

**SECTION 4 :
DETAILED STUDY OF THE
FLOODING INCIDENT
AT TUEN MUN ROAD
YAU KOM TAU
ON 2 AND 3 JULY 1997**

Halcrow Asia Partnership Ltd

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FOREWORD

This report presents the findings of a detailed study of a flooding incident on 2 and 3 July 1997, which caused considerable disruption to the east- and west-bound carriageways of Tuen Mun Road. Stormwater from the Tai Lam Chung Catchwater overflowed into a natural stream course as a result of blockage of the catchwater with debris from three landslides. The stormwater caused considerable erosion of the stream bed and banks. Debris from the stream was carried into and choked the drainage system above a registered cut slope adjacent to Tuen Mun Road. As a consequence, water and debris was discharged onto the road and caused its closure for 5.5 hours west-bound and up to 15.5 hours east-bound. No fatalities or injuries were reported.

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

The report was prepared as part of the 1997 Landslip Investigation Consultancy (LIC), for the Geotechnical Engineering Office (GEO), Civil Engineering Department (CED), under Agreement No. CE 68/96. This is one of a series of reports produced during the consultancy by Halcrow Asia Partnership Ltd (HAP). The report was written by Mr R J Simonds and reviewed by Dr R Moore and Mr H Siddle. The assistance of the GEO in the preparation of the report is gratefully acknowledged.



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1. INTRODUCTION

Prior to midnight on 2 July 1997 three landslides occurred on cut slope No. 6SE-D/CR135 above the Tai Lam Chung Catchwater near Yau Kom Tau new village resulting in complete blockage of the catchwater (Figures 1 and 2). As a consequence, stormwater was discharged through an overflow weir 'X' (Figure 2) into a natural stream course below. The stormwater eroded the banks and bed of the stream including dilapidated masonry walls constructed on abandoned squatter platforms adjacent to the stream. Boulders and debris mobilised by the stormwater blocked a trapezoidal drainage channel located at the crest of cut slope No. 6SE-D/C64 above the east-bound carriageway of Tuen Mun Road. As a result of the blockage of the trapezoidal drainage channel, stormwater and debris cascaded down the cut slope and the intervening fill slope (No. 6SE-D/F17) onto the east- and west-bound carriageways of Tuen Mun Road, causing flooding and total blockage of the road. The east- and west-bound carriageways were closed for 15.5 hours and 5.5 hours respectively. No fatalities or injuries were reported.

Following the flooding incident, Halcrow Asia Partnership Ltd (the 1997 Landslip Investigation Consultants) carried out a detailed study of the incident for the Geotechnical Engineering Office (GEO), Civil Engineering Department (CED), under Agreement No. CE 68/96. This is one of a series of reports produced during the consultancy by Halcrow Asia Partnership Ltd (HAP).

The key objectives of the study were to document the facts about the incident, present relevant background information and establish the probable causes of the incident. The scope of the study was limited to site reconnaissance, desk study and 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) a review of relevant documents relating to the history of the site,
- (b) analysis of rainfall records,
- (c) detailed observations and measurements at the site, including a height survey of the catchwater parapet wall and overflow weirs,
- (d) a review of reports produced after the incident by Highways Department (HyD) and Water Supplies Department (WSD), and
- (e) diagnosis of the probable causes of the incident.

2. THE SITE

2.1 Site Description

The flooding incident occurred on Tuen Mun Road below the abandoned squatter village of Hon Man Tsuen, about 100 m east of the new village at Yau Kom Tau (Figure 1). Tuen Mun Road is grade-separated at the location of the flooding incident, with the east-bound carriageway some 7 m above the west-bound carriageway. The carriageways are separated by fill slope No. 6SE-D/F17. A partly modified natural hillside is present above the 7 m high cut slope (No. 6SE-D/C64) adjacent to the east-bound carriageway.

The three landslides occurred on cut slope No. 6SE-D/CR135 above the Tai Lam Chung Catchwater at locations 'A', 'B' and 'C' (Figure 1 and Plates 1 to 3). The slope is about 550 m long and has been cut at an angle of about 60° with no berms, into soil and rock to a maximum height of about 18 m. About 40% of the slope face is sealed, 50% vegetated and 10% remains bare. The types of seal along the slope face vary between shotcrete, chunam and stone pitching. There is a 250 mm U-channel crest drainage system which connects to a number of 300 mm stepped channels which discharge into the catchwater. Running along the length of the toe of the slope is a 1.7 m high concrete retaining wall which forms the upslope side of the catchwater.

The hillside between the Tai Lam Chung Catchwater and Tuen Mun Road is about 23° to the horizontal, and has in the past been modified to form cut slopes and platforms for squatter huts. The heavily vegetated natural hillside above the catchwater cut slope forms the southern flank of Ha Fa Shan and is at an angle of about 34° to the horizontal.

The Tai Lam Chung Catchwater is a concrete-lined channel approximately 1.6 m deep and 2.2 m wide. There is a 3 m wide WSD access road adjacent to the catchwater separated by a concrete parapet wall which is about 0.5 m high. Overflow weirs on the catchwater regulate water flow within the catchwater. One such overflow weir 'X' (Figure 1) regulates water flow into a natural stream course which passes through the abandoned squatter village of Hon Man Tsuen. The stream discharges into a trapezoidal drainage channel 'D' (Figure 1), which is about 0.8 m deep and 1.5 m wide. A flat concrete slab forms an access footbridge over the outfall of the trapezoidal drainage channel, which discharges into a cascade channel 'E' (Figure 1) down cut slope No. 6SE-D/C64. A 1.5 m diameter culvert 'F' (Figure 1) is located at the bottom of the cascade channel allowing water to drain beneath Tuen Mun Road.

As part of the detailed study, HAP carried out a height survey of the catchwater parapet wall between overflow weirs 'W', 'X', 'Y' and 'Z'. The results of the survey are presented in Section 5.

2.2 Site History

The site history was traced from a sequential series of aerial photographs of the site spanning the period 1954 to 1996 and a review of other available documentary information (Tables 1 and 2).

Aerial photographs taken in 1954 show that prior to the construction of the Tai Lam Chung Catchwater there were several prominent drainage lines on the natural hillside at Ha Fa

Shan. The section of catchwater affected by landslides was constructed in 1956 by WSD. Aerial photographs taken in 1963 show the catchwater and cut slope and a heavily vegetated natural hillside directly upslope. Bouldery colluvium can be seen in the stream bed below overflow weir 'X' (Figure 3). A small number of squatter huts were present at Hon Man Tsuen, having been constructed on platforms cut into the natural hillside below the catchwater to the east and west of the stream.

The number of squatter huts in Hon Man Tsuen had increased by 1974. There were no apparent changes to the Tai Lam Chung Catchwater cut slope, overflow weirs or the natural hillside above the catchwater. Aerial photographs taken in 1975 show a colluvial debris fan in the area through which the trapezoidal drainage channel 'D' was subsequently constructed. The 1975 aerial photographs also show the U-channel crest drainage system above the catchwater cut slope. The crest drainage system is connected to a number of stepped channels down the catchwater cut slope. At this time the natural hillside above the catchwater was heavily vegetated with the exception of a small area, partially bare of vegetation, which is considered to be the scarp of a minor landslide (Figure 3). Aerial photographs show that Tuen Mun Road and Slope Nos. 6SE-D/C64 and 6SE-D/F17 were constructed in two stages between 1975 and 1984. Apart from a small amount of erosion in the area of the 1975 landslide, that is visible on photographs taken in 1976, there were no significant changes to the Tai Lam Chung Catchwater or roadside slopes between 1984 and 1990.

The 1992 aerial photographs indicate that there may have been uncontrolled discharge of surface water adjacent to cascade channel 'E' on cut slope No. 6SE-D/C64. About one year later, the dark surface staining was no longer present.

By 1993, some of the squatter huts in the village at Hon Man Tsuen had been rendered uninhabitable and only the foundation slabs remained. These actions were the result of the Non-Development Clearance (NDC) programme at Hon Man Tsuen which was implemented jointly by Lands Department and Housing Department in 1992. The approximate area covered by the NDC programme is shown in Figure 1.

2.3 Previous Studies

2.3.1 Slope Registrations

The catchwater cut slope No. 6SE-D/C135 and the highway cut slope No. 6SE-D/C64 were both registered by consultants engaged by the Government to prepare the 1977/78 Catalogue of Slopes.

In 1992, the GEO initiated a consultancy agreement entitled 'Systematic Inspection of Features in the Territory' (SIFT) to update information on existing registered slopes based on studies of aerial photographs. Slope Nos. 6SE-D/C135 and 6SE-D/C64 were both entered in the SIFT database in July 1996, the former being allocated the new Slope No. 6SE-C/CR135 in recognition of the fact that the catchwater formed a retaining structure at the toe of the slope. The category 'Class C1' was assigned to both slopes as they had "been formed or substantially modified before 30.6.78" and satisfied the criteria for slope registration.

2.3.2 Inspections of Catchwater Cut Slope No. 6SE-D/CR135

The catchwater cut slope No. 6SE-D/CR135 was inspected in December 1996 by consultants engaged by the Government for the 'Systematic Identification and Registration of Slopes in the Territory' (SIRST) to update the 1977/78 Catalogue of Slopes and to compile the New Catalogue of Slopes. The condition of the cut slope face was recorded as being "fair" with past instability referred to as "multiple minor". The stepped channels were recorded as "clear"; however, the crest U-channel was reported as "blocked". The concrete retaining wall showed no "inferred past instability" though a U-channel at the toe was "blocked" and weepholes were "partially blocked". A further study of the slope was recommended and this has been instigated by WSD (Section 2.3.4).

