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GEOTECHNICAL HAZARD ASSESSMENTS FOR GOSLIN AND L'HEUREUX CREEKS, TÊTE JAUNE CACHE, BRITISH COLUMBIA

PROJECT 1088 **NOVEMBER 1993**

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1. SUMMARY AND RECOMMENDATIONS

Piteau Associates Engineering Ltd. (PAEL) was retained by the Ministry of Transportation and Highways (MOTH) to assess the geotechnical hazards and to prepare conceptual layouts and order of magnitude cost estimates for remedial measures required to protect existing residences, property and Highway 16 in the vicinity of Goslin and L'Heureux Creeks near Tête Jaune Cache, British Columbia (Fig. 1). This report summarizes the results of the geotechnical investigations and provides recommendations concerning the hazards identified and remedial measures.

1.1 ENGINEERING GEOLOGY AND TERRAIN ASSESSMENTS

Engineering geology, terrain assessments and geotechnical hazards identified in the study area are shown on the 1:5000 scale plan in Fig. 2. Geotechnical hazards identified include landslides, avalanches, debris flows (including debris torrents and mudflows) and floods.

Several major landslides involving several million cubic metres each have been identified in the upper reaches of both creeks (Fig. 2). Active zones of ravelling and erosion have been identified along the toes of these landslides along the creek channels and active scree slopes extend from the creek channel to the ridge crest in several areas along the west side of Goslin Creek above 1260m elevation. The zones of active instability are contributing debris to the creek channels and could contribute to channel blockages or provide source material for debris flows and debris torrents. In addition, a number of smaller landslides up to 200,000m^3 have been identified which could also contribute debris to the channels of each creek.

Snow avalanches have been documented in the basins of both creeks. The event in L'Heureux Creek in January 1989 has been classified as a snow avalanche. Detailed assessment of the avalanche hazards and remedial measures required for avalanche protection are the subject of detailed studies by others.

Debris flows in both creeks have led to development of alluvial/debris fans as shown on Fig. 2. Whereas L'Heureux Creek does not appear to have experienced any recent debris flows, Goslin Creek has been subject to several debris flows, floods or related flow events in the last 50 years (see Fig. 5).

1.2 ASSESSMENT OF DEBRIS FLOW HAZARDS

The investigations have indicated that the major events which occurred in Goslin Creek in May 1986 and May 1993 were debris flows or mudflows. Debris flows could occur from either creek at any time due to the extensive volumes of debris along each creek channel and the presence of major landslides which provide a continuing contribution of debris. More frequent recurrence could be anticipated in Goslin Creek in the short term due to the recent erosion in the creek channel. Although there is little evidence of recent debris flows in L'Heureux Creek, there is a potential for future debris flows under unusual climatic conditions and/or reactivation of the large landslide in the upper reaches of the creek.

Future debris flows are expected to display similar behaviour to previous events. Debris could be expected to be deposited anywhere on the fans of both creeks. Hence, a number of residences and portions of Highway 16 are at risk in the event of a major debris flow in either creek.

Design parameters for future debris flow events are difficult to determine because of the chaotic interaction of the various climatic and geotechnical parameters which could lead to initiation of a particular event. Parameters have been derived from behaviour of past events and historical evidence from air photos. Maximum volumes of material in a future debris flow event are estimated to range from 100,000m^3 in L'Heureux Creek to in excess of 300,000m^3 in Goslin Creek. Discharges of the order of 1000 to 1500m^3/s are anticipated for confined channels or in debris lobes on the fan. Velocity will depend on the discharge, channel geometry, gradient and area of the flow.

1.3 REMEDIAL MEASURES OPTIONS

It is not possible to effectively control the debris flows at the source due to the enormous volumes of debris and major landslides in the upper reaches of both creeks. However, it is our opinion that the risk to residences and property could be significantly reduced by construction of appropriate remedial measures which would control or contain future debris flow events. These measures consist primarily of realignment and training of the creek channels to direct debris away from the existing residences, and construction of large capacity basins for containment of debris. Construction of these measures is based primarily on excavation of existing debris within the area of the previous debris flows and utilization of excavated debris to construct berms using cut and fill techniques.

A number of alternative options for remedial measures are illustrated on plans and sections in Figs. 6a to 6c, 7 and 8 which provide conceptual layouts and details of each option, and the areas protected. Order of magnitude costs for each option are presented in Table V. A description of the construction items and a breakdown of estimated costs for the option required to reduce the risk to all residences and a majority of lots in the study area is provided in Table VI. The costs for ongoing inspection, maintenance and removal of accumulated debris which will be required are not included in these estimates.

The recommended remedial measures are based on the requirements to control future debris flow events of the same magnitude as those previously experienced in Goslin Creek. The suitability of these measures to provide protection against avalanches should be reviewed by the avalanche experts retained by MOTH.

1.4 TIMING OF REMEDIAL MEASURES

All permanent remedial measures should be completed as soon as possible and preferably prior to the spring thaw in 1994.

In order to provide immediate temporary protection to the exiting residences south and east of Peterson Road, we recommend that temporary interim remedial measures be completed immediately (during the fall of 1993). These temporary measures should consist of limited channel realignment, construction of limited training berms, a small debris basin and ditch improvement along Highway 16 as shown in Fig. 9. These are viewed as interim measures to reduce the risk from possible small to intermediate sized debris flows which may arise as a result of the recent erosion in Goslin Creek.

Costs of these temporary measures are expected to be approximately $50,000.

1.5 INSPECTION AND MAINTENANCE

Regular ongoing inspection and maintenance will be required to maintain as clean a channel as possible. The creek channels and debris basins should be inspected at least three times a year (April, July and October). Any debris buildups in the containment basins or lower channel areas should be removed immediately.

Any future debris flows should be documented to help assess the effectiveness of the design and the need for additional remedial measures.

1.6 DETAILED DESIGN

A detailed design layout should be prepared for the remedial measures selected based on the above recommendations. Detailed topography will be required to determine the existing grades and elevation, and to lay out the realigned channel and armouring details. The location, geometry and shape of the debris basin should also be refined.

1.7 DETAILED INVESTIGATIONS OF MAJOR LANDSLIDES

The current degree of stability and the potential for acceleration and/or catastrophic failure of the major landslide areas identified in the upper reaches of both Goslin and L'Heureux Creek must be determined. Detailed geotechnical mapping and related investigations should be conducted to enable an accurate assessment of the geometry, failure mechanisms and stability of each landslide area.

We further recommend installation of an appropriate network of monitoring stations based on Global Positioning Systems (GPS) or precise aerial photograph surveying as soon as possible to assess the current activity and rate of movement, if any, of each landslide area. Recommended locations of monitoring stations are given in Fig. 2.

1.8 FUTURE DEVELOPMENT IN THE STUDY AREA

The recommended remedial measures are designed to reduce the risk to the existing residences and a portion of Highway 16. Further development, subdivision or erection of permanent structures must not be permitted at any location on the fan as defined in Fig. 2, or on any portion of district lots DL3150, DL3151, DL6005 or DL6006 lying north of Highway 16 unless further studies can more accurately define the hazards and appropriate remedial measures are installed.

1.9 CONCLUSIONS

The geotechnical assessments and preliminary conceptual designs of alternative remedial measures presented in this report are based on reconnaissance geotechnical mapping, examination of available information and photographs, and 1:20,000 scale topographic maps. Assessment of detailed topographic plans may indicate that a modification of the selected remedial measures option may be required.

It must be appreciated that the proposed conceptual designs are considered to be the optimum approach for the hazards identified in the study area. There is always a possibility that a larger event could occur which could result in the partial failure of a portion of the remedial measures. The recommended remedial measures option appear to be the most practical solution in terms of total cost.

The geological processes which have resulted in the debris flows are the same processes which have led to the formation of the alluvial/debris fan on which a number of residences and Highway 16 are located. These processes are expected to continue as part of the natural ongoing process of formation of the fans. Existing and/or proposed future developments on or adjacent to the fans must accept the inherent risks associated with development in such areas.

Respectfully submitted,

PITEAU ASSOCIATES ENGINEERING LTD.

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2. INTRODUCTION

This report summarizes the geotechnical assessments conducted by Piteau Associates Engineering Ltd. (PAEL) for the debris flow hazards within the areas of Goslin and L'Heureux Creeks near Tête Jaune Cache, British Columbia (Fig. 1). The site in question occurs along Highway 16 approximately 2.5 km west of the junction with Highway 5 at Tête Jaune Cache. The area has experienced at least two debris flows (1986 and 1993) and one avalanche (1989) since development of a subdivision on the north side of Highway 16 in the early 1980's. A number of residences located on both sides of Highway 16 on and adjacent to the alluvial/debris fans of Goslin and L'Heureux Creeks were affected by a recent debris flow/debris torrent event in May 1993 and to a lesser extent by events in 1986 and 1989.

The terms of reference and scope for this study are outlined in an invitation for proposal prepared by the Ministry of Transportation and Highways (MOTH) dated August 30, 1993. A description of the scope of work was provided in PAEL's proposal to MOTH dated August 31, 1993.

The purpose of these investigations was to evaluate the nature and extent of geotechnical hazards which have led to the events on Goslin Creek and L'Heureux Creeks, to provide recommendations concerning hazard mitigation and to provide order of magnitude costs for remedial measures.

The details of the investigations and recommendations are summarized in this report.

3. DESCRIPTION OF THE INVESTIGATIONS

The investigations consisted of a desk study to assess the extent of geotechnical hazards within the area affected by Goslin and L'Heureux Creeks, based on examination of airphotos, terrain evaluation, review of previous reports and documentation of previous washouts/debris flows.

Field reconnaissance was conducted between September 7 and 10, 1993. The reconnaissance investigation consisted of a detailed examination of accessible areas of the creek channels from the limits of the fan to approximately 1200m elevation in each creek. A three-hour helicopter reconnaissance was conducted in the upper reaches of both creeks on September 8, 1993.

