Hong Kong Housing Authority

Agreement No. CB20120293 Planning and Engineering Study for the Public Housing Site and Yuen Long Industrial Estate Extension at Wang Chau

Final Technical Report No.3C (TR-3C) Natural Terrain Hazard Study

REP-017-01

Final | April 2014

IMPORTANT – CONFIDENTIALITY

This project and study shall be kept confidential and any information contained in and/or related to the project/study shall not be disclosed to any person not involved in the project/study.

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1 INTRODUCTION

1.1 Project Background

1.1.1.1 As stated in the Chief Executive's 2011-12 Policy Address, the Administration is committed to expanding the land resources and increasing housing land supply. To meet this policy objective, the Planning Department (PlanD) has carried out a comprehensive review of the areas zoned "Green Belt" (GB) on the Outline Zoning Plans (OZPs) focusing on sites which are no longer green or spoiled. A number of "GB" and "Open Storage" (OS) sites in Wang Chau, Yuen Long were identified as having potential for public housing (PH) development.

1.1.1.2 Subsequently, the Innovation and Technology Commission (ITC) and the Hong Kong Science and Technology Parks Corporation (HKSTP) advised of the need to expand the Yuen Long Industrial Estate (YLIE), in addition to the existing three Industrial Estates (IEs) at Tai Po, Tseung Kwan O and Yuen Long. It was requested to use a portion of the Wang Chau potential housing site for this purpose.

1.1.1.3 After due consideration, an agreement was reached between the Housing Department (HD) and ITC to share the site, tentatively with the northerly portion to be allocated for the YLIE extension (YLIEE), while the remaining south portion would be developed for public housing use. It was further agreed that no Potential Hazardous Installations (PHIs) would be located at the YLIEE so as to minimize the potential adverse impact on the neighbouring PH developments.

1.1.1.4 **Figure 1.1.1** shows the location of the Project site. The PH and YLIEE sites at Wang Chau are zoned GB and OS on the Ping Shan OZP No. S/YL-PS/14. It is currently occupied by open storage, vehicle parks, farmland, fallow land, grassland, rural residential dwellings and temporary structures.

1.1.1.5 Ove Arup & Partners Hong Kong Limited (Arup) was commissioned by Hong Kong Housing Authority (HKHA) under entrustments from the Government of the Hong Kong Special Administrative Region (HKSAR) & Hong Kong Science and Technology Parks Corporation (HKSTP) to conduct the Planning and Engineering Study for Public Housing Site and YLIEE at Wang Chau (the Study), which will examine the feasibility on developing public housing and YLIEE at Wang Chau by conducting planning, engineering and environmental assessments to formulate proposal for the PH site and YLIEE, and the implementation strategies and programme for the proposed development.

1.2 Objectives of the Report

1.2.1.1 Following on the endorsement of the Technical Report (TR) on Option Generation, Evaluation and Preliminary Assessments (TR-2) in the Study Steering Group Meeting on 28 June 2013, a preferred development option has been formulated. According to the Clause 5.3(c) of the brief, technical assessments are required to demonstrate the feasibility of the preferred development option.

1.2.1.2 The Technical Report (TR-3) – Preferred Option and Technical Assessments under this P&E study is to undertake the technical assessments including traffic and transport assessments, drainage and sewerage impact assessment, water supply and utilities impact assessments, geotechnical assessments, foundation assessment, natural terrain hazard study, environmental impact assessment, financial assessment, air ventilation assessment and land requirement study to confirm the feasibility of the preferred development option and ascertain the implications that may arise.

1.2.1.3 This report forms part of the TR-3 and is to conduct a Natural Terrain Hazard Study following guidelines given in GEO Report No. 138, to review and assess the location, type and magnitude of potential natural terrain hazards (NTH) from the adjoining hillside, and to propose practical and financially viable mitigation measures, and to identify the extent of any non-buildable zones within the development platform.

1.2.1.4 In accordance with Clause 5.3 (ix) of the Brief, this report includes the following:

- NTHS Screening of adjacent natural hillsides in accordance with GEO Report No. 138
- Details of site conditions, geology, evidence of instability based on desk study, API and detailed field mapping used to develop an engineering geological model
- Identification of potential NTH using an NTH model
- Assessment and quantification of potential NTH using debris run-out analysis
- Assessment of any constraints on the proposed development, including a proposal for NTH mitigation measure
- Recommendations for further ground investigation and assessment at detailed study stage

1.2.1.5 Recently published new guidance on NTHS (GEO TGN 36, 37 and 38) has also been considered.

1.2.1.6 It should be noted that the condition of existing manmade slope features and retaining walls will be discussed in TR3b, the Geotechnical Assessment.

1.3 Structure of this Report

1.3.1.1 The structure of this Technical Report is as follows:

Section 1 Introduces the project background, as well as the purpose of this report.

Section 2 Provides the site description and presents the preferred development option.

Section 3 Presents a description of the PH and YLIEE sites.

Section 4 Presents the details of the desk study undertaken for the NTHS.

Section 5 Presents an engineering geological assessment of the NTHS catchments.

Section 6 Presents details of the NTHS field mapping and hazard assessment.

Section 7 Presents the proposed mitigation strategy.

Section 8 Discusses the conclusions of this study.

1.4 Nomenclature and Abbreviations

1.4.1.1 The following **Table 1.1** lists out the meaning of abbreviation for expressions adopted in this report:

Table 1.1.1: Abbreviations

Abbrevations	Term
API	Aerial Photograph Interpretation
BH	Borehole
CDF	Channelised Debris Flow
CE	Conservative Event
DEM	Digital Elevation Model
ENTLI	Enhanced Natural Terrain Landslide Inventory
GB	Green Belt
GFA	Gross Floor Area
GI	Ground Investigation
G/IC	Government/ Institution/ Community
GIU	Geotechnical Information Unit
HKGS	Hong Kong Geological Survey
LOS	Local Open Space
NTH	Natural Terrain Hazards
NTHM	Natural Terrain Hazard Mitigation
NTHS	Natural Terrain Hazard Study
OS	Open Storage
OHL	Open Hillslope Landslide
OZP	Outline Zoning Plan
PH	Public Housing
PR	Plot Ratio

Abbrevations	Term
PTI	Public Transport Interchange
TR3c	Technical Report No. 3c
TR-2	Technical Report No. 2
TR-3	Technical Report No. 3
VE	Village Environs
YLIEE	Yuen Long Industrial Estate Extension
YLIE	Yuen Long Industrial Estate

2 PROJECT DESCRIPTION

2.1 Site Location

2.1.1.1 The Project site is bounded by the existing YLIE, Fuk Hi Street and Fuk Hing Garden and Sai Tau Wai to the east, Long Ping Road and Long Ping Estate to the south, Kai Shan to the west, as well as Shing Uk Tsuen, Tai Tseng Wai and Ng Uk Tsuen to the north as indicated in **Figure 1.1.1**.

2.2 Existing Conditions

2.2.1.1 According to the approved Ping Shan OZP No. S/YL-PS/14, the PH and YLIEE sites are currently zoned as "Green Belt" (GB) and "Open Storage" (OS) (**Figure 2.1.1**). It is occupied by open storage, vehicle parks, farmland, fallow land, grassland, rural residential dwellings and temporary structures.

2.2.1.2 The surrounding areas of the Project site are characterized by a mixture of various land use zonings as well as different existing major land uses. These include high-rise residential development, villages and low-rise residential developments, natural landscapes, burial grounds and graves, industrial uses, major roads and railway tracks.

2.2.1.3 The Project site is irregular in shape. In terms of topography, it is generally flat on its northern and central portions and has a slightly hilly terrain on the south strip. The major land uses within the Project site include open storage/workshops, residential dwellings, agricultural and vegetated land, nullah with footpaths and watercourses.

2.3 The Preferred Option

2.3.1.1 During the process of option generation, a number of key elements which play determining roles in the formulation of initial development options have been identified. The key elements that have been paid with due respect include the burial ground at Kai Shan, Village Environs (VE) of Wing Ning Tsuen (D.D. 122), VE of Fung Chi Tsuen and Shui Tin Tsuen (D.D 120 & 122) and the Umah International Primary School. A preferred development option for PH site and YLIEE site has been formulated in the TR-2 Option Generation, Evaluation and Preliminary Assessments.

2.3.1.2 Since the approval of TR-2, discussions with various government departments have been carried out; and subsequently the Project site boundary, site layout and development parameters of the preferred option have been slightly refined and optimised to address different concerns of particular departments. This TR-3 is carried out based on the refined preferred option which is illustrated in **Figure 2.1.2**.

2.3.1.3 The revised Project site boundary, land use budget, site layout, urban design element and development scheme with parameters are briefly described in the following sections.