It is understood from WSD "that the slopes along the catchwaters are usually inspected by our catchwater gang. The catchwater gang will report to their Inspector and Engineer the abnormal features of the slopes for follow-up actions on the routine maintenance and repair works of the slopes" (WSD, 1998a). Aerial photographs show evidence that a protective surfacing was applied to cut slope No. 6SE-D/CR135 to the west of overflow weir 'X' at sometime between 1963 and 1975 and near overflow weir 'X' at sometime between 1992 and 1993. WSD (1997a) reported that slope protection works were undertaken at three locations on the catchwater cut slope in 1995 (Figure 3).

2.3.3 Inspections and Stage 1 Study of Cut Slope No. 6SE-D/C64

A Stage 1 Study of highway cut slope No. 6SE-D/C64 was undertaken in May 1989 by the Geotechnical Control Office (GCO, 1989). The report recommended "no further study is considered necessary for the slope under the present circumstances. However, based on site inspection, the following maintenance works are considered necessary for the slope :

- (a) clear the unplanned vegetation from the slope face and repair the cracks on the chunam slope cover, and
- (b) clear the drainage channels and repair cracks, if any."

In February 1996, the highway cut slope No. 6SE-D/C64 was inspected by consultants Fugro Mouchel Rendel (FMR, 1995) appointed by HyD in a project entitled 'Roadside Slope Inventory and Inspections' to, inter alia, carry out Engineer Inspections on about 4 000 HyD slopes which satisfy GEO's slope registration criteria. The Engineer Inspection Report noted that routine maintenance had not been carried out satisfactorily. In particular, culverts, drainage channels and natural drainage lines were noted to be "blocked with rubbish". A "high consequence to life" category was assigned to the slope and, together with yearly inspections, a "detailed stability analysis of the suspect slope" was recommended. The Engineer Inspection Report stated that the overall state of maintenance of the slope was "fair" according to guidelines given in the Guide to Slope Maintenance (GEO, 1995). A Stage 1 Study was subsequently carried out by FMR in February 1996 which recommended the need for further study of Slope No. 6SE-D/C64.

2.3.4 Catchwater Studies and Subsequent Actions

In November 1979, WSD and GCO jointly commenced a study of catchwaters in Hong Kong. The purpose of the study "was to investigate the stability of catchwaters and associated slopes and to make appropriate recommendations to reduce the potential risk to downslope developments." The Catchwater Study First Report (WSD & GCO, 1980) provided recommendations for a systematic study and ranking of all catchwaters. These recommendations were fulfilled by the Catchwater Study Second Report (GCO, 1982). The principal conclusions were that "there are a small number of catchwaters which are of concern for their whole length" and "there are a number of isolated sections of other catchwaters which are of concern." Further studies were carried out "on six catchwaters considered to present the greatest potential risks in terms of consequences of failure." One section of the Tai Lam Chung Catchwater, Section O, which includes the slope on which 1997 landslides occurred was included in the study. The report (GCO, 1982) stated that "in the section CH6465-7350 there are several squatter villages situated on the steep slopes between the catchwater and the Tuen Mun Highway". Risk to the cut slope No. 6SE-D/C64 was also noted. For all the catchwater sections of concern, the report recommended :

- (a) "WSD undertake a detailed hydrological study ,"
- (b) "A review of all recent remedial work carried out during regular or special maintenance should be done"
- (c) "For the lengths of major catchwaters that remain at risk by blockage or collapse WSD should then make specific requests to GCO for further studies"

In March 1986, WSD prepared a report (WSD, 1986) on the Tai Lam Chung Catchwater addressing recommendations (a) and (b). The report considered the hydraulics of the catchwater in relation to flood flows and compared a 1 in 200 year flood flow in the catchwater with the existing catchwater overflow capacity. The report determined that overflow weirs 'W' and 'X' were of sufficient design, however modifications were recommended to increase the capacity of overflow weirs 'Y' and 'Z'. According to WSD, "this section of the Tai Lam Chung Catchwater has been upgraded since 1992 to ensure that it will cope with a risk of 1 to 200 year return period" (WSD, 1997b).

Following the recommendation (c) above, WSD nominated seven cut slopes, all upstream and to the east of cut slope No. 6SE-D/CR135, for inclusion in the Landslip Preventive Measures (LPM) Programme. In 1994 the slopes were selected by the Interdepartmental Landslip Preventive Measures Committee for inclusion in the 1995/96 LPM Programme. A Stage 3 Study Report (GEO, 1997) was prepared by GEO in July 1997 and the LPM works including, inter alia, soil nailing, provision of surface drainage channels, sprayed concrete surface cover, hydro-seeding and rock slope stabilization commenced in August 1997 and were completed in January 1998. No works were undertaken on Slope No. 6SE-D/CR135.

In November 1997, Binnie Consultants Limited (BCL) prepared a draft working paper for the Drainage Services Department (DSD), which summarised the findings of an investigation into the impacts of overflow from WSD reservoirs and catchwaters on downstream drainage systems, as part of the Tuen Mun and Sham Tseng Stormwater

Drainage Master Plan Study (BCL, 1997). In their report, BCL analysed the flows during flooding incidents and assessed various options for reducing the impact of overflow together with design improvements to the drainage system.

WSD intend to engage consultants in connection with a project to reconstruct catchwaters. The scope of the work "will cover all slopes adjoining (sic) the catchwaters and those potentially dangerous slopes downstream of the catchwaters, the failure of which will affect Tuen Mun Road. Slope No. 6SE-D/CR135 will be included in the study" (WSD, 1998a).

2.4 Previous Landslides

Inspection of aerial photographs dated 1975 shows a minor landslide above the catchwater cut slope about midway between overflow weirs 'W' and 'X' (Figure 3). However, the failed material did not reach the catchwater. Minor erosion just below this area is apparent on aerial photographs taken in 1978.

The Catchwater Study Second Report (GCO, 1982) describes that "during the 1981 rainy season part of the existing slide scar at CH6710-6720 was reactivated by a joint controlled failure in rock behind the chunam. This blocked the catchwater and resulted in considerable overflows along the two channels immediately upstream (CH6863 and CH6978). Below the first overflow this caused some erosion to both cut and fill slopes adjoining the Tuen Mun Highway. The increased discharges below the second overflow resulted in the undermining of several squatter huts built over the gully below the Tuen Mun Highway. No casualties were reported in these incidents". The location of this incident corresponds with the location of a landslide (GCO Incident No. NT 23/81) recorded in GEO's Landslide Incident Report database.

GEO's Landslide Incident Report database also contains a record of an incident (GEO Incident No. MW93/6/56) which occurred on 16 June 1993 and involved blockage of the trapezoidal drainage channel 'D' (Figure 3). The incident was reportedly caused by "run off washing down boulders in natural stream course". Unblocking of the channel and reinstatement of the ground was recommended by GEO in the incident report.

GEO's Natural Terrain Landslide Inventory (NTLI) indicates there have been seven natural terrain landslides on the hillsides of Ha Fa Shan above the Tai Lam Chung Catchwater. The nearest failure to cut slope No. 6SE-D/CR135 was natural terrain landslide 'D' which was first observed on aerial photographs taken in 1973 (Figure 3). The main scarp was completely covered in vegetation and was less than 20 m wide. The debris trail was about 50 m long and was confined to a drainage line.

2.5 Subsurface Conditions

The geological memoir (Langford et al, 1989) and Sheet 6 of the Hong Kong Geological Survey 1:20 000 scale Map Series (GCO, 1988) indicate that the site is underlain by dacite, a very fine-grained equivalent of granodiorite.

There has been no previous ground investigation along the catchwater cut slope No. 6SE-D/CR135. The subsurface conditions of the cut slope have been assessed from field observations by HAP of the main scarps of the three landslides. All three main scarps exposed weak to very weak, highly to completely decomposed dacite, and material of a similar nature was also observed in the banks of the stream. In the bed of the stream, moderately strong to strong, slightly decomposed dacite was exposed.

At the time of inspection by HAP on 3 July 1997, Slope Nos. 6SE-D/C64 and 6SE-D/F17 had been shotcreted as part of the urgent repair works. The closest borehole to the site was drilled at the crest of Slope No. 6SE-D/C64 during the ground investigation for Tuen Mun Road Stage II works supervised by HyD consultants Scott Wilson Kirkpartick & Partners (SWKP). The borehole encountered 3 m of colluvium described as a dense light brown slightly gravelly sand with some cobbles overlying dense light brown and white clayey gravelly sand (completely decomposed volcanics).

A geological cross-section from the Tai Lam Chung Catchwater to Tuen Mun Road is presented in Figure 4.

