment and the QRA (Sheet 2 of 2)

Structure No.	Qualitative Risk Category from Qualitative Risk Assessment	Landslide Risk in terms of PIR from QRA	Rating based on Comparative Assessment
TS5	1	1.78×10^{-3}	0
TS8	3	0.00	0
TS9	1	1.48×10^{-5}	-1
TW30_007_1	1	3.53×10^{-4}	0
TW30_008_1	1	4.87×10^{-5}	-1
TW30_008_2	2	3.48×10^{-6}	-1
TW30_028_0	1	6.62×10^{-5}	-1

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Table G5 - Rating Matrix Used in Comparative Assessment

Quantitative / Qualitative		Personal Individual Risk based on QRA		
		(>= 10^{-4})	(>= 10^{-5} and < 10^{-4})	(< 10^{-5})
Qualitative Risk Category	1	0	-1	-2
	2	+1	0	-1
	3	+2	+1	0

Notes :

(1) The comparison is based on the consideration of (i) the qualitative risk categories and (ii) the QRA results and the risk tolerability limits given in GEO Report No. 75 for natural terrain landslide risk.

(2) '+1' indicates that the risk calculated using QRA is one grade greater than qualitative risk category.

(3) '-1' indicates that the risk calculated using QRA is one grade lower than qualitative risk category.

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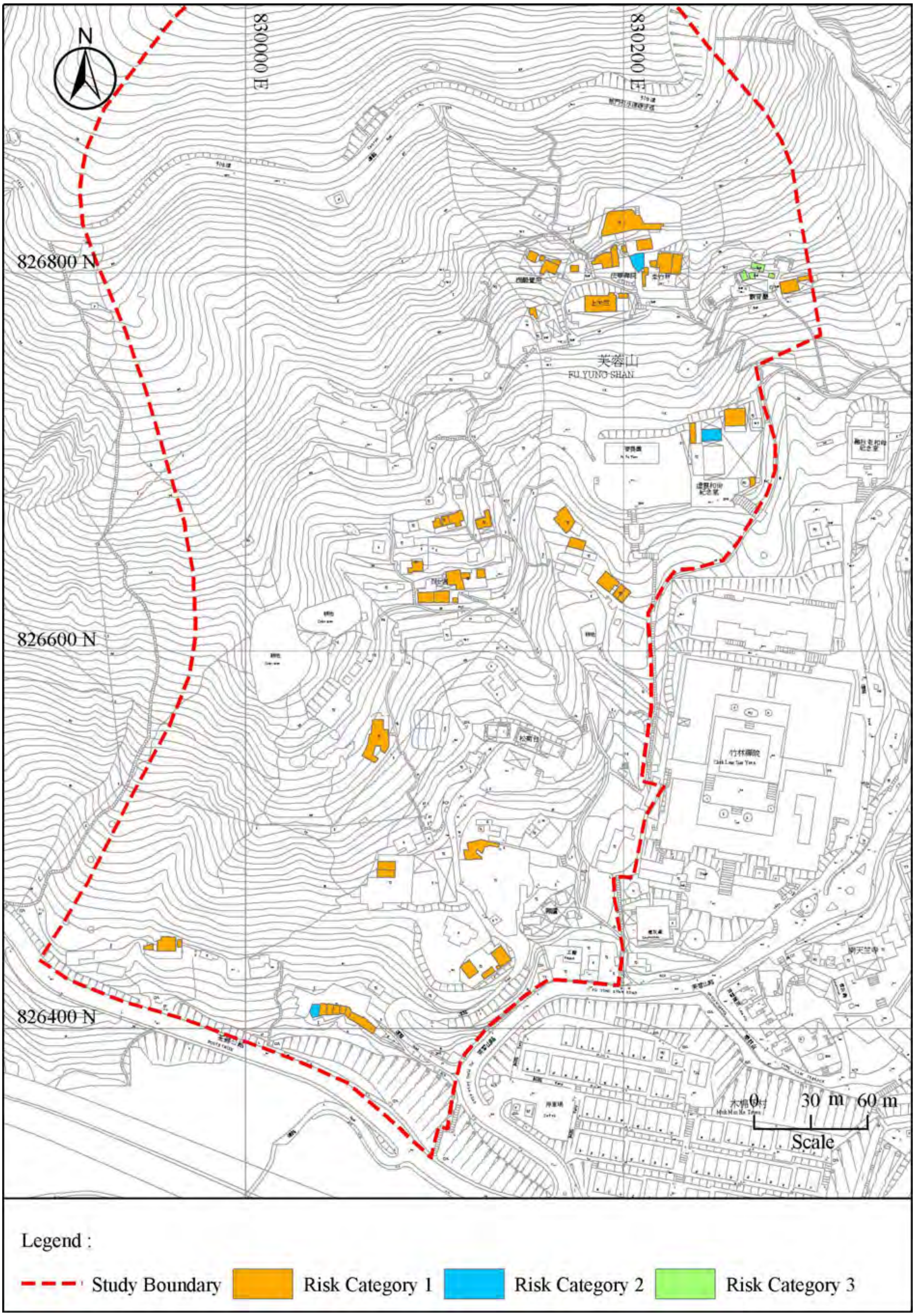

Figure G1 - Results of Qualitative Risk Assessment

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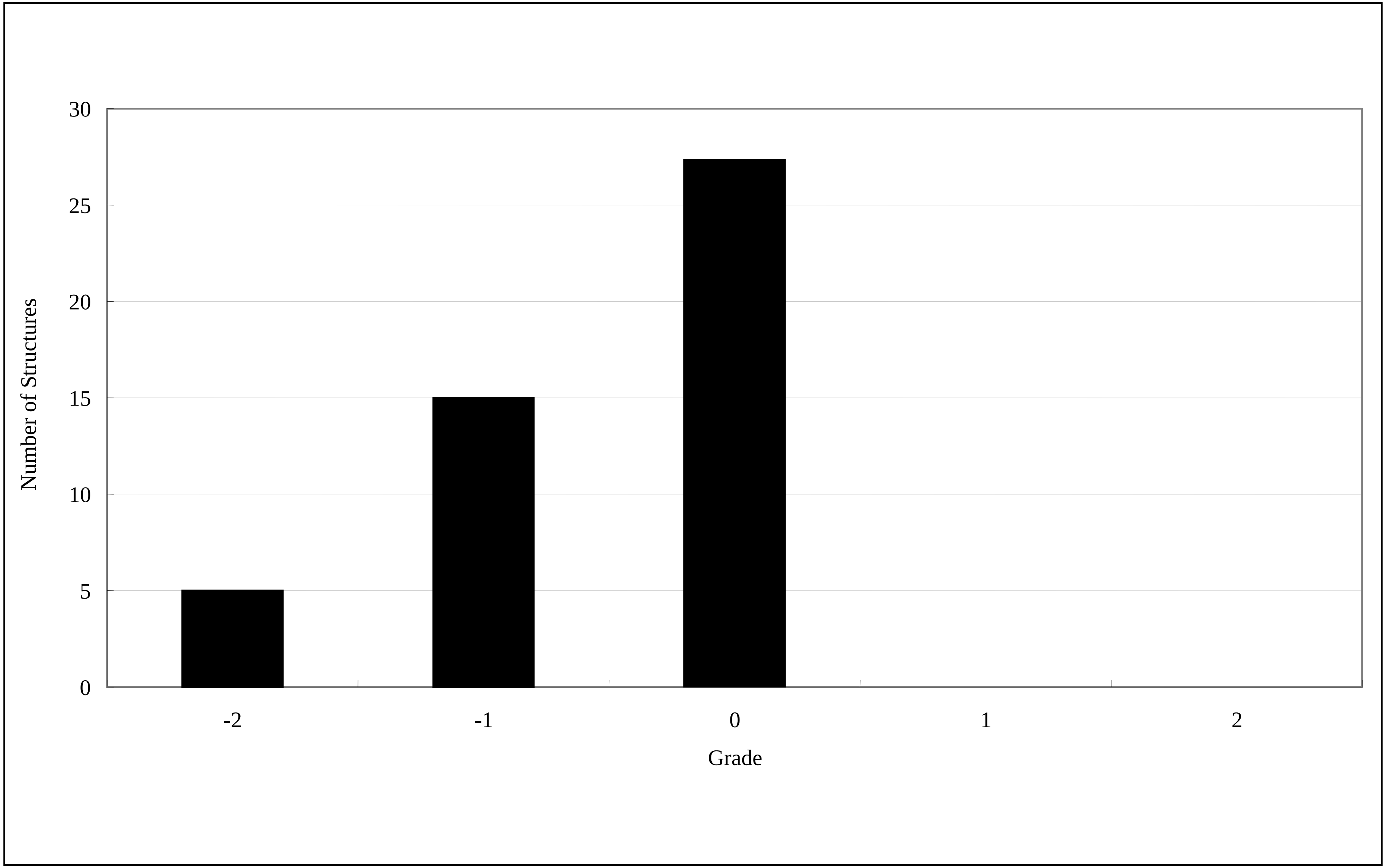