Results of the field reconnaissance were used to assess the geotechnical hazards from landslides and debris flows in each creek, to prepare estimates of the volume of future events and to make recommendations concerning possible mitigation of the hazards.

Preliminary conceptual layouts of remedial measures alternatives were prepared based on available 1:5000 scale topographic maps and results of ground reconnaissance. Order of magnitude cost estimates were prepared for a number of remedial measures options.

4. SITE DESCRIPTION

4.1 LOCATION AND PHYSIOGRAPHY

The site is located on the east side of the Rocky Mountain Trench in the Robson Valley approximately 25 km northwest of Valemont and 70 km southeast of McBride, British Columbia. Goslin and L'Heureux Creeks are located in the Park Ranges of the Rocky Mountains on the east side of the Fraser River Valley (Fig. 1). The valley sides in this area consist of moderately steep natural slopes of the order of 15 to 20°, with vertical relief of approximately 1700m. A number of creeks have been incised into the bedrock and surficial deposits forming the mountain slopes. Goslin Creek has an overall gradient of about 16° and a catchment area of 3.8 km^2. L'Heureux Creek has an overall gradient of 17° and a catchment area of 3.2 km^2. Gradients on both creeks range from about 4 to 7° on the alluvial/debris fans (below about 1000m elevation) to 30 to 35° in the upper reaches of each creek (Figs. 3 and 4).

Relatively large alluvial/debris fans have been formed where the creeks run out on natural terraces and/or the floodplain of the Fraser River. It is likely that fan development has been ongoing, and will continue as part of the natural processes of erosion and deposition in the area.

4.2 CLIMATE

Climate records are available through Environment Canada for meteorological stations at McBride and Valemont. The area receives 500 to 600mm of annual precipitation, which consists of 300 to 400mm of rainfall and 200mm equivalent snowfall. Greater snowfall is expected at higher elevations. High snowpacks in the upper valley slopes typically melt during warm weather, often accompanied by heavy rains in late May to mid-June. Average monthly precipitation varies from 30 to 70mm during the months of May to October. Maximum recorded rainfall in a 24 hour period is 62mm. Minimum daily temperatures are above 0°C from May to October. The combination of high snowpack, heavy rains and minimum daily temperatures above freezing leads to high flows in the creeks in May and June.

These climatic conditions are ideal for the generation of floods, washouts, debris flows and other flow phenomena in the creeks in the early spring. In addition, sudden thaws (often accompanied by heavy rains) during winter months may lead to avalanche conditions at any time from November to May.

5. ENGINEERING GEOLOGY

An interpretation of the engineering geology, landforms and channel conditions has been prepared based on an examination of available photographs, helicopter reconnaissance and field mapping along accessible sections of both creeks below about 1200m elevation. Examination of aerial photographs, oblique photographs and video tapes of the site have been used to evaluate the various geotechnical features in both creeks.

Geotechnical hazards identified in the study area consist of landslides, avalanches, debris flows (including debris torrents and mudflows) and floods.

The distribution of the various engineering geology features and hazard areas are shown on a 1:5000 scale plan of the study area in Fig. 2. Figures 3 and 4 are profiles which indicate the gradient and main geotechnical features along the centreline of each creek channel. The results of our assessments of the bedrock, surficial sediments and various geotechnical hazards identified in the study area are presented in the following.

5.1 BEDROCK

Bedrock on the main valley slopes consists of sedimentary and metamorphic rocks of Lower Cambrian or Hadrynian age. Mountjoy (1978) and Campbell, et al (1973) indicate that the bulk of the bedrock is expected to consist of units of phyllite, shales, sandstones and conglomerates of the Middle Miette Group (Hadrynian Age). Bedrock outcrops consisting mainly of phyllites and slates were mapped in both creek channels above about 1150m elevation. Similar rocks were also mapped on the ridges in the upper reaches of both creeks. Bedrock has an estimated unconfined compressive strength in excess of 100 MPa (15,000 psi).

All rock exposures examined contained well developed foliation and related foliation joints which generally strike to the northwest and dip moderately to steeply (45 to 75°) to the southwest towards the Robson Valley. A number of natural joints and cracks were also observed which strike at oblique angles to the foliation. A detailed assessment of the patterns of structural discontinuities in the area is beyond the scope of this study.

5.2 SURFICIAL SEDIMENTS

Surficial soils on the mountain slopes consist of colluvium, alluvium and glacial deposits. Examination of the available airphotos and oblique photos, and reconnaissance mapping along the channel, indicates extensive deposits of colluvium, avalanche debris, landslide debris, talus and scree. There is also evidence of glacial morainal soils in some areas.

Colluvial soils mapped in the creek channels and fans consist of silt, sand and gravel with a high percentage of fines (passing the No. 200 sieve) as well as variable amounts of cobbles and boulders. The predominance of fine grained minerals comprising the bedrock has resulted in a high percentage of fine grained silt and clay size particles. The depositional environment of the colluvial materials generally results in poorly sorted deposits with variable amounts of fines and oversize cobbles and boulders throughout the deposits.

Examination of air photos and ground reconnaissance has indicated the presence of two natural terraces within the area of the subdivision east of Goslin Creek (Fig. 2). Material exposed in road cuts and natural cuts in these terraces consisted of silt, sand and gravel of possible alluvial origin. The fan of L'Heureux Creek appears to have formed in part by running out onto the terraces and in part by erosion into the terrace material.

5.3 LANDSLIDES

The locations and estimates of the volumes of the main landslide areas identified in the basins of Goslin and L'Heureux Creeks are shown on Fig. 2. Several different types of landslides ranging from several hundred to several million cubic metres in size have been identified. For purposes of this study, landslides with an estimated volume greater than 500,000m^3 are classified as major landslides.

A preliminary estimate of the volume of each major landslide in the upper reaches of each creek was prepared from examination of the air photos and development of postulated representative sections through each landslide area. These estimates are summarized in Table I. Additional detailed mapping and assessments would be required to prepare more accurate estimate of the volume of each landslide.

Volumes of smaller landslides ($<500,000m^3$) have been estimated from visual assessments within the creek channels during the field mapping.

5.3.1 Landslides in Goslin Creek

A total of three major landslide areas have been identified in the upper reaches of Goslin Creek above 1260m elevation. These landslides consist of very large areas of deep seated mass movement which are bounded by headwalls near the ridge crest on either side of the creek and which extend to the creek channel. Active zones of ravelling and erosion have been identified along the toes of these landslides along the creek channels and active scree slopes extend from the creek channel to the ridge crest in several areas along the west side of Goslin Creek above 1260m elevation.

Zones of deep seated mass movement and associated development of tension cracks were also observed on the west side of Goslin Creek and extending into the drainage basin of Spittal Creek (see Fig. 2).

A number of small landslides have been identified from the mapping along the channel of Goslin Creek as noted in Fig. 2. These landslides consist of unstable deposits of colluvium and debris which has been oversteepened as a result of erosion in the creek channel. The volume of these landslides is estimated to range from several hundred to several thousand cubic metres.

5.3.2 Landslides in L'Heureux Creek

One major landslide has been identified in the upper reaches of L'Heureux Creek above the 1680m elevation (Fig. 2). The toe of this landslide occurs in the creek channel between about 1680 and 1820m elevation. It appears that this landslide initially blocked the creek and that the current channel was subsequently eroded through the debris along the creek.

Two rock slides involving planar sliding and/or ploughing failure mechanisms involving west dipping foliation joints have also been identified in the upper section of the basin. A number of open cracks were also noted on the ridges at the head of the L'Heureux Creek basin. These features may represent incipient zones of instability which may affect the slope stability within the basin area.

A number of small to intermediate sized landslides have been identified from the mapping along the channel of L'Heureux Creek as noted in Fig. 2. These landslides range from an estimated volume from several hundred cubic metres to one hundred thousand cubic metres and consist of unstable deposits of colluvium and debris which have been oversteepened as a result of erosion in the creek channel. There appears to be a larger number of landslides in colluvium in the lower reaches of L'Heureux Creek than in the lower reaches of Goslin Creek.

5.3.3 Summary of Landslides

Major landslides involving several million cubic metres have been identified in the upper reaches of both creeks. There appears to be locally active zones of instability which are currently contributing debris to the creek channels and could contribute to channel blockages or provide source material for debris flows and debris torrents. In addition, a number of smaller landslides up to 200,000m^3 have been identified which could also contribute debris to the channels of each creek.

A number of the major landslides in the upper reaches of each creek have contributed debris to the creek and have undoubtedly been the source of considerable debris for previous debris flows and debris torrents. There is a potential for increased movement of these landslides and blockage of the creek over a considerable length along the toe of these slides. Preliminary estimates of the possible volume of debris which may block the creek channel due to sudden displacement or accelerations of individual major landslides ranges from 100,000 to 300,000m^3 (Table I).

The current rate of movement and the potential for the major landslides to accelerate and/or to fail catastrophically is unknown. Additional detailed mapping is recommended to assess the nature and morphology of each landslide. In addition, a monitoring system should be installed on each landslide to assess if movements are occurring and to determine the rate of any movements.

5.4 SNOW AVALANCHES

Snow avalanches are a common occurrence in the high mountains in the study area. Avalanche tracks which have been identified on the basis of vegetation patterns on the air photos and from the helicopter reconnaissance are noted on Fig. 2. Additional avalanches undoubtedly occur on most slopes above treeline in the upper reaches of each creek. It is noteworthy that a major avalanche occurred in L'Heureux Creek in January 1989. This avalanche involved extensive snow and trees and extended onto the fan of L'Heureux Creek within about 200m of the east end of Peterson Road. Examination of the creek in September 1993 indicated that the avalanche did not involve appreciable amounts of soil or rock debris and examination of the aerial photos and helicopter reconnaissance of the upper creek channel did not indicate any extensive erosion of the creek channel as a result of the avalanche.

Additional details of the avalanche hazards in both creeks are being addressed by others.

