SECTION 2 : DETAILED STUDY OF THE LANDSLIDE AT FUNG SHING STREET, NGAU CHI WAN, KWUN TONG ON 9 JUNE 1998

Fugro Scott Wilson Joint Venture

This report was originally produced in December 1999 as GEO Landslide Study Report No. LSR 21/99

FOREWORD

This report presents the findings of a detailed study of the landslide (GEO Incident No. K 98/6/1) that occurred within fill slope No. 11NE-A/F116 at Fung Shing Street, Ngau Chi Wan, Kwun Tong on 9 June 1998. An approximately 15 m length of this fill slope adjacent to Fung Shing Street failed resulting in the release of about 250 m^3 of debris. The debris inundated a wooden watchmen's hut at the toe of the slope before continuing onto Fung Shing Street and partially blocking the northbound lane of the road. The subsequent alluvial outwash from the landslide debris travelled a further 250 m or so down Fung Shing Street towards its junction with Clear Water Bay Road. No fatalities or injuries were reported following the landslide.

The key objectives of the detailed study were to document the facts about the landslide, present relevant background information and establish the probable causes of the failure. The scope of the study was generally limited to site reconnaissance, desk study and engineering analysis. Recommendations for follow-up actions are reported separately.

The report was prepared as part of the 1998 Landslide Investigation Consultancy (LIC), for the Geotechnical Engineering Office (GEO), Civil Engineering Department (CED), under Agreement No. CE 74/97. This is one of a series of reports produced during the consultancy by Fugro Scott Wilson Joint Venture (FSW). The report was written by Mr G Taylor and reviewed by Mr Y C Koo. The assistance of the GEO in the preparation of the report is gratefully acknowledged.

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1. INTRODUCTION

At about 5:00 p.m. during the severe rainstorm of 9 June 1998, a landslide (GEO Incident No. K 98/6/1) occurred within fill slope No. 11NE-A/F116 adjacent to Fung Shing Street, Ngau Chi Wan, Kwun Tong (Figure 1 and Plates 1, 2 and 3). The landslide involved the failure of an approximately 15 m wide section of the slope adjacent to an existing stepped channel and resulted in the release of about 250 m^3 of debris. The landslide debris inundated a watchmen's hut at the toe of the slope before continuing onto the adjacent Fung Shing Street, partially blocking the northbound lane of the road. The subsequent alluvial outwash from the landslide debris travelled about a further 250 m down Fung Shing Street towards its junction with Clear Water Bay Road. The watchmen's hut has subsequently been removed. No fatalities or injuries were reported as a result of the landslide although two watchmen are understood to have been present in the hut during the incident.

Following the incident, Fugro Scott Wilson Joint Venture (the 1998 Landslide Investigation Consultants) carried out a detailed study of the failure for the Geotechnical Engineering Office (GEO), Civil Engineering Department (CED), under Agreement No. CE 74/97. This is one of a series of reports produced during the consultancy by Fugro Scott Wilson Joint Venture (FSW).

The key objectives of the study were to document the facts about the landslide, present relevant background information and establish the probable causes of the failure. The scope of the study was generally limited to site reconnaissance, desk study and engineering analysis. Recommendations for follow-up actions are reported separately.

This report presents the findings of the detailed study, which comprised the following key tasks:

(a) desk study, including a review of relevant documentary records and plans relating to the history of the site,

(b) aerial photograph interpretation (API),

(c) interviews with witnesses of the landslide and other concerned persons,

(d) field mapping and detailed observations and measurements at the landslide site,

(e) analysis of rainfall data,

(f) engineering analysis of the slope that failed, and

(g) diagnosis of the probable causes of the failure.

2. THE SITE

2.1 Site Description

The Ngau Chi Wan Landfill is located within the valley immediately to the east of Hammer Hill. Slope No. 11NE-A/F116 forms part of this landfill, a series of "fill" platforms on both sides of Fung Shing Street in Ngau Chi Wan, Kwun Tong (Figures 1 and 2). It is part of the middle platform of a series of three, which have been constructed along the western side of Fung Shing Street. Three registered slopes - Nos. 11NE-A/F116, 11NE-A/F117 and 11NE-A/F124 - are associated with these platforms. Fill slope No. 11NE-A/F68 and associated platform on the eastern side of Fung Shing Street complete the Ngau Chi Wan Landfill.

Slope No. 11NE-A/F116 is approximately 300 m in length with a maximum height of about 16 m. The feature comprises a main slope approximately 225 m in length and a subsidiary slope, about 75 m long. The angle of inclination of these slopes typically varies between 20° and 25°. The fill slope is densely-vegetated. The 1998 landslide occurred at the junction between the main and subsidiary slopes, in the southeastern corner of the platform adjacent to a stepped channel. In the vicinity of the landslide the fill slope is approximately 14 m high (crest level about 84.6 mPD, toe level about 70.6 mPD) with an angle of inclination of approximately 25°. A wooden watchmen's hut was also located at the toe of the slope adjacent to the stepped channel and 1998 landslide site.

In addition to this stepped channel, surface water drainage to slope No. 11NE-A/F116 also includes a stepped channel approximately 60 m to the north of this junction. U-channels, 600 mm and 400 mm wide in the vicinity of the 1998 landslide, run along the toes of both the main and subsidiary slopes. The U-channel/catchpit along the toe of the main slope ran underneath the watchmen's hut (Plate 4). Surface water drainage provisions at the crest of slope No. 11NE-A/F116 are limited. There is no drainage provision at the crest of the subsidiary slope whilst part of the length of U-channel (300 mm wide) provided at the crest of the main slope had been infilled and paved over prior to the 1998 landslide (see Section 3.2).

The platform above slope No. 11NE-A/F116 has an area of approximately 1.3 hectares with a general fall towards its southeastern corner. In places the platform has a hard surface cover (concrete/asphalt).

2.2 Maintenance Responsibility

According to the "Systematic Identification of Maintenance Responsibility of Registered Slopes in the Territory" (SIMAR) project, the maintenance responsibility for slope No. 11NE-A/F116 at the time the landslide occurred rested with the tenant of Short Term Tenancy Agreement No. KX1725, West Coast International (Parking) Limited (WCI). The platforms in this area of Kwun Tong, most of which have been created by landfilling operations, have generally been let on a Short Term Tenancy basis for the past 15 to 20 years by the District Lands Office/Kowloon East. The proposed land-use specified for the site in Short Term Tenancy Agreement No. KX1725 was fee-paying public parking.

2.3 Services

As part of this investigation, FSW contacted both Government and private utility providers for details of any services in the vicinity of the landslide. The responses indicate that no utilities are located within the immediate vicinity of the landslide site.

2.4 Site History

2.4.1 General

The history of development at the site has been determined from an interpretation of a sequential series of aerial photographs (Table 1, and Figures 3, 4 and 5) as well as a review of the relevant documentary information. The information sources consulted during this detailed study are summarised in Table 2. The key findings of this work are presented in the following sections of the report.

2.4.2 History of Development

Slope No. 11NE-A/F116 forms part of the Ngau Chi Wan Landfill, a series of fill platforms on both sides of Fung Shing Street (Figure 1). The Ngau Chi Wan Landfill is a 7.5 hectare valley-infill type of landfill. The floor of the existing decomposed granite valley was firstly deepened, before landfilling commenced in January 1976. Between this time and December 1977, about 0.7 million tonnes of material, consisting of both domestic and commercial waste (relative proportions not known), was placed to depths in excess of 30 m.

Drawings (Figure 6) and photographs (Plates 5 and 6) associated with the original landfill site formation contract administered by the Development and Airport Division of the Public Works Department indicate that the landfilling operation generally comprised the following stages:

(a) the dumping (end-tipping) of the “refuse”,

(b) the subsequent (daily) spreading and compaction (by bulldozer) of this material to form 2 m high square cells, and

(c) the placing of a 300 mm thick covering (of “earth or ash”) over all of the exposed faces of each cell (on a daily basis). This covering (sealing) layer was also spread and compacted by bulldozer.

Settlement was monitored at twelve locations within the Ngau Chi Wan landfill during the period 1976 to 1985 (Binnie, 1991). The depth of refuse varied from 10 to 34 m. The measured strain (S/H where S is settlement and H is thickness of refuse) varied from 10% to 20% over the measurement period. This is significantly higher (up to 20%) than for the other urban landfills in Hong Kong (Binnie, 1991). This difference is attributed to the relatively loose state of the refuse at Ngau Chi Wan. The maximum, recorded differential settlement was 3 m. This magnitude of differential settlement was attributed to the difference in thickness of refuse between monitoring stations.

According to the "as-built record" drawings, perimeter U-channels (at both the crests and toes of the slopes) were provided to the completed fill platforms. These drawings also indicate that the slopes were formed to a side slope of 1 in 2 and that the platform, at the crest of fill slope No. 11NE-A/F116, was to have a general level of 85 mPD. No details were obtained regarding the intended thickness of the final overall capping layer to each landfill platform.

The stepped channel adjacent to the 1998 landslide was not constructed as part of the above original works. It appears from API and documentary evidence (GCO, 1981) that this channel was built between 1980 and 1981.

In 1980, consultants working on behalf of the Geotechnical Control Office (GCO, renamed GEO in 1991) were asked to comment on the Draft Engineering Conditions of the Tenancy Agreements for the landfill platforms. GCO noted, following a site inspection, that much surface erosion, in the form of gullies, was evident on the slopes and commented that several of the surface water drainage channels and catchpits were also blocked. Although the proposed development involved a low risk to life (and no special Engineering Conditions were thus required for the Tenancy Agreement) GCO recommended that any administration huts should be located away from the toe of fill slope No. 11NE-A/F116 and that the surface water drainage network should be properly maintained.

From 1980 onwards the western fill platforms of the Ngau Chi Wan Landfill have generally been used as temporary car/lorry parks.

In 1982, in connection with a further development proposal for the site GCO inspected the slopes and subsequently reported erosion on fill slope No. 11NE-A/F124. GCO recommended re-compaction of the surficial layer of fill and the reinstatement of the surface protection layer. It has not been possible to establish definitively whether these recommendations were implemented. In addition, GCO noted that the peripheral surface water drains at the site were blocked and considered that the surface water drainage provision on the fill slopes themselves was inadequate and that more maintenance was required.

In 1987, in connection with another development proposal for the site, GCO was asked for comments. It was noted that the landfill comprised fill slopes with side slopes between 20° and 30° in inclination (steeper than those adopted for landfill slopes at this time, i.e. 1 in 3). GCO suggested that the slopes might require to be flattened before the site could be used for the then intended use – a refugee centre. GCO also noted that the surface protection layer provided to some of these slopes was in a poor condition, and that repair and maintenance works were required.

The first indications that the U-channel at the crest of the main slope of the feature had been filled over were noted on the 1990 aerial photographs. Site inspection by FSW in June 1998 revealed that this U-channel was infilled and an asphalt layer laid over the infilled U-channel (Plates 7 and 8).

2.4.3 Past Instabilities

The GEO's landslide database indicates that there have been no record of reported past landslide incidents within slope No. 11NE-A/F116 or the adjacent slopes, Nos. 11NE-A/F117 and 11NE-A/F124. However, a history of previous instability has been determined for the landfill site from field inspection, desk study and examination of both high and low level aerial photographs (Table 1 and Figures 3, 4 and 5).

The Ngau Chi Wan Landfill slopes were considered in 1981 by the GCO as part of the Fei Ngo Shan Geotechnical Area Study (GCO, 1981), which comprised aerial photograph interpretation, field mapping and an assessment of existing site investigation records. The Engineering Geology Map (dated January 1981) for the study area included in the report noted a "zone of instability containing distinct landslip scars" adjacent to the site of the 1998 landslide. The associated Terrain Classification Map (also dated January 1981) classified this "zone of instability" as disturbed terrain of 15° to 30° slope angle, "straight-colluvial", with a well-defined landslide scar, and comprising a fill slope between 15 m and 30 m in height. The portions of the slope flanking this "zone of instability" were classified as disturbed terrain also of slope angle 15° to 30°, "straight-colluvial", exhibiting signs of very severe rill erosion and comprising a fill slope between 15 m and 30 m in height. In the southeastern corner of slope No. 11NE-A/F116, severe (i.e. > 40% bare ground) sheet erosion was also noted. A photograph included in the report and in the vicinity of the 1998 landslide shows remedial works comprising protective matting placed over the slope following severe gully and rill erosion (GCO, 1981). The stepped channel adjacent to the 1998 landslide is also evident in this photograph.

Numerous slips/erosion scars have been observed on the slopes since their formation. Within the vicinity of the 1998 landslide, slips/erosion scars/gullies were noted on the 1979, 1980, 1986, 1987, 1988, 1992, 1993, 1995 and 1996 aerial photographs (Figure 5). In the 1979 photographs bare strips (possible evidence of past erosion) were also noted on the slopes to the west of the 1998 landslide site, whilst in 1980 standing water was evident on the platform above. Additionally, from about the mid-1980's to the mid-1990's bare ground (possible evidence of past erosion) was noted at the crest of the slopes immediately to the north of the stepped channel (and adjacent to the 1998 landslide scar). Indications from the API (1993 photographs) and subsequent site inspections by FSW during this detailed study (Plate 9), are that a protective layer of chunam has been applied to these bare patches.

In addition to the erosion noted in the 1995 photographs, an area of possibly dead vegetation (with corresponding enhanced susceptibility to erosion) was observed adjacent to the stepped channel in the southeast corner of slope No. 11NE-A/F116 at this time (Figure 5). Both of these features coincide approximately with the location of the 1998 landslide. Normal vegetation replaced the area of possibly dead vegetation in the 1996 photographs.

Significant erosion scars/gullies have also been noted in the western half of the subsidiary slope of the feature as well as within the adjacent upper and lower landfill slopes, Nos. 11NE-A/F117 and 11NE-A/F124, in the last 20 years (Figure 5).

In 1989, during routine inspections along Fung Shing Street representatives of the Highways Department (HyD) noted a washout type of failure (volume unknown) near the crest of slope No. 11NE-A/F116, about 60 m to the north of the 1998 landslide site, also

adjacent to a stepped channel (Figure 2). Although the tenant subsequently repaired the slope HyD expressed concern over the possibility of similar types of failures occurring in the future and the subsequent debris reaching the road below. In addition, GCO, following an inspection of the slopes after the above landslip (during which time the absence of a proper surface protection layer at the crest of the slope was noted), warned of the incidence of similar events during heavy rainfall in the future.

2.5 Previous Studies and Assessments

No detailed stability assessments are known to have previously been carried out on slope Nos. 11NE-A/F116, 11NE-A/F117 and 11NE-A/F124.

2.5.1 Slope Registration

The landfill slopes were registered in the 1977/78 Catalogue of Slopes as Nos. 11NE-A/F116, 11NE-A/F117 and 11NE-A/F124 respectively.

2.5.2 SIFT Studies

In 1992, the GEO initiated the consultancy agreement entitled "Systematic Inspection of Features in the Territory" (SIFT), which aimed to update information on existing registered slopes in the 1977/78 Catalogue of Slopes, based on studies of aerial photographs and limited site inspections. Fill slopes, Nos. 11NE-A/F116, 11NE-A/F117 and 11NE-A/F124, were considered as part of this consultancy in September 1995. All three fill slopes were assigned to Class "B1", i.e. a slope "formed or substantially modified before 30.6.78".

2.5.3 SIRST Studies

In 1994, the GEO initiated the consultancy entitled "Systematic Identification and Registration of Slopes in the Territory" (SIRST), which aimed to update the 1977/78 Catalogue of Slopes and prepare a New Catalogue of Slopes. Fill slope No. 11NE-A/F116 was considered as part of this consultancy in 1996. It was noted during an inspection of the slope on 9 August 1996 that the stepped channel adjacent to the 1998 landslide was severely cracked (Plate 10). However, no signs of seepage were identified. The covers to both the slope face and the adjacent platform were noted as being in a poor condition during this inspection.

In addition, although no past instabilities were inferred the record of field inspection indicates that "reasonable" signs of distress "near crest" and within the "midportion" of the slope were noted at this time (based on a grading system comprising the categories "severe", "reasonable", "minor" and "none").

The "critical section" of slope identified during this SIRST field inspection corresponds approximately with the location of the 1998 landslide.

2.6 Geology

The Hong Kong Geological Survey's 1:20 000 scale map, Sheet 11 Hong Kong and Kowloon Solid and Superficial Geology (GCO, 1986a) indicates that the site is underlain by Mesozoic medium-grained granite, Jurassic-Cretaceous in age (Figure 7). Jointing within the granite dips at 80° in southeasterly, southwesterly and northwesterly directions. In addition, pegmatite has been mapped to the southwest of the Ngau Chi Wan Landfill at Hammer Hill.

Quaternary debris flow deposits have been mapped within the footslopes of the adjacent Kowlooon Peak (Fei Ngo Shan) whilst fill deposits, comprising natural earth and waste, have been mapped in the valley below. These fill deposits correspond approximately to the Ngau Chi Wan Landfill. The accompanying geological memoir (GCO, 1986b) confirms this interpretation.

The engineering geology map from the Geotechnical Area Studies Programme (GASP) Report I, Hong Kong and Kowloon (GCO, 1987), generally confirms the above stratigraphic sequence indicating that the landslide site is underlain by colluvial deposits. In addition, a geological photolineament is shown trending in a generally NNW-SSE direction along the Hammer Hill ridge line. No past instabilities were noted within the landfill slopes, Nos. 11NE-A/F116, 11NE-A/F117 and 11NE-A/F124, in the GASP report.