3. THE INCIDENT

3.1 The 1997 Landslides

The catchwater cut slope (No. 6SE-D/CR135) was affected by three landslides on 2 July 1997 (Plates 1 to 3). The locations of the landslides 'A', 'B' and 'C' are shown in Figure 1. Landslide 'A' was about 1.5 m deep with an estimated volume of 280 m³ and occurred on a part-vegetated, part-surfaced, 55°, 18 m high soil cut slope. Landslides 'B' and 'C' were about 1 m deep with estimated volumes of about 100 m³ and 35 m³. They occurred on vegetated, 60°, soil cut slopes of around 10 m high and 5 m high respectively. The material involved in each of the landslides was completely decomposed dacite. The travel angle for all three landslides was in excess of 30° and the debris mobility is therefore not unusual for rain-induced landslides in Hong Kong (Wong & Ho, 1996).

In May 1997, there was an incident (GEO Incident No. MW97/5/37) behind block M of Allway Gardens, Tsuen Wan about 800 m upstream from overflow weir 'X' on the Tai Lam Chung Catchwater. GEO reported that "a minor landslip occurred on a slope above a catchwater near Allway Gardens, resulting in blockage of the catchwater and overflowing at the overflow weir (upstream of the landslip) down to a natural stream course. Debris and minor landslips were found respectively inside and beside a large catchpit at the end of the natural stream course" (GEO, 1998).

The previous reported incidents, together with the 1997 landslides, form a notable cluster (Figure 3).

3.2 The Flooding Incident

A landslide warning was issued at 06:25 hours on 2 July 1997 and cancelled at 08:40 hours on 5 July 1997 and a flood warning was issued at 15:15 hours on 2 July 1997 and cancelled at 09:30 hours on 3 July 1997.

The following sequence of events has been established based on reports produced by HyD (1997a) and WSD (1997b). Three landslides occurred on cut slope No. 6SE-D/CR135 above the Tai Lam Chung Catchwater prior to midnight on 2 July 1997. The exact time of the landslides and their sequence are not known. The landslide debris completely blocked the catchwater. As a result of the blockage, water levels in the catchwater rose and water was discharged through overflow weir 'X' (Plate 4) into the stream. Flooding was first reported at midnight on 2 July 1997 and continued until around 03:45 hours on 3 July 1997, at which time, an emergency gang from WSD had cleared the landslide debris in the catchwater and re-established flow.

The stormwater eroded the banks of the stream. Existing boulders in the bed of the stream together with eroded soil, vegetation, loose masonry and rubbish from the adjacent abandoned squatter platforms were all transported downstream (Plates 5, 6 & 7). As a result, the whole length of the trapezoidal drainage channel 'D' above the highway cut slope (No. 6SE-D/C64) became completely blocked with debris (Plates 8 & 9). As a consequence, there was an uncontrolled discharge of stormwater and debris down the highway cut slope on either side of the cascade channel 'E' (Plate 10), onto both carriageways of Tuen Mun Road.

The impact of debris striking the road and the scouring action of the water caused damage to the surface of the east-bound carriageway of Tuen Mun Road for a length of approximately 50 m (HyD, 1997a).

HyD contractors undertook urgent repair works to Tuen Mun Road between 02:15 hours and 15:15 hours on 3 July 1997. Apart from clearing the flood and washout debris, they applied shotcrete to the damaged slope Nos. 6SE-D/C64 and 6SE-D/F17. The west-bound carriageway was re-opened at 05:30 hours on 3 July 1997 and the east-bound carriageway was re-opened at 15:30 hours on 3 July 1997. There was significant disruption to traffic during the flooding incident and subsequent urgent repair works.

Following the incident, WSD contractors trimmed the main scarps of landslides 'A', 'B' and 'C', applied shotcrete protection and carried out repairs to drainage channels and the concrete catchwater channel. HyD propose to undertake "survey, design and modification to the inlet channel system" (HyD, 1997b). HyD also arranged for the stream to be cleared out and the banks of the stream above the trapezoidal drainage channel to be protected with shotcrete.

4. RAINFALL

The nearest GEO automatic raingauge No. N03 is located at Tsuen Wan Treatment Works, Shing Mun Road, about 3 km to the east of the flooding incident. The daily rainfall recorded between 1 June and 11 July 1997 is shown in Figure 5a. There was 837 mm and 546 mm of rainfall in the 31 days and 15 days before the onset of the flooding incident respectively. The hourly rainfall from 30 June to 3 July 1997 is shown in Figure 5b. There was 364.5 mm and 182.5 mm of rainfall in the 24 hours and 12 hours before the flooding respectively. Isohyets of rainfall prior to the flooding incident are shown in Figure 6. The figure shows that the distribution of peak intensity rainfall was centred about 12 km northeast of the site.

The estimated return periods for maximum rolling rainfall of selected durations based on historical rainfall data at the Hong Kong Observatory (Lam & Leung, 1994) are presented in Table 3. The maximum rolling 24-hour and 2-day rainfall totals were the most extreme with corresponding return periods of about 9 years and 11 years respectively.

The 5-minute rainfall recorded at GEO raingauge No. N03 is shown in Figure 7. The figure shows that the maximum intensity of the rainstorm between 17:00 hours on 2 July and 00:00 hours on 3 July was 8.5 mm and occurred between 21:35 hours and 21:40 hours on 2 July 1997.

The maximum daily rainfall in each month recorded at the GEO raingauge No. N03 since June 1983 is shown in Figure 8. Rainfall on 2 July 1997 was the highest daily total recorded by the raingauge (HKO, 1997).

5. CAUSES OF THE LANDSLIDES AND FLOODING INCIDENT

It is considered that the three landslides on the catchwater cut slope were probably triggered by the heavy rainfall prior to midnight on 2 July 1997. The principal contributory cause of the failures was infiltration of surface water into an oversteep slope.

The flooding incident probably developed in the following stages:

- (a) Heavy rainfall in the 24 hours prior to the flooding incident will have resulted in wetting of the hillside above the catchwater and overland flows to the catchwater.
- (b) Infiltration into both the natural terrain and cut slope above the catchwater caused three landslides which completely blocked the catchwater. The landslides were not caused by an increase in water level in the catchwater. The close proximity of the three landslides and their possible occurrence within a short period of time would have made it very difficult for the catchwater to self-clean through the action of stormwater flow.
- (c) Complete blockage of the catchwater by the landslide debris resulted in the discharge of stormwater through the overflow weir 'X', causing the erosion of a large quantity of debris from the bed and banks of the stream.
- (d) The constriction made by the footbridge at the outfall of the trapezoidal drainage channel 'D', which discharges to cascade channel 'E' on the highway cut slope, was liable to have contributed to the blockage of the trapezoidal channel by flood debris.
- (e) Blockage of the trapezoidal channel with debris prevented drainage of stormwater and resulted in uncontrolled

discharge of stormwater and debris down the highway cut slope onto both carriageways of Tuen Mun Road.

There is a notable cluster of past incidents near the location of the three landslides which occurred on the catchwater cut slope in July 1997. Up to seven natural terrain landslides have been identified on the hillside above the catchwater. Protective surfacing has been applied to sections of the catchwater cut slope (No. 6SE-D/CR135) on at least four occasions, one of which was at the location of GCO Incident No. NT23/81. There was also a previous blockage of the trapezoidal drainage channel 'D' above highway cut slope No. 6SE-D/C64 in June 1993 (GEO Incident No. MW93/6/56).

An issue of relevance in respect of the flooding incident is whether the stormwater discharge at overflow weir 'X' was within, or in excess of, the design capacity of the weir. WSD design information indicates that the design capacity of overflow weir 'X' was sufficient to cope with a 1 in 200 year flood flow, provided that the catchwater was not blocked. In the report on the incident by WSD (1997b), it is stated that "there are control intakes and overflow weirs along the catchwater at chosen locations for discharging water in excess of the designed capacity of the catchwater to the natural stream courses below to avoid overtopping of the catchwater. The weirs will also discharge water to the natural stream courses automatically when there is a sudden rise in the catchwater caused by blockages resulting from the failure of the uphill slopes." The implication therefore, is that blockage of the catchwater is taken into account in the hydraulic design.

It has been established that landslide debris completely blocked the catchwater immediately downstream of overflow weir 'X'. At 01:45 hours on 3 July 1997, HyD engineers inspected the catchwater and reported that "there was overflowing at the overflow weir and overtopping of the catchwater by about 50 mm over the adjacent road surface" (HyD, 1997). Engineers from WSD inspected the overflow weir 'X' at 03:15 hours on 3 July 1997 and reported that "the water was observed to discharge freely from the overflow weir and the maximum discharge capacity of the overflow weir had not been reached" (WSD, 1997b). Subsequent checks were made on the design capacity of the catchwater and overflow weirs by WSD who reported that "based on our observation on the environmental evidence on site and our detailed calculation for the run off from the catchment concerned at the time of the incident which indicated that neither the capacity of the catchwater system nor that of the overflow weirs had been exceeded, we still hold the view that there has been no uncontrolled overtopping of the catchwater" (WSD, 1998b).

The results of a level survey of the catchwater carried out by HAP after the incident, indicated that the height of the catchwater parapet wall above overflow weir 'X' was probably sufficient to prevent overtopping of the catchwater in the event of blockage at the locations of the three landslides (Figure 9). It is considered likely that overflow weirs 'Y' and 'Z' would also have discharged stormwater as a result of the blockage of the catchwater. There was no evidence of overtopping of the parapet wall of the catchwater upstream of overflow weir 'X'.

In addition, the level survey determined that an 80 m long section of the catchwater parapet wall immediately upstream from overflow weir 'W' is vulnerable to overtopping in the event of a complete blockage of the catchwater along this section with landslide debris (Figures 1 and 9).