Figure G2 - Distribution of Rating of Comparative Assessment

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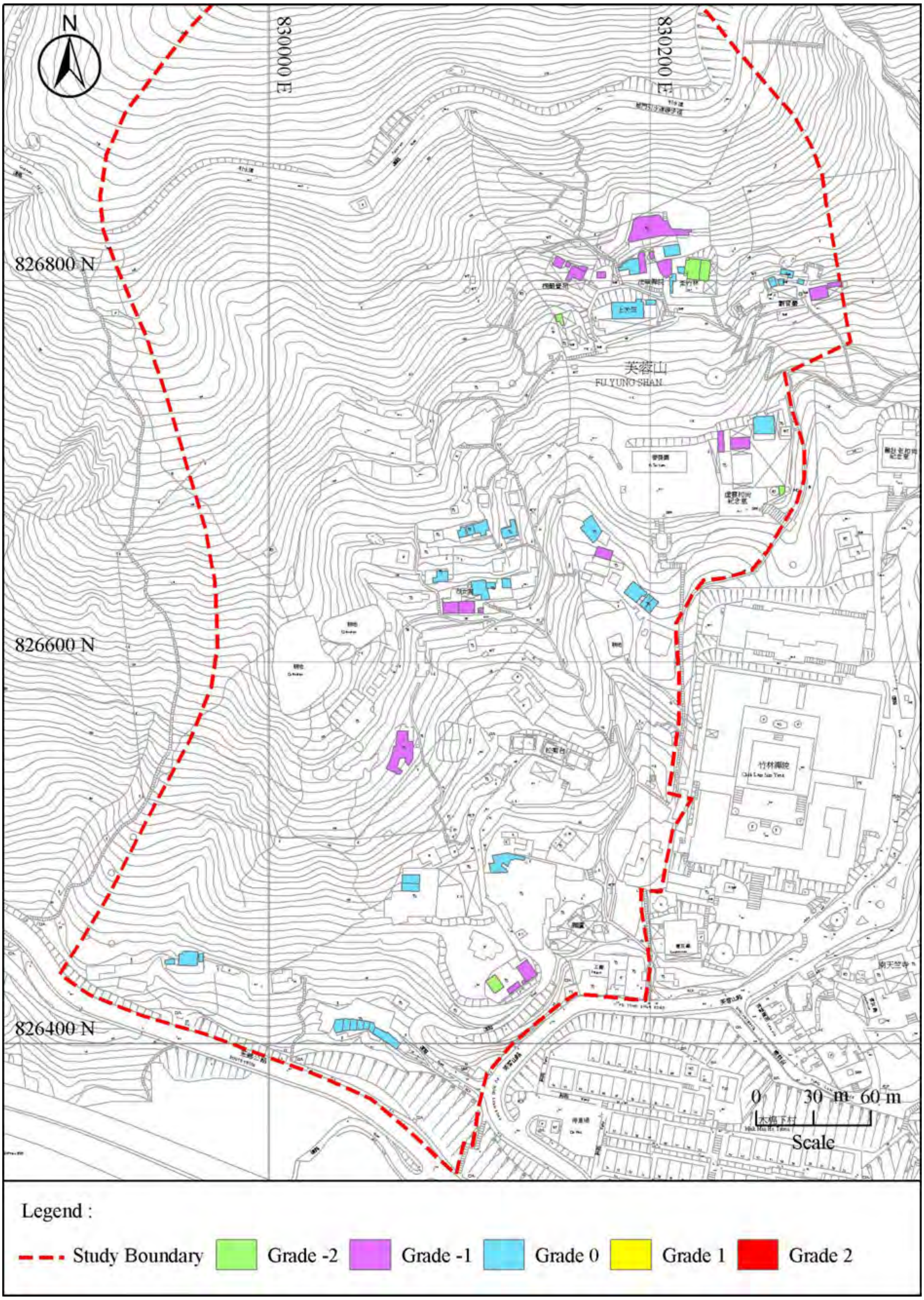

Figure G3 - Results of Comparative Assessment

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APPENDIX H

ASSESSMENT OF RISK DUE TO OVERTOPPING OF CATCHWATER

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CONTENTS

H1. INTRODUCTION

This Appendix describes the risk assessment for the structures in Fu Yung Shan Tsuen with respect to overtopping of the Shing Mun catchwater (the catchwater) due to blockage by landslide debris from the man-made slopes and the natural hillside overlooking it.

H2. DESCRIPTION OF CATCHWATER AND OVERFLOW WEIRS

The length of the section of the catchwater that would affect the structures in Fu Yung Shan Tsuen in the event of overtopping of surface water is shown in Figure H1. Its length is about 360 m. The locations of the overflow weirs along the catchwater are also indicated in Figure H1. For ease of reference, the overflow weirs in question have been labeled as overflow weirs A to F.

The catchwater is largely in the form of an open trapezoidal channel (except near the overflow weir A), having a depth of 2.7 m, and top and base widths of 5.1 m and 2.3 m respectively. The catchwater near and upstream of the overflow weir A is in the form of a box section of about 70 m long, 3.0 m deep and 4.0 m wide. The catchwater generally has a gradient of 1:700 to 1:800. Based on the WSD Sketch No. SK 3879/1, the catchwater has different capacities at different sections. Near Chainage CH 4401, the capacity is 32.34 m^3/s while near Chainage CH 4179, 41.88 m^3/s. Typical sections of the catchwater are shown in Figure H2.

The overflow weirs are in the form of one or multiple of rectangular openings and are provided along the catchwater at an approximately interval of 200 m to 250 m. The chainages, invert levels and dimensions of the overflow weirs are summarized in Table H1.

The dimensions and levels of the catchwater and the overflow weirs were determined based on the 1:1000 topographic base map, field surveys and measurements carried out in connection with the QRA, and WSD as-built records.

H3. LIKELIHOOD OF BLOCKAGE OF CATCHWATER

H3.1 Man-made Slopes

There are four man-made slopes on the sides of the overtopping section of the catchwater, namely, features No. 6SE-D/CR208, 7SW-C/C559, 7SW-C/C560 and 7SW-C/C561 (Figure H3). The hazard model described in Appendix D for man-made slopes was adopted to assess the frequency of failures of the slopes for different types of landslide hazards.

The component for assessing proximity in the consequence model described in Appendix E for man-made slopes was adopted. Given that the slopes are at the immediate edge of the catchwater, it was assumed that should the slopes fail, the landslide debris would definitely fall into the catchwater. The probability of landslide debris reaching the catchwater is therefore a unity. The part on the determination of vulnerability factors is not relevant to the present case, as the event of blockage involves no risk-to-life with respect to the catchwater itself.

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H3.2 Natural Hillside

H3.2.1 Hazard Model

As discussed in Appendix D, the study area was divided into two main portions: the hillside below the catchwater and that above. The hillside above the catchwater affects the facilities at Fu Yung Shan Tsuen in the event that landslide debris block the catchwater and cause overtopping of muddy water downhill to Fu Yung Shan Tsuen.

The open hillside overlooking the overtopping section of the catchwater is largely natural. An open hillside catchment was delineated as shown in Figure H3.