3. THE LANDSLIDE

3.1 Time of Failure

Concerned persons interviewed following the landslide indicated that two watchmen were on duty in the hut at the toe of the slope at the time of the failure. Unfortunately, these potential eye-witnesses were not willing to be interviewed by FSW about the incident. The three concerned persons, a watchman from the platform above, a watchman from the platform below and the HyD Inspector who organised the urgent emergency works were interviewed. One of these interviewees indicated that the landslide occurred at about 5:00 p.m. on 9 June 1998.

3.2 Description of the Landslide

A plan of the landslide is shown in Figure 2 whilst a section through the failed part of the slope, based on the results of field examination and topographical survey plans, is shown in Figure 8.

An inspection of the landslide site was carried out by representatives of both HyD and Environmental Protection Department (EPD) on 10 June 1998. Water was evident discharging into the landslide scar from the platform above (Plates 1, 2 and 3). The remains of the debris fan at the toe of the slope were also apparent (Plate 1). In addition, areas where water had caused the wetting-up of the capping layer material within the landslide scar, forming erosion channels, were evident (Plate 3). The densely-vegetated nature of the slopes in the vicinity of the landslide was also apparent during this inspection (Plates 1 and 2).

The first inspection of the landslide site by FSW was made during the afternoon of 16 June 1998. A comprehensive inspection of the landslide scar was made at this time.

The landslide comprised the failure of an approximately 15 m wide section of the landfill slope adjacent to an existing stepped channel at the junction between the main and subsidiary slopes of the feature, and resulted in the release of about 250 m^3 of debris (Plates 11, 12 and 13). The upper part of the landslide scar was generally "L-shaped" in plan, approximately 15 m wide at the crest of the slope reducing to about 5 m in width, some 5 m downslope (Figure 2). The scar remained at this relatively constant width for a further 18 m. At this point, near the toe of the slope, an "erosion channel", approximately 0.5 m wide, 1.0 m deep and 2.0 m in length, was evident within the landslide scar (Plate 14). The sides of both the landslide scar and "erosion channel" were generally sub-vertical whilst the base of the scar was generally inclined at an angle of about 20°. The landslide scar was about 2 m deep generally, and up to 2.5 m deep locally. Based on site observations and accounts by witnesses the debris is considered to have formed a fan below the "erosion channel", which spread out onto Fung Shing Street below this channel (Figure 2 and Plate 1).

Examination of the landslide scar revealed that the failure was confined essentially to the capping layer of the landfill. This capping layer was typically 2 m deep and comprised a medium dense light brown slightly gravelly silty fine- to coarse-grained sand with some cobbles and occasional boulders. Layering was evident within the capping layer (Plate 7) as were probable erosion channels within the base of the scar (Plates 15 and 16).

There was evidence that construction waste was being stored at the crest of the slope prior to the landslide. Some of this waste appeared to have fallen into the landslide scar during the incident (Plate 12).

The underlying landfill in the base of the landslide scar comprised predominantly construction waste – concrete, timber and general building rubble generally of maximum dimension about 0.3 m. The remnants of a U-channel and a lighting column (both originally located at the crest of the slope) were also evident within the landslide scar (Plates 11, 12 and 13). The U-channel, 300 mm wide and 550 mm deep, had been infilled and an asphalt layer placed over the infill (Plates 7 and 8).

The landslide scar was dry at the time of FSW's first inspection. This inspection was, however, made several days after the incident occurred.

A stepped channel, 400 mm wide and 600 mm deep, was located adjacent to the landslide scar, and several significant voids (maximum dimension in excess of 0.5 m) were observed in the fill underlying the channel (Plates 12, 17 and 18). Although surface water runoff appeared to be concentrated towards the stepped channel at the crest of the slope no drainage connections were observed between the crest U-channel and the stepped channel.

The debris fan is understood to have had the general areal extent shown in Figure 2. This is partly corroborated by the remnants of this feature shown in Plate 1. The debris fan is thought to have been of the order of 0.5 m in depth maximum (Plates 19 and 20). The remains of the fan that were inspected by FSW on 16 June 1998 comprised generally a loose light brown slightly gravelly silty fine- to coarse-grained sand with some cobbles and boulders. No construction waste was identified in the remains of the debris fan.

The travel angle of this landslide, determined after Wong & Ho (1996), was approximately 17°. This value is towards the lower bound of the range of values usually encountered in Hong Kong for landslides involving wash-out by concentrated surface water flow. The subsequent outwash from the landslide debris, which travelled southwards down Fung Shing Street for a distance of approximately 250 m (according to HyD's Inspector) following the incident, was ignored in this determination.

3.3 Consequences of the Landslide

As a result of the landslide one lane of Fung Shing Street was temporarily blocked by debris. This debris was subsequently removed by HyD during the evening of 9 June 1998 and the northbound lane of Fung Shing Street re-opened to traffic.

After the landslide, urgent repair works comprising trimming the loose material from within the vicinity of the landslide scar, diverting the surface water collected upslope of the landslide scar to a proper discharge point and unblocking the surface water drainage network were undertaken by HyD.

Initial remedial works comprising loosely dumping sandfill without proper compaction into the landslide scar were undertaken by the tenant of the fill platform, WCI, shortly after the event. This was done apparently in an effort to protect the core of the landfill which had been largely unaffected by the landslide. WCI were subsequently instructed by DLO/KE, on the advice of the GEO, to cease these remedial works and remove the already placed fill. GEO warned of the danger of "liquefaction-type failures" occurring if this material remained in place.

Following these initial remedial works further remedial works proposals were prepared by Au Posford Consultants Ltd on behalf of WCI (Au Posford, 1998). These works, comprising the removal of the uncontrolled sandfill and replacement with compacted general fill, and reinstatement of the surface drainage network in the vicinity of the 1998 landslide, were implemented between 4 January and 5 February 1999 (Plates 21, 22 and 23, Au Posford, 1999).

4. SUBSURFACE CONDITIONS

4.1 General

The ground conditions at the site were determined using information obtained from both desk and field studies. Desk studies included a review of the available documentation supplemented by API, whilst field studies included the results of post-failure mapping. Field inspection of the landslide site was carried out by FSW during June 1998.

4.2 Field Mapping and Previous Ground Investigations

4.2.1 Field Mapping

Field mapping of the landslide site indicates that the slope that failed is composed of a completely decomposed granite fill capping layer overlying landfill (construction site waste). The capping layer fill exposed in the landslide scar was typically described as a medium dense light brown slightly gravelly silty fine- to coarse-grained sand with some cobbles and occasional boulders. Erosion gullies were noted adjacent to and undermining the stepped channel. In addition, an "erosion channel" was observed towards the toe of the slope (see Section 3.2 for details).

The features mapped at the site by FSW following the 1998 landslide are shown in Figures 2 and 8 whilst a section through the landslide scar showing the inferred ground conditions is given in Figure 9.

4.2.2 Previous Ground Investigations

Ground investigation associated with the Urban Landfills Restoration Project (ULRP) was carried out at the Ngau Chi Wan Landfill by Gammon Construction Limited during 1991/1992 (Gammon, 1992a). The fieldworks comprised the sinking of auger holes, gas monitoring wells, combined gas/groundwater monitoring wells and combined gas/leachate monitoring wells. In addition, a number of service voids as well as a number of other locations were selected for gas pressure monitoring.

Of the exploratory holes sunk at the Ngau Chi Wan Landfill during this fieldwork two, combined gas/leachate monitoring wells, NCWGL2 and NCWGL3, and 8 No. 75 mm diameter auger holes were located in the general vicinity of the 1998 landslide (Figure 2). The 150 mm diameter monitoring wells were sunk to depths of approximately 13.5 m and 13.6 m below the existing ground surface and encountered both the landfill capping, described typically as a brown silty medium- to coarse-grained sand, to a maximum depth of 4 m and the underlying waste, fragments of plastic bags, cloth and wood in a silty medium- to coarse-grained sand matrix. The auger holes were all sunk to a depth of 3 m and encountered only the landfill capping, which typically comprised a brown silty medium-grained sand with some gravel.

The laboratory testing (Gammon, 1992b) associated with this fieldwork comprised a comprehensive suite of chemical tests on samples of waste, groundwater and leachate. Otherwise, no testing was undertaken on the samples recovered from the site.

Further ground investigation also associated with the ULRP was undertaken by The Hong Kong Landfills Restoration Group (HKLRG) during the summer of 1998 (before the landslide) within the Ngau Chi Wan Landfill. The fieldworks included 5 trial pits, TB1 to TB5, located within the platform at the crest of slope No. 11NE-A/F116. At the time of preparing this report this information was not available to FSW. Additionally, it is not known what, if any, insitu or laboratory testing was carried out in association with this fieldwork.

4.2.3 Groundwater Conditions

The closest groundwater monitoring stations to the 1998 landslide are the combined gas/leachate monitoring wells, NCWGL2 and NCWGL3 (Figure 2), installed during the fieldworks undertaken by Gammon Construction Limited in 1991/1992 (Gammon, 1992a). The tips of the standpipes installed in these monitoring wells were located within the landfill waste at depths of approximately 13.5 m and 13.6 m below the existing ground surface respectively. These instruments were monitored generally on a daily basis for two weekly periods during the fieldworks, one during December 1991 and one during January 1992.

The groundwater monitoring records indicate that the water level in combined gas/leachate monitoring well NCWGL2, located within the platform at the crest of fill slope No. 11NE-A/F116, was generally about 13 m below the existing ground surface whilst combined gas/leachate monitoring well NCWGL3, located within the platform at the toe of slope No. 11NE-A/F116, was dry throughout both monitoring periods. Halcrow buckets were not installed in either of these instruments.

Although the groundwater monitoring data is limited it does suggest that subsurface groundwater probably did not play a part in the 1998 landslide. Additionally, no seepages were noted in the landslide mainscarp during field inspection by FSW in June 1998 following the incident.

5. SURFACE WATER DRAINAGE IN THE VICINITY OF THE LANDSLIDE

The general form of the fill platform above slope No. 11NE-A/F116 is such that in general water sheds towards the stepped channel and the 1998 landslide site in the southeast corner of the platform. This is in contrast to the information given on the "as-built record" drawings for the landfill platforms which suggests that surface water was to be concentrated towards the north and away from the 1998 landslide site. The depth of landfill placed appears to have been greater in the southeast corner of the site than in the north (Table 1) and it may be that settlement has subsequently taken place altering the fall of the platform. Also, the Surface Hydrology Map (dated January 1981) from the Fei Ngo Shan GAS report (GCO, 1981) indicates that (pre-development) an ephemeral drainage line traversed close to the location of the 1998 landslide, serving as further evidence that a greater depth of landfill might have been placed in this vicinity.

Additionally, surface water drainage provision to the platform and adjacent slopes is limited. Moreover, site inspections indicate that not all the surface water drainage originally proposed has actually been constructed. No evidence has been found on the "as constructed drainage" drawings or on site of either the chevron drains or the associated stepped channels, which were proposed on the "drainage layout" drawings for the landfill slopes.

In addition, the surface water drainage network provided in the vicinity of the 1998 landslide has been infilled and paved over. Also, the stepped channel in the southeast corner of the platform does not appear to have had any physical connection to the adjacent surface water drainage provisions at the crest of the slope prior to the 1998 failure.

6. ANALYSIS OF RAINFALL RECORDS

The nearest GEO automatic raingauge to the landslide site is raingauge No. K04, located at Lee Cheung House in Shun Lee Estate (Figure 1). This raingauge records and transmits rainfall at 5-minute intervals via a telephone line to the GEO.

For the purposes of rainfall analysis and based on witness accounts, it is assumed that the landslide occurred at 5:00 p.m. on 9 June 1998.

The daily rainfall recorded by this raingauge for one month preceding, and seven days following the incident, is presented in Figure 10. This daily rainfall figure shows that the storm was concentrated around the day that the landslide occurred, i.e. 9 June 1998. The corresponding hourly data for the period from 5:00 p.m. on 7 June 1998 to midnight on 9 June 1998 is also shown on Figure 10. Peaks in rainfall between 5:00 a.m. and 9:00 a.m., between 11:00 a.m. and 2:00 p.m., and between 4:00 p.m. and 6:00 p.m. on 9 June 1998, generally in the range 30 mm/hr to 70 mm/hr, are indicated by this figure.

Isohyets of rainfall for the 24-hour period preceding the landslide are given for the whole of Hong Kong in Figure 11. This figure indicates that the rainfall conditions in the Ngau Chi Wan area were relatively severe on 9 June 1998.

Table 3 presents the estimated return periods for the maximum rolling rainfalls recorded at raingauge No. K04 for selected durations preceding the landslide, based on historical rainfall data recorded at the Hong Kong Observatory (Lam & Leung, 1994). The 5-minute to 4-hour maximum rolling rainfalls recorded (i.e. short-term duration storms) were only moderately severe with return periods generally less than 6 years. The 12-hour and 24-hour maximum rolling rainfalls recorded were the most severe (373.5 mm and 447 mm, respectively), with the corresponding return periods ranging from about 30 years to 40 years.

A comparison between the patterns of rainfall preceding the landslide on 9 June 1998 and those of selected previous major rainstorms recorded at raingauge No. K04 is given in Figure 12. It can be seen from this figure that the maximum rolling rainfalls recorded for the 4-hour to 24-hour durations were the most severe experienced by the landslide site since installation of raingauge No. K04 in the mid-1980' s.

7. THEORETICAL STABILITY ANALYSIS

Given the type and nature of the landslide, essentially an erosion/washout type of failure of the capping layer of a landfill, detailed theoretical stability analyses are not considered necessary to assist in the diagnosis of the probable causes and mechanism of the landslide. Additionally, based on post-failure site inspections by FSW, no exceptionally low strength materials appear to have been involved in the landslide.

8. DIAGNOSIS OF THE PROBABLE CAUSES OF THE LANDSLIDE

8.1 The Mode and Likely Sequence of the Landslide

The shape of the landslide scar together with the disposition of the resultant debris as well as the witness accounts, is the key information upon which a reconstruction of the mode and sequence of the failure is based.

The "erosion channel", at the base of the 1998 landslide scar together with the disposition of the debris in the corresponding fan, suggest that the failure did not occur all at once but that the instability had developed progressively probably involving pulses of failure. It is postulated that the initial failure of the fill slope took the form of either an erosion gully or a local landslip towards the toe of the slope as a result of concentrated surface water runoff from the platform above. Continued rainfall and surface water runoff probably led to increased erosion/gullying of the slope. The landslide subsequently retrogressed upslope towards the platform at the crest of the feature, with associated lateral enlargement of the corresponding scar.

The above postulation is supported by the shape of the landslide scar at the crest of the slope, the disposition of the debris at the toe of the slope and in particular the observation that some of the debris was deflected "uphill", around the watchmen's hut at the toe of the slope before forming a debris fan on Fung Shing Street. Had the failure occurred all at once it is considered likely that the wooden watchmen's hut would have been destroyed or carried away by the landslide given its flimsy construction and the volume of debris involved in the landslide.

A schematic representation of the inferred sequence of events is given in Figure 13.

8.2 Factors Contributing to the Landslide

The close correlation between the rainfall recorded on 9 June 1998 and the timing of the landslide together with witness accounts indicate that the failure was triggered by rainfall. Furthermore, based on the information collected during this study, it is postulated that the failure is attributable to a combination of the following factors:

(a) poor surface drainage provisions with corresponding concentrated overland flow following relatively severe rainfall,

(b) a history of past instability,

(c) lack of slope maintenance, and

(d) possible past/continuing ground movement.

8.3 Probable Causes of the Landslide

Based on the information collected during this study, it is postulated that the failure is attributable to poor surface water drainage provision on the platform above the slope with corresponding concentrated overland flow and subsequent erosion of the fill slope.

The API, desk studies and field inspections carried out as part of this study have revealed a history of past instability, primarily in the form of erosion scars and gullies, within the vicinity of the 1998 landslide. These instabilities may have caused local weakening of the landfill capping layer. It appears that these past incidents of erosion had not been reported to the GEO and that no proper repair works were carried out. It is therefore possible that the previously failed areas of the slope contain loose disturbed material (Plates 24 and 25).

The landslide involved the failure of the capping layer of a landfill slope standing at an angle of between 20° and 25°. There were no surface water drainage provisions at the crest of the slope and there has been a lack of slope maintenance generally (Plates 26 and 27). The 300 mm wide U-channel originally provided at the crest of the slope had been infilled and subsequently paved over prior to the 1998 landslide, thus promoting concentrated overland flow from the platform onto the slope below, particularly in the southeast corner of the fill platform which is the low point.

Significant distress was noted in the stepped channel adjacent to the 1998 landslide in August 1996 during an inspection associated with GEO's SIRST consultancy. This distress may be indicative of past/recent collapse/ongoing settlements within the underlying landfill as suggested by the voids noted beneath the stepped channel adjacent to the 1998 landslide (Plates 12, 17 and 18). In addition, the general fall of the platform may have been affected by continuing settlement of the landfill (see Section 5) and altered the drainage regime of the platform.

Estimates of the continuing long term secondary settlement as well as immediate settlement resulting from the landfill restoration works have been made (Golder, 1998). The estimates vary from about 100 mm to in excess of 600 mm. This ongoing settlement of the underlying landfill may have led to opening up of the ground at the surface thus increasing the susceptibility to water ingress with resultant erosion/gullying. This effect would have been exacerbated by the concentration of overland flow in this locality.

9. FUTURE DEVELOPMENTS

The Ngau Chi Wan Landfill is to be restored as part of the EPD's Urban Landfills Restoration Project. The design and build contract for this work has recently been awarded to the HKLRG.