2.4 The Project Site Boundary

2.4.1.1 As recommended in TR-2, the Project site of the original preferred option is about 33.31 ha in size, with about 18.69 ha for the PH site and about 14.62 ha for the YLIEE site.

2.4.1.2 Taking into account the existing burial urns at Kai Shan, impacts to private land lots, woodland cutting, woodland compensation provision, existing boundaries of adjacent VE, interfacing with existing land use zonings and further optimisation of land use between PH and YLIEE sites, some minor refinements have been proposed.

2.4.1.3 The refined development site boundary is shown in **Figure 2.1.2**. With the refinement, the total area of the Project site is about 33.46 ha, with about 18.81 ha for PH site and about 14.65 ha for YLIEE site.

2.5 Land Use Budget

2.5.1.1 Subsequent to the refinement of the Project site boundary, with an aim to keep up with the development intensity and land use mix in the preferred option as generated under the guiding principles and relevant regulations, minor adjustments have also been made onto the land use budget.

2.5.1.2 **Table 2.5.1** below summarizes the land use budget for the refined site boundary.

Table 2.5.1: Proposed land use budget for the refined site boundary

Land Use	Land use budget
PH Site	
Residential	About 14.49 ha
School	About 1.94 ha (3 school sites)
G/IC (Integrated Social Welfare Building)	About 0.47 ha
Public Transport Interchange	About 0.41 ha
Roads, amenity greening and slope	About 1.49 ha
Total site area	**About 18.81 ha**
YLIEE Site	
Industrial	About 11.66 ha
Local Open Space (On-site preserved woodland area)	About 0.27 ha
Roads	About 1.81 ha
Slope	About 0.31 ha
Woodland compensation area & on-site ecological compensation area	About 0.41 ha
Parking Spaces	About 0.19 ha
Total site area	**About 14.65 ha**

2.6 Proposed Development of the PH Site

2.6.1 Guiding Planning Design Principles for the Public Housing Site

2.6.1.1 There are three major planning & urban design guiding principles followed in the design of the preferred option. These include:

- Establishing view corridors to Kai Shan - This is achieved by aligning the northern road toward the foothills of the mountain, by strategically placing the schools to provide visual and spatial relief around the taller residential structures, and by utilizing the 50-metre buffer area separating the public housing site from the proposed industrial estate extension site.
- Placing public functions closer to the existing road networks - Commercial activities and the public transport interchange (PTI) have been placed along Fuk Hi Street and Long Ping Road in order to serve the greater community.
- Creating a tapering building height profile. The buildings taper down from 41 to 31 storeys. The tapering occurs at 5-storey intervals, in order to minimize the effect of the flat-head development.

2.6.2 Land Use Proposals

2.6.2.1 With the proposed refinement of the PH site boundary, types of land use remain unchanged. These include residential with local open space and parking spaces, retail, schools, integrated social welfare building (ISWB), PTI, roads, amenity greening and slope.

2.6.2.2 The PH site can be roughly divided into three portions. The southwestern portion of the PH site consists of the area around residential blocks 1 to 10 (Phase 1), the middle portion consists of the area around residential blocks 11 to 17 (Phase 2), and the northern portion consists of the area around buildings 18 to 24 (Phase 3). The middle and northern portions are bisected by the proposed northern access road.

2.6.2.3 **The Southwestern Portion**: The southwestern portion occupies an area of about 5.5ha. It consists of 10 residential buildings, two underground parking structures, a 2-storey commercial area, a social welfare building, i.e. ISWB, one school, and complementary recreational functions. All residential buildings in this portion will be of either 31 or 36 storeys. Single-aspect buildings have been utilized in all of the residential buildings, except Block 3, in order to minimize any potential conflicts from traffic noise issues. A two-storey retail facility has been placed strategically along Long Ping Road to allow street-front retail as well as serve the residents within the proposed new residential housing estate. A footbridge tentatively linking the pedestrian walkway system of Long Ping Estate would land at the same level as the podium level. The ISWB at the southwestern tip of

this portion will provide a minimum net operating floor area of approximately 6000 m^2 for various social welfare facilities. A site of a primary school is reserved and proposed with a maximum building height of 8 storeys. Areas for two children playgrounds, two badminton courts, and one basketball court have also been reserved to serve the future residents. An existing shrine exists adjacent to the ISWB. Minimal disturbance has been taken into consideration with site formation in order to preserve this shrine.

2.6.2.4 **The Middle Portion**: It has an area of about 5.8ha. It consists of 7 residential buildings, a commercial area, one underground parking area, and other complementary recreational functions as well as a new road. The residential buildings in this portion taper from tallest (41 storeys) to the west to lowest (31 storeys) to the east. A pedestrian corridor with retail facilities on both sides is proposed. This design will minimize the adverse interface conflict between pedestrians and vehicles. In terms of complementary recreational functions, areas for four children playgrounds, three badminton courts, and two basketball courts have been served. An existing well currently situated between the proposed Blocks 12 and 13 is proposed to be preserved and beautified to give the area more character.

2.6.2.5 **The Northern Portion**: This portion occupies an area of about 7.5ha. It consists of 7 residential buildings, a commercial area, a semi-covered PTI, a non-buildable area, one underground parking area, two schools and complementary recreational functions. The residential buildings taper from tallest to the west (41 storeys) to lowest to the east (31 storeys). This tapering is of similar nature as to the buildings tapering in the middle portion. The commercial area in this portion is placed in the vicinity of the PTI, and creates a gateway to the pedestrian street found in the middle portion with the intention that it would serve both the PH site as well as the YLIEE site. In order to minimize the adverse interface conflicts generated between the YLIEE and the PH sites, a 50-metre buffer has been created between these two distinct zones. The buffer area would comprise of open space, a football pitch, badminton courts, and two playgrounds. Due to the shape of the 50-metre buffer area, this area is also most suitable for an underground parking area. Two schools have been placed strategically at the end of the proposed road, in order to further expand the frame of vision toward Kai Shan, as well as to provide a visual buffer from the high-density developments of the middle and northern portions. Apart from the recreational functions found along the 50-metre buffer, areas for two additional children playgrounds and two basketball courts have been reserved.

2.6.3 Development Schemes with Parameters

2.6.3.1 In the refined development scheme, the PH site has a site area of 18.81 ha. While the total site area is 18.81 ha, the total residential site area is of a total of 14. 49ha which excludes 30-degree cut slope areas, local roads, and non residential structures, like the PTI, the ISWB, and

the three school sites, based on the abovementioned land use proposals. Taking the opportunities to further optimize housing supply in response to the territorial need for housing by visiting various factors with a plot ratio (PR) of 6.0 (i.e. 5.86 domestic and 0.14 non-domestic) and maximum building height of 41 storeys, a total of a domestic GFA of 848,750 m^2 and retail GFA of 19,760 m^2. will be accommodated (**Table 2.6.1**). The proposed development option could then provide a total of 16,975 flats to cater for around 52,113 populations (**Table 2.6.2**). The breakdown of the GFA of each portion is as follows:

Table 2.6.1: Domestic and Retail GFA of the Three Portions

	Domestic GFA (m^2)	Retail GFA (m^2)
Southwestern Portion	213,750	6,784
Middle Portion	324,000	8,589
Northern Portion	311,000	4,383
Total	**848,750**	**19,756**

Remarks: It is assumed that the social welfare facilities, PTI, underground parking areas, schools and recreational functions are not accountable for GFA.

Table 2.6.2: The Estimation and Number of Flats of the Three Portions

	Area of Residential Site (ha)	Number of Flats^	Population*
Southwestern Portion	3.83	4,275	13,124
Middle Portion	5.00	6,480	19,894
Northern Portion	5.68	6,220	19,095
Total	**14.49#**	**16,975**	**52,113**

An adjustment of 0.02ha has been applied and subtracted from the total site area to avoid overprovision of domestic GFA.
^ It is also assumed that 50% of the flats will be for PRH and 50% will be for HOS.
* It is assumed that the person per flat is 3.07.

