SECTION 2: DETAILED STUDY OF THE 24 AUGUST 1999 LANDSLIDE AT SLOPES NOS. 9SW-D/C114 AND 9SW-D/C115 AT SHAM WAT ROAD LANTAU ISLAND

Fugro Maunsell Scott Wilson Joint Venture

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FOREWORD

This report presents the findings of a detailed study of the landslide (GEO Incident No. MW1999/8/107) that occurred on 24 August 1999 at slopes Nos. 9SW-D/C114 and 9SW-D/C115 located above Sham Wat Road, Lantau Island. The landslide blocked the single lane road that serves as the sole road access to Sham Wat Wan village. There were no casualties or damage to property as a result of the landslide.

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

The report was prepared as part of the 1999 Landslide Investigation Consultancy (LIC), for the Geotechnical Engineering Office (GEO), Civil Engineering Department (CED), under Agreement No. CE 101/98. This is one of a series of reports produced during the consultancy by Fugro Maunsell Scott Wilson Joint Venture (FMSW).

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CONTENTS

1. INTRODUCTION

At about 12:00 p.m. on 24 August 1999, a landslide (GEO Incident No. MW1999/8/107) occurred on soil cut slopes Nos. 9SW-D/C114 and 9SW-D/C115 located above Sham Wat Road, Lantau Island (Figures 1 and 2 and Plates 1 to 3). The landslide blocked the single lane road that serves as the sole road access to Sham Wat Wan village. There were no casualties or damage to property as a result of the landslide.

Following the incident, Fugro Maunsell Scott Wilson Joint Venture (FMSW), the 1999 Landslide Investigation Consultant, commenced a study of the failure on 25 August 1999 for the Geotechnical Engineering Office (GEO), Civil Engineering Department (CED), under Agreement No. CE 101/98.

The key objectives of the study were to document the facts about the landslide, present relevant background information and establish the probable causes of failure. The scope of the study comprised site inspections, detailed site mapping, 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) desk study, including a review of relevant documentary records relating to the history of the site,

(b) aerial photograph interpretation (API),

(c) topographical survey, geological mapping and detailed observations and measurements at the landslide site,

(d) analysis of rainfall records, and

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

2. THE SITE

2.1 Site Description

Sham Wat Road generally follows a north-northwest to south-southeast trending valley leading to Sham Wat Wan village to the west of Lantau North Country Park, the road traverses the landslide site at an elevation of approximately 40 mPD. A disused irrigation channel and catchwater traverse the hillside above the landslide site at an elevation of approximately 52 mPD and 127 mPD respectively (Figure 1). The 350 mm wide irrigation channel is in a poor condition of maintenance with blocked and severed sections within the vicinity of the landslide site, such that water flowing along the channel could discharge onto the ground about 3 m to 4 m above the failed cut slopes. The condition of the channel would indicate that it is no longer used for irrigation purposes, but it would still intercept surface water flows and direct them towards the landslide site. The 2.5 m wide catchwater is in fair condition with no significant cracks or signs of distress.

The landslide occurred within cut slope No. 9SW-D/C115, and extended into the natural terrain above, where the ground stands at about 30° (Figures 2 and 3). The bottom northern portion of the landslide encroached onto the lower corner of the adjoining cut slope No. 9SW-D/C114. Based on site observations, the failed slope had a maximum height of approximately 10 m and stood at angle of 35° to 40°. The slope was covered by shotcrete surface protection, which was in fair condition from a photograph taken in November 1998 as part of a separate study of the slopes along Sham Wat Road (Section 2.3.4). The photograph shows a shallow concave depression in the upper portion of the slope in the same location as the 1999 landslide (Plate 4). This depression corresponds to where GEO Incident No. MW92/7/43 occurred in July 1992 (Section 2.3.3). From the photograph, a number of repaired cracks can be seen on the shotcrete below the toe of the shallow depression, which suggests further slope movement following the 1992 failure. No details of when or who undertook the repair works were found in the GEO files.

The intact portion of slope No. 9SW-D/C114 adjoining the 1999 landslide to the south stands at an angle of about 45° and is about 5.5 m high. This slope was covered by chunam protection, which was in a poor maintenance condition being completely overgrown with vegetation at the time of the inspection.

Surface drainage channels are present at the crest of the features and a stepped channel descends the slopes at the junction between and at either end of the features. In places, the surface drainage channels were blocked with soil (from localised instability above), cracked and severely deformed indicating ground movement and poor maintenance. Sections of the surface drainage channels were also removed by the 1999 landslide.

2.2 Maintenance Responsibility

According to the "Systematic Identification of Maintenance Responsibility of Slopes in the Territory" (SIMAR) project undertaken by the Lands Department, the maintenance responsibility of the failed slopes Nos. 9SW-D/C114 and 9SW-D/C115 lies with the Highways Department (HyD).

2.3 Site History

2.3.1 General

The site history has been established based on an aerial photograph interpretation (API), together with a review of desk study information. A list of the photographs examined and a summary of the observations are presented in Table 1. Salient points arising from the API are discussed below and illustrated on Figure 4.

2.3.2 History of Site Development

The earliest available aerial photographs were taken in 1963. At this time the irrigation channel above the 1999 landslide site could be observed and the catchwater above

the site appears to be under construction. Sham Wat Road and the cut slopes above have not yet been formed, but a small track/footpath follows the current road alignment.

According to the API, construction work to widen the track/footpath into a single lane road began in 1985, at which time slopes Nos. 9SW-D/C114 and 9SW-D/C115 were formed by cutting into the natural terrain above the road alignment. This is corroborated by desk study records, which show that the road was constructed as part of Stage IB extension and improvement works for the "Access Road to Sha Lo Wan from Ngong Ping Road" between 1985 and 1986. The scheme was initially proposed to the GEO in October 1984 by the City and New Territory Administration through the District Office/Islands. Due to the minor nature of the road, the GEO agreed that the road did not have to be constructed "to the new works standard for main roads" and that a formal submission was not required. GEO stated that the minimum factor of safety for the works should be greater than unity.

Two failures were recorded in cut slopes Nos. 9SW-D/C112 and 9SW-D/C39, about 100 m and 160 m respectively to the north of the 1999 landslide, during the formation of the road (Figure 1). No GEO Incident Reports were prepared for these failures, but the GEO files records show that the failed slopes, which were originally formed at 45°, were regraded to a shallower angle of about 35°, with the provision of a 2 m high gabion toe wall and counterfort filter drains.

2.3.3 Previous Landslides and Distress

In the 1963 aerial photographs, three concave depressions interpreted as relic failure scars (63-a to 63-c) are apparent approximately 100 m to 120 m east (upslope) of the 1999 landslide site (Figure 4). These relic failure scars are typically 20 m to 25 m wide and lie below a sharp convex break of slope, which defines the upper limit of a large depression that lies about 120 m east of the 1999 landslide site. This depression forms a sub-catchment (CA1), with an approximate surface area of 3 000 m^2, within a larger catchment (CA2), with an approximate surface area of 50 000 m^2 (Figure 5).

In the 1986 aerial photographs, a shallow concave depression (86-a) approximately 10 m wide is evident above the crest of the cut slope in the same location as the 1999 landslide. No detail of the failure could be found in the GEO files. In the 1987 aerial photographs, slope No. 9SW-D/C115 and an approximately 60 m long section of slope to the north have been regraded and appear to have been covered by rigid surface protection. By October 1991, vegetation appears to obscure much of the regraded portion of the slopes, and in December 1993 it is apparent that new surface protection has been applied to the area of the former 1986 failure and approximately a 20 m long section of slope to the north. This indicates renewed instability between October 1991 and December 1993, which is confirmed by the fact that a landslide was recorded in this area in July 1992 (GEO Incident No. MW92/7/43, discussed below).

Further signs of instability, in the form of shallow depressions up to 15 m wide, were evident within CA1 in 1991, 1993 and 1994 (Figure 4). In particular, one of the failures in 1993 occurred in the same area as the washout failure scar adjoining the 1999 landslide observed by FMSW on 25 August 1999. This failure (93-b) retrogressed further up the hillside in 1994, with the crown of the landslide (94-a) located above the irrigation channel.

The altitude of the aerial photograph is such that detailed observation of the channel is not possible, but from the shape and size of the scar it appears likely that the channel was damaged/disrupted by this failure. Site mapping by FMSW following the 1999 landslide identified information to suggest that this was the case (Section 4.4.2).

A number of extensive linear features, interpreted as possible tension cracks/minor scarps, were apparent in the lower part of CA1 from the aerial photographs taken after 1985, i.e. following the construction of Sham Wat Road and the formation of cut slopes Nos. 9SW-D/C114 and 9SW-D/C115. These features generally follow the contours of the natural terrain within CA1, although some trend obliquely to the hillside.

One landslide (GEO Incident No. MW92/7/43), was identified as having previously occurred at the same location of the 1999 landslide in the GEO landslide database (Plate 4). In accordance with the GEO Incident Report, the landslide occurred on 18 July 1992 and was recorded as having a failure volume of approximately 10 m^3. The causes of failure were identified as groundwater perching and infiltration. "The landslide was about 20 m wide and affected the upper portion of the cut slope and extended about 10 m into the natural terrain above" (Figure 4). Based on photographs of the failure attached with the Incident Report, the failed volume is estimated to be about 25 m^3 to 30 m^3, which is greater than that quoted in the Incident Report (Plate 5). From the photograph of the landslide, the shotcrete cover to the failed slope was relatively new and appeared fresher than the rigid surface cover to the adjoining feature to the north, which is a possible indication of previous instability since formation of the slope in 1985.

Another landslide with a failed volume of 25 m^3, GEO Incident No. SP93/11/198, was recorded as having occurred approximately 90 m to the south of 1999 landslide site on 5 November 1993 (Figure 1). Information relating to the incident noted that the failure mechanism was "one of erosion resulting from water overflowing the irrigation channel in the hillside approximately 25 m above, southwest of the main failure scarp." This suggests the possibility that the poor maintenance condition of the irrigation channel could have an adverse effect on the stability of the hillside.

In the GEO files, two landslides were recorded in cut slopes Nos. 9SW-D/C112 and 9SW-D/C39 to the north of the landslide site during road formation between 1985 and 1986 (Figure 1), details of which are discussed in Section 2.3.2. No incident reports were prepared for these failures.

2.3.4 Previous Studies

In mid-1992, the GEO initiated a consultancy agreement, entitled "Systematic Inspection of Features in the Territory" (SIFT), to search systematically for slopes not included in the 1977/78 catalogue of slopes and to update information on previously registered features by limited site inspections and studying aerial photographs. Slope No. 9SW-D/C115 was categorised as a Class C2 feature, under the SIFT project, i.e. "assumed constructed post-1977".

In 1994, the GEO commenced a consultancy agreement, entitled "Systematic Identification and Registration of Slopes in the Territory" (SIRST), to systematically update

the 1977/78 Catalogue of Slopes and to prepare the New Slope Catalogue. The GEO's consultants for the SIRST project inspected the slope in November 1997, the condition of the slope was recorded as "Fair". Minor distress was noted at the crest, mid-portion and toe and inferred past instability was recorded as "Minor". No information concerning the condition of the irrigation channel above the slope was presented in the SIRST report.

The slopes along Sham Wat Road were studied as part of an initial review by Fugro Scott Wilson, the 1998 Landslide Investigation Consultant. The study showed the slopes had largely been formed by 1986, but that surface protection works, drainage channels and minor maintenance works were still outstanding in 1988. These works do not appear to have been completed until 1990. This indicates that the rigid surface cover on the slopes adjacent to Sham Wat Road varies in age. No information on tension cracks or drainage channel conditions were detailed in the report.

2.3.5 Events Following the 1999 Landslide

Following the landslide, a joint site inspection by GEO's Mainland West Division and the HyD on 25 August 1999 identified an area of disturbed ground adjoining slope No. 9SW-D/C115. The disturbed area was about 50 m long and extended upslope from Sham Wat Road for a distance of 15 m (Figure 2). GEO recommended that the HyD should close the affected section of road to allow urgent repairs to be carried out to the disturbed area. These works were to include the removal of slip debris and reinstatement of the area to the original slope angle of 45° by installing a gabion wall at the slope toe and back filling with rockfill or equivalent.

During slope trimming works, under which the designated section of slope was cut back as far as the irrigation channel upslope of the road, a minor scarp, about 10 m wide, developed in the central portion of the regraded slope in the vicinity of the 1999 landslide (Figure 2). Photographs of the instability, taken on 22 September 1999, show the presence of a 200 mm to 300 mm wide soil pipe and many shallow erosion rills below the minor scarp and the area of slope above appears wet (Plate 6). Also, additional instability in the form of tension cracks and minor scarps were found in the hillside above the regraded section of slope (Appendix A).

After a follow-up site inspection by GEO's Mainland West Division on 14 October 1999, additional recommendations were made to the HyD. These included:

(a) provision of 3 rows of type 3 raking drains 12 m long 3 m horizontal and 3 m vertical spacing inclined at 27° to the horizontal to the lower part of the slope (the lowest row being 1 m above the slope toe),

(b) sealing up the tension cracks, and

(c) provision of monitoring stations including settlement markers and tell-tales at the tension cracks for monitoring of the slope.

FMSW inspected the disturbed area of slope on 25 October 1999, following which, it was proposed that a series of vegetation strips be cleared so that the extent of instability could be established. These works were completed by the HyD term contractor in early November 2000. Detailed mapping following clearance works confirmed the presence of widespread distress in the hillside (Section 4.4).

Further recommendations for urgent repair works were made by GEO to HyD in a memo dated 21 October 1999. These included:

(a) construction of a 3 m high rectangular shaped, mass concrete/gabion retaining wall with base width not less than 1.5 m along the toe of the failed slopes,

(b) placement of rockfill or equivalent against the whole slip scar to form an approximately 35° rockfill slope above he retaining wall,

(c) provision of 12 rows of soil nails 32 mm dia, (100 mm hole dia.), 15 m long at 2 m horizontal spacing and dipped at 20° to the slope above the crest of the slip scar up to the largest tension crack,

(d) provision of 2 additional rows of type 3 raking drains to those previously instructed,

(e) provision of shotcrete with weepholes to the soil nailed slope, and

(f) provision of surface drainage channels.

A subsequent review of these proposals by the GEO identified that the installation of soil nails was not necessary in view of the regraded slope angle following the installation of the toe retaining wall as detailed in a memo dated 27 January 2000.

At the time of FMSW's last site inspection on the 20 August 2000, the raking drains and the gabion toe wall had been installed, but backfilling works have not yet commenced.

3. DESCRIPTION OF THE LANDSLIDE

The initial inspection of the landslide by FMSW on 25 August 1999 revealed that the failure affected the entire portion of slope No. 9SW-D/C115 as well as the hillside above and part of slope No. 9SW-D/C114 to the north (Figure 2 and Plates 1 and 2). It is estimated that the crown of the landslide had extended into the natural hillside above the slope to a height of about 12 m above Sham Wat Road.

