SECTION 2 : DETAILED STUDY OF THE LANDSLIDE BELOW AU TAU VILLAGE ROAD, TSEUNG KWAN O ON 9 JUNE 1998

Fugro Scott Wilson Joint Venture

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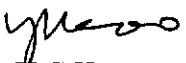
FOREWORD

This report presents the findings of a detailed study of a landslide (GEO Incident No. ME 98/6/10) which occurred on 9 June 1998 in a fill slope below Au Tau Village Road, near Tsui Lam Estate at Tsueng Kwan O. Debris from the landslide was deposited on the natural hillside below, extending almost to the crest of rock cut slopes adjacent to Tsui Lam Estate at one location. No fatalities or injuries were reported.

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 comprised site reconnaissance, inspection of buried services, 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), 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 I Muir 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

In the early afternoon of 9 June 1998, a landslide (GEO Incident No. ME 98/6/10) occurred in slope No. 11NE-D/F284 located below Au Tau Village Road, near Tsui Lam Estate at Tseung Kwan O during a rainstorm (Figure 1 and Plate 1). Debris from the landslide was deposited on the natural hillside below, and at one location extended almost to the crest of the rock slopes above Tsui Lam Estate, about 80 m to the east. Au Tau Village Road as well as the open space at the toe of the rock slopes were closed to the public following the landslide. No fatalities or injuries were reported as a result of the landslide.

Following the landslide, Fugro Scott Wilson Joint Venture (FSW, 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 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 comprised site reconnaissance, inspection of buried services, 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) a review of relevant documents relating to the history of the site,

(b) detailed observations and measurements at the landslide site,

(c) limited ground investigation and laboratory testing,

(d) analysis of rainfall records,

(e) engineering analysis of the slope, and

(f) diagnosis of the probable causes of the landslide.

2. THE SITE

2.1 Site Description

Slope No. 11NE-D/F284 is located on the eastern side of Au Tau Village Road at Tseung Kwan O (Figure 1 and Plate 1), approximately 140 m north of the intersection with Tsui Lam Road.

The general landform in this area consists of a series of north-easterly trending spurs and valleys, which form part of the foothills of Tai Sheung Tok, located approximately 800 m to the west.

The natural terrain falls away towards Tsui Lam Estate to the east at angles of between 20° and 30°. The estate platform cuts into the hillside at an elevation of around 60 mPD, with slopes No. 11NE-D/C194 and No. 11NE-D/C241 along its western perimeter being up to 30 m to 35 m in height. The crest line of these slopes lies about 80 m east of the fill slope that was involved in the failure.

Au Tau Village Road above slope No. 11NE-D/F284 roughly follows the 130 mPD contour around the hillside and turns through approximately 90° (north to west) around a spur at the location of the fill slope. Approximately 40 m west of the feature, the road again turns through 90° (west to north) and crosses two natural stream courses, one at the location of the bend (stream course "A") and a second approximately 120 m to the north (stream course "B"), as indicated on Figure 1. Locally, the road has been formed predominantly in cut, resulting in small, steep roadside slopes with face angles up to approximately 60° on the western side of the carriageway. The natural hillside below slope No. 11NE-D/F284 trends towards the east and north-east at angles of between 20° and 30°. Isolated fill slopes are located on the eastern side of the carriageway, most notably at the landslide site, where the road has been widened to form an apron (Figure 1) on the apex of the bend.

The road construction comprises a flexible pavement within concrete edge beams, which are flush with the pavement surface. The apron immediately above the failed slope is paved with concrete. Road drainage is generally absent.

Based on the remaining intact portions of the fill slope and measurements taken at the site, slope No. 11NE-D/F284 is estimated to have a maximum height of 8 m to 10 m with a slope angle of around 35°. No trace of surface or sub-surface drainage provision has been located. The slope was covered by vegetation prior to failure. A photograph of the fill slope taken in 1996 is shown in Plate 2.

2.2 Geology

Sheet 11 of the Hong Kong Geological Survey 1:20 000 scale map series HGM20 (GCO 1986) indicates that the solid geology of the landslide site and its surroundings is fine ash vitric tuff from the Ap Lei Chau Formation of the Repulse Bay Volcanic Group (Figure 2).

2.3 Water-carrying Services and Utilities

The locations of existing services in the vicinity of the landslide site are shown in Figure 3, and are based on Government Departments Utilities Plans and site observations by FSW.

Water-carrying services comprise a 400 mm diameter ductile iron pressurised freshwater main installed by the Water Supplies Department (WSD) between 1977 and 1984 (subsequently exposed in the main scarp of the landslide approximately 1.5 m below ground surface) and a 450 mm diameter pressurised freshwater main of similar construction commissioned in 1993 as part of WSD Contract No. 27/WSD/90 "Improvement to Tseung

Kwan O Mainland (South) Water Supply System" works. The nominal pressure in the water mains, as advised by WSD, is of the order of 300 kPa.

A WSD tunnel constructed in the late 1980's is located approximately 90 m to the south-west of the landslide site, oriented on a north-west/south-east axis. The tunnel invert is at about 100 mPD over the majority of its length.

An overhead electricity power line traversed the landslide site prior to the failure, with a timber pole located near the slope crest. The power line was re-located after the landslide. The original and present alignments of the power line are indicated on Figure 3.

2.4 Maintenance Responsibility

According to the consultant engaged by the Lands Department (LD) on the "Systematic Identification of Maintenance Responsibility of Registered Slopes in the Territory" (SIMAR) project, slope No. 11NE-D/F284 is under the maintenance responsibility of LD.

3. SITE HISTORY AND PREVIOUS STUDIES

3.1 General

The development history of the landslide site and details of previous studies carried out on slope No. 11NE-D/F284 have been compiled through a review of documentation held by various Government Departments and aerial photograph interpretation (API). Details of observations from aerial photographs are given in Appendix A.

3.2 Site History

The main observations in relation to the history of the landslide site from 1984 to 1993 are summarised in Figure 4. Aerial photographs from 1973 indicate natural hillside in and around the landslide site, which is traversed by a narrow footpath following the present alignment of Au Tau Village Road. The 1976 aerial photographs indicate the completed road formation predominantly in cut and generally following the natural contours. The spur landform near the landslide site results in a left-hand bend (north to west) in the road, which was unpaved.

Dumping of fill onto the downhill side of the road is visible on the apex of the road bend in the 1976 aerial photographs. Further dumping on or near the area is visible in the 1977, 1984, 1986, 1988, 1989, 1990 and 1991 aerial photographs. Dumping of fill is also observed at other locations along the road during this time. The result of dumping of fill at the apex was the gradual formation of a platform at the present location of the concreted apron, with a fill body below.

The 1984 aerial photographs indicate a manhole (subsequently identified on site as a valve chamber) and a pipeline extending north which is consistent with the 400 mm diameter

ductile iron water main installed between 1977 and 1984 (Section 2.3).

Upgrading of Au Tau Village Road was carried out between 1986 and 1988 under NTDD Contract 2/5B/82 "Junk Bay Development: Road Improvement and Formation of Platforms, Roads and Reclamation". Road widening by cutting into the uphill slope near the landslide site is visible on the 1986 and 1987 aerial photographs and is complete in the 1988 aerial photographs. An overhead power line is first visible on the 1988 aerial photographs with a pole installed east of the valve chamber.

Little change is noted between the 1989 and 1991 records, except for further dumping of fill as noted previously. Ponding of surface water on the road immediately south of the landslide site, which is visible in the 1989 and October 1990 aerial photographs, is no longer visible in November 1990 photographs.

Works associated with the installation of the 450 mm diameter ductile iron water main (Section 2.3) are visible on the 1991 and 1992 aerial photographs. The works comprised formation of an access road on the slope to the north of the present apron area and the excavation of an open trench down the slope to the north of the apron area and east of the access road. The fill platform at the present location of the apron is observed to have been altered by these works largely to its present geometry. A drainage structure at the present location of the catchpit opposite the apron area is first visible on the 1992 aerial photographs. In addition, what appears to be an outlet structure on the eastern side of the road opposite the catchpit is visible.

The apron area has been concreted in the 1993 aerial photographs (Figure 4). The access road and portion of the slope affected by the water main installation works gradually become re-vegetated over the ensuing years. An overhead electricity line (Figure 3) is visible in the 1994 aerial photographs, with a pole installed on slope No. 11NE-D/F284, immediately south of the valve chamber.

There is little change to the landslide site indicated by aerial photographs from 1994 through to 1997. Re-surfacing of Au Tau Village Road with asphalt to the south of the landslide site is visible in the 1996 aerial photographs.

Au Tau Village Road was re-constructed in early 1998 under the Home Affairs Department (HAD) Contract SK 34/97-98: "Improvement to Van Track at Au Tau Village, Hang Hau". The works included a flexible pavement overlay to the existing pavement, with concrete edge beams (HAD, 1997).

The available information indicates that slope No. 11NE-D/F284 was formed by the accumulation of illegally dumped fill on the hillside below the Au Tau Village Road. The fill received some profiling during earthworks associated with installation of the 450 mm diameter water main in the early 1990's, which resulted in a levelled area adjacent to the road. This was subsequently concreted to form an apron area. The portion of the fill slope (which was formed by dumping between 1976 and 1991) involved in the 1998 landslide has not been substantially modified since formation.

3.3 Previous Studies

Slope No. 11NE-D/F284 was not registered in the 1977/78 Catalogue of Slopes.

There is no record in the GEO files regarding the installation of the 400 mm diameter water main between 1977 and 1984.

In September 1989, details of a proposed water supply scheme, entitled "Improvement to Junk Bay Hinterland (South) Water Supply System – Mainlaying Stage I" (Contract No. 27/WSD/90), were issued by WSD to potential interested parties for comment. The project included the laying of a 450 mm diameter freshwater main in Junk Bay (Tseung Kwan O) starting from an existing reservoir in Ma Yau Tong to a proposed reservoir near Clear Water Bay Road, Tai Po Tsai.

The Geotechnical Control Office (GCO, re-named GEO in 1991) responded to WSD by noting that two sections of the proposed 450 mm water main encroached upon the boundaries of "major fill slopes supporting the roads". One of the slopes included the fill body that was subsequently registered as slope No. 11NE-D/F284. At this location, the water main alignment extended north along Au Tau Village Road, crossing the carriageway at the left-hand bend and extending across the fill slope from crest to toe and continuing in a northerly direction. The subsequent works associated with installation of the water main, as described below, substantially altered the fill body to the north of the apron area. Slope No. 11NE-D/F284 includes the portion of the fill body to the east of the area affected by the water main installation.

The GCO inspected three fill bodies incorporating slope Nos. 11NE-D/F284, 11NE-D/F382 and 11NE-D/F383 (Figure 1) on 29 November 1990, in response to a request from DLO (Sai Kung) to advise on the stability of illegally dumped fill slopes adjacent to Au Tau Village Road. GCO subsequently noted that the fill slopes were up to 3 m in height, at a maximum angle of 40^{o} and were composed of building debris. However, as the slopes were "remote from any lodgings and partially covered with vegetation" GCO considered that there was "no cause for public safety concern at this stage".

In respect of the 450 mm water main installation, the GCO noted that if it was not possible to divert the route of the water main away from the fill slope, then the provision of a leakage collection system should be provided over the lengths of pipework located within fill. The system subsequently proposed by WSD comprised two 100 mm diameter perforated PVC pipes laid within no fines concrete bedding material beneath and to each side of the water main.

The WSD also proposed that the water main should be laid on "solid virgin ground", thus necessitating the excavation and trimming of a substantial portion of the dumped fill as noted above. The excavation details included the cutting of an open trench within the fill from crest to toe with side slopes at 20^{o}. Following installation of the water main, these slopes were to form the sides of a permanent trapezoidal drainage channel overlying the water main, with a 200 mm stepped channel in the base (above and to one side of the main) providing discharge to runoff from the side slopes (Figure 3). These works were completed in early 1993. A section through the western side of the trapezoidal channel from this time shows the side slope cut at 22^{o} in completely decomposed volcanics (CDV), which suggests that the fill

had been completely removed along this side of the channel. A temporary access road to the slope below was formed adjacent to the western edge of the channel. A trimmed fill slope, referred to in correspondence as the "cut fill slope" (i.e. the remaining part of the original body of fill), was located between this access road and Au Tau Village Road to the west. This would now appear to comprise the eastern portion of the slope No. 11NE-D/F425 (Figure 1).

The installation works for the section of 450 mm water main running along Au Tau Village Road included some excavation into existing cut slopes. The surface drainage system for the cut slopes comprised crest channels to intercept surface runoff from the hillside above and divert it to pipes traversing the road and discharging downslope, and isolated lengths of toe channels discharging in a similar manner. Discharge onto the hillside below the road appears to be largely uncontrolled, with outlets placed well clear of natural drainage features. In the vicinity of the landslide site crest channels discharge into a pipe via a stepped channel and catchpit located immediately south of the left-hand bend in the village road. The pipe traverses the road in a northerly direction, discharging into the stepped channel located in the base of the open trapezoidal channel mentioned above.

Where no drainage channels were proposed by WSD at the toe of the cut slopes (most of the route) the GCO required that the road be "paved and graded to have a cross-fall towards the downslope side". This was initially the situation at the crest of the landslide site with the surface run-off from the road directed onto the fill slope.

Concern was raised by the GCO regarding the stability of the trimmed fill slope west of the trapezoidal channel (the eastern portion of slope No. 11NE-D/F425, as described above) due to the potential overflow of runoff from the road. In response, WSD noted that they would "ensure that no surface run-off from all other (upstream) areas would be allowed to discharge onto" the slope. It is not known whether and how this was complied with. A section through the road to the east of the 450 mm water main (within the boundary of slope No. 11NE-D/F284) indicates crossfall towards the slope crest. It is unclear as to whether the GCO was aware of the full extent of the illegally dumped fill body present in this area.