6. CONCLUSIONS

The flooding of Tuen Mun Road in the early hours of 3 July 1997 was caused by uncontrolled discharge of stormwater and debris from a natural stream course above the road. Stormwater was discharged into the stream via an overflow weir on the Tai Lam Chung Catchwater which was blocked with debris from three landslides on the uphill cut slope No. 6SE-D/CR135. The cut slope was not designed to or proved to comply with current geotechnical safety standards. The stormwater eroded boulders and debris from the stream bed and banks, which resulted in the blockage of a trapezoidal drainage channel at the crest of the cut slope above the east-bound carriageway of Tuen Mun Road. The stormwater cascaded down the cut slope and deposited water and debris onto the carriageways below. The access footbridge over the outfall of the trapezoidal drainage channel may have contributed to the blockage by constricting the flow of debris-laden stormwater.

7. REFERENCES

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Table 1 – Summary of Site Development from Aerial Photograph Interpretation
(Sheet 1 of 3)

Year	Photographic Reference No.	Altitude	Observations
1954	Y02727/8	-	These photographs were taken prior to construction of the catchwater and show that the natural hillside on the southern flanks of Ha Fa Shan had several prominent drainage lines.
1963	Y08918/9	-	The Tai Lam Chung Catchwater had been constructed with a cut slope directly above and a heavily vegetated natural hillside beyond the cut slope. Overflow weirs 'W' 'X' and 'Y' and 'Z' had been constructed on the catchwater above the drainage lines. Bouldery colluvium was evident in the drainage line below overflow weir 'X'. There were a small number of squatter huts on the hillsides below the catchwater to the east and west of the natural stream course.
1974	8256/7	-	The catchwater cut slope remained unchanged and the natural hillsides above were heavily vegetated. The village of Hon Man Tsuen had developed by this time to the east and west of the stream.
1975	11324/5	1500 ft	A U-channel drainage system was visible above the catchwater cut slope. The natural hillsides above the catchwater were heavily vegetated and there was evidence of a minor landslide above the catchwater cut slope. In addition, a section of the catchwater cut slope downstream from overflow weir 'X' had a protective surfacing. The highway cut slope was under construction and the trapezoidal drainage channel 'D' had not been constructed at this time. The relatively flat area immediately above the highway cut slope had the form of a colluvial debris fan.

Table 1 – Summary of Site Development from Aerial Photograph Interpretation
(Sheet 2 of 3)

Year	Photographic Reference No.	Altitude	Observations
1977	17976	4000 ft	There were no apparent changes to the catchwater cut slope. The highway cut slope had been constructed together with the slope drainage system. The trapezoidal drainage channel 'D' and the cascade channel 'E' were under construction. The fill slope between the east- and west-bound carriageways had been constructed in the natural drainage line and the culvert 'F' under the Tuen Mun Road was in place.
1978	24035/6	4000 ft	The footbridge over the east- and west-bound carriageways to Nam Hoi Pui had been constructed. Traffic was flowing east and west on what is now the east-bound carriageway i.e. Tuen Mun Road Stage I works had been completed. The access footbridge over the outfall of the trapezoidal drainage channel 'D' had been constructed by this time. There was a small area of surface erosion on the hillside below the minor landslide which occurred in 1975. The U-channel drainage system above the crest of the catchwater cut slope was barely visible through the dense vegetation.
1984	57517/8	4000 ft	The construction of Tuen Mun Road Stage II works had been completed and east- and west-bound carriageways were open to traffic.
1988	A3174/5	10000 ft	No changes were apparent.
1989	A16446/7	2500 ft	No changes were apparent.
1990	A20981/2	4000 ft	No changes were apparent.
1992	A31217/8	4000 ft	The photographs show that there may have been an uncontrolled discharge of surface water down the highway cut slope which resulted in a dark staining on the surface of the slope.

Table 1 – Summary of Site Development from Aerial Photograph Interpretation
(Sheet 3 of 3)

Year	Photographic Reference No.	Altitude	Observations
1993	A35991/2	4000 ft	The dark staining on the surface of the highway cut slope was not evident.
1994	A38170/1	5000 ft	No changes were apparent.
1996	CN15761/2	4000 ft	No changes were apparent.

Table 2 – Summary of Information Sources (Sheet 1 of 2)

Source	Information Obtained
Geotechnical Information Unit (GIU) at the Civil Engineering Department (CED) Library.	Stage 3 Study Report. Slopes 6SE-D/C70, C128, C130 to C134 Tai Lam Chung Catchwater Section O Chainage 7100 to 7950, Tsuen Wan, prepared by GEO Design Division.
Slope Files and District Files from Mainland West Division and Files from Design Division of GEO.	<p>(a) Stage 1 Study for Slope Nos. 6SE-D/C135 and 6SE-D/C64.</p> <p>(b) GEO Incident Report No. MW93/6/56.</p> <p>(c) Provisional Brief for Reconstruction of Catchwaters in Tai Lam Chung, Hong Kong Island and Lantau Island.</p> <p>(d) Tuen Mun and Sham Tseng Drainage Master Plan Study.</p>
GEO Publications, Reports, Maps and Memoirs.	<p>(a) Yuen Long : Solid and superficial geology, Hong Kong Geological Survey, Map Series HGM 20, Sheet 6, 1:20 000 scale.</p> <p>(b) Geology of the Western New Territories, Hong Kong Geological Survey Memoir No. 3.</p> <p>(c) Catchwater Study First Report.</p> <p>(d) Catchwater Study Second Report, GEO Report No. 26/82, vols 1 & 2.</p>
GEO Planning Division.	Aerial Photographs from 1954, 1963, 1974, 1975, 1976, 1977, 1978, 1984, 1988, 1989, 1990, 1992, 1993, 1994 and 1996.
GEO Slope Safety Division.	<p>(a) SIRST Report on Slope No. 6SE-D/CR135.</p> <p>(b) Slope Record and Engineers Inspection Record for slope No. 6SE-D/C64 prepared by Fugro Mouchel Rendel for HyD.</p>
GEO Landslide Incident Report Database.	Details of past landslides reported to GEO.
Lands Department and District Lands Office (DLO).	<p>(a) Land Status.</p> <p>(b) Maintenance Responsibility.</p>

Table 2 – Summary of Information Sources (Sheet 2 of 2)

Source	Information Obtained
Water Supplies Department (WSD).	<p>(a) Summary Report on 3 July 1997 Landslip Incident on Tai Lam Chung Catchwater Section N Chainage 6700 to 6863.</p> <p>(b) Full Incident Report.</p> <p>(c) Flood Study on Tai Lam Chung Catchwater. Resources Planning Report No. RP4/84 (HS42).</p>
Drainage Services Department (DSD).	Existing Utility Information.
LPM / SIRST / SIFT Databases.	Registration Status of Slope Nos. 6SE-D/CR135, 6SE-D/C64 and 6SE-D/F17.
Highways Department (HyD).	<p>(a) Report on the Drainage to the Kowloon-Bound Carriageway Surface of Tuen Mun Highway At Yau Kom Tau, Tsuen Wan on 2 and 3 July 1997.</p> <p>(b) Video of TVB Pearl News Report on the Flooding Incident.</p>
Hong Kong Observatory (HKO).	<p>(a) Daily rainfall data between June 1983 and July 1997.</p> <p>(b) Isohyets of rainfall between 00:00 hours 2 July and 00:00 hours 3 July 1997.</p>

Table 3 – Maximum Rolling Rainfall at GEO Raingauge No. N03 for Selected Durations Preceding the 2 and 3 July 1997 Flooding Incident and The Corresponding Estimated Return Periods

Duration	Maximum Rolling Rainfall (mm)	End of Period	Estimated Return Period (Years)
5 minutes	13.5	08:40 hours on 2 July 1997	2
15 minutes	35	08:50 hours on 2 July 1997	6
1 hour	89	09:00 hours on 2 July 1997	5
2 hours	120	09:00 hours on 2 July 1997	4
4 hours	129.5	09:00 hours on 2 July 1997	1
12 hours	197.5	15:00 hours on 2 July 1997	3
24 hours	364.5	00:00 hours on 3 July 1997	9
2 days	441	00:00 hours on 3 July 1997	11
4 days	459.5	00:00 hours on 3 July 1997	6
7 days	468	00:00 hours on 3 July 1997	4
15 days	546	00:00 hours on 3 July 1997	3
31 days	837	00:00 hours on 3 July 1997	5
<p>Notes: (1) Return periods were derived from the Gumbel equation and data published in Table 3 of Lam & Leung (1994).</p> <p>(2) Maximum rolling rainfall was calculated from 5-minute data for durations up to one hour and from hourly data for longer rainfall durations.</p>			