The failed area was about 30 m wide and could be divided into two distinct portions (Figure 2). The northern portion (Zone A) comprised an area of disturbed ground about 20 m wide by 18 m long with a maximum depth of about 1 m. Debris along the southern flank of

Zone A was more mobile and had inundated the single track road at the toe of the slope with a travel angle of the debris of about 30° (Wong & Ho, 1996). It is estimated that the failed volume in Zone A was between 75 m^3 and 100 m^3. The southern half of the landslide (Zone B) was less mobile involving about 0.5 m of vertical displacement and 1 m of outward horizontal movement without complete detachment of the unstable material from the surface of rupture. The failed area within Zone B was about 10 m wide by 18 m long, with an estimated volume of about 100 m^3 (assuming the depth of failure to be 1 m). Following vegetation clearance and slope trimming undertaken by the HyD, more widespread instability with an estimated volume of displaced material of 1 500 m^3 was observed above Sham Wat Road (Section 4.4.2).

The greater mobility of material in Zone A would appear to be due to the lower lying nature of the ground in this area and the influence of the natural drainage line to the north. The ground in Zone B lies at a slightly higher elevation such that the drainage line to the south passes around the southern flank of Zone B without discharge of water across the slope surface.

Initial observations from the road identified that the landslide involved residual soil and completely decomposed tuff, but detailed inspection of the main scarp and area above the landslide was not possible at that time because of the danger of further instability. The landslide debris was noted as being very wet with heavy seepage observed at the base of Zone A and surface water flows above the main scarp.

An old washout failure scar and erosion channel, along which there had been renewed movement of material, was observed to the south of Zone B (Plate 3). This failure scar corresponds to where instability was observed in 1993 and 1994 from the aerial photographs (Figure 4) and would appear to be separate from the 1999 landslide incident.

4. SUBSURFACE CONDITIONS

4.1 Regional Geological Setting

The published solid and superficial geological map (HKGS Sheet 9 HGM20 1:20 000) indicates that the landslide site is underlain by metamorphosed Rhyolite lava and Tuff of the Repulse Bay Volcanic Group (Figure 6). Further upslope, the underlying rock type changes to metamorphosed Siltstone. This geological boundary is located about 50 m downslope from the catchwater and coincides with a slight concave break in slope. Based on site measurements, the contact dips in a southerly direction at an angle of between 10° and 30°. Large areas of debris flow deposits are mapped to the north and south of the landslide site, and a smaller area of debris flow deposits lies on the hillside upslope to the southwest.

4.2 Regional Geomorphological Setting

The 1963 aerial photographs show that the area surrounding the landslide site is dominated by a series of northeast to southwest trending spur lines, which descend the hillside in a northeasterly direction towards the main north-northwest to south-southeast trending valley. The spur lines delineate a series of sub-parallel depressions, within which lie a

number of drainage lines (Figure 5). An extensive colluvial debris fan lines the floor of the valley below Sham Wat Road and colluvial deposits are also evident in some of the depressions to the north and south of the landslide site (Figure 6). In particular, three large colluvial debris lobes, referenced Sham Wat Road Debris Lobes 1, 2 and 3 (King, 1998), have been mapped to the north (Lobe 1) and south (Lobes 2 and 3) of the landslide site by the Planning Division of the GEO (Figure 7). These provide evidence of possible large-scale relic instability within the regional setting.

The 1999 landslide site lies towards the base of one of the northeast to southwest trending depression, referenced CA1, which in turn lies within a larger depression, referenced CA2. These depressions have approximate catchment areas of 3 000 m^2 and 50 000 m^2 respectively and are typically defined by a sharp continuous convex break in slope, which are considered to define areas of relic instability (Figure 7). Further catchment (CA3) and sub-catchment (CA4) areas are present within and adjoining CA2, but these are outside the scope of this study and have not been discussed further.

The upper portion CA1 is characterised by a broad spoon-shaped depression that narrows towards the base in the direction of southern flank of the catchment. The lower northern flank of CA1 is less distinct, as the area comprises hummocky ground formed by a series of small rounded hills (hummocks). These features may represent colluvial deposits from a relic instability indicated by the spoon-shaped depression further uphill. In addition, recent failure scars with debris runout within CA1, as observed from API, identifies continued instability and the likelihood of colluvium within the depression. Recent instability was also observed within CA2.

A number of drainage lines are apparent within catchment area CA2, two of which, referenced DL1 and DL2, occur within the smaller sub-catchment CA1 (Figure 5). Both of these drainage lines have no obvious stream courses and are probably ephemeral. DL1 starts in the upper northern corner of the catchment and descends southeastwards towards the mid- to lower-portion where it branches into two separate drainage lines around an area of higher ground. The area of higher ground extends uphill from the crown of slope No. 9SW-D/C115, such that the northerly branch of DL1 discharges onto the upper northern flank of slope No. 9SW-D/C115, i.e. Zone A of the 1999 landslide. The southerly branch discharges into the area of the washout scar observed to the south of the 1999 landslide. DL2 is much shorter and starts in the lower northern portion of the catchment in the area of hummocky ground and discharges onto the crest of slope No. 9SW-D/C114.

The section of Sham Wat Road in the vicinity of the landslide site trends in a northerly direction such that the lower part of CA1 and CA2 is truncated by the road, intersecting the hummocky ground and drainage channels contained within these catchments. Therefore, it is probable that the cut slopes along this section of road have at least in part been formed in colluvium, with the potential for concentrated surface water runoff and subsurface seepage arising from the ephemeral drainage lines.

4.3 Previous Ground Investigations

No previous ground investigation works have been carried out within the vicinity of the 1999 landslide site.

4.4 Current Investigation

4.4.1 General

Investigation works under this study comprised vegetation clearance and detailed mapping of the hillside surrounding slope No. 9SW-D/C115. Initially, vegetation clearance works were concentrated in the area immediately upslope from the 1999 landslide, the purpose being to confirm the nature and lateral extent of the tension cracks identified by the HyD. At a later stage, clearance works were extended to include the area to the north in an attempt to verify the possible existence and details of features interpreted as tension cracks/minor scarps from API. The extent of clearance works and results of the field mapping are shown in Figure 8.

4.4.2 Detailed Mapping

Detailed field mapping was undertaken by FMSW in November 1999, following the completion of slope trimming and the first phase of vegetation clearance works. Initial mapping identified a major scarp and a number of tension cracks/minor scarps, referenced MS1 and TC1 to TC8 respectively. Further vegetation clearance and mapping in August 2000 revealed another old main scarp and two further tension cracks/minor scarps, referenced MS2 and TC9 to TC10 respectively (Figure 8). The overall area of instability mapped by FMSW was about 100 m long and between 15 m and 20 m wide, with an estimated volume of displaced material of about 1 500 m^3.

The major scarp MS1 was located to the west of the 1999 landslide and occurred in the same place as where API identified the presence of possible tension cracks/minor scarps in 1986 and 1998 (TC 86-b and TC 98-b) and a failure scar in 1993 (93-b), as shown in Figure 4. The failure scar was about 20 m long and increased in width in a downslope direction from about 2 m at the crown to 20 m at the toe. The main scarp was about 2 m high and exposed between 1 m and 1.5 m of colluvium overlying residual soil. Five open soil pipes, typically 50 mm to 150 mm wide, were observed with the thin colluvium mantel (Plate 7). An intact raft of debris, 7 m wide by 10 m long, remained within the central portion of the scar (Figure 8 and Plate 8).

The colluvium exposed in the main scarp of MS1 comprised a firm, light yellowish brown to orangish brown, slightly sandy, clayey silt with many angular to sub-angular cobbles of highly decomposed Tuff and volcanic Rhyolite. The residual soil comprised a firm light yellowish brown mottled white, slightly sandy silt.

The tension cracks/minor scarps were typically discontinuous on the ground surface and were between 3 m and 10 m long with a horizontal separation between 50 mm and 350 mm and vertical displacements up to1 m. In contrast, TC5 was laterally persistent and formed about a 30 m-long extension to the northerly flank of MS1. TC5 corresponds to the location of TC86-a observed from API. The minor scarps were typically orientated north to south, parallel to the line of cutting along Sham Wat Road. The exception to this was TC2, which trended northeast to southwest, parallel to the northern flank of the regraded cut slope. Minor scarps TC1 to TC 5 showed signs of discolouration, with some vegetation growth over the exposed back scarp of TC2, and were partly infilled with dead plant debris and slope wash

material (Plate 9). In contrast, there were no signs of infill material within minor scarps TC6 to TC8, and the back scarps exposed comparatively fresh material with no vegetation growth (Plate 10). Details of the tension cracks/minor scarps are summarised in Table 2.

TC5 had two main orientations, namely north-south and northwest-southeast. The northwest-southeast orientated sections of TC5 were tightly closed with an en-echelon orientation and strike slip ground movements observed. The north-south orientated sections of TC5 were generally open suggesting extension. This provides evidence to suggest the main direction of ground movement within catchment CA1 is generally in an easterly direction, i.e. downslope.

Local bulging and shallow ground movement were observed close to minor scarps TC3, TC4 and TC7, which had resulted in breaching of the irrigation channel, and blocking of the channel with debris in the process (Plate 11). These localised ground movements had also resulted in severe distress to the channel, which was crushed and severed at a number of locations (Plate 12). A section of channel above and to the northwest of the 1999 landslide was missing following slope regrading works (Figure 8). This section may have been removed as a result of the regrading works or, based on API, it is possible that this missing section may have been displaced/badly deformed by previous instability in the hillside above between 1993 and 1994. The observed condition of the adjoining section of channel (north of the regraded area) was cracked and appeared deformed. This provides further evidence to suggest that the missing channel section was also cracked and deformed prior to the 1999 landslide.

Further vegetation clearance was undertaken in August 2000 in the area to the north of the regraded slope in an attempt to confirm the existence of possible tension cracks/minor scarps observed from API (Figure 8). This work confirmed the presence of minor scarps, TC9 and TC10, in the area where possible distress (TC 98-a) was observed from API (Figure 4). TC9 was about 25 m long, with a horizontal separation of 150 mm and a vertical displacement of 250 mm. The back scarp of TC9 was slightly discoloured with no vegetation growth. TC10 was about 3.5 m long, with no horizontal separation and a vertical displacement of 250 mm. The back scarp to TC10 was discoloured with vegetation growth.

Remnants of an old major scarp, MS2, and evidence of ground bulging and shallow movement were identified above the crest of slope No. 9SW-D/CR112 (Figure 8). The main scarp of this failure, which was about 20 m long with no horizontal separation and a vertical displacement of 400 mm, was discoloured and had vegetation growth over it (Plate 13). The location and condition of the scarp indicate that it may have been linked to the instability recorded above this feature during the formation of the road in 1985/86.

Localised ground distress in the form of erosion hollows was also observed along both drainage lines DL1 and DL2. At the time of FMSW's inspection, these drainage lines were dry but there was a pronounced damp area within the upper section of the regraded slope below the northerly branch of DL1. This damp area is where a minor failure and soil pipe was observed in October 1999 following slope regrading works. A similar darker tone, possibly denoting another damp area, was observed below the major scarp MS1 (Plate 8).

4.5 Deduced Ground Conditions

Field mapping has confirmed the presence of a thin mantle of colluvium approximately 1 m to 1.5 m thick with a network of soil pipes, overlying residual soil within and above the landslide site. In accordance with API, this mantle of colluvium appears to be pervasive throughout the lower lying areas of catchments CA1 and CA2, such that it is likely that all the slopes in this area are at least in part formed in colluvium. Extensive near-surface distress in the form of tension cracks/minor scarps and shallow landsliding has been observed within the lower portion of catchment CA1 with larger-scale and possibly deeper-seated instability observed in the upper portion of the catchment. This shows that the hillside above the landslide site is in a marginally stable condition.

4.6 Deduced Groundwater Conditions

It is considered that the site setting of a thin mantle of loose colluvium overlying completely decomposed tuff is favourable to direct infiltration and the formation of a perched water table, giving rise to transient elevated water pressures within the colluvium. Due to the shallow and loose nature of the colluvium, it is probable that perching develops rapidly and that near-surface materials become saturated quickly. This process would be exacerbated by the presence of open tension cracks within the colluvium, some of which truncate the ephemeral drainage lines. Furthermore, the presence of soil pipes provides localised preferential pathways for rapid water flow into the area of the 1999 landslide site and below the ephemeral drainage lines DL1 and DL2.

The geological contact in the hillside above the landslide site may also have some influence on the regional groundwater setting of the area within catchment CAI, but the exact influence, if any, is not known.

The size and shape of the catchment above the failed slope, defined by CA1, would tend to channel surface and subsurface water flows towards the ephemeral drainage lines above the cut slopes leading to concentrated water flows at specific locations. Due to the proximity of the northerly branch of DL1 to the 1999 landslide, it is possible that surface and subsurface water flows along DL1 were concentrated into the area of the 1999 landslide.

5. RAINFALL ANALYSIS

The nearest operational GEO automatic raingauge No. N17 is located at Tung Chung Sub-unit, 1 Ha Ling Pei, Tung Chung, North Lantau, about 5 km to the east of the landslide site. The raingauge records and transmits rainfall data at 5-minute intervals via a telephone link to the GEO. These records have been analysed to determine the characteristics of the rainstorm associated with the landslide.

For the purpose of the rainfall analysis, the landslide was assumed to have occurred at 12:00 p.m. on 24 August 1999. The daily rainfall recorded by the raingauge for the period from 24 July to 25 August 1999, together with the hourly rainfall from 22 to 24 August 1999, are shown in Figure 9. It can be seen that on the day of the landslide, about 90 mm of rainfall was recorded prior to the landslide event and that nearly 250 mm rainfall was recorded in the

previous day. The maximum 12-hour and 24-hour rolling rainfall recorded in the two days prior to the landslide was 205 mm and 310.5 mm respectively (Table 3).

Table 3 presents the estimated return periods for the maximum rolling rainfall recorded at raingauge No. N17 for selected durations preceding the landslide based on historical rainfall data recorded at the Hong Kong Observatory (Lam & Leung, 1994). The maximum 48-hour rainfall of 424 mm was the most severe with a return period of about 9 years.

A comparison of the patterns of previous severe rainstorms recorded by raingauge No. N17 is shown in Figure 10. It is evident that the rolling rainfall for the 22 to 24 August 1999 rainstorm was not the most severe event experienced by the site, with a particularly severe storm experienced on 5 November 1993.

6. DISCUSSION

The close correlation between the rainstorm and the occurrence of the 1999 landslide suggests that the failure was probably triggered by rainfall. The fact that the slope failed during a rainstorm that was not particularly severe in comparison with previous rainstorms indicates that ground conditions in this area may have been subjected to progressive deterioration with time. This is corroborated by API and site mapping, which has identified the existence of older and more recent instability in the hillside above the cut slopes, which takes the form of major and minor scarps. This has given rise to the formation of open cracks, some of which traverse drainage lines within the lower portion of the catchment, increasing the susceptibility of the hillside to infiltration and the formation of cleft and transient elevated water pressures.