In 1992, the GEO initiated the consultancy agreement entitled "Systematic Inspection of Features in the Territory" (SIFT) which, inter alia, aimed to identify features not registered in the 1977/78 Catalogue of Slopes and to update information on registered slopes based on studies of aerial photographs and limited site inspection. The portion of the fill body affected by the 450 mm water main installation and extending north from the apron was included in a feature (Figure 1, Note (2)) extending north along the water main alignment, which was assigned class "WC" by SIFT in August 1995, i.e. "Works complete, registerable features may be present". The remaining portion of the fill body, east of the water main (i.e. slope No. 11NE-D/F284), was assigned class "B1", i.e. "formed or substantially modified before 30.6.78 or illegally formed after 30.6.78".

In 1994, the GEO initiated the consultancy agreement entitled "Systematic Identification and Registration of Slopes in the Territory" (SIRST) to update the 1977/78 Catalogue of Slopes and to prepare a New Catalogue of Slopes. The sloping ground east of the 450 mm water main was registered as slope No. 11NE-D/F284 in September 1995. A SIRST inspection carried out on 9 May 1996, indicated that no signs of seepage, distress or previous failure were observed.

3.4 Past Landslides

There are no past failures in the natural terrain in the vicinity of the landslide site recorded in the GEO's Natural Terrain Landslide Inventory (NTLI). This is consistent with the detailed API carried out by FSW.

The GEO Landslide Database indicates no records of past failure at slope No. 11NE-D/F284 and the other fill slopes below the Au Tau Village Road in the vicinity.

4. THE LANDSLIDE

4.1 Description of the Landslide

The landslide affected the full height of the fill slope. The landslide scar is about 8 m to 20 m in width. Landslide debris comprising wet soil, boulders and other assorted rubbish with a volume estimated at about 170 m^3 was deposited in the scar and on the hillside below slope No. 11NE-D/F284.

The maximum depth of the scar occurs at the main scarp, which is of the order of 3 m in height. The southern flank of the scar was near vertical and extended in an easterly direction from the main scarp. The northern flank was less well defined than the right and extended to the north-east. A general view of the landslide is presented in Plate 1. Material exposed in the main scarp comprised various layers of predominantly fine grained fill material, with layering exposed in the southern flank parallel to the slope face which is characteristic of end-tipping .

The travel distance of the landslide debris was generally of the order of 50 m (in plan) beyond the original toe of the fill slope, where the debris was split to form "tongues" by vegetation on the hillside and came to rest. The debris deposited in a relatively thin (less than 0.5 m) layer beyond the original toe of the slope, with only the lower 10 m to 20 m of deposition having a thickness in excess of 1 m. The debris was very wet (unable to walk on without sinking) and comprised a heterogeneous mix of material comprising predominantly sand-sized material with gravel, cobbles, construction debris and other detritus (domestic waste, automotive parts, etc). An eyewitness account (Section 4.3) indicates that the initial debris runout distance increased by 30% in the hours following the landslide. Taking this information at face value, the travel angle of the landslide debris (Wong & Ho, 1996) would initially have been of the order of 26^o, decreasing to a final value of around 23^o (ignoring secondary outwash).

A number of eroded gullies were present in the debris, exposing the original ground surface below. A narrow debris trail extended east beyond the southern-most tongue over a further distance of approximately 20 m to approach the crest of slope No. 11NE-D/C194 adjacent to the Tsui Lam Estate. It is noted that the largest of the eroded gullies is located above this debris trail. The debris runout relative to the slopes above Tsui Lam Estate is shown in Plates 5 and 6.

Based on the results of the post-failure topographic survey of the landslide site, the general topography and profile of the landslide are presented in Figures 5 and 6 respectively.

4.2 Observations Made Prior to the Landslide

The following observations specific to the landslide site and the immediate surrounds are based on accounts from villagers passing the landslide site obtained by FSW.

(a) The portion of the slope that failed had received various quantities of uncontrolled fill, rubbish and other assorted detritus over the preceding years.

(b) Since reconstruction of the road pavement approximately three months prior to the landslide (Section 3.2), the road had tended to direct flow from the two natural stream courses (A and B respectively, Figure 1) along the road alignment towards the south (i.e. towards the landslide site) during heavy rainfall. Prior to reconstruction the road camber was such that overland flow was shed directly back into the stream courses below the road.

4.3 Observations Made Following the Landslide

The landslide was first noted by a resident from Choi Lam House in the Tsui Lam Estate around 13:45 hours on 9 June 1998. The resident reported the landslide to the building management, who in turn contacted the Police and the Hong Kong Housing Authority (HKHA). The HKHA contacted Fugro (Hong Kong) Ltd (FHK) as the 1997-99 Geotechnical Advisory Consultant to the HKHA and requested an emergency geotechnical inspection.

The FHK representatives arrived at the landslide site at approximately 17:40 hours and photographed the landslide scar from Tsui Lam Estate (Plate 3). The photograph indicates a substantial flow of free water issuing from two locations along the main scarp. The quality of the photograph was insufficient to identify the source of the flow as being from within the scarp (i.e. subsurface), or from the crown (i.e. overland flow). FHK's discussion with the resident indicates that the accumulated debris had continued to move downslope in the hours following the landslide, extending the original debris trail by about 30%. A second photograph taken by FHK staff the following morning on 10 June 1998 (Plate 4) indicates a much-reduced flow of water emanating from the main scarp, as well as the exposed pipework at this location. Rainfall had ceased by this time.

The GEO and Highways Department (HyD) inspected the site at around 15:00 hours on 9 June 1998. GEO reported "broken drainage pipes discharging onto slope" and that the "capacity of the surface drainage system was inadequate". They did not recall overland flow onto the landslide scar during subsequent discussion with FSW. The GEO recommended closure of Au Tau Village Road and the playground at the toe of slope No. 11NE-D/C194 adjacent to Choi Lam House.

FSW staff first inspected the site in the afternoon of 10 June 1998. The pertinent observations from this inspection are as presented below.

(a) The main scarp and southern flank of the landslide indicated layering parallel to the slope face (Plates 7 and 8). The pipelines

exposed in the main scarp comprised an intact 400 mm diameter ductile iron water main extending north from a concrete valve chamber and a 150 mm diameter PVC pipe aligned parallel and close to the water main which also extended north from the valve chamber. No leakage from the 400 mm water main was observed. A concrete thrust block was exposed in the scarp approximately 3 m north of the valve chamber, through which both pipelines passed (Figure 7).

(b) The PVC pipe, where exposed, comprised a series of 2 m to 3 m long sections placed end to end (i.e. no joints) from which water was continuing to flow at the gaps between individual sections of the pipe (Plate 7). The heaviest flow was occurring from the gap nearest the valve chamber, with the through-flow at this location causing leakage at the next gap to the north.

(c) Heavy scouring had occurred beneath the pipelines at the locations of the gaps in the PVC pipe. The locations of the gaps are consistent with the main flow of water observed to be issuing from the scarp in Plate 3.

(d) The pipelines described in (a) above were also exposed in the northern flank of the landslide scar (Plate 9), extending downslope at less than approximately 1 m below the slope face. The 400 mm water main was intact and the PVC pipe was observed to be broken in the exposure at a location which appears to be consistent with a source of water flow in Plate 3.

(e) The continued flow of water from the gaps of the PVC pipe had exposed insitu material beneath the debris in the scar and along the debris trail (Plates 10 to 12). The insitu material was predominantly fine-grained material.

(f) The narrow debris trail extending beyond the largest of the eroded gullies is shown in Plate 13.

(g) Ponding of surface water on Au Tau Village Road was observed to the south of the concreted apron (Plates 16 to 18), opposite a length of soft verge/slope crest which appeared to have experienced overland flow (Plate 17). Additionally, a fall of the village road from the south towards the apron area was noted (Plate 18).

(h) Overland flow along Au Tau Village Road towards the south and the landslide site was occurring from both of the natural stream courses (Plates 19 to 22 and Figure 8). The catchment area for the two natural stream courses was relatively substantial (Plates 14 and 15). The flow from stream course ‘B’ extended some 60 m along the road before entering stream course 'A' below the road alignment. The flow from stream course 'A' extended

across the road to drain back into the stream course below the road, as well as extending along the road towards the apron area. This flow ultimately fed into a 300 mm U-channel located on the western side of Au Tau Village Road on the apex of the bend and from there into a catchpit south of the apex (Plate 28).

Mapping of the landslide scar and debris runout was carried out on 11 August 1998. Reduction of vegetation over the main scarp afforded a better view of the arrangement of exposed services (Plate 23). Re-growth of vegetation lower on the slope also aided in defining the extent of gully erosion and the original toe-line of the slope (Plate 24).

FSW organised site clearance work in early September 1998 to permit survey works and investigation of certain portions of the landslide site to be undertaken. During these works, the upper portion of the slope formation resulting from the water main installation in 1991-1993 (Sections 3.2 and 3.3) was observed north of the apron. Also of interest was a narrow failure scar located around 10 m south of the south flank of the landslide (Plates 25 to 27 and Figure 9). The scar was of the order of 1 m to 2 m wide and extended some 10 m to 15 m downslope. The scar had been heavily vegetated prior to clearance, indicating that it was a pre-existing feature. The geometry of the scar near the road level was complicated by a random assortment of concrete slabs which had been (apparently recently) undermined (Plate 27), exposing layers of fill beneath.

Arrangements were made with WSD to remove the cover of the valve chamber exposed in the main scarp, which was carried out on 17 November 1998. The 400 mm water main was observed to have been cast into the chamber floor. The PVC pipe adjacent to the water main was also cast into the floor of the chamber below the chamber invert. Further inspection of the PVC pipe indicated that it was continuous through the structure and extended further to the south.

The WSD advised that "Based on our recent investigation, we trust that the concerned 150 mm diameter UPVC pipes should not be part of our leakage collection system …", given that no Butynol sheeting was found, the pipe size was larger than their standard detail, the pipes were not perforated and no leakage collection system was marked in that location on their mains record plan. The WSD also advised that " …there was no main burst or leak at or in the vicinity of the captioned location for the specified time span [8 to 10 June 1998] based on our office record" and that the water supply to the mains was not turned off following the landslide.

Additional site clearance works were carried out in late November 1998 to establish the discharge point for the catchpit located opposite the landslide scar (Plate 28) and the potential for the road drainage system to introduce water to the landslide site. A concrete structure was subsequently located approximately 5 m downslope to the north of the apron, consistent with WSD details for works associated with the 450 mm water main installation (Section 3.3). A 225 mm diameter pipe outlet was located adjacent to the structure (Plate 29), discharging into a 300 mm stepped U-channel, which extended downslope beyond the extent of site clearance.

4.4 Urgent Repair Works

Urgent repair works recommended by the GEO included removal of debris, trimming of the main scarp and application of a hard surfacing with weepholes to the scar. To facilitate the trimming works in the main scarp, the WSD were requested to re-locate the 400 mm diameter water main exposed by the landslide a distance of 1.5 m back from the edge of the apron. These works were subsequently carried out in late 1998 to early 1999.

4.5 CCTV Survey

A Closed Circuit Television (CCTV) survey was arranged in an attempt to determine the extent of the PVC pipeline south of the landslide site and to confirm the 225 mm pipe outlet located north of the apron (Plate 29) as the discharge point for the catchpit (Section 4.3.2).

The CCTV survey was carried out on 18 December 1998. Details of the survey are reported separately (EGS, 1998). The survey coincided with diversion works for the 400 mm water main exposed in the landslide scar by WSD (Section 4.4). The diversion works involved the excavation of a trench to expose the water main along the full length of the apron area (Plates 30 to 32). A 2 m long section of the PVC pipe, also exposed in the trench, was cut and removed by WSD to provide clearance for the construction of thrust blocks at the diversion location. The granular surround to the 400 mm water main is visible in Plate 31.

The CCTV survey found that the PVC pipe extended upstream to the south by approximately 8 m beyond the extent of the WSD diversion trench and remained beneath the road and within the WSD pipeline trench. Open butt joints between lengths of pipes (as exposed in the main scarp) and major deformation of the pipe were observed. The pipe terminated at a large void underneath the road surrounding the water main. At this point, the survey could not proceed further due to the oblique entry of the pipe into the void preventing further advance. However, it could be seen that the void was of a similar size to the trench excavation (about 1 m wide) for the original 400 mm water main installation (i.e. the granular surround to pipeline was apparently lost). The length of the void could not be determined. The floor of the void appeared to consist of a silty deposit, consistent with a sediment deposited following passage of water. The approximate location of the void is shown in Figure 9.

It is noted that the location of the void is adjacent to the narrow failure scar described earlier (Figure 9), although no direct link between these features can be established. It is not certain how the void was formed. Other significant unknowns are the purpose of the PVC pipe and the source of the water observed flowing from the pipe in the landslide scar.

The CCTV survey confirmed the 225 mm diameter pipe outlet as the discharge point to the catchpit. The pipe was observed to be in a sound structural condition, with some minor movement at the joints. It indicated that runoff entering the catchpit would discharge through the pipe to the outlet and stepped channel, away from the landslide site.

5. SUBSURFACE CONDITIONS

5.1 General

The subsurface conditions within the landslide site have been assessed on the basis of information obtained from the desk study, field mapping and limited post-failure ground investigation.

5.2 Previous Ground Investigations

No previous ground investigation was carried out at the failed slope. The locations of investigation stations from previous investigations in the vicinity of the landslide site and reference information are presented on Figure 3.

5.3 Current Investigation

Field mapping of the landslide was carried out by FSW on 11 August 1998. Logging of the WSD trench associated with the water main diversion was carried out on 18 December 1998. The results of the mapping are presented on Figure 9.

Insitu density tests were carried out in trial pits dug within the remaining portion of the fill slope within a distance of 10 m of the landslide scar. The results of the density tests together with laboratory tests on maximum dry density (Materialab, 1999) are discussed in Section 5.4.1.

5.4 Deduced Conditions

5.4.1 Ground Profile

The ground profile within the landslide site comprises fill overlying colluvium, which in turn overlies an insitu weathering profile of volcanic rock (tuff).