5.5 ASSESSMENT OF DEBRIS FLOW HAZARDS IN GOSLIN CREEK

Field traverses were conducted along the main channel and tributary channels in the lower reaches of each creek using a compass and hip chain. Channel orientation, gradient and geometry were estimated for stations at regular intervals along each traverse. Assessments of slope stability, materials in the creek bed and on the channel sides, volumes of debris eroded or deposited in the channel and quantitative assessments of erosion, deposition and volumes of debris along the channel were also conducted along each traverse. Trimlines of past debris flows on the creek banks and trees on the channel sides were also mapped at selected locations, to assist with subsequent calculations of debris flow discharge and velocity in Goslin Creek. Difference in trimline heights on either side of the creek, which provide evidence of superelevation of the debris flow in the creek bends, were also mapped. In some locations, trimlines were not considered reliable indicators of debris flow discharge because of channel blockages and/or side slumping and related movement of the slopes subsequent to the recent flow events in May 1993.

5.5.1 Review of Historical Evidence of Previous Flow Events

Government of British Columbia aerial photographs taken in 1949, 1958, 1973, 1986 and 1991 were examined to assess the extent of previous geotechnical hazards from debris flows, debris torrents, floods and avalanches in both creeks. Air photos do not define the exact nature of the events. However, they are a useful means for determining if changes have occurred with time and for assessing the extent of ground disturbance due to specific natural events such as landslides, floods, washouts, etc.

Results of the air photo examination indicate that at least five events have taken place in Goslin Creek and one major event has taken place in L'Heureux Creek during the period of historical record (see Fig. 5). The plan area affected by these events ranges from 6 hectares to 33 hectares. The recent debris flow event in Goslin Creek is estimated to have affected an area of approximately 33 hectares which is similar to the 30 hectare area defined by trim lines and vegetation patterns of a previous debris flow which appear on the 1949 air photos. Figure 5 further indicates that whereas an event has occurred on average about once every 10 years in Goslin Creek, two very large events have occurred within the period of record.

5.5.2 Debris Sources and Nature of Recent Events

The field investigations have indicated that debris from the May 1993 debris flow event was probably derived from several sources along the creek. Information and photographs provided by MOTH has indicated that snow avalanches in the upper reaches of the creek basin above about 2000m elevation contributed extensive snow, meltwater and some debris to the creek channel. Additional debris was subsequently contributed to the event as a result of erosion of the channel sides as well as contribution of debris from the large landslides between about 1260m and 2040m elevation in the creek channel. It is likely that landslides of the order of several thousand cubic metres may have occurred from the channel sides, resulting in debris dams which were subsequently overtopped, contributing large volumes of debris to the event.

Debris plugs occurred at the canyon and waterfalls at approximately 1160 to 1180m elevation, and also in the vicinity of bends and constrictions of the channel near the apex of the fan at about 990m elevation (mapping station G15), at the west debris lobe at about 955m elevation (stations G12 to G14) and at the main debris lobe at 855m elevation (stations G7 to G8). Debris plugs resulted in evulsion of debris from the channel at each location which resulted in formation of debris lobes and deposition of large volumes of debris on the fan. The natural tendency of the creek to plug and divert debris out of the creek channel and across the fan is typical of the manner in which the fan has been formed in the past and will continue to be formed in the future.

5.5.3 Volume of Recent Deposit

The distribution, thickness and volume of debris deposited from the recent event has been determined from the field reconnaissance mapping. Sections prepared from the mapping were used to estimate the width and thickness of the deposited debris. Quantities determined from the sections were used to estimate the total debris quantities by interpolating between the sections. Results of these estimates are summarized in Table II and estimated quantities for various areas of the debris deposit are noted on Fig. 2.

The total quantity of debris estimated in the deposit by this means is 273,000m^3 (Table II). It is likely that the total quantity of debris may have been as high as 300,000m^3 as some debris may have been removed during the highway cleanup and considerable fines may have been washed away by the creek.

Although the total volume of debris is estimated to be 300,000m^3 it is noteworthy that only about 50,000 m^3 appears to have entered the areas of the residences east of Peterson Road. The remainder of the debris was deposited in various areas on the fan as shown on Fig. 2 and summarized in Table II.

5.5.4 Discharges and Velocities

Discharge and velocities of debris flows are difficult to estimate, because of the influence of numerous physical parameters of the debris material and the channel. Three methods used to estimate possible discharges and velocities of debris flows are described in the following:

i) Discharge Based on Documented Geometry of Previous Flows Using Bagnold's Equation

Empirical estimates of the discharge were prepared using the estimated cross-sectional area of flow and gradient at 17 locations along the channel. The trimline height (where evident), channel geometry and channel gradient were measured at each location, and were used to calculate the velocity of flow using the empirical formula presented by Hungr et al (1984) from Bagnold (1954):

$$V = 2/3 \times E \times (S)^{\frac{1}{2}} \times (h)^{3/2}$$

where: V = velocity (m/s)

E = dimensional coefficient inversely proportional to the volume concentration of solid particles in the debris

$= 3.25\ m^{-\frac{1}{2}}s^{-1}$

S = creek gradient (%)

h = flow depth (m)

Discharges were calculated by multiplying the velocity by the area of the section as summarized in Table III.

Calculated discharges through the channel range from 248 to $45{,}500m^3/s$. The higher discharges (> 2000 to $3000m/s^3$) in some areas are likely related to a sudden narrowing of the channel or a sudden change in orientation (bends) or gradient which would tend to cause a backup resulting in temporary deposition of debris followed by surging. Bagnold's relationship is not considered to be valid for flow across the debris lobes where the debris is unconfined.

It is noteworthy that small changes in the channel gradient or the trimline height results in a significant variation in the velocity and discharge calculated using Bagnold's formula, which confirms the difficulty in estimating discharges and velocities for these types of events.

ii) Calculation of Discharge Based on Superelevation of Flow Surfaces

An alternative method of calculating velocity and discharge is based on the superelevation of the debris surface and radius of curvature through the bends in the channel. Differences in trimline heights, observed at five locations on either side of the creek, were used to calculate the flow velocity using the formula from Mears (1981):

$$h = \frac{k \times b \times V^2}{r \times g}$$

where h = elevation difference between the two sides of flow (m)
b = surface width of the flow (m)
V = mean velocity (m/s)
r = mean curvature radius (m)
g = acceleration due to gravity = 9.81 m/s^2
k = correction coefficient = 2.5

Discharges calculated from these velocities are summarized in Table III for comparison with results of the calculations based on Bagnold's formula. Calculated discharges range from 470 to 1518m^3/s, and are generally less than discharges calculated using Bagnold's relationship.

iii) Eyewitness Accounts

Discussions with MOTH personnel present during the events indicate that flow velocities in the vicinity of the highway were of the order of 4 to 5m/s and that individual surges behaved as mudflows or very rapid debris flows. Assuming a width of 100 to 160m for the unconfined flow up to 1m deep on the debris lobes, a discharge of 400 to 800m^3/s is indicated from the eyewitness accounts.

5.5.5 Channel Gradients, Blockages and Debris Deposition

There appears to have been limited deposition of debris in confined channel areas particularly where channel gradients are steeper than 7°. Furthermore, there is evidence of considerable erosion of debris from the channel sides in areas where the channel is confined or where gradients are greater than 7 to 8°. The bulk of the debris deposition appears to have occurred primarily in areas where sharp bends in the channel lead to blockages, or on unconfined lobes where the gradient of the natural slope is less than about 5 to 7°. This indicates that, provided channel blockages do not occur and the channel can be confined and maintained in a uniform alignment with a gradient steeper than 7°, it appears feasible to control the direction and maintain the flow of debris.

5.5.6 Debris Lobes and Runout Distance

Debris lobes were formed at six locations along the creek channel during the recent event. Constrictions or areas of sharp bends in the channel apparently led to a reduction in the velocity of flow leading to blockages and evulsion of debris from the channel. Debris from the West Lobe and the Main Lobe crossed Highway 16 at the locations shown in Fig. 2. It is likely that material deposited on the lower sections of the fan consisted of a higher percentage of silt and sand. The extent of remobilization of debris by subsequent erosion after the initial debris flow is difficult to determine.

5.6 ASSESSMENT OF DEBRIS FLOW HAZARDS IN L'HEUREUX CREEK

Examination of air photos indicate little evidence of recent debris flows or related events in L'Heureux Creek. As noted previously, examination of debris from the major snow avalanche in January 1989 confirmed that there was little soil or rock debris associated with that event. Examination of the air photos indicates that a poorly defined alluvial/debris fan exists between the 860m and 820m elevation. This fan appears to have run out on a terrace deposit located above the main valley. Evidence of debris from this fan was noted in a 3m deep test pit on Lot 7 (Crews) on the north side of Peterson Road. The air photos provide further evidence that debris from prehistoric debris flows may have been deposited in the creek gully and a portion of the low lying area north of Highway 16. Fig. 2 indicates the limits of the fan and associated debris flow hazards from L'Heureux Creek.

Field examination of the creek channel and upper reaches of the L'Heureux Creek basin indicates little recent erosion and no evidence of recent debris flow activity. However, extensive deposits of colluvium and debris were mapped in landslides and related deposits along the entire creek channel (Fig. 2). A number of these landslides could be reactivated and could contribute debris to a debris flow or debris torrent given the appropriate conditions.

Although, there is no evidence of recent debris flow activity in L'Heureux Creek, the potential for an event of a magnitude of $100,000m^3$ cannot be discounted, particularly if the major landslide in the upper reaches of the creek is reactivated. One residence and several lots on the east side of the subdivision could be affected by a debris flow event in L'Heureux Creek. Remedial measures will be required for protection.

5.7 DESIGN PARAMETERS FOR DEBRIS FLOW HAZARDS

The field investigations and office analyses have indicated that hazards from debris flows exist in both Goslin and L'Heureux Creeks. Design of any remedial measures to mitigate the hazards arising from future events must be based on the anticipated nature of the flows for the design event in each creek. Because of the inherent variability of the nature of a particular event, determination of design parameters is extremely difficult and is most realistically based on the empirical evidence from past events and debris volumes remaining in the creek channels.