Based on API, the instability in the lower portion of the catchment above the failed cut slope is a fairly recent development that has occurred since the construction of Sham Wat Road in 1985/86. It is considered that the formation of the cut slopes (45°) in an area of marginally stable hillside has resulted in the removal of support, which, combined with the adverse hydrogeological setting of the site (i.e. colluvial mantle with erosion pipes overlying saprolites), has led to the development of widespread instability. This instability has typically involved minor slumping type failures within colluvium and residual soil, with the formation of open cracks, but without full detachment of material from the rupture surface. Field mapping and API has shown that the instability in the lower portion of the catchment has become more widespread with time and that in areas it was retrogressing uphill.

Localised ground movements occurring since the formation of Sham Wat Road have resulted in the blockage and distortion of the irrigation channel above the cut slopes. In particular, it would appear that the channel above and to the south of slope No. 9SW-D/C115 was badly damaged, such that water would discharge around Zone B onto the hillside in the location of Zone A (as Zone B is higher in elevation than Zone A). This would have exacerbated the adverse groundwater conditions at the site and may have been a significant contributory factor in the 1999 landslide.

The 1999 landslide in part involved complete detachment of failed debris and therefore was comparatively more mobile than the previous instability, probably due to the

deteriorating ground conditions that have promoted an increased rate of infiltration into the distressed near-surface materials.

The cut slopes along the road have been designed to a low, nominal Factor of Safety because of a negligible direct risk to life. No site-specific drainage measures have been installed to deal with colluvial deposits and truncated drainage lines. These are significant contributory factors.

This study has identified the dominant instability as being a relatively shallow landsliding process that principally involves colluvium. However, the laterally extensive nature of distress may indicate some regional generic factors controlling hillside instability. Joint orientations within the tuff could not be ascertained as no drillholes had been carried out. However, if laterally persistent joints were found, orientated parallel to the trend of the road, hillside instability may have an element of structural control and not necessarily be confined to near-surface materials. Therefore, the potential for deeper-seated, larger-scale instability cannot be ruled out.

It is apparent that there is another mode of instability ongoing within catchment CA1 above slope No. 9SW-D/C115. This relates to individual larger-scale landslides with debris runout in the upper portion of the catchment, where the ground profile is locally steeper, typically 45° to 50° (which is the result of past instability) and landslide activity is essentially natural retrogressive behaviour associated with locally over-steep terrain. The steeper terrain and instability may be related to the geological boundary located in this area (Section 4.1).

Given the development of extensive surface distress in the lower portion of the catchment, the near-surface colluvial deposits in this area are more susceptible to reactivation. A landslide with debris runout in the upper catchment is liable to result in a greater degree of entrainment in the lower catchment and longer debris runout.

7. CONCLUSIONS

It is concluded that the 24 August 1999 landslide was probably triggered by rainfall with an estimated return period of about 9 years.

The failure during the 24 August 1999 rainstorm is considered to be due to progressive deterioration of the condition of slope No. 9SW-D/C115 and the ground above, including the formation of open tension cracks, which led to an increase in infiltration into the near-surface materials. This, combined with the adverse hydrogeological setting of the site, i.e. colluvial mantle with erosion pipes overlying saprolites, were significant contributory factors to the landslide.

The cut slopes formed along Sham Wat Road in 1985/86 were designed to a low nominal Factor of Safety and do not have appropriate drainage measures to deal with the adverse hydrogeological setting of the site. This has led to the removal of lateral support to the hillside above the road giving rise to instability in the near-surface materials and the development of widespread distress in the lower portion of the catchment.

The principal mode of instability in the lower portion of the catchment above the failed slope appears to primarily involve localised shallow ground movements within near-surface colluvial deposits and residual soil giving rise to the formation of minor scarps, with occasional detachments and debris runout, probably during heavy rainfall. This type of instability is extensive over much of the hillside within the catchment and has led to a progressive deterioration in ground conditions. Based on the available information, the potential for deeper-seated larger-scale instability cannot be ruled out.

8. REFERENCES

King, J.P. (1998). The Sham Wat Road Debris Lobes Interim Report, Technical Note TN 6/98. Geotechnical Engineering Office, Hong Kong, 37 p.

Lam, C.C. & Leung, Y.K. (1994). Extreme rainfall statistics and design rainfall profiles at selected locations in Hong Kong. Royal Observatory, Hong Kong, Technical Note No. 86, 89 p.

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

Wong, H.N. & Ho, K.K.S. (1995). The 5 November 1993 Lantau Landslip Study – General Report on Landslips at Man-Made Features, Special Projects Report, Geotechnical Engineering Office, Hong Kong, SPR 7/94.

LIST OF TABLES

Table 1 – Record Details of Aerial Photographs Studied (Sheet 1 of 5)

Photograph Details	Observations
25/02/63 7000' Y06392 Y06393	High Level photographs, good resolution In these early photographs Sham Wat road does not exist. The irrigation channel, which runs across the site above the present day road can be seen and appears relatively new. The catchwater, which traverses the hillside above the present day road appears to be under construction and freshly tipped fill material can be seen directly below it. A small track can also be seen below the catchwater above the irrigation channel. The study area at this time comprises mainly natural terrain with some agricultural terracing along the floor of the valley below the landslide site, which is clearly still in use. Several large colluvial fans can be seen descending the hillsides to the north, south and west (up slope) of the studied area. Many boulders of various sizes can also be seen throughout the area. Several natural drainage lines descend from the surrounding hills. One of these drainage lines can be viewed passing through the area of the site near the location of the present day cut slope 9SW-D/C114. A further minor drainage line can also be identified to the south of slope 9SW-D/C115. A number of concave depressions, interpreted as relic failure scars, can be seen in the hillside below the catchwater. In particular, three scars, referenced 63-a to 63-c, lie in a broad well-defined depression above the landslide site. This depression (CA1) lies within a larger depression (CA2), both of which are defined by a sharp convex break of slope. These features in themselves may also be older relic scars. A tear-drop shaped lobe of debris is evident below scar 63-c, and a larger fan of bouldery material extends to the middle part of CA1 below scars 63-a and 63-b, from where it appears to converges with debris from scar 63-c towards the southern flank of CA1. This indicates that colluvium lines the depression. A drainage line (DL1) descends CA1 below scar 63-b. It appears to have cut its way through the colluvial deposits lining the depression. In the central portion of the depression the drainage line branches into two, separated by an area of higher ground. Further downslope the two branches merged again and discharge into the extensive colluvial deposit lining the floor of the valley. In the lower. A second shorter and less distinct drainage line, DL2, is evident to the north of DL1.

Table 1 – Record Details of Aerial Photographs Studied (Sheet 2 of 5)

Photograph Details	Observations
22/11/84 6000' 57271 57272	High level good resolution photographs The agricultural terracing below the site has now been mostly abandoned. A track or footpath has been formed below the irrigation channel and follows an alignment resembling that of the present day Sham Wat Road, but the road has not been formed yet. The vegetation cover across CA1 is denser than in the 1963 aerial photographs and less detail is evident, but the outline of the three 1963 failure scars are still apparent. The lower portion of CA1 appears to comprise a series of rounded hillocks, which form an irregular surface profile. Patches of erosion (or remnants of fill slopes not yet vegetated) can be observed below the catchwater, and a recent failure can be seen along a drainage line about 100 m to the north of the landslide site. A number of narrow strips of bare/thinly vegetated soil are apparent cutting across the track following the alignment of Sham Wat Road, in the immediate vicinity of the present-day slopes 9SW-D/C115, D/C114 and D/CR112. This is possible evidence to suggest instability, which could have occurred between 1963 and 1984.
23/04/85 3,500' 65781 65782	Low level good resolution photographs. The track below the irrigation channel identified in the 1984 aerial photographs has been widened and cut slopes have been created within the area of present day slopes 9SW-D/C115 and D/C114. End tipped fill material from the road widening can be seen down slope (east) of the site. The road still appears to be under construction. The irrigation channel and catchwater are clearly visible.
12/02/86 10,000' A04181 A04183	High level good resolution photographs Sham Wat road remains unchanged as do the previous years road cuts. The natural drainage lines are still visible and can be seen descending down through the site. Areas of erosion have been noted downslope (west) of Sham Wat Road. These areas correspond to the location of the natural drainage lines DL1 and DL2. Patches of erosion can also be seen below the catchwater, possibly as a result of localised failure within the unconsolidated end tipped fill material.

Table 1 – Record Details of Aerial Photographs Studied (Sheet 3 of 5)

Photograph Details	Observations
1986 cont.	The vegetation within the terraced area, (observed in 1963) is now well-established, no trace of the terraces can be seen. A recent failure scar, 86-a, can be seen above the original road cut, within the location of present day slope No. 9SW-D/C115 and at the same location as the 1999 landslide. A linear feature (TC 86-a) 20 m to 30 m long trends parallel to the road in the hillside above the irrigation channel. This may be a possible tension crack or indication of local instability (minor scarp). An angular feature formed by two intersecting lighter-tone lines, TC 86-b (interpreted as a tension crack) can be seen above present day slope No. 9SW-D/C115, and appears to cross-cut the irrigation channel. In the southern part of the slope No. 9SW-D/C114, an area of dark material can be seen covering the original cut face. The material appears uniform, however, it is difficult to see any detail, possibly chunam/ shotcrete or a temporary cover to prevent erosion. A further small debris slide, 86-b, with a debris trail approximately 6 m long, can be observed within the area of present day slope No. 9SW-D/CR112.
14/01/87 5,000' A08745-A08744	Low level good resolution photographs Outside of the site area further along Sham Wat Road, slide debris material can be seen in several areas extending across the road. The irrigation channel above the site is still visible and intact. Cut slopes Nos. 9SW-D/C115, D/C114 and D/CR112 have now been modified as part of the repair works following the failures in 1986, and their boundaries' now resemble the shape as recorded by the GEO. The surface along this approximately 80 m long section of regraded slope appears as a highly reflective area, which may indicate newly applied rigid surface cover. Above slope No. 9SW-D/C115 tension cracks and patches of bare/thinly vegetated soil can be observed. This provides evidence to suggest that the area above the cut slope D/C115 is unstable. The natural drainage lines are still visible, the southern line appears to drain into an area of hummocky ground above slope D/C115 near the angular tension cracks (1986). The irrigation channel above the site is also still visible.

Table 1 – Record Details of Aerial Photographs Studied (Sheet 4 of 5)

Photograph Details	Observations
30/10/91 5,000' A28939 A28940	High level good resolution photographs.v The configuration of cut slopes along Sham Wat Road now resembles the present day layout. Vegetation is now starting to grow on slopes No. 9SW-D/C115 and D/C114. A recent landslide (91-a), with a small debris trail can be seen down slope of the irrigation channel, approximately 10 m to 20 m above slope D/C114. The irrigation channel above the slide appears to have been damaged, possibly as a consequence of the failure. Construction of the power line (small equally spaced patches of cleared ground), which traverses the site at present, appears to be under way. Laterally extensive (40 m long) linear features, interpreted as tension cracks/minor scarps, are evident trending parallel to the road, behind slopes Nos. 9SW-D/CR112 & D/C114 and curving around the side of slope D/CR112. The 'angular' tension crack, TC 86-b, is still visible above slope D/C115 upslope of the drainage channel. Patches of bare/thinly vegetated soil are apparent above slopes D/CR112, D/C114, and D/C115.
5/12/93 6,000' CN5200	Mid-level poor resolution photographs. Many land-slides and debris trails can be seen in the area of the landslide site. These slides are probably the result of a severe rainstorm on 15 November 1993. Eight landslides, 93-a to 93-h, can be observed up slope of the landslide site below the catchwater. One landslide, 93-a, has occurred in the area adjoining slope No. 9SW-D/C115 to the south and another, 93-b, in the area of the inverted 'angular' shaped tension cracks (TC 86-b), above slope No. 9SW-D/C115. Both landslides appear to have occurred along the southern branch of the drainage line DL1 identified in the 1963 aerial photographs. Debris material from these slides can be seen downslope of the road, therefore the road must have been blocked. The irrigation channel below 93-b has either been breached or undermined by the failure as the scar descends below the channel alignment. The crests of slopes Nos. 9SW-D/C115 and D/CR112 seem to have progressed further upslope, as they appear wider than in the previous photographs (1991), also, vegetation visible on these slopes in 1991 can no longer instead a highly reflective area is visible, inferring new surface protection. This suggests that the slopes D/CR112 & D/C115 may have been subjected to further instability. Further evidence to suggest instability is the presence of gabions at the foot of slope D/CR112.

Table 1 – Record Details of Aerial Photographs Studied (Sheet 5 of 5)

Photograph Details	Observations
4/02/94 5,500' A33896	Medium level good resolution. Very little change since 5/12/93. Vegetation has obscured several of the previous slides above the site (below the catchwater). Vegetation is starting to re-grow on slopes 9SW-D/CR112, D/C114 and D/C115.
20/12/94 4,000' CN9052	Low level good resolution photographs. Evidence of retrogressive failure of scar 93-a above slope No. 9SW-D/C115, which appears to have undermined the irrigation channel. The gabions at the toe of slope D/CR112 have been reinforced with barrels.
30/10/95 3,500' CN11435	Low level good resolution photographs. No significant change. Vegetation starting to colonise the slide adjacent to 9SW-D/C115.
29/10/96 3,500' A43547	Low level good resolution photographs. No significant change.
29/01/97 6,000' CN16637	High level good resolution photographs. The sun is at low angle, therefore site in shade. Increased vegetation cover at site within the area of the stream line above D/C114 suggests damp or wet conditions exist in this area compared to other parts of the hill side, which exhibit reduced vegetation, indicative of dryer conditions.
28/05/98 4,000' CN19891-19892	Low level, very hazy, poor resolution photographs. Well-established vegetation in areas corresponding to natural drainage channels. An extensive tension crack/minor scarp, TC 98-a, is visible upslope of slope Nos. 9SW-D/C115, D/C114 and D/CR112. It is difficult to accurately assess it's length (persistence) due to vegetation cover, but it is approximately 30 m to 35 m long.