A geological section through the landslide is shown in Figure 6.

Mapping of the back scarp showed that the fill body comprises up to seven heterogeneous layers of fill soils ranging from 0.25 m to 0.85 m in thickness. These layers are variously described as generally firm clay, loose sand, gravel and cobbles and are approximately parallel to the original slope profile. This is consistent with staged, uncontrolled end-tipping of fill (Section 3.2).

The results of the insitu density tests carried out in the fill immediately south of the landslide scar, together with the laboratory compaction tests indicate that the fill is in an extreme loose condition with a relative compaction of about 70%.

The insitu material exposed in the base of the eroded gullies is described as a firm to stiff, silty clay and is classified as debris flow deposits.

5.4.2 Groundwater

Observations made during the 1998 wet season did not locate any signs of seepage on the uphill cut faces of Au Tau Village Road, the landslide scar or the hillside below. It is likely that there is no permanent high groundwater within the fill slope.

6. ANALYSIS OF RAINFALL RECORDS

The nearest GEO automatic raingauge to the landslide is No. N08, which is located at the Staff Quarters of the Pik Uk Correctional Institute, about 1.7 km to the north of the site. The raingauge records and transmits rainfall data at 5-minute intervals via a telephone line to the GEO.

For the purposes of rainfall analysis, it is assumed that the landslide occurred at 13:45 hours on 9 June 1998, based on eyewitness account (Section 4.3).

Daily rainfall for one month preceding, and seven days following the landslide, together with hourly rainfall for 48 hours before and 24 hours following the landslide, are given in Figure 10. The daily rainfall records show that the storm was concentrated around 9 June 1998 (the day of the landslide), with the hourly data indicating intense peaks from 02:45 to 03:45 hours, 04:45 to 08:45 hours and 11:45 to 13:45 hours, generally in the range of 30 mm/hr to 60 mm/hr.

Isohyets of rainfall for the 24-hour period preceding the landslide are given in Figure 11.

Table 1 presents the estimated return period for the maximum rolling rainfall for various durations based on historical rainfall data at the Hong Kong Observatory (Lam & Leung, 1994). The 12-hour maximum rolling rainfall (323 mm) was the most severe with a return period of about 18 years. A comparison of the severity of the June 1998 rainstorm and other historical major rainstorms is presented in Figure 12. This shows that the June 1998 rainstorm was the most severe for durations of between about 2 hours and 24 hours, since installation of the raingauge in the mid-1980's.

7. DIAGNOSIS OF PROBABLE CAUSES OF THE LANDSLIDE

The landslide involved loose fill, which was dumped progressively over the period between 1976 and 1991 with no record of submissions made to the GEO. The close correlation between the severe rainstorm on 9 June 1998 and the reported timing of the landslide suggests that the failure was probably triggered by the severe rainfall.

The failure was quite mobile and involved run out of debris for a considerable distance over relatively gently sloping ground with a fairly low travel angle of about 23^{o} to 26^{o}. Based on the morphology of the debris, together with the very loose nature of the fill (relative compaction about 70%) and the almost complete detachment of the failed material from the main scarp, the failure probably occurred in a sudden and fast-moving manner, involving liquefaction of loose fill.

The postulated failure mechanism involves wetting up of the loose fill body and the possible development of elevated water pressures (which may occur as a perched water table above the interface between the fill and the insitu ground profile below or as a result of downslope seepage flow along interfaces of fill layering), leading to collapse of the metastable structure and liquefaction failure.

Three possible sources of water at the landslide site have been identified:

(a) direct infiltration of rainfall into the unprotected fill slope,

(b) overflow from the road above the crest of the fill slope, and

(c) discharge of water from the open-jointed PVC pipe.

Given the absence of an impermeable cover and the severity of the rainstorm, direct infiltration of rainfall into the slope was likely to be an important source of water at the landslide site.

A notable recent change to the environmental conditions in the vicinity of slope No. 11NE-D/F284 was the reconstruction of the Au Tau Village Road pavement in the months preceding the landslide. A significant effect of the road reconstruction work was the altering of crossfalls which direct overland flow from two natural stream courses to the north of the concerned slope along the road towards the landslide site (Sections 4.2 and 4.3). Substantial ponding of water behind the crest of the slope was observed in the hours following the landslide. Overflow from the crest area directly onto the slope face, which would promote surface erosion and infiltration, could have contributed to water ingress into the fill slope.

The origin and function of the open-jointed PVC pipe are not known. The source of water in the pipe is not exactly known, but it is probably from the uphill area. Discharge of water from the open-jointed pipe was likely to have been a source of water ingress into the fill slope, but the extent of the discharge and its contribution to causing the failure is not certain.

8. CONCLUSIONS

It is concluded that the landslide which occurred on slope No. 11NE-D/F284 below Au Tau Village Road, Tseung Kwan O primarily involved liquefaction of a loose fill slope.

The probable contributory factors of the landslide include the following:

(a) the uncontrolled dumping of fill between 1976 and 1991,

(b) the loose nature of the fill which was susceptible to collapse and liquefaction upon water ingress,

(c) overland flow from the road bend above the crest of the fill slope following recent road reconstruction works which adversely affected the surface water flow regime, and

(d) discharge of water from an open-jointed PVC pipe which was cast into the floor of the valve chamber for the WSD 400 mm diameter water main.

9. REFERENCES

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Geotechnical Control Office (1986). Hong Kong & Kowloon: Solid and Superficial Geology. Hong Kong Geological Survey, Map Series HGM 20, Sheet No. 11, 1:20 000 scale. Geotechnical Control Office, Hong Kong.

Home Affairs Department (1997). Contract SK 34/97-98, Improvement to Van Track at Au Tau Village, Hang Hau, construction Drawing No. SKW 1061 Site Plan, Sections and Details, November 1997.

Lam, C.C. & Leung, Y.K. (1994). Extreme Rainfall Statistics and Design Rainstorm Profiles at Selected Locations in Hong Kong. Royal Observatory Technical Note No. 86, 89 p.

Materialab (1999) Test Report No. 981207 SL90779. Materialab Ltd, Hong Kong. 4 p.

Wong, H.N. & Ho, K.K.S. (1996). Travel distance of landslide debris. Proceedings of the Seventh International Symposium on Landslides, Trondheim, Norway, vol. 1, pp 417 – 422.

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Table 1 - Maximum Rolling Rainfall at GEO Raingauge No. N08 for Selected Durations Preceding the 9 June 1998 Landslide and the Estimated Return Periods

Duration	**Maximum Rolling Rainfall (mm)**	**End of Period**	**Estimated Return Period (Years)**
5 Minutes	10	06:10 on 9 June 1998	2
15 Minutes	21	03:15 on 9 June 1998	1
1 Hour	61	06:45 on 9 June 1998	2
2 Hours	117	07:25 on 9 June 1998	5
4 Hours	173	08:40 on 9 June 1998	7
12 Hours	323	13:45 on 9 June 1998	18
24 Hours	365	13:45 on 9 June 1998	8
48 Hours	377	13:45 on 9 June 1998	5
4 Days	425	13:45 on 9 June 1998	5
7 Days	503	13:45 on 9 June 1998	5
15 Days	586	13:45 on 9 June 1998	4
31 Days	911	13:45 on 9 June 1998	8

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 data for longer 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.

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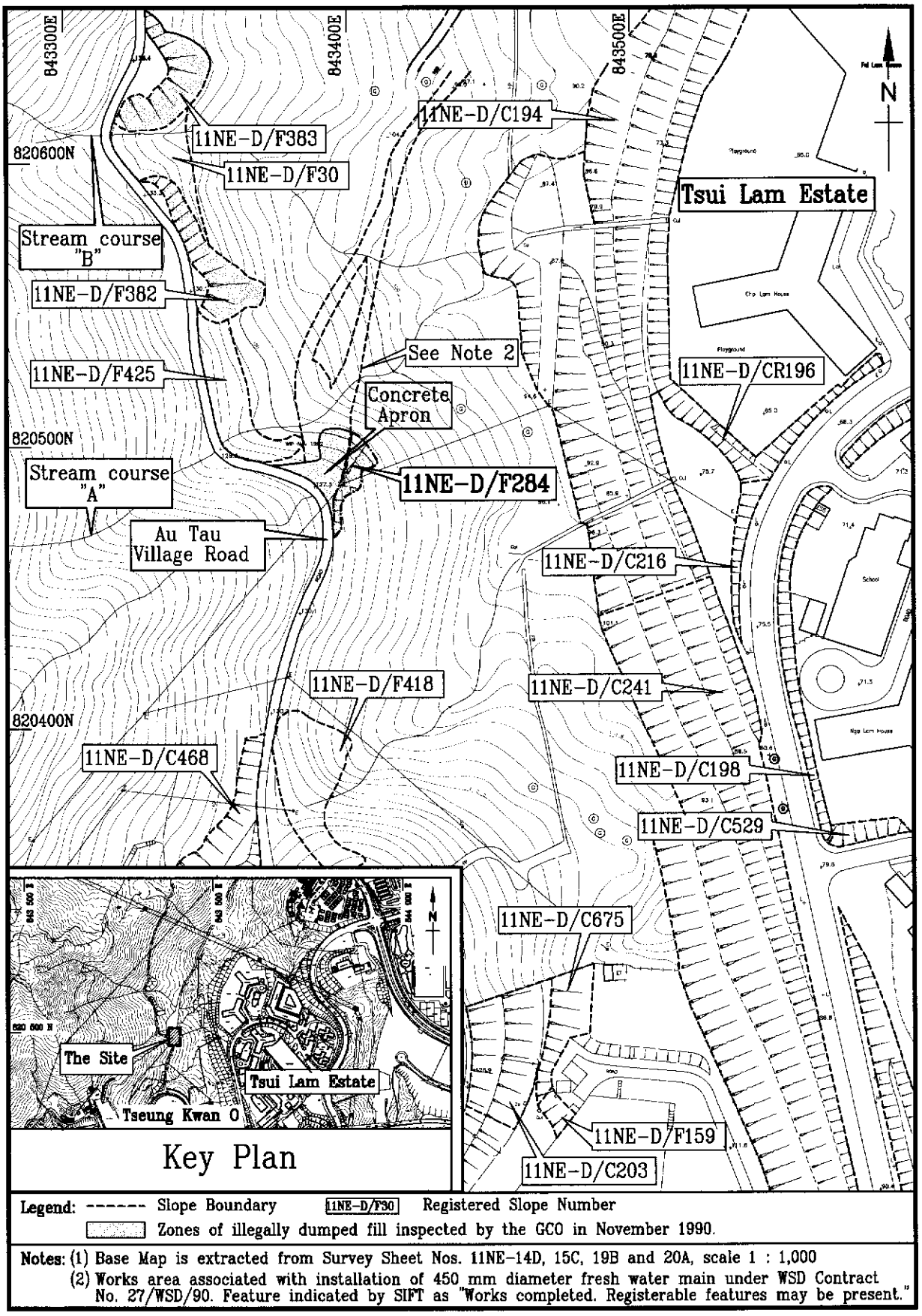
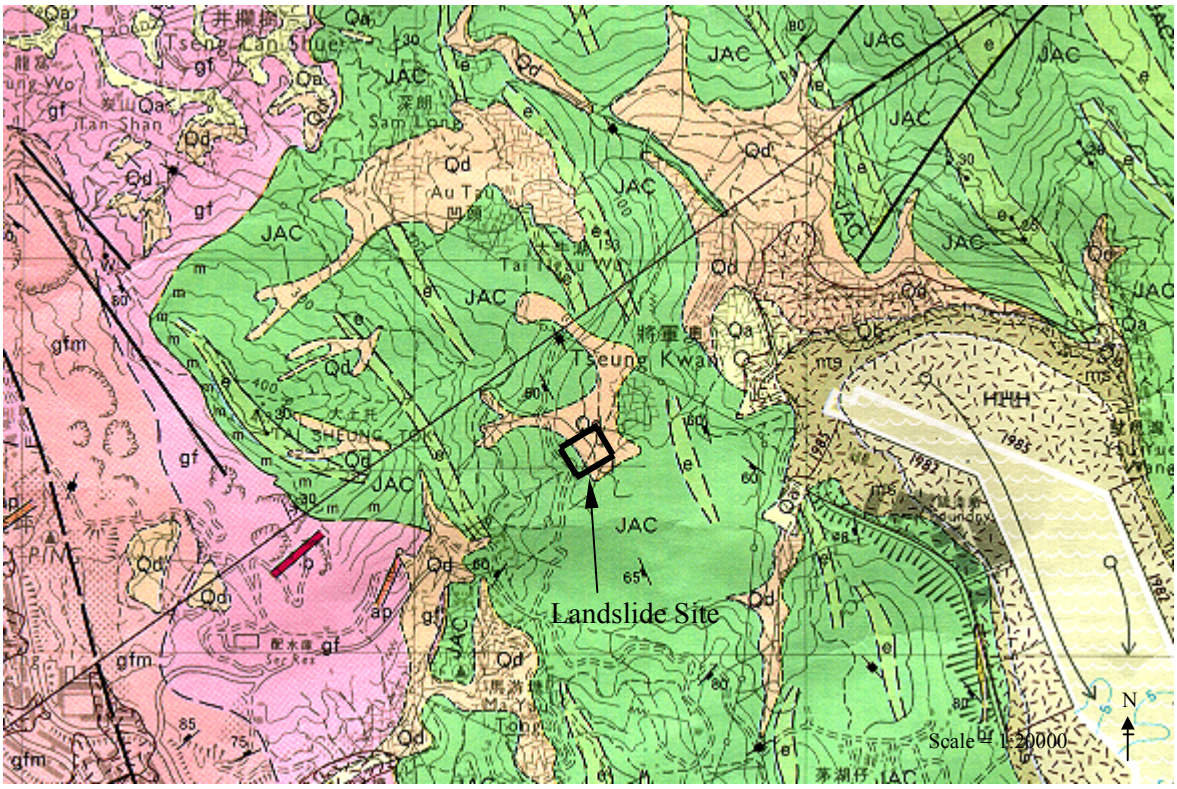