Under this contract the Contractor "shall investigate all existing slopes (including for the avoidance of doubt any natural slopes) and retaining structures within the Site Boundary". Where the factors of safety determined are less than those stipulated in Geotechnical Control Conference Paper No. 260 "Geotechnical Standards for the Restoration of Landfill Slopes" (or subsequent document upgrading these requirements) the Contractor "shall Design and construct remedial Works necessary to achieve the required factor of safety". Subsequently,

the Contractor "shall submit a Geotechnical Design Submission as part of the Design" to the EPD. This submission "shall also be forwarded by the Contractor to the Geotechnical Engineering Office of the Hong Kong Government (GEO), in accordance with the procedures in Lands and Works Branch Technical Circular No. 3/88 (or subsequent circular updating these requirements)".

10. CONCLUSIONS

It is concluded that the landslide, which occurred on 9 June 1998 within fill slope No. 11NE-A/F116, was triggered by severe rainfall with an estimated return period of up to 40 years. The failure essentially affected the capping layer to a landfill slope with a history of instability and took the form of an erosion/washout type of failure. It was caused by concentrated overland flow from the platform above the old landfill slope. The crest U-channel at the head of the landslide scar had previously been infilled and paved over.

Other contributory factors may include past/ongoing settlement of the underlying landfill material altering the surface water drainage regime of the platform and increasing susceptibility to ingress of water on the slopes in the southeast corner of the site.

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LIST OF TABLES

Table 1 – Summary of Site Development from Aerial Photograph Interpretation

Year	Photograph Reference No.	Altitude (feet)	Observations (refer to Figures 3, 4 and 5)
1949	Y01750, Y01751	8,000	The site is undeveloped and consists of a NorthNorthWest-SouthSouthEast (NNW-SSE) trending valley bordered to the west and north by a well-defined ridge. Several west-east trending spurs and gullies enter the valley from the western portion of this ridge. Jats Incline is noted to the east of the site. The tops of the ridges and spurs are fairly barren and vegetation comprises mainly small trees and shrubs along the valley lines. Vegetation on the hillsides appears to consist largely of grass. Gully erosion is evident on the lower slopes to the south of the western ridge.
1963	Y08089, Y08090 Y08038, Y08039	2,700 2,500	The site remains largely undeveloped with the exception of an area of intense terracing immediately to the east of the NNW-SSE trending valley. Erosion is evident on the tops of the ridges and on the lower slopes to the southwest of the site.
1967	Y13422, Y13423	6,250	The site continues to remain largely undeveloped with the exception of two areas of intense terracing. In addition to the terracing noted on the 1963 photographs, to the east of the NNW-SSE trending valley, another area of terracing, to the southeast of the area affected by the 1998 landslide, is noted. The upper slopes of the main ridge to the west of the site are very barren and vegetation appears to be confined to the hillsides below the footpath.
1973	5254, 5255	5,000	Development of the site has commenced. Major earthworks, comprising excavation into the hillside, are in progress on the ridge to the west of the site. A substantial portion of the southern end of the ridge has been removed. The terraced area to the east of the NNW-SSE trending valley appears to have been enlarged. Otherwise no further changes apparent.
1974	10445, 10446	4,000	Two well-developed platforms as well as an associated access road are evident on the ridge. The areas of terracing noted previously remain well-established. The lower slopes below Jats Incline appear heavily-vegetated.
1976	15362, 15363	4,000	Very good quality photographs which show the site development very well. Major earthworks consisting largely of landfilling are in progress and the NNW-SSE trending valley has largely been infilled. Cutting of the lower slopes to the east of the NNW-SSE trending valley, below Jats Incline, is also in progress. In addition, Fung Shing Street has now been constructed on the lower hillside. At the area of interest the road is

Year	Photograph Reference No.	Altitude (feet)	Observations (refer to Figures 3, 4 and 5)
			benched-in to the hillside, with a small cut slope to the north which appears to be vegetated. The large cutting to the east of the road is fresh and unvegetated. There is evidence of drainage material being placed at the base of the fill in the north of the site. Filling is already well-advanced in the area affected by the 1998 landslide.
1977 (Sept)	19280, 19281	3,000	The middle platform is now fairly well-formed (though not yet to full height). The main slope of this platform comprises largely the cut slope formed during the construction of the adjacent Fung Shing Street. To the south this slope becomes composed increasingly of fill. The subsidiary slope of the platform consists entirely of fill. Additionally, a drain has been observed running along the crest of the main (fill) slope of the middle platform. This drain connects into a down-channel before outfalling at the base of the slope.
1977 (Dec)	20305, 20306	4,000	Very good quality photographs. The upper, middle and lower platforms are now well-formed. The drain noted on the main slope of the middle platform in the September photographs is not evident. It is assumed that it has either been removed or filled over. A drainage channel is now present along the toe of the subsidiary slope of the middle platform. Additionally, a linear excavation is evident in the northwest corner of the platform running down from the upper platform to the toe of the slope.
1978	24118, 24119	4,000	Very good quality photographs. The upper platform slopes are now well-formed, with drainage completed and vegetation in places. Excavation for the reservoir to the west of the site is well-advanced. Otherwise no further changes evident.
1979	27302, 27303	4,000	The middle platform is now fully formed. Apart from some bare strips at the junction between the main and subsidiary slopes of the middle platform and the western end of the subsidiary slope (where there is also some gully erosion) the slopes are vegetated. Additionally, a drain is noted running along the crest of the main slope. A stepped channel is also present about halfway along this slope.
1980	30125, 30126	4,000	The lower platform is now almost complete. There are still strips of bare vegetation on the subsidiary slope of the middle platform. The western half of the subsidiary slope remains unvegetated. Additionally, standing water is evident on the middle platform itself.

Year	Photograph Reference No.	Altitude (feet)	Observations (refer to Figures 3, 4 and 5)
1981	36611, 36612	5,500	All three platforms are well-developed and drainage is now in place on the lower platform. A northeast-southwest trending drain has been placed across the middle platform. There are two dark patches adjacent to the end of this drain (at the toe of the upper platform slope). The southwestern end of the drain appears to outfall to the drainage channel running along the western edge of the platform at the fill/natural slope boundary. Additionally, a stepped channel is now in place at the junction of the main and subsidiary slopes of the middle platform, which extends down the slope before outfalling to the toe drain on the lower platform. There is a bare strip of slope around this stepped channel. Erosion patches are evident on the upper platform slopes.
1986 (Sept)	A06276, A06277	4,000	The Ngau Chi Wan Service Reservoir is now present to the west of the site. The middle and lower platforms have been surfaced and are being used as car/lorry parks. The drain running along the crest of the main slope of the middle platform ends at the stepped channel. There is no crest drainage on the subsidiary slope of the platform. There is a relatively thin strip of erosion on the main slope of the middle platform to the north of the stepped channel, in the southeast corner of the platform. The Watchmen's Hut (damaged by the 1998 landslide) is now present at the toe of the slope at the entrance to the lower platform adjacent to the stepped channel.
1986 (Nov)	A06875, A06876	2,000	No real changes apparent. The toe drain for the upper platform (i.e. situated along the northern edge of the middle platform) is unclear and may be infilled.
1987 (Jan)	A08621, A08622	2,000	There is a small erosion gully on the main slope of the middle platform to the north of the stepped channel (similar location to that noted in 1986). The channel along the northern edge of the middle platform, at the toe of the upper platform slopes, appears to be blocked along most of its length. Trucks appear to back into the toe of the upper platform, causing small ledges to form at the toes of these slopes.
1987 (Jun)	A09043, A09044	2,000	The upper platform remains unsurfaced. At the time the photographs were taken several vehicles were parked on the platform. Vegetation is becoming established on the upper platform slopes. Erosion gullies are evident on the main slope of the middle platform adjacent to the stepped channel (in the southeast corner of the site).
1988	A14669, A14670	4,000	The upper platform remains unsurfaced. At the time the photographs were taken there were no vehicles parked on

Year	Photograph Reference No.	Altitude (feet)	Observations (refer to Figures 3, 4 and 5)
			the platform. The middle and lower platforms continue to be used as car/lorry parks. Vegetation is well-developed on all of the fill slopes with the exception of the midslopes of the southern portion of the main slope of the middle platform where there are signs of erosion. A strip of bare ground is also evident at the crest of this slope adjacent to the drainage channel. Many lorries appear to back over the edge of the crest of this slope and the bare strip may be due to a combination of shade and drivers walking around the back of their lorries.
1990	A23627, A23628	4,000	The ' U' channel at the crest of the main slope of the middle platform appears to have been filled-in. The adjacent bare patch noted in 1988 is, however, still evident. The areas of erosion observed in 1988 are covered and the slope is generally well-vegetated. The upper platform has now been surfaced and has vehicles parked on it. The associated fill slopes are well-vegetated and in good condition. A section of Fung Shing Street and adjacent footpath appear to have been repaired to the north of the area affected by the landslide.
1991	A27476, A27477	4,000	The ' U' channel at the crest of the main slope of the middle platform still appears filled-in. The adjacent bare patch however seems to be less well-pronounced. Lorries continue to park on this platform.
1992 (Apr)	A30436, A30437	4,000	An erosion strip is evident to the north of the stepped channel at the junction between the main and subsidiary slopes of the middle platform. They appear to be in similar locations to those noted from the 1986 and 1988 photographs. Some slight erosion is also noted to the west of this stepped channel, towards the toe of the subsidiary slope. Some erosion scars are also evident on the southern slopes of the lower platform. The upper platform and slopes appear to be in good condition.
1992 (Oct)	A32811, A32812	4,000	Good quality photographs. In addition, to the erosion strip and scars noted adjacent to the stepped channel, in the southeastern corner of the middle platform fill slopes from the April 1992 photographs, a further more extensive area of erosion is observed at the toe of the subsidiary slope. This area of erosion extends over almost the entire western half of these fill slopes. Vegetation is well-established on the remaining slopes, consisting of grass with some small shrubs.
1993	CN4606, CN4607	4,000	Very good quality colour photographs. The band of erosion along the crest of the main slope of the middle fill platform to the north of the stepped channel in the southeast corner of the platform is grey in colour (possibly shotcrete). Additionally, there has been some tipping of what appears to be cardboard boxes onto the main slope.

Year	Photograph Reference No.	Altitude (feet)	Observations (refer to Figures 3, 4 and 5)
			Also, there is a small triangular feature on the subsidiary slope of the middle platform to the west of the stepped channel which may be a small failure. There is a small cut strip at the toe of the upper fill slope adjacent to the middle platform. A strip of vegetation has been removed from the southern slopes of the lower fill platform. In addition, erosion patches are evident in the western corner of this slope and the northern corner of the western slopes. What appears to be shotcrete has been sprayed in the northwest corner of the lower platform. This may indicate repair of a previous failure.
1994	A39264, A39265	4,000	No real changes apparent. Possibly some slight erosion (or recent shotcrete) noted adjacent to the junction of the stepped channel in the southeast corner of the fill platform and the slope crest. Otherwise, no further changes evident.
1995	CN1333, CN1334	3,500	The upper and lower fill platform slopes appear to be in good condition. However, there is a band of what looks like dead vegetation (brown in colour) immediately to the north of the stepped channel (at the junction between the main and subsidiary slopes of the middle platform), which extends from the crest to just above the toe (possibly also some associated erosion). This area of dead vegetation coincides approximately with the location of the 1998 landslide. The rest of the vegetation on the surrounding slopes is green and lush.
1996	CN13541, CN13542	4,000	Very good quality photographs. The area of dead vegetation noted in 1995 in the southeast corner of the fill slopes of the middle platform, adjacent to the stepped channel, has returned to normal. However, the U-channel at the crest of this slope is still not visible. There are also some small erosion scars at this junction between main and subsidiary slopes of the fill platform. Otherwise the slopes for upper, middle and lower platform appear to be in generally good condition. Vegetation on the slopes consists of grass, shrubs and small trees.
1997 (May)	CN17238, CN17239	4,000	The slopes of all of the fill platforms are heavily-vegetated but nevertheless appear to be in generally good condition. A Go-kart (or model car) tarmac track has been built on the southern end of the upper platform. Otherwise, no further changes noted.
1997 (Nov)	CN18915, CN18916,	4,000	The tarmac track on the upper fill platform has been covered by a roof and the vegetation on the western slope adjacent to the track is brown in colour and sparse. Otherwise, the slopes associated with the fill platforms are green and lush and appear to be in generally good condition.

Table 2 – Summary of Sources of Information

Source	Documents
GEO Planning Division	(a) Relevant available aerial photographs (see Table 1 for details). (b) Terrain Classification Map
Hong Kong Geological Survey (HKGS)	(a) HKGS Section's Field Notes, Field Data Master and Original Traverse Master. (b) EG/2.5/GAS5/2, Geotechnical Area Study 5, Engineering Geology Map – Fei Ngo Shan.
GEO Mainland East Division	File GCME 2/E2/98-1 File GCME 3/1/346 File GCMd 5/3/2 Pts 2, 23, 45, 46, 59. File GCMd 4/1C/2-8/Pts 2, 43, 44. File GCD 2/A1/11NE-A/F124 File GCME 4/1C/2-8 Pt 36 File GCME 2/E1/11NE-A/F124 File GCME 2/E1/11NE-A/F117 File GCME 2/E1/11NE-A/F116 File GCME 2/EI/11NE-A/F68 File GCME 2/B1/21 Pt 4 File GCME 2/B15/7-1 (Parts 1 & 2)
Civil Engineering Library (CEL) of the Civil Engineering Department (CED)	(a) 1997/78 Catalogue of Slopes
Geotechnical Information Unit (GIU) at the CEL	No relevant information
GEO Planning Division	SIFT & SIRST.
GEO Publications, Reports, Maps, Memoirs	(a) Geotechnical Control Office (1987). Geotechnical Area Studies Programme – Hong Kong and Kowloon GASP Report No. I. (b) Geotechnical Control Office (1986). Hong Kong & Kowloon : Solid and Superficial Geology. Hong Kong Geological Survey, Map Series HGM20, Sheet No. 11, 1:20 000 scale.

Source	Documents
	(c) Geotechnical Control Office (1986). Geology of Hong Kong Island and Kowloon. Hong Kong Geological Survey Memoir No. 2.
GEO Landslide Incident Report Database	Records of reported and inspected landslide incidents.
GEO Landslip Investigation Division	SIS database – slope registration details.
Environmental Protection Department	(a) Various as-built record drawings for the Ngau Chi Wan Landfill (see Appendix A). (b) Various documents associated with the Urban Landfills Restoration Project (see Appendix A).
Lands Department SIMAR Unit, Estate Management Section	Slope Report for Slope No. 11NE-A/F116 – confirming maintenance responsibility.
Interviews with Concerned Persons	Regarding timing and sequence of events.
Hong Kong & China Gas Co., Ltd	Existing utility information - no existing plant within the vicinity of the landslide.
Hong Kong Telecom Co., Ltd	Existing utility information – copy of utility plan obtained.
Wharf Cable Ltd	Existing utility information – no existing plant within the vicinity of the landslide.
Hutchison Telephone (HK) Ltd	Existing utility information – no existing plant within the vicinity of the landslide.
New T&T Hong Kong Ltd	Existing utility information – no existing plant within the vicinity of the landslide.
New World Telephone Ltd	Existing utility information – no existing or proposed plant or services within the vicinity of the landslide.
WSD/MSE	Existing utility information – no existing plant within the vicinity of the landslide.
HyD/NTW	Existing utility information – no existing plant within the vicinity of the landslide.
DSD/MS	Existing utility information – no existing plant within the vicinity of the landslide.
Rediffusion (HK) Ltd	Existing utility information – no existing plant within the vicinity of the landslide.
China Light & Power Co., Ltd	Existing utility information – copy of overhead line record sheets obtained.

Table 3 - Maximum Rolling Rainfalls at GEO Raingauge No. K04 and Estimated Return Periods for Different Durations Preceding the Landslide of 9 June 1998

Duration	Maximum Rolling Rainfall (mm)	End of Period (Hours)	Estimated Return Period (Years)
5 Minutes	12	6:05 on 9 June 1998	2
15 Minutes	29.5	16:55 on 9 June 1998	3
1 Hour	71	6:25 on 9 June 1998	3
2 Hours	116	7:25 on 9 June 1998	4
4 Hours	168	8:50 on 9 June 1998	6
12 Hours	373.5	17:00 on 9 June 1998	40
24 Hours	447	17:00 on 9 June 1998	28
48 Hours	460.5	17:00 on 9 June 1998	14
4 Days	505	17:00 on 9 June 1998	9
7 Days	590.5	17:00 on 9 June 1998	12
15 Days	671	17:00 on 9 June 1998	7
31 Days	957.5	17:00 on 9 June 1998	11

Notes :

(1) Return periods were derived from Table 3 of Lam & Leung (1994).

(2) Maximum rolling rainfall was calculated from 5-minute data for durations up to 48 hours, and from hourly rainfall data for longer rainfall durations.

(3) The use of 5-minute data for durations between 2 hours and 48 hours results in better data resolution, but may slightly over-estimate the return periods using Lam & Leung (1994)'s data, which are based on hourly rainfall for these durations.