2.6.3.2 A summary of the key planning parameters for the PH development is given in **Table 2.6.3** below.

Table 2.6.3: Summary of Key Planning Parameters for PH development

Development Parameters	Units
Residential Site Area	14.49 ha
Domestic Plot Ratio	5.86
Domestic GFA	848,750 m^2
Estimates No. of Flats	16,975
Estimated Population	52,113
Non-domestic Plot Ratio	0.14
Non-domestic GFA	19,760 m^2
Maximum Building Height (in storeys) (Ground floor included)	31 / 36 / 41
Maximum Building Height (in metres)	87.1m / 100.85m / 114.6m

Development Parameters	Units
Maximum Number of Residential Storeys	30 / 35 / 40
Assumed No. of Units Per Storey	11 - 29 units
No. of Towers	24

2.7 Proposed Development of the YLIEE Site

2.7.1 Guiding Planning & Design Principles for the YLIEE Site

2.7.1.1 There are four planning & design principles that should be considered:

- Optimising the development potential by partitioning the individual site with an optimal plot size between 0.65 and 0.75 ha as advised by HKSTPC.
- Minimising disturbance to existing woodland and providing an on-site woodland compensation area to minimise the need for off-site woodland compensation.
- Providing sufficient local open space for the enjoyment of local employees.
- Providing a pedestrian connection from the existing YLIE to the proposed YLIEE site.

2.7.2 Land Use Proposal

2.7.2.1 With the proposed refinement of the YLIEE site boundary, the major types of land use remain unchanged. These include industrial, local open space, car parking space, road and slope area. While chances have been taken to further bring forward capitalization on existing natural resources within the YLIEE site, it is proposed to allow more on-site woodland compensation and ecological conservation area.

2.7.2.2 The YLIEE site has an area of 14.65ha. It consists of 16 individual plots, connected by a local road that terminates at a roundabout. Adequate Local Open Space (LOS) and parking areas have also been provided within the site. The LOS is currently occupied by woodland which will be preserved on-site. One on-site ecological compensation area has been proposed to the west of development plot VIII, and a woodland compensation area to the west of development plot VII has also been proposed.

2.7.3 Development Schemes with Parameters

2.7.3.1 In the refined preferred option, the total area for YLIEE site is 14.65 ha with 11.66 ha reserved for industrial use. A PR ratio of 2.5 and a maximum building height of 8 storeys for the industrial lots are proposed to remain unchanged. Chances were also taken to optimize industrial GFA provision and as a result, a maximum GFA of 291,545 m^2 will be provided to accommodate about 3,887 workers. A summary

of the key planning parameters for the YLIEE development is given in **Table 2.7.1** below.

Table 2.7.1: Summary of key planning parameters for YLIEE development

Development Parameters	Units
Industrial Site Area	11.66 ha
Plot Ratio	2.5
Maximum GFA	291,545 m^2
Estimated No. of Worker*	About 3,887
Maximum Building Height (in storeys)	8 storeys
Maximum Building Height (in metres)	32m

* It is assumed that a worker density is 75 workers/ m^2.

2.7.3.2 In terms of the distribution of industrial lots, a summary is given in **Table 2.7.2** below.

Table 2.7.2: Summary of industrial lot sizes

Industrial lot size	Number of lots
1.10 ha -1.19 ha	1
1.00 ha - 1.09 ha	0
0.90 ha - 0.99 ha	0
0.80 ha - 0.89 ha	2
0.70 ha - 0.79 ha	4
0.60 ha - 0.69 ha	8
0.50 ha - 0.59 ha	1
Total number of lots	16

2.8 Tentative Implementation Programme

2.8.1.1 The PH site would be implemented in three phases and the YLIEE site would be developed in a single phase. The following summarises the tentative commissioning dates for both the PH and the YLIEE sites:

- Year 2022: Granting of YLIEE's land starting from 2022 which will take about 4 years to complete
- Year 2024: Population intake of PH Site Phase 1
- Year 2026: Population intake of PH Site Phases 2 & 3

3 SITE DESCRIPTION

3.1 The Study Area

3.1.1 Site Location

3.1.1.1 The project site is located in Yuen Long, bounded by Fuk Hei Street and Long Ping Road to the east and southeast, and by natural terrain in the west as indicated in **Figure 1.1.1.** This Natural Terrain Hazard Study covers the natural terrain immediately to the west of the proposed development.

3.1.2 Current Land Use

3.1.2.1 The PH and YLIEE sites are currently zoned Green Belt (GB) and Open Storage (OS) on the Ping Shan Outline Zoning Plan (OZP) No. S/YL-PS/14. The YLIEE site is currently occupied by open storage, vehicle parks, farmland, fallow land, grassland; whilst the PH site is currently occupied by rural residential dwellings and temporary structures.

3.2 Natural Terrain Hillsides

3.2.1 Natural Terrain Catchments

3.2.1.1 The extent of the natural terrain with potential to impact on the YLIEE and PH sites has been determined based on the topographic setting of the hillside. 31 No. of natural terrain catchments have been identified immediately adjacent to the site boundary (Catchments A to AE) as shown in **Figure 3.2.1**.

3.2.2 Catchments Requiring Natural Terrain Hazard Assessment

3.2.2.1 The extent of the natural terrain hillside requiring Natural Terrain Hazard Study (NTHS) has been determined based on the identification of the proposed facilities that satisfy the Inclusion Guidelines defined within Section 1.5 of GEO Report No. 138 (**Figure 3.2.2**). According to this report sites/facilities that are located beyond the influence zone where landslide debris may reach would not be subject to natural terrain hazards even if landslides occur on the hillside. Such areas may therefore be excluded from further screening and study of natural terrain hazards. Initial screening carried out as part of the TR-1 Baseline Review Report (REP-002-01) concluded that Catchments D to J, M, R to S and V to AD satisfy the Inclusion Criteria set out in GEO Report No. 138, and thus required NTHS, whilst the remaining catchment do not meet the inclusion criteria and therefore required no further study.

3.2.2.2 The Inclusion Guidelines defined within GEO Report No. 138 are summarised below, whilst Facility Groups are defined in **Table 3.2.1**.

Table 3.2.1: NTHS facility groups (extracted from GEO Report No. 138, adapted from Wong, 1998)

Group No.	Facilities
1	(a) Buildings -any residential building, commercial office, store and shop, hotel, factory, school, power station, ambulance depot, market, hospital/polyclinic/ clinic, welfare centre
	(b) Others -bus shelter, railway platform and other sheltered public waiting area -cottage, licensed and squatter area -dangerous goods storage site (e.g. petrol station) -road with very heavy vehicular or pedestrian traffic density
2	(a) Buildings -built-up area (e.g. indoor car park, building within barracks, abattoir, incinerator, indoor games' sport hall, sewage treatment plant, refuse transfer station, church, temple, monastery, civic centre, manned substation)
	(b) Others -road with heavy vehicular or pedestrian traffic density -major infrastructure facility (e.g. railway, tramway, flyover, subway, tunnel portal, service reservoir)
3	-densely-used open space and public waiting area (e.g. densely-used playground, open car park, densely-used sitting out area, horticultural garden) -quarry -road with moderate vehicular or pedestrian traffic density
4	-lightly-used open-air recreation area (e.g. district open space, lightly-used playground, cemetery, columbarium) -non-dangerous goods storage site -road with low vehicular or pedestrian traffic density
5	-remote area (e.g. country park, undeveloped green belt, abandoned quarry) -road with very low vehicular or pedestrian traffic density
Note: **For roads, the Facility Group should be based on Figure A13 (Wong, 1998) taking into account the actual Annual Average Daily Traffic and the number of road lanes. For footpaths alongside roads, it may be assumed that footpaths are within the same group as the adjoining roads, except for Expressways (EX), Urban Trunk Roads (UT) and Rural Trunk Roads (RT). Footpaths alongside EX, UT and RT roads may be taken, by default, as a Group 5 facility, unless dictated otherwise by site-specific conditions.**	

3.2.2.3 *In-principle Objection Criteria*: The site is faced with severe natural terrain hazards. A site falls within this category if any proposed Facility Groups 1(a), 1(b) and 2(a) is either (i) located within an angle of reach of 35° from any natural terrain at an elevation of 50 m or more above the proposed site formation level, or (ii) located on or immediately below terrain that is known to be affected by active, large scale, deep seated movement (e.g. Tuen Mun Area 19).

3.2.2.4 *Alert Criteria*: (a) It is a new development site involving provision of Group 1 to 3 facilities, or it is a development that requires modification of lease conditions and involves either a significant population at risk or a significant increase in population at risk; and (b) Where there is natural terrain outside the site, but within the same

catchment that is at an angular elevation of 20° or more from the site and where there is sloping ground at more than 15° within 50 m horizontally upslope of the site, provided that there is a credible debris flow path to the site.

3.2.2.5 The locations of the screening sections used for the proposed development are shown in **Figure 3.2.1**. Where the proposed development includes the formation of new man-made slopes or retaining walls within the toe of the existing natural terrain catchments, the angular elevation has been determined assuming that the crest of the proposed slopes/walls are coincident with the development site boundary. The screening sections showing angular elevations for the catchments overlooking the proposed development site are presented on **Figures 3.2.3a**, **3.2.3b**, and **3.2.3c**.

3.2.2.6 Catchments that meet the alert criteria stated above are shown in **Figure 3.2.1** and include 17 No. of catchments namely, D, E, F, G, H, I, J, M, R, S, X, Y, Z, AA, AB, AC, AD. These catchments require NTHS and are hereafter referred to as the NTHS Catchment. 12 No. of catchments have been screened out during TR-1 Baseline Review Report (REP-002-01) as a result of not meeting the above alert criteria, namely A, B, C, K, L, N, O, P, Q, T, U, AE. Further to this, following a reduction of the site boundary adjacent to catchments V and W, catchments V and W no longer meet the requirement for NTHS, and have been screened out as part of this report. These 14 No. of screened out catchments are not considered in further detail in this report.

4 DESK STUDY

4.1 Approach and Data Sources

4.1.1.1 An engineering geological assessment of the terrain setting and the ground conditions of the NTHS catchments has been conducted based on desk study, aerial photograph interpretation (API), supplemented by detailed field mapping, and landslide and boulder/rock fall modelling.

4.1.1.2 Due account of the current Geotechnical Engineering Office (GEO) requirements for Natural Terrain Hazard Assessments and Mitigation Works Design has been made within the Study, including the following guidance documents:

- Geotechnical Manual for Slopes (1984);
- GEO Report No. 75: Landslides and Boulder falls from Natural Terrain: Interim Risk Guidelines (1998);
- GEO Report No. 104: Review of Natural Terrain Landslide Debris-resisting Barrier Design (2000);
- GEO Report No. 138: Guidelines for Natural Terrain Hazard Studies (2002);
- GEO Report No. 174: Design Basis for Standardised Modules of Landslide Debris-resisting Barriers (2005);
- GEO Report No. 182: Use of Standardized Debris-resisting Barriers for Mitigation of Natural Terrain Landslide Hazards (2006);
- GEO Circular No. 28: Study and Mitigation of Natural Terrain Hazards (2004);
- GEO Circular No. 31: Boulders;
- GEO Technical Guidance Note No. 22 (TGN 22): Guidelines on Geomorphological Mapping for Natural Terrain Hazard Studies (2004);
- Highway Slope Manual (2000);
- GEO Technical Guidance No. 36 (TGN 36), Guidelines on Enhanced Approach to Natural Terrain Hazard Studies (2013);
- GEO Technical Guidance Note No. 37 (TGN 37), Guidelines on Empirical Design of Flexible Barriers for Mitigating Natural Terrain Open Hillslope Landslide Hazards (2013);
- GEO Technical Guidance Note No. 38 (TGN 38), Guidelines on the Assessment for Debris Mobility for Failures within Topographic Depression Catchments (2013).
- The majority of the above publications are available for download at: http://www.cedd.gov.hk/eng/publications/index.htm

4.2 Topographic Setting

4.2.1 Topographic Data

4.2.1.1 The topographic data (Digital Elevation Model (DEM)) for the NTHS Catchments is based on 1:1,000 scale mapping available from the Lands Information Centre of the Lands Department, and LiDAR data available from Lands Department. The topographic information contained within this has been used to derive the topographic information provided in this report. Based on the DEMs, Hill Shade TIN Models have been created within ArcGIS 10.1. Based on the DEM derived from the 1:1,000 scale topographic map, summary details for each of the NTHS Catchments are provided in **Table 4.2.1** below, whilst the DEM produced from LiDAR data has been used to determine flow/runout path characteristics for debris mobility modelling discussed in **Section 6.5.6**:

Table 4.2.1: Topographic characteristics of the NTHS catchments

Catchment No.	Area (m^2)	Maximum Elevation (mPD)	Minimum Elevation (mPD)
D	14,772	53	15
E	6,085	46	13
F	3,976	44	16
G	3,051	34	12
H	2,141	34	14
I	1,631	34	16
J	3,155	52	12
M	4,561	35	12
R	4,346	34	13
S	4,616	33	13
X	2,804	60	25
Y	3,062	74	28
Z	1,581	48	28
AA	7,125	50	12
AB	7,607	49	8
AC	30,332	112	8
AD	23,870	108	8

4.2.1.2 The topographic data indicates that the largest catchment is Catchment AC, comprising an area of 30,332m^2. The maximum elevation is +112mPD, found within Catchment AC, whilst the minimum elevation is +8mPD, at the edge of Catchments AB, AC, and AD.

4.2.2 Slope Angle

4.2.2.1 The slope angle map for the NTHS Catchments is presented in **Figure 4.2.1**. Typical slope gradients within the Catchments range between 0° and 30°, which account for nearly 86% of the Study Area. The remainder of the NTHS Catchments have slope angles between 30o and 90o, with only 0.4% sloping at an angle greater than 45o. The distribution of slope angles within each of the NTHS Catchments is presented in **Table 4.2.2**, below.

Table 4.2.2: Slope angle distribution within NTHS catchments

Catchment No.	Area of Slope Class m²								
	0°-15°	15°-20°	20°-25°	25°-30°	30°-35°	35°-40°	40°-45°	45°-50°	50°-90°
D	3,782	3,675	3353	2532	1164	195	65	0	0
E	2,363	1,695	1163	654	153	56	0	0	0
F	605	1,366	1294	507	116	87	0	0	0
G	460	1,060	1029	391	71	38	1	0	0
H	286	625	694	268	142	109	16	0	0
I	158	330	506	504	100	19	13	0	0
J	248	1,631	963	237	52	9	9	5	0
M	2,359	1,273	666	181	65	12	5	0	0
R	2,274	1,096	801	156	6	8	5	0	0
S	1,659	1,250	1118	421	129	31	8	0	0
X	484	1,050	899	243	95	10	10	6	7
Y	454	762	1014	617	202	13	0	0	0
Z	469	777	453	298	100	0	0	0	0
AA	2,073	1,910	1193	995	345	81	3	1	0
AB	3,144	2,160	1185	667	341	98	9	2	2
AC	3,572	3,807	6167	7428	5413	2699	893	297	56
AD	3,729	4,497	5426	5151	3263	1314	348	103	39
Angle %	27.7	29.5	24.8	12.5	4.3	1.0	0.2	0.0	0.0

4.2.3 Slope Aspect

4.2.3.1 The slope aspect plan for the NTHS catchments is presented in **Figure 4.2.2**. Typical slope Catchments are located on a predominantly northeast to southeast-facing hillside, which comprises 76% of the NTHS catchments. The distribution of slope aspect within each of the NTHS catchments is provided in **Table 4.2.3** below.

Table 4.2.3: Slope aspect distribution within NTHS catchments

Catchment No.	Area of Slope Aspect m²								
	Flat	N	NE	E	SE	S	SW	W	NW
D	448	243	2462	2492	1831	4354	2656	179	103
E	11	1	29	313	4458	1272	0	0	0
F	14	1	123	1901	1259	663	9	1	4
G	28	2	4	869	2,136	9	0	0	1
H	15	628	1,267	229	0	0	0	0	0
I	11	519	85	0	0	0	27	989	0
J	24	35	2,108	960	28	0	0	0	0
M	241	1,528	696	261	279	41	0	0	1,515
R	41	282	1,857	2,086	4	25	0	2	49
S	145	2,045	1,849	238	45	12	13	1	268
X	3	0	16	1,729	987	37	0	32	0
Y	9	1	31	1,144	1,720	158	0	0	0
Z	53	1	30	38	1,195	658	87	27	7
AA	57	2	29	1,107	5,118	265	0	21	0
AB	81	331	5,129	1,950	101	0	4	8	2
AC	855	3,589	4,692	13,115	5,530	217	15	12	2,307
AD	730	970	8,229	7,704	4,418	1,109	661	6	43
Aspect %	1.9	9.4	18.8	21.8	24.8	12.8	5.0	2.2	3.5

4.3 Published Geological Information

4.3.1.1 All available published geological information for the NTHS catchments has been reviewed, this includes the relevant 1:20,000 scale (GEO, 1991) & 1:5,000 scale (Sewell et al, 2000) map sheets published by the Hong Kong Geological Survey (**Figures 4.3.1**, **4.3.2a**, and **4.3.2b**), the accompanying geological memoir (GEO, 1992), as well as the relevant reports and the maps prepared for the Geotechnical Area Studies Programme (GASP) (GCO, 1988).

4.4 Ground Investigation Data

4.4.1.1 A detailed search of ground investigation (GI) records held in the Geotechnical Information Unit (GIU) has been conducted. No ground investigation information exists within the NTHS catchments, however two (2) drillhole reports have been identified within 100m of the NTHS catchments within the GIU archive. A summary of these is provided in **Table 4.4.1** below, and the locations of existing GI locations are presented in **Figure 4.4.1**. Full details of the findings of these drillholes including relevant ground investigation records are provided in **Appendix A1 and A2**. Logs from the 1978 investigation do not provide details of the soil stratum encountered. The log from the 1981 investigation may not be accurate as it records volcanics which are not anticipated in this area according to the published maps.

Table 4.4.1: List of existing relevant ground investigation reports

GIU Ref.	Year	Report Name	Contractor	Location	Comments
13713	1978	Yuen Long Industrial Estate Development	[redacted]	Approximately 40 metres to the west of the crest of catchment AC, located towards the crest of registered man-made feature 6NW-B/C4	Four (4) Boreholes all terminating within soil after "touching rock surface".
02878	1981	Borrow Area K, Northwest New Territories	[redacted]	Approximately 50 metres to the west of the crest of catchment AC, adjacent to a footpath along the ridgeline of Kai Shan (hill)	One (1) borehole terminating in "Completely Weathered Volcanics". Not consistent with mapping which suggests meta-sedimentary bedrock.

4.5 Boulder Field Inventory

4.5.1.1 The details recorded within the Boulder Field Inventory (Emery, 1998) have been reviewed and are presented in **Figure 4.5.1**, and summarised in **Table 4.5.1**. The Inventory shows that boulders have been recorded within the upper portions of NTHS Catchments X, Y, Z, AC and AD, which are adjacent to the YLIEE site.

Table 4.5.1: Summary of Boulder Field Inventory

Boulder Field ID	Percentage Area Covered	Boulder Type	Boulder Size	Boulder Shape
1791	-	-	-	-
60	-	-	-	-
72	10-20%	Corestone and Tor	90% Less than 1m 10% 1 – 2m in size	Angular

4.6 Instability Records

4.6.1 Published Instability Records

4.6.1.1 A review of GEO Landslide Incident Records as well as the Enhanced Natural Terrain Landslide Inventory (ENTLI) (MFJV, 2007), and the Large Landslide Dataset (Scott Wilson, 1999) was undertaken. The locations of all recorded or interpreted instabilities within the Study Area are presented, with the Boulder Field Inventory, in **Figure 4.5.1**.

4.6.2 Enhanced Natural Terrain Landslide Inventory

4.6.2.1 The ENTLI includes the records of zero (0) recent and seventeen (17) relict natural terrain landslides within the NTHS Catchments up to 1993. The locations of the ENTLI features are presented in **Figure 4.5.1**.

Table 4.6.1: Summary of ENTLI within NTHS catchments

NTHS Catchment	ENTLI	Recent/Relict	Class	Description
D	06NWB0053E	Relict	C2	Depression may have been formed by landslide-related activity.
D	06NWB0054E	Relict	C2	Depression may have been formed by landslide-related activity.
D	06NWB0055E	Relict	B1	Minor depression.
F	06NWB0056E	Relict	C2	Depression may have been formed by landslide-related activity.
R	06NWB0104E	Relict	B1	Depression.
AA	06NWB0096E	Relict	C2	Wide depression may have been formed by landslide-related activity.
AC	06NWB0091E	Relict	C2	Wide depression may have been formed by landslide-related activity.
AC	06NWB0092E	Relict	C2	Wide depression may have been formed by landslide-related activity.
AC	06NWB0093E	Relict	A2	Sharp scarp with some evidence of downslope debris but indefinitely related.
AC	06NWB0094E	Relict	A2	Sharp scarp with some evidence of downslope debris but indefinitely related.
AC	06NWB0095E	Relict	A2	Sharp scarp with some evidence of downslope debris but indefinitely related.
AC	06NWB0089E	Relict	B1	Minor depression.
AD	06NWB0083E	Relict	B1	Minor depression.
AD	06NWB0084E	Relict	B1	Minor depression.
AD	06NWB0085E	Relict	B1	Minor depression.
AD	06NWB0086E	Relict	B1	Depression.
AD	06NWB0090E	Relict	B1	Depression.

4.6.3 Large Landslide Dataset

4.6.3.1 Four (4) large landslides from the Large Landslide Dataset are recorded within the natural terrain adjacent to the proposed site, however only one (1) of those large landslides (6NWBL005) is

located within the NTHS Catchments, catchment AC as indicated in **Figure 4.5.1**. Further details are provided in **Table 4.6.2** below.

Table 4.6.2: Summary of Large Landslide Dataset within NTHS catchments and surrounding area

NTHS Catchment	Large Landslide	Description
AC	6NEBL005	Located in the southern portion of NTHS catchment AC
-	6NEBL006	Immediately north of NTHS catchment AD
-	6NEBL003	170m west of NTHS catchment S
-	6NEBL004	100m south of NTHS catchment R

4.6.4 GEO Incident Reports

4.6.4.1 A review of GEO Incident Reports identified no incident reports within or adjacent to the NTHS Catchments between 1991 and 2012.

4.7 Registered Man-made Features

4.7.1.1 A total of eight (8) registered man-made features are located within or partially within the NTHS catchments. Of these features, a total of seven (7) are recorded as being cut slopes, whilst one (1) is a fill slope. The location of these registered man-made features are indicated in **Figure 4.7.1**, and summarised with details in **Table 4.7.1**. The condition of these will be reviewed along with other man-made slope features as part of the Geotechnical Assessment, with findings presented in TR3b.

Table 4.7.1: Registered man-made features

Slope Registration No.	Catchment	Slope Type	Maintenance Responsibility
6NW-B/C24	D	Cut Slope	Partly Private and partly Government Responsible Government Department: Lands D Responsible Private Party: DD122 Lot1236
6NW-B/C98	AD	Cut Slope	Lands D
6NW-B/C99	AB	Cut Slope	Responsible Government Department: Lands D
6NW-B/C103	M	Cut Slope	Partly Private and partly Government Responsible Government Department: Lands D Responsible Private Party: DD122 Lot1144 DD122 Lot1143
6NW-B/C104	M	Cut Slope	Lands D

Slope Registration No.	Catchment	Slope Type	Maintenance Responsibility
6NW-B/C145	X	Cut Slope	Partly Private and partly Government Responsible Government Department: Lands D Responsible Private Party: DD126 LOT568A DD126 LOT572B DD126 LOT573 DD126 LOT574
6NW-B/C146	AA	Cut Slope	Partly Private and partly Government Responsible Government Department: Lands D Responsible Private Party: DD126 LOT568A DD126 LOT569
6NW-B/F204	AA	Fill Slope	Partly Private and partly Government Responsible Government Department: Lands D Responsible Private Party: DD126 LOT565 DD126 LOT581G DD126 LOT563 DD126 LOT557

4.7.1.2 The condition of existing man-made slopes will be considered in further detail in TR3b Geotechnical Assessment Report.

4.8 Aerial Photograph Interpretation

4.8.1.1 Aerial Photograph Interpretation (API) of the NTHS catchments and the surrounding area has been conducted using the photographs available from the Aerial Photograph Library of the GEO. A total of five (5) relict debris slides have been identified within the NTHS catchments, which all correspond with ENTLI records. Confirmed landslides are detailed in **Table 6.3.1**. A summary of the photographs used for the assessment, together with a detailed presentation of the key findings, is included in **Appendix B**.

5 ENGINEERING GEOLOGICAL ASSESSMENT

5.1 Solid Geology

5.1.1.1 The 1:20,000 HKGS Geological Map (GEO, 1991) and the 1:5,000 HKGS Geological Map (Sewell et al, 2000) indicate that the NTHS Catchments are underlain by metasiltstone and phyllite with metasandstone of the Lok Ma Chau Formation, deposited during the Carboniferous. The presence of metasiltstone was confirmed by inspection of rock outcrops during detailed field mapping. An extract of the 1:20,000 geological map is presented in **Figure 4.3.1**, whilst an extract of the 1:5,000 map is presented in **Figures 4.3.2a** and **4.3.2b**.

5.1.1.2 Five existing boreholes have been identified in the natural terrain within 200m of the NTHS Catchments. Of these boreholes four (4) were available within the GIU, namely 13713/P4, 13713/P5-A, 13713/P5-B, and 2878/K-2. Of these boreholes 13713/P4, 13713/P5-A, and 13713/P5-B are all shown as terminating in soil, with only a brief description of the geology as being "Soil". The remaining borehole 2878/K-2 is located approximately 50m west-southwest of NTHS Catchment AC, and indicates moderately to slightly weathered volcanic from 19.75mbGL. This description is not consistent with the geological maps for the area, nor the observations made during the detailed field mapping. Further details of these boreholes are included in **Appendix A**, with borehole logs and a summary table.

5.2 Superficial Geology

5.2.1.1 The 1:20,000 HKGS Geological Map and the 1:5,000 HKGS Geological Map indicate that the Lok Ma Chau formation is overlain locally by Quaternary colluvial deposits comprising gravelly, clayey silt and sand with cobbles and boulders. These colluvial deposits are mapped predominantly in the footslopes of the natural terrain, and can be expected to have accumulated predominantly within open valley areas.

5.3 Uncertainties in the Ground Model

5.3.1.1 There is currently insufficient data to confirm the geological profile below the NTHS Catchments. This is due to local opposition to the proposed ground investigation, and prevention of access to proposed drillhole locations. However, it is considered that the desk study information and observations made during field mapping are sufficient to determine potential landslide character and design event volumes for this NTHS. Having considered this, a degree of conservatism has been applied during the hazard assessment and hazard modelling in the following sections.

6 NATURAL TERRAIN HAZARD ASSESSMENT

6.1 Enhanced Approach to NTHS

6.1.1.1 Whilst the brief requires this NTHS to be undertaken in accordance with GEO Report No. 138, it is noted that GEO published a new Technical Guidance Note (GEO TGN 36) on Enhanced Approach to Natural Terrain Hazard Studies on 5th July 2013. The implications of this new approach have also therefore been reviewed.

6.1.1.2 Given that the proposed development comprises of public housing, the areas of which are currently undifferentiated, and the extension of a private industrial estate, it is found that the revised design event approach and framework and the adoption of the react to known hazard principle are not relevant to this study.

6.2 Detailed Field Mapping

6.2.1.1 Detailed field mapping was carried out over several days during April and May 2013. The purpose of the mapping was to verify the geological and geomorphological features identified during the desk study and API, and to carry out detailed geomorphological mapping of the NTHS Catchments. Geomorphological mapping of possible landslide features was undertaken, with their dimensions recorded. Boulders were also mapped with their dimensions recorded. These details were used together with information from the desk study to produce Engineering Geological Maps for the area, and are provided as **Figures 6.2.1 and 6.2.2**. These details were also used during the debris mobility modelling and boulder/rock fall analysis. Copies of field mapping sheets are provided in **Appendix C**.

6.2.1.2 The NTHS Catchments were found to comprise broad open valleys and broad interfluve terrain, which was consistent with observations made during the API. The drainage lines within catchments AC and AD were identified as being predominantly ephemeral, with no flow observed except in the lower reaches of the channels. Minor seepage was observed below approximately +22mPD, and flow occurring below approximately +12mPD.

6.2.1.3 Vegetation throughout the NTHS Catchments generally comprised dense shrub and brush of between 0.5m and 1.0m in height. Particularly dense vegetation was identified within the drainage channels of catchments AC and AD. More mature vegetation including dense trees and brush was identified in the footslopes of catchments AC, AB, S, R, M, J and D.

6.2.1.4 Graves were located throughout the NTHS Catchments and adjacent slopes, with the exception of catchment I. No sign of instability associated with these graves was observed.

6.2.1.5 Of the five ENTLI features located in the NTHS Catchments and confirmed during API, two were further confirmed during field mapping, namely ENTLI 06NWB0084E and 06NWB0085E. Of all of the confirmed ENTLI features, ENTLI 06NWB0084E was identified as having the largest of the landslide volumes within all NTHS Catchments.

6.2.1.6 The field mapping recorded boulders within the northern portion of the study area adjacent to the YLIEE site only in NTHS Catchments X, AC, and AD. Although rock outcrops were identified during the field mapping, these were not prominent, and no potential rockfall hazard could be identified from these outcrops. The field mapping identified no signs of distress or deterioration of the hillside that may pose an immediate danger to the downslope facilities.

6.3 Natural Terrain Hazard Susceptibility

6.3.1 Susceptibility Class

6.3.1.1 The assessment of susceptibility class has taken due consideration of the five hazard models presented in Section 2.5 of GEO Report No. 138, namely Open Hillslope Landslides (OHL), Channelised Debris Flow (CDF), Deep-seated Slide, Rock Fall and Boulder Fall. The evidence for susceptibility of the NTHS Catchments to landslide and rock/boulder fall hazards is described in sections 6.5, below.

6.3.2 Landslides

6.3.2.1 ***Landslide types are further defined below (as per GEO Report No. 138).***

Open Hillslope Landslide (OHL): OHL hazards comprise slope failures where the landslide debris remains wholly on the open hillside and is not channelized along a stream course. Mechanisms of slope failure can include debris slides, avalanches and flows.

Channelised Debris Flows (CDF): CDF hazards occur when saturated landslide debris becomes constrained within a steeply inclined stream channel. These types of failure are typically extremely mobile and landslide volumes can well exceed that of the source area due to entrainment of material within the stream bed and channel sides.

Deep-seated Slides: This type of failure involves the displacement of a relatively large volume of intact debris by sliding along a deep-seated basal rupture surface. The occurrence of these types of failures within Hong Kong has not been widely reported and is relatively rare.

6.3.2.2 A summary of all confirmed landslides identified from available records, and confirmed by API and site reconnaissance is provided in **Table 6.3.1** below. Whilst the ENTLI indicates seventeen (17) relict landslide features within the study area, only five (5), ENTLI Nos. 06NWB0056E, 06NWB0084E, 06NWB0085E, 06NWB0091E and

06NWB0096E could be confirmed by API and detailed field mapping. The remaining ENTLI features could not be confirmed through API or detailed field mapping and are considered to be topographic depressions. All ENTLI features within the NTHS Catchments are shown in **Figure 4.5.1**. Details of those landslide features that were mapped during the detailed field mapping are included in **Appendix D1**.

Table 6.3.1: Summary of landslides confirmed through either API and/or field mapping

Catchment	ENTLI Ref.	Source	Recent / Relict	Landslide Type	Year first Observed	Geometry from		Source Area				
						API	Field	Slope Length (m)	Width (m)	Depth (m)	Estimated Volume (m3)	ENTLI Class
F	06NWB0056E	ENTLI	Relict	CDF	1963	✓		8	10	2	84	C2
AA	06NWB0096E	ENTLI	Relict	CDF	1963	✓		7	10	2	73	C2
AC	06NWB0091E	ENTLI	Relict	CDF	1963	✓		9	12	*1*	57	C2
AD	06NWB0084E	ENTLI	Relict	CDF	1963	✓	✓	9	10	2	94	B1
AD	06NWB0085E	ENTLI	Relict	CDF	1963	✓	✓	8	9	2	75	B1

Table Footnotes:
Landslide Type:
CDF = Channelised Debris Flow

Landslide Depth:
Where landslide geometry could not be confirmed by the Field Mapping, depths have been assumed based on the characteristics of other nearby failures. Assumed depths are indicated in italics
Landslide Volume: Estimated based on (L*W*D*π)/6 (after WP/WLI, 1990)

6.3.2.3 It should be noted that there is no evidence of any recent natural terrain landslides within the study catchments or indeed within any surrounding hillslope areas.

6.3.3 Boulder/Rock Fall Susceptibility

6.3.3.1 ***Boulder or rock fall are defined below as per GEO Report No. 138.***

6.3.3.2 Rock Falls: Rock Falls occur when one or several, typically angular rock blocks are displaced from a rock face.

6.3.3.3 Boulder Falls: Boulder Falls occur when one or several, typically rounded rock blocks are transported down slope from their source area by rolling, bouncing or sliding. The source areas typically comprise poorly embedded surface boulders that have been exhumed by hillside erosion around them.

6.3.3.4 As part of the site reconnaissance, details of boulders or potentially unstable rock blocks within areas of outcrop were recorded. Details of boulders observed or largest boulder within a cluster are provided in **Table 6.3.2** below. Although rock outcrops were observed during the detailed mapping, no potentially unstable rock blocks were identified.

Table 6.3.2: Summary of Boulders confirmed through field mapping

Catchment	Boulder Ref.	Geometry from		Average Slope Angle at Source (°)	Boulder/Rock Block Dimensions	
		API	Field		Estimated Boulder Volume (m^3)	Estimated Boulder Mass (kg)
X	X-B1		✓	30	2.0	5,200
AC	AC-B1		✓	28	2.5	6,500
AC	AC-B2		✓	20	2.0	5,200
AD	AD-B1		✓	27	3.0	7,800

6.3.4 Susceptibility Class

6.3.4.1 The natural terrain setting of the NTHS Catchments is considered to have a moderate susceptibility to landslides as per Table 4 of GEO Report No. 138. This is confirmed by the lack of recent instability identified in ENTLI, landslide incidents, API and field mapping within the NTHS Catchments. Therefore Susceptibility Class C is adopted for the NTHS Catchments.

6.4 Landslide Consequence

6.4.1 Consequence Group

6.4.1.1 An assessment of the general consequence group for each of the NTHS Catchments has been carried out in accordance with Table 1 of GEO Report No. 138 and the explanatory notes or the grouping of toe / crest facilities in the Slope Information System (GEO, 2006). The findings of the assessment are presented below, and facility groups are shown in **Figure 6.4.1**.

6.4.2 Facility Groups

6.4.2.1 Proposed facilities to be located adjacent to the natural terrain in the northern portion are those associated with the YLIEE (Catchments R, S, X, Y, Z, AA, AB, AC, AD). At the toe of the natural terrain, the open industrial space associated with the industrial lots is considered to fall within Facility Group 4. Beyond the open industrial space are industrial buildings considered to be of Facility Group 2a.

6.4.2.2 Proposed facilities to be located adjacent to the natural terrain in the southern portion of the study area are those associated with the PH site (Catchments D, E, F, G, H, I, J, M). At the toe of the natural terrain the residential areas are considered to fall within Facility Group 3. Beyond the open space associated with the residential area, the residential buildings are considered to fall within Facility Group 1a.

6.4.3 Proximity Assessment

6.4.3.1 A review of the angular elevations of the hillside areas above the critical facility within each of the NTHS catchments indicates that the facilities adjacent to catchments S and H are classified as "moderately close" (i.e. angular elevation between 25° to 30°), whilst the remaining catchments are classified as being "far" (i.e. angular elevation of less than 25°). The sections used for the assessment are presented in **Figures 3.2.3a**, **3.2.3b**, and **3.2.3c**. Therefore, in accordance with Table 2 from GEO Report 138, Consequence Class II is applicable for Catchment S and H, whilst Consequence Class III is applicable for the remaining catchments. This dictates the requirements for the Design Event approach which is discussed further in **Section 6.5**.

6.5 Landslide Design Event

6.5.1 Design Event Requirements

6.5.1.1 The design requirements for a design event assessment approach have been determined based on the guidelines presented in Table 2 of GEO Report No. 138. With due reference to the detailed desk studies, API and field mapping, the Susceptibility Class and Consequence Class

determined for each of the catchments overlooking the proposed development, all catchments require the adoption of a Conservative Event (CE) for design purposes.

6.5.1.2 A CE is defined as:

"*a reasonably safe but not overly cautious estimate of the hazard that may affect the site, with a notional return period in the order of 100 years, and is generally based on the largest historical landslide over the past 50 to 100 years (e.g. identified from aerial photographs) in the catchment and its vicinity as appropriate*".

6.5.1.3 Summary of the Design Event requirement for the NTHS catchments is provided in **Table 6.5.1** below:

Table 6.5.1: Design event requirements as per GEO Report No.138

Proposed Development at Toe	Catchment	Facility Group No.	Consequence Class	Susceptibility Class	Required Design Event Approach
PH	D	1a	III	C	CE
PH	E	1a	III	C	CE
PH	F	1a	III	C	CE
PH	G	1a	III	C	CE
PH	H	1a	II	C	CE
PH	I	1a	III	C	CE
PH	J	1a	III	C	CE
PH	M	1a	III	C	CE
YLIEE	R	2a	III	C	CE
YLIEE	S	2a	II	C	CE
YLIEE	X	2a	III	C	CE
YLIEE	Y	2a	III	C	CE
YLIEE	Z	2a	III	C	CE
YLIEE	AA	2a	III	C	CE
YLIEE	AB	2a	III	C	CE
YLIEE	AC	2a	III	C	CE
YLIEE	AD	2a	III	C	CE

6.5.2 Design Event Source Magnitudes

6.5.2.1 An assessment of the magnitude of the design events to be adopted for the NTHS Catchments has been determined based on the CE design event requirements (**Table 6.5.1** above). Landslide history, geomorphological setting and geological condition of the NTHS Catchments as determined from the desk study, API and detailed field mapping have all been used to determine the design event. Details of

design event magnitudes based on relict landslide features were determined from field observations. Details of relict landslide features confirmed in the field are presented in **Appendix D1**, whilst their viable travel paths are presented in **Appendix D2**. Both landslides within the NTHS Catchments and those formed within similar terrain adjacent to the NTHS Catchments have been considered in accordance with GEO Report No. 138.

6.5.3 Landslides within NTHS Catchments

6.5.3.1 The geomorphological setting of the NTHS Catchments has been divided into six (6) terrain units, which are detailed in **Table 6.5.2** below.

Table 6.5.2: Terrain unit characteristics

Terrain Unit	Terrain Characteristics	Evidence of Instability	Design Event Source Volume
Rock Outcrop	Terrain where rock is identified at surface, with little or no soil covering.	None	-
Channel Terrain	Incised channel located at the base of valley terrain, with indication of water flow along the channel.	No confirmed landslide events. However on-going erosion along the stream channel and undercutting of the stream bank may result in instability.	100m^3
Anthropogenically Modified Terrain	Modification of the terrain by human activities. May include small retaining structures or graves.	None	<50m^3
Valley Terrain	Valley terrain generally with drainage line at the base. Sides of the valley are generally greater than 30^o	None. Although there were no confirmed previous landslides within this terrain unit, it is anticipated that there is potential for instability triggered by erosion within the channel terrain unit. Landslide volumes will be similar to the Open Valley Terrain unit.	100m^3

Terrain Unit	Terrain Characteristics	Evidence of Instability	Design Event Source Volume
Open Valley Terrain	As above but broader valley, with valley sides generally less than 30°	Confirmed previous landslides include 06NWB0084E (84m³), 06NWB0084E (94m³), 06NWB0085E (75m³), 06NWB0091E (57m³), and 06NWB0096E (73m³).	100m³
Interfluve Terrain	Broad open generally convex terrain. Typically located along spur lines.	No evidence of previous instability. Site observations indicated intermittent rock outcrop along many of the spurlines. Soil covering where present, is thin. Erosion along these spurlines may give rise to small, low volume landslides.	50m³

6.5.3.2 The geomorphological setting of the NTHS catchments is shown in **Figures 6.5.1** and **6.5.2** as Terrain Units Maps, produced using information from the desk study, API, and detailed field mapping. The locations of the five confirmed landslides listed in **Table 6.3.1** are also shown on these figures for ease of reference.

6.5.3.3 Catchments AD, and AC include channel terrain and as such may be subject to channelized debris flow (CDF) or initiate as Open Hillslope Failure (OHF) and become CDF. The geomorphological setting of Catchments AB, AA, S, R, M, J, I, H, G, F, E, D are such that landslide hazards will predominantly relate to Open Hillslope Failure (OHF).

6.5.3.4 A review of the ENTLI, API and detailed field mapping identified that the confirmed source volumes of relict failures within the NTHS Catchments and relevant adjacent catchments comprise relatively small-scale (source volume <100 m³ for CDF and 50 to 100 m³ for OHL) landslide failures. In order to apply design event volumes to terrain units indicated in **Table 6.5.2**, above, volumes of confirmed landslides occurring in each of the terrain unit were evaluated. The largest confirmed landslide for each terrain unit was adopted. From the observations, it was noted that CDF was the dominant landslide type for both valley terrain and open valley terrain, whilst OHL was

the dominant landslide type for interfluve terrain. No landslides were identified as initiating within anthropogenically modified terrain.

6.5.3.5 It is considered that the CE for landslides initiating in the channel terrain, valley terrain and open valley terrain are less than 100 m^3; and the CE for landslides initiating in the interfluve terrain unit are 50 m^3. Details of Design Event source volumes applied to each terrain unit are summarised in **Table 6.5.2**, above, and shown as terrain hazard units (**Figures 6.5.3** and **6.5.4**).

6.5.4 Design Event Entrainment Magnitudes

6.5.4.1 The potential volume of entrainable material along CDF run-out paths has been determined based on the drainage line characteristics observed during the detailed field mapping. These volumes have been estimated using a channel yield approach (Hungr, 1984), whereby the drainage line is divided into a number of segments along its length, with each segment being assigned a typical channel width and depth of entrainable material based on the conditions present in the field. The depths of material applied are typically conservative in nature, applying the maximum observed thickness across the entire channel width. This approach is considered sufficient to address the potential for additional material being generated through localised incidences of channel bank erosion and collapse during a CDF.

6.5.4.2 A summary of the channel characteristics recorded during the detailed field mapping as well as the various channel segments defined for each of the major drainage paths in the NTHS Catchments is included in **Appendix E1** and the drainage channel segments in **Appendix E2**. This information has been used during the debris mobility modelling carried out for CDF in order to determine the potential volumes of entrainment that each CDF could generate.

6.5.5 Rock Fall and Boulder Fall Hazards

6.5.5.1 The design magnitudes for potential rockfall and boulder fall events have been determined based on the maximum volumes of boulder observed within the boulder clusters.

6.5.5.2 The API carried out identified a number of areas that could potentially be capable of producing a boulder or rock fall that may pose a potential hazard to the proposed development. During the detailed field mapping these areas were further refined, and details of potential boulder fall sources recorded, together with geometry of boulders. No potential sources of rock instability were identified. Areas of potential boulder fall were identified in NTHS catchments AD, AC, and X as shown in **Figure 6.5.3**. Maximum volumes of the boulders were measured during the field mapping, and subsequently used during modelling of boulder falls. Volumes of boulders ranged from 2 m^3 to 3m3. Further details are provided in the Boulder Inspection Record

sheet included in **Appendix F1**, whilst viable travel paths for recorded boulders in **Appendix F2**.

6.5.6 Debris Runout Assessment

6.5.6.1 Potential debris runout paths have been simulated using GIS and are shown in **Figure 6.5.5**. Runout paths have been calculated using modelled drainage flow paths within the NTHS Catchments. Landslide debris mobility modelling was carried out using the modelling software Dan-W in order to assess the potential impact of the OHL and CDF hazards on the proposed development.

6.5.6.2 As no recent landslides have been identified, a database of site-specific debris mobility characteristics and debris mobility parameters could not be developed for this analysis. As such, parameters from Figure 21 of GEO Report 104 and GEO Technical Guidance Notes (TGN) Nos. 29 and 34 have been adopted for the analysis, i.e.

- Friction angle of 25° for the modelling of low volume open hillslope landslides (for volume < 500 m^3) using Friction Rheology;
- Friction angle of 11° (Friction Coefficient input as 0.2 in DAN/W) for channelised debris flows using Voellmy Rheology and turbulence coefficient of 500 m/s^2 for the modelling of channelised debris flows using the Voellmy Rheology.

6.5.6.3 With reference to TGN 29, none of the adverse site settings which can lead to the development of sizeable CDF's with watery debris of high mobility are present.

6.5.6.4 A total of seventeen (17) landslide models have been run for the various NTHS Catchments, as presented in **Appendix G**.

6.5.6.5 Of the seventeen landslides that were modelled two (2) produced runout that reached the boundary of the proposed development. The runout distances of these landslides are displayed in **Figure 6.5.5**, and landslide details are summarised in **Table 6.5.3** below. Volumes and thickness of debris reaching the proposed development site are expected to be very low.

Table 6.5.3: Landslides reaching proposed development

Catchment ID	S	H
Failure ID	F-S1	F-H1
Hazard Type	OHL	OHL
Estimated Source Volume (m^3)*	50	50
Total Debris Volume (m^3)	49.49	49.7
Total Debris Volume passing OP (m^3)	0.07	5.99
Maximum Debris Thickness at OP (m)	0.01	0.016
Maximum Debris Velocity (m/s)	4.56	8.08
Maximum Debris Velocity at OP (m/s)	2.25	3.5
Potential Site to be affected	YLIEE	PH Site

6.5.6.6 Failure F-S1 which initiated in Catchment S adjacent to the YLIEE enters the site boundary of the proposed development (indicated at the Observation Point (OP)) with a maximum thickness of 0.01m, a maximum velocity at the OP of 4.56m/s, and a total volume passing the OP of 0.07m^3 (i.e. reaching the site).

6.5.6.7 Failure F-H1 located in Catchment H adjacent to the PH site is indicated to enter the site boundary of the proposed development with a maximum thickness of 0.016m, a maximum velocity at the OP of 8.08m/s, and a total volume passing the OP of 5.99m^3.

6.5.6.8 Subsequent to the completion of the above analysis, it is noted that GEO published a new Technical Guidance Note (TGN 38) on The Assessment of Debris Mobility on Failures within Topographic Depression Catchments on 5th July 2013. Taking the new guidance into consideration, it is found that the Open Valley Terrain Units detailed in **Table 6.5.2** could alternatively be considered as Topographic Depression terrain. However, given that the debris mobility modelling parameters recommended in TGN38 for topographic depressions are less conservative than those suggested in GEO Report No. 104 for Channelised Debris Flows (ϕ=18°, ξ=1000m/s^2, as compared to ϕ=11°, ξ=500m/s^2), the adoption of TDF parameters for areas currently labelled as open valley terrain would result in reduced debris mobility. As the existing run-out modelling based on the CDF parameters indicates that the debris would have negligible potential to affect facilities within the site, reassessment of debris mobility using less conservative parameters has not been conducted.

6.5.7 Boulder Fall Analysis

6.5.7.1 In addition to the landslide hazards, potential sources boulder fall hazard have been identified in catchments X, AC and AD. In order to assess the potential impact of these hazards on the proposed development, boulder fall modelling has been carried out using the software programme RocFall.

6.5.7.2 Source locations for the boulder falls have been determined based on the locations of boulder clusters identified from API and detailed field mapping. Potential block sizes have been determined based on the maximum observed size of blocks with potential for instability. A total of four (4) boulder fall models have been carried out for the various NTHS Catchments, which covers the sources of potential boulder fall hazard and all of the potential boulder fall paths. The runout paths of the modelled boulder falls are presented in **Figure 6.5.6**, whilst the findings of the assessment are presented in **Appendix H** and summarised below.

6.5.7.3 The RocFall analysis indicated that none of the boulders and rock blocks modelled will reach the site boundary of the proposed development.

7 MITIGATION STRATEGY

7.1 Hazards to be Mitigated

7.1.1.1 The hazard assessment has identified that no boulder or rock fall hazard is likely to impact on the proposed development. OHLs have been identified as having potential to affect the proposed development adjacent to catchments S and H only. CDFs are not expected to impact on the proposed development.

7.1.1.2 It should be noted however, that the total OHL debris volume expected to reach the site boundary at catchments S and H is approximately $0.1m^3$ and $6.0m^3$ respectively. As a result of the low volume and thickness of material expected to enter the proposed development, the consequence of a landslide is more likely to cause inconvenience at the proposed development rather than pose a hazard to human life or have a significant impact on the proposed building and infrastructure.

7.2 Possible Hazard Mitigation Strategy

7.2.1.1 It is anticipated that landslides occurring within the study area will consist of very small volumes of debris, and pose only minor inconvenience to the proposed facilities. As such, it is considered that mitigation measures in the form of flexible barriers often specified to mitigate OHLs are unnecessary, as they are not justifiable for such a low volume of material.

7.2.1.2 It should be noted that a significant thickness of vegetation is present at the footslopes of those catchment identified as posing potential for landslide material entering the proposed development. This dense vegetation is not taken into consideration during the debris mobility modelling. It is considered that the vegetation would have a significant effect on the small volumes of landslide debris; reducing the energy of the debris flow, and promoting deposition of debris flow material before it reaches the site boundary. It is considered that the existing dense vegetation located on the footslopes of the catchments would act to reduce the flow of landslide debris, and prevent low volumes of debris from entering the site. Due to the very small volumes of material expected to enter the proposed development site in the event of OHLs, the construction of mitigation measures is not recommended.

7.2.1.3 Although the analysis presented here is in accordance with GEO report No. 138, it is recognised that the GEO published new guidelines in NTHS (TGN Nos. 36, 37 and 38) in July 2013. A review of the implications of this guidance on this project suggests there would be no difference in the recommended mitigation strategy.

8 CONCLUSIONS AND RECOMMENDATIONS

8.1.1.1 In total, seventeen (17) catchments were studied as part of this NTHS, which considered the potential for landslide hazards and boulder or rock fall hazards. Following detailed API and field mapping, modelling undertaken in accordance with GEO Report No. 138 indicated the possibility of OHLs entering the proposed development at catchments S and H. Modelling discounted the potential for boulder or rock fall hazards. Modelling of landslide hazards at catchments S and H concluded that the total volume of material expected to enter the proposed site was $0.1m^3$ and $6m^3$ respectively.

8.1.1.2 Due to the very small volumes of material expected to enter the proposed development site in the event of OHLs, the construction of mitigation measures is not recommended.

8.1.1.3 The brief also requires a review of the condition of all existing man-made slopes within the adjoining natural hillside and Study Area. The condition of existing man-made slopes will be considered in further detail in TR3b Geotechnical Assessment Report.

8.1.1.4 The requirements of recently published guidance of an Enhanced Approach for NTHS (TGN No.s 36, 37 and 38) have been reviewed. As the proposed developments comprise of public housing and private industrial estate development, there would be no impact on the outcome of the study by adopting these new guidelines.

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