The events which occurred in Goslin Creek in May 1986 and May 1993 were debris flows or mudflows. The difference between a debris flow and a mudflow is based on the gradation of the material, and the percentage of water in the flow. Absolute definition of the documented events is not possible, due to the limited information available.

The frequency of occurrence, magnitude, discharge, velocity and distribution of debris from a flow depend on a number of varying conditions, including:

i) volume of debris available in or adjacent to the channel
ii) water flows in the channel
iii) material type and gradation
iv) climate conditions (precipitation, temperature, snowpack, presence of frost) at the time of the event
v) possible generation of anomalous conditions such as a landslide or avalanche forming a debris dam which overtops and/or breaches, releasing large volumes of debris and dammed up water

In general, the prediction of the timing and nature of events is very difficult because of the chaotic interaction of the variables described above. In the case of Goslin and L'Heureux Creeks, the historical evidence from air photos and parameters determined from the analyses of the recent flow events in Goslin Creek provide an appropriate means of determining design parameters for remedial measures as discussed in the following.

5.7.1 Maximum Volumes of a Debris Flow Event

The investigations have indicated that a large debris flow, possibly in the order of 300,000m^3 or higher, could occur in Goslin Creek. Although there is no recent evidence of debris flows in L'Heureux Creek the potential for a large debris flow, possibly in the order of 100,000m^3 cannot be ruled out. The volume of debris reaching various locations on the fan of each creek will depend on the nature of the debris and the channel geometry at the time of a particular event. Any location on the debris fans as shown in Fig. 2 could be subject to future flow events.

5.7.2 Discharges and Velocities

i) Initial Discharge at the Source

The documented occurrence of large landslides in the upper reaches of the creeks indicates that significant blockages could occur which could be overtopped and/or breached, and which could result in the initiation of a debris flow event. An estimate of the possible range of initial discharge at the source has been prepared based on the dam break formula included in Hungr et al (1984), as follows:

$$Q = 8/27 \times (g)^{\frac{1}{2}} \times b \times (h)^{3/2}$$

where Q = discharge (m^3/s)
g = acceleration due to gravity ($9.81m/s^2$)
b = width of blockage (m)
h = height of blockage (m)

Analysis results using the above formula indicate that peak discharges of 100 to 500m^3/s could occur as a result of the overtopping of a debris dam 3 to 5m high over a valley width of 30 to 50m. Reactivation of a major landslide could result in blockage of the creek channel to heights in excess of 20 to 30m, which could increase the estimated discharges to several thousand m^3/s at the source.

It is important to note that the high discharges that could arise from overtopping a large debris dam in Goslin Creek may be controlled by the constrictions and bends in the canyon at about 1160 to 1180m elevation, which may tend to limit the discharges into the lower reaches of the creek. Although this canyon has limited the discharge in past events, large volumes of debris have overtopped the canyon rim and continued into the lower reaches of the creek.

ii) Discharge on the Fan

Discharge and velocities of possible future debris flows on the fan and in the vicinity of the subdivision and Highway 16 may be estimated from the empirical methods described in Section 5.5 and summarized in Table III. Discharges in confined and partially confined channels on the fan of Goslin Creek indicated from Table III range from 250 to >2000m^3/s. Estimated discharges in excess of

$1500m^3/s$ are probably a result of deposition in the channel. Eyewitness accounts indicate that discharge rates for unconfined flow lower on the fan ranged from 400 to $800m^3/s$. Based on the available evidence we recommend that design of remedial measures for the lower area of the fan be based on discharges in the order of 1000 to $1500m^3/s$.

The radius of curvature of the channel also influences the discharge. Qualitatively, the larger the radius of curvature, the more continuous the flow through the channel. Quantitatively, it is difficult to correlate discharges with the radius of curvature of the channel because of the number of parameters influencing the flow. The radius of curvature for relocated channels should be as great as possible, and preferably greater than 100m, to reduce the potential for deposition and/or evulsion of the flows from the channel.

5.7.3 Channel Gradients and Geometry

It is important to assess the potential for debris to deposit in the channel if gradients are reduced. Observations by Hungr et al (1984) and Van Dine (1985) have indicated that deposition of debris can depend on a number of variables, including cross-sectional area, discharge and channel gradient. In general, the specific conditions and parameters required to determine the channel gradients which lead to deposition of debris are not well understood. Hungr et al (1984) indicates that deposition is not expected in confined channels with gradients in excess of 8 to 12°. Evidence from the recent debris flow in Goslin Creek indicates little deposition at gradients as low as 7° in areas where the channel is straight and confined. Deposition generally appears to have occurred at bends in confined channels, in unconfined channels or on debris lobes where the gradients are less than 6 to 8°. It is also important to note that although deposition has occurred at gradients of 7°, flows have continued to advance across the fan at gradients of 5° or less. This has resulted in runout of debris from individual lobes to the extreme limits of the fan in two areas.

Based on the above observations, it is concluded that, provided the creek channel remains confined without sharp bends, the potential for deposition is reduced for channel gradients greater than 7°. Wherever possible, channel gradients should be kept to a maximum.

The tendency for deposition of debris could also be reduced by using a channel geometry to maintain velocity at lower flows, and by lining the channel with a suitably "smooth" surface such as concrete lock blocks or using a concrete lined channel.

The requirements to prevent evulsion of debris from a uniform straight channel will depend on the discharge, the channel geometry and the gradient. Table IV summarizes the channel depth required for various discharges for a nominal 5m wide channel at various gradients based on Bagnold's relationship. Table IV indicates that a channel depth of 6 to 7m would be required for control of most anticipated debris flow discharges at this site.

5.7.4 Runout Distance

Runout distance is difficult to predict because the nature and flow parameters of individual events can be expected to vary. Applicability of runout equations such as those developed by Hungr et al (1984, after Takahashi and Yoshida, 1979) are limited, because the channel width cannot be maintained for the full length of the fan. The optimum approach would be to construct a confined channel at as steep a gradient as possible across the fan, with the channel flaring out into a wider runout and deposition area (containment basin) at a shallower gradient in an appropriate location where there is minimal risk to permanent structures.

6. ASSESSMENT OF REMEDIAL MEASURES OPTIONS

The field investigations and office analyses have indicated that a debris flow hazard exists on both Goslin and L'Heureux Creeks. Events of the magnitude recently experienced on Goslin Creek can be anticipated to recur with possible increasing frequency as a consequence of the more rapid erosion which has occurred in the upper reaches of the creek during and subsequent to the major debris flow in May 1993. The maximum discharge and velocity of events would be limited by the existing channel geometry and the tendency of bends and constrictions in the channel to regulate flows and cause evulsion of the debris material onto the fan at a number of locations. Although there is little evidence of recent debris flows in L'Heureux Creek, there is a potential for future debris flows under unusual climatic conditions and/or reactivation of the large landslide in the upper reaches of the creek.

A number of residences and portions of Highway 16 are at risk in the event of a major debris flow in either creek.

It is not possible to effectively control the debris flows at the source due to the enormous volumes of debris and major landslides in the upper reaches of both creeks. However, it is our opinion that the risk to residences and property could be significantly reduced by construction of appropriate remedial measures which would control or contain future debris flow events. The conceptual layout for a number of remedial measures options are illustrated on plans and sections in Figs. 6a to 6c, 7 and 8. Order of magnitude cost estimates for each option are presented to enable MOTH to evaluate the cost-benefit of the various alternatives. The various options are presented in Table V, and a breakdown of estimated costs for the alternative required to reduce risk to all residences and a majority of lots in the study area is provided in Table VI.

6.1 OPTION A - NO REMEDIAL MEASURES

A total of three existing residences and 8 lots are expected to be at minimal risk from debris flows should no remedial measures be undertaken (see Fig. 6a). These structures are located on the upper section of Peterson Road above the fan of Goslin Creek and west of the hazard area from L'Heureux Creek. If no remedial measures are undertaken these areas would still be subject to loss of access in the event that a debris flow were to occur and block Peterson Road or Goslin Road. Other residences and Highway 16 will continue to be subject to an ongoing proportionately high level risk unless specific remedial measures are constructed.

6.2 OPTION B - REMEDIAL MEASURES FOR L'HEUREUX CREEK

Limited remedial measures are recommended to reduce the risk to the area within and adjacent to the fan of L'Heureux Creek. This work would consist of realigning and deepening the creek channel and creating a training berm with the excavated material. A balanced cut and fill could be achieved by excavating an approximately 2.5m deep channel and side casting material to create and approximately 6m high berm as shown in Section A-A' in Fig. 7. In conjunction with this work we recommend removal of accumulated logs and debris from the creek to prevent debris buildups and reduce the potential for plugging and evulsion of debris from the channel.

Remedial measures for L'Heureux Creek are expected to cost approximately $45,000. They would reduce the risk for 4 lots and one residence (Peterson) on the east side of the existing subdivision (see Fig. 6a).

While these measures may help to reduce the avalanche hazard from L'Heureux Creek, their effectiveness in controlling the design snow avalanche must be reviewed by the avalanche experts retained by the MOTH to assess the avalanche hazards.

6.3 OPTION C - TRAINING WORKS ON LOWER GOSLIN CREEK

Construction of an approximately 520m long x 6m high training berm along the east side of the lower section of Goslin Creek as shown in Fig. 6a would be required to reduce the risk to one additional lot (Dewey) with an existing residence. This work would involve channel realignment and construction of an appropriate berm using cut and fill techniques. This work could be conducted using a dozer and large backhoe over a short period. Costs of this option are estimated to be approximately $40,000.

6.4 OPTION D - REMEDIAL MEASURES TO PROTECT ENTIRE SUBDIVISION

It would be possible to reduce the risk to all residences in the subdivision and provide some hazard mitigation for Highway 16 near Peterson Road by installation of remedial measures consisting of creek realignment, channel straightening, construction of training berms and a debris containment basin in the area west of Peterson Road as shown on Fig. 6b. Preliminary conceptual layouts and details of the construction requirements for berms and the containment basin for this option are shown on representative plans and sections in Figs. 6b, 7 and 8.

