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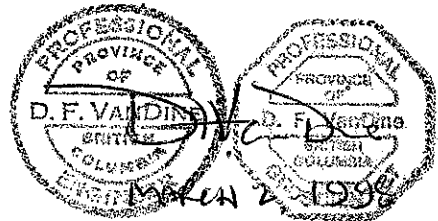
Assessment of Debris Flow Potential Newman Creek, Howe Sound

A Report to
British Columbia
Ministry of Transportation and Highways
South Coast Region



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ASSESSMENT OF DEBRIS FLOW POTENTIAL NEWMAN CREEK, HOWE SOUND

CONCLUSIONS AND RECOMMENDATIONS

There is a high likelihood of further ravelling of the slopes in the vicinity of the landslide that reportedly occurred on January 23, 1998 (Slide A). In particular, the recently exposed highly fractured bedrock, weathered bedrock and colluvium exposed by this landslide, and the similar materials in the narrow ridge between Slide A and the pre-1982 landslide immediately upstream (Slide C) show a very high likelihood of further ravelling or even landsliding.

A small, relatively recent landslide on the south side of the creek (Slide D), appears relatively stable, however, the exposed colluvium along the slide path of a larger, relatively recent landslide on the south side (Slide E), appears to have a high likelihood of ravelling. The relatively fresh looking de-barked logs along the path of Slide E, and the pile of fresh looking debris at the toe of this landslide indicate very recent reactivation of this feature.

As the steep slopes of Newman Creek have shown in the past, the likelihood of other landslides occurring at other locations along the main creek channel is also high. The likelihood of landslides occurring along the major tributary is considered low to moderate.

Considering the amount of debris and potential sources of debris in the upper reaches of the creek channel, considering the steep gradient of the upper creek channel, and based upon the past behaviour of Newman Creek, the likelihood of future debris flows on Newman Creek is very high.

Based upon the past behaviour of Newman Creek, the design debris flow (the maximum volume of debris that is likely to reach the fan during a debris flow) is estimated to be 20,000 m³. A debris flow of this magnitude could occur in the short term, however, smaller debris flows are likely to continue to occur more frequently.

Recommendation 1: So as not to increase the amount of debris in the creek channel, and/or increase the likelihood of an occurrence of a debris flow, it is recommended that future road crossings of the upper reaches of Newman Creek should only be permitted if the road crossing and its approaches are designed and constructed to minimize adding additional material to the creek channel, and if the road crossing is removed and the approaches are deactivated as soon as possible after the road is no longer required.

Based on my re-calculations, the design of the diversion channel for debris flows and the clearances beneath both the Highway 99 and the BC Rail bridges are adequate. Based on the fact that the assumed debris flow discharges are approximately 10 times those estimated for the 200-year water flood discharge, the diversion channel appears well designed to handle water flood discharges.

During the January 1, 1997 debris flow, the debris came close to overtopping the south side of the Newman Creek diversion channel just upstream of the water supply reservoir. Reasons for this likely include the sinuous path that the debris had to follow around the waterfall, the fact that this debris flow event may have been more fluid than most debris flows in this area, and the vertical height from the bottom of the channel to the top of the south side slope is less than the 8 m called for in the original BCMOTH design.

It is likely that if overtopping of the south side of the diversion channel occurs, the water supply reservoir, highway, railway and other structures on the fan would be at some risk.

Recommendation 2: To immediately reduce the likelihood of overtopping the south side of the diversion channel, it is recommended that the top of the south side of the channel be raised from the apex of the fan to the downstream end of the water supply reservoir. One relatively simple, quick and practical method of raising this section of the berm would be to use several lifts of anchored lock-blocks. I have discussed the design concepts of such a structure with Mr Jacques Dupas, PEng, BCMOTH Howe Sound District Engineer.

Recommendation 3: As a longer term measure to reduce the sinuous flow path around the waterfall, consideration could be given improving the geometry of the flow path immediately below the waterfall. One method would be to extend the north side of the upstream end of the diversion channel further to the north and to then, with a large radius curve, direct the flow back into the existing diversion channel. The area of suggested extension is the area covered by riprap up until January 1, 1997. On this date, this riprap was removed by a debris flow and the area was subjected to a great deal of scour. After the 1997 event, BCMOTH replaced this riprap and the associated scour hole with concrete.

INTRODUCTION

At the request of Bruce Hayden, PEng, British Columbia Ministry of Transportation and Highways (BCMOTH) South Coast Regional Geotechnical Engineer, on February 9, 1998 I carried out a helicopter reconnaissance of the entire Newman Creek. On the same day I inspected the upper portion of the Newman Creek diversion and the fan area on the ground. I understand that on or about January 23, 1998 a landslide from the north side of the creek occurred and entered the upper reaches of the creek channel. The event is reported to have discoloured the creek water and an unknown volume of coarse granular material flowed down the Newman Creek diversion to Howe Sound. Since January 23, 1998, the water in Newman Creek has turned brown several times and the water discharge in the creek has been irregular. I also understand that on January 1, 1997 Newman Creek experienced a debris flow.

This report summarizes the observations made during the helicopter flyover and ground inspections, and the subsequent assessment of the existing and future hazards and risks associated with debris flows along and at the mouth of Newman Creek. As requested by Mr Hayden, I prepared a brief letter for BCMOTH on February 11, 1998 summarizing my preliminary thoughts and assessment.

On February 9, 1998 I made two helicopter trips to Newman Creek. I was accompanied by:

- Al Brown, PEng, BCMOTH South Coast Regional Geotechnical Manager
- Bruce Hayden, PEng, BCMOTH, South Coast Regional Geotechnical Engineer
- Jim Hagen, Engineering Assistant, BCMOTH Howe Sound District
- Scott Aitken, BCMOTH Snow Avalanche Technician
- Dave Buckley, Capilano Highway Services Limited (CHSL)
- Jonathan Fannin, PEng, University of British Columbia

During the ground inspection of the upper portion of the Newman Creek diversion I was accompanied by Bruce Hayden and Dave Buckley. I inspected the remainder of the fan area by myself.

For this assessment, BCMOTH supplied me with the following information:

- BCMOTH 1:500 scale plan of the Newman Creek diversion, Drawing 4 of 10, Project C-3027, no date, but presumably from the mid-1980s
- BCMOTH reduced plan entitled "Plan, Highway No 99, Newman Creek, Sta 82+56.000 - Sta 90+55.000", dated July 30, 1985, showing the location of the Newman Creek diversion
- BCMOTH 1:250 scale plan of the upper portion of the Newman Creek diversion, entitled "Highway 99, Newman Creek Debris Chute, Site Plan for PEP Repairs", no date but presumably from 1997

- a copy of "Debris Flow Study for Residential Development at Newman Creek, BC", prepared for Baccarat Investments Ltd by Nigel Skermer, PEng of SRK-Robinson Inc, November 1990
- a video and 4 stills of Newman Creek taken from a helicopter by Jim Hagen on January 31, 1998 and a video of Newman Creek taken from a helicopter by Jim Hagen on February 9, 1998
- precipitation and temperature data for the 30 days preceding January 23, 1998 for two BCMOTH Snow Avalanche climate monitoring sites along Howe Sound

I supplemented this information with:

- a copy of the report "Debris Torrent and Flooding Hazards, Highway 99, Howe Sound", prepared for BCMOTH by Thurber Consultants Limited (TCL), April 1983
- file notes from the TCL Newman Creek file 15-3-32 and 15-3-32B dated 24 November 2, 1982, November 24, 1983, February 23, 1994 and March 16, 1984
- helicopter and ground photos from the TCL Newman Creek file 15-3-32, taken in 1973, 1982 and 1983
- three rolls of helicopter and ground photos which I took on February 9, 1998
- preliminary earthquake epicentre and magnitude determinations for the lower mainland of British Columbia and Vancouver Island from January 6, 1998 to February 7, 1998, prepared by the Geological Survey of Canada, Pacific Geoscience Centre
- a stereoscopic interpretation of BC government airphotos of the Newman Creek area taken in 1990, 1994 and 1996, at an approximate scale of 1:20,000
- British Columbia Climate Normals for 1961-1990, published by Environment Canada.

Between 1982 and 1984 I was employed by Thurber Consultants Limited (now Thurber Engineering Limited), and was a co-author of the April 1983 report, the author of the file notes dated 1982 through 1984, and the photographer for most of the 1982 and 1983 helicopter and ground photos.

BACKGROUND

Figure 1 is an approximate 1:10,000 scale overlay sketch of 1996 BC airphoto BCC96097-105 (enlarged from 1:20,000 scale) that shows the locations of many of the features discussed in this report.