Figure 1 - Site Location Plan



Legend:

Quaternary Superficial Depoits (Onshore)

- Fill; sanitary fill (Qfs) – Natural earth and waste
- Qa — Alluvium – Clay/silt, sand and gravel; well-sorted to semi-sorted
- Qd — Debris Flow Deposits – Unsorted sand, gravel, cobbles and boulders; clay/silt matrix

Solid Geology

- JAC — Fine ash vitric tuff
- e — Eutaxite
- gf — Fine-grained granite
- gfm — Fine- to medium-grained granite
- b — Basalt
- ap — Aplite
- m m m — Hornfels

Quaternary Superficial Deposits (Offshore)

- HHH — Undivided, mainly dark grey marine mud
- ms — Marine sand, partly silty

Geological Lines

- Geological Boundary, Superficial Deposits
- Geological Boundary, Solid Rock
- Faults (crossmark indicates downthrow side)
- Photogeological Lineament
- * Broken lines on map face denote uncertainty

Notes: (1) Geology relevant to study area shown bold.
(2) Extract from Sheet 11 of the Hong Kong Geological Survey 1:20,000 Scale Map Series HGM20 (GCO, 1986)

Figure 2 - Solid and Superficial Geology of the Landslide Site

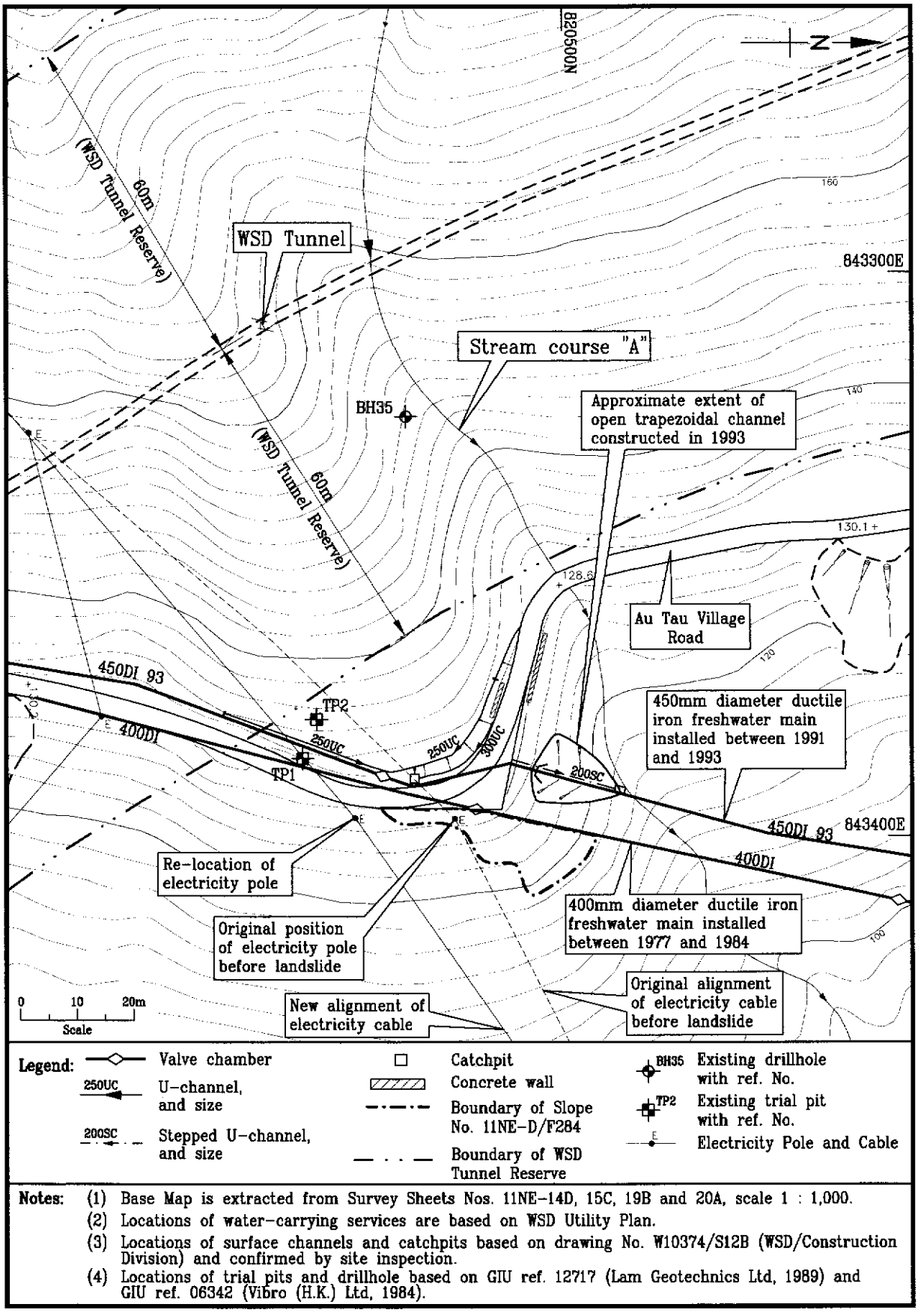
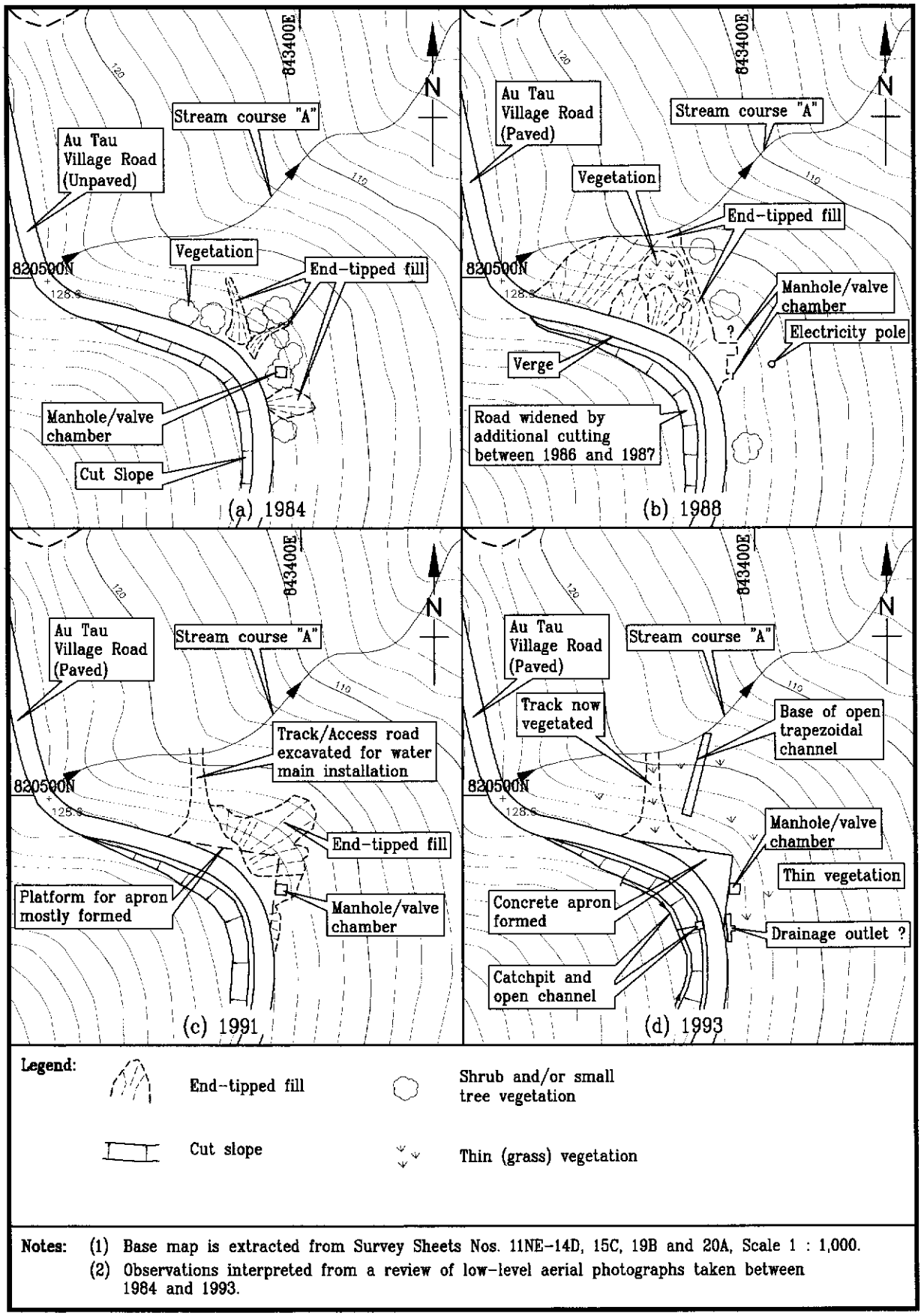


Figure 3 - Existing Services and Ground Investigation Stations



Notes: (1) Base map is extracted from Survey Sheets Nos. 11NE-14D, 15C, 19B and 20A, Scale 1 : 1,000.
(2) Observations interpreted from a review of low-level aerial photographs taken between 1984 and 1993.