Option D involves a number of separate construction items and would result in considerably greater cost than the limited remedial measures presented for Options B and C. The various construction tasks and costs for this option are discussed below and summarized in Table VI.

6.4.1 Channel Cleanout and Realignment

Clean out and realignment of the channel is strongly recommended for an approximately 400m section of the existing creek upstream of the main area of remedial measures. The objectives of this work are to provide a uniform channel geometry and gradient to reduce the potential for debris deposition and evulsion of debris from the channel in future events. Estimated costs for this work are based on use of a large backhoe, dozer and dump truck for approximately 8 to 10 days.

6.4.2 Construction of Training Berms and Containment Basin

The main feature of the protective works for the subdivision and highway is the diversion of the existing channel of Goslin Creek along the west side of Peterson Road to a debris containment basin near Highway 16, as shown in Fig. 6b. Various geometries and heights of training berms and sizes of containment basins were evaluated. The optimum layout chosen consists of creating a 6 to 8m high training berm located approximately 20m west of Peterson Road which diverts future debris to a containment basin constructed by excavating debris to a depth of 2 to 3m below the existing grade over an approximate area of 200m x 300m north of Highway 16 (Fig. 6b). Debris from the excavation would be used to construct berms up to 7m high which would result in a total capacity of about 180,000 to 270,000m^3 for the debris basin. Total excavation required for this alternative is about 108,000m^3 and could result in a small excess of material after berm construction. Reduced excavation would result in lower berms and reduced capacity for the debris basin.

Information provided by MOTH and eyewitness accounts of the debris flow events have indicated that the debris for the various events behaved as a fluid material. It is possible that fluid debris may build up rapidly within the containment basin or, in fact, flow over the containment berm along a uniform front. The hazard from such an overflow could be reduced by shifting the containment basin further to the west away from Peterson Road. This alternative to Option D should be investigated based on accurate topographic surveys as part of the detailed design.

It is recommended that a culvert be installed to convey water from Goslin Creek through the containment basin and prevent ponding of water within the containment basin. This culvert could be placed under Highway 16 west of Peterson Road, however this would result in possible debris flow and/or flooding in the property immediately south of Highway 16. It is therefore recommended that the culvert be placed at the southeast corner of the debris basin to convey water from Goslin Creek through the containment basin and into the ditch along the north side of Highway 16.

We also recommend that a spillway be constructed in this area in the event that the culvert plugs and debris builds up rapidly within the basin. The conceptual layout and construction details of training berms and the spillway area are provided in the plans in Figs. 6b and 8 and on Sections C-C', D-D' and E-E' in Fig. 7.

Training berms and the spillway area must be armoured with suitably placed rip rap armouring which can be derived from the excavation of the debris for the containment basin. Use of slush concrete between the armouring blocks should be considered in the spillway area. Alternatively, lock blocks could be used at greater cost.

6.4.3 Ditch Improvement between Goslin Road and Highway 16

We recommend that the western access road between Highway 16 and Goslin Road be removed, and that the ditch on the north side of Highway 16 between the containment basin spillway and the east end of the subdivision be deepened, widened and suitably armoured to convey any excess fluid debris to the southeast, away from the subdivision. Section F-F' in Fig. 7 provides a conceptual layout for the ditch improvements.

Removal of the access road is considered mandatory to reduce the risk of debris flowing over Highway 16 and towards the residence on the south side of the highway (Fidler). The excavated debris from the ditch improvement would be used to construct a training berm on the northeast side of the spillway to divert potential debris passing over the spillway into the ditch along the north side of Highway 16.

It must be appreciated that these measures could result in plugging of the Goslin Creek culvert under Highway 16 at the east end of the subdivision. It is possible that evulsion of debris could occur at this location and debris could cross the highway or access road. Individual residences are not expected to be at risk, although access could be lost.

6.4.4 Remedial Measures at the Upper Reaches of the West Lobe

The recent debris flow in Goslin Creek resulted in an evulsion of debris from the channel and additional deposition of debris on the West Lobe. This has resulted in additional entrenchment of the existing channel, which will reduce the amount of debris which may run out onto the West Lobe in future events. This implies that a greater volume of debris could remain in the creek and enter the subdivision area in future flows.

To reduce the volume of debris which could reach the containment basin in Option D, we recommend that specific remedial measures be undertaken to enable debris from future events to leave the channel at the West Lobe. Approximately 8,000m^3 of excavation at an estimated cost of about $42,000 is required for these measures as shown in the conceptual layout in Fig. 6b and Section G-G' in Fig. 7. These measures could increase the risk to Highway 16 at the south end of the West Lobe, resulting in a requirement for additional remedial measures in that area.

6.4.5 Order of Magnitude Cost Estimate

Order of magnitude cost estimates for the various items in Option D are included in Table VI. These cost estimates are based on the following unit costs as discussed with MOTH:

-	Cut and fill excavation and berm construction with haulage distances up to 500m	\$5/m^3
-	Selection and placement of rip rap armouring utilizing boulders from the debris excavation	\$15/m^3
-	Culvert installation	\$250/m
-	Clearing and grubbing, where required	\$1/m^2

Clearing and grubbing costs are expected to be minimal in most areas covered by the recent debris flow events. In addition, excavation costs may be as low as \$3 to \$4/m^3 in some areas where short hauls may be used.

The total costs in Table VI include the cost of remedial measures on L'Heureux Creek (Option B) which will also be required for protection of the east side of the subdivision. The cost for engineering, design and supervision are also included and a contingency of 15% has been incorporated to account for any unforeseen requirements which may become apparent during the detailed design.

The conceptual layouts and cost estimates are based on the available topographic information which is very limited. Detailed design and more accurate estimates of costs will require detailed topographic surveys to be conducted and additional field investigations to enable an accurate layout of all the required works. The final costs for the remedial measures could vary substantially, depending on the actual detailed design and nature of the construction contracts for the work.

6.4.6 Maintenance Costs

The costs of ongoing inspection and maintenance of the creek channels, culverts and training berms have not been included in the cost estimates described above. These costs are likely to be considerable. It would be necessary to plan for inspections of the entire creek channel at least three times per year (April, July and October). Although debris removal may not be required every year, maintenance costs could be estimated based on annual cleanout of culvert areas and removal of approximately 20,000m^3 of debris per year. Debris which may have to be removed after a major debris flow event could be as high as 200,000 to 300,000m^3.

6.5 OPTION E - CONSTRUCTION OF REMEDIAL WORKS AT WEST LOBE

Mitigation of hazards to Highway 16 at the West Lobe approximately 1 km west of Peterson Road could be achieved by channel deepening and construction of a debris containment basin on the north side of the highway as shown in Fig. 6b. A debris containment basin with a capacity of approximately 75,000m^3 could be constructed by excavation of approximately 15,000m^3 and construction of berms approximately 6m high as shown on Section H-H' in Fig. 7. It would be advisable to place a culvert through the berm and improve the ditches along Highway 16 to prevent ponding of water in the basin.

Construction of the berms, containment basin, channel deepening and ditch improvements are estimated to cost about $135,000. These works are only considered to be necessary for highway protection and are not required for protection of existing residences. Ongoing inspection, maintenance and removal of accumulated debris would also be required.

6.6 OPTION F - CONSTRUCTION OF CHANNEL TO DIVERT DEBRIS UNDER HIGHWAY 16 WEST OF PETERSON ROAD

It is possible that during a very large event, fluid debris may build up rapidly within the containment basin proposed for Option D and flow over the containment berm along a uniform front along Highway 16. This could result in loss of access along the highway and possible movement of debris flow material across Highway 16 as well as to the east on the highway as was experienced during the May 1993 event. Mitigation of this hazard could be provided by creating a deep channel approximately 100m west of Peterson Road and conveying future debris under Highway 16 to a containment basin south of Highway 16 (Fig. 6c). This concept would require excavation of a channel up to 20m deep to maintain a sufficient grade to prevent debris deposition in the channel. Construction of a single span bridge or installation of a super span or Armadillo culvert with sufficient clearance to pass a design event would also be required. Costs for a suitable bridge or culvert and associated construction works would likely exceed $3,000,000 to $4,000,000. Detailed assessments of this alternative have not been conducted.

6.7 OPTION G - CHANNEL REALIGNMENT AT APEX OF FAN

Reduction of the hazards from future debris flows at all locations on the fan of Goslin Creek would require straightening and entrenchment of the creek channel at the apex of the fan or at the location of the West Lobe. This work would have the advantage that all future flows would be controlled nearer to the source and debris would be directed in a confined channel at a steep gradient to a large debris containment basin in an undeveloped area of the fan. This work could also reduce the hazard to other undeveloped areas of the fan and Highway 16.

Two alternative alignments for the required channel realignment are shown for Option G in Fig. 6c. These options require in excess of 300,000m^3 and 600,000m^3 of excavation, respectively, to develop a channel of the required dimensions and gradient. These quantities are more than two to three times those estimated for Options B, D and E combined. Hence, the cost of Option G is expected to be two to three times the cost of Option D. Detailed estimates of quantities and costs have not been prepared for these options.

6.8 INTERIM REMEDIAL MEASURES

The erosion and landslide activity which have occurred as a result of the recent debris flow event in Goslin Creek could lead to an increase in frequency of major events. Hence, there is an increased risk of a large debris flow at any time during heavy rains or a sudden thaw. We recommend that temporary interim remedial measures be completed immediately (during the fall of 1993) to reduce the risk from possible small to intermediate sized debris flows originating in Goslin Creek. These temporary measures are shown in Fig. 9 and should consist of the following:

- i) Channel realignment, cleaning and straightening between stations G6 and G10
- ii) Construction of an approximately 4m high training berm and diversion of Goslin Creek into the Main Lobe west of Peterson Road.
- iii) Excavation of a 2m deep debris basin and construction of limited training berms north of Highway 16 at the south end of the Main Lobe.
- iv) Removal of the western access to Peterson Road and creation of a shaped ditch to direct Goslin Creek along the north side of Highway 16 and divert possible debris flow material to the culvert under Highway 16 at the east end of the subdivision.