Newman Creek is located along the east side of Howe Sound approximately 6 km north of Horseshoe Bay. It is one of 26 creeks along Howe Sound that was the subject of an intensive study by TCL for BCMOTH in 1982 and 1983, and resulted in the 1983 report "Debris Torrent and Flooding Hazards, Highway 99, Howe Sound". At that time "debris torrent" was the term used for "debris flow".

The following summary information about Newman Creek is largely abstracted from the 1983 TCL report.

- the catchment area is 1.8 km²
- the highest portions of the catchment range from 1200 m to 1500 m elevation
- the uppermost catchment area has a number of snow avalanche tracks
- the main creek channel length is approximately 2400 m: 300 m on the fan and 2100 m above the fan. An approximate 7 m high waterfall just above the apex of the fan, separates the fan from the upper creek.
- 16% of the main creek channel was logged sometime between 1950 and 1980. Most of this logging took place on the north side of the creek.
- above the fan the main creek channel gradient ranges from 27 ° to 42 ° and averages 30 °
- above the fan the geology consists of colluvium and till overlying granodiorite, quartz diorite and volcanic rock types
- above the fan, 20% of the main creek channel banks (valley sides) are considered stable, 40% potential unstable and 40% unstable
- a major tributary enters from the south side. Its length is approximately 1225 m, its gradient ranges from 29 ° to 45 ° and averages 40 °. It mainly flows over bedrock with only a minor amount of inorganic and organic debris in the channel. Approximately 40% of the tributary creek channel banks (valley sides) are considered stable, 30% potential unstable and 30% unstable.
- between 1906 and 1983, three debris flow events and one flood event were recorded as having occurred. Debris flows on September 18, 1969, approximately 4000 m³; December 4, 1981, approximately 3000 m³; and February 11, 1983, approximately 7500 m³. The flood event occurred on October 6, 1982.

The following is a summary of TCL's 1983 assessment.

- the likelihood of debris flow occurrence on Newman Creek is very high. Very high indicates that the design debris flow could occur in the short term, however, debris flows less than that could occur more frequently. Very high is the most severe rating given to the creeks along Howe Sound in the TCL 1983 report, and only 2 other creeks have this rating, Charles and Magnesia creeks.
- the estimate of the available debris along the main channel and tributary is 36,000 m³
- the estimated design debris flow (the maximum volume of debris that is likely to make it to the fan during a debris flow) is 20,000 m³
- the estimated 200-year water flood discharge is 32.2 m³/sec

Since 1983, the following have occurred:

- in 1986 BCMOTH diverted the fan portion of Newman Creek to the northern side of the fan and constructed a diversion channel the entire way from the fan apex to Howe Sound. The diversion channel was designed by BCMOTH with some limited input by TCL.

- according to the SRK-Robinson Inc 1990 report, in 1987 a logging road was constructed across Newman Creek at approximate elevation 350 m to access timber in the Lone Tree Creek catchment area, the catchment adjacent to the north. According to Dave Buckley, the crossing was constructed as a large coarse bouldery fill without a culvert. Sometime after 1990, the logging road was deactivated, and the fill across the creek was removed.
- sometime after 1990 the marina and associated facilities were removed from the Newman Creek fan, a number of single family residences were constructed along the shore of Howe Sound and a water supply reservoir was constructed just downstream from the apex of the fan
- at the present time a multiple-family dwelling is under construction on the fan between Highway 99 and the BC Rail tracks
- no debris flow or water flood events were recorded between 1983 and January 1, 1997 (see below).

1998 LANDSLIDE EVENT

It is my understanding that a landslide occurred on the north side of the creek on or about January 23, 1998. Although the landslide was not actually seen until January 31, 1998, according to Dave Buckley, about 07:00 on the morning of January 23, 1998 Newman Creek was noted to be discoloured and an unknown volume of coarse granular material flowed down the Newman Creek diversion to Howe Sound. Enough material deposited at the mouth of the creek to warrant CHSL removing some of this material in early February 1998. I understand that for several weeks after the landslide, the water in the creek turned brown a number of times and the water discharge was irregular.

This landslide (Slide A on Figure 1) is located along the north side of the upper reaches of Newman Creek, approximately 1650 m upstream from where Newman Creek enters Howe Sound. A smaller landslide at the same location (Slide B on Figure 1) is visible on airphotos as having occurred sometime 1994 and 1996. The scar of an older landslide (Slide C on Figure 1) is evident immediately upstream of, and on the same side as, the January 23, 1998 landslide (Photo 1). Comparing the helicopter photos taken in 1982 and 1998, this older slide occurred prior to 1982.

As estimated from the helicopter altimeter, Slide A began at approximate elevation 885 m. The mid-point of the toe of the slide at the creek is at approximate elevation 800 m. From the 1:50,000 topographic map, the creek gradient at that point is approximately 32°. From the topographic map, the average side slope at the slide location is approximately 38°, although it appears steeper in the field (Photo 2).

As shown on Photos 1 and 2, Slide A is roughly an elongated triangle in shape. As estimated from the helicopter and the helicopter photos, the downstream side of the triangle has an approximate 110 m slope length, the upstream side has an approximate 70 m slope length and the base has an approximate 75 m slope length along the creek. The majority of the slide debris originated from the upper 1/3 of the slide. It is estimated that the headscarp has a height of approximately 8 m,

and the thickness of material removed is approximately 5 m. It is estimated that approximately 1 m to 2 m of material was removed from the lower 2/3s of the landslide. The failure plane of the upper portion is very steep and in places approaches vertical. The failure plane of the lower portion is steep and approximates the overall slope angle of the valley side.

Disregarding the existence of a smaller older landslide at the same location (Slide B), it is estimated that approximately 3500 m³ of material was removed from the upper 1/3 of Slide A and approximately 2000 m³ of material was removed from the lower 2/3s, for a total of approximately 5500 m³. If Slide B previously removed 1500 m³ of material, the total estimated volume of material that was involved in the January 23, 1998 event, Slide A, is 4000 m³, not including the standing timber that was also removed.

From the material exposed in the headscarp and along the sides of slide A, the material in the upper portion of the landslide was moderately to highly fractured, fresh to weathered granitic bedrock overlain by a thin layer of colluvium. Moderately fractured and sound fresh bedrock is left exposed at the base of this upper portion, however, highly fracture fresh and weathered bedrock is exposed in the sides (Photos 3 and 4). The material derived from the lower portion of the landslide was highly fractured weathered granitic bedrock and colluvium. For the most part, sound fresh bedrock is exposed in the bottom of the lower portion of the slide and weathered highly fractured bedrock and colluvium is exposed in the sides. The bedrock and overlying material on the upstream side of Slide A forms relatively narrow ridge of material between Slide A and Slide C (Photo 5).

Based on the material and apparent mechanics involved in Slide A, the January 23, 1998 landslide is classified as a rock fall/debris slide.

The landslide debris from Slide A entered the creek channel in a very steep-sided bedrock canyon reach of the creek. Likely because of the steepness of the side slopes, combined with the steep creek gradient, landslide debris did not "run up" the opposite south bank of the creek, but turned and travelled down the creek channel. Based upon the freshly de-barked logs in the creek channel and the fresh looking coarse inorganic debris, most of the landslide debris came to rest over a distance of approximately 500 m downstream (Photo 6). No obvious trim line is apparent along the sides of the creek. An average creek channel width of 4 m, an average landslide debris thickness of 1 m in the creek channel and an approximate travel distance of 500 m down the creek channel, accounts for the approximate 4000 m³ of material involved in the landslide. It is estimated that the largest fragments of coarse landslide debris are approximately 2 m in diameter.

From the helicopter photos and video taken on January 31, 1998 by BCMOTH and the helicopter reconnaissance on February 9, 1998, snow is evident in the creek channel immediately upstream of the Slide A. It is likely that at least the upstream portion of the landslide debris fell onto snow. Similarly, on both January 31, 1998 and February 9, 1998, the water in the creek was flowing beneath the snow from approximately 30 m upstream of the upper reach of the landslide, beneath the landslide debris, and for approximately 50 m downstream of the landslide (Photo 7). A

comparison of the helicopter photos and videos taken on January 31, 1998 and February 9, 1998 indicate that during the interval there was some, but not a great deal of, movement of landslide debris down the creek channel.