Similar to that described in Appendix D, the base-line natural hillside landslide frequency for the catchment was calculated as below:

- Natural hillside area within the study area = 0.105 km^2
- Total catchment area affecting catchwater = 0.035 km^2
- Base-line natural hillside landslide frequency for the entire study area = (1/24 + 3.5/70) = 0.092 no./ yr
- Base-line natural hillside landslide frequency, $(f_{bc})_{NT}$, for the catchment affecting the catchwater = (1/24 + 3.5/70) × (0.035/0.105) = 0.031 no./ yr

The catchment was sub-divided into a number of hillside units (Figure H3) and each hillside unit, *i*, has, similarly, a weighted percentage share of the base-line landslide frequency, $(f_{bc})_{NT}$, that depends on the plan area of the hillside unit only. There are no other attributes adjusting the base-line landslide frequency because of a lack of quality information on the terrain characteristic of the catchment. On the other hand, the relatively uniform terrain profile of the catchment renders the effects of terrain susceptibility not very significant.

The landslide frequency for each hillside unit, *i*, of the catchment was calculated as below:

$$f_i = (f_{bc})_{NT} \times \frac{(A_{NT})_i}{\sum (A_{NT})_i}$$

The magnitude-frequency model as adopted in Appendix D was also employed for assessing the landslide frequency of different types of landslide hazards. Section D4.2.1 should be referred to and is not repeated here.

H3.2.2 Consequence Model

Similar to the consequence model adopted for man-made slopes, the parts of the consequence model described in Sections E3.1 to E3.3 of Appendix E were adopted in assessing the likelihood of landslide debris reaching the catchwater. The model included the division of hillside units, the assessment of possible debris runout paths and the assessment of debris mobility. The part on assessment of vulnerability factors is not relevant.

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H3.3 Assessment of Likelihood of Blockage of Catchwater

In applying the hazard models and the consequence models to assess the likelihood of blockage of the catchwater, the chances of blockage by landslide debris of different volumes were assumed and shown in Table H2.

The likelihood of blockage of the catchwater is given by a combined consideration of the likelihood of failure of the man-made slopes and the hillsides, the likelihood of landslide debris reaching the catchwater and the chance of blockage by landslide debris of different volumes. Based on this, the calculated probability of blockage of the catchwater due to failures from the man-made slopes is 8.45×10^{-4} per year while that due to failures from the natural hillside is 3.78×10^{-3} per year, which give the total probability of blockage of the catchwater to 4.63×10^{-3} per year.

H4. OVERTOPPING OF CATCHWATER

H4.1 Overtopping Behaviour

Based on the above information of the catchwater and the overflow weirs together with the reference to historical landslide incidents affecting catchwater, it was estimated that, in the event of blockage by landslide debris at any location along the overtopping section of the catchwater, an overtopping length upstream of the blockage location would be about 60 m. From this, the overtopping section of the catchment can be divided into six sub-sections of equal length of 60 m.

H4.2 Overtopping Effects to Facilities

Overtopping of the catchwater would increase the amount of infiltration into the hillsides just below the catchwater. This would worsen the hillside conditions and aggravate the chance of failures of that part of the hillsides. Overtopping of the catchwater would also result in uncontrolled overflow of surface water together with entrained debris in the form of debris flood downhill to Fu Yung Shan Tsuen possibly at a high speed. It may impact on the structures and cause damages. The effects on footpaths were considered negligible and were therefore not assessed in the QRA.

H4.2.1 Increase in Chance of Failures

Given a blockage of the catchwater, it was assumed that a 50-m infiltration zone downhill of the 360-m overtopping section (Figure H4) would have a failure frequency an order higher than that in the normal condition.

Because of the increase in the failure frequency of the hillside units within the 50-m influence zone, there would be a corresponding increase in landslide risk of the structures affected by the hillside units. The results, calculated using the frequency models and the consequence models for the disturbed and natural hillsides, are summarized in Table H3.

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H4.2.2 Overland Flow of Muddy Water

The extent and depth of overland flow due to overtopping of the catchwater from each of the overtopping sub-sections was assessed using numerical modelling provided by FLO-2D (Julien et at, 1997). The results are shown in Figure H5, which illustrate the extent of lateral influence zones and overflow depths for determining the increase in landslide risk to each affected structure.

It was assumed that risk-to-life from the overland flow becomes significant when the depth of flow is greater than 0.40 m. Based on this assumption, vulnerability factors, which comprise the considerations on the chance of death for an individual in a given structure and the chance to escape, were determined and are summarized in Table H4.

Given a blockage of the catchwater, the structures affected by the overflowing events are summarized in Table H3 together with their corresponding increase in landside risk.

H5. REFERENCE

Julien, P.Y., O'Brien, J.S.O. & Fullerton, W.T. (1997). On the importance of mud and debris flow rheology in the structural design. Proceedings of the First International Conference of Debris-flow Hazards Mitigation: Mechanics, Prediction and Assessment, ASCE, pp 350-359.

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Table H1 - Information of Overflow Weirs

Overflow Weir	Chainage (m)	Invert Level (mPD)	Top Level (mPD)	Top Level of Catchwater (mPD)	No. of Weirs	Approximate Width (m)
A	CH. 4179	203.50	204.06	204.27	2	3
B	CH. 4401	203.86	204.43	204.53	1	3
C	CH. 4673	204.28	204.84	204.86	1	3
D	CH. 4886	204.51	205.09	205.30	1	3
E	CH. 5133	204.81	205.38	205.60	2	3
F	CH. 5352	205.06	205.63	205.90	12	3

Note: Levels of overflow weirs A to C are based on topographic survey and field measurements. Those of the others are estimated from base map and field measurements.

Table H2 - Chance of Blockage by Landslide Debris for Different Types of Landslide Hazards

(a) Man-made Slopes

	Landslide Volume (m^3)			
	< 20	20 - 50	50 - 500	>= 500
Chance of Blockage (%)	0	0	75	100

(b) Natural Hillside

	Landslide Volume (m^3)			
	< 60	60 - 200	200 - 600	600 - 2000
Chance of Blockage (%)	0	50	100	100

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Table H3 - Increase in Individual Risk Due to Overtopping of Catchwater

Structures Affected by Catchwater Overtop	Individual Risk without Catchwater Overtop	Increase in Individual Risk Due to Catchwater Overtop			
		Infiltration	% Increase	Overflow	% Increase
1992/039_010_0	0.00E+00	-	-	6.94E-06	-
1992/039_019_0	5.08E-03	0.00E+00	0.00	9.25E-05	1.82
1992/039_026_0	0.00E+00	-	-	4.78E-06	-
1992/039_049_0	1.93E-04	4.96E-07	0.26	-	-
1992/039_051_0	1.70E-04	1.11E-06	0.65	-	-
1992/039_052_1	5.58E-04	2.95E-06	0.53	-	-
1992/039_052_2	7.83E-04	5.71E-06	0.73	-	-
1992/039_052_3	2.76E-04	1.35E-06	0.49	-	-
1992/039_053_0	8.17E-04	5.48E-06	0.67	-	-
1992/039_054_0	6.45E-04	4.94E-06	0.77	-	-
1992/039_055_0	7.75E-04	5.67E-06	0.73	-	-
1992/039_056_1	1.55E-03	1.03E-05	0.66	-	-
1992/039_056_2	1.53E-03	1.02E-05	0.66	-	-
1992/039_056_3	1.14E-03	6.61E-06	0.58	-	-
1992/039_S005_0	8.69E-04	6.56E-06	0.75	1.54E-07	0.02
1992/039_S008_0	9.95E-04	-	-	3.08E-05	3.10
CKT_003_0	1.15E-04	0.00E+00	0.00	-	-
CKT_004_0	5.49E-04	0.00E+00	0.00	-	-
CKT_005_0	7.17E-04	0.00E+00	0.00	9.25E-06	1.29
FYS_002_0	4.36E-05	-	-	7.94E-05	182.29
FYS_006_0	1.47E-05	-	-	6.17E-07	4.20
FYS_009_1	3.01E-04	-	-	1.70E-06	0.56
FYS_009_2	1.79E-04	-	-	3.08E-05	17.20
FYS_010_2	3.22E-04	-	-	3.08E-06	0.96
FYS_011_0	4.09E-04	-	-	3.08E-06	0.75
TS1_1	9.75E-03	1.24E-05	0.13	3.08E-07	0.00
TS11	2.61E-04	0.00E+00	0.00	3.08E-07	0.12
TS12_1	3.89E-04	0.00E+00	0.00	6.17E-06	1.59
TS12_2	5.45E-04	0.00E+00	0.00	6.17E-06	1.13
TS12_3	6.29E-04	0.00E+00	0.00	6.17E-06	0.98
TS14	4.07E-05	-	-	3.08E-05	75.80
TS2	1.89E-03	6.64E-06	0.35	-	-
TS7	1.10E-03	3.47E-07	0.03	-	-
TS8	4.71E-04	1.96E-07	0.04	-	-
TS9	5.13E-04	2.14E-08	0.00	-	-
TW30_025_0	7.65E-05	-	-	3.08E-05	40.33