Costs of these temporary measures are expected to be approximately $50,000.

7. REFERENCES

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TABLES

TABLE I
SUMMARY OF MAJOR LANDSLIDES IDENTIFIED IN THE UPPER REACHES OF GOSLIN AND L'HEUREUX CREEKS

LOCATION/ DESCRIPTION	ELEVATION IN CREEK (m.a.s.l.)	HEADWALL ELEVATION (m.a.s.l.)	AVERAGE SLOPE (°)	ESTIMATED PLAN AREA (m^2)	PRELIMINARY ESTIMATE OF LANDSLIDE VOLUME (m^3)	ESTIMATED VOLUME OF DEBRIS CONTRIBUTED TO CREEK (m^3)	COMMENTS
GOSLIN CREEK WEST SIDE	1260 – 1860	1660 – 2040	27 – 35	7.1×10^5	34×10^6	–	Major zone of possible deep–seated deformation defined by linear troughs on ridge on west side of creek valley.
	1260 – 1360	1660 – 1780	37	1.0×10^5	2.6×10^6	250,000	Zones of possibly active landsliding on west side of Goslin Creek which have resulted in extensive debris deposits in creek bottom.
	1360 – 1540	1720 – 1940	32	2.8×10^5	4×10^6	200,000	
	1540 – 1860	1940 – 2040	29	3.3×10^5	7×10^6	300,000	
	1860 – 2060	2100 – 2480	32	2.5×10^5	15×10^6	–	Zone of deep–seated rock mass deformation and cracking.
	1860 – 2040	2080 – 2200	34	1.5×10^5	4×10^6	–	Active rock slide involving planar slab sliding and ploughing.
GOSLIN CREEK EAST SIDE	1600 – 1960	1980 – 2120	27	3.3×10^5	13×10^6	200,000	Deep–seated landslide in bedrock.
L'HEUREUX CREEK EAST SIDE	1680 – 2140	2100 – 2300	26	2.1×10^5	8.5×10^6	100,000	Deep–seated landslide in bedrock involving extensive movement and development of debris lobe in creek.
L'HEUREUX CREEK WEST SIDE	2300 – 2440	2400 – 2440	35	0.31×10^5	0.4×10^6	–	Planar slab/ploughing mechanism involving northwesterly dipping foliation.
	2080 – 2200	2200	27	0.13×10^5	0.2×10^6	–	Planar slab/ploughing mechanism involving northwesterly dipping foliation.

TABLE II
SUMMARY OF DEBRIS VOLUMES ESTIMATED FOR MAY 1993 DEBRIS FLOW IN GOSLIN CREEK

AREA DESCRIPTION	APPROXIMATE ELEVATION (m.a.s.l.)	AVERAGE GEOMETRY OF DEPOSITED DEBRIS			ESTIMATED QUANTITY (m^3)
		GRADIENT (°)	WIDTH (m)	MAXIMUM DEPTH (m)	
A. Main Creek below Peterson Road	780 – 815	1 – 5	0 – 120	1.5	32,000
B. Main Creek between Peterson Road and Station G8	818 – 855	5 – 6	40 – 100	1.0	18,000
C. Main debris lobe north of Highway 16	810 – 855	4 – 7	130 – 160	2.0	64,000
D. Main debris lobe south of Highway 16	785 – 810	5 – 8	30 – 150	1.5	21,500
E. Main Creek between Main Lobe and West Lobe	855 – 918	7	–	1.0	12,000
F. West Lobe north of Highway 16	808 – 930	0 – 10	35 – 160	5.0	82,000
G. West Lobe south of Highway 16	803 – 808	0 – 2	40 – 60	1.0	2,500
H. Main Creek between West Lobe and waterfall	918 – 1180	7 – 16	–	–	–
H'. Lobe on east side of creek between Stations G12 and G13	920 – 935	–	90	1.5	19,000
I. Lobe on west side of creek between Stations G15 and G16	950 – 970	5 – 10	10 – 170	3.0	22,000
TOTAL					273,000

TABLE III

CALCULATED DISCHARGE OF MAY 1993 DEBRIS FLOW EVENTS BASED ON TRIMLINES IN CONFINED CHANNEL AREAS

STATION	ESTIMATED ELEVATION (m.a.s.l.)	CHANNEL GRADIENT (°)	ESTIMATED TRIMLINE HEIGHT, H_T (m)	ESTIMATED SUPER ELEVATION HEIGHT, H_S (m)	ESTIMATED SURFACE WIDTH OF DEBRIS FLOW, b (m)	RADIUS OF CURVATURE OF CHANNEL (m)	ESTIMATED FLOW AREA, A_T (m^2)	VELOCITY		DISCHARGE		COMMENTS
								FROM BAGNOLD'S (m/s)	FROM MEARS (m/s)	FROM BAGNOLD'S (m^3/s)	FROM MEARS (m^3/s)	
G-7	850	6.0	2.0	0	0	0	125	2.0	0.0	248	0	
G-8	855	7.0	2.0	0	0	0	120	2.1	0.0	258	0	
G-9	860	7.0	6.0	5	20	480	85	11.2	21.7	948	0	
G-10	890	7.0	10.0	0	0	0	103	24.0	0.0	2473	0	Sudden confinment
G-11	910	7.0	6.0	0	0	0	130	11.2	0.0	1451	0	
G-12	930	7.0	8.0	2	17	65	110	17.2	5.5	1890	603	Channel blockage and
G-13	940	7.0	8.0	1	15	150	75	17.2	6.3	1288	470	evulsion of debris
G-14	950	5.0	7.0	0	0	0	75	11.9	0.0	890	0	
G-15	960	6.5	12.0	2	25	260	168	30.4	9.0	5107	1518	Channel blockage and
G-16	975	7.5	7.0	0	0	0	128	14.6	0.0	1864	0	evulsion of debris
G-17	990	10.0	7.0	0	0	0	44	16.8	0.0	741	0	
G-18	1015	10.5	6.0	2	17	260	65	13.7	11.0	891	712	
G-19	1030	13.0	6.5	5	30	260	75	17.3	13.0	1294	978	
G-20	1040	15.0	7.0	0	0	0	90	20.8	0.0	1869	0	
G-21	1095	16.0	11.0	0	0	0	90	42.3	0.0	3810	0	
G-22	1100	18.0	20.0	0	0	0	412	110.5	0.0	45512	0	Canyon Section
G-22A	1100+	18.0	20.0	0	0	0	188	110.5	0.0	20767	0	

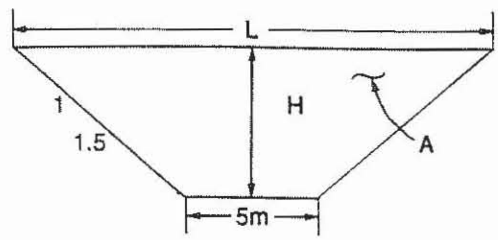
NOTES:

1. Channel width, trimline heights, channel gradient and cross sectional area are estimated from field observations.
2. Velocities and discharges were calcualted using the formula proposed by Hunger et al (1984) modified after Bagnold (1954).
3. Velocities and discharges were calculated using the formula proposed by Mears (1981).

TABLE IV

CALCULATED CHANNEL GEOMETRY REQUIRED FOR VARIOUS DISCHARGES AND CHANNEL GRADIENTS

CHANNEL GEOMETRY



DISCHARGE (m³/s)	CHANNEL GRADIENT 6°	CHANNEL GRADIENT 8°	CHANNEL GRADIENT 10°
500	A = 63 H = 5.03 L = 20.1	A = 59 H = 4.80 L = 19.4	A = 55 H = 4.63 L = 18.9
1000	A = 91 H = 6.28 L = 23.8	A = 84 H = 6.00 L = 23.0	A = 79 H = 5.78 L = 22.3
1500	A = 112 H = 7.14 L = 26.4	A = 104 H = 6.82 L = 25.5	A = 98 H = 6.58 L = 24.7
2000	A = 130 H = 7.81 L = 28.4	A = 121 H = 7.46 L = 27.4	A = 114 H = 7.20 L = 26.6

Notes:

1. Calculations based on empirical formula from Bagnold (1954) where:

   A = Area of flow (m^2)

   H = Height of flow (m)

   L = Surface width of flow (m)

TABLE V
SUMMARY OF REMEDIAL MEASURES OPTIONS

OPTION/DESCRIPTION	APPROXIMATE EXCAVATION QUANTITY (m^3)	ESTIMATED COST ($)	COMMENTS
A. No remedial measures.	–	0	Total of 8 lots with 3 existing residences (Barthel, Beck and Koenig) have minimal risk from debris flow. Residents could lose access if an event covers Peterson Road.
B. Removal of debris from creek and construction of 300 m long x 6 m high berm on west side of L'Heureux Creek.	7,000	45,000	Total of 4 lots and one residence (Peterson) protected. Includes $10,000 for clearing and debris removal.
C. Construction of 520 m long x 6 m high berm on east side of lower Goslin Creek.	9,000	40,000	One additional lot and one residence (Dewey) protected. Based on 10 to 12 days work for backhoe and dozer.
D. Protection of existing residences and highway by realigning Goslin Creek, constructing training berms, containment basin west of Peterson Road, and ditch improvement along Highway 16.	135,000	1,073,258	Includes Option B, armouring, culvert installation, engineering costs and contingency. Does not include ongoing maintenance costs. Breakdown of quantities and costs included in Table VI.
E. Additional protection of Highway 16 by construction containment basin at West Lobe.	21,000	135,000	Not required for protection of existing residences on Goslin Road. Includes channel deepening, ditch improvement, culvert, armouring, engineering and contingency. Does not include maintenance costs.
F. Protection of greater area of fan by construction of training berm and realignment of creek at apex of fan or along West Lobe.	–	>2,000,000 to >3,000,000	Detailed estimate of quantities and costs not prepared.
G. Protection of existing residences by realigning Goslin Creek, constructing training berms, bridge or culvert under Highway 16 and containment basin south of Highway 16.	–	>3,000,000 to >4,000,000	Detailed estimate of quantities and costs not prepared.