Figure 4 - Site History

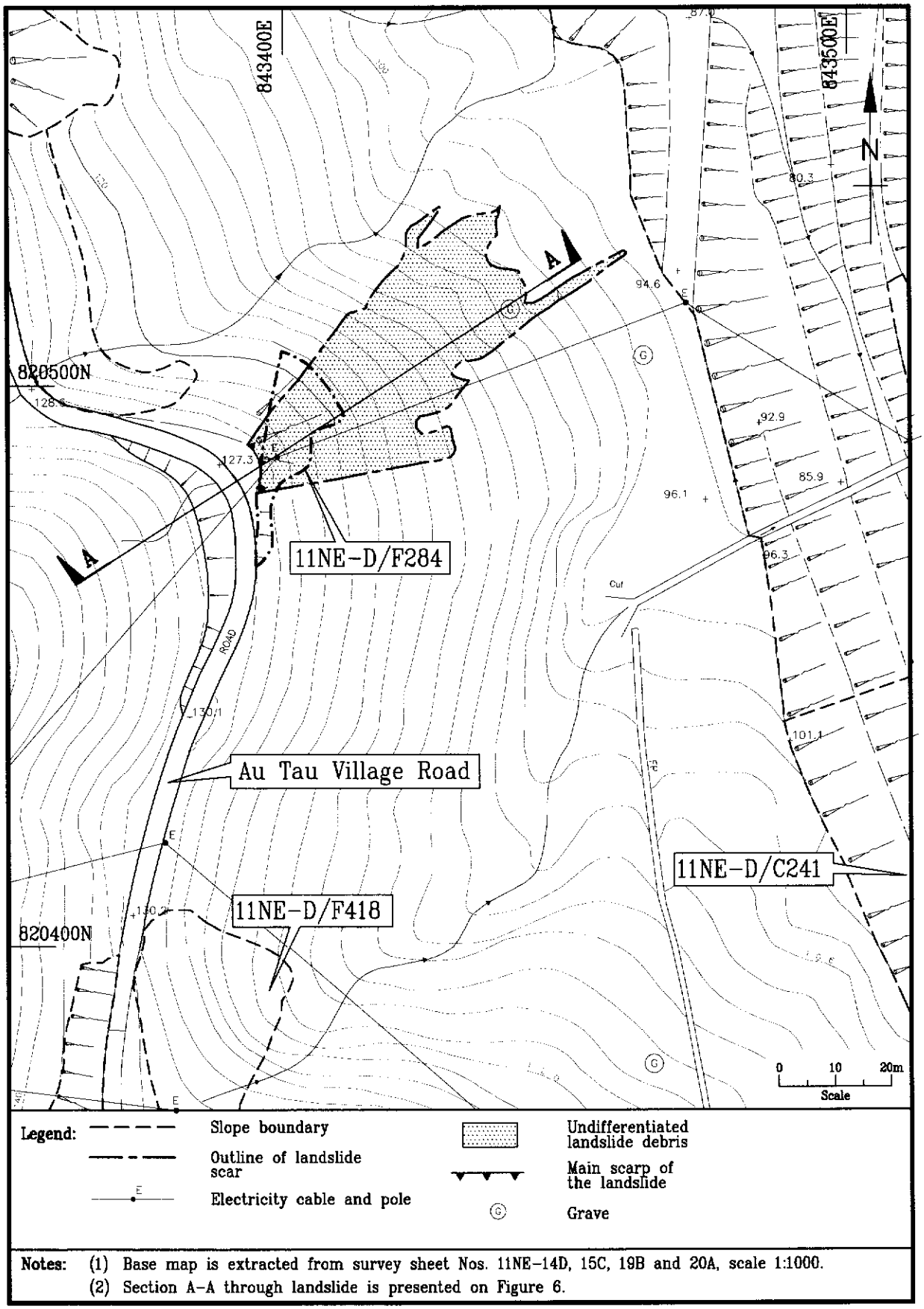


Figure 5 - Plan View of the Landslide

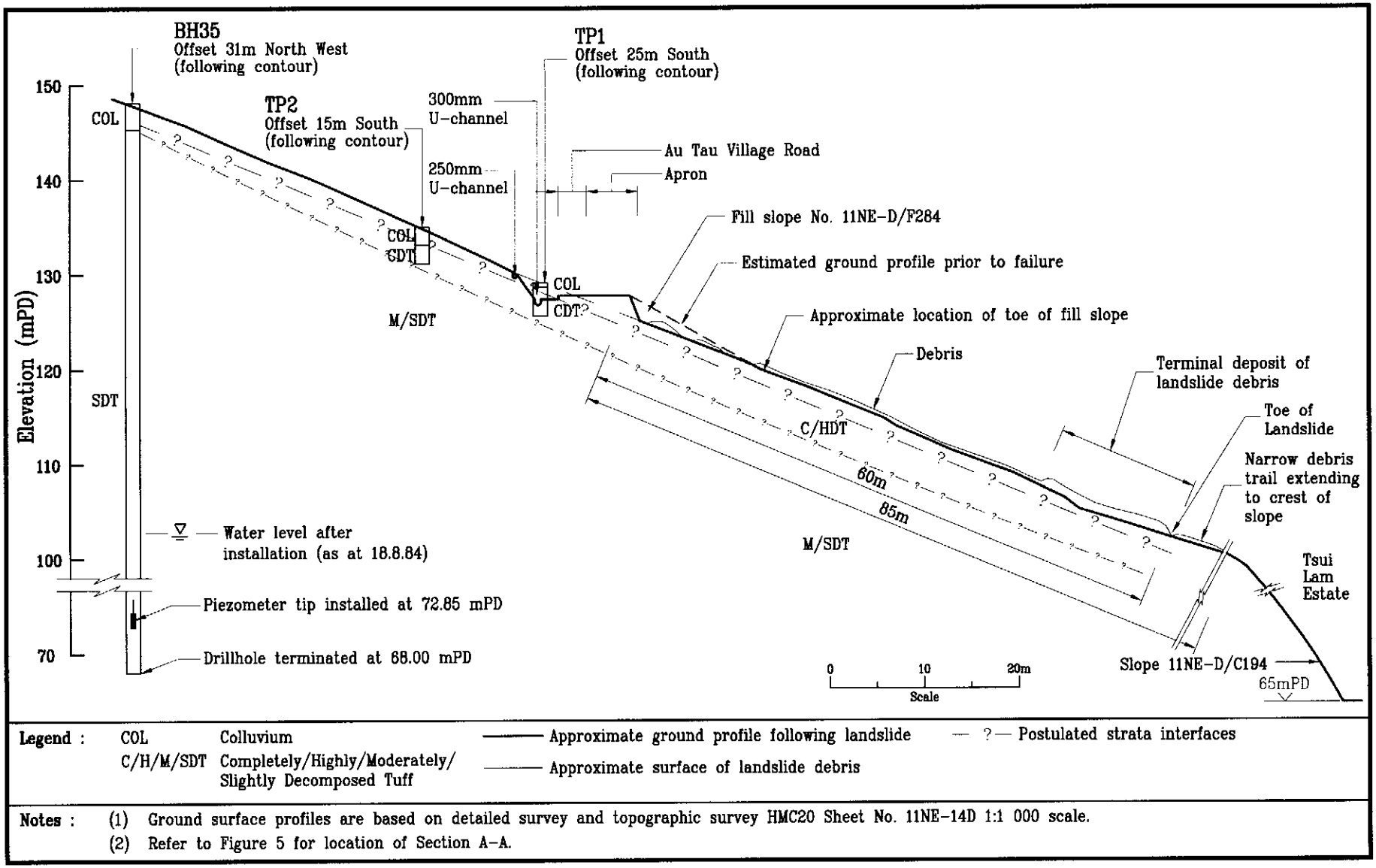


Figure 6 - Section A-A Through the Landslide

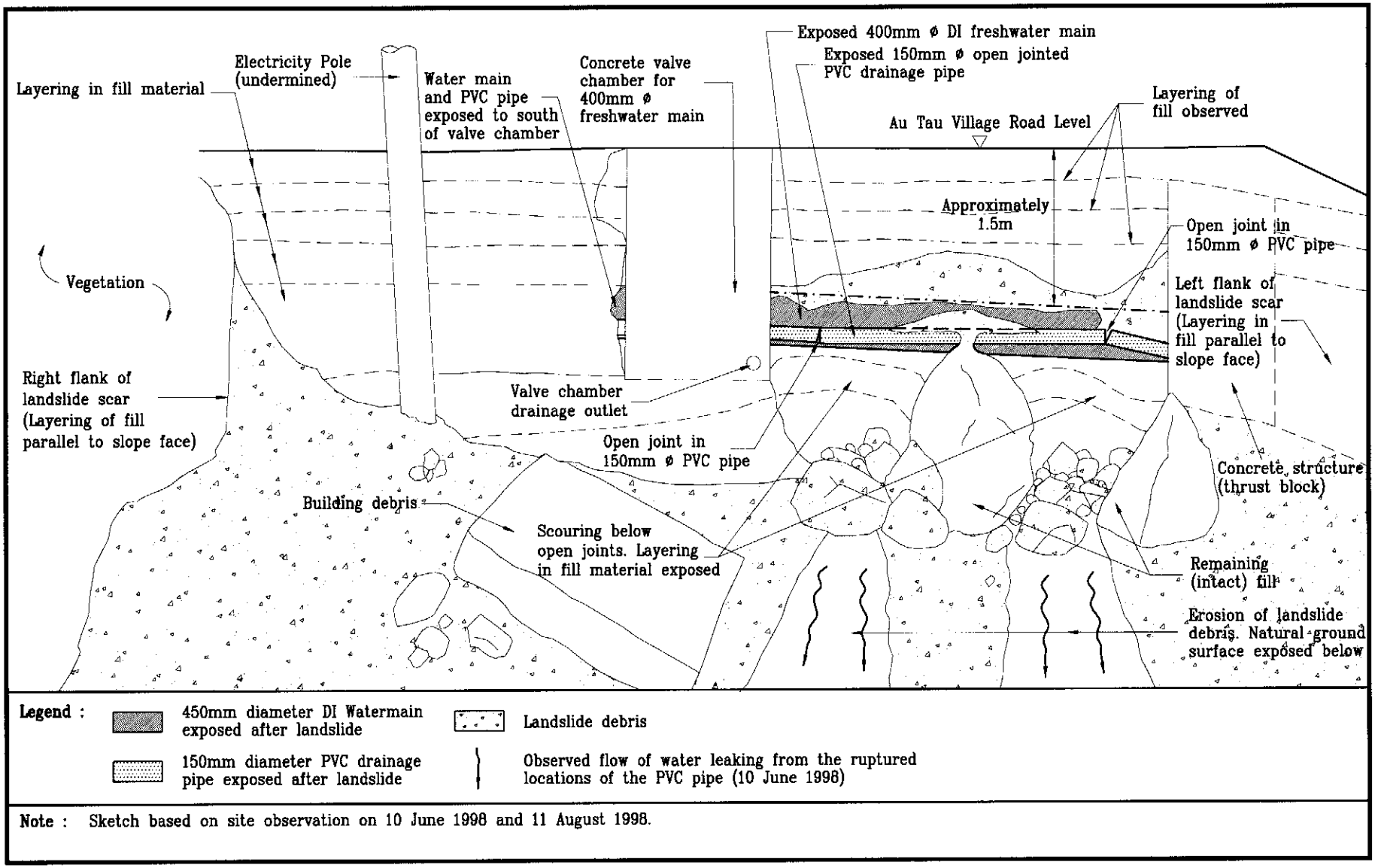


Figure 7 - Local Arrangement of Services Exposed in the Main Scarp

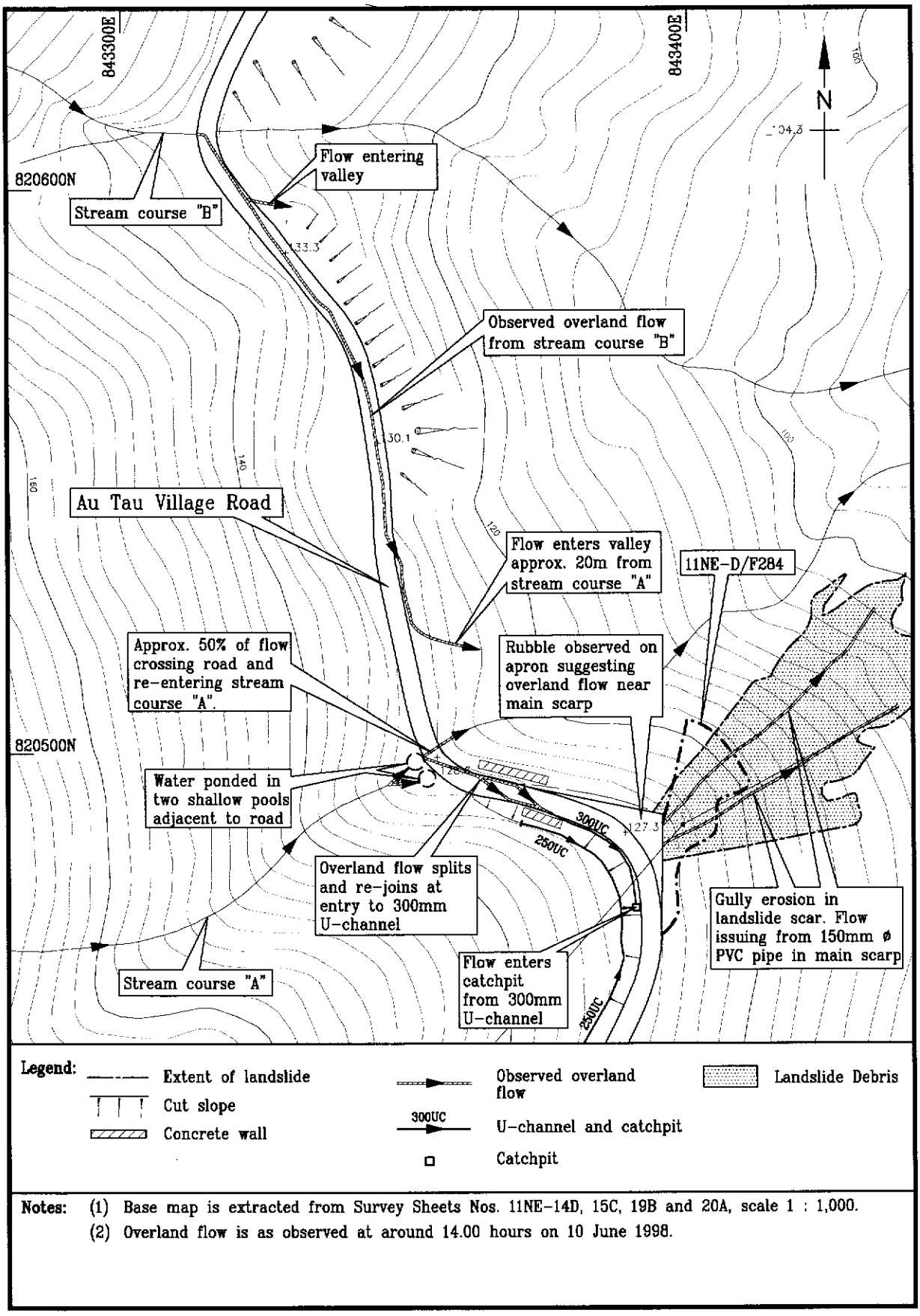


Figure 8 - Observed Overland Flow Paths

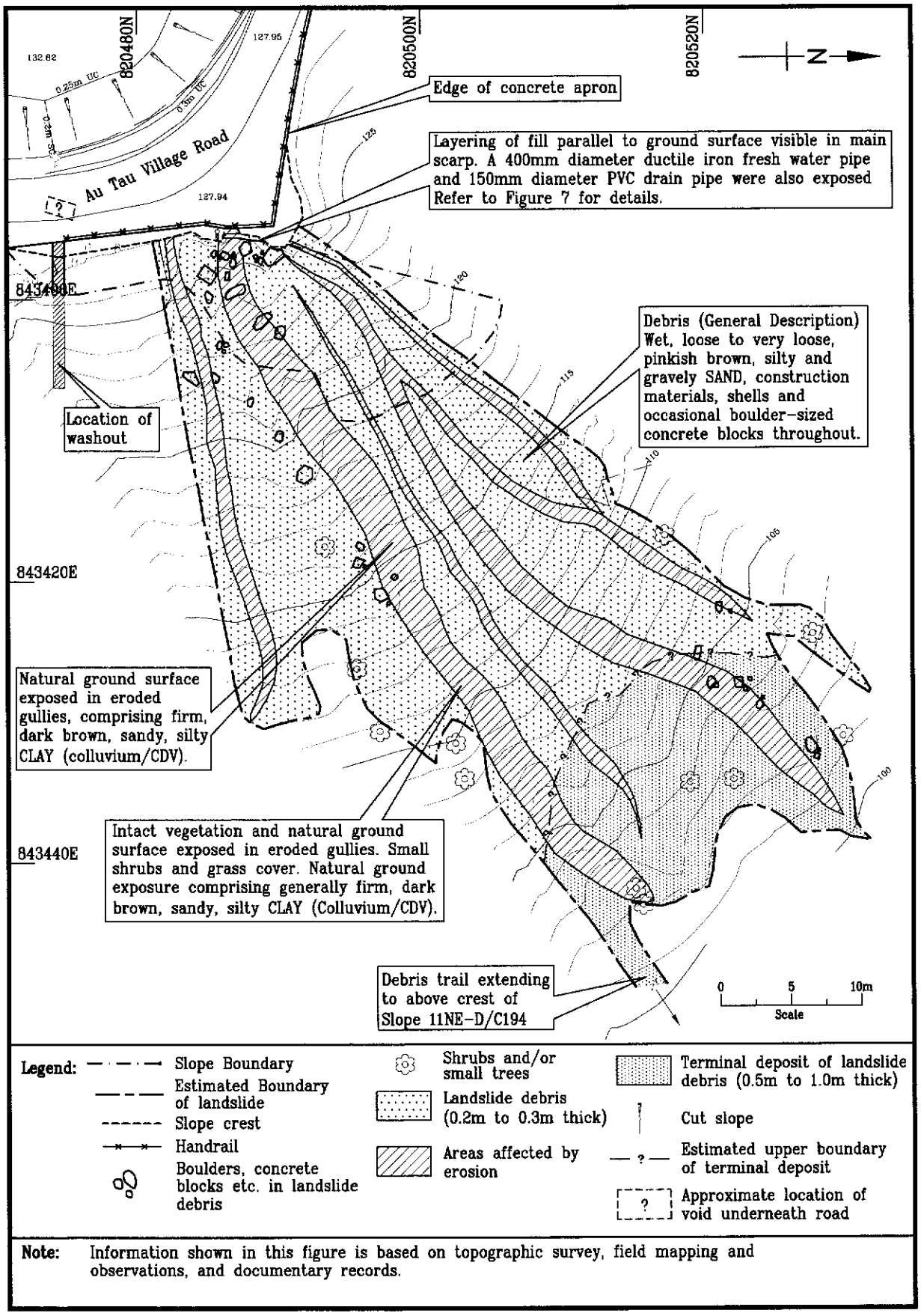
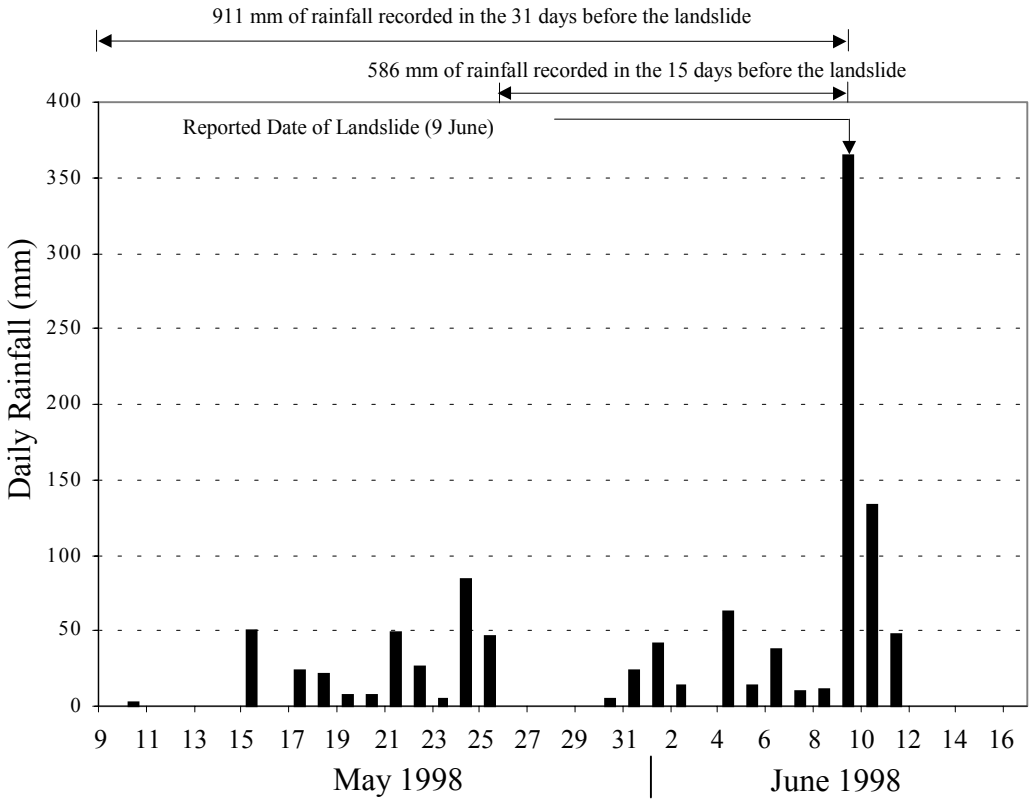
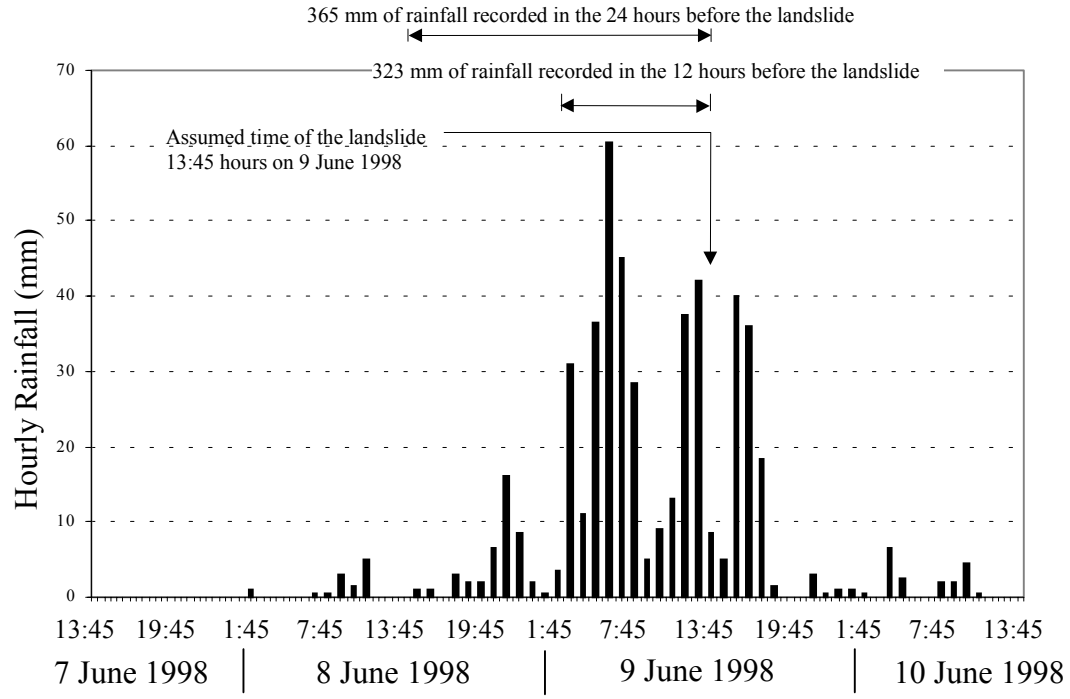


Figure 9 - Mapping of the Landslide Scar



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