LIST OF FIGURES

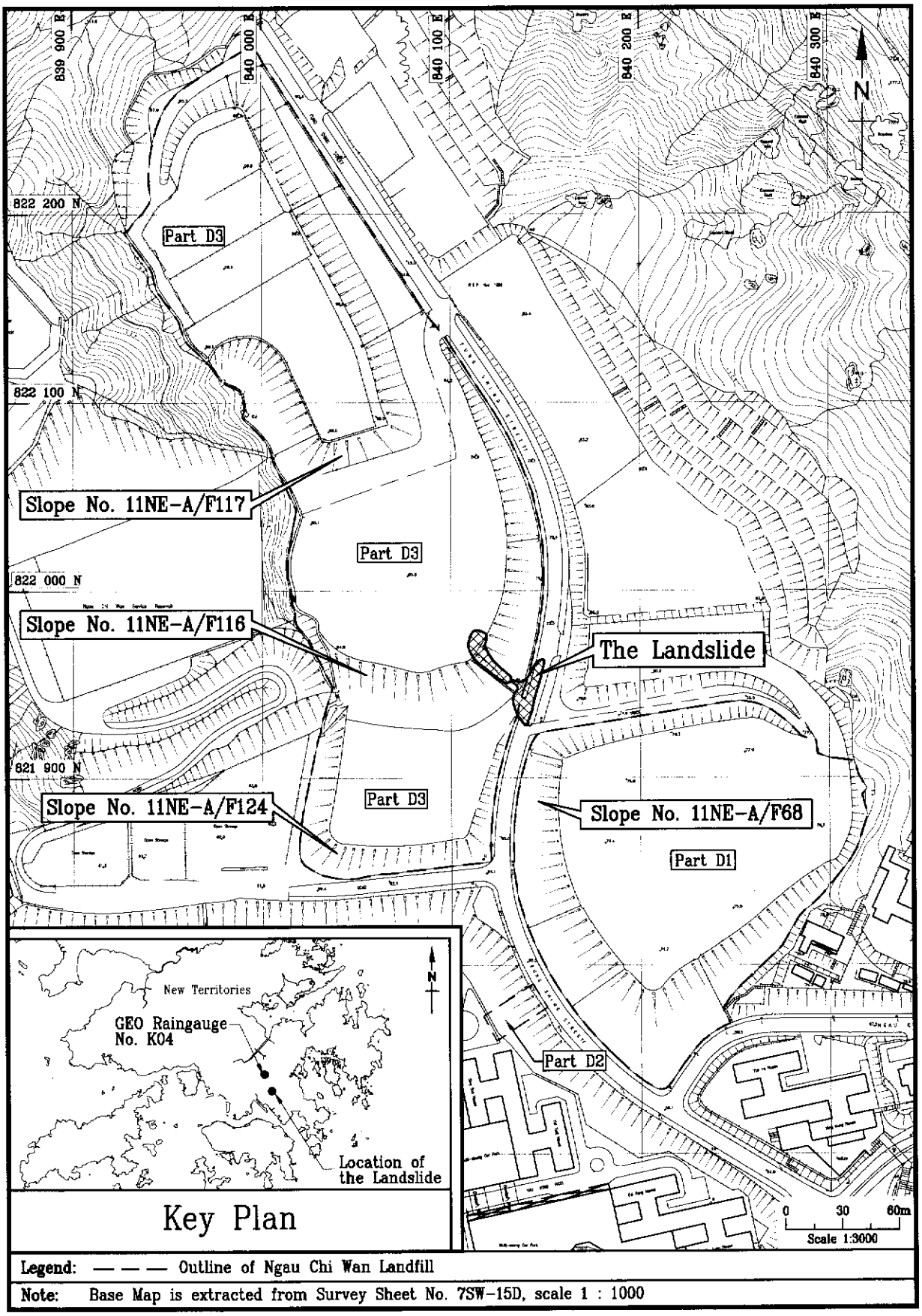


Figure 1 - Site Location Plan

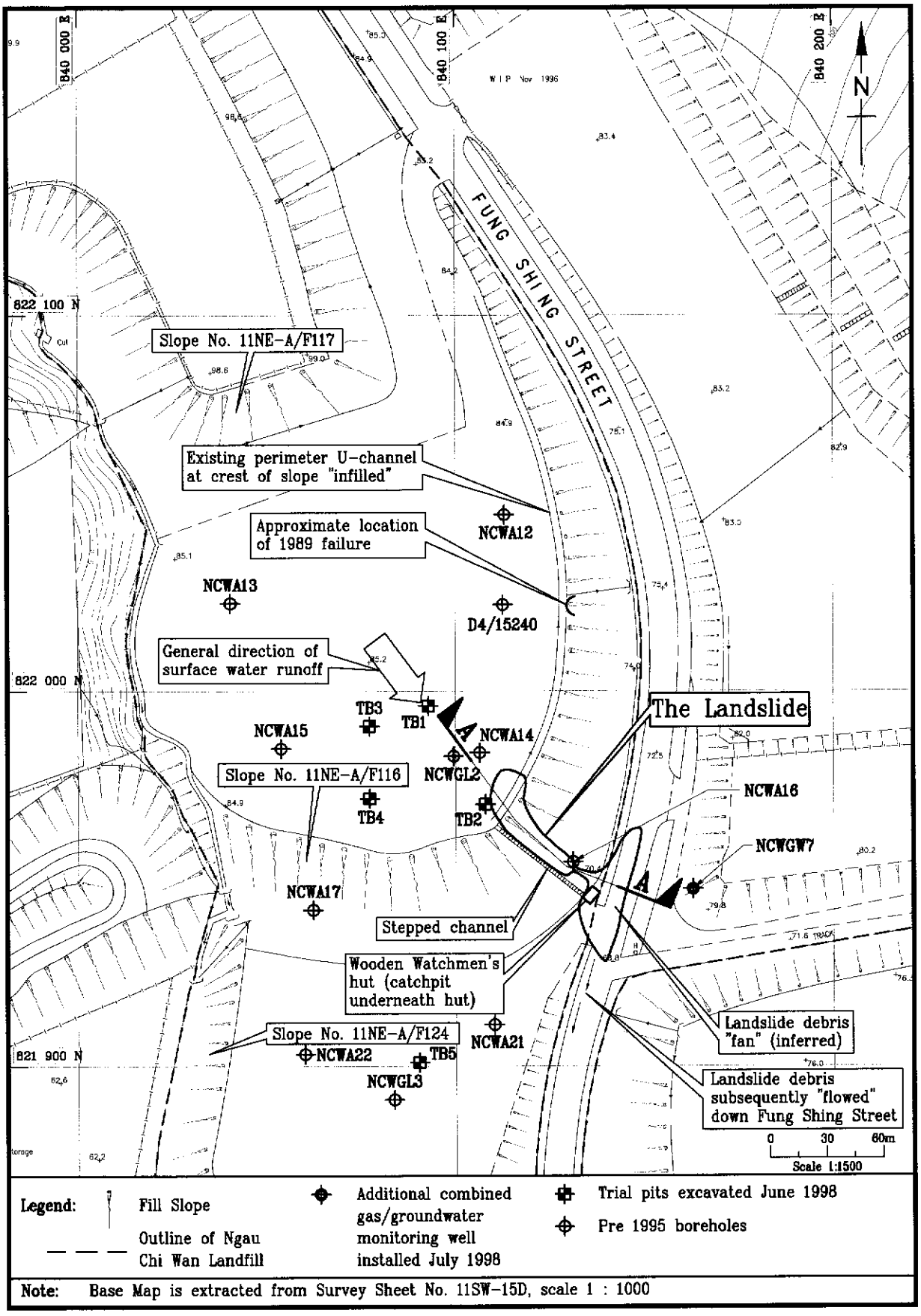
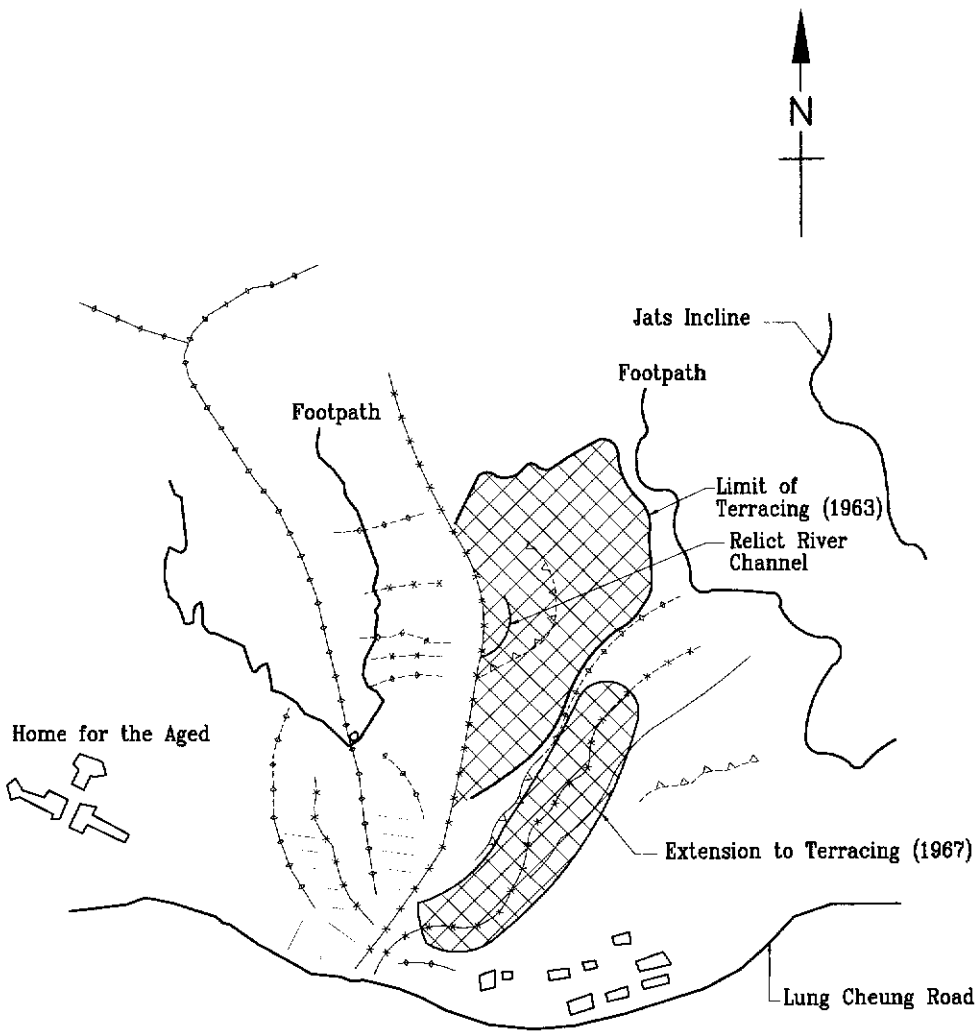


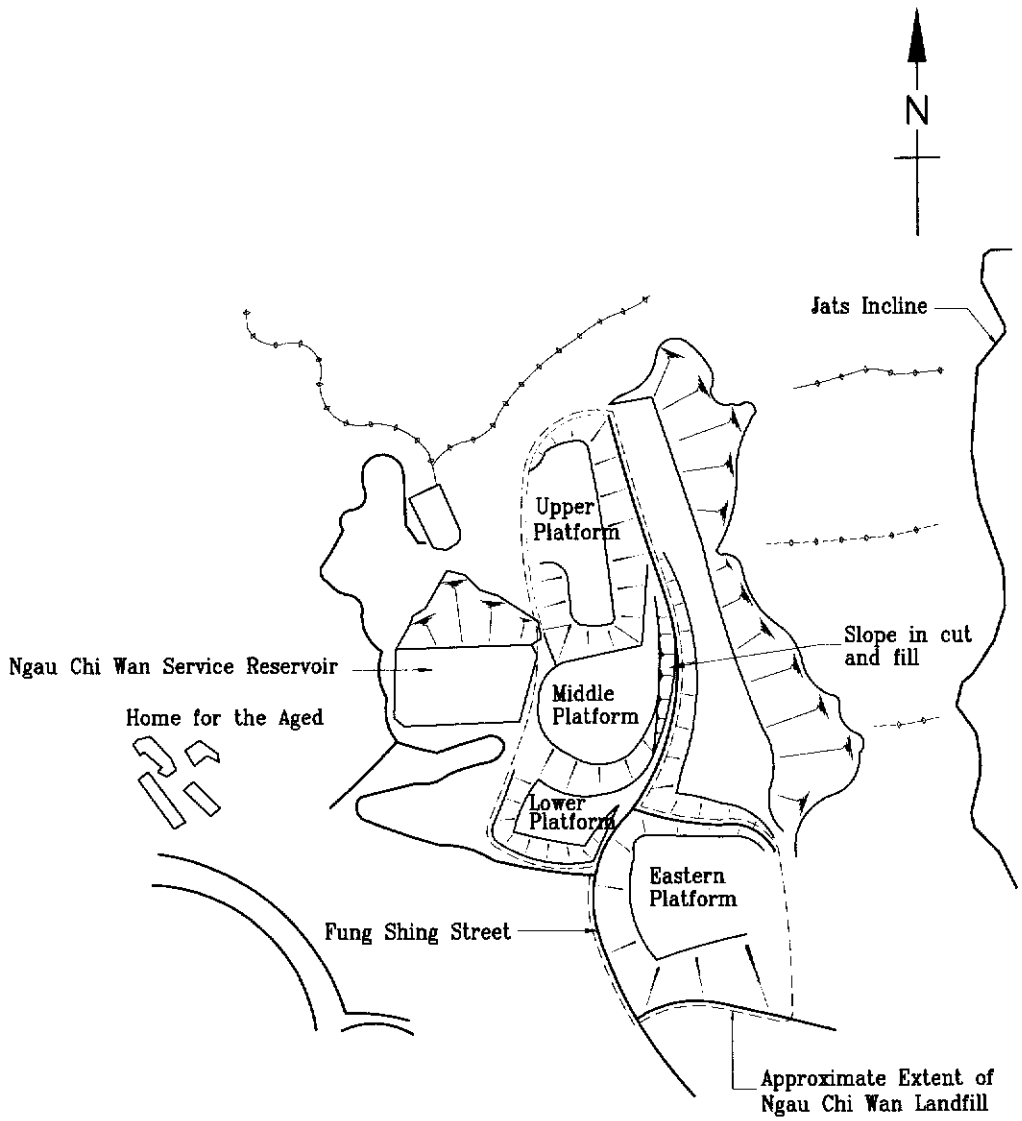
Figure 2 - Plan of the Landslide



Legend:
- Ridge crest (sharp)
- Ridge crest (rounded)
- Valley axis (sharp)
- Valley axis (rounded)
- Break of slope (concave)
- Break of slope (convex)
- Building
- Terracing
- Footpath / Road
- Gully Erosion

Notes: (1) Traced from 1963 Aerial Photographs 4000'.
(2) Not to scale.

Figure 3 - Summary of Observations 1949 - 1967

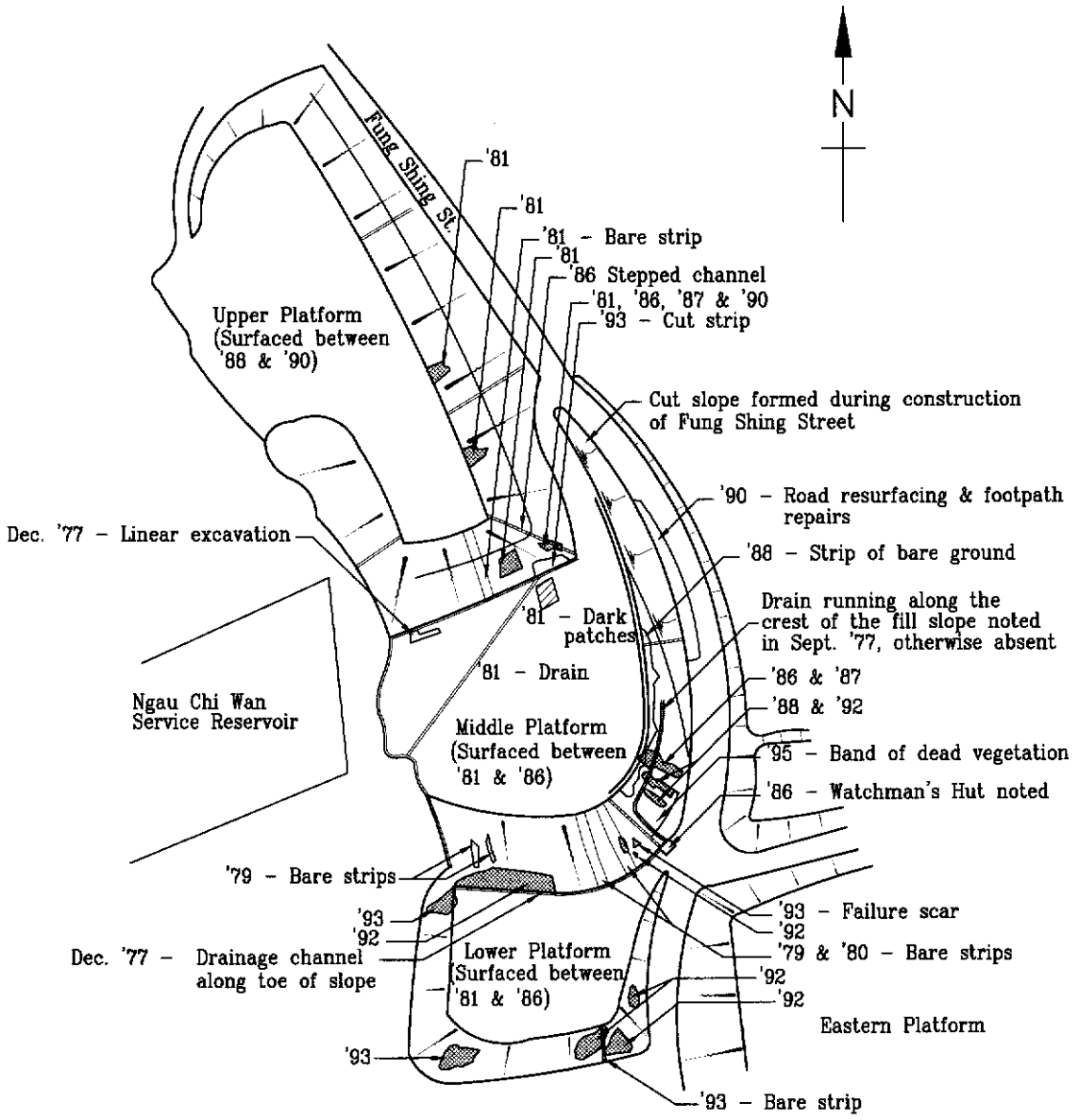


Legend:

- Ridge crest (sharp)
- Ridge crest (rounded)
- Road
- Cut slope
- Fill slope

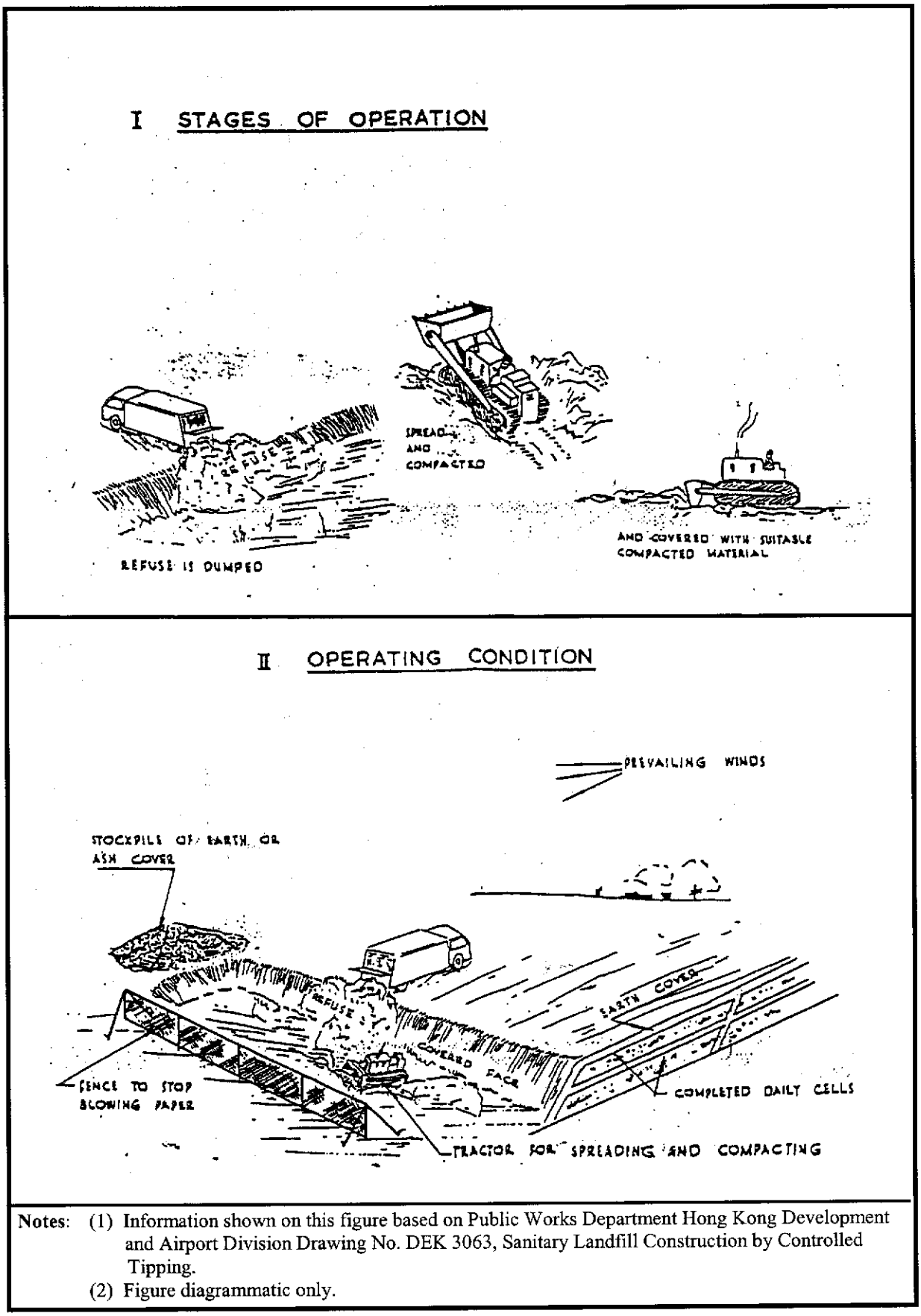
Notes: (1) Traced from 1993 Aerial Photographs 4000'.
(2) Not to scale.

Figure 4 - General Layout of Ngau Chi Wan Landfill



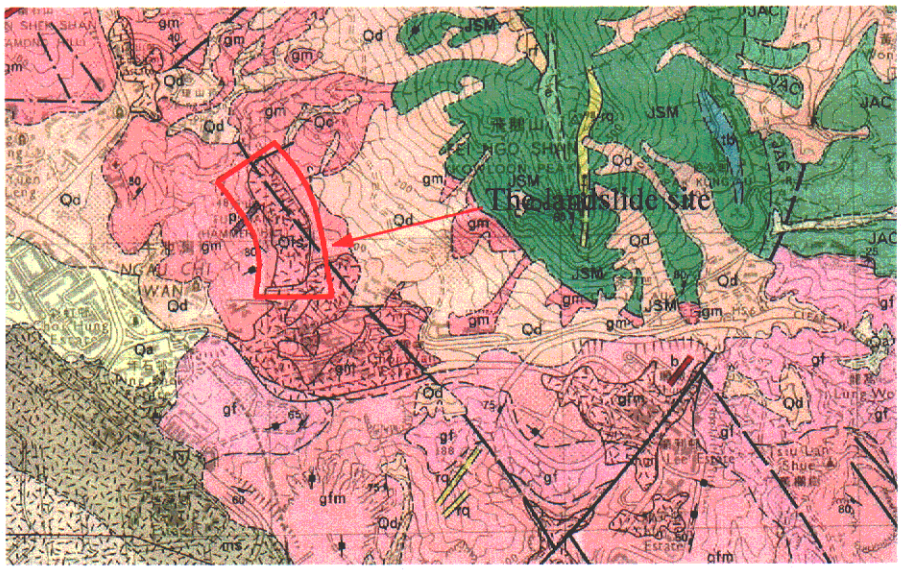
Notes: (1) The information shown in this figure is based on aerial photograph interpretation.
(2) Not to scale.

Figure 5 - Summary of Observations 1977 - 1997



Notes: (1) Information shown on this figure based on Public Works Department Hong Kong Development and Airport Division Drawing No. DEK 3063, Sanitary Landfill Construction by Controlled Tipping.
(2) Figure diagrammatic only.

Figure 6 – Schematic Representation of Landfilling Operations



LEGEND:

SUPERFICIAL DEPOSITS (Onshore)

	主要物質成份 PRINCIPAL MATERIALS
	填泥和廢物 Natural earth and waste
Qb	砂 Sand
Qa	分選性良好至中等的粘土／粉砂、砂和礫石 Clay/silt, sand and gravel; well-sorted to semi-sorted
Qat	分選性良好至中等的砂、礫、粉砂和粘土 Sand, gravel, silt and clay; well-sorted to semi-sorted
Qd	未分選的砂，礫至漂礫，基質爲粘土／粉砂 Unsorted sand, gravel, cobbles and boulders; clay/silt matrix
Qt	礫石、中礫和漂礫 Gravel, cobbles and boulders
Qdt	Qd和Qt的混合物 Mixed Qd and Qt

SOLID GEOLOGY

	主要岩石類型／特徵 PRINCIPAL ROCK TYPES/CHARACTERS
JTM	粗火山灰晶屑凝灰岩 Coarse ash crystal tuff
JAC	細火山灰玻屑凝灰岩 Fine ash vitric tuff
JSM	細粒至粗粒火山灰凝灰岩，凝灰角礫岩和層凝灰岩 Fine ash to coarse ash tuffs, tuff-breccia and tuffite

gf	細粒花崗岩，＜2毫米 Fine-grained granite, < 2mm
gfm	中細粒花崗岩 Fine- to medium-grained granite
gm	中粒花崗岩，2－6毫米 Medium-grained granite, 2-6mm
gc	粗粒花崗岩，＞6毫米 Coarse-grained granite, > 6mm

GEOLOGICAL LINES

Geological boundary, superficial deposits

1982 Fill boundary, with limit of reclamation at date shown

Geological boundary, solid rock

Fault (crossmark indicates downthrow side)

Mineral vein

Photogeological lineament

STRUCTURAL SYMBOLS

傾斜 Inclined

30 Bedding

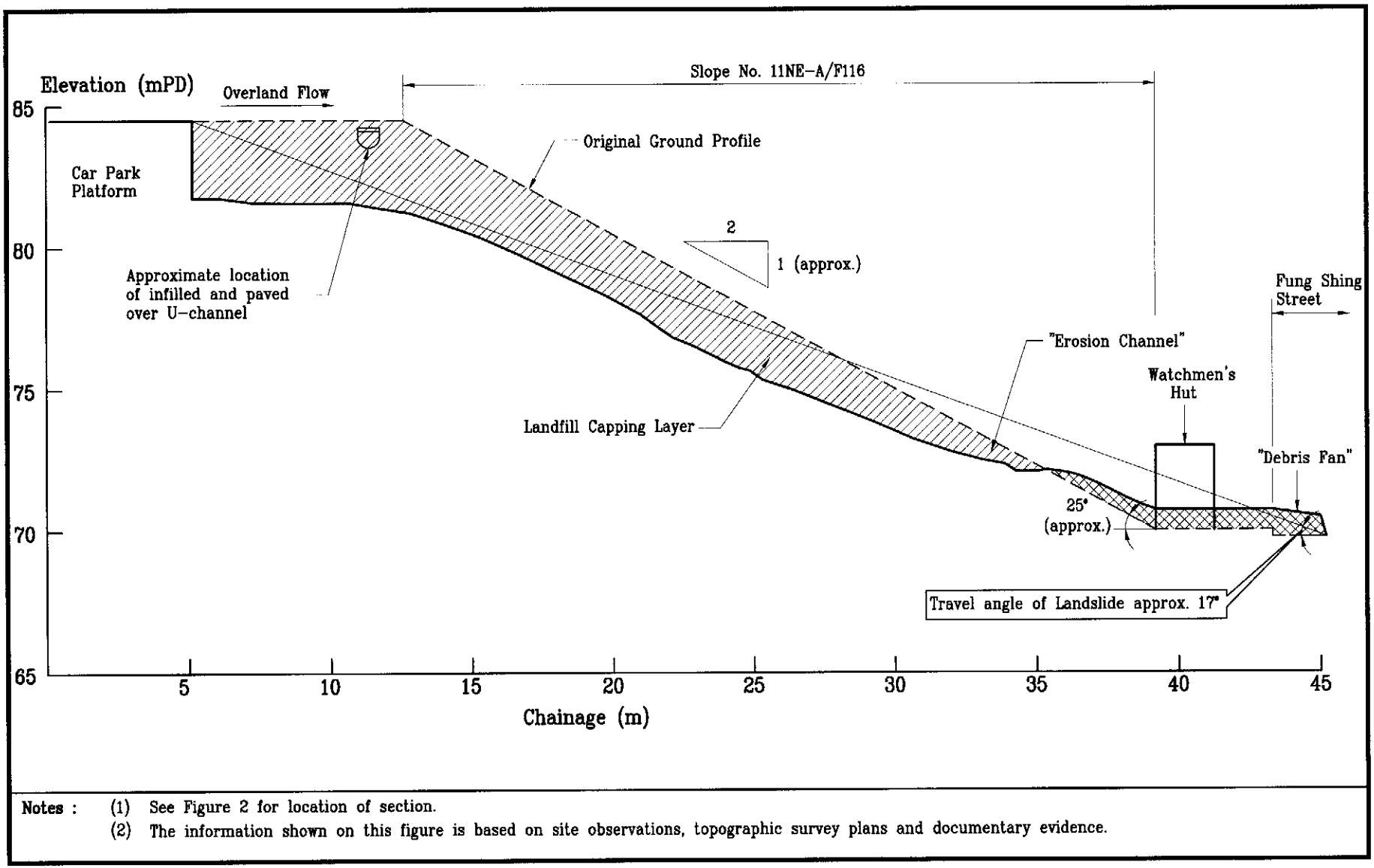
20 Flow fabric

20 Intrusive contact

20 Jointing

Notes: Extracted from Hong Kong Geological Survey Sheet 11 (1:20,000) Map Series HGM20 (GCO, 1989)

Figure 7 – Regional Geology



Notes : (1) See Figure 2 for location of section.
(2) The information shown on this figure is based on site observations, topographic survey plans and documentary evidence.

Figure 8 - Section A-A Through the Landslide

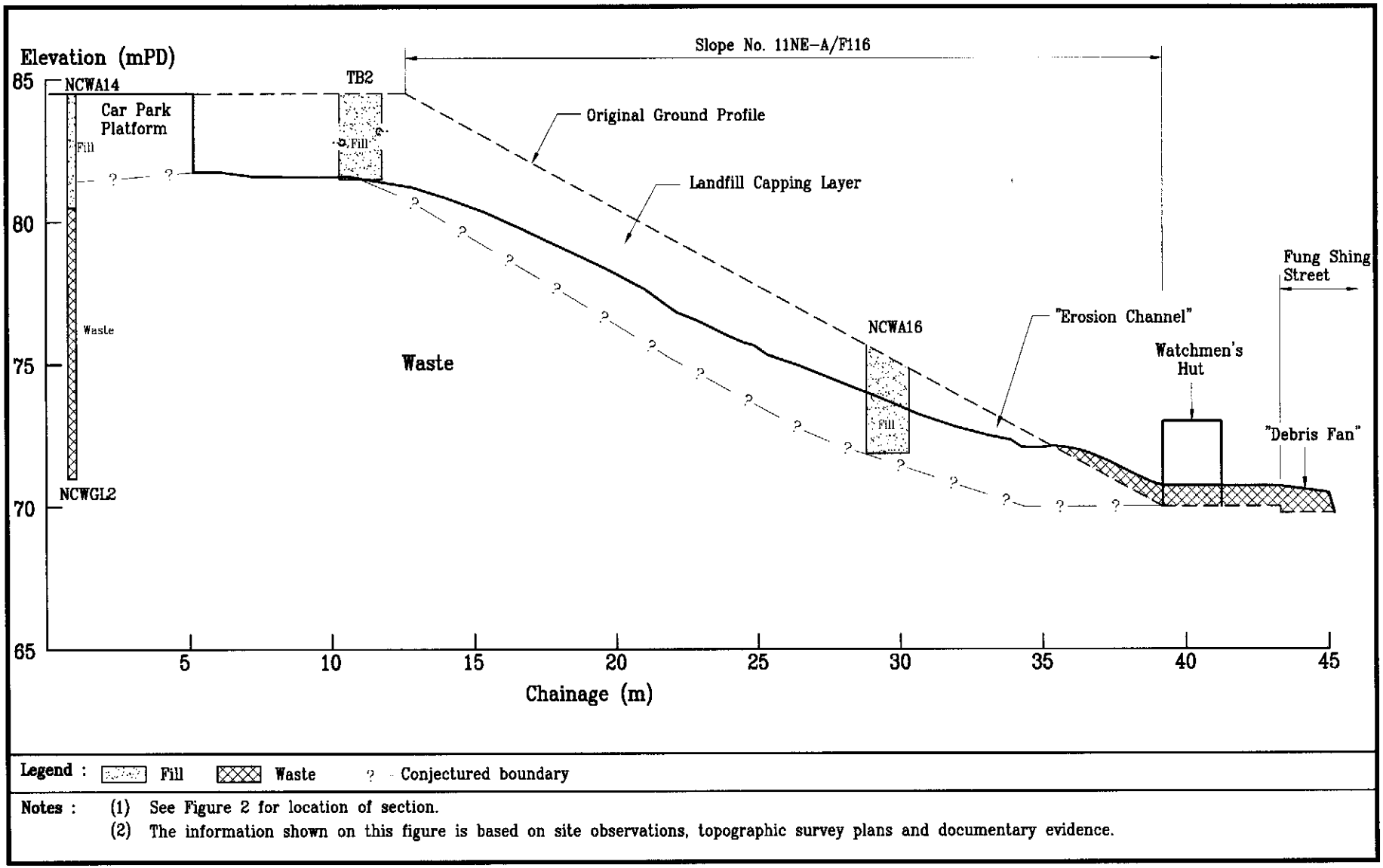
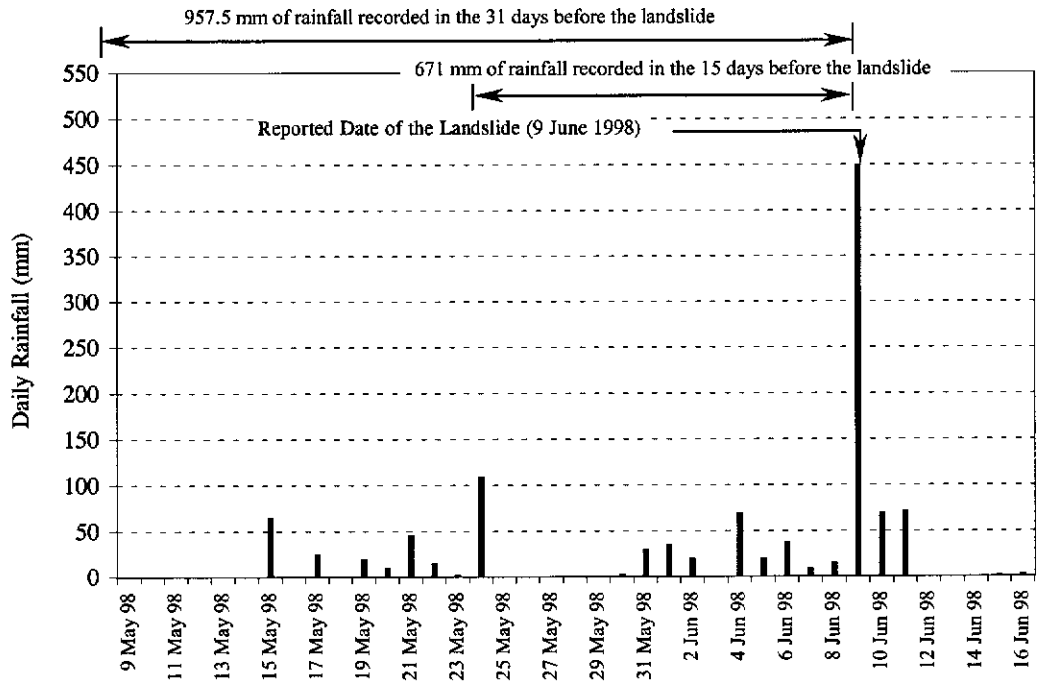
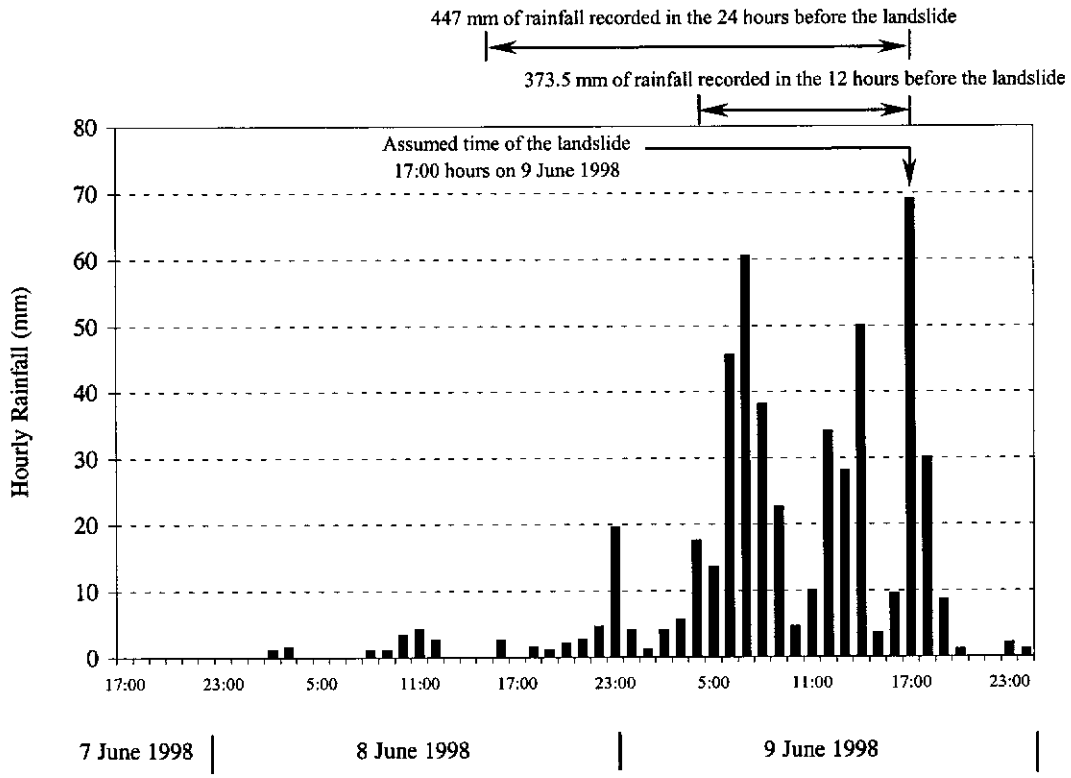