BCMOTH precipitation data for the month preceding January 23, 1998, for two neighbouring weather stations is summarized in Table 1: Mt Harvey is located at elevation 1560 m, 4.5 km to the north of Newman Creek, and Mt Strachan is located at elevation 1400 m, 3 km to the south. In the preceding 30 days Mt Harvey received 460 mm of precipitation, while Mt Strachan received 410 mm. In the preceding 10 days, Mt Harvey received 311 mm (68%) of that 460 mm, and Mt Strachan received 254 mm (62%) of that 410 mm. The maximum 24 hour precipitation for the preceding 30 days was 71 mm at Mt Harvey and 68 mm at Mt Strachan both occurring on January 14, 1998.

Based on hourly weather data, according to Scott Aitken, rain likely started at the site during the night of January 22/23. Hourly precipitation in the 12 hours prior to 07:00 January 23, 1998 was steady at 2 mm to 3 mm/hour. It then doubled to 6 mm/hour between 0:700 and 08:00, which is considered a moderate rainfall intensity for the area. Precipitation continued throughout January 23, 1998 and the total measured at Mt Harvey was 84 mm and at Mt Strachan was 80 mm.

In the preceding 10 days the average air temperatures at both stations was approximately -2°C . In the preceding 12 hours before 07:00 January 23, 1998 the air temperature at both stations rose from -3°C to zero.

Based on climate normals for Hollyburn Ridge, located at elevation 930 m, 5.5 km south of Newman Creek, the long term average precipitation for December is 403 mm and for January is 331 mm. The greatest 24 hour precipitation recorded in the years 1960 to 1990 for December is 125 mm and for January is 162 mm.

Based upon the above information, the 30 days preceding January 23, 1998 appear to be somewhat wetter than normal, especially the 10 days preceding that date. At no time during the preceding periods, however, does the rainfall intensity appear to be extreme, especially in the days immediately preceding January 23, 1998.

Based upon the Geological Survey of Canada's seismic record events for the lower mainland of British Columbia and Vancouver Island between January 6, 1998 and January 23, 1998 (Table 2), it is unlikely that an earthquake with a magnitude large enough to trigger a landslide occurred in the area during that period.

OTHER RELATIVELY RECENT LANDSLIDE EVENTS

During the helicopter reconnaissance, two other relatively recent landslides were noted along the south side of Newman Creek. A smaller landslide, Slide D on Figure 1, enters the creek approximately 700 m upstream from Howe Sound; a larger landslide, Slide E on Figure 1, enters

the creek approximately 900 m upstream from Howe Sound. Based on airphotos, both Slides D and E occurred sometime between 1990 and 1994. From airphotos, it appears that Slide E retrogressed a very short distance upslope sometime between 1994 and 1996.

In my letter of February 11, 1998, I stated that "one or both [of Slides D and E] may have been associated with the debris flow which, I understand, occurred on Newman Creek on January 1, 1997". Based upon the evidence from the 1990, 1994 and 1996 airphotos, it is unlikely that these landslides were directly associated with the January 1, 1997 debris flow.

Slide D begins as a rock failure immediately above the deactivated logging road at approximate elevation 375 m. The landslide travelled down an approximate 35 ° slope and entered Newman Creek at approximate elevation 300 m (Photos 8 and 9). The slide path is relative narrow, estimated to average less than 15 m wide, and 150 m in length. The landslide removed the standing timber and approximately 1 m thickness of colluvium. Coarse granular inorganic material and weathered logs are exposed along the slide path. It is unclear whether the logging road was deactivated before or after Slide D occurred.

The headscarp of Slide E is at approximate elevation 700 m as estimated from the helicopter altimeter. Slide E, which parallels the major tributary to Newman Creek, travelled down an estimated 40 ° to 50 ° slope, and entered Newman Creek at approximate elevation 350 m, which is the approximate location of the deactivated logging road crossing (Photos 10 and 11). The headscarp is near vertical and exposes fractured granitic bedrock (Photo 12). The slide path is estimated to average 10 m to 15 m in width, and 500 m in length. The landslide removed the standing timber, some weathered bedrock and the overlying colluvium. Over the length of the slide path, the thickness of material removed is estimated to be less than 1 m. Presently exposed along the slide path are patches of relatively sound bedrock, patches of coarse granular inorganic material and some relatively fresh looking de-barked logs and fallen trees with the needles still on the branches. A small pile of fresh looking debris was noted at the toe of this landslide (Photo 13).

Both Slides D and E are classified as rock fall/debris slides.

RECENT DEBRIS FLOW EVENTS

As discussed above, 3 debris flow events were recorded on Newman Creek between 1906 and 1983: 1969, 1981 and 1983. Since 1983 it is likely a number of small, but unrecorded, events have occurred. According to Dave Swales, BCMOTH Howe Sound Area Manager, a larger event occurred on December 19, 1994 that stopped the water flow of Newman Creek for a short period of time. An unknown volume of material was involved, but included boulders up to 3 m in diameter being brought down in a slurry of water and debris.

According to Dave Swales and Dave Buckley, another debris flow occurred on January 1, 1997 that brought coarse granular material and some woody debris down to the mouth of the creek. One estimate of the volume of material involved is 5000 m³, however, this is probably a minimum

volume as it was estimated from the material remaining at the mouth of the creek. I also understand that once the debris passed the sinuous restriction at the waterfall (immediately upstream of the apex of the Newman Creek fan) it continued to flow in a sinuous manner down the upper portion of the Newman Creek diversion channel. The debris eroded the rip-rap on the north side of the diversion channel, immediately below the waterfall, and according to Dave Buckley, the upper surface of the debris came to within 0.6 m (2 feet) of the top of the diversion channel on the south side of the channel just upstream from the water supply reservoir. Below that point, the debris "sloshed" back and forth across the diversion one more time before it reached the highway bridge (Photo 14).

From the 1997 BCMOTH 1:250 scale plan of the upper portion of the diversion, entitled "Highway 99, Newman Creek Debris Chute, Site Plan for PEP Repairs", I estimated the flow path of the January 1, 1997 debris flow. Using the superelevation formula, I estimated the velocity of the debris flow just downstream from the waterfall. Based on the assumptions used, the velocity of the debris flow just upstream of the water supply reservoir was 11.2 m/s, and the velocity just downstream of that reservoir was 9.9 m/s. These velocities are greater than the 5.3 m/s average velocity of debris flows along Howe Sound calculated by Hungr et al, 1984 (Quantitative analysis of debris torrents for design of remedial measures; Canadian Geotechnical Journal, v 21, n, 4, pp 663-677). Because velocity is indirectly proportional to apparent dynamic viscosity, this could indicate that the viscosity of the January 1, 1997 Newman Creek debris flow was less than that assumed, or in other words, this event was more fluid.

According to Dave Buckley, evidence of another small debris flow event having occurred sometime in later in 1997 was noted when material from the January 23, 1998 event was removed from the mouth of Newman Creek in early February 1998.

PRESENT CONDITION OF NEWMAN CREEK

From the helicopter reconnaissance there appears to be a high likelihood of further ravelling of the slopes in the vicinity of Slide A. In particular, the recently exposed, highly fractured bedrock, weathered bedrock and colluvium exposed by Slide A, and the similar materials in the narrow ridge between Slides A and C, show a very high likelihood of further ravelling or even landsliding (Photos 2, 3, 4 and 5).

Slide D on the south side of the creek appears relatively stable, however, the exposed colluvium along the slide path of Slide E appears to have a high likelihood of ravelling. Indeed the relatively fresh looking de-barked logs along the path of Slide E, and the pile of fresh looking debris at the toe of this landslide indicate very recent reactivation of this feature.

As the steep slopes of Newman Creek have shown in the past, the likelihood of other landslides occurring at other locations along the main creek channel is also high. The likelihood of landslides occurring along the major tributary is considered low to moderate.

At the present time, partially as a result of the recent rock fall/debris slide activity, there is a large volume of debris in the bottom of the main creek channel upstream of the waterfall. Comparing the helicopter photos taken in 1998 with those taken in 1982, there appears to be more debris in the main creek channel and it appears to have a fresher appearance. In 1983 TCL estimated that 36,000 m³ of debris was available along the main creek channel and tributary channel. I estimate that the volume of available debris is presently approximately 40,000 m³.

Both future ravelling of older landslides and material generated from new landslides should be considered as future potential sources of debris for the main creek channel.

Considering the amount of debris and potential sources of debris in the upper reaches of the creek channel, considering the steep gradient of the upper creek channel, and based upon the past behaviour of Newman Creek, I feel that debris in the upper creek channel will continually migrate downstream. My assessment of the likelihood of a debris flow on Newman Creek is very high, the same as the TCL 1983 assessment.