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Table H4 - Chance of Death and Chance of Escape for Individuals in Structures Affected by Overland Flow

	Depth of Overland Flow (m)							
	< 0.40		0.40 - 0.60		0.60 - 0.80		0.80 - 1.00	
Type of Structures	F	S	F	S	F	S	F	S
Chance of Death (%)	0	0	3	0.2	10	1	20	2
Chance of Escape (%)	100		90		80		70	

Note: F = Flimsy structures; S = Substantial structures.

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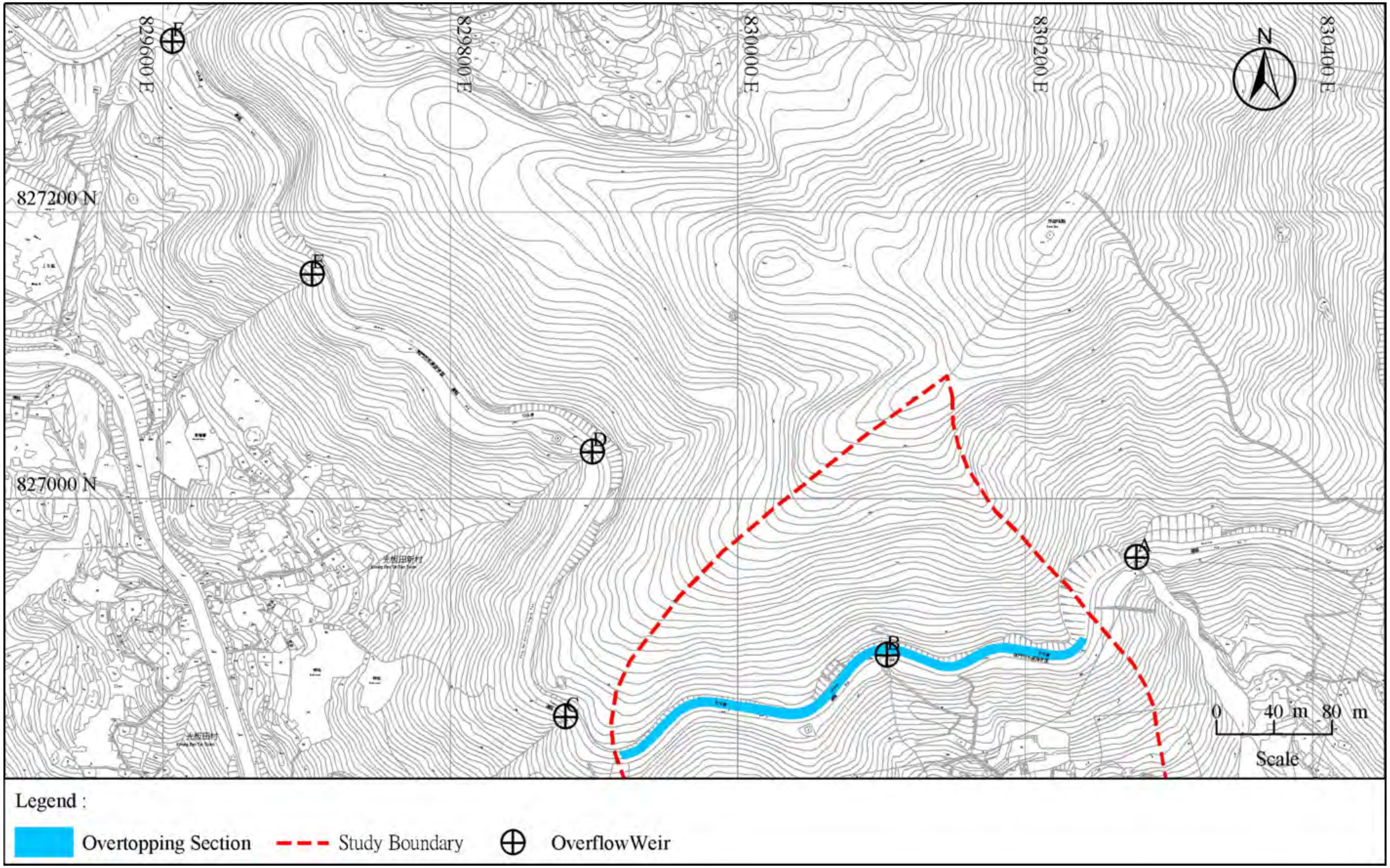

Figure H1 - Location of Overtopping Section of Catchwater and Overflow Weirs

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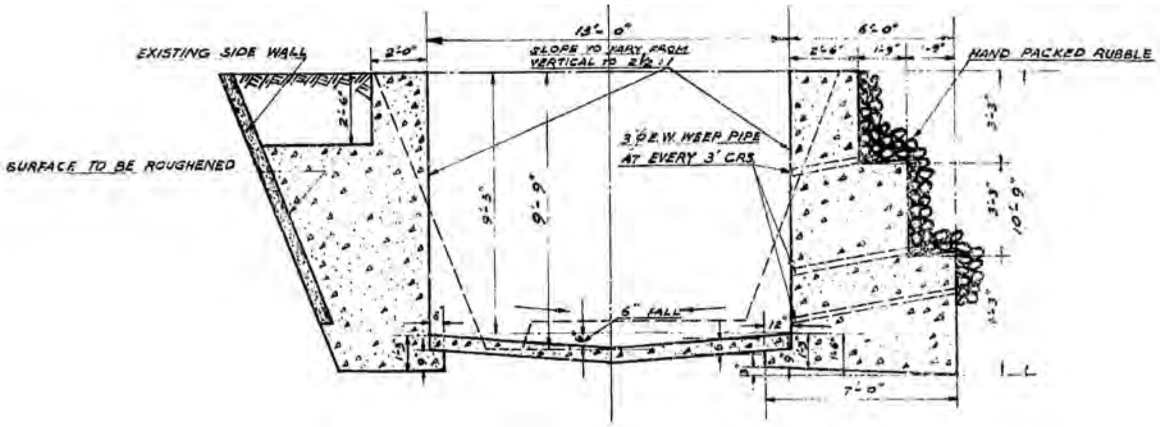
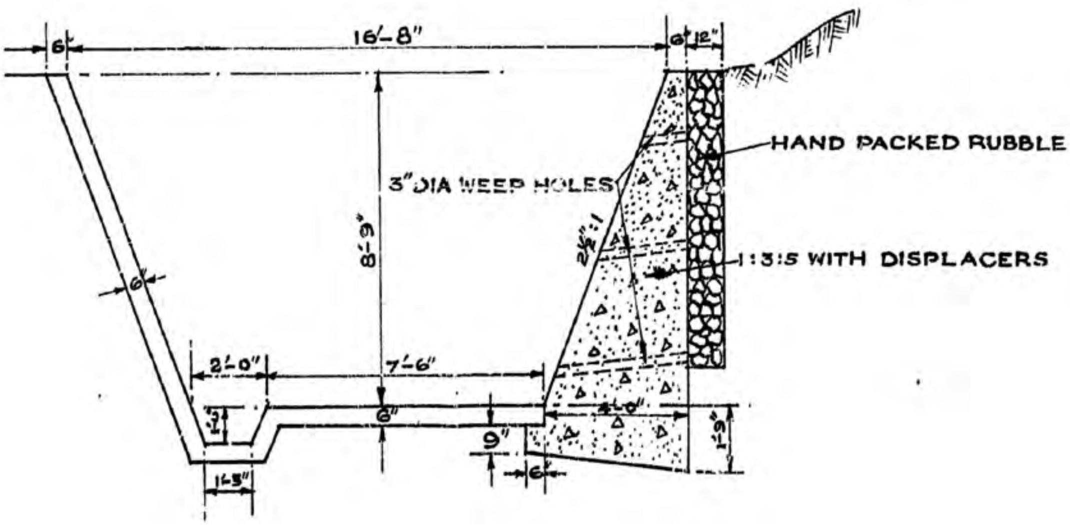