Figure 9 - Section Showing the Inferred Ground Conditions at the Landslide Site



(a) Daily Rainfall Recorded between 9 May and 16 June 1998



(b) Hourly Rainfall Recorded between 17:00 hours on 7 June and 24:00 hours on 9 June 1998

Figure 10 - Rainfall Recorded at GEO Raingauge No. K04

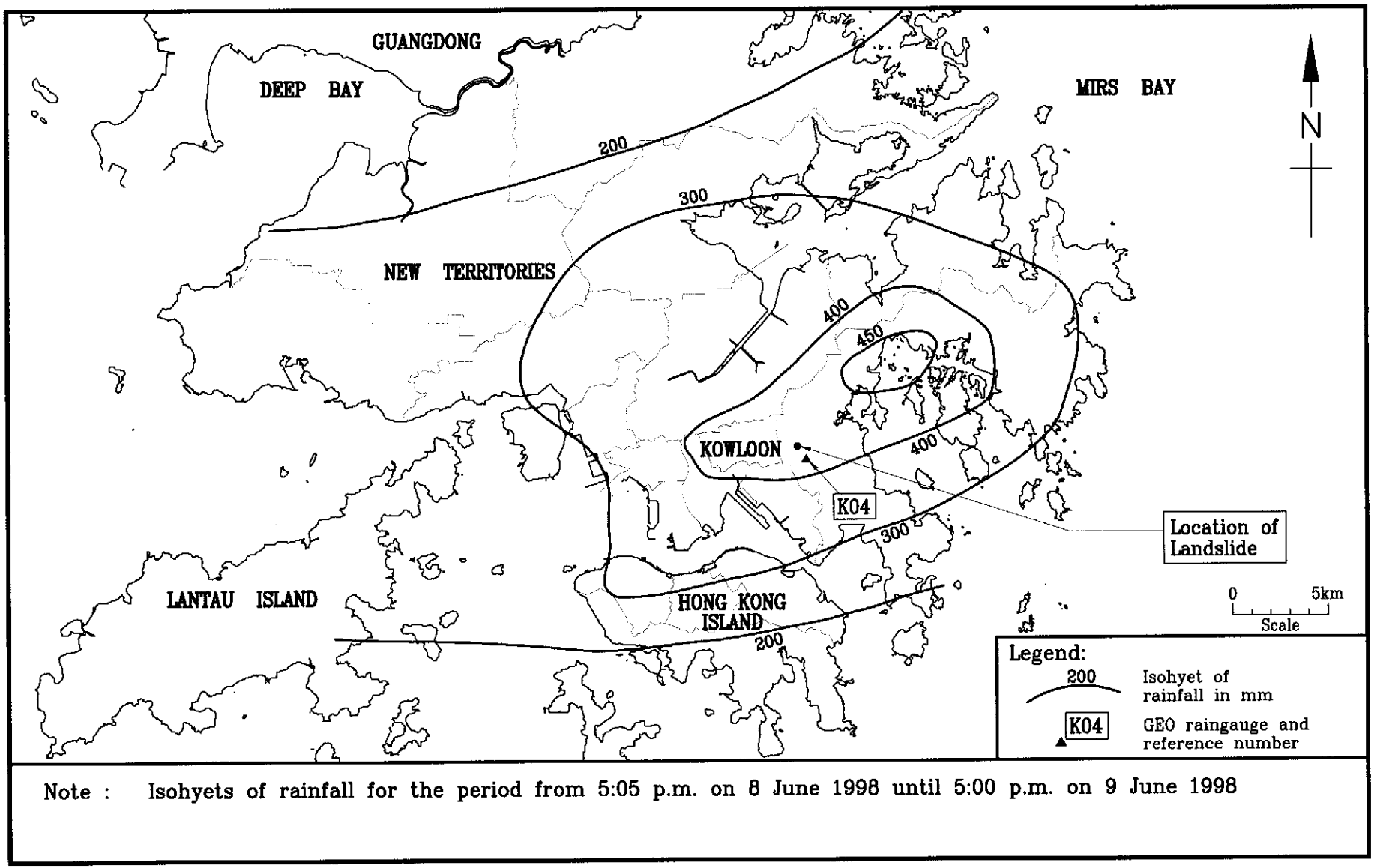


Figure 11 - Rainfall Distribution in the 24-Hour Period Preceding the Landslide of 9 June 1998

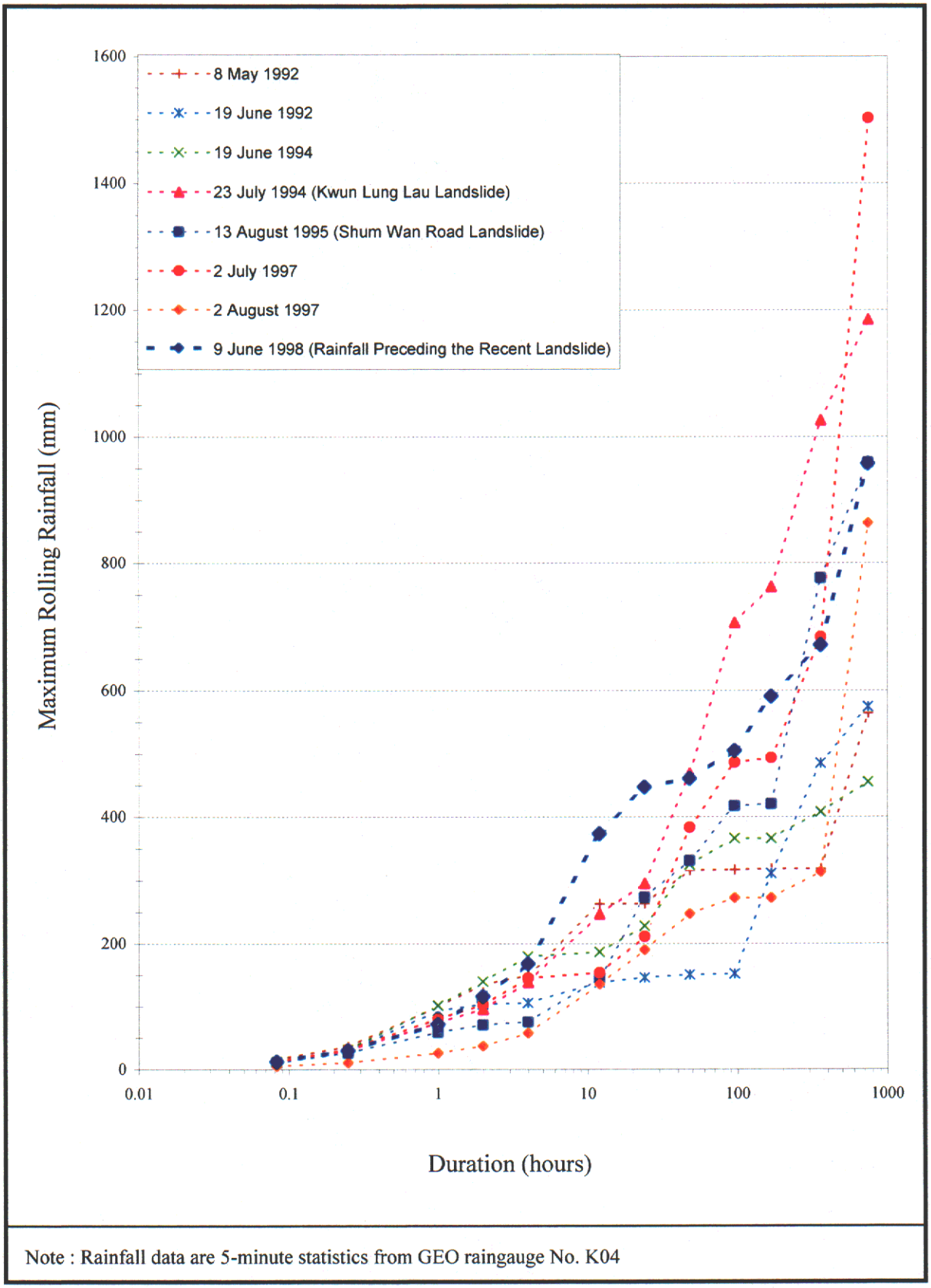
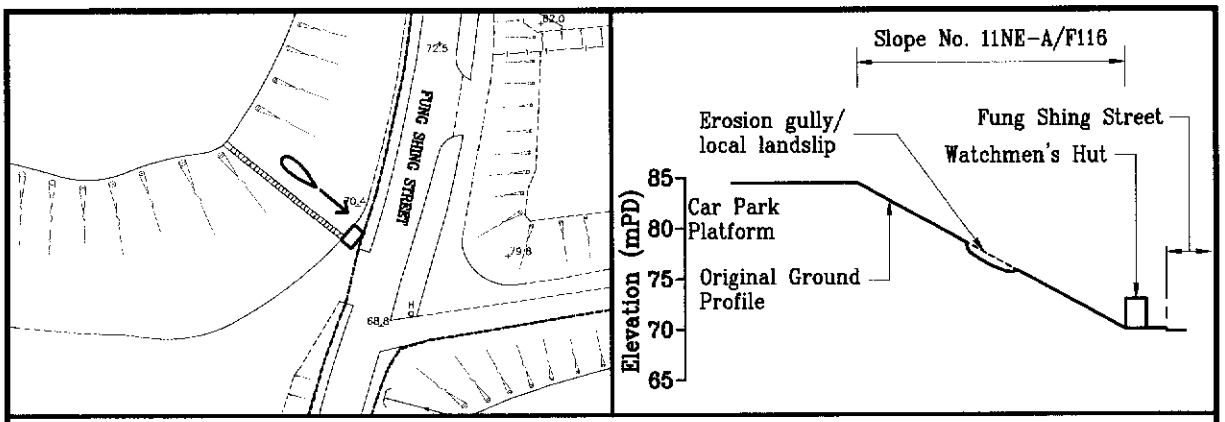


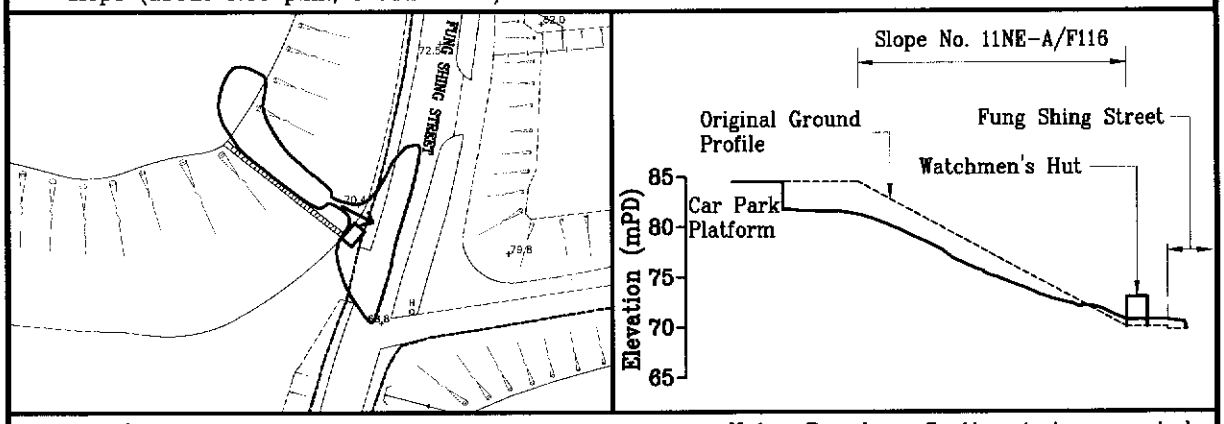
Figure 12 - Maximum Rolling Rainfalls Preceding the Landslide on 9 June 1998 (and Selected Major Rainstorms to 2 August 1997) - GEO Raingauge No. K04



Legend: 1998 landslide scar
Direction of movement

Note: Based on Section A–A, presented as Figure 8 in this report.

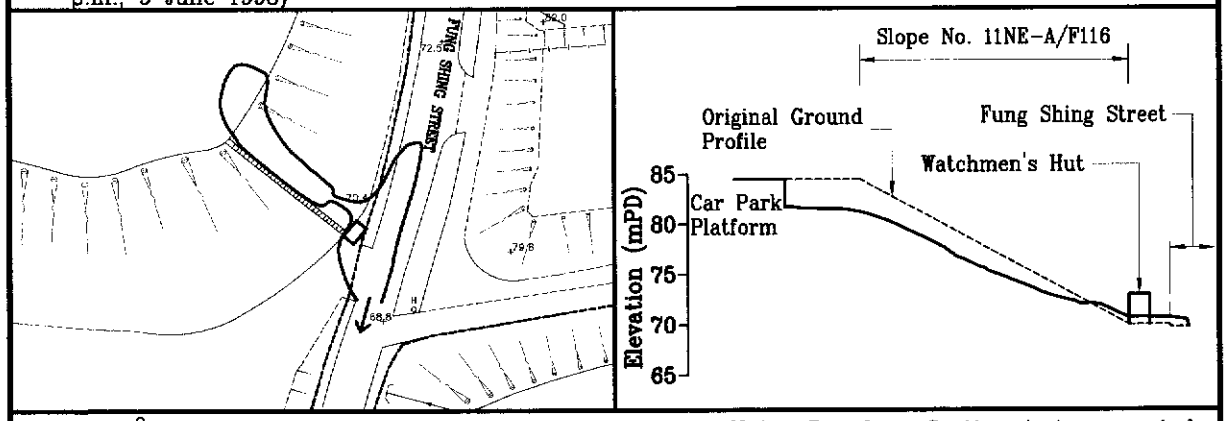
(a) Initial failure involving either an erosion gully or a local landslip towards the toe of the slope (about 5:00 p.m., 9 June 1998)



Legend: 1998 landslide scar
Direction of movement

Note: Based on Section A–A, presented as Figure 8 in this report.

(b) Continuing erosion/gullying of the slope with corresponding upward retrogression towards the platform with associated lateral enlargement of the resulting scar. (shortly after 5:00 p.m., 9 June 1998)



Legend: 1998 landslide scar
Direction of movement

Note: Based on Section A–A, presented as Figure 8 in this report.