Table 2 – Scarp Details

Reference No.	Dimensions			Condition of Back Scarp	Corresponding Feature Observed from API	Comments
	Length (m)	Crack Width (mm)	Vertical Displacement (mm)			
TC1	2.6	100	300	Slight discolouration no vegetation growth	Not Observed from API	Recently formed
TC2	9	150	250	Discoloured with vegetation growth	TC 91-a	Old
TC3	5	50	150	Slight discolouration no vegetation growth	Not Observed from API	Recently formed
TC4	3.5	250	400	Slight discolouration no vegetation growth	Not Observed from API	Recently formed
TC5	30	350	800	Varies – some sections with slight discoloration and some vegetation growth, others no discolouration or vegetation growth	TC 86-a and TC 98-b	Old with recently propagated portion
TC6	13	100	300	No discolouration no vegetation growth	Not Observed from API	Recently formed
TC7	4.6	100	400	No discolouration no vegetation growth	Not Observed from API	Recently formed
TC8	8.2	300	1000	No discolouration no vegetation growth	Not Observed from API	Recently formed
TC9	25	150	250	Slight discolouration no vegetation growth	TC 98-a	Relatively new
TC10	3.4	0	300	Discoloured with vegetation growth	TC 91-a	Old
MS1	40	0	2000	No discolouration no vegetation growth	TC 98-b	Relatively new
MS2	20	0	400	Discoloured with vegetation growth	TC-91-a	Old

Table 3 - Maximum Rolling Rainfall at GEO Raingauge No. N17 for Selected Durations Preceding the 24 August 1999 Landslide and the Estimated Return Periods

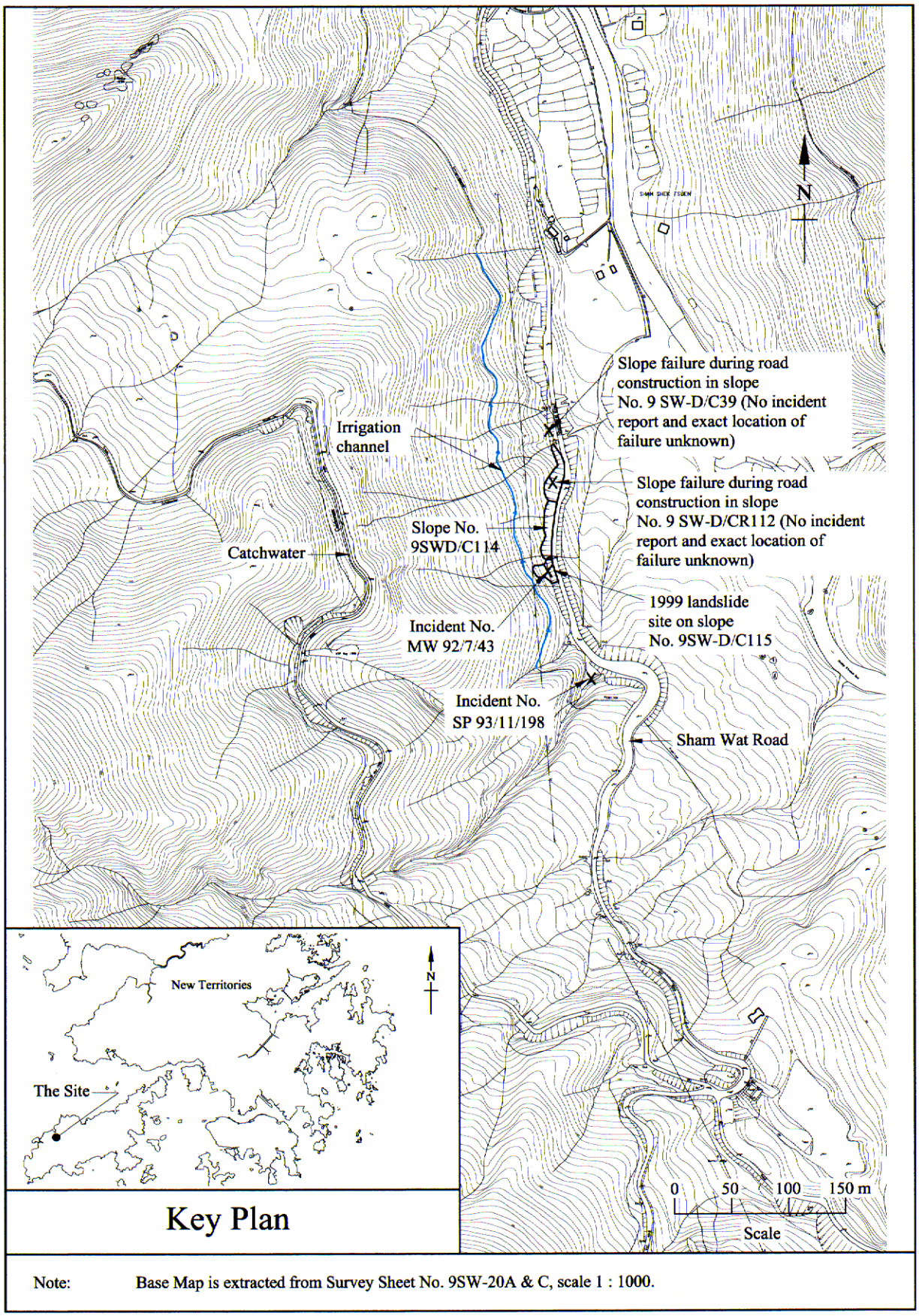
Duration	Maximum Rolling Rainfall (mm)	End of Period	Estimated Return Period (Years)
5 Minutes	6.0	06:15 on 23 August 1999	< 2
15 Minutes	16.5	06:20 on 23 August 1999	< 2
1 Hour	54.5	07:05 on 23 August 1999	< 2
2 Hours	95.5	08:00 on 23 August 1999	2
4 Hours	130.5	08:50 on 23 August 1999	3
12 Hours	205.0	08:25on 23 August 1999	3
24 Hours	310.5	14:40 on 23 August 1999	5
2 Days	424.0	10:00 on 24 August 1999	9
4 Days	433.0	10:00 on 24 August 1999	5
7 Days	433.0	10:00 on 24 August 1999	3
15 Days	516.0	10:00 on 24 August 1999	2
31 Days	578.6	10:00 on 24 August 1999	< 2

Notes: (1) Return periods were derived from Table 3, of Lam and Leung (1994).

(2) Maximum rolling rainfall was calculated from 5-minute data.

(3) The use of 5-minute data for durations between 4 hours and 31 days results in better data resolution, but may slightly over-estimate the return periods using Lam and Leung (1994)'s data, which are based on hourly rainfall for these durations.

LIST OF FIGURES



Note: Base Map is extracted from Survey Sheet No. 9SW-20A & C, scale 1 : 1000.

Figure 1 - Site Location Plan

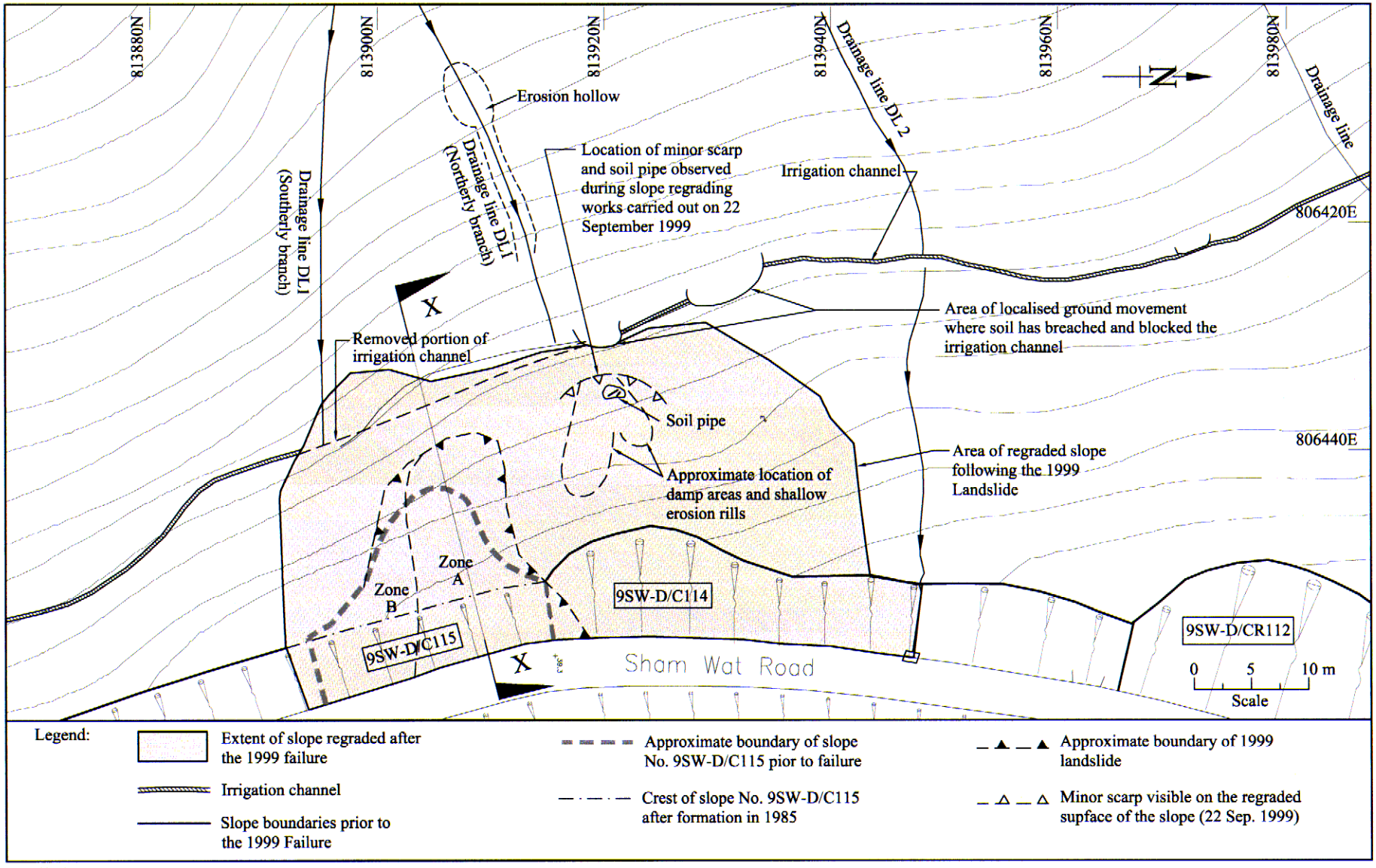
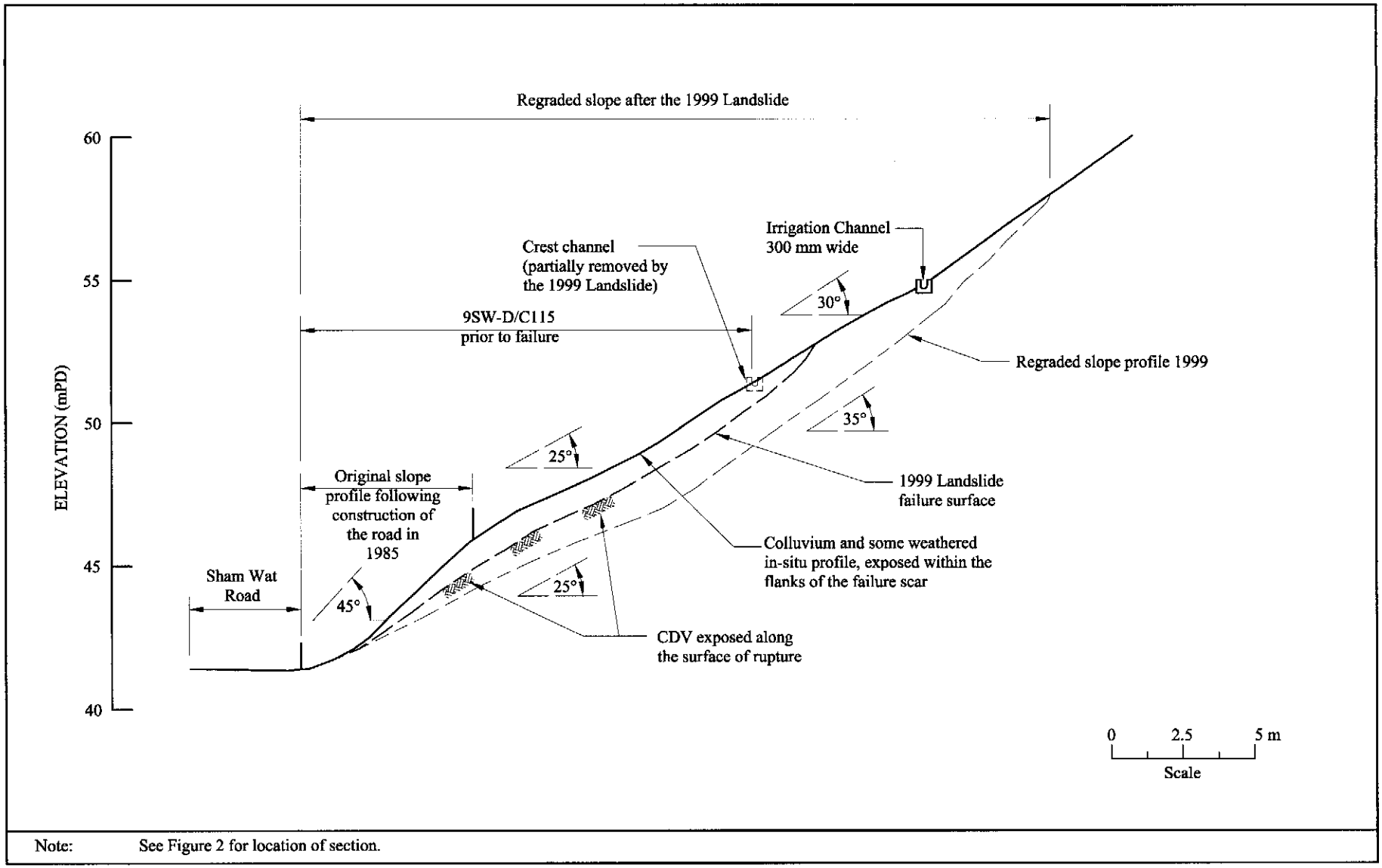
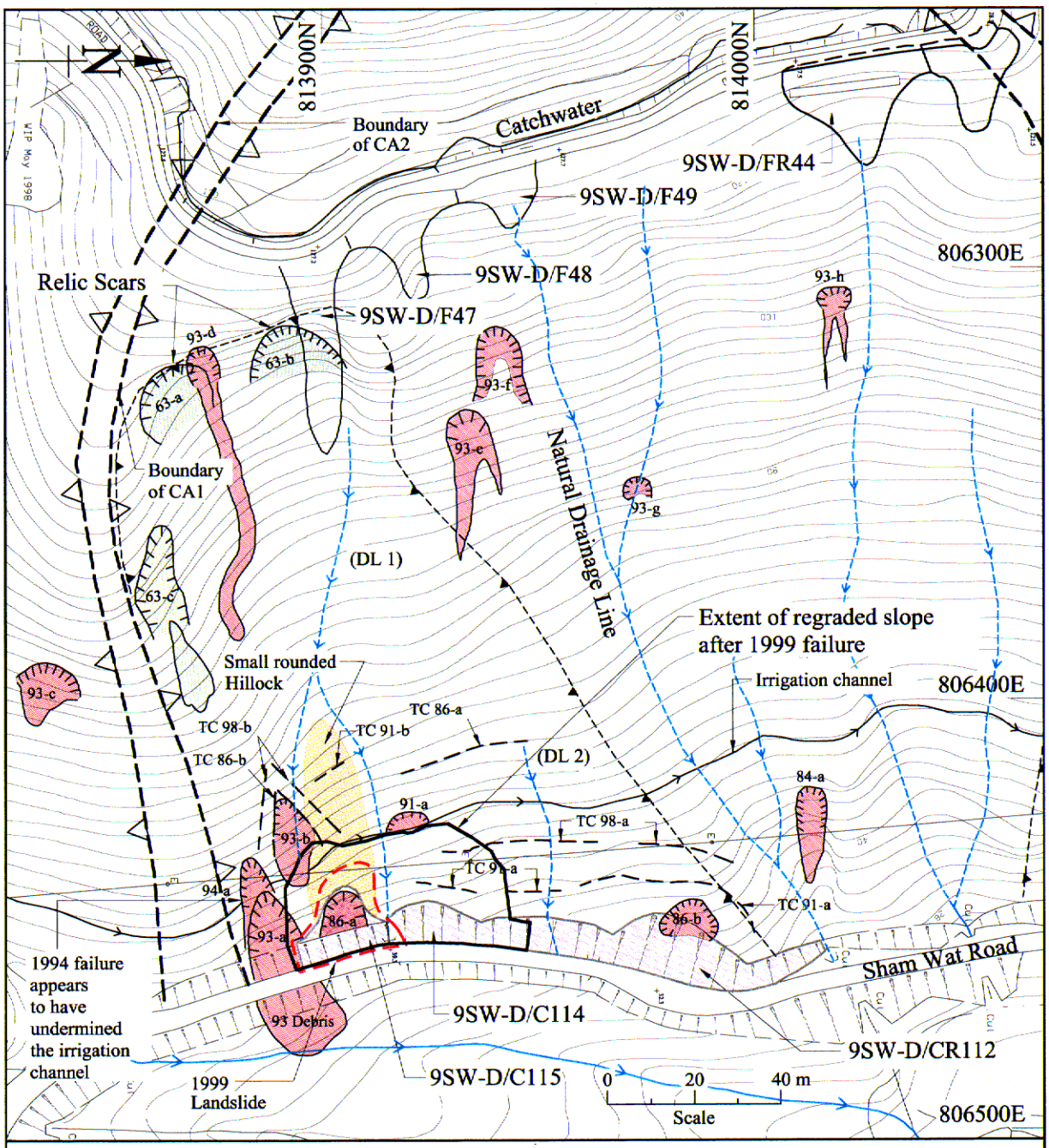


Figure 2 - Plan of the Landslide Site



Note: See Figure 2 for location of section.