(a) Cross section of catchwater near and upstream of overflow weir A



(b) Cross section of catchwater near overflow weirs B to F

Figure H2 - Typical Sections of Catchwater

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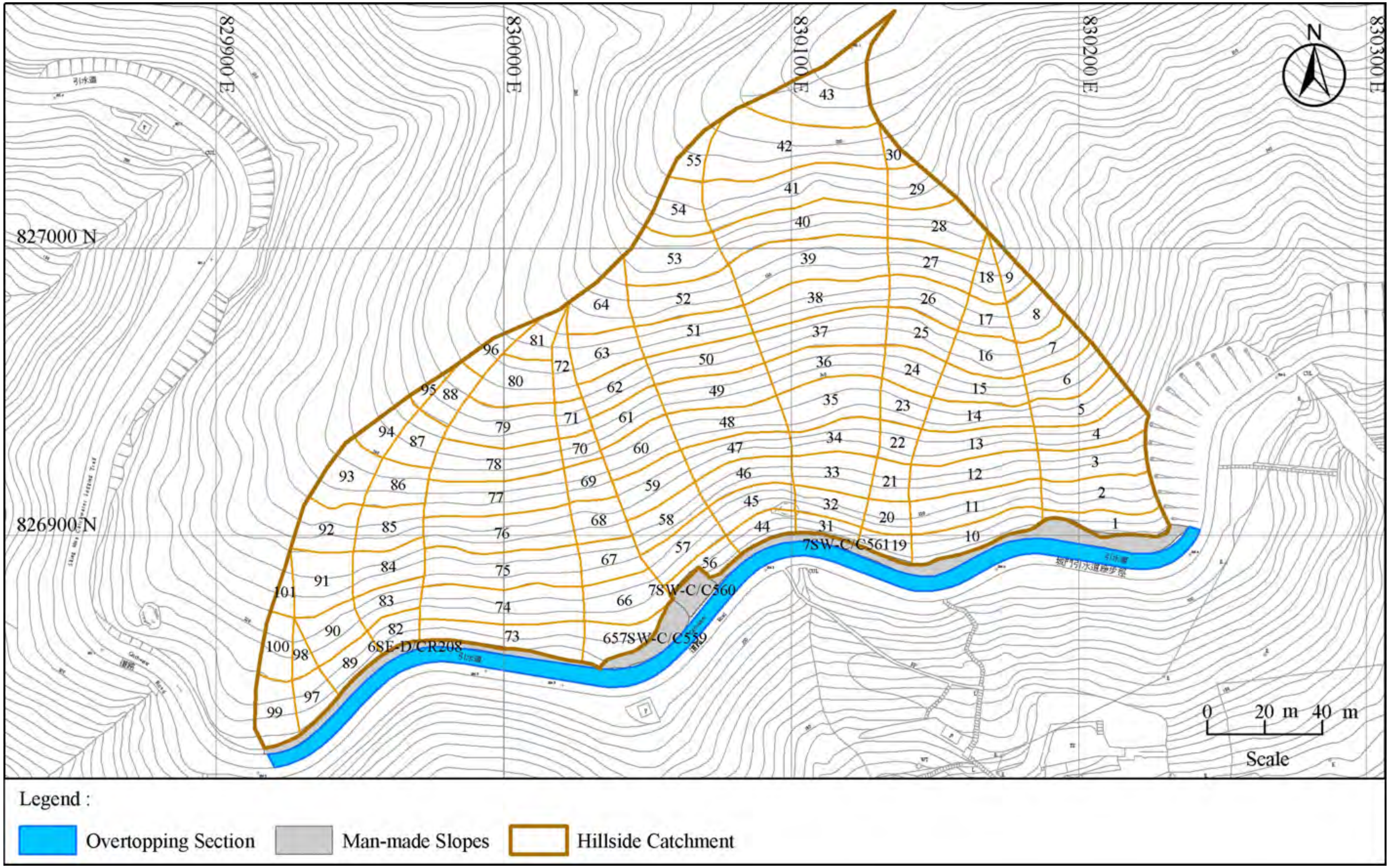

Figure H3 - Man-made Slopes and Boundary of Hillside Affecting Overtopping Section of Catchwater

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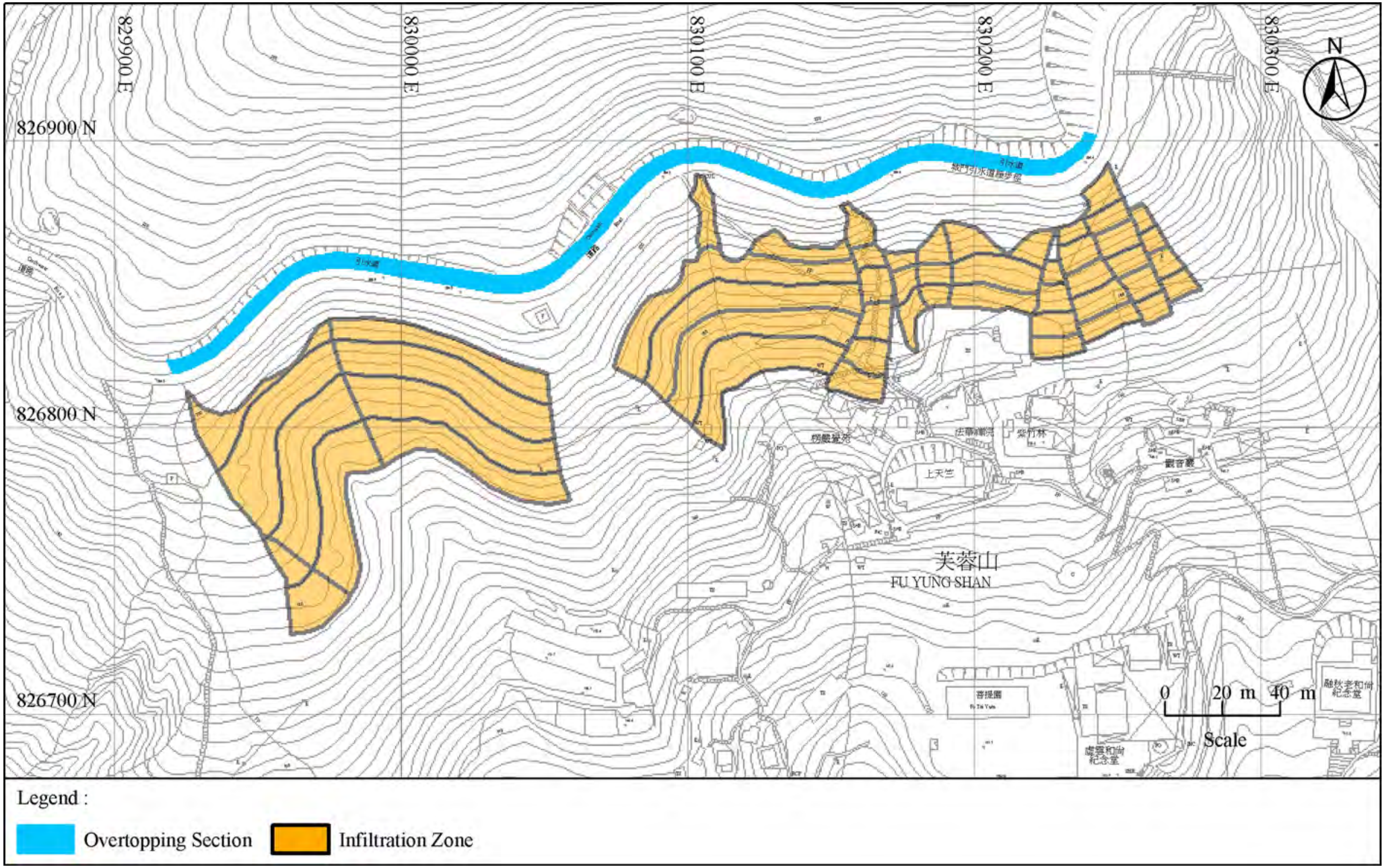