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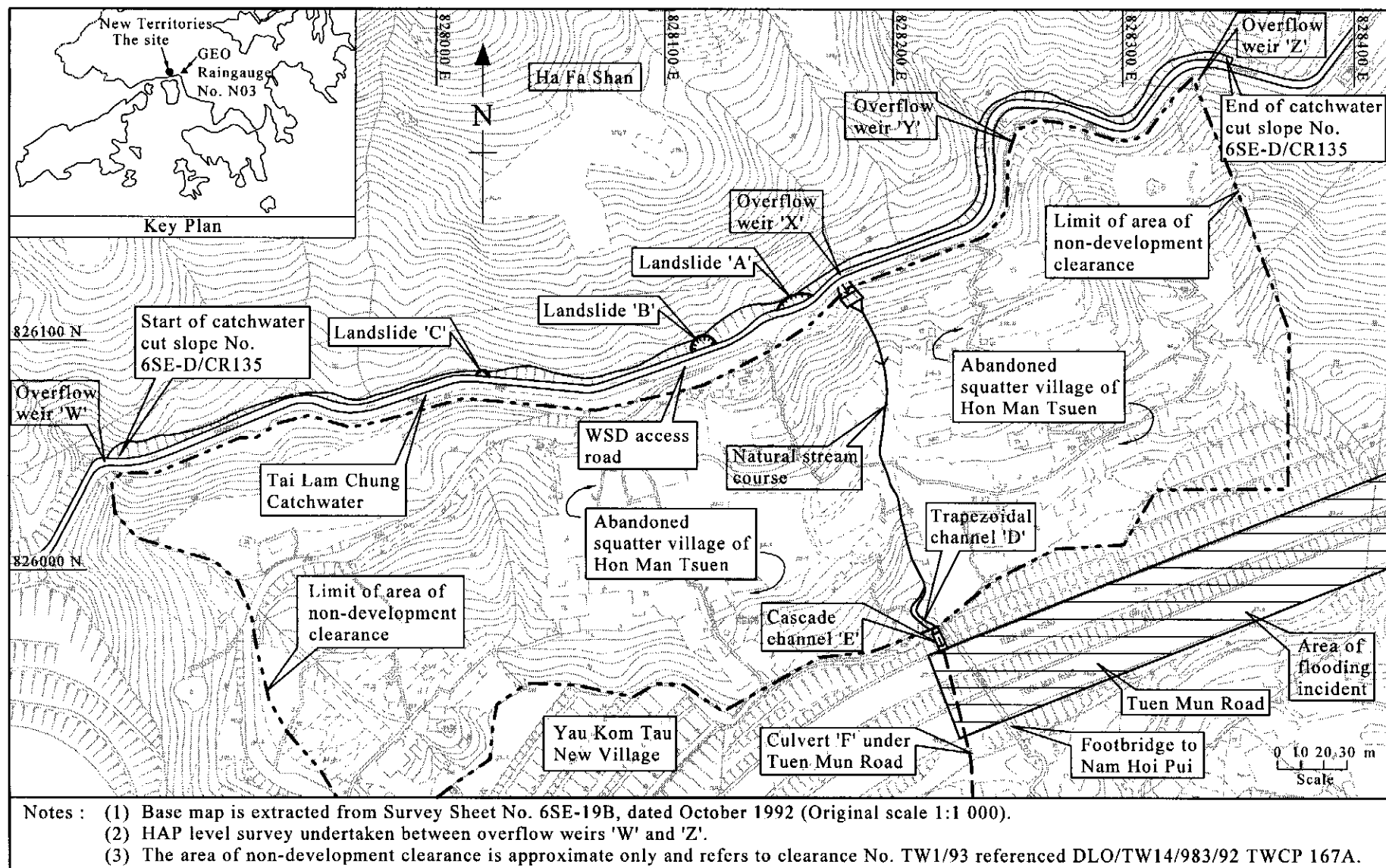