(b) Hourly Rainfall Recorded between 13.45 hours on 7 June and 13.45 hours on 10 June 1998

Figure 10 - Rainfall Recorded at GEO Raingauge No. N08

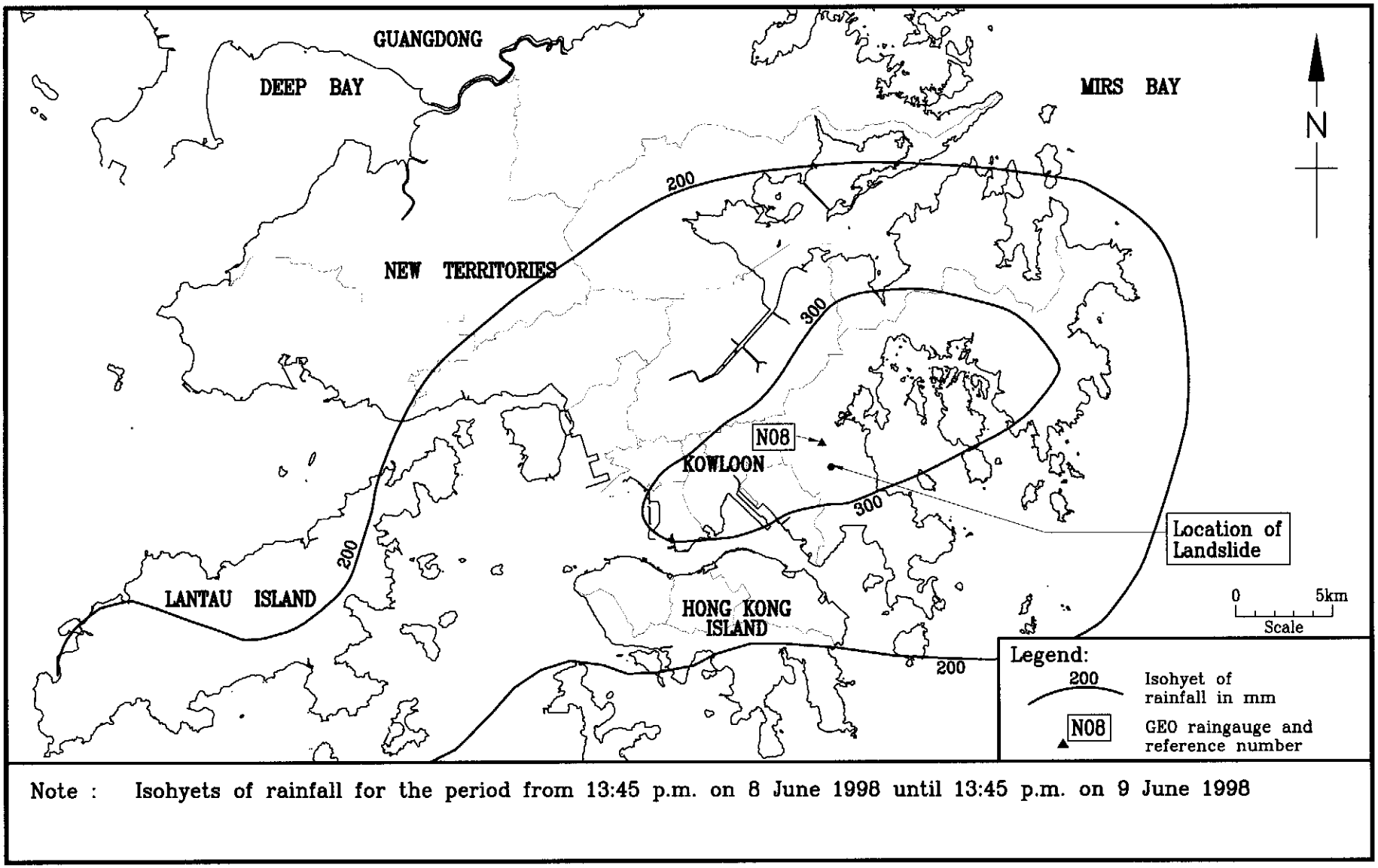


Figure 11 - Rainfall Distribution for the 24-Hour Peroid Preceding the Landslide of 9 June 1998

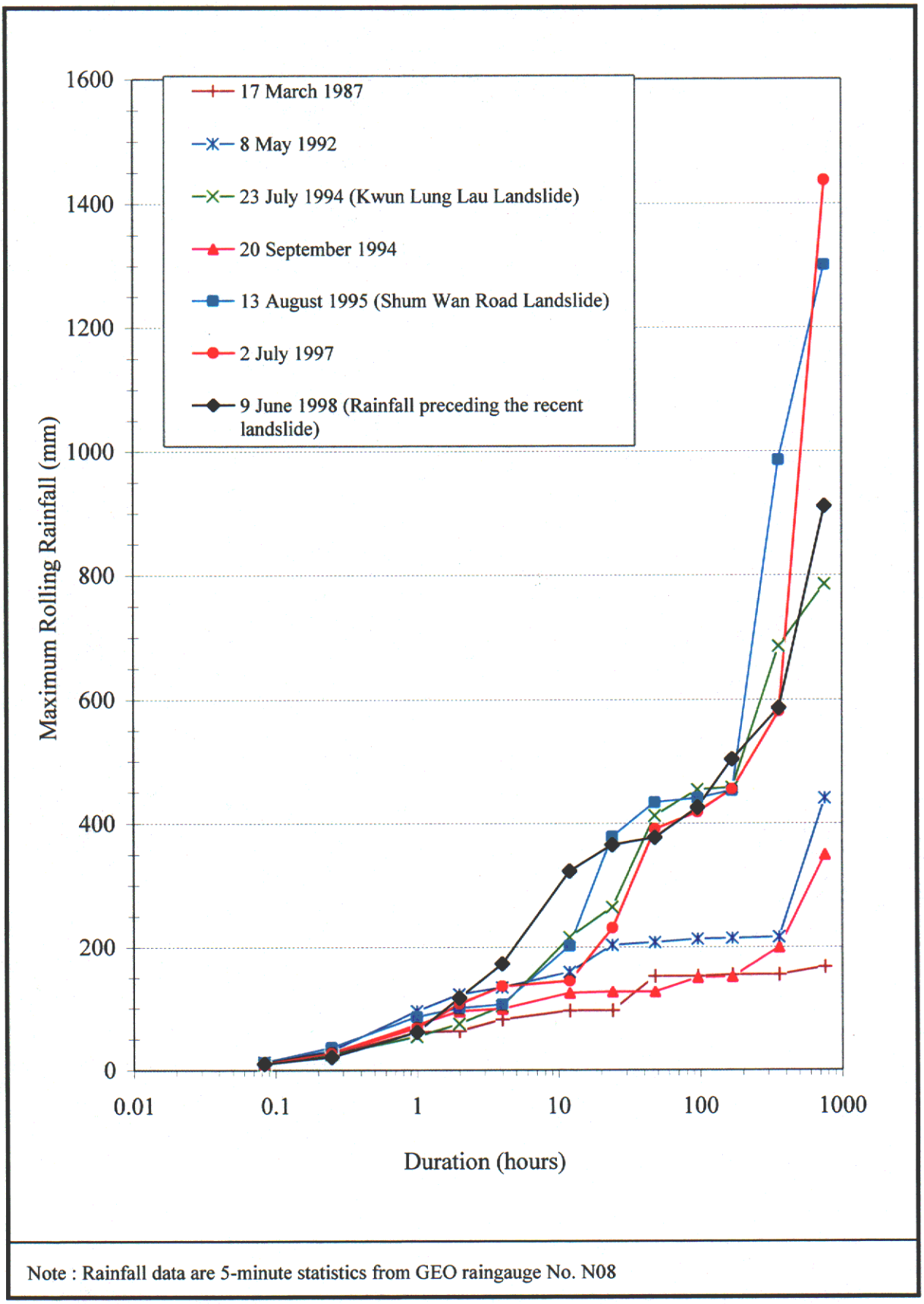


Figure 12 - Maximum Rolling Rainfall Preceding the Landslide of 9 June 1998 and Selected Previous Major Rainstorms Recorded at GEO Raingauge No. N08

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Plate 1 – Oblique View of the Study Area. (Photograph Taken on 29 June 1998).