Figure H4 - Boundary of Infiltration Zone

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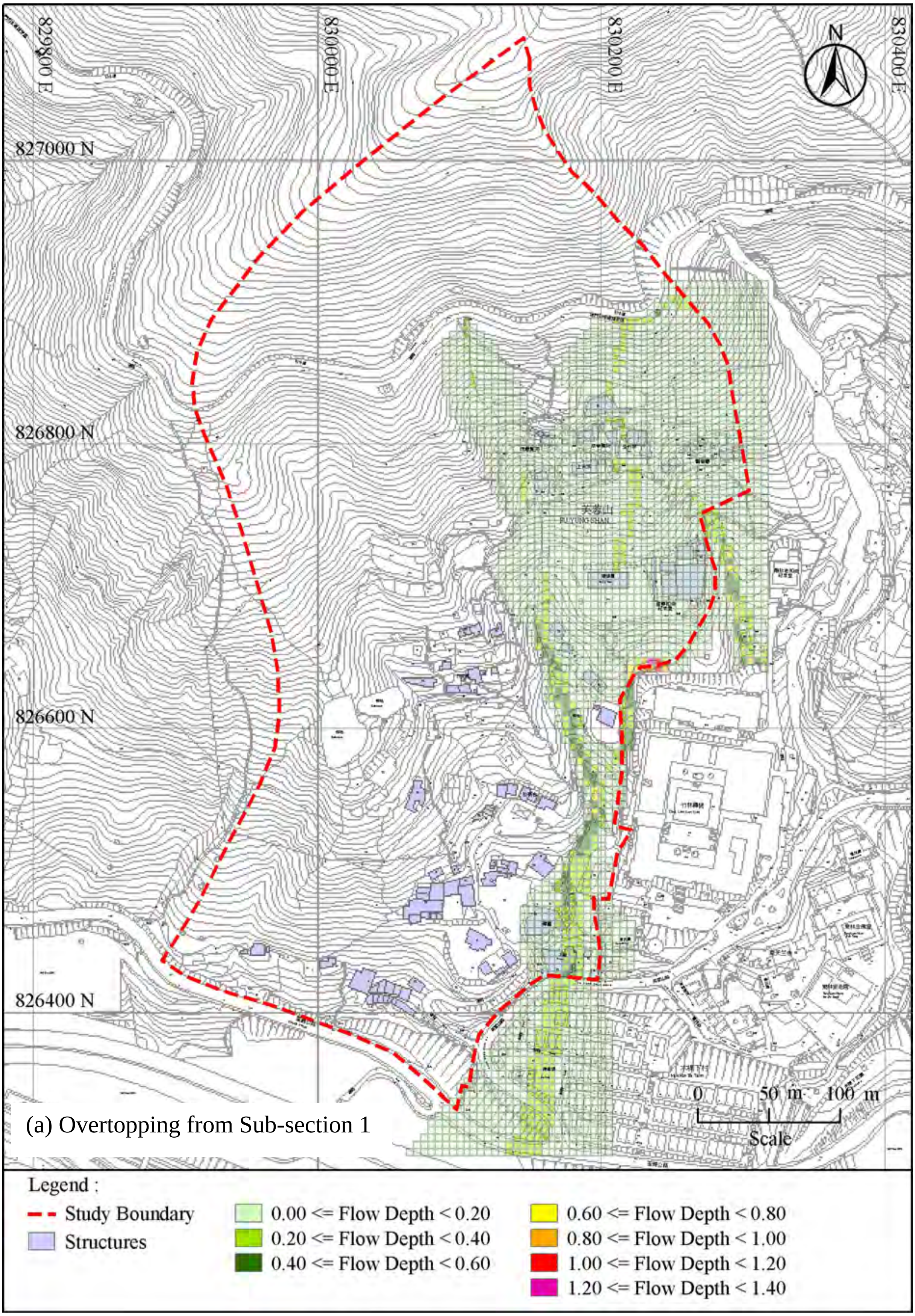

Figure H5 - Influence Zones and Flow Depths of Overland Flow (Sheet 1 of 6)

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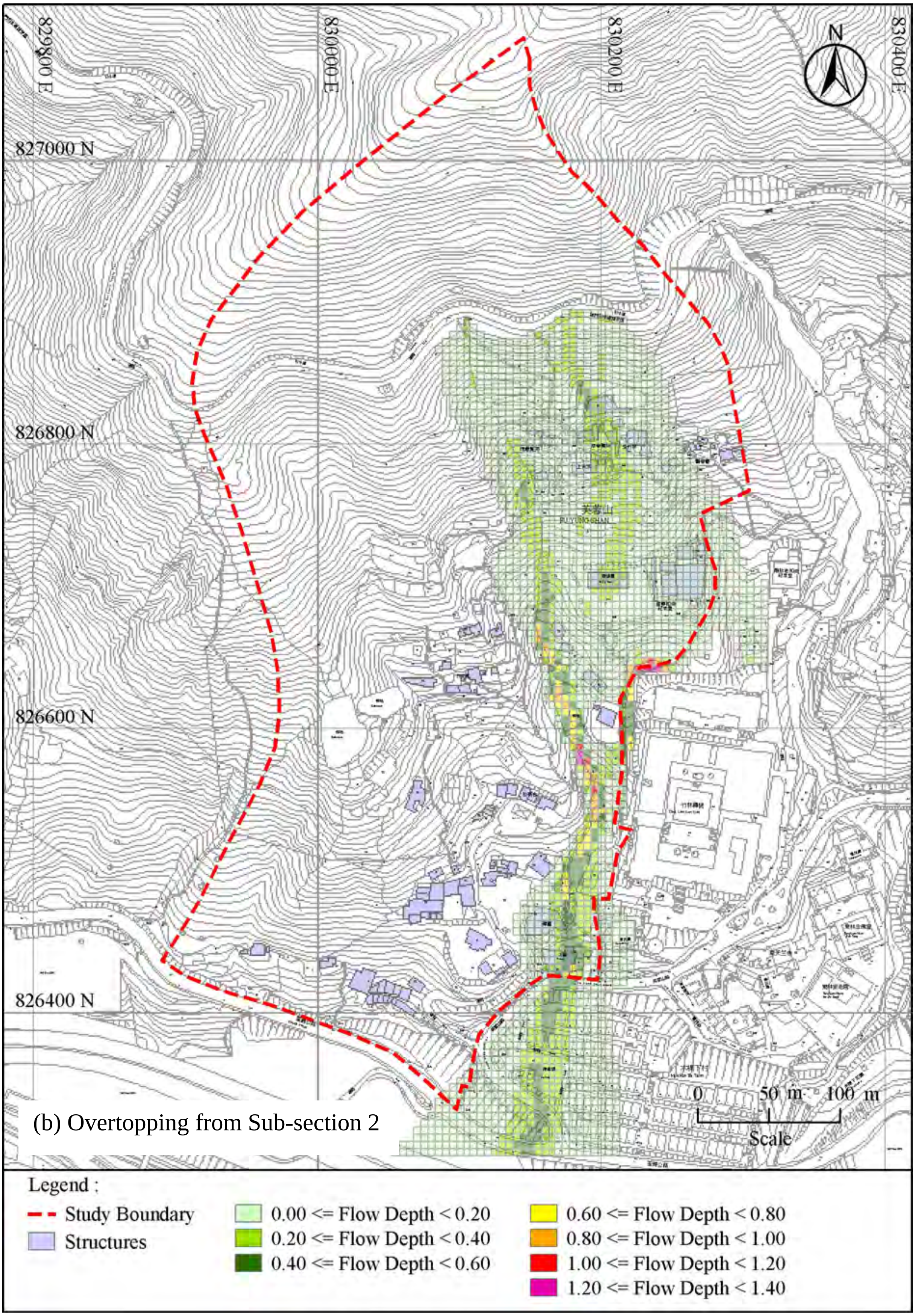