Notes:
1. Detailed topographic survey required to enable detailed design and cost estimates to be prepared.

TABLE VI
ORDER OF MAGNITUDE ESTIMATES OF QUANTITIES AND COSTS FOR REMEDIAL MEASURES REQUIRED TO REDUCE THE RISK TO ALL RESIDENCES AND HIGHWAY 16 (OPTIONS B AND D)

ITEM/DESCRIPTION	ESTIMATED QUANTITY	ESTIMATED COST
Construction of 300 m long x 6 m high protective debris deflection structure on L'Heureux Creek, and removal of debris along creek. (Option B.)	7,000 m^3	45,000
Channel alignment, straightening and removal of debris/boulders G8 to G10.	400 m	30,000
Berm construction to train channel and create debris basin west of Peterson Road.	107,900 m^3	539,500
Ditch widening and improvement along Highway 16 from debris basin to Goslin Road access.	19,500 m^3	97,500
Rip Rap Armouring	4,770 m^3	71,550
Culvert installation (2 x 1200 mm diameter)	93 m	23,250
Debris removal and channel construction on upper reaches of West Lobe.	8,325 m^3	41,625
Engineering, design and supervision (10% of total)	–	84,843
SUBTOTAL	–	933,268
CONTINGENCY (15%)	–	139,990
TOTAL ESTIMATE		1,073,258

Notes:
1. Order of magnitude cost estimate only. Detailed topographic surveying required for engineering design.
2. Inspection and maintenance costs not included.
3. Does not include cost of remedial measures to protect Highway 16 at the West Lobe (Option E).

FIGURES

JOB NUMBER 1088

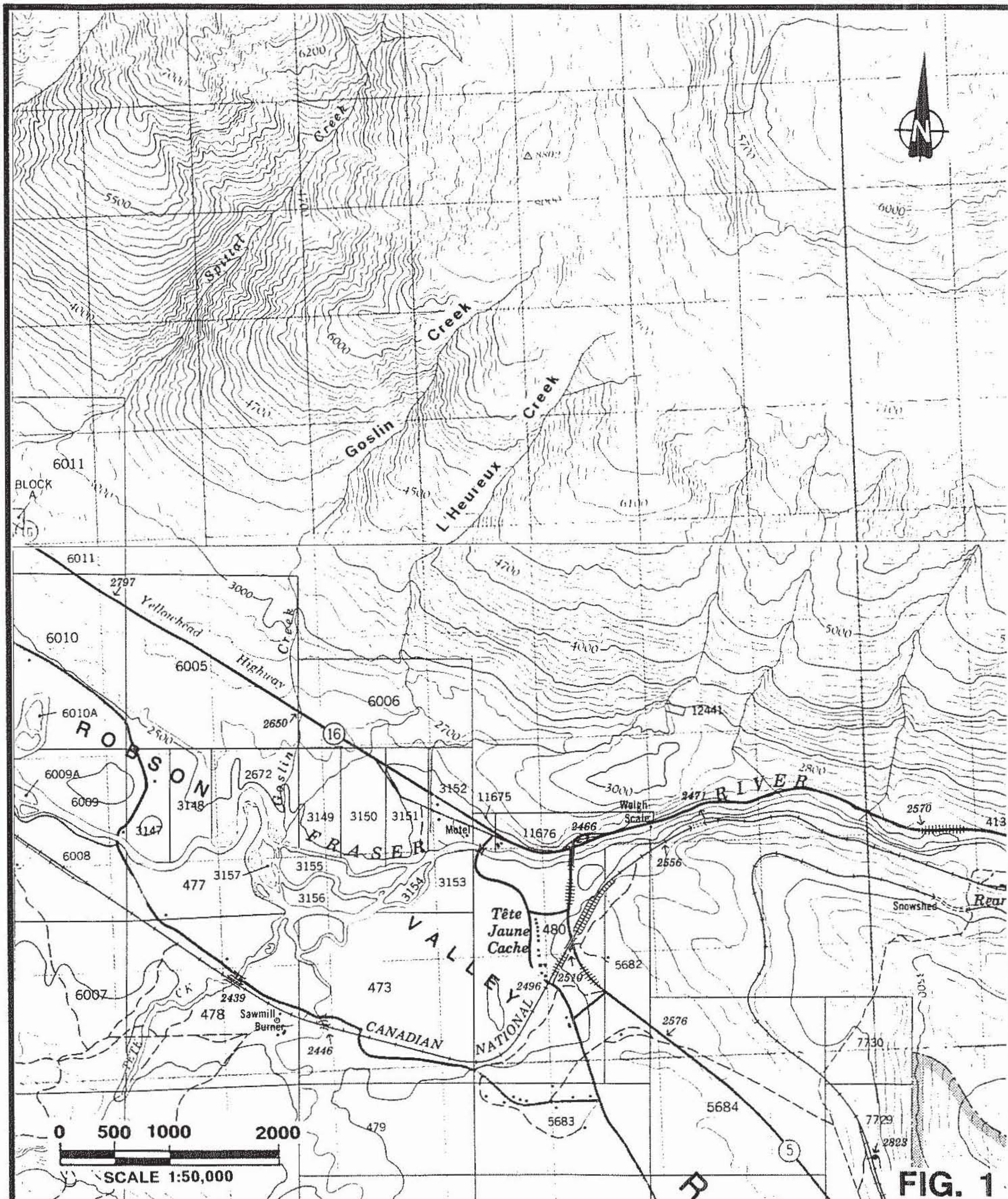


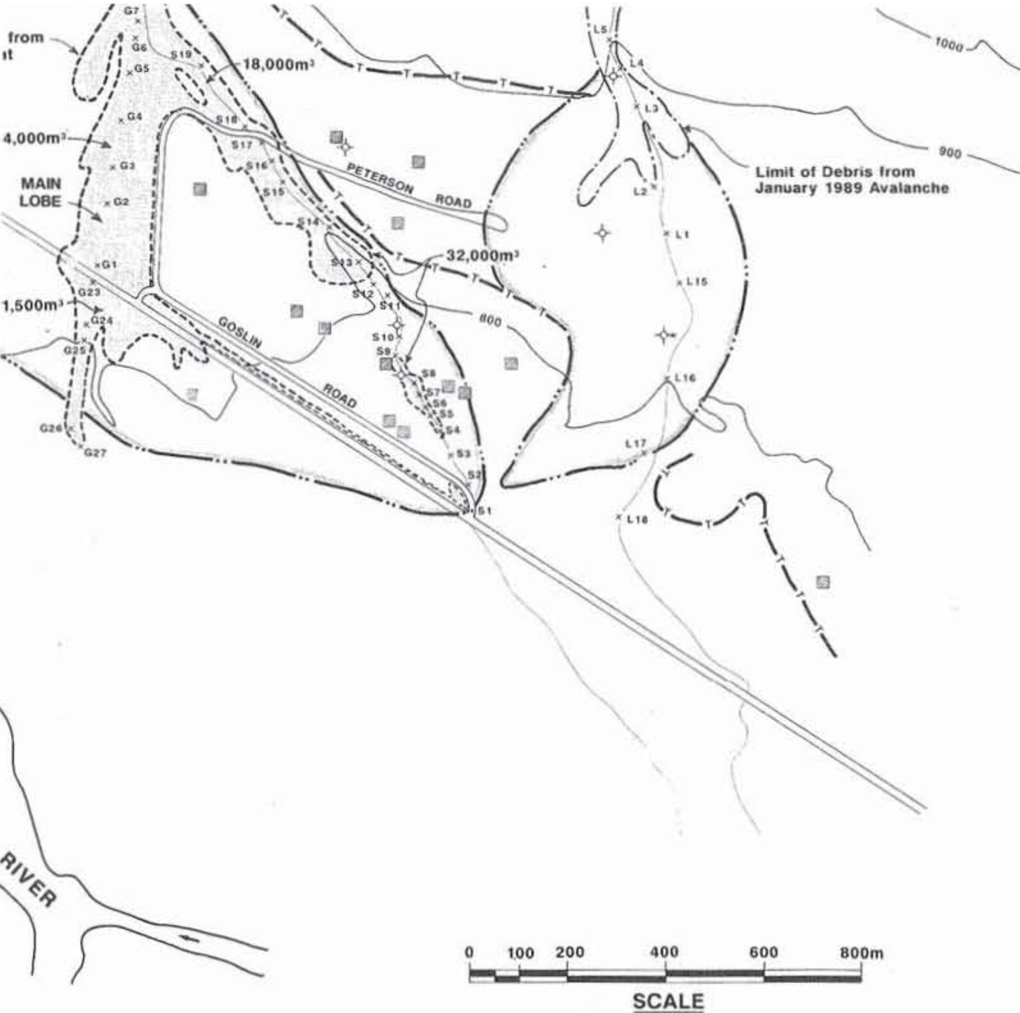
FIG. 1

MINISTRY OF TRANSPORTATION AND HIGHWAYS
GOSLIN/L'HEUREUX CREEKS, TETE JAUNE CACHE, B.C.
GEOTECHNICAL ASSESSMENTS

PITEAU ASSOCIATES
GEOTECHNICAL CONSULTANTS
VANCOUVER CALGARY

LOCATION MAP

BY:	DATE: OCT.93
APPROVED:	DWG: 1088-1



SYMBOLS

LIMIT OF LANDSLIDE AND ESTIMATED VOLUME	3,000,000m³ — HEADWALL
CRACK OR LINEAR DEPRESSION	
DEFINED AVALANCHE TRACK	
LIMITS OF EROSION SCARS IN CREEK CHANNEL	
AREAS OF RECENT ACTIVE EROSION	
LIMITS OF MAY 1993 DEBRIS FLOW AND ESTIMATED VOLUME OF DEPOSITED DEBRIS FOR INDIVIDUAL AREAS	25,000m³
LIMITS OF ALLUVIAL / DEBRIS FAN	
NATURAL TERRACE	—T—T—T—
BEDROCK OUTCROP IN CREEK CHANNEL	(R)
RECOMMENDED LOCATION OF LANDSLIDE MONITORING STATION	
CONTOUR (m.a.s.l.)	1400
FIELD MAPPING STATION	× G19
EXISTING RESIDENCE	
WELL / PUMPHOUSE	