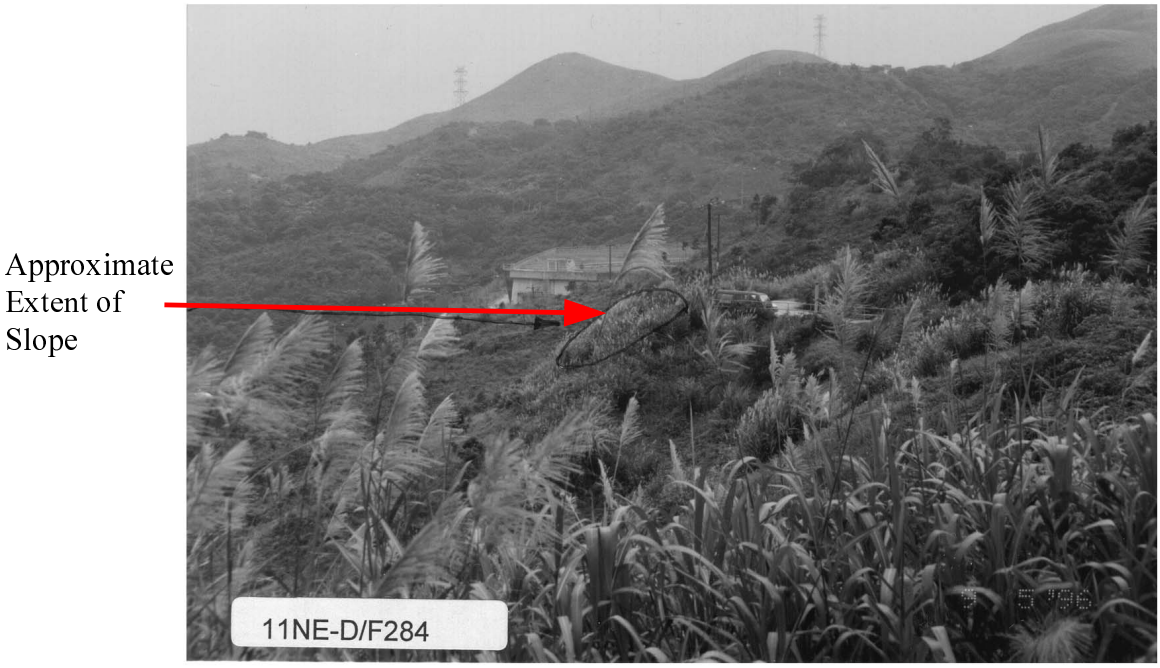

Plate 2 – View South Towards Slope No. 11NE-D/F284 From Au Tau Village Road (Photograph Taken on 9 May 1996).

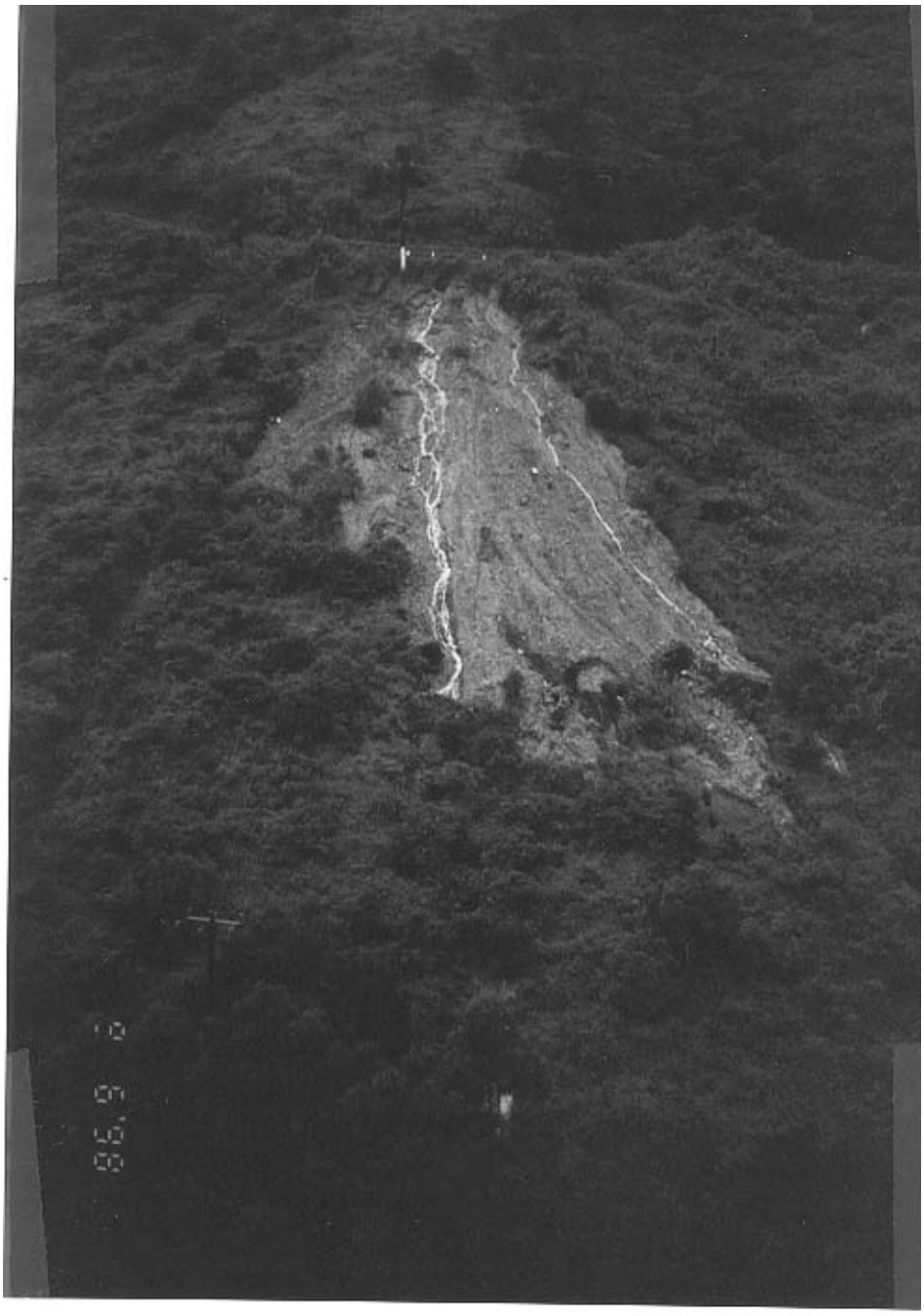

Plate 3 – View West from Choi Lam House, Tsui Lam Estate, Indicating Landslide Scar and Debris Runout. Note Heavy Flow of Water From Two Sources in Main Scarp. Poor Quality of Image Noted. (Photograph Taken Around 17:30 Hours on 9 June 1998)

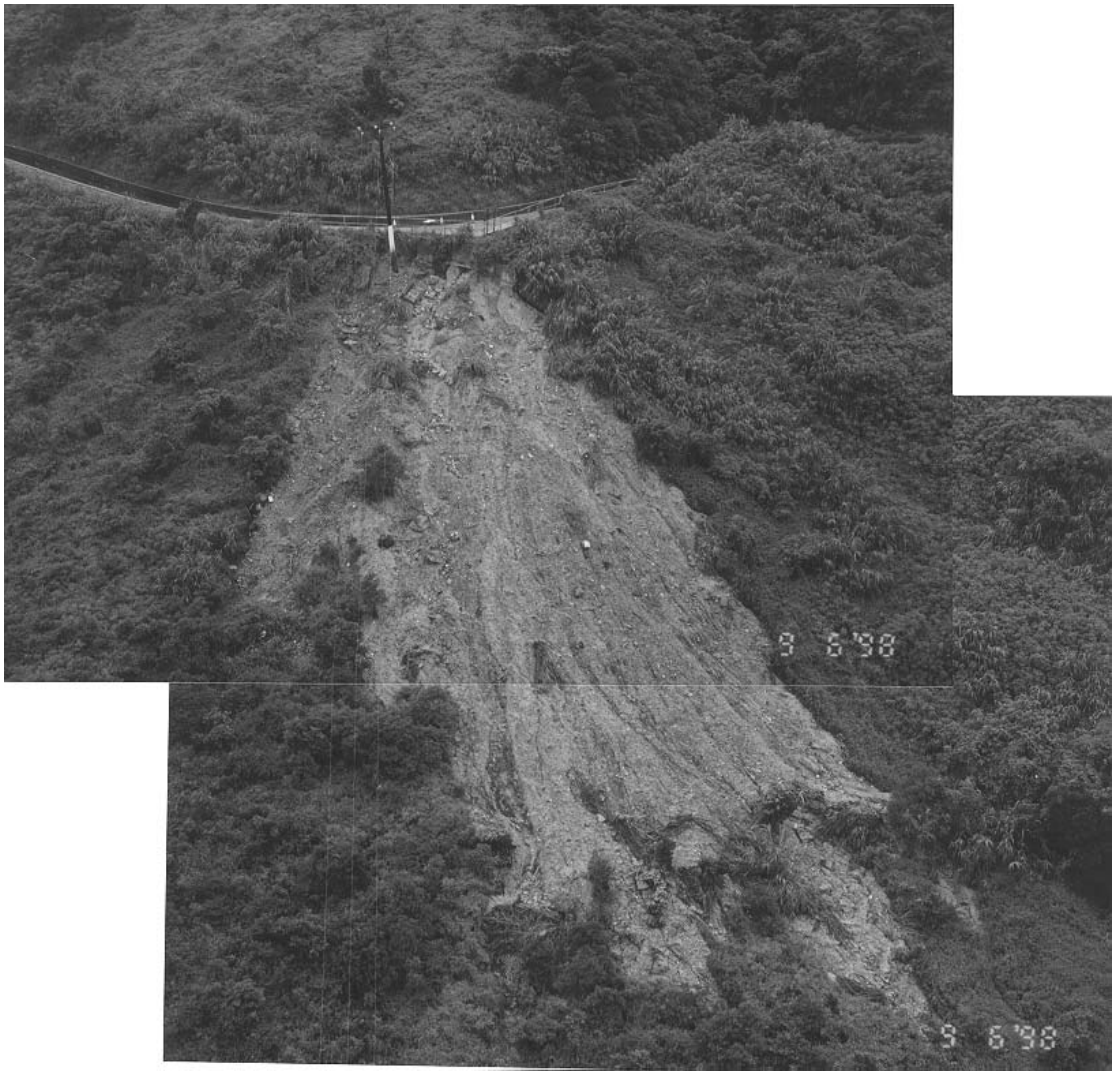

Plate 4 – View West from Choi Lam House, Tsui Lam Estate, Indicating Landslide Scar and Debris Runout. Note Pipework Exposed in Main Scarp. Note Also Apparent Fluid Appearance of Debris Deposition and Secondary Gully Erosion through Debris. (Photograph Taken on Morning of 10 June 1998)

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Plate 6 – View West from Choi Lam House, Tsui Lam Estate, Indicating Runout of Debris (Top of Frame) Relative to Crest of Rock Slopes Adjacent to Building. (Photograph Taken on 10 June 1998)

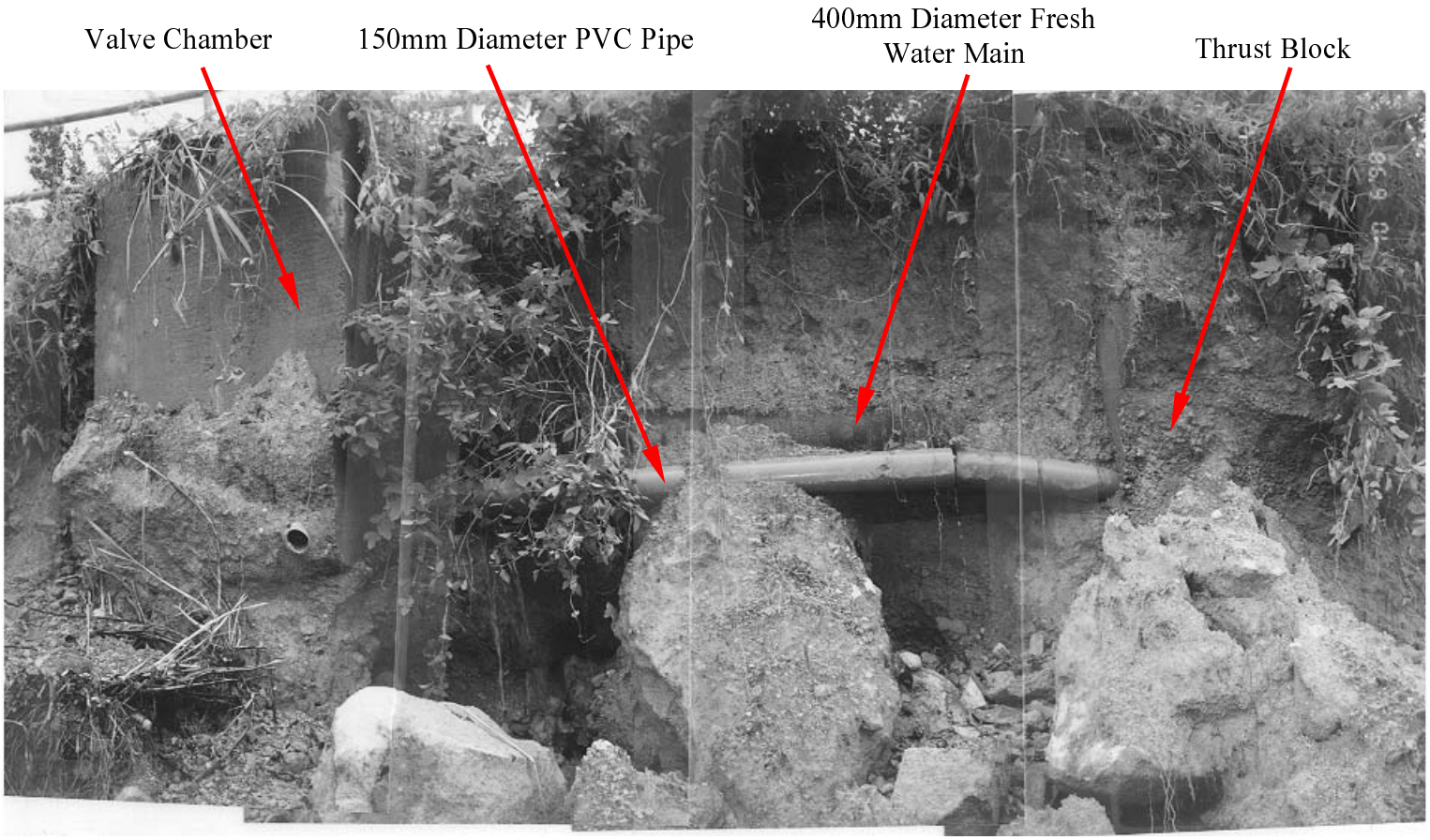

Plate 7 – View of Pipework Exposed in Main Scarp of Landslide Indicating Valve Chamber on Left of Frame, 400 mm Diameter Water Main and 150 mm Diameter PVC Pipe in Centre of Frame and Mass Concrete Structure on Right of Frame. Note Open Butt Joints in PVC Pipe (Water Still Flowing From Pipe) and Heavy Gully Erosion in Scarp Below. (Photograph Taken on 10 June 1998)