Figure H5 - Influence Zones and Flow Depths of Overland Flow (Sheet 2 of 6)

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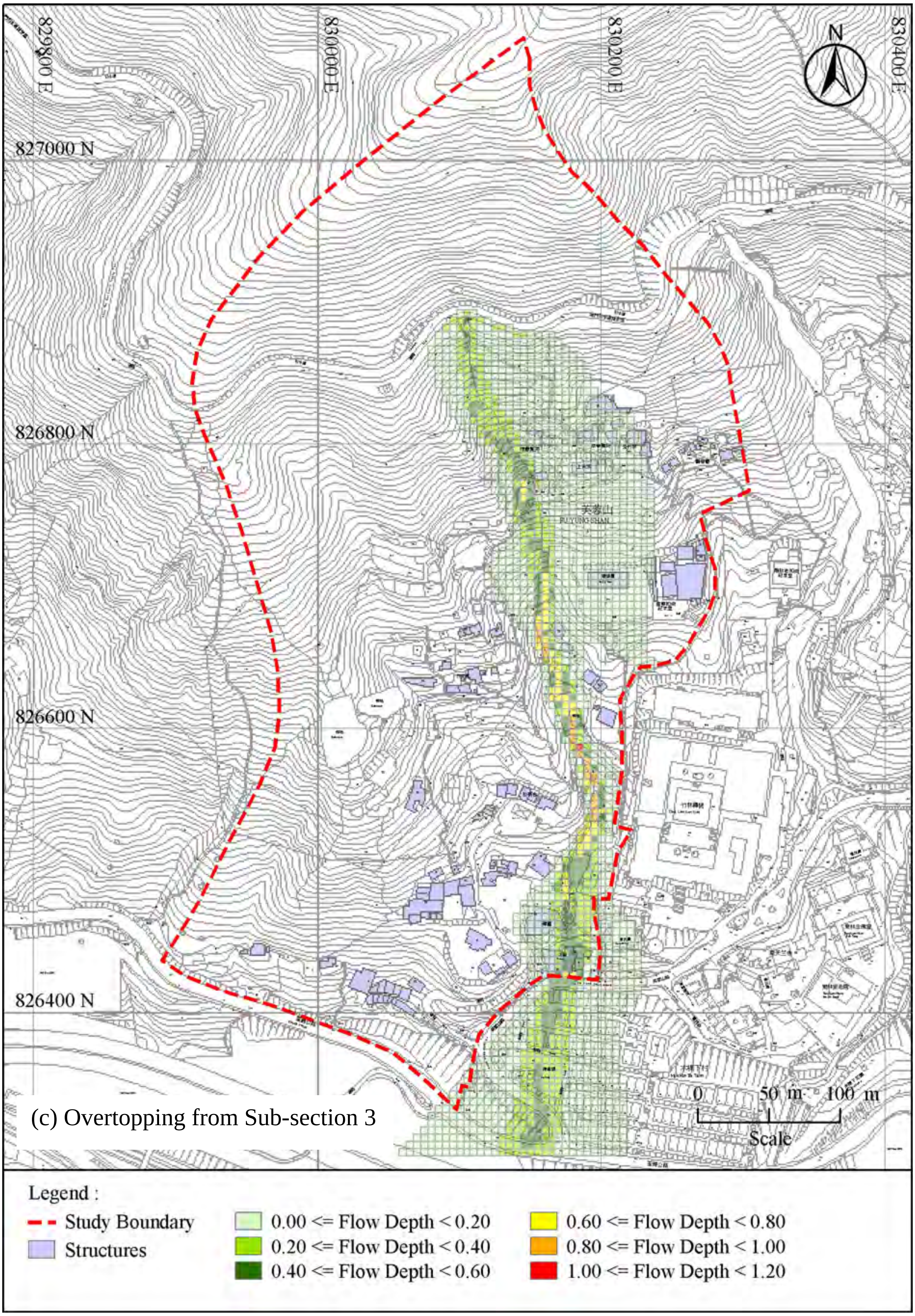

Figure H5 - Influence Zones and Flow Depths of Overland Flow (Sheet 3 of 6)

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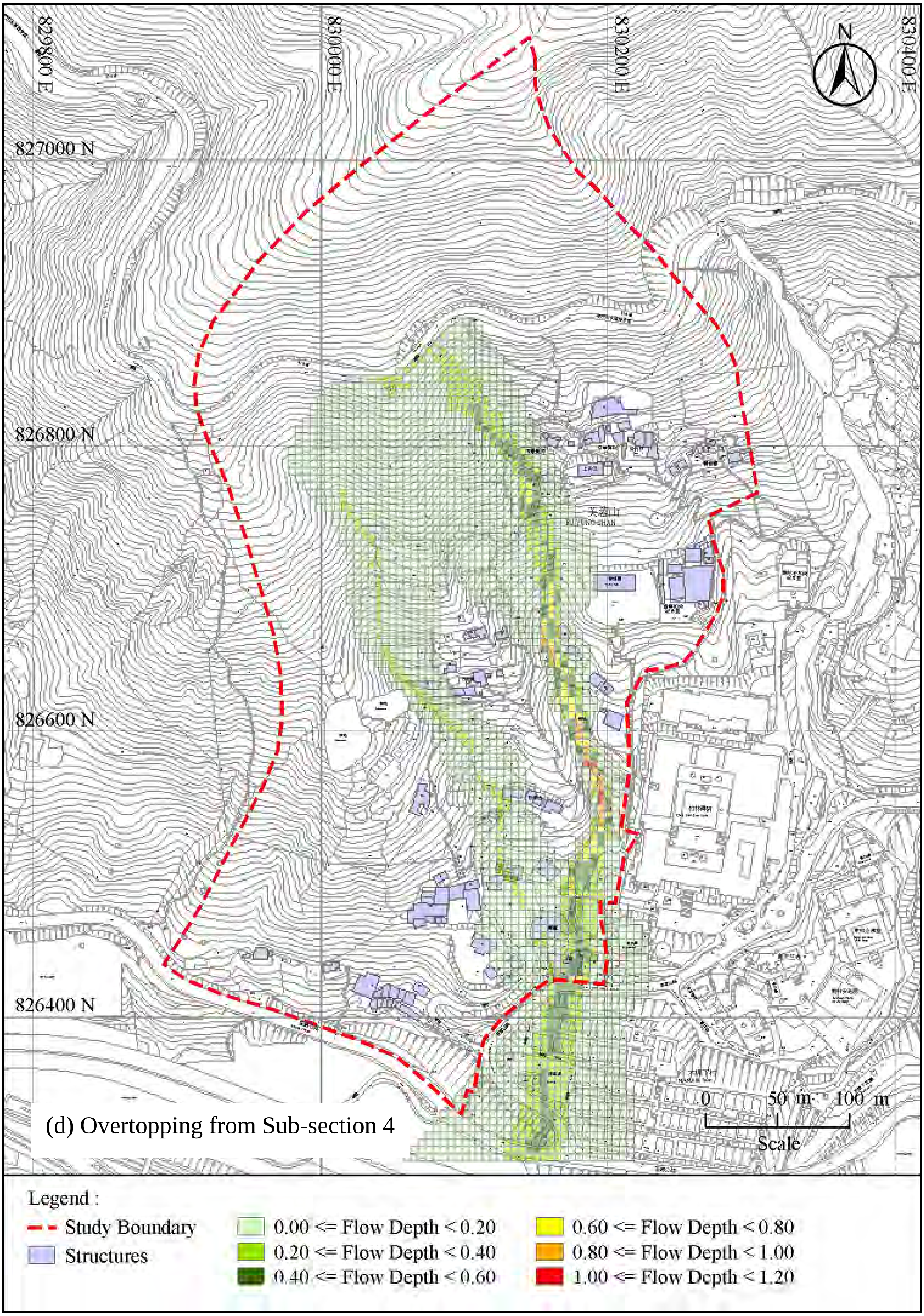

Figure H5 - Influence Zones and Flow Depths of Overland Flow (Sheet 4 of 6)