Even though the estimated volume of available debris along the main creek channel and tributary channel is approximately 40,000 m³, it is unlikely that all of this material would mobilize in during a single debris flow event. Based upon the past behaviour of Newman Creek, my assessment of the design debris flow (the maximum volume of debris that is likely to reach the fan during a debris flow) is 20,000 m³. This volume is the same as the TCL 1983 estimate. As noted in the TCL 1983 report, even though the design debris flow could occur in the short term, smaller debris flows are likely to continue to occur more frequently.

The design 200-year water flood discharge, as estimated by TCL in 1983, is 32.2 m³/s. This discharge is likely not critical, because the intensity of the storm that could produce a 200-year water flood discharge would very likely initiate a debris flow and, as discussed below, debris flow discharges can be up to 10 times the 200-year water flood discharge.

NEWMAN CREEK DIVERSION

In 1986, BCMOTH diverted the creek to the north side of the fan and constructed a partially-lined, relatively straight diversion channel from the apex of the fan (immediately below the waterfall) to Howe Sound. Based upon BCMOTH drawings, the diversion is approximately 270 m in length and ranges in gradient from 14 ° to 19 °, and averages 18 °. The diversion has two curves: the first, a 115 m radius curve upstream of the highway bridge; the second, a 165 m curve between the Highway 99 and the BC Rail bridges. The channel is trapezoidal in shape with a 5 m wide bottom and side slopes at 1.5:1 (true slope, but apparent slope of 1.6:1). The side slopes were designed to extend a minimum vertical height of 8 m from the bottom of the channel to the top of the side slopes. The base has embedded boulders, and the base and the lower 2 m (vertical) of the side slopes are covered by steel fibre reinforced shotcrete. Based upon the SRK-Robinson 1990 report, clearances from the channel bottom to the upstream undersides of the Highway 99 and the BC Rail bridges are 10.6 m and 8.2 m respectively.

It is my understanding that BCMOTH, with TCL's input, designed this diversion channel for discharges associated with a debris flow of 20,000 m³ over a 60 second duration, or between 300 m³/s and 375 m³/s. These discharges are approximately 10 times those estimated for the 200-year water flood discharge of 32.2 m³/s.

During this assessment, I re-calculated the debris flow height in the diversion channel for discharges of 300 m³/s and 400 m³/s, for both a straight channel and a channel with a 115 m curve (the curve with the shorter radius), both without and with an assumed 3 m of extra clearance to accommodate rolling and tumbling boulders and logs. The results are shown below:

Assumed Discharge	300 m ³ /s	300 m ³ /s	400 m ³ /s	400 m ³ /s
Flow depth with: --	-- no extra clearance	-- assumed 3 m extra clearance	-- no extra clearance	-- assumed 3 m extra clearance
Gradient -- with straight channel				
14 °	4.0 m	7.0 m	4.3 m	7.3 m
19 °	3.6 m	6.6 m	4.0 m	7.0 m
Gradient -- with 115 m radius curve in channel				
14 °	4.4 m	7.4 m	4.8 m	7.8 m
19 °	4.1 m	7.1 m	4.7 m	7.7 m

Based on the above, the design of the diversion channel for debris flows and the clearances beneath both the highway and railway bridges are adequate. Based on the fact that the assumed debris flow discharges are approximately 10 times those estimated for the 200-year water flood discharge, the diversion channel appears well designed to handle water flood discharges.

Based upon the design of the diversion channel and the above calculated flow heights, the likelihood of the diversion channel being overtopped should have been very low. However, based upon Dave Buckley's report that the upper surface of the debris came to within 0.6 m (2 feet) of the top of the diversion channel just upstream from the water supply reservoir, the diversion channel came close to being overtopped. There are likely several reasons for this.

During my site visit to the upper portion of the diversion channel, I noted that when water or debris reaches the waterfall, the flows have to make a very sharp-angled turn to the north, and then another very sharp-angled turn to the west before the flows can enter the diversion channel (Photo 14). Based upon the velocity estimations for the January 1, 1997 debris flow, this event may have been more fluid than most debris flows in this area. This, and the sinuous flow path around the waterfall, may account for the relatively high flows on the south side of the diversion channel just upstream of the water supply reservoir.

In addition, the BCMOTH design for the diversion called for a minimum 8 m vertical height from the base of the channel to the top of side slopes. Based upon the 1997 BCMOTH 1:250 scale plan of the upper portion of the diversion, entitled "Highway 99, Newman Creek Debris Chute, Site Plan for PEP Repairs", from the upstream end of the diversion to just downstream of the water supply reservoir, the vertical height from the bottom of the channel to the top of the south side slope is less than 8 m and is only 6 m at its lowest point (Photos 14 and 15).

It is likely that if overtopping of the south side of the diversion channel occurs, the water supply reservoir, highway, railway and other structures on the fan would be at some risk (Photo 15).

ACKNOWLEDGEMENTS

I would like to thank the following individuals who provided background information for this report: Bruce Hayden, PEng, Jacques Dupas, PEng, Dave Buckley, Dave Swales, and Scott Aitken. All except Dave Buckley are with BCMOTH. Dave Buckley is with Capilano Highway Services Limited.

TABLE 1: PRECIPITATION DATA FOR MT HARVEY AND MT STRACHAN
(in millimetres)

Year	Month	Day	Mt Harvey (elevation 1560 m)	Mt Strachan (elevation 1400 m)
1997	December	24	4	4
		25	1	--
		26	5	14
		27	5	8
		28	20	17
		29	49	44
		30	11	6
		31	2	1
1998	January	1	11	14
		2	5	1
		3	2	1
		4	7	5
		5	18	31
		6	4	8
		7	--	1
		8	1	1
		9	2	--
		10	2	--
		11	--	--
		12	--	1
		13	14	22
		14	71	68
		15	17	38
		16	23	22
		17	40	18
		18	32	13
		19	27	28
		20	29	11
		21	48	22
		22	10	11
	TOTAL		460 mm	410 mm

TABLE 2: PRELIMINARY EARTHQUAKES EPICENTRES AND MAGNITUDES

Recorded by the Geological Survey of Canada, Pacific Geoscience Centre, Sidney, BC for the Lower Mainland of British Columbia and Vancouver Island

Below is a list of PRELIMINARY epicentre and magnitude determinations for the last 50 earthquakes in the lower mainland and Vancouver Island area. These solutions may be updated at any time. All times are in UTC (Coordinated Universal Time). This is 8 hours ahead of Pacific Standard Time and 7 hours ahead of Pacific Daylight.