Figure 1 - Site Location Plan

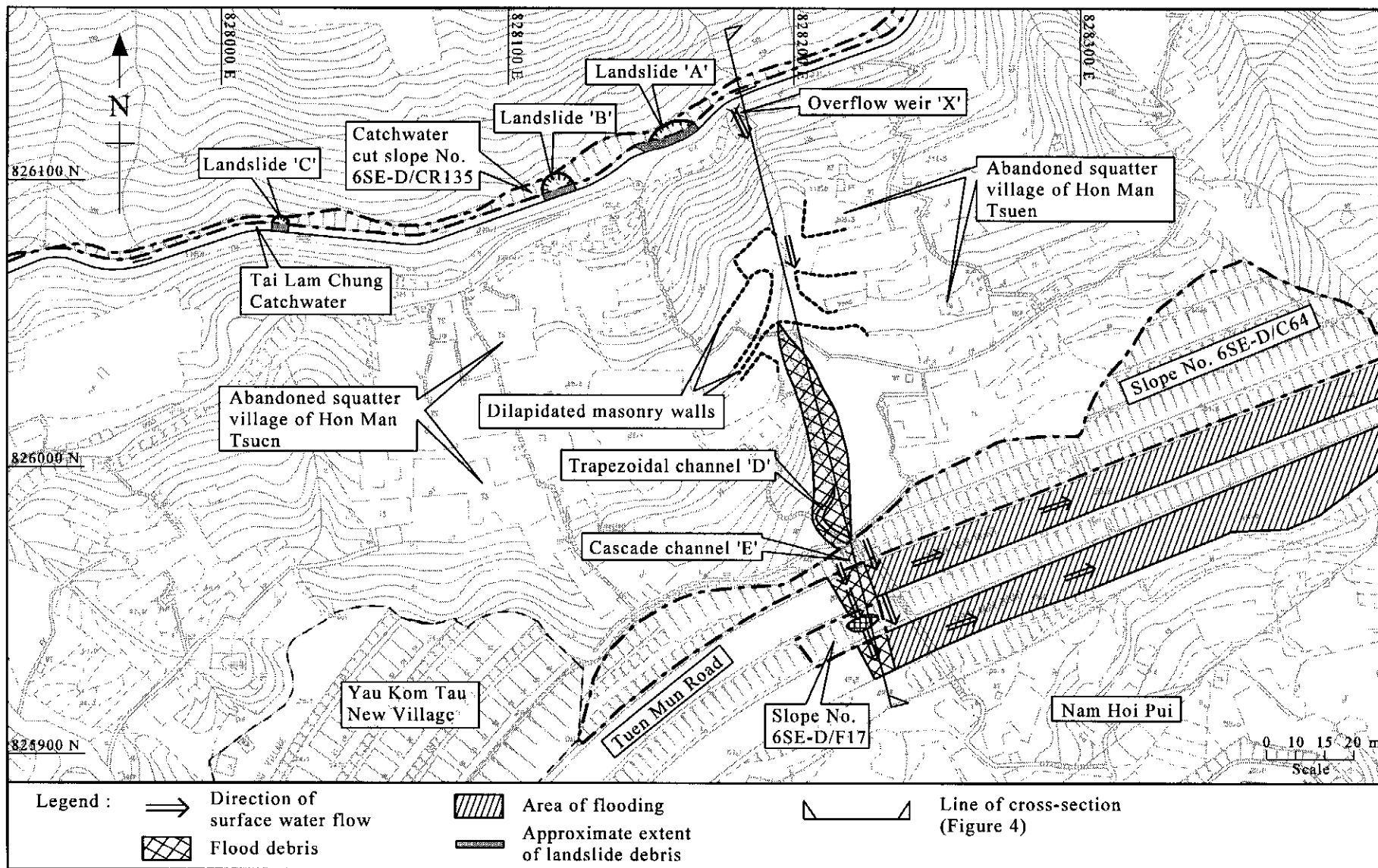


Figure 2 - Site Plan and Incident Details

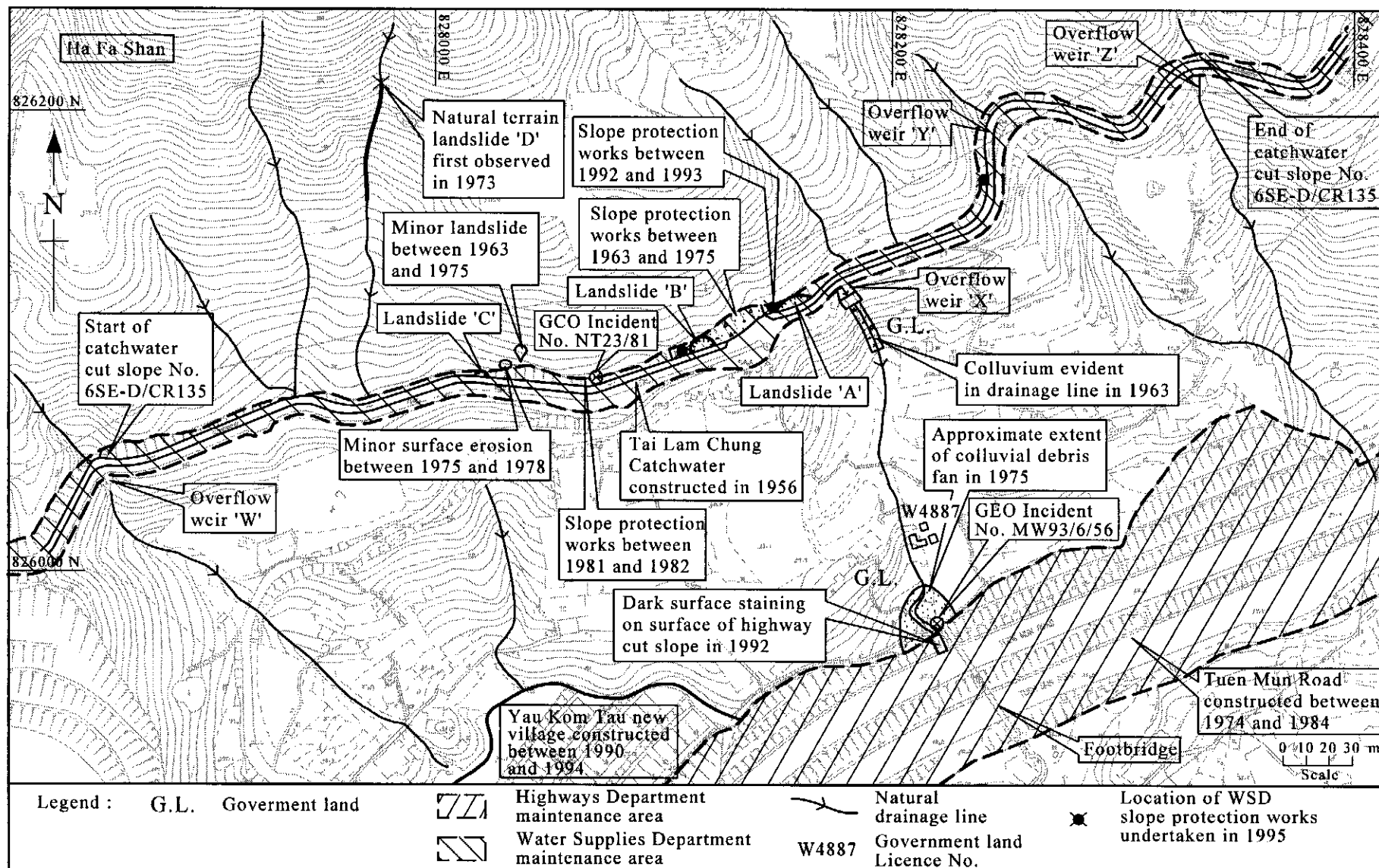


Figure 3 - Site History and Land Status

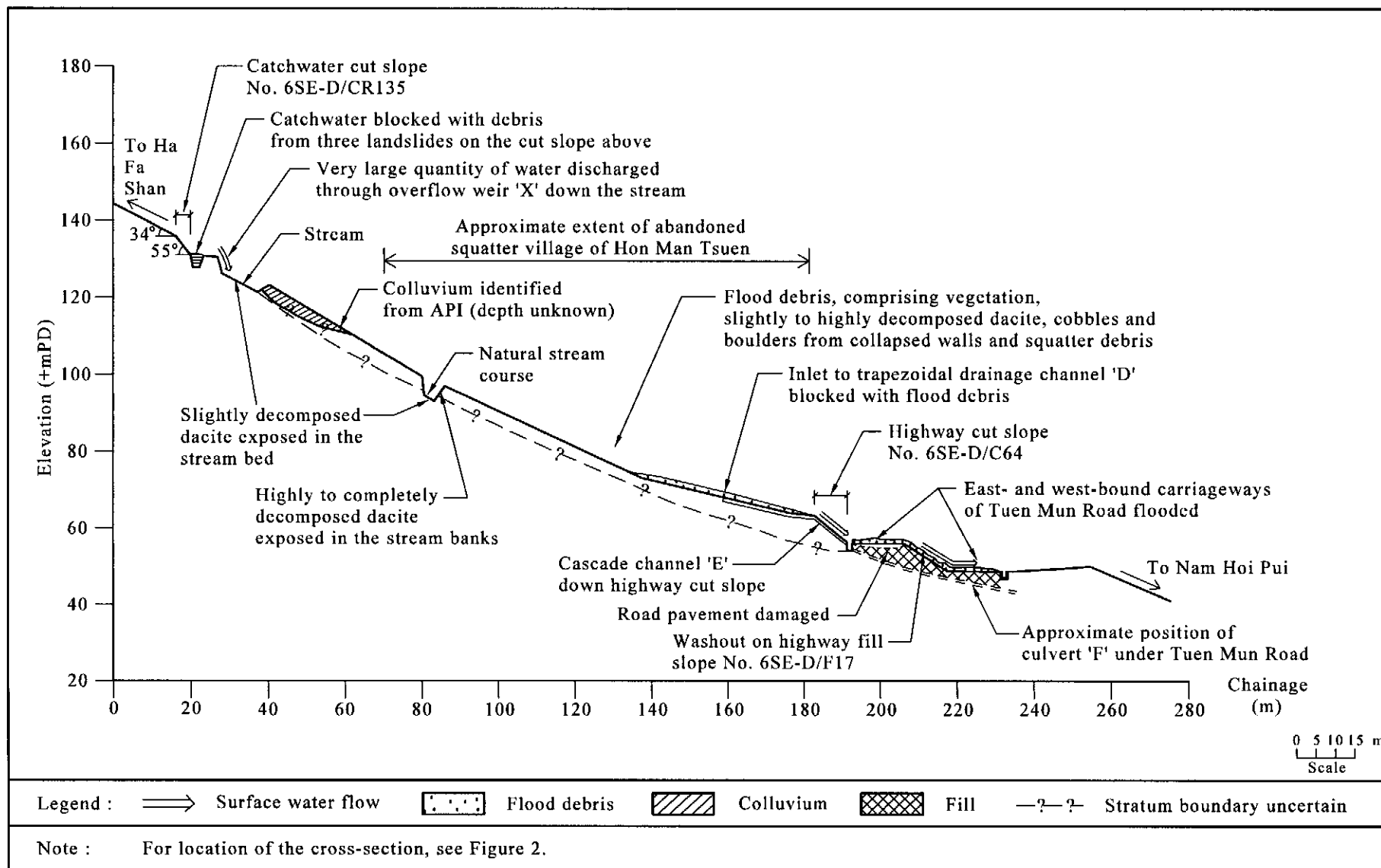
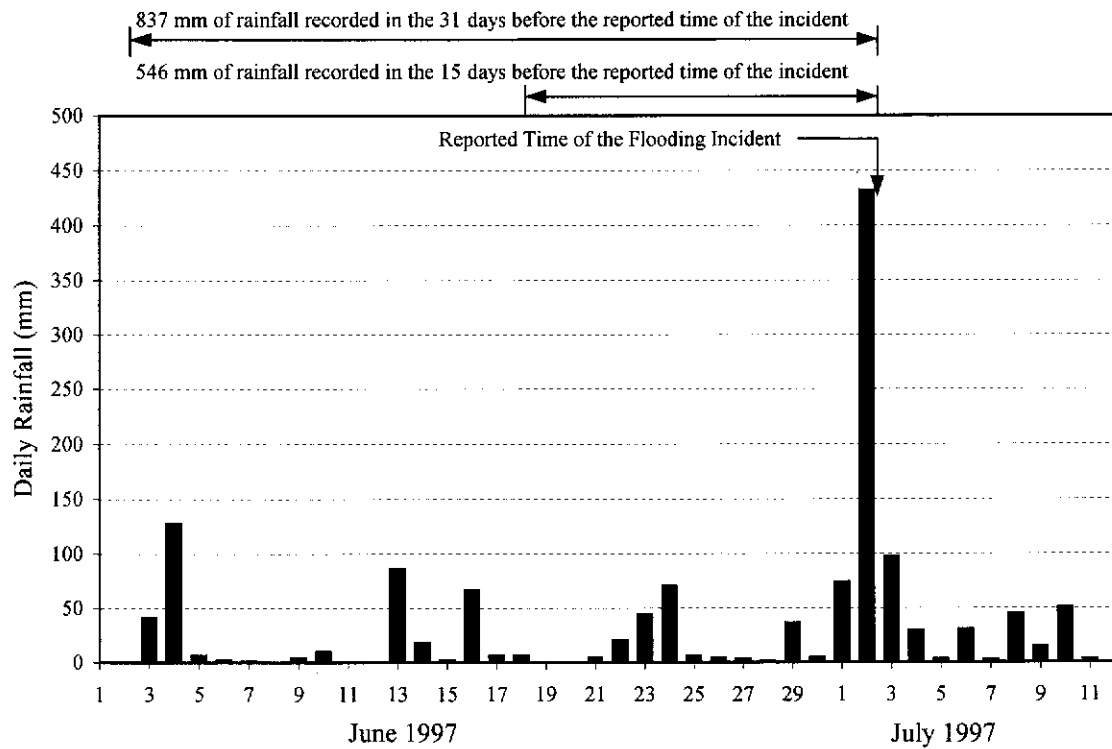
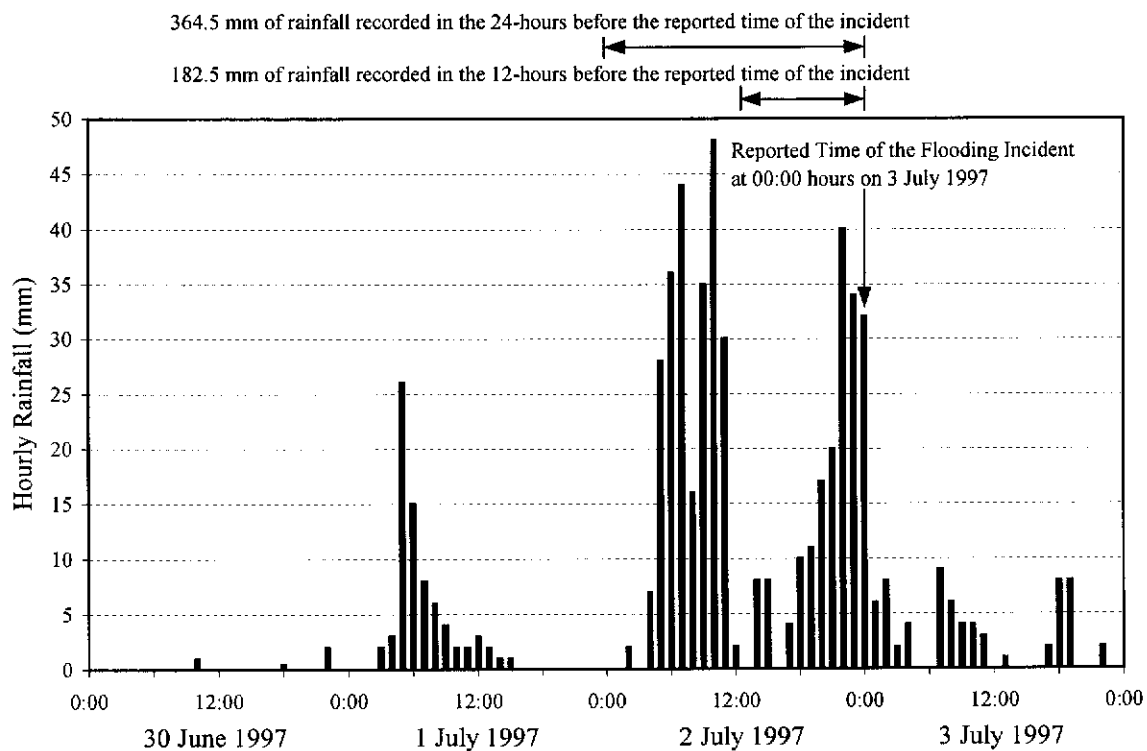