Figure 3 - Cross-section X-X through the Landslide Site



Legend:

- Linear features (possible tension cracks)
- Relic failure scars prior to 1963
- Landslide scars (year observed)
- Area of locally higher ground around which drainage line DL1 branches
- Cut slope boundaries prior to 1999 failure
- Location of 1999 landslide
- Boundary of large depression/catchment, defined by a continuous convex break in slope
- Boundary of smaller depression/catchment, defined by a continuous convex break in slope
- (DL1) Drainage line without obvious stream course
- Drainage line with obvious stream course

Notes:

(1) Base Map is extracted from Survey Sheet No. 9SW-20A, scale 1:1000. and also based on topographical survey carried out by Survey Section, Highways Department after the landslide.

(2) Information shown on this figure is based on topographic survey, geomorphological and engineering geological mapping, field observations and documentary records.

Figure 4 - Landslide and Slope Distress History Observed from API

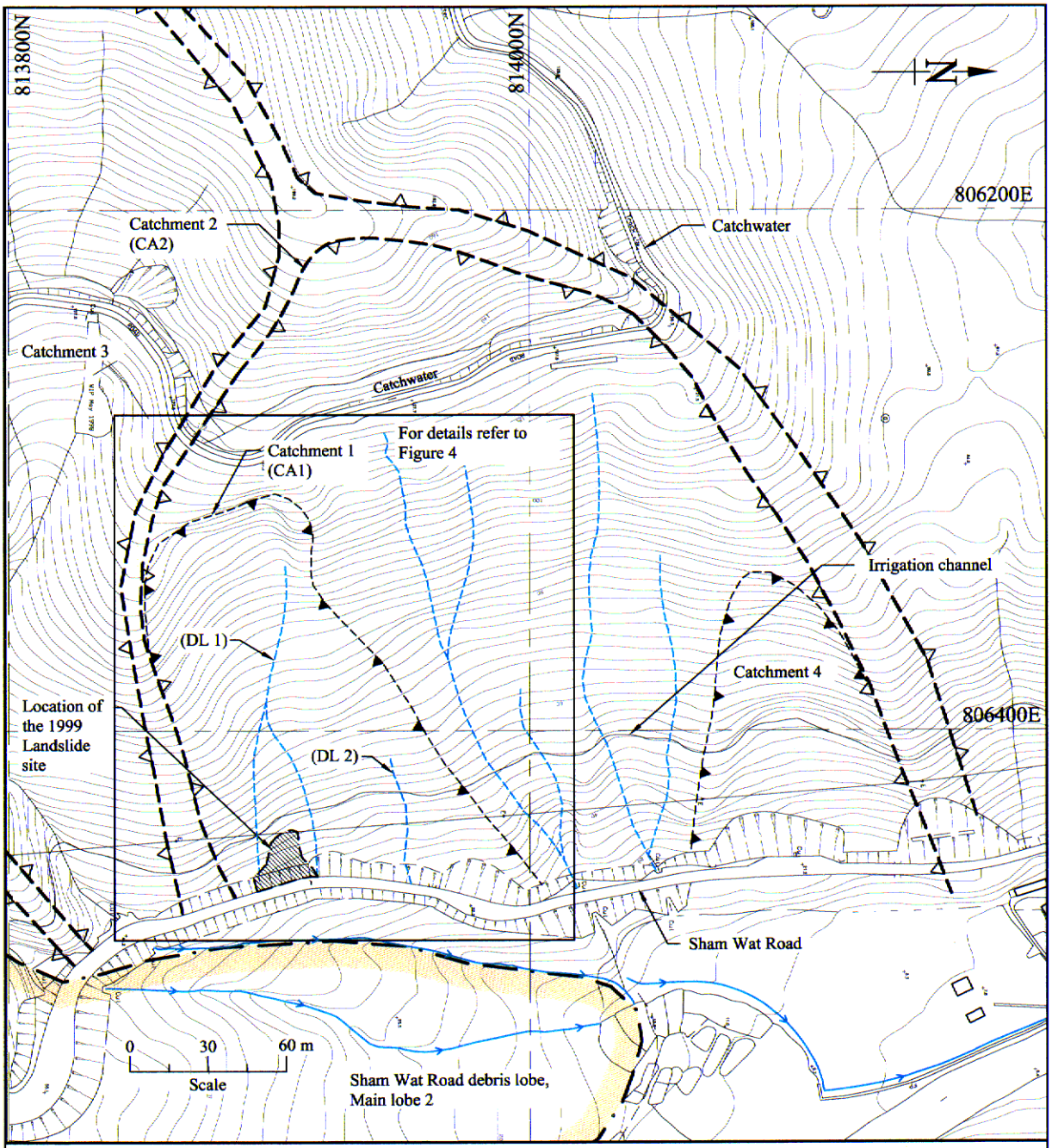
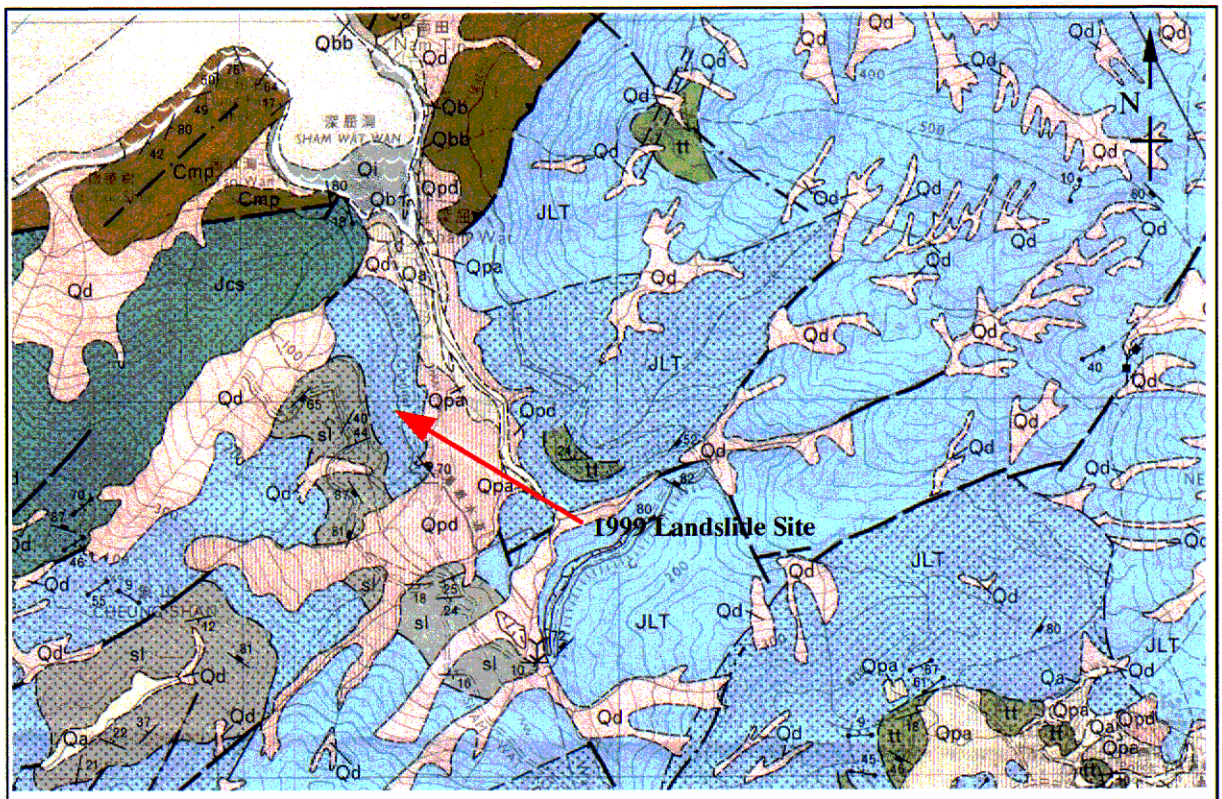


Figure 5 - Geomorphology of the Landslide Site



LEGEND:

SUPERFICIAL DEPOSITS

- Qd — Slope debris (Pleistocene and Holocene)
- Qpa — Terraced Alluvium
- Qpd — Slope debris (Pleistocene)

SOLID GEOLOGY

- JLT — **Rhyolite lava and tuff**
- Jcs — Eutaxite
- sl — Siltstone
- Cmp — Metasiltstone, metasandstone; graphite-bearing
- Metamorphosed

GEOLOGICAL LINES

- Geological boundary, superficial deposits
- Geological boundary, solid rock
- Fault (crossmark indicates downthrow side)
- Photogeological lineament

(* Broken lines on map face denote uncertainty)

STRUCTURAL SYMBOLS

- 20 — Inclined bedding
- 20 — Inclined flow fabric
- 20 — Inclined jointing
- Vertical jointing

MINERAL AND MISCELLANEOUS SYMBOLS

- Sedimentary younging direction

Notes: (1) Geology relevant to study area shown bold.
(2) Extracted from Sheet 9 of the Hong Kong Geological Survey 1 : 20,000 Scale Map Series HGM20 (GEO, 1994).