F after depth indicates fixed depth

UT date yyyy/mm/dd	time hh:mm:ss	lat (deg)	lon (deg)	depth (km)	mag	felt	location (km)
1998/01/06	07:11:41	49.98N	129.84W	10F	2.1		190 km WSW Pt. Hardy BC
1998/01/06	16:59:19	50.17N	127.86W	21	1.0		66 km SSW Pt. Hardy BC
1998/01/07	00:10:44	48.71N	127.88W	10F	1.7		152 km WSW Tofino BC
1998/01/07	02:19:29	50.15N	127.82W	23	0.7		67 km SSW Pt. Hardy BC
1998/01/08	06:23:27	49.65N	127.32W	25	0.8		88 km W Gold R. BC
1998/01/08	14:39:57	48.81N	125.37W	29	1.1		20 km SE Ucluelet BC
1998/01/09	12:59:54	49.08N	126.52W	33	1.5		45 km W Tofino BC
1998/01/11	05:42:27	48.59N	125.40W	25	0.6		41 km SSE Ucluelet BC
1998/01/11	07:02:16	49.92N	127.86W	15	1.0		92 km SSW Pt. Hardy BC
1998/01/11	09:25:09	48.93N	129.38W	10F	2.6		243 km SW Pt. Hardy BC
1998/01/12	03:53:06	48.82N	125.53W	29	1.1		14 km S Ucluelet BC
1998/01/13	07:04:05	48.18N	125.79W	10F	1.5		88 km SSW Ucluelet BC
1998/01/13	20:01:51	48.94N	128.74W	10F	2.2		208 km W Tofino BC
1998/01/14	11:40:10	48.76N	123.39W	15	0.8		12 km N Sidney BC
1998/01/15	01:00:26	49.31N	126.51W	29	1.2		47 km WNW Tofino BC
1998/01/15	12:59:51	49.94N	128.06W	17	1.7		96 km SSW Pt. Hardy BC
1998/01/16	12:30:31	49.74N	122.72W	2	1.5		33 km E Squamish BC
1998/01/22	03:39:26	50.11N	127.88W	23	1.5		74 km SSW Pt. Hardy BC
1998/01/22	11:31:10	48.78N	123.75W	21	0.7		4 km W Duncan BC
1998/01/22	18:56:11	51.21N	126.28W	10F	1.6		98 km NE Pt. Hardy BC
1998/01/22	19:41:50	48.73N	122.40W	0F	0.8		37 km SSW Abbotsford BC
1998/01/23	11:55:30	49.07N	125.60W	18	1.1		14 km NNW Ucluelet BC
1998/01/23	22:32:33	49.60N	126.97W	32	1.6		63 km W Gold R. BC
1998/01/27	14:02:24	49.63N	123.73W	13	1.2		18 km N Sechelt BC
1998/01/29	15:36:58	48.25N	123.13W	21	1.1		27 km SE Victoria BC
1998/01/31	05:44:34	50.53N	129.32W	10F	3.0		136 km W Pt. Hardy BC
1998/01/31	11:23:44	49.12N	126.71W	38	2.0		58 km W Tofino BC
1998/02/01	09:56:49	49.30N	121.19W	0F	1.0		21 km ESE Hope BC
1998/02/02	17:56:47	48.76N	129.11W	10F	2.3		238 km W Tofino BC
1998/02/03	02:47:17	50.74N	121.84W	0F	1.2		83 km NE Pemberton BC
1998/02/03	07:51:14	48.89N	123.44W	21	0.5		23 km ENE Duncan BC
1998/02/03	13:22:06	49.85N	123.56W	1	0.7		33 km WNW Squamish BC
1998/02/03	15:05:25	49.81N	127.41W	18	1.7		95 km W Gold R. BC
1998/02/03	23:51:43	48.48N	123.25W	26	0.4		10 km ENE Victoria BC
1998/02/05	00:49:48	50.17N	127.82W	26	1.4		66 km SSW Pt. Hardy BC
1998/02/05	04:01:06	49.00N	129.16W	10F	3.3		227 km SW Pt. Hardy BC
1998/02/05	11:20:35	48.89N	122.41W	2	1.4		20 km SSW Abbotsford BC
1998/02/06	04:15:31	49.18N	122.51W	5	1.1		14 km NE Langley BC
1998/02/06	17:53:32	50.60N	123.98W	0	1.3		90 km WNW Pemberton BC
1998/02/07	01:37:14	48.50N	123.28W	30	1.2		10 km NE Victoria BC

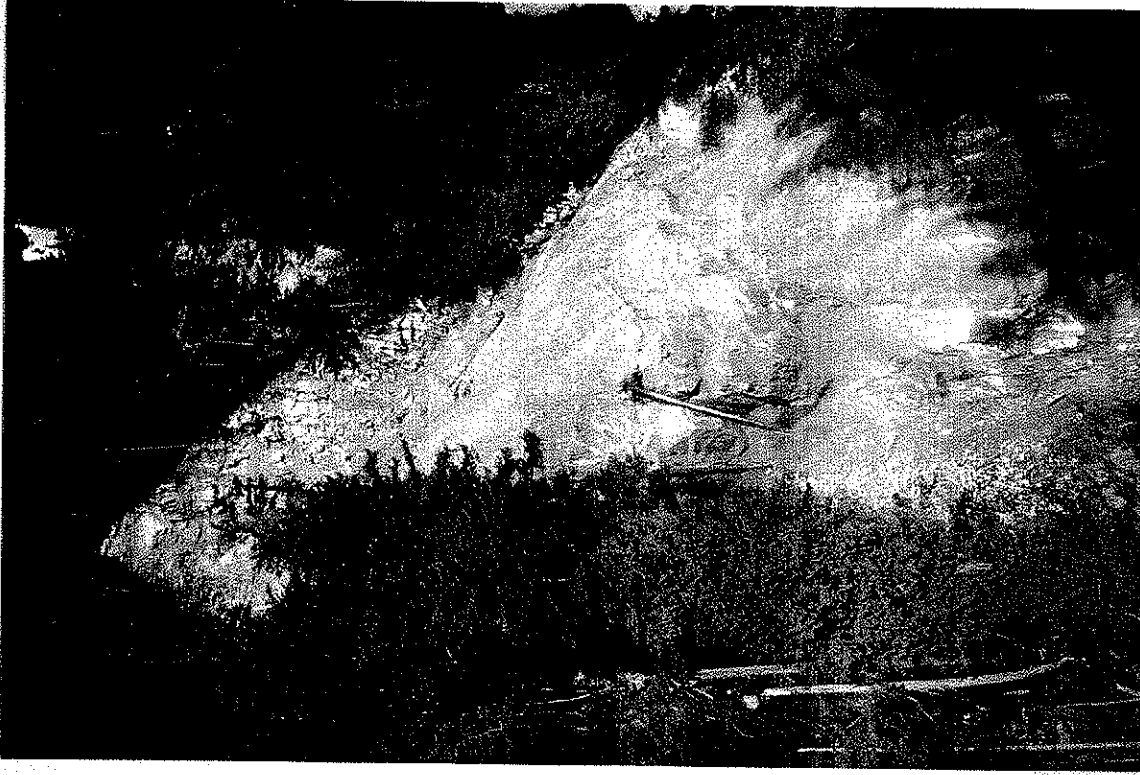


Photo 2 (DFV98/02/09/1-19)
Close-up of Slide A showing the steep side slopes and near vertical headscarp.

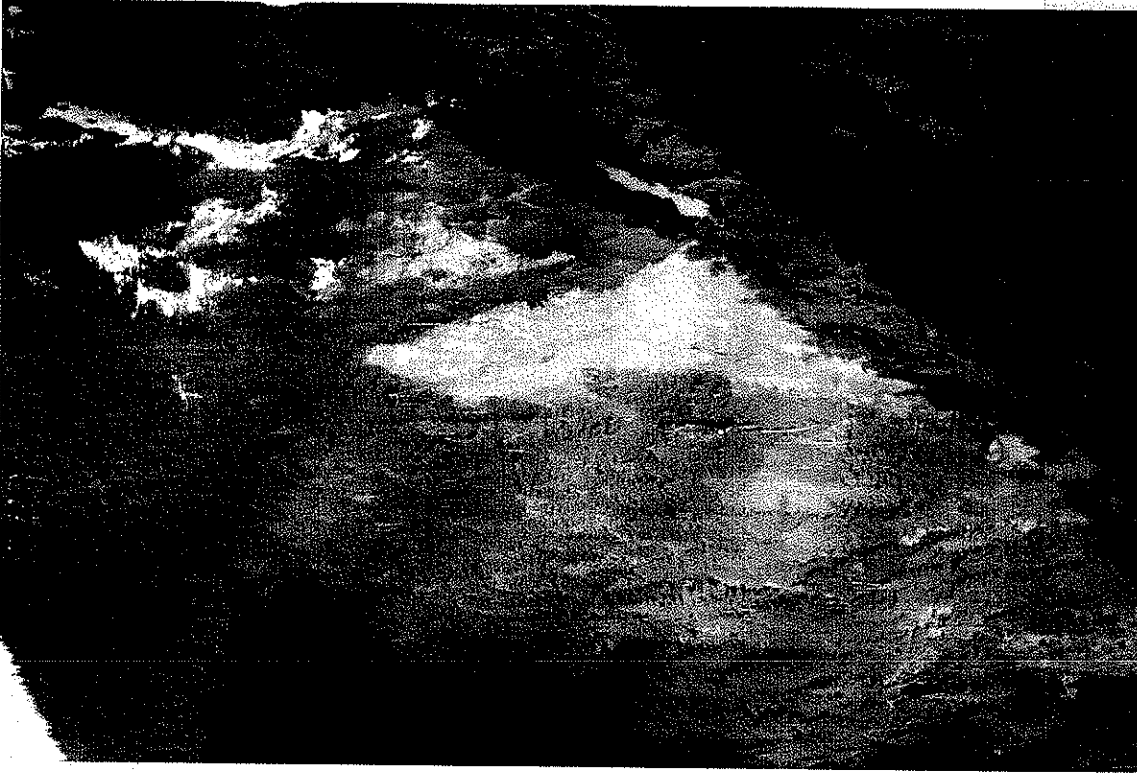


Photo 1 (DFV98/09/02/1-7)
Overview of Slide A which reportedly occurred on January 23, 1998. The smaller, older (pre-1983) Slide C is immediately upstream (to the right) of Slide A.



Photo 3 (DFV98/02/09/1-21)
Front view of Slide A showing the material
exposed on the failure plane.