Plate 8 – View of Southern Flank of Landslide Near Main Scarp Indicating Loose Nature of Fill Material and Layering Parallel to Slope Face. (Photograph Taken on 10 June 1998)

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Plate 11 – View East Over Debris Deposition Zone From Approximate Location of Slope Toe Prior to Failure. Grass Rootlets and Standing Shrubs Indicate Deposition Zone Below. (Photograph Taken on 10 June 1998)

Plate 12 – View West Towards Main Scarp From Within Main Eroded Gully in Deposition Zone. Intact Vegetation Exposed in Eroded Gully. (Photograph Taken on 10 June 1998)

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Plate 19 – View East Towards Apron on Outside of Bend in Au Tau Village Road Above Location of Landslide. Note Overland Flow on Road in Foreground and Continued Flow To East. (Photograph Taken on 10 June 1998)

Plate 20 – Over-Flow From "Soak-aways" Located on West Side of Au Tau Village Road at Stream Course "A". (Photograph Taken on 10 June 1998)

Plate 21 – View North Along Au Tau Village Road to West of Landslide Indicating Overland Flow From Stream Course "B". Flow Discharges into Valley Below Road on Right of Frame. (Photograph Taken on 10 June 1998)

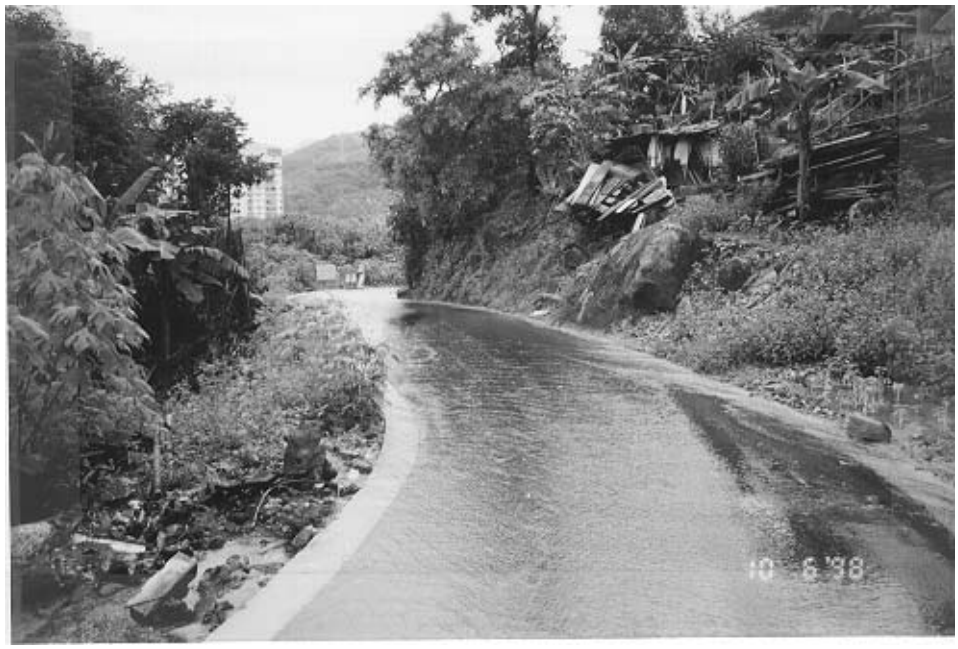

Plate 22 – View South-East Along Au Tau Village Road From Intersection of Road and Stream Course "B". Note Substantial Overland Flow Along Road. (Photograph Taken on 10 June 1998)

Plate 23 – View of Pipework Exposed in Main Scarp. Note Open Butt-Jointed Placement of 150 mm Diameter PVC Pipe (Refer Plate 7). (Photograph Taken on August 1998)

Plate 24 – View West from Choi Lam House Across Landslide Scar. Re-Vegetation in Debris Deposition Zone Provides Indication of Gully Erosion. Locations and Original Toe-Line of Fill Slope No. 11NE-D/F284 Prior to Failure. (Photograph Taken on 11 August 1998)

Plate 25 – View East Down Cleared Section of Slope to South of Landslide Scar (refer Plate 17) Exposing Narrow Washout. Note Vegetation Cover Suggests Washout is a Historic Feature. Note Also Concrete Slab and Tree with Broken Limb as Reference for Plate 26. (Photograph Taken on 9 September 1998)

Plate 26 – View East Down Cleared Section of Slope Exposing Narrow Washout (Refer Plate 25). Note Vegetation Growth in Gully Erosion, Suggesting Historic Feature. (Photograph Taken on 9 September 1998)

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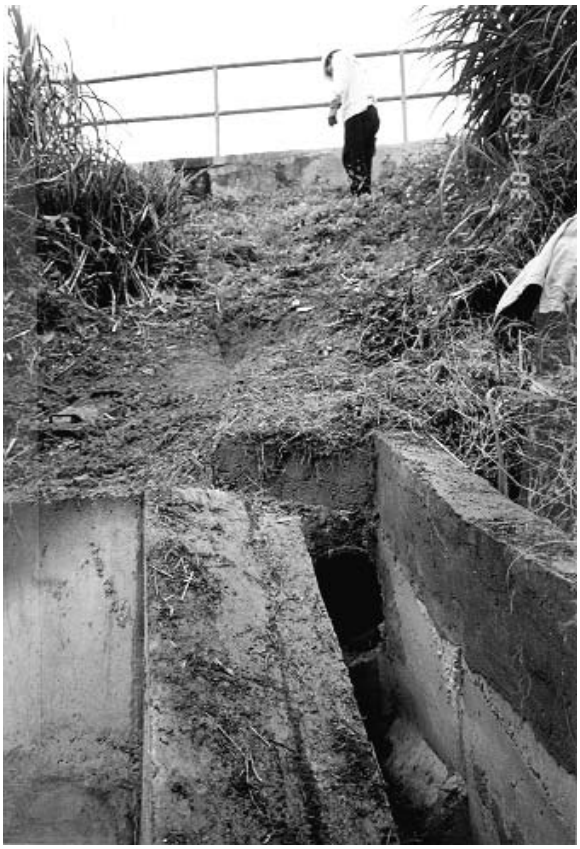

Plate 29 – Outlet to 225 mm Diameter Pipe Draining Catchpit Opposite Landslide Scar (refer Plate 28) Exposed in Slope to North of and Below Concrete Apron. Stepped Channel Extends to North. Concrete Structure Adjacent to Channel Associated with 1992 Water Main Installation by WSD. (Photograph Taken on 30 November 1998)

Plate 30 – View North Along Trench Excavated to Expose 400 mm Diameter Water Main Behind Landslide Scar Associated with WSD Diversion Works to Re-Locate Main Away From Slope Crest. Note Section of 150 mm Diameter PVC Pipe Removed During Trench Excavation. (Photograph Taken on 17 December 1998)

Plate 31 – View South Along 400 mm Diameter Water Main From Within WSD Trench Associated with Main Diversion Works. Note Granular Pipe Bedding Material and Layering in Fill Exposed in Sides of Excavation. (Photograph Taken on 17 December 1998)

Plate 32 – View North-East Across WSD Trench Associated with Diversion Works for 400 mm Diameter Water Main Exposed in Landslide Scar. Note Variation and Layering in Fill Material Parallel to Slope Face. (Photograph Taken on 17 December 1998)

APPENDIX A

AERIAL PHOTOGRAPH INTERPRETATION

A.1 DETAILED OBSERVATIONS

The following comprise the detailed observations made from the photographs studied. Relevant photographs are referenced in Section A.2.

YEAR	OBSERVATIONS
1973	A footpath exists along the present Au Tau Village Road alignment (road not yet constructed).
1976	Au Tau Village Road formed by cutting into the natural hillside along contours. Spur landform in the study area results in the formation of a left hand bend in the road approximately 140m north of the intersection with Tsui Lam Road. Some loose-tipped fill on the slope below the left hand bend. Village road is unpaved. No apron or manhole visible. No electricity visible.
1977	More loose-tipping of fill, as indicated above, but mainly north-west of the apex of the bend.
1978	Loose-tipped fill noted in 1976 and 1977 photographs now vegetated. Village road remains unpaved. No apron or manhole has been constructed. No electricity pole has been erected.
1984	Additional loose-tipped material on apex of left hand bend of road, with spoil extending to north and east. Manhole visible on eastern side of road just south of apex of bend. Pipeline extending north from manhole visible on slope. There is a clear space between the road and the manhole. Some loose-tipped material visible to the south of the left hand bend. Road remains unpaved. No apron has been constructed. No electricity pole visible.
1986	Village road widened by cut south of the left hand bend and by filling to the north-west, but there is no road widening on the bend itself. The manhole is still visible through vegetation, and it is possible that there has been some filling between the road and the manhole. Village road remains unpaved. No apron has been constructed but loose-tipped fill is accumulating in that area. No electricity pole visible
1987	Further loose-tipping of fill visible to the west of the left hand bend and immediately before the right hand bend (to the west of the left hand bend). No further end-tipping/filling visible to the south or on the apex of the left hand bend. Widening of the road by further cutting at the apex of the left hand bend. No apron has been constructed. Road paving commenced to the south of left hand bend. No electricity pole visible.
1988	Further loose-tipping of fill on the apex of the left hand bend and immediately to the west. The section of road approaching the left hand bend and the bend itself have been paved with concrete. Manhole is still visible. There does not appear to have been any further filling on either side of the manhole. An electricity pole has been erected to the east of the manhole cover.

YEAR	OBSERVATIONS
1989	Further loose-tipped fill immediately west of the apex of the bend. The edge of the manhole is visible, with more filling on either side. More material has accumulated by loose-tipping in the area of the apron (not yet constructed). Electricity pole still visible. Water draining onto the road south of the left hand bend from the cut slope.
12/10/1990	Wall constructed on northern edge of the road between the left hand bend and the right hand bend to the west. Spoil pile in area of apron on apex of bend. Water appears to be ponding on the road, south of the left hand bend and appears to be emanating from the cut slope on the western side of the road. Electricity pole has been removed.
13/11/1990	Ponding on road noted in October photographs not visible. Vegetation has grown around the spoil pile on apex of bend noted above.
1991	An access road is under construction below and to the north of the left hand bend and appears to be related to installation of pipeline. The platform at the location of the apron has taken more shape due to the above construction. Eastern edge of platform now in line with manhole. Spoil visible below the manhole.
16/04/1992	Open trench excavated for pipeline, located below and to the north of the platform at the apron location. Although the edge of the manhole is still defined, the slope below this and below the apron platform created on the outer edge of the left hand bend are now vegetated. The platform for the apron has now been levelled, however it is not yet covered in concrete. There is a drain on the western side of the road south of the apex of the left hand bend, and what appears to be an outlet structure located opposite this on the eastern edge of the road.
20/10/1992	Filling on the slope between the outlet noted in April photographs and the manhole cover further north. No electricity pole visible on the slope but another observed further south on a right hand bend in the village road. Apron platform visible, but not yet concreted.
1993	Apron now concreted and eastern and northern edges are well-defined. Access road observed in 1991 photographs now disused and partially vegetated. Manhole remains visible on the eastern edge of the apron. No electricity pole visible.
1994	An electricity pole has been erected on the outside edge of the apron immediately south of the manhole. The slope below the road and apron is now completely covered with vegetation.

YEAR **OBSERVATIONS**

1995 Vegetation is heavier than observed in 1994 photographs. Rectangular-shaped hut visible on the eastern edge of the apron. Manhole no longer visible due to dense vegetation.

1996 Section of road south of the left hand bend has been resurfaced with asphalt. Apron appears unchanged. The rectangular hut noted above is no longer visible. A smaller hut is visible on the northern edge of the apron.

1997 There is no hut on the apron. No change apparent in village road. Hut observed on northern edge of platform in 1996 photographs no longer visible.

A.2 LIST OF AERIAL PHOTOGRAPHS

A list of aerial photographs used in this API study is presented below.

YEAR	PHOTOGRAPHS
1973	5257 5258
1976	15335 15336
1977	20345
1978	24176 24177 24178
1984	56960 56961
1986	A6328 A6329
1987	A9521 A9522
1988	A14688
1989	A17205 A17206 A17207
Oct/1990 Nov/1990	A23123 A23659 A23660
1991	A27451 A27452
1992	A30420 A30421 A30422 A32794 A32795 A32796 A30393 A30394
1993	A36153 A36154
1994	A39212 A39213 A39214
1995	CN9965 CN9966
1996	CN15616 CN15617 CN15725 CN15726 CN15727
May/1997 Nov/1997	CN17203 CN17204 CN18948 CN18949