Figure 6 – Geological Plan of the Landslide Site

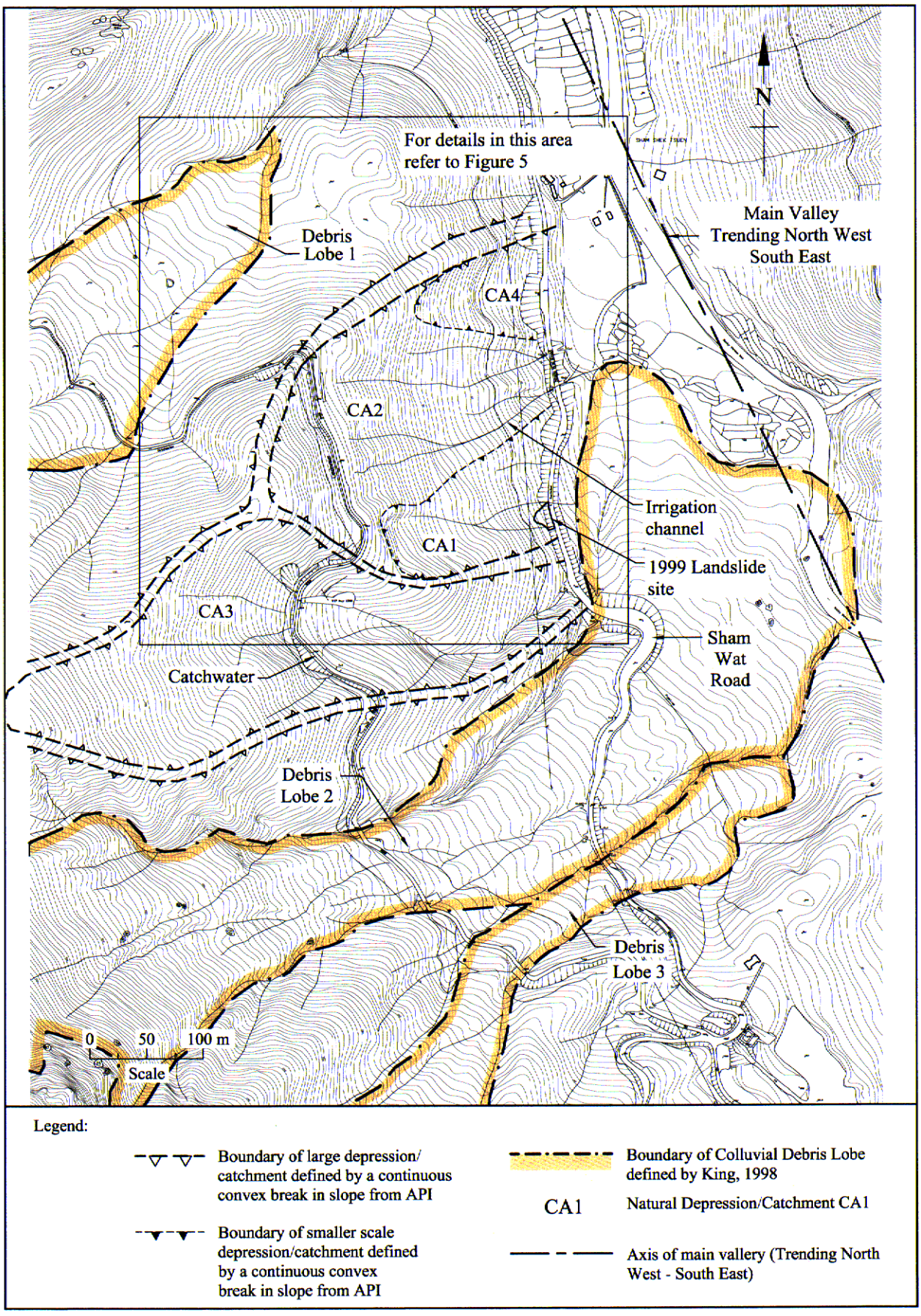


Figure 7 - Regional Map Showing the Location of Sham Wat Debris Lobes

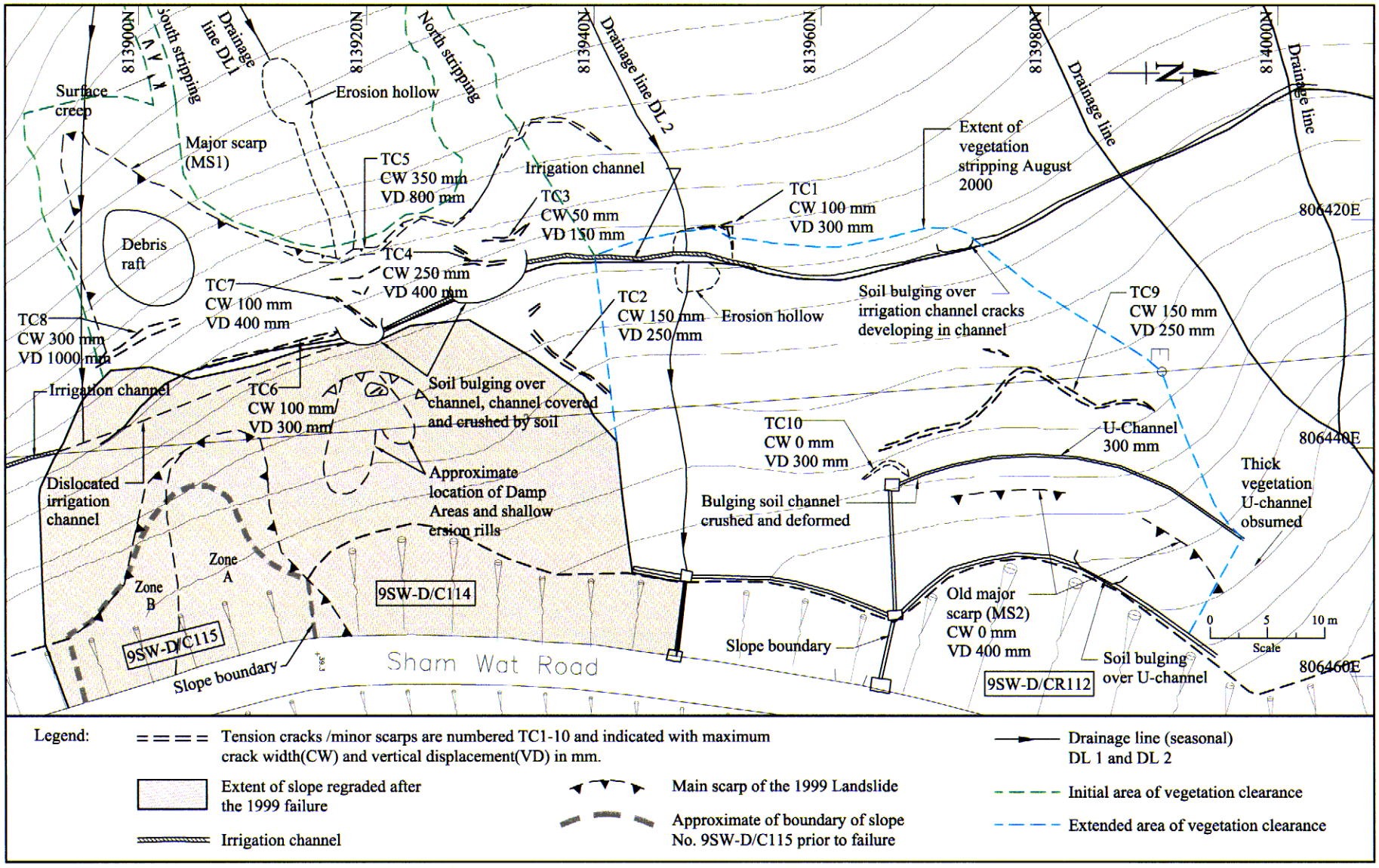
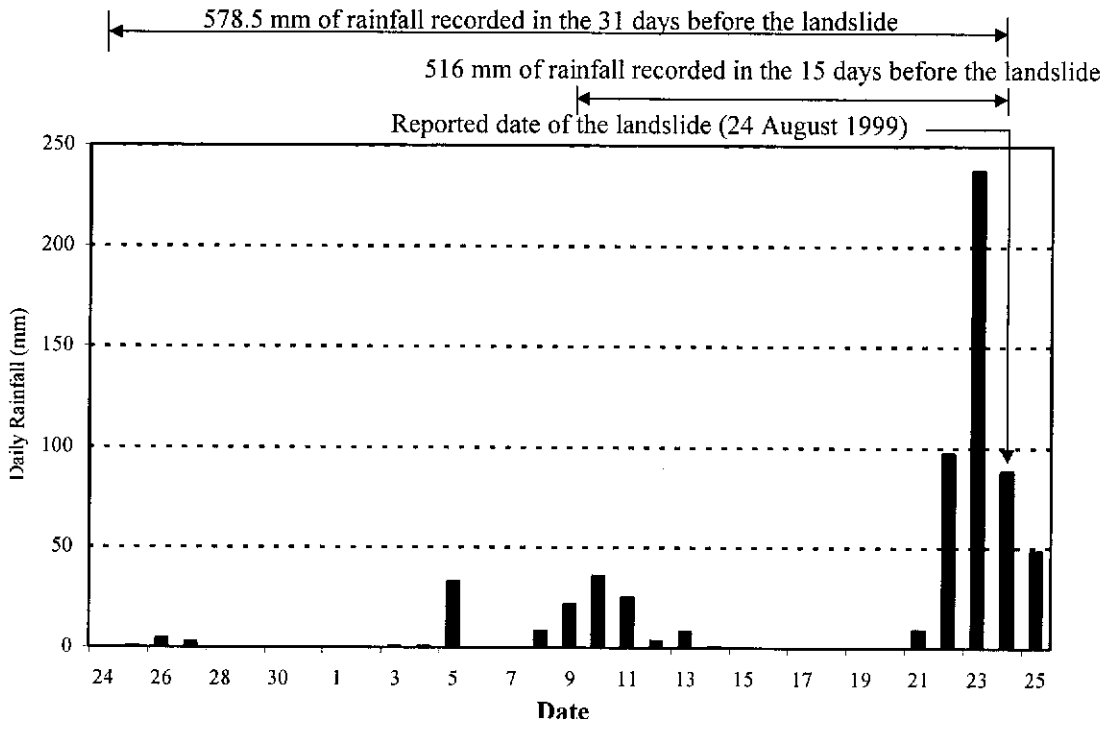
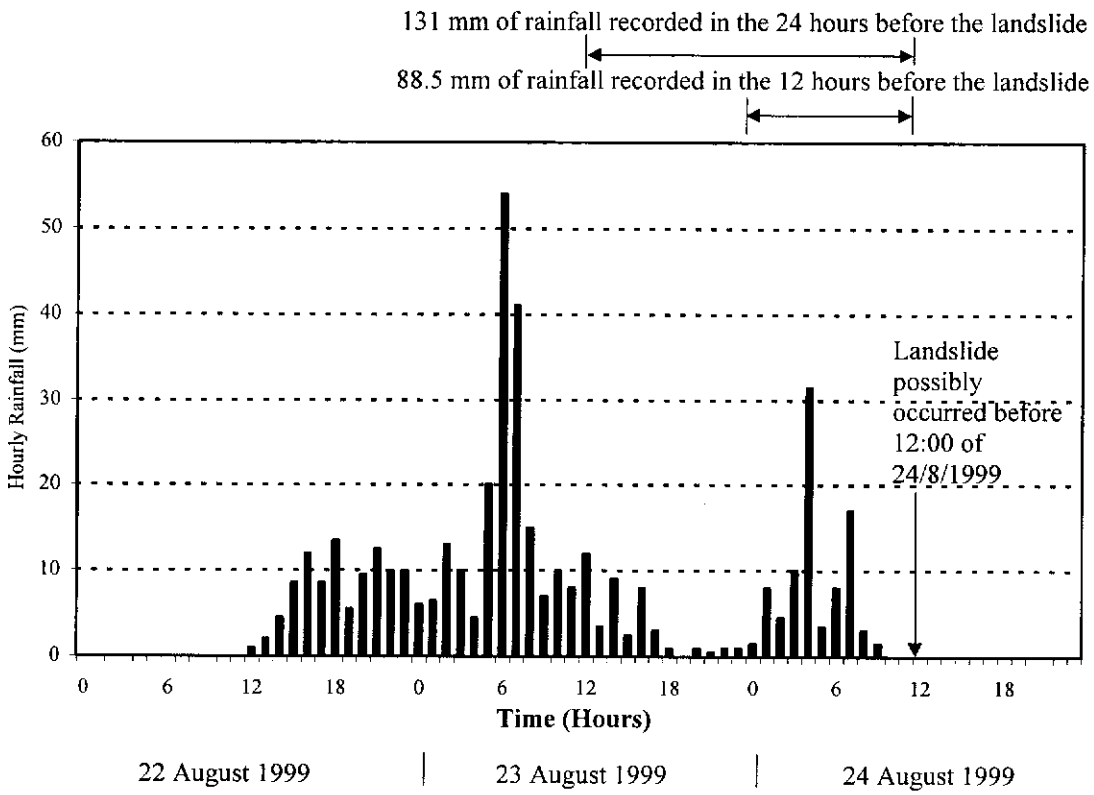


Figure 8 - Ground Movement and Distress Plan from Field Mapping

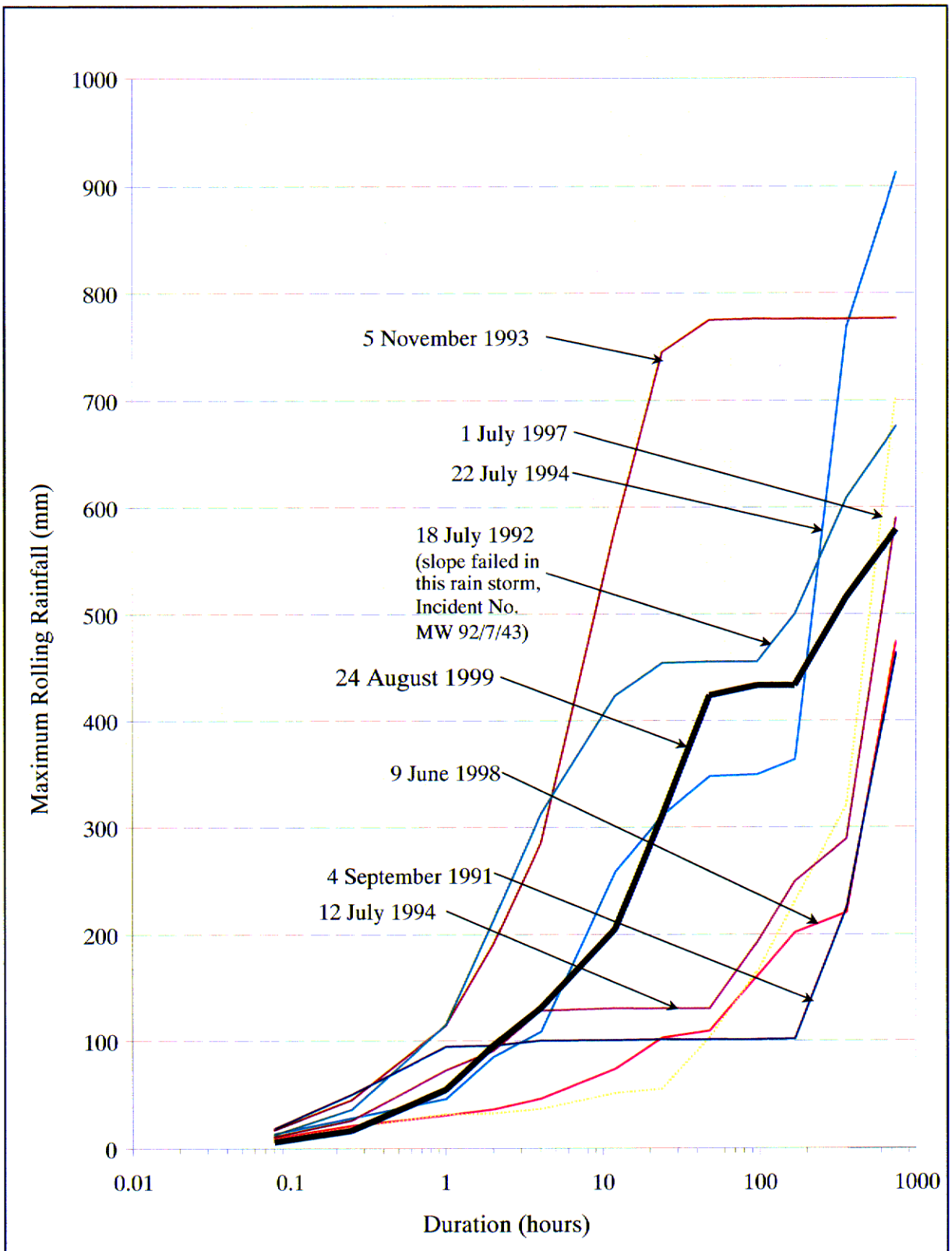


(a) Daily Rainfall Recorded between 24 July and 25 August 1999



(b) Hourly Rainfall Recorded between 00:00 hours on 22 August and 24:00 hours on 24 August 1999

Figure 9 – Rainfall Recorded at GEO Raingauge No. N17



Note: Rainfall data are 5-minute statistics from GEO raingauge No. N17.