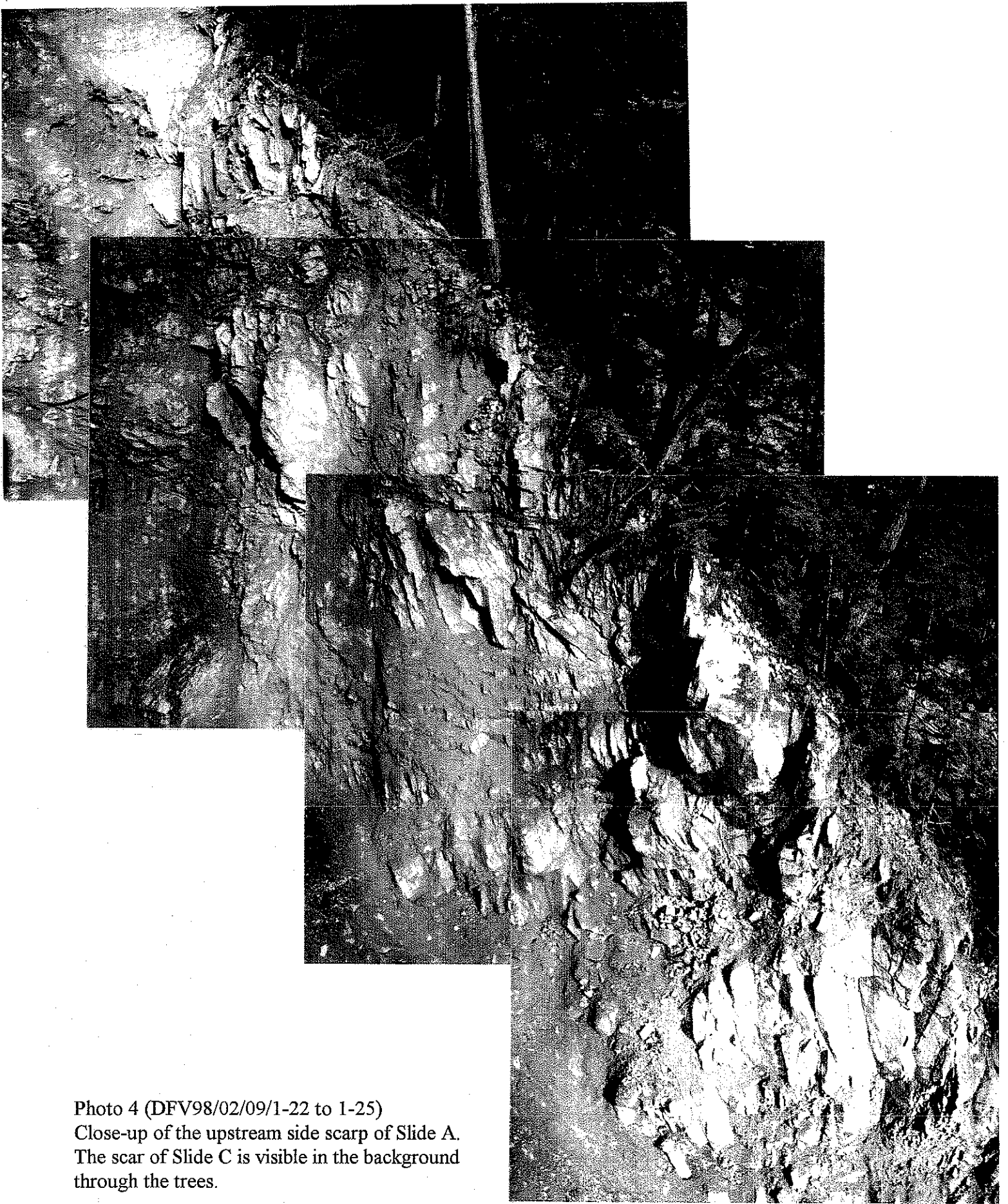


Photo 4 (DFV98/02/09/1-22 to 1-25)
Close-up of the upstream side scarp of Slide A.
The scar of Slide C is visible in the background
through the trees.



Photo 5 (DFV98/02/09/1-20)
Overview of the upper portions of Slides A and
C showing the narrow ridge that separates the
two.



Photo 6 (DFV98/02/09/1-12,1-13)

Looking upstream along the flow path of Slide A debris along the creek channel.
The toe of Slide A is visible in the left background of the panorama.



Photo 7 (DFV98/02/09/1-17,1-18)

Close-up of toe of Slide A. The water flow in the creek channel is beneath the snow in the background and the landslide debris in the foreground.

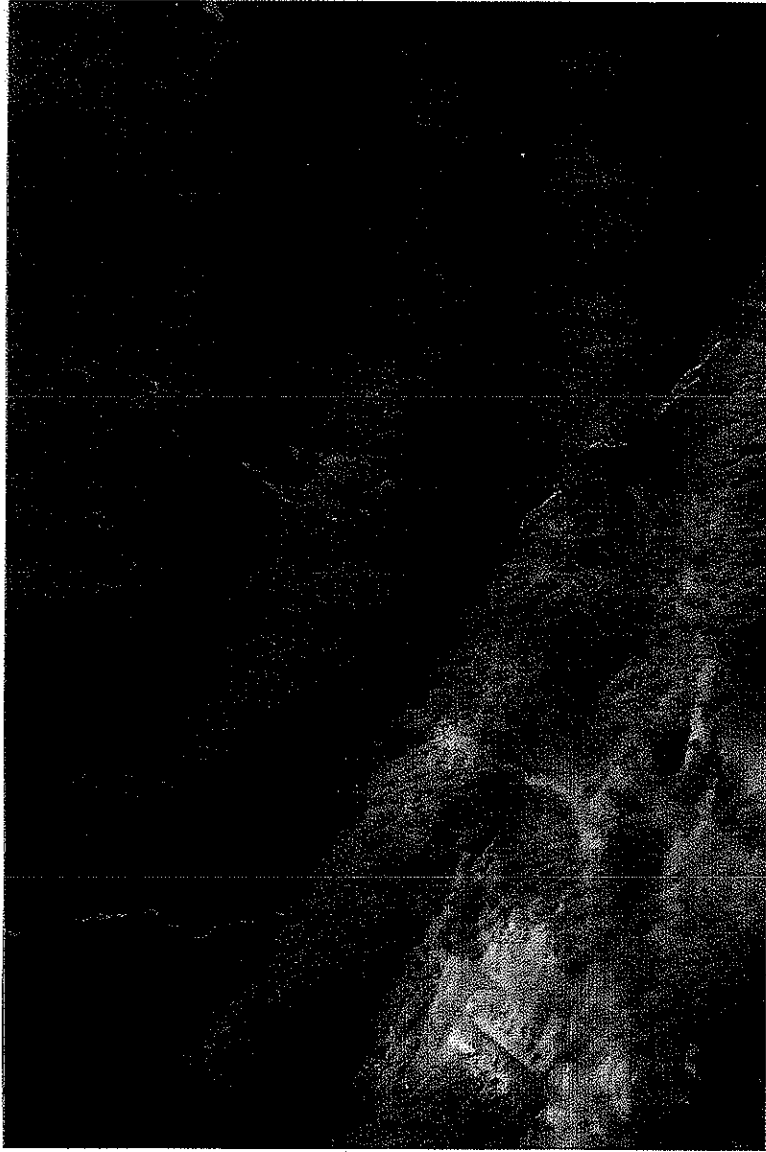


Photo 8 (DFV98/02/09/2-11)
Overview of Slide D. Note the headscarp in
rock just above the deactivated logging road.