Figure 4 - Geological Cross-section



(a) Daily Rainfall Recorded between 1 June and 12 July 1997



(b) Hourly Rainfall Recorded between 30 June and 3 July 1997

Figure 5 - Rainfall Records at GEO Raingauge No. N03

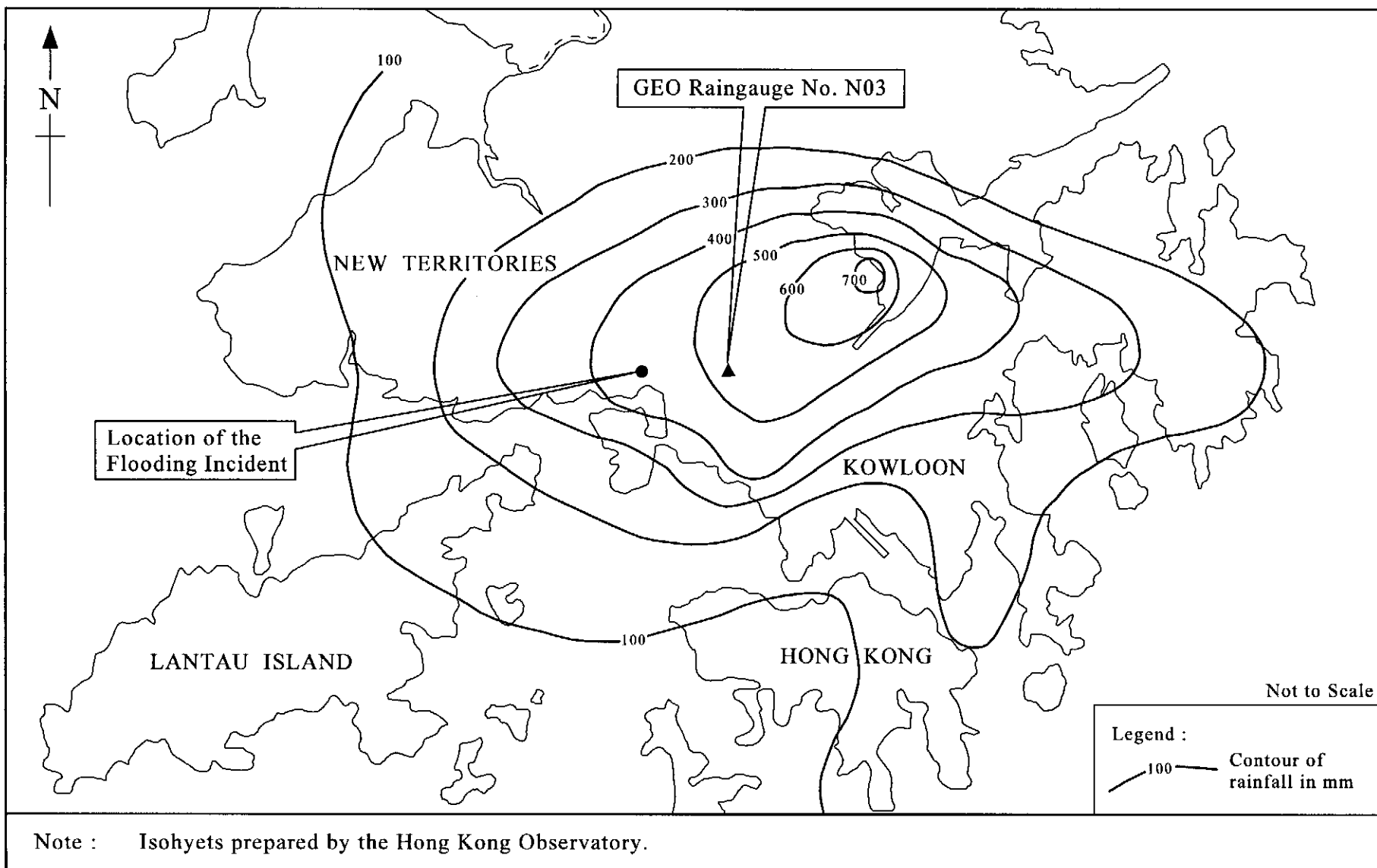


Figure 6 - Isohyets of Rainfall between 00:00 Hours on 2 July and 00:00 Hours on 3 July 1997

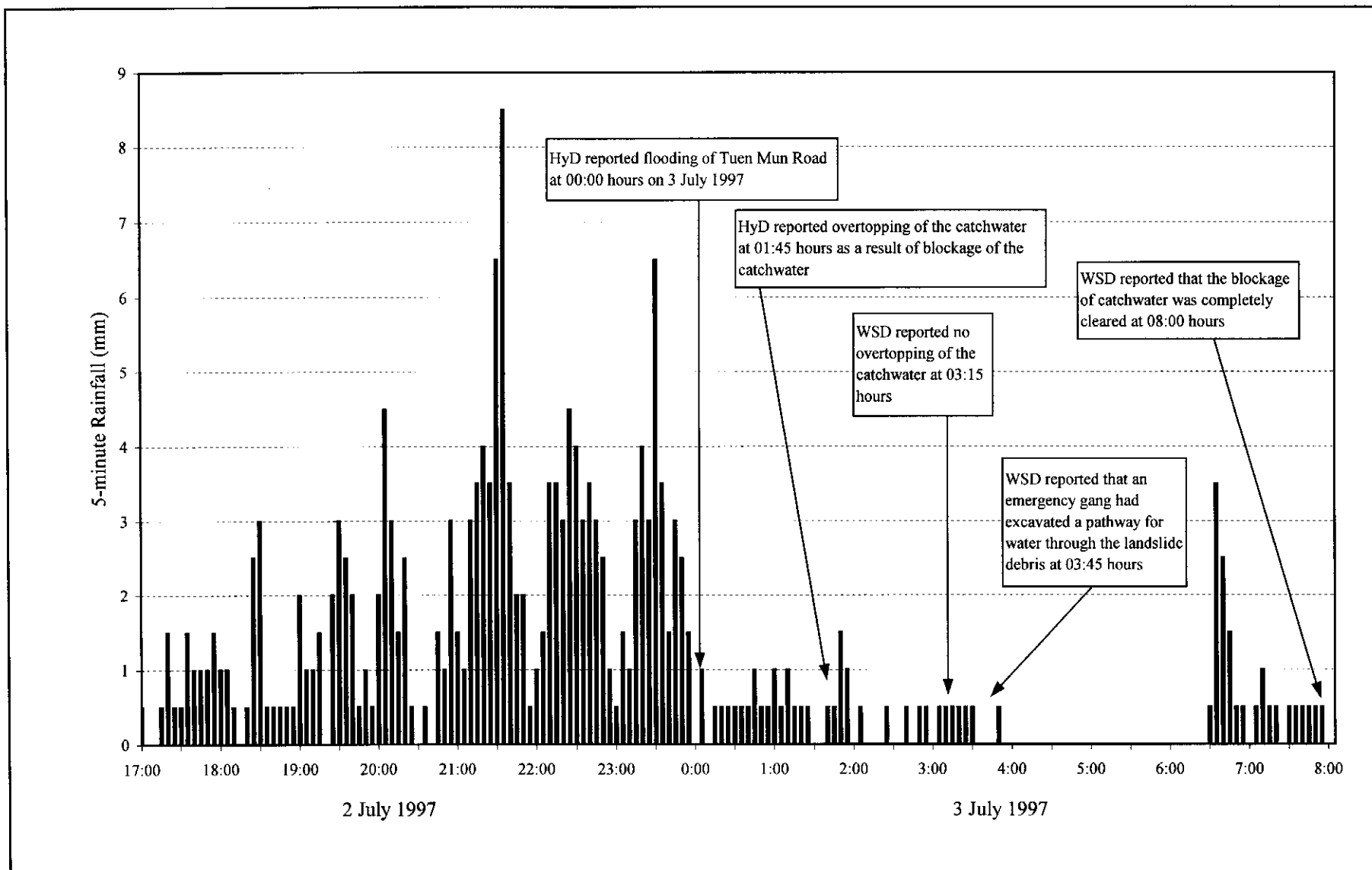


Figure 7 - Rainfall Recorded at GEO Raingauge No. N03 at 5-minute Intervals on 3 July 1997