Figure 10 – Maximum Rolling Rainfall at GEO Raingauge No. N17 for Selected Major Rainstorms between 1991 and 1999

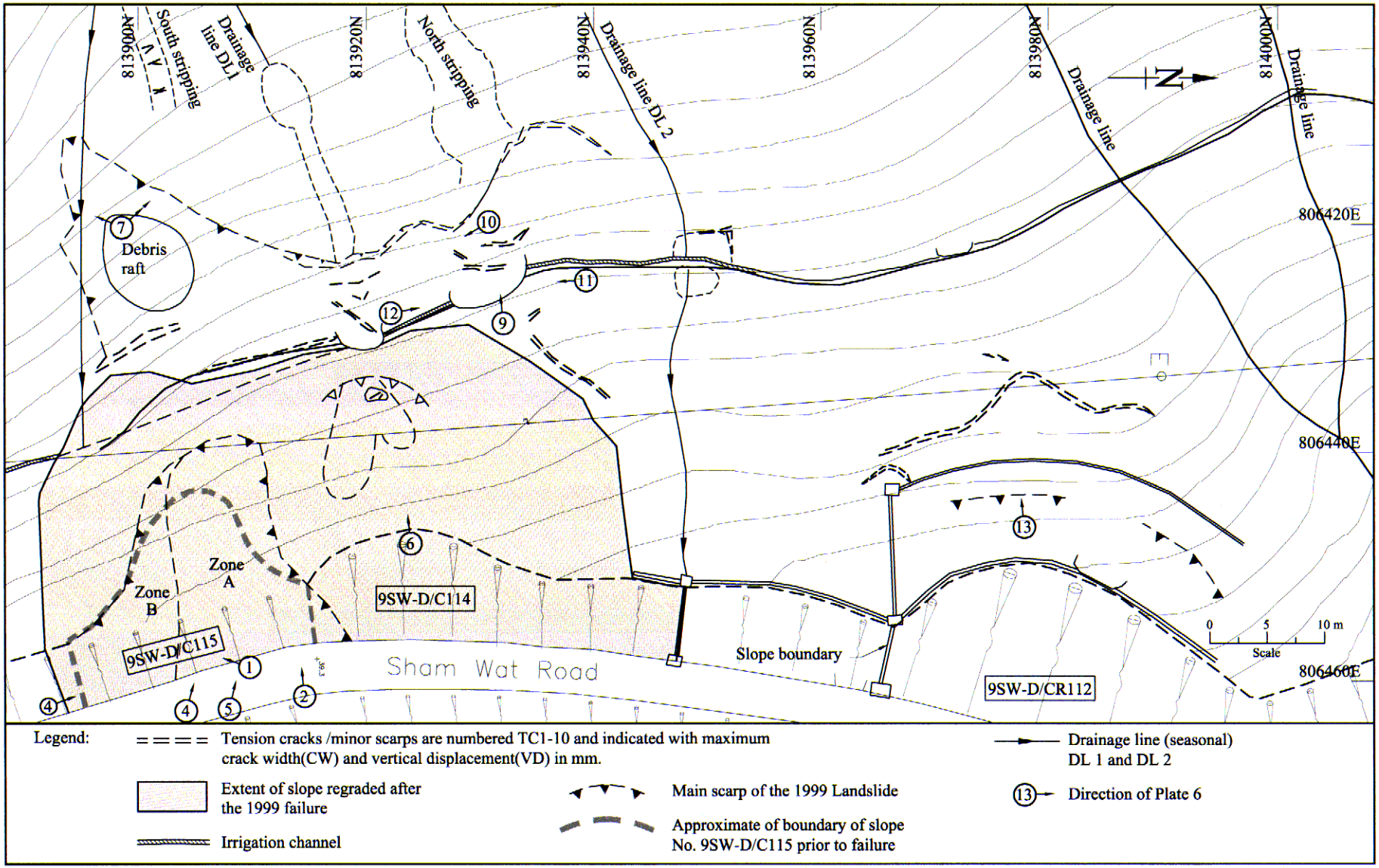


Figure 11 - Locations and Directions of Photograph Plates

LIST OF PLATES

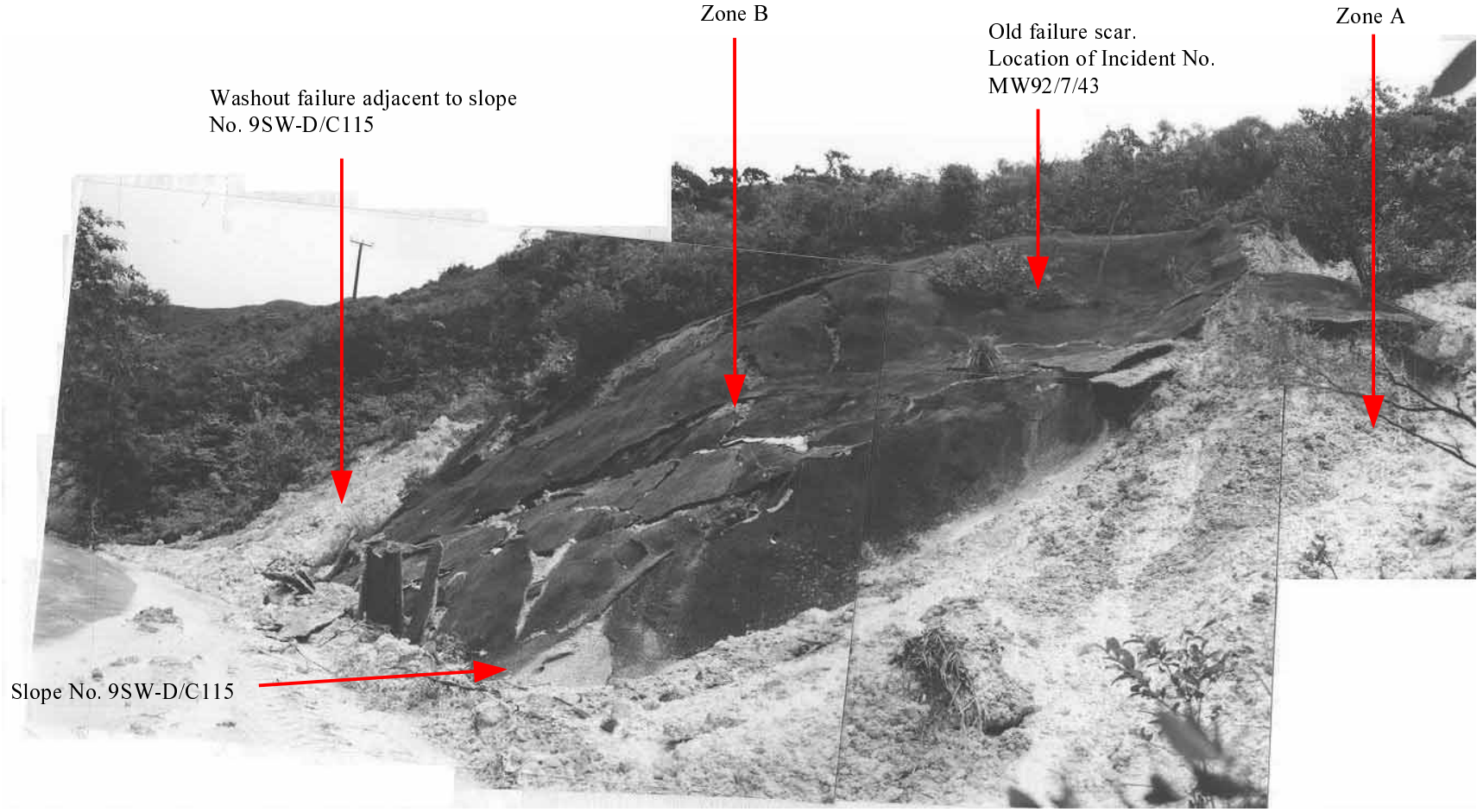


Plate 1 – General View of the 1999 Landslide Looking Southwest
(Photograph Taken on 25 August 1999)

Plate 2 – View of Northern Portion of Landslide (Zone A)
(Photograph Taken on 25 August 1999)

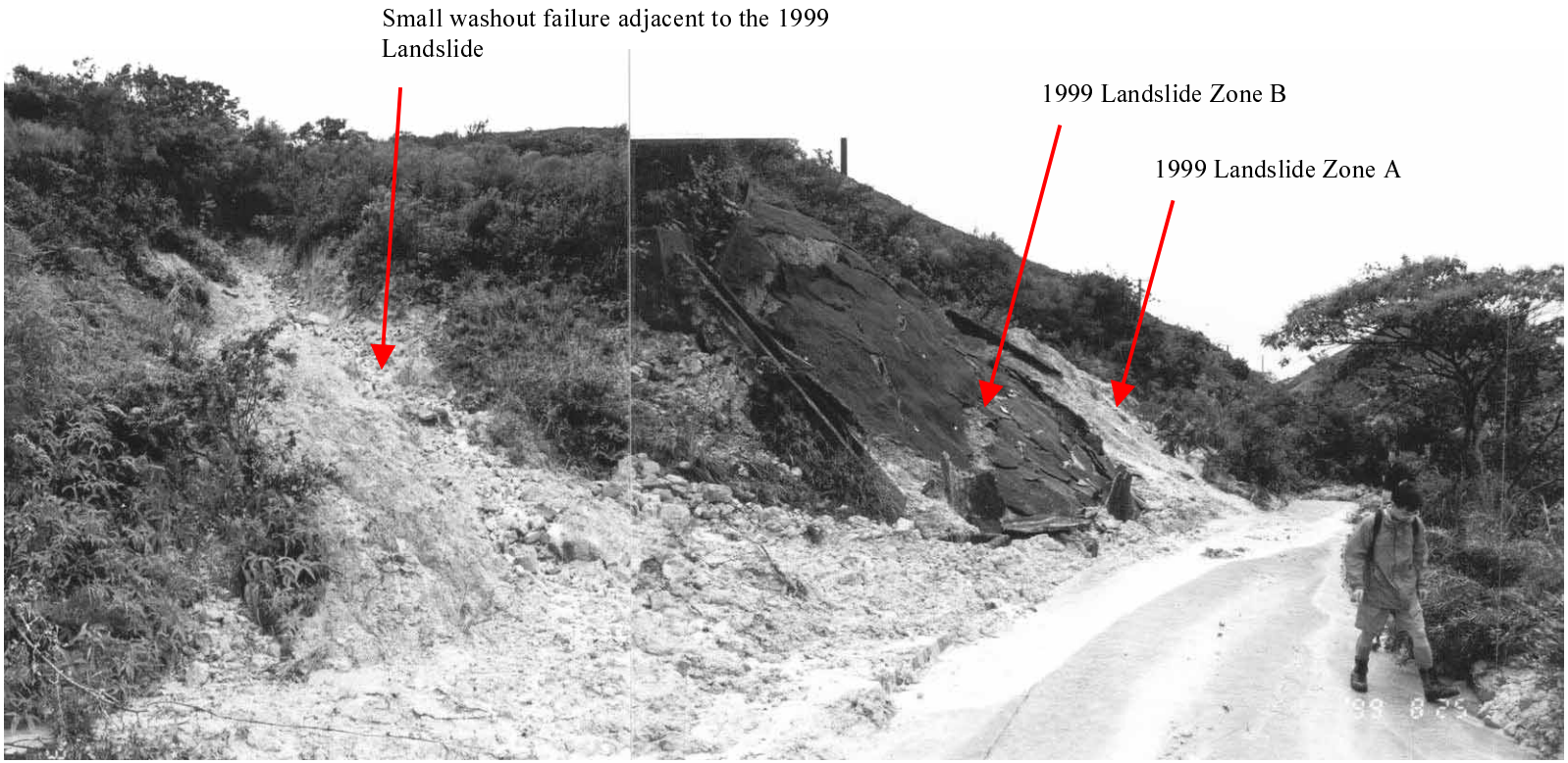


Plate 3 – View Looking North of the Small Washout Failure Adjoining the 1999 Landslide
(Photograph Taken on 25 August 1999)

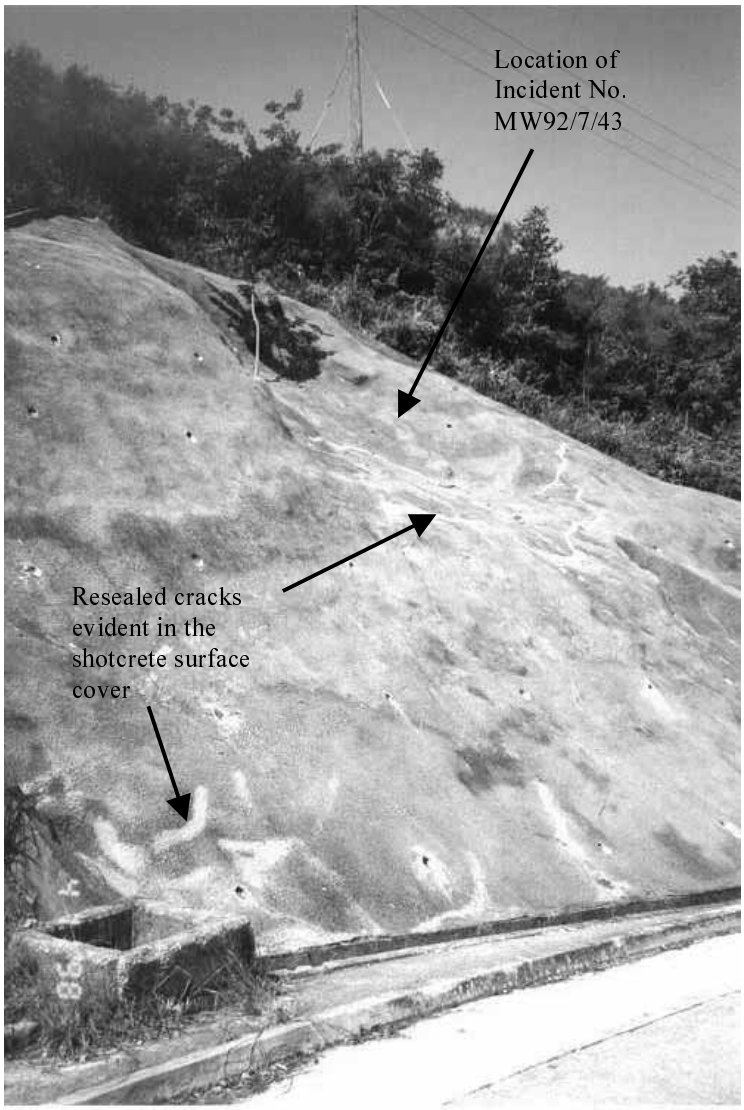
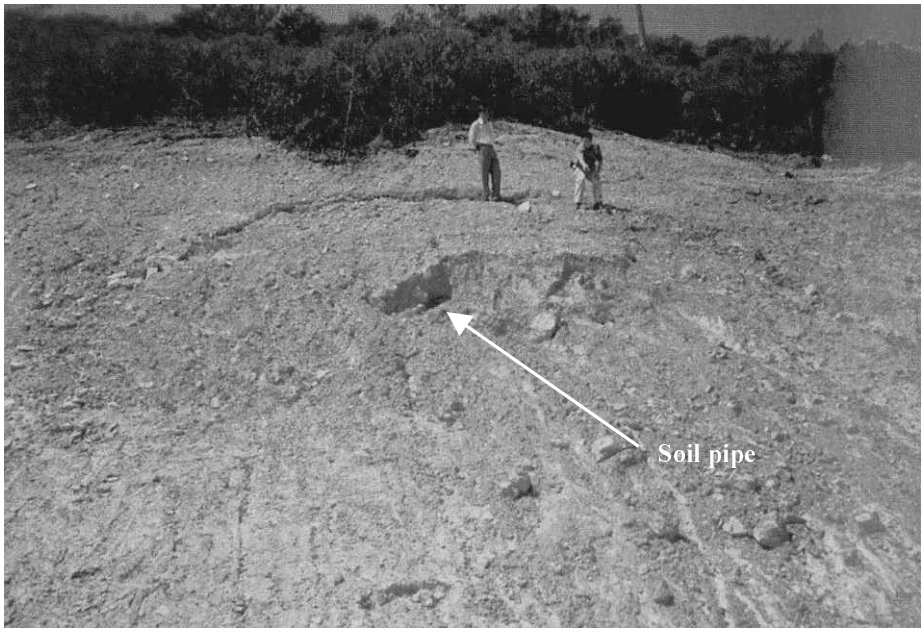


Plate 4 – View of Slope No. 9SW-D/C115 Showing Concave Depression Following a Landslide in 1992 (GEO Incident No. MW1999/7/43) (Photograph Taken on 4 November 1998)

Plate 5 – View Looking Northwest of the 1992 Landslide (GEO Incident No. MW92/7/43) (Photograph Extracted from GEO Incident Report No. MW 92/7/43) (Photograph Taken on 21 July 1992)