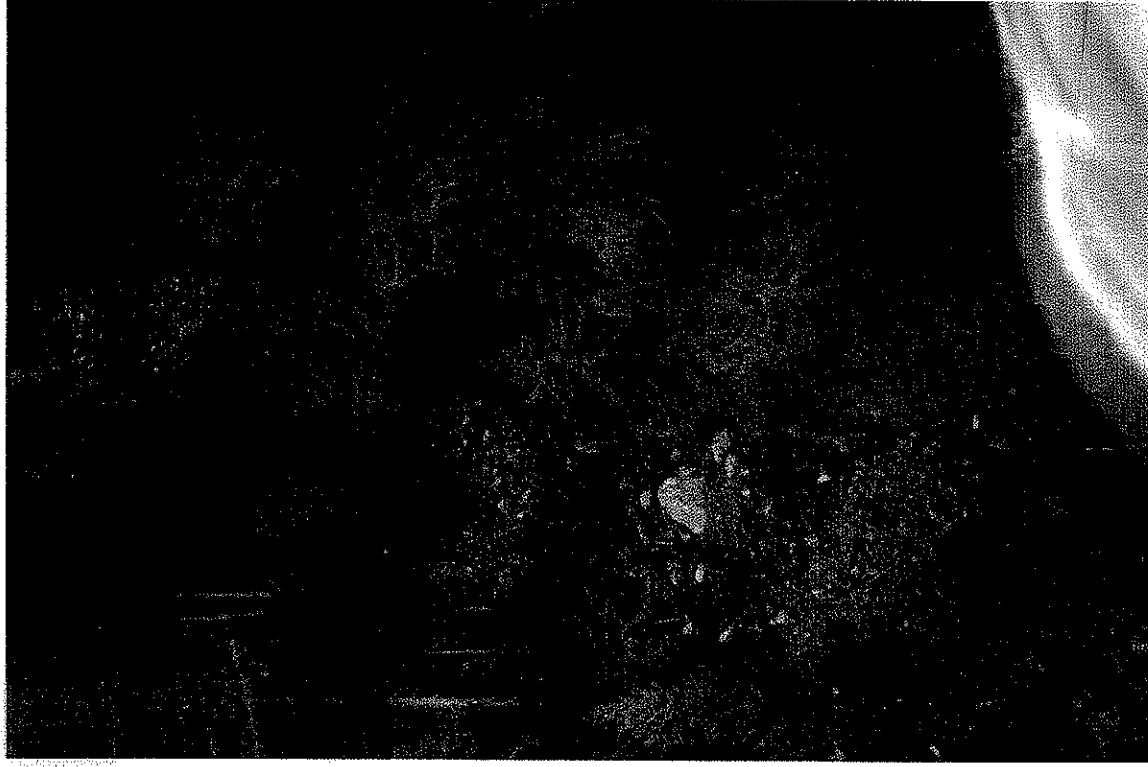


Photo 9 (DFV98/02/09/2-2)
Close-up of the slide path of Slide D.

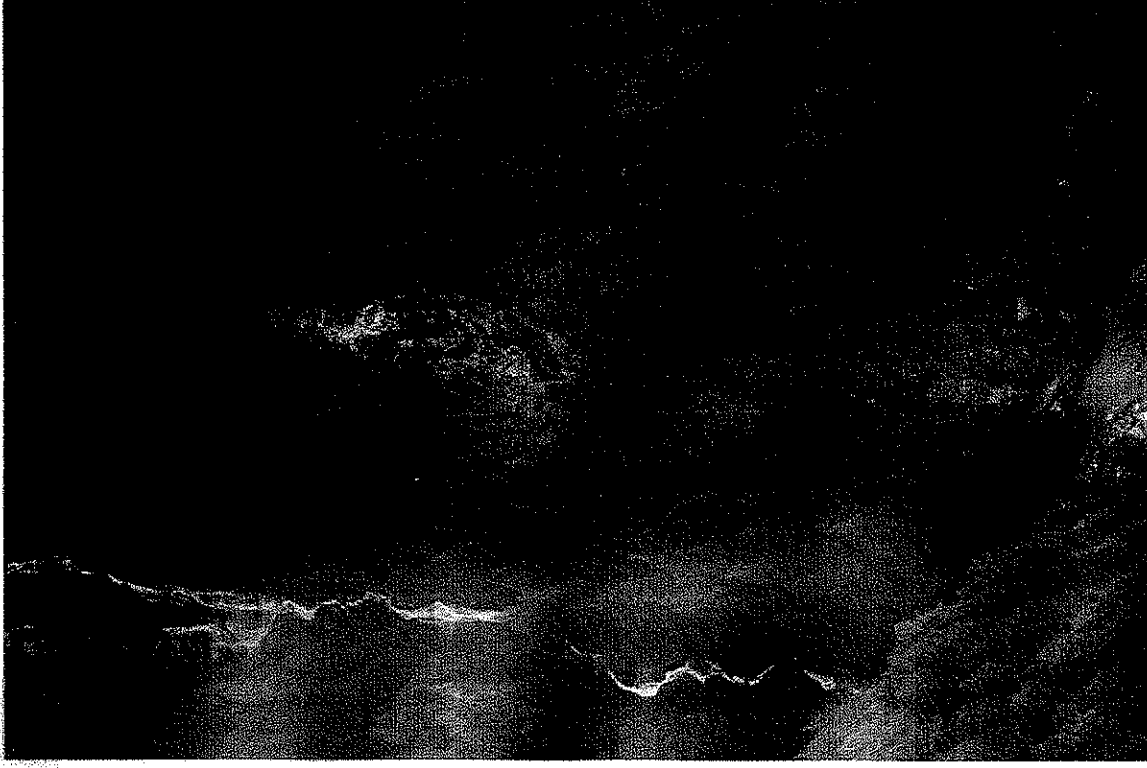


Photo 11 (DFV98/02/09/2-13)
Overview of the lower portion of Slide E. The major tributary is just upstream (to the left of the photo), and main channel is just visible at the bottom of the photo.

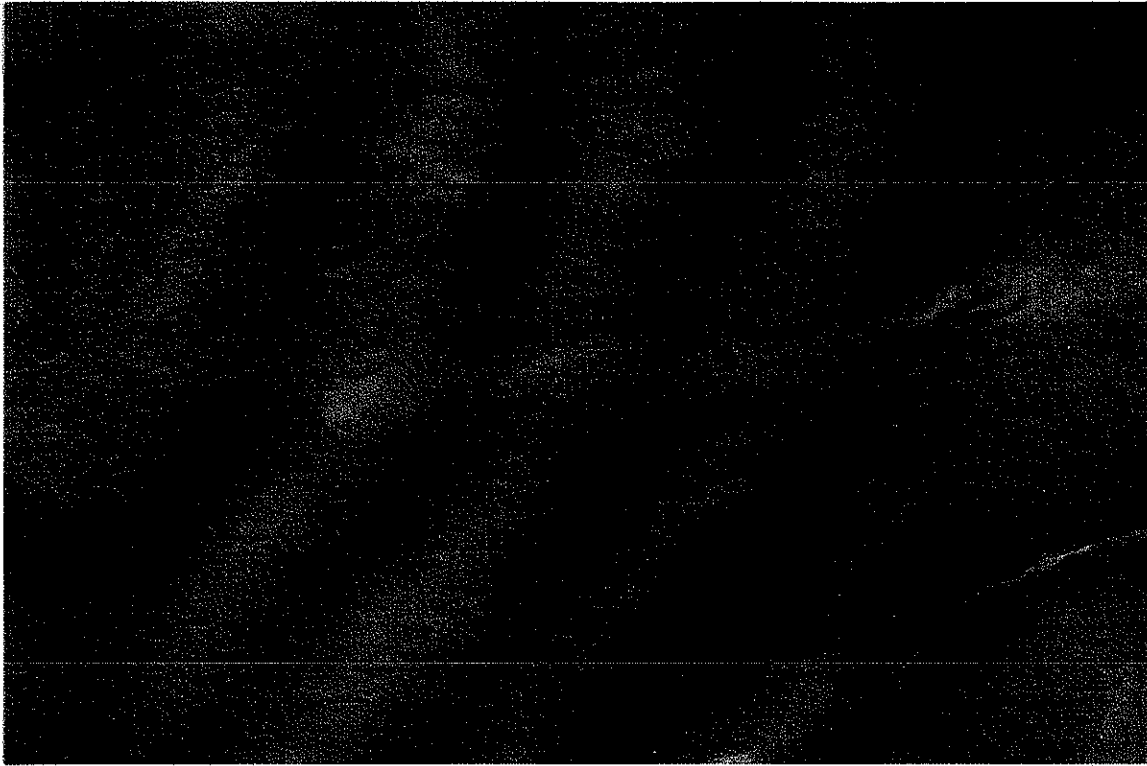


Photo 10 (DFV98/02/09/2-10)
Overview of the upper portion of Slide E. The major tributary is just upstream (to the left of the photo).



Photo 12 (DFV98/02/09/2-4)
Front view of the headscarp of Slide E.