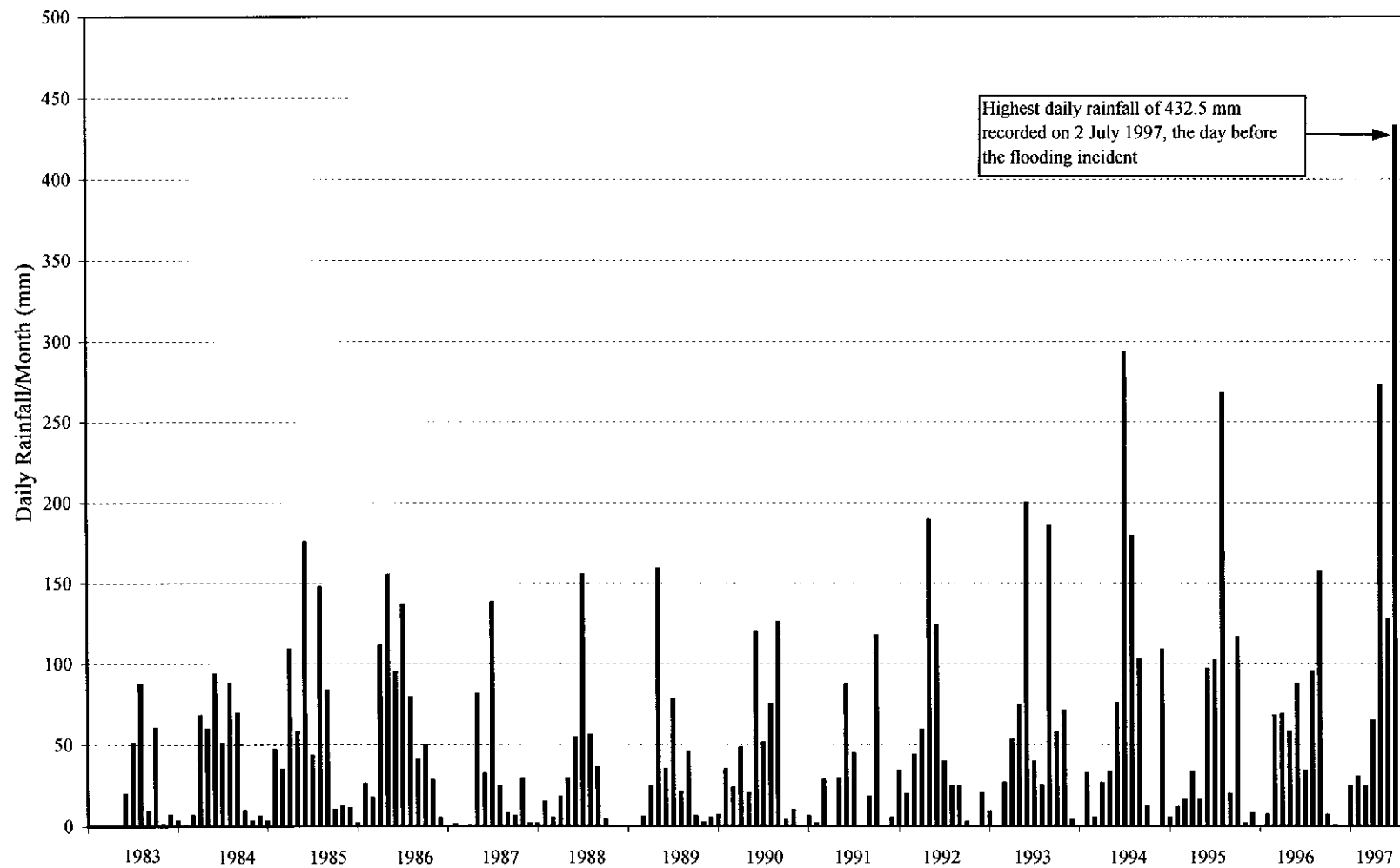


Figure 8 - Maximum Daily Rainfall in Each Month at GEO Raingauge No. N03

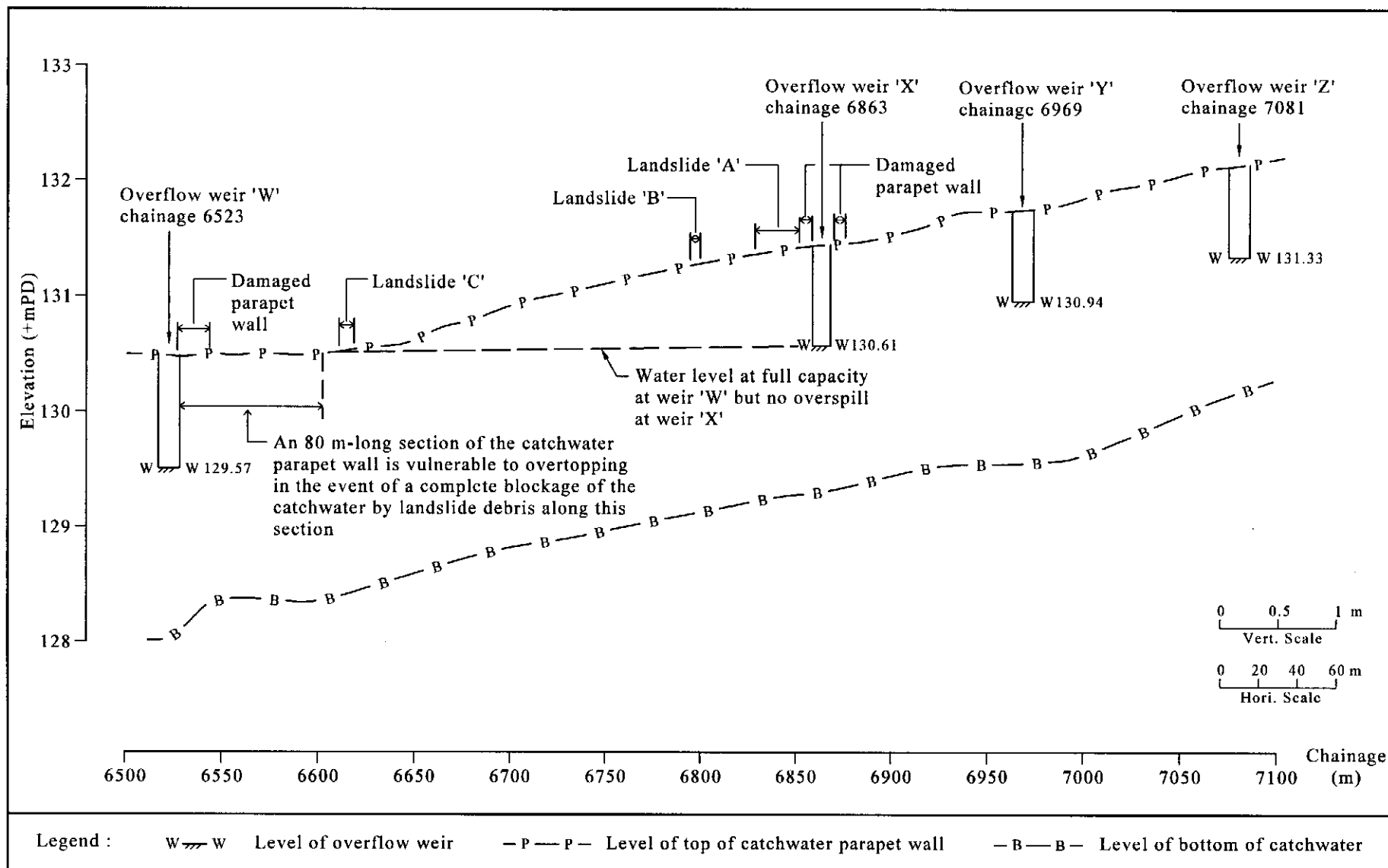


Figure 9 - Interpretation of Level Survey Results along the Tai Lam Chung Catchwater

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Plate 1 - View Showing Overflow Weir 'X' and Landslide 'A' on the Tai Lam Chung Catchwater Cut Slope No. 6SE-D/CR135 (Photograph Taken on 10 July 1997)



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Plate 3 - Landslide 'C' on the Tai Lam Chung Catchwater Cut Slope No. 6SE-D/CR135 (Photograph Taken on 7 August 1997)



Plate 4 - View Down the Stream from Overflow Weir 'X' on the Tai Lam Chung Catchwater (Photograph Taken on 10 July 1997)



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Plate 6 - Erosion of Banks of the Stream (Photograph Taken on 10 July 1997)



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Plate 8 - Trapezoidal Drainage Channel 'D' Completely Blocked with Flood Debris (Photograph Taken on 4 July 1997)



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