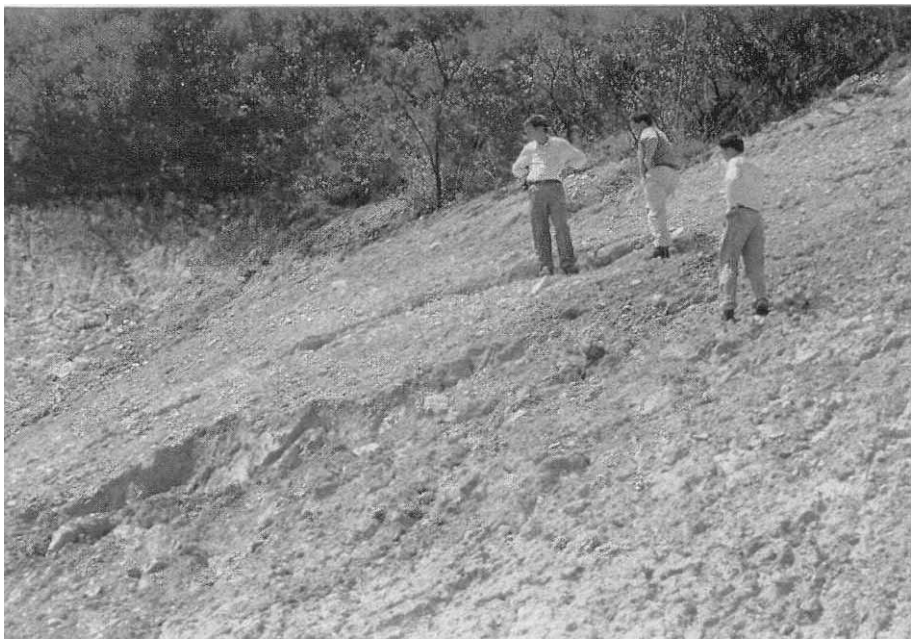


Plate 6 - View of Minor Failure and Exposed Soil Pipe in Regraded Portion of Slope (Photograph Taken on 22 September 1992)

Plate 7 – View of Open Soil Pipes within the Colluvial Material Exposed in the Main Scarp MS1 (Photograph Taken on 21 October 1999)

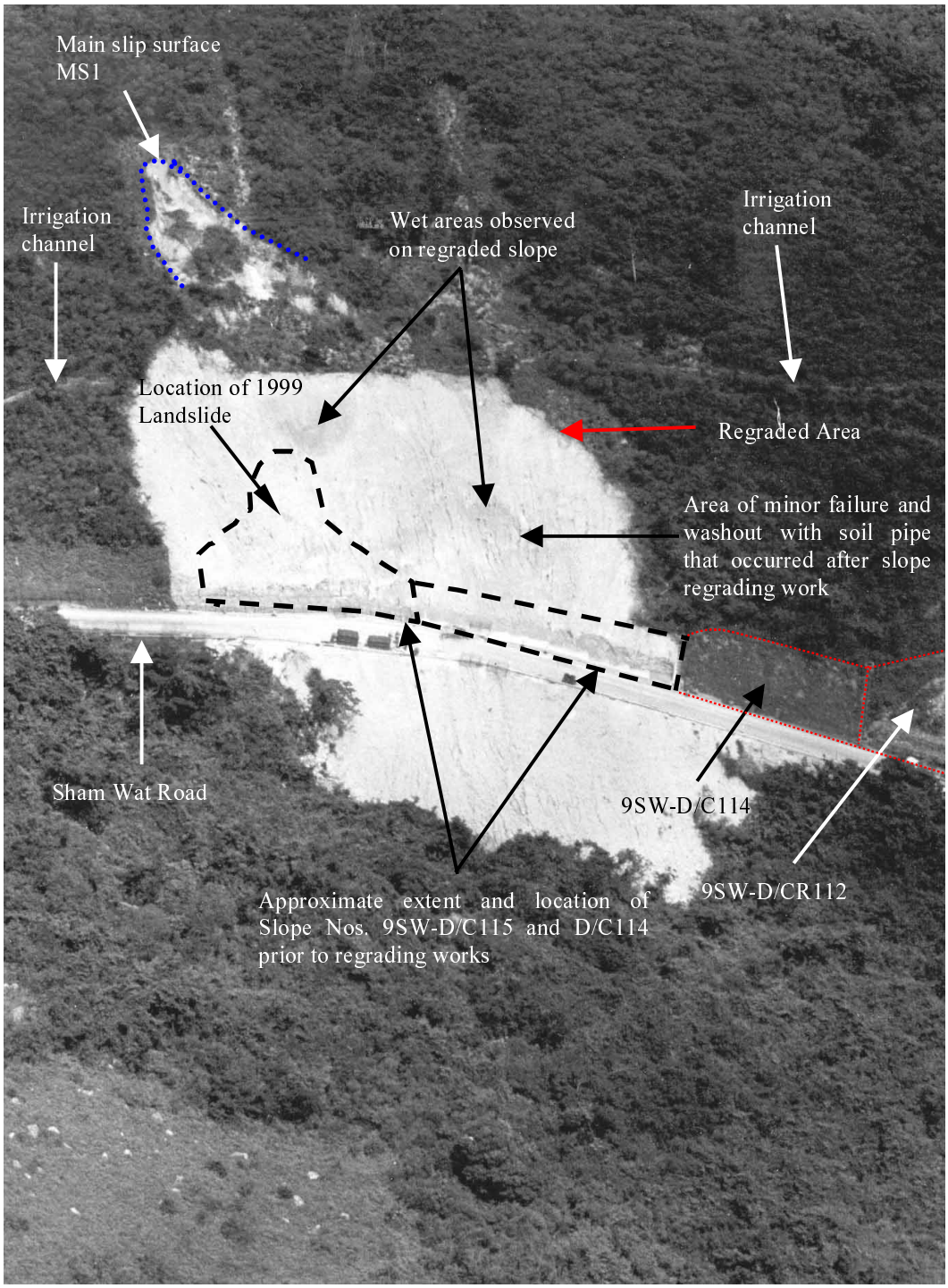


Plate 8 – Oblique Aerial Photograph of the Urgent Repair Works Following the 1999 Landslide (Photograph Taken on 10 June 2000)

Plate 9 – View of Old Exposure of Colluvial Material in Minor Scarp TC4 (Photograph Taken on 21 October 1999)

Plate 10 – View of Recent Exposure of Colluvial Material in Minor Scarp TC5 (Photograph Taken on 21 October 1999)

Plate 11 – View of Irrigation Channel Breached by Movement of Colluvium
(Photograph Taken on 10 November 1999)

Plate 12 – View of Crushed Irrigation Channel (Photograph Taken on 10 November 1999)

Plate 13 – View of the Discoloured and Vegetated Main Scarp of MS2 (Photograph Taken on 30 August 1999)

APPENDIX A

PHOTOGRAPHS OF TENSION CRACKS/MINOR SCARPS

PHOTOGRAPHS	File Ref. No. : 2/E2/99-9	Neg. No. : MW99516/1, 2
Date Taken : 14.10.99	Location : Shan Wai Rd ch 28850. (MW99/8/107)	

(Where appropriate, please attach a location plan showing direction of shooting and provide caption to the photographs)

Geotechnical Engineering Office	District Division	

GCDIST 45 (Apr 98)

PHOTOGRAPHS	File Ref. No. : 2/E2/99-9	Neg. No. : HW99516/3.4
Date Taken : 14.10.99	Location : Sham Wat Road Ch (28+50)	

(Where appropriate, please attach a location plan showing direction of shooting and provide caption to the photographs)

Geotechnical Engineering Office	District Division	

GCDIST 45 (Apr 98)

PHOTOGRAPHS	File Ref. No. : 3/E-199-9	Neg. No. : MW99516/6,7
Date Taken : 14.10.99	Location : Sham Wat Road ch (28 + 50)	

(Where appropriate, please attach a location plan showing direction of shooting and provide caption to the photographs)

Geotechnical Engineering Office	District Division	

GCDIST 45 (Apr 98)

PHOTOGRAPHS	File Ref. No. : 2/E-/99-9	Neg. No. : MW99516/8,9
Date Taken :	Location : Sham Wat Road Ch (28+50)	

(Where appropriate, please attach a location plan showing direction of shooting and provide caption to the photographs)

Geotechnical Engineering Office	District Division	

GCDIST 45 (Apr 98)

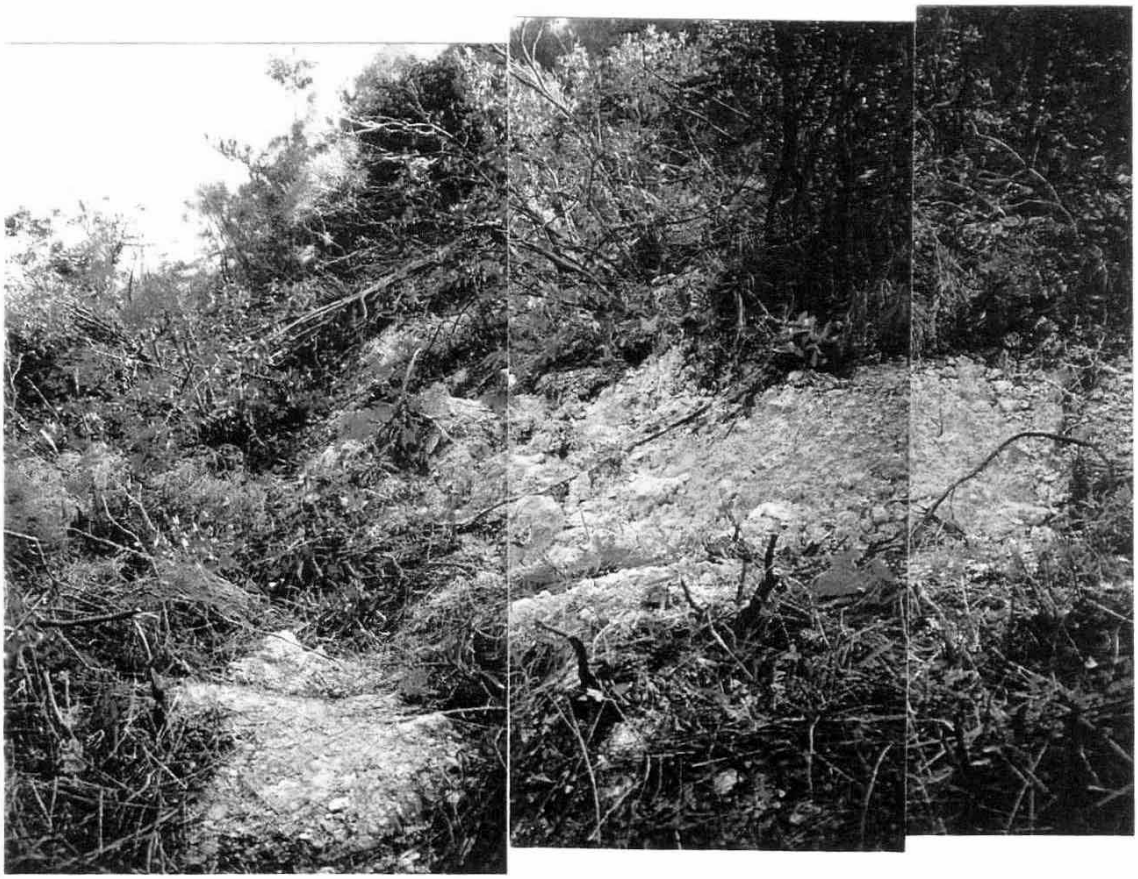
PHOTOGRAPHS	File Ref. No. : 2/E>/99-9	Neg. No. : HW99516/10, 11
Date Taken : 14.10.99	Location : Sham Wat Road	

(Where appropriate, please attach a location plan showing direction of shooting and provide caption to the photographs)

Geotechnical Engineering Office	District Division	

GCDIST 45 (Apr 98)

PHOTOGRAPHS	File Ref. No. : 2/E>/99-9	Neg. No. : HW99516/12-14
Date Taken : 14.10.99	Location : Sham Wat Road	



(Where appropriate, please attach a location plan showing direction of shooting and provide caption to the photographs)

Geotechnical Engineering Office	District Division	

GCDIST 45 (Apr 98)

PHOTOGRAPHS	File Ref. No. : 2/E-1999-9	Neg. No. : MW99516/15,16
Date Taken : 14.10.99	Location : Sham Wat Road	

(Where appropriate, please attach a location plan showing direction of shooting and provide caption to the photographs)

Geotechnical Engineering Office	District Division	

GCDIST 45 (Apr 98)

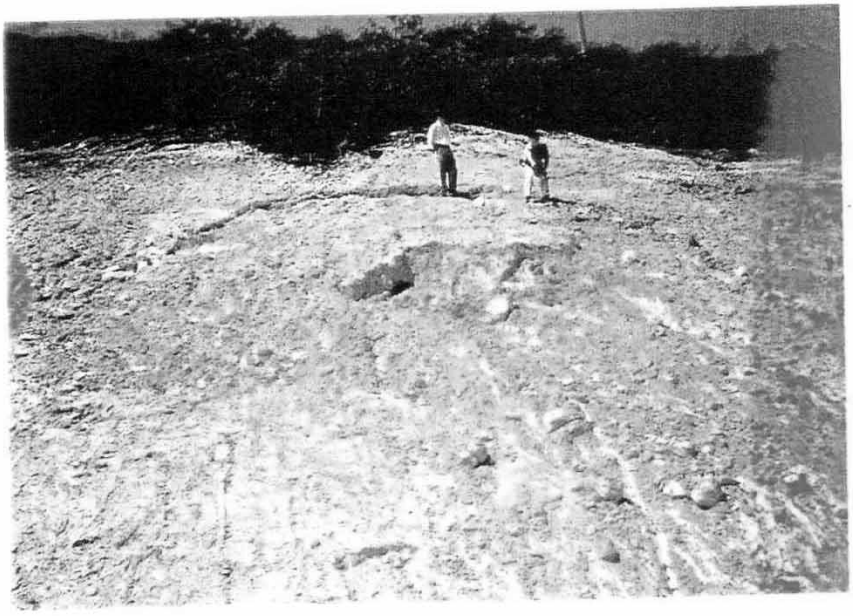
PHOTOGRAPHS	File Ref. No. : 2/E2/99-9	Neg. No. : HW99516/17
Date Taken : 14.10.99	Location : Sham Wat Road	

(Where appropriate, please attach a location plan showing direction of shooting and provide caption to the photographs)

Geotechnical Engineering Office	District Division	

GCDIST 45 (Apr 98)

PHOTOGRAPHS	File Ref. No. : 2/E2/99	Neg. No. : MW 99464 - [illegible]
Date Taken : 22-9-99	Location : Shan Wat Rd Ch 28+50 Incident No MW 1999/8/107	



(Where appropriate, please attach a location plan showing direction of shooting and provide caption to the photographs)

Geotechnical Engineering Office	District Division	

GCDIST 45 (Apr 98)