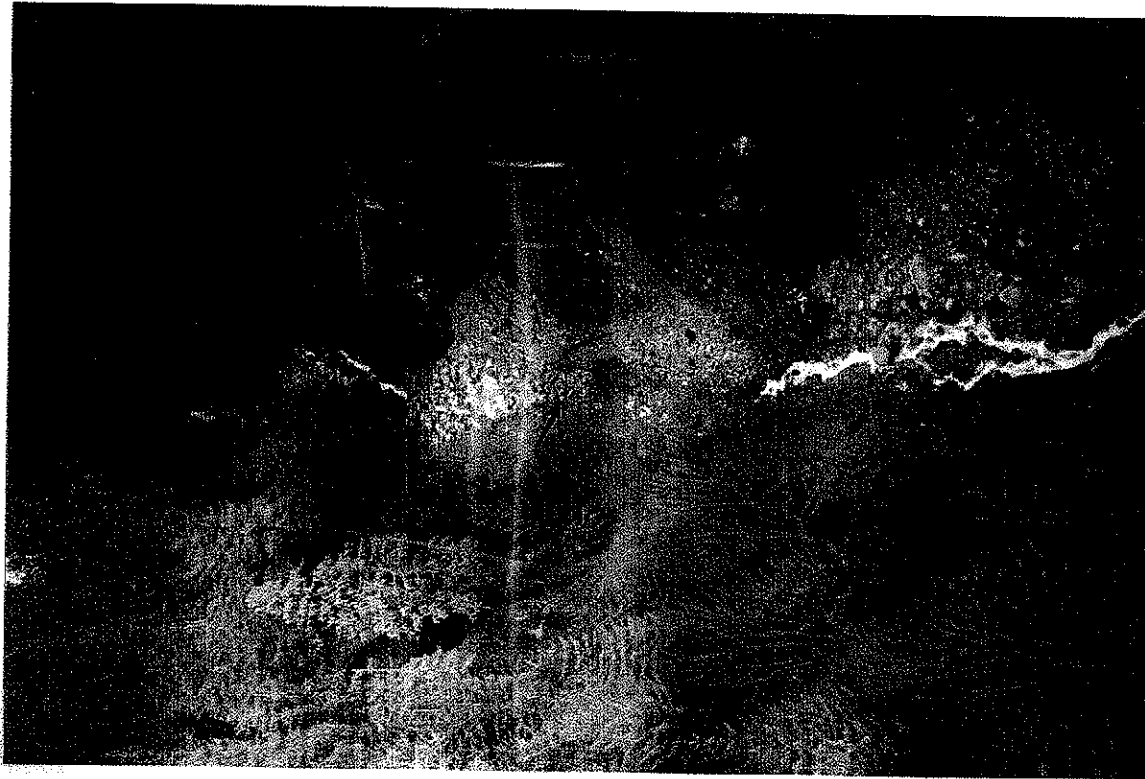


Photo 13 (DFV98/02/09/2-3)
Looking upstream along the main channel
showing the recent debris accumulation at the
toe of Slide E.

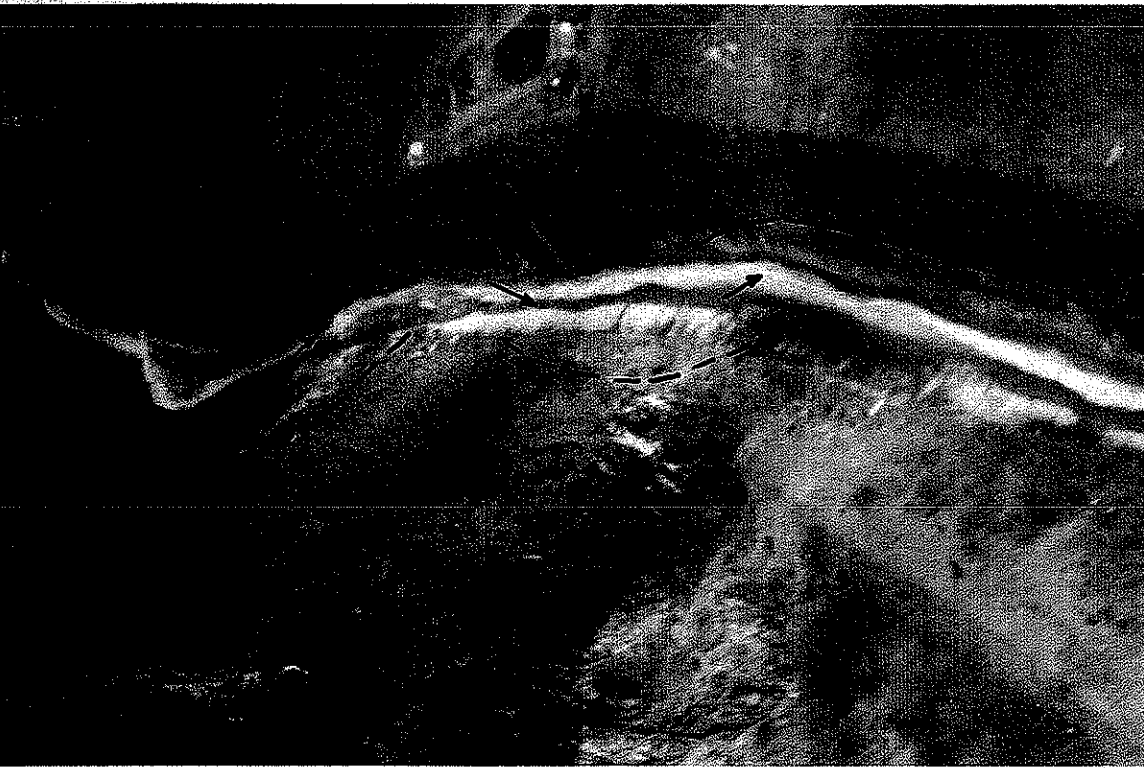


Photo 14 (DFV98/02/09/3-3)
Overview of the upper portion of the Newman Creek diversion. Indicated on the photo is the approximate flow path of the January 1, 1997 debris flow. The water supply reservoir is located on the right side of the photo.

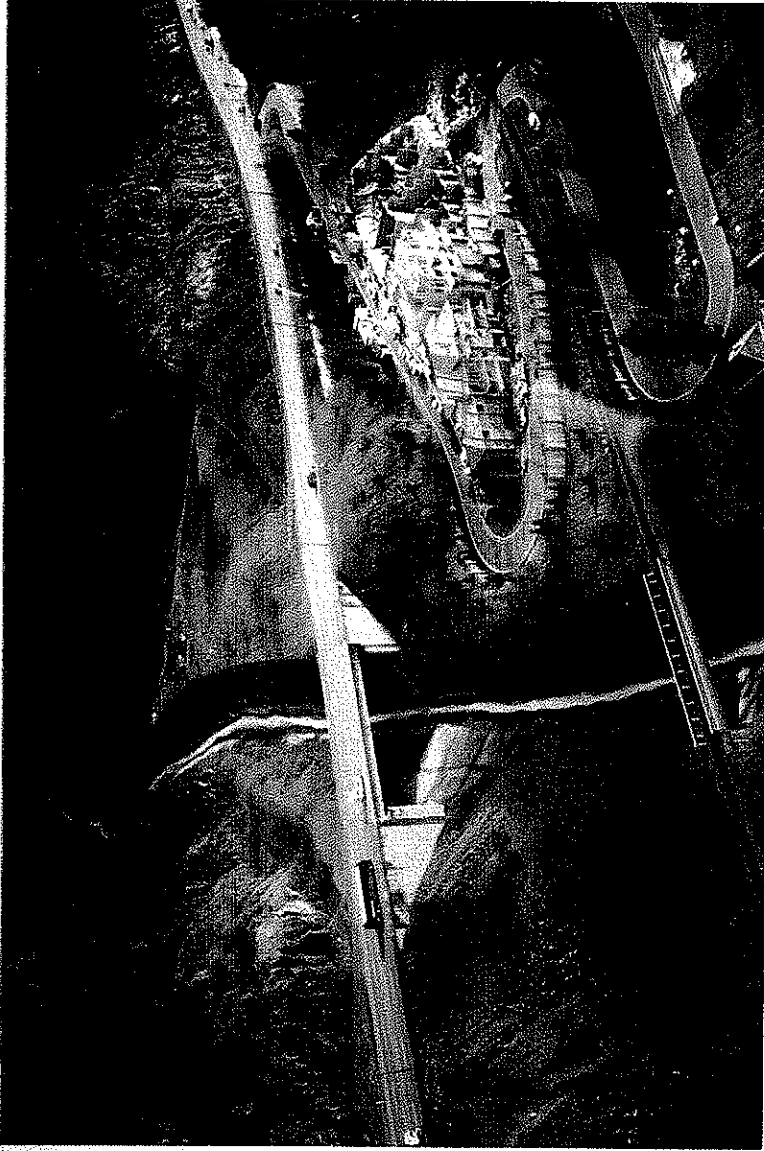


Photo 15 (DFV98/02/09/2-25)
Overview of the upper portion of the Newman Creek fan. The water supply reservoir is in the background, and the multiple-family dwelling under construction is in the right mid-ground.