(c) Formation of subsequent debris fan at the toe of the slope with alluvial outwash from this fan travelling a further 250 m or so down Fung Shing Street, (shortly after 5:00 p.m., 9 June 1998)

Figure 13 - Schematic Representation of Inferred Sequence of Events

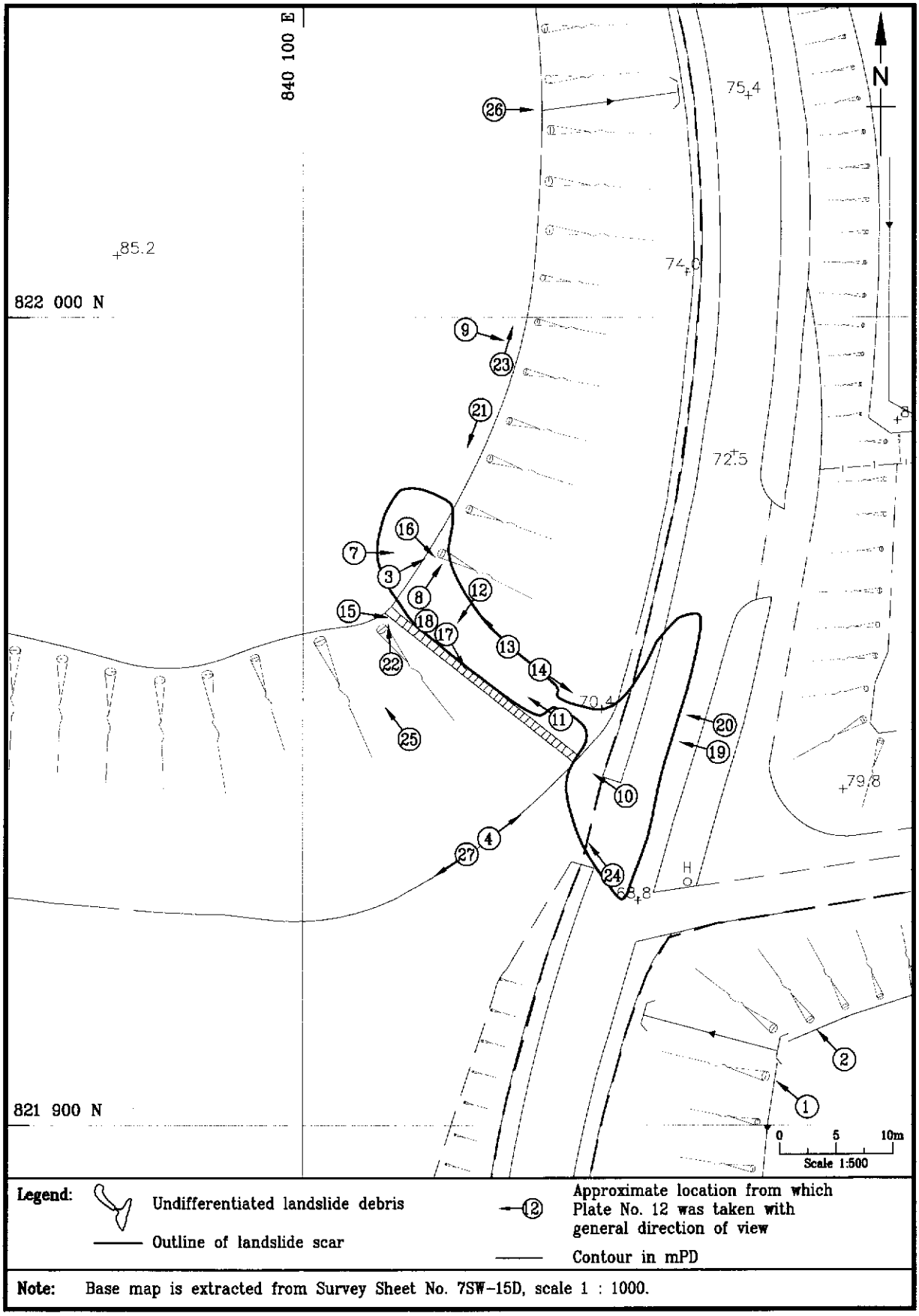


Figure 14 - Location Plan of Photographs Taken

LIST OF PLATES

Plate 1 – General View of Landslide Scar and Remnants of Debris Fan
(Photograph taken on 10 June 1998)

Note : See Figure 14 for Location of Photograph.

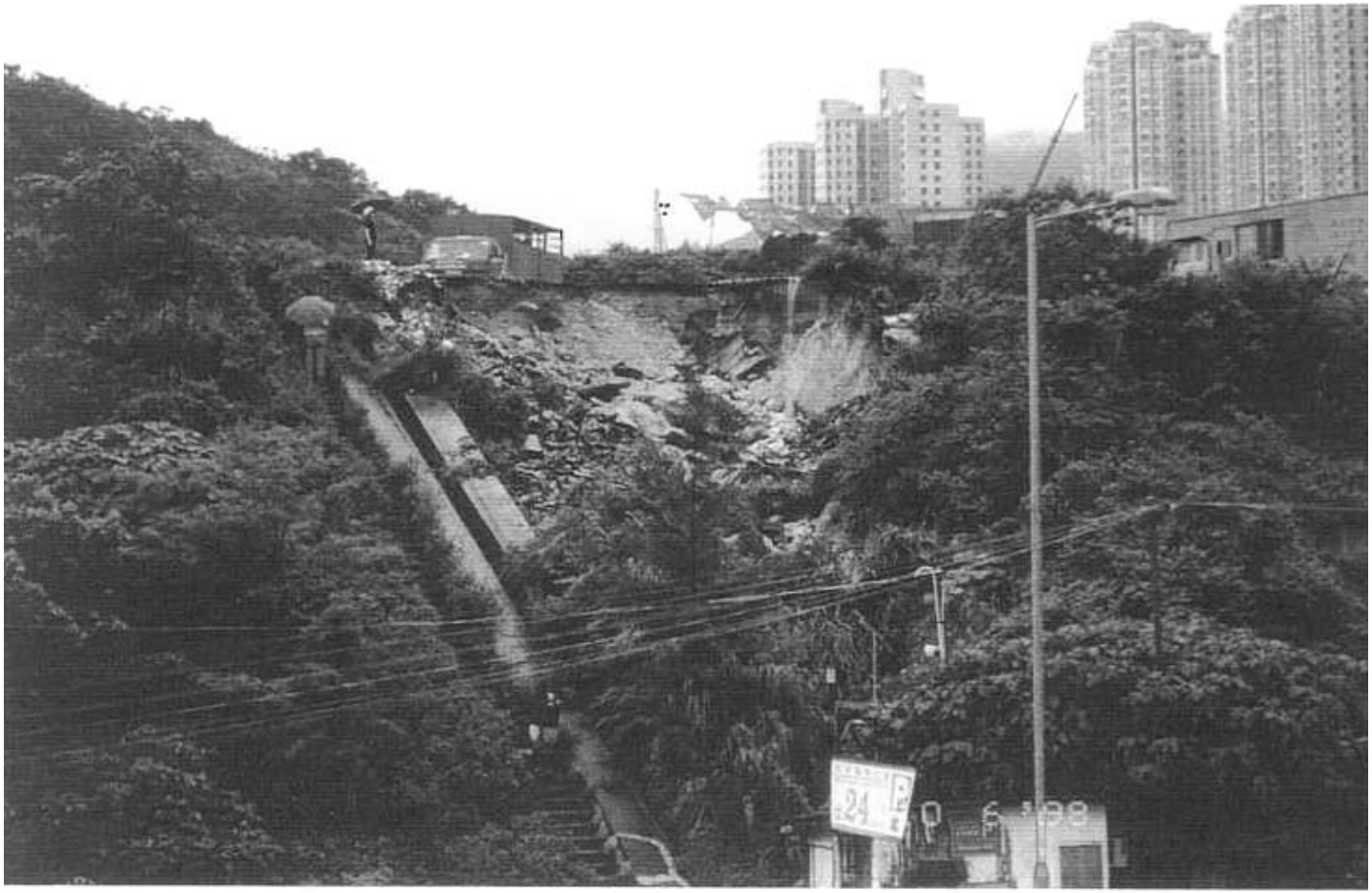


Plate 2 – View of Landslide Scar. Note Water still Discharging into Landslide Scar
(Photograph taken on 10 June 1998)

Note : See Figure 14 for Location of Photograph.

Plate 3 – Close-up View of Landslide Mainscarp
(Photograph taken on 10 June 1998)

Note : See Figure 14 for Location of Photograph.

Sand bags indicate previous Location of Watchmen's Hut.

Plate 4 – View at the Toe of the Slope following the Removal of the Watchmen's Hut. Note Deformation of Upslope Wall of U-channel. (Photograph taken on 8 July 1998)

Note: See Figure 14 for Location of Photograph.

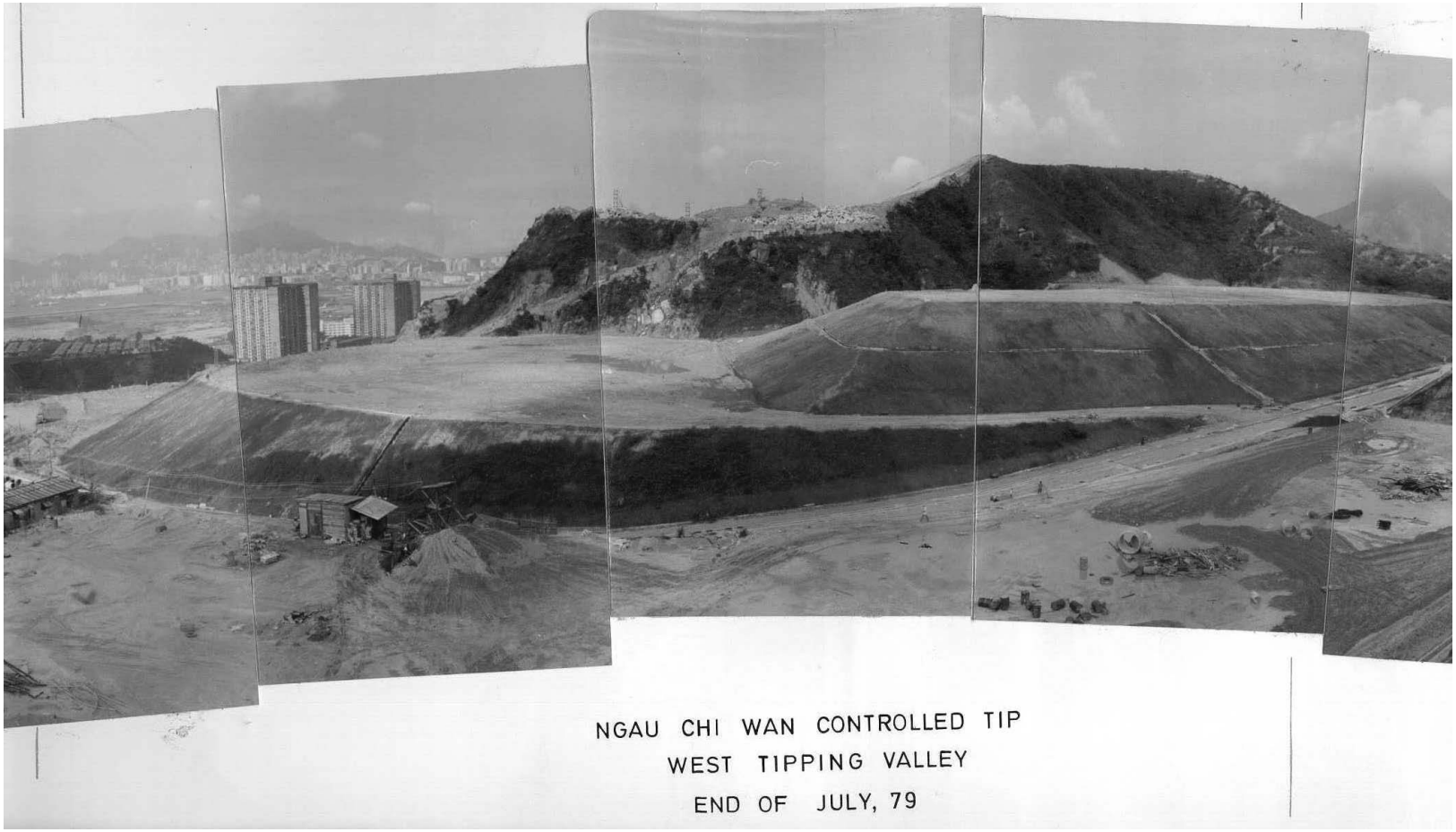


Plate 5 – General View of Landfill during Formation

Note : See Figure 14 for Location of Photograph.

Plate 6 – View of Landfilling Operations

Note : See Figure 14 for Location of Photograph.

a)

b)

Plate 7 – Views of "Infilled" Concrete U-channel at Crest of Slope. Layering of Fill Capping to Landfill evident as is Erosion around U-channel (Photographs taken on 16 June 1998)

Note: See Figure 14 for Locations of Photographs.

Plate 8 – View of "Infilled" Concrete U-channel within Landslide Scar. Asphalt Overlay to U-channel also clearly evident (Photographs taken on 16 June 1998)

Note: See Figure 14 for Location of Photograph.

Plate 9 – Chunam Cover at Crest of Main Slope of Feature
No. 11NE-A/F116 (Photograph taken on 17 March 1999)

Note: See Figure 14 for Location of Photograph.

Plate 10 – View of Stepped Channel. Note Repairs to Channel and adjacent Steps (Photograph taken on 8 July 1998)

Note: See Figure 14 for Location of Photograph.

Plate 11 – General View looking up the Landslide Scar and Debris Trail. General Fill Capping Layer, in excess of 2 m thick, exposed in left flank of Landslide Scar. Note the Lighting Column within the Landslide Scar. Landfill Material exposed in scar includes Concrete, Wood and Stone Rubble. "Infilled" Concrete U-channel evident within Landslide Mainscarp (Photographs taken on 16 June 1998)

Note: See Figure 14 for Locations of Photograph.

Plate 12 – General View looking across and down the Landslide Scar. Undermining of the Stepped Channel clearly evident. Note the Nature of the Material within the Landslide Scar – Heterogeneous Construction Waste and a Fill Capping. Layering of Capping clearly evident. Construction Waste also appears to have been stored at the Crest of the Slope adjacent to the Stepped Channel. Some of this Waste appears to have subsequently fallen into the Landslide Scar (Photographs taken on 16 June 1998)

Note : See Figure 14 for Locations of Photograph.

Plate 13 – General View looking up and across the Landslide Scar. Note "Erosion Channel" in bottom right hand side of picture (Photographs taken on 16 June 1998)

Note : See Figure 14 for Location of Photograph.

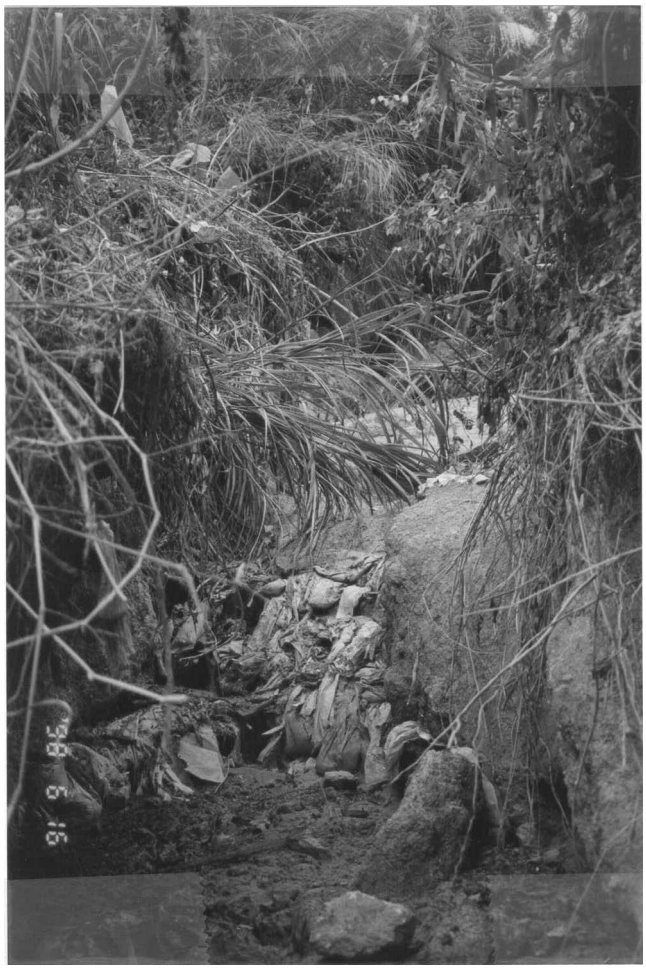


Plate 14 – View of the "Erosion Channel" at the Toe of the Slope
(Photograph taken on 16 July 1998)

Note: See Figure 14 for Location of Photograph.