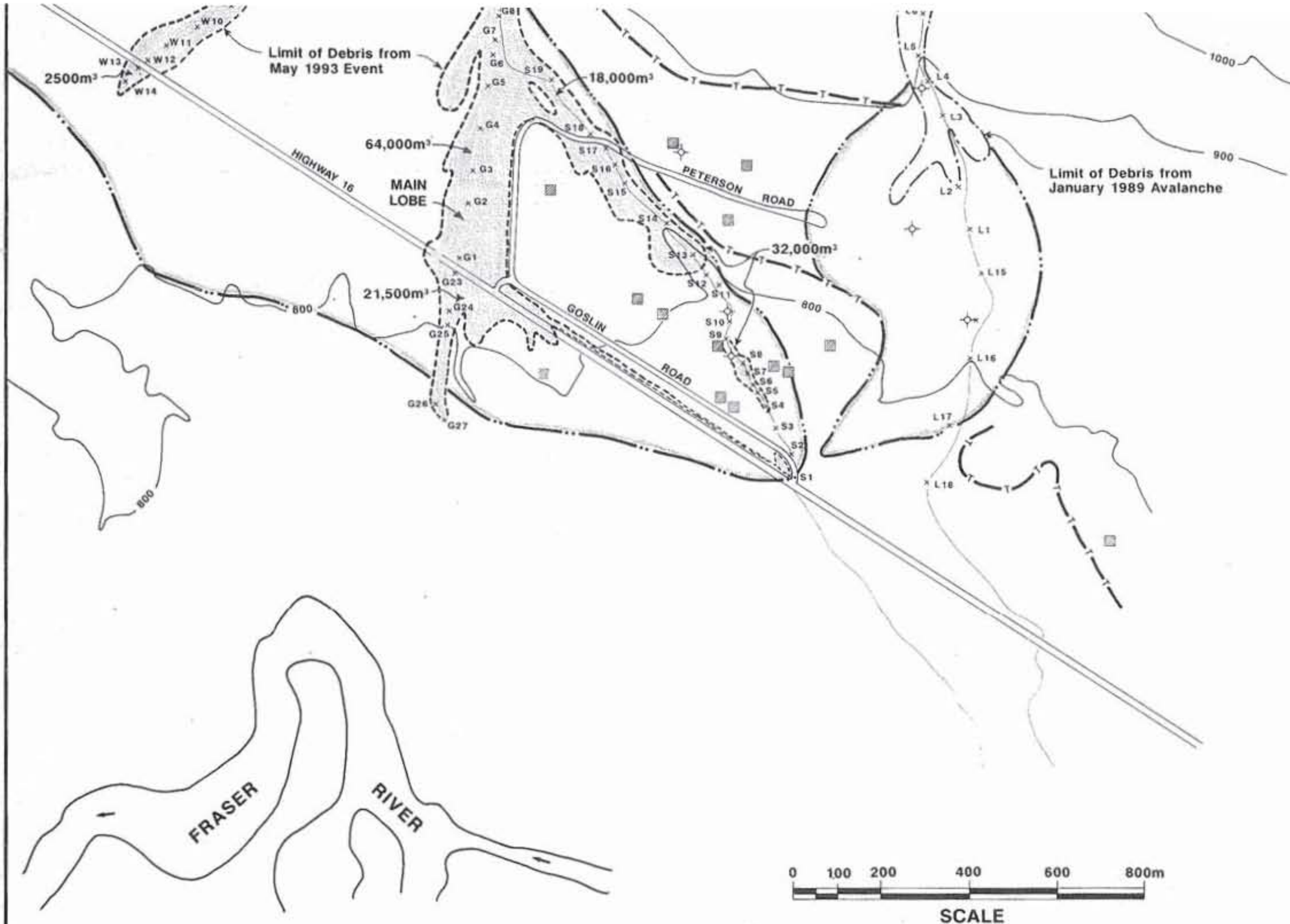
FIG. 2

NOTES

… based on examination of aerial photographs and reconnaissance mapping in September 1993.

… derived from Government of British Columbia 1:20,000 Scale TRIM mapping.

MINISTRY OF TRANSPORTATION AND HIGHWAYS GOSLIN/L'HEUREUX CREEKS, TETE JAUNE CACHE, B.C. GEOTECHNICAL ASSESSMENTS	PITEAU ASSOCIATES GEOTECHNICAL CONSULTANTS VANCOUVER CALGARY	
ENGINEERING GEOLOGY AND TERRAIN ASSESSMENTS	BY: DCM/BL	DATE: OCT.93
	APPROVED:	DWG: 1088-2



SYMBOLS

LIMIT OF LANDSLIDE AND ESTIMATED VOLUME

CRACK OR LINEAR DEPRESSION

DEFINED AVALANCHE TRACK

LIMITS OF EROSION SCARS IN CREEK CHANNEL

AREAS OF RECENT ACTIVE EROSION

LIMITS OF MAY 1993 DEBRIS FLOW AND ESTIMATED VOLUME OF DEPOSITED DEBRIS FOR INDIVIDUAL AREAS

LIMITS OF ALLUVIAL / DEBRIS FAN

NATURAL TERRACE

BEDROCK OUTCROP IN CREEK CHANNEL

RECOMMENDED LOCATION OF LANDSLIDE MONITORING STATION

CONTOUR (m.a.s.l.)

FIELD MAPPING STATION

EXISTING RESIDENCE

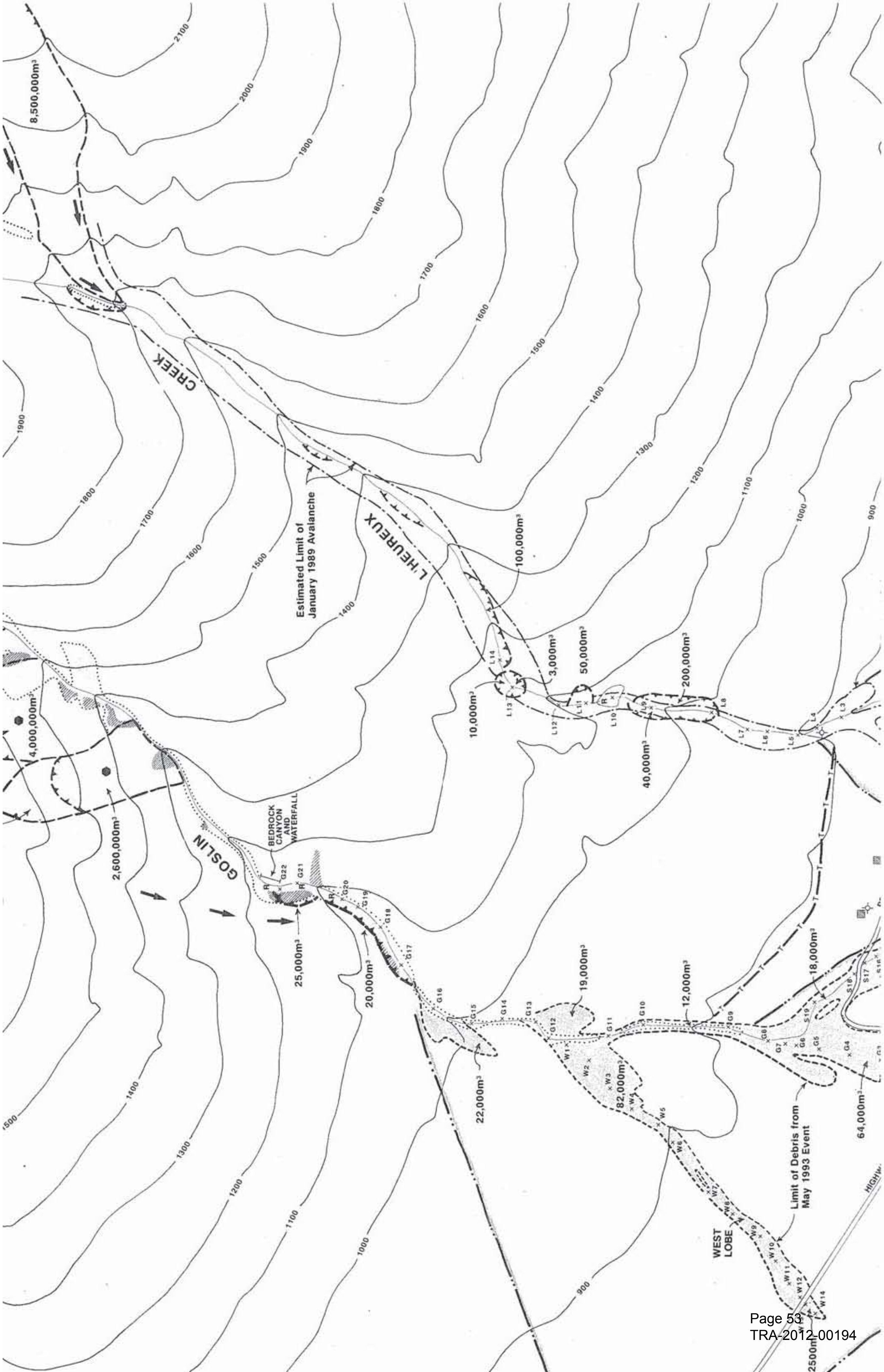
WELL / PUMPHOUSE

NOTES