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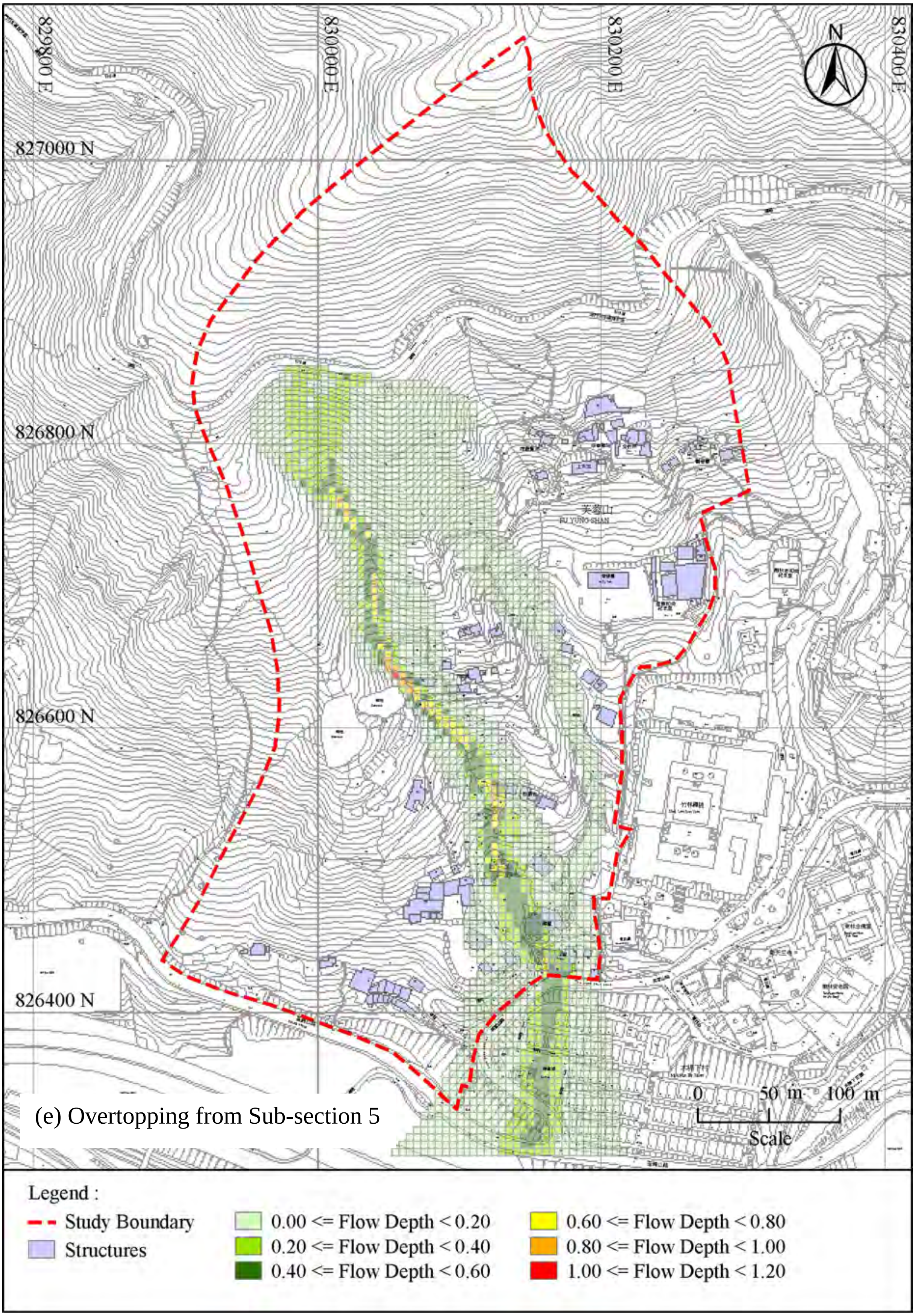

Figure H5 - Influence Zones and Flow Depths of Overland Flow (Sheet 5 of 6)

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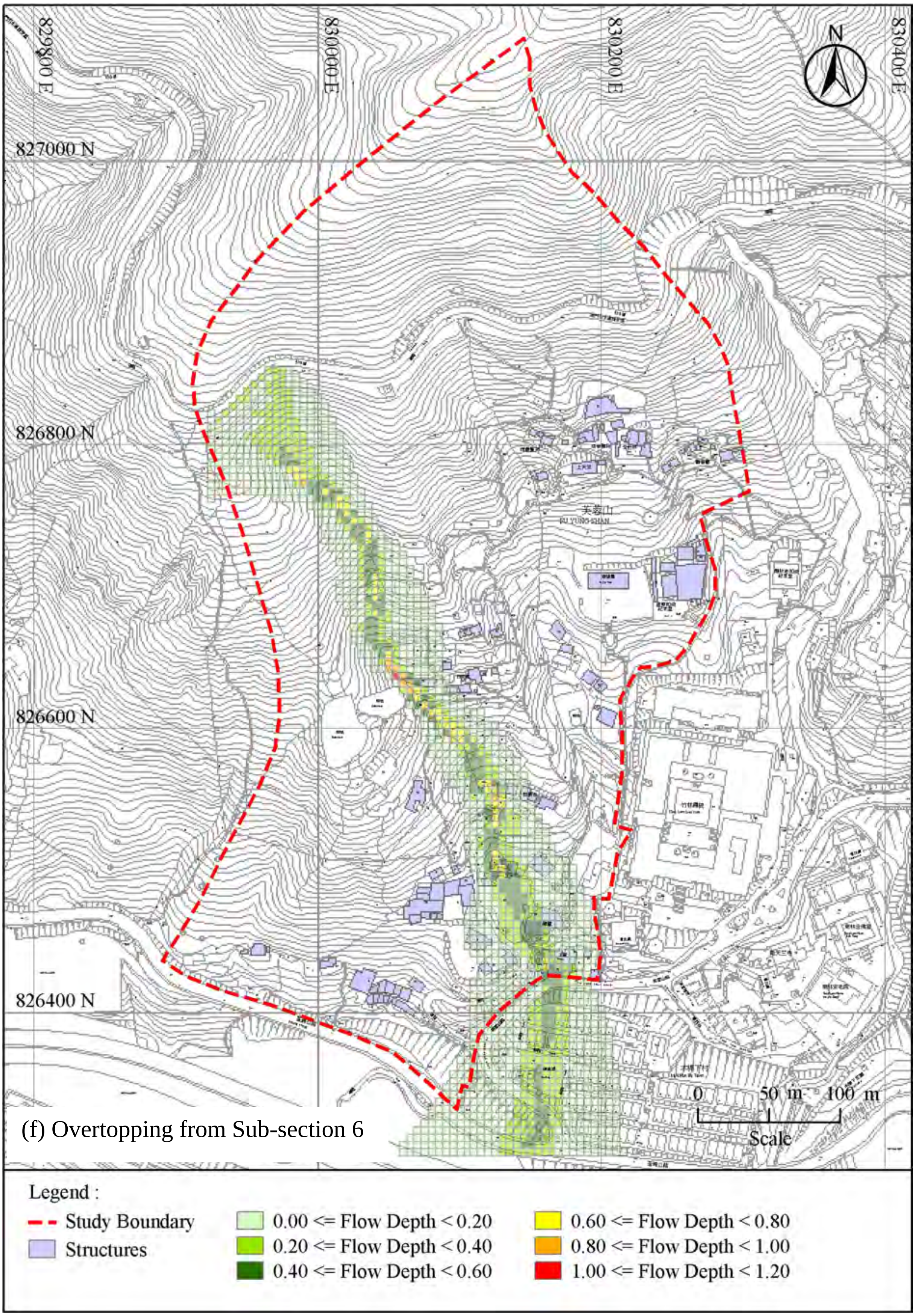

Figure H5 - Influence Zones and Flow Depths of Overland Flow (Sheet 6 of 6)

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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), 300 p. (English Version), (Reprinted, 2000).

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. 1/2000	Technical Guidelines on Landscape Treatment and Bio-engineering for Man-made Slopes and Retaining Walls (2000), 146 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.

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

TGN 1	Technical Guidance Documents