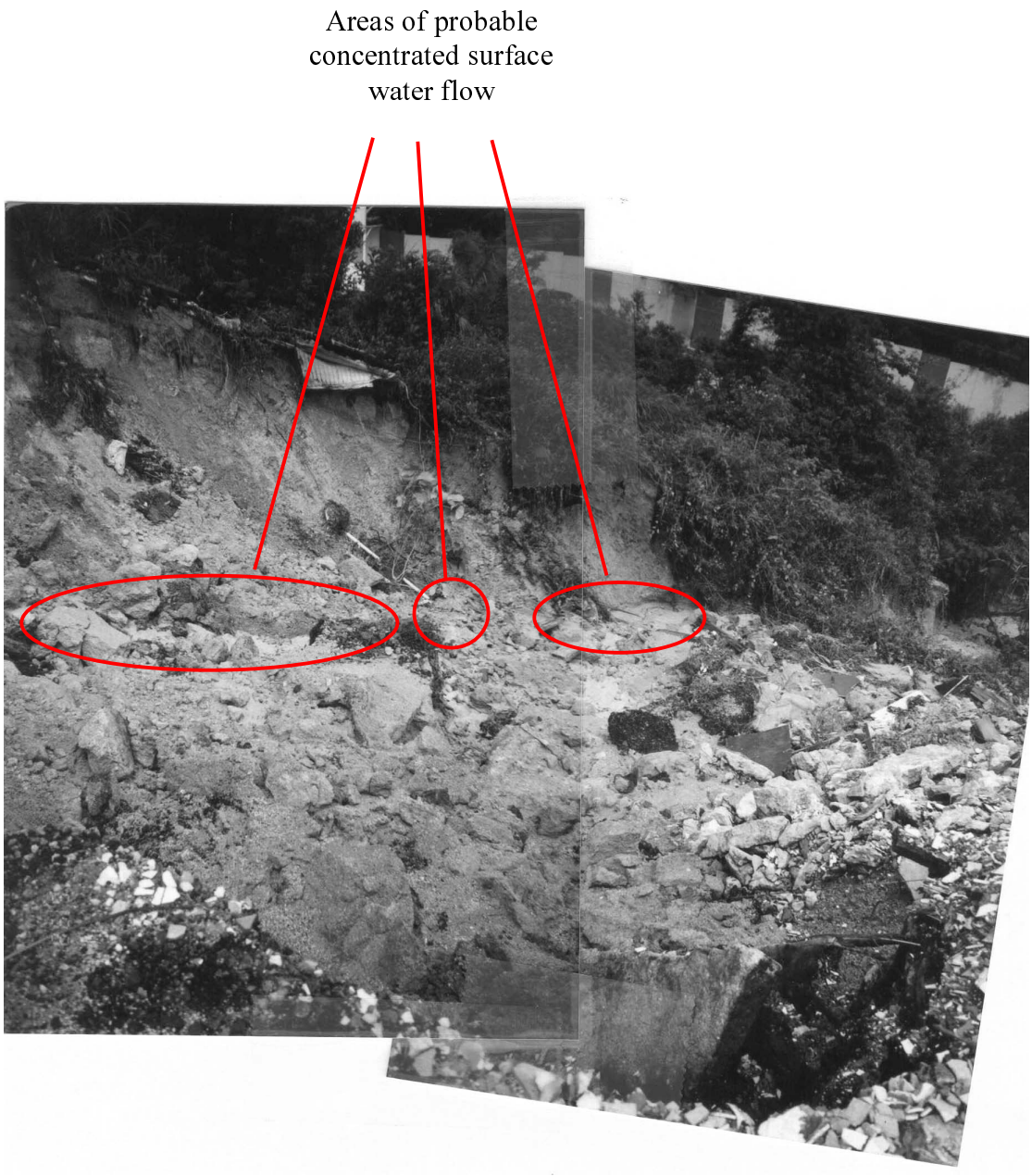


Plate 15 – View of Landslide Scar looking down from Stepped Channel. Note Lighter Coloured Areas in the Scar – Probable Areas of Concentrated Surface Water Flow/Erosion Gullies during Failure (Photographs taken on 10 June 1998)

Note: See Figure 14 for Locations of Photograph.

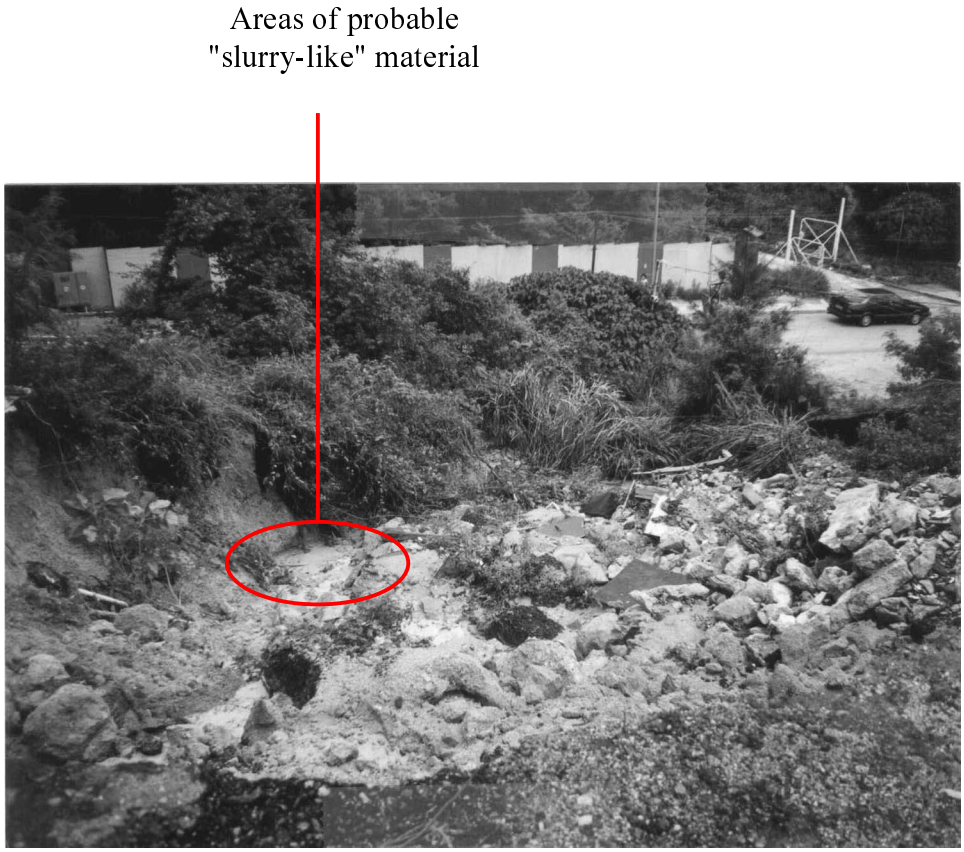
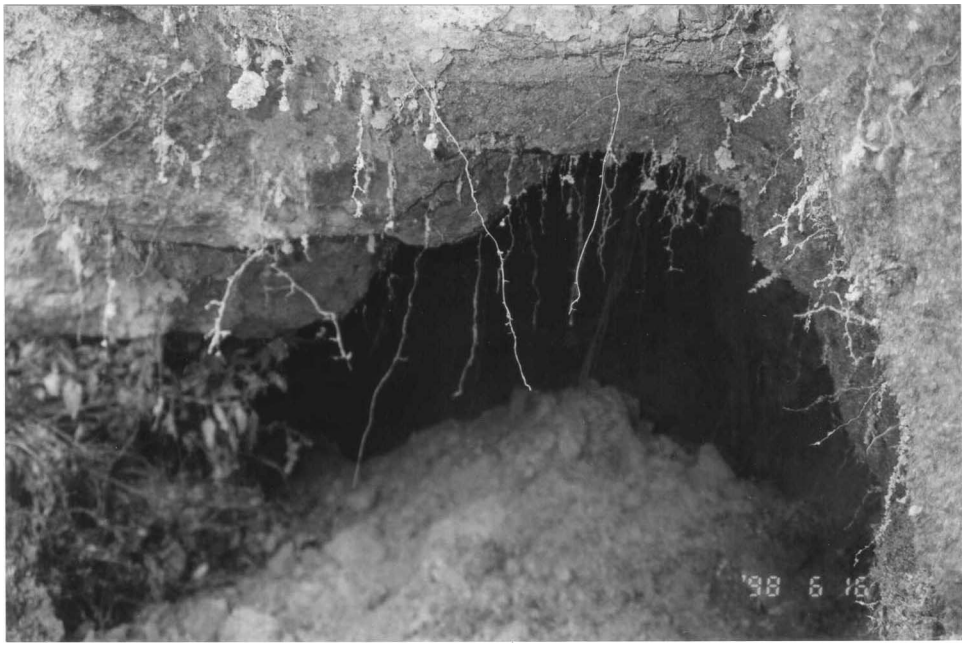


Plate 16 – General View of Landslide Scar Showing Nature of Landfill. Note Lighter Coloured Area within the Scar – suggesting a "Slurry-like" Material during Failure (Photograph taken on 10 June 1998)

Note: See Figure 14 for Location of Photograph.

a)



b)

Plate 17 – Views of a Void beneath the Stepped Channel. Maximum Dimension in excess of 0.5 m (Photographs taken on 16 June 1998)

Note: See Figure 14 for Locations of Photographs.

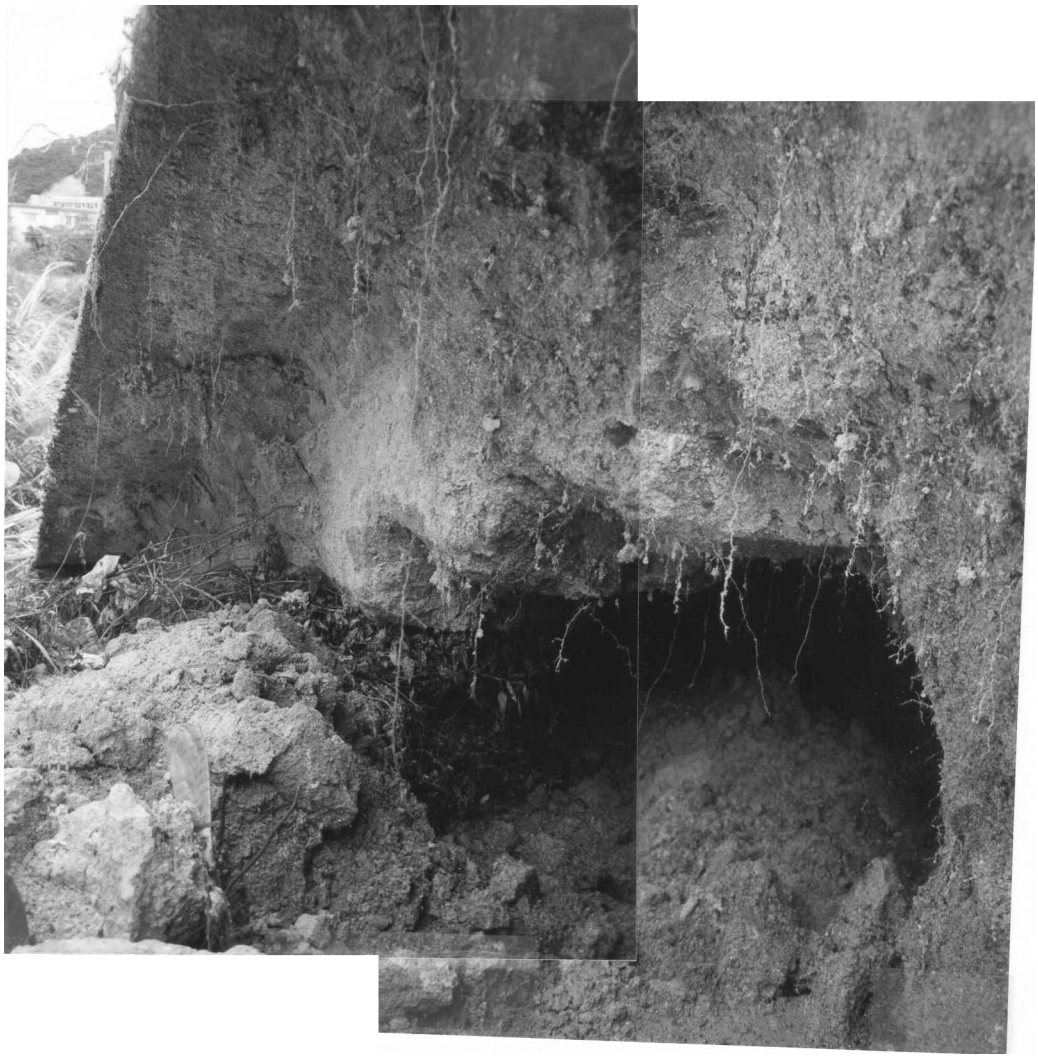


Plate 18 – Further View of a Void beneath the Stepped Channel
(Photograph taken on 16 June 1998)

Note: See Figure 14 for Location of Photograph.

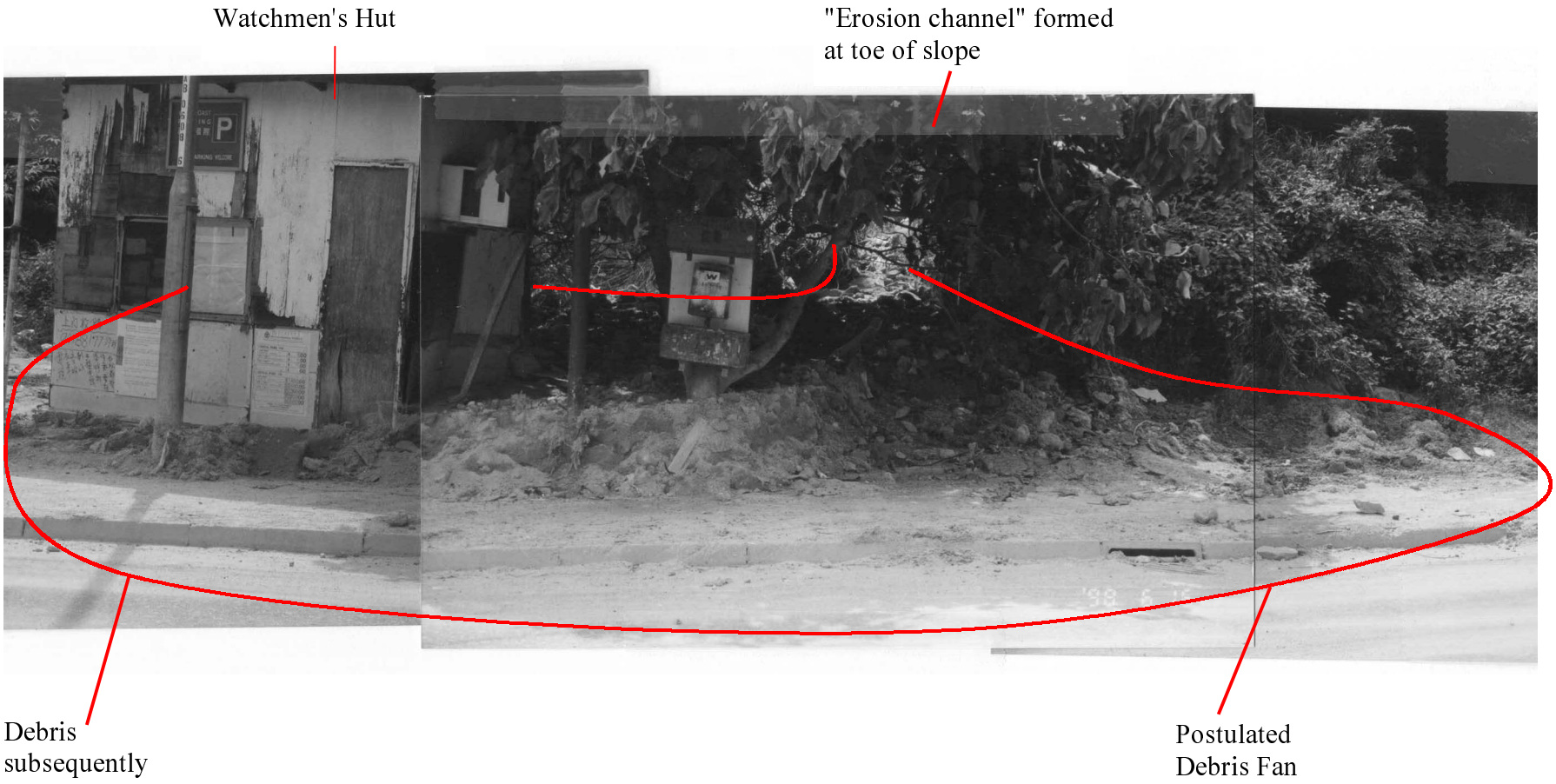


Plate 19 – Panoramic View of the Remains of the Debris Trail at the Toe of the Slope. Postulated Extent of Debris Fan also shown. Note the Watchmen's Hut which was inundated with Debris (Photographs taken on 16 June 1998)

Note : See Figure 14 for Location of Photograph.

Plate 20 – View of the Remains of the Debris deposited at the Toe of the Slope. Depth of Debris up to 0.5 m (Photograph taken on 16 June 1998)

Note: See Figure 14 for Location of Photograph.

Plate 21 – View Looking towards Southeast Corner of Platform and Stepped Channel following completion of Remedial Works. Note Catchpit at Head of Slope (Photograph taken on 17 March 1999)

Note: See Figure 14 for Location of Photograph.

Plate 22 – View of Catchpit at Head of Stepped Channel
(Photograph taken on 17 March 1999)

Note: See Figure 14 for Location of Photograph.

Plate 23 – General View of Reinstated Crest Channel
(Photograph taken on 17 March 1999)

Note: See Figure 14 for Location of Photograph.

Plate 24 – General View of Slopes at Southeast Corner of Middle Fill Platform (Photograph taken on 17 March 1999)

Note: See Figure 14 for Location of Photograph.

Plate 25 – View of Erosion Gullying on Fill Slope adjacent to
1998 Landslide (Photograph taken on 17 March 1999)

Note: See Figure 14 for Location of Photograph.

Plate 26 – View of Catchpit and Stepped Channel to the North of the 1998 Landslide Site. Note Deformation and Rubbish blocking the Flowpath (Photograph taken on 17 March 1999)

Note: See Figure 14 for Location of Photograph.

Plate 27 – View of U-Channel at Toe of Subsidiary Slope of Feature No. 11NE-A/F116 adjacent to Stepped Channel and 1998 Landslide (Photograph taken on 17 March 1999)

Note: See Figure 14 for Location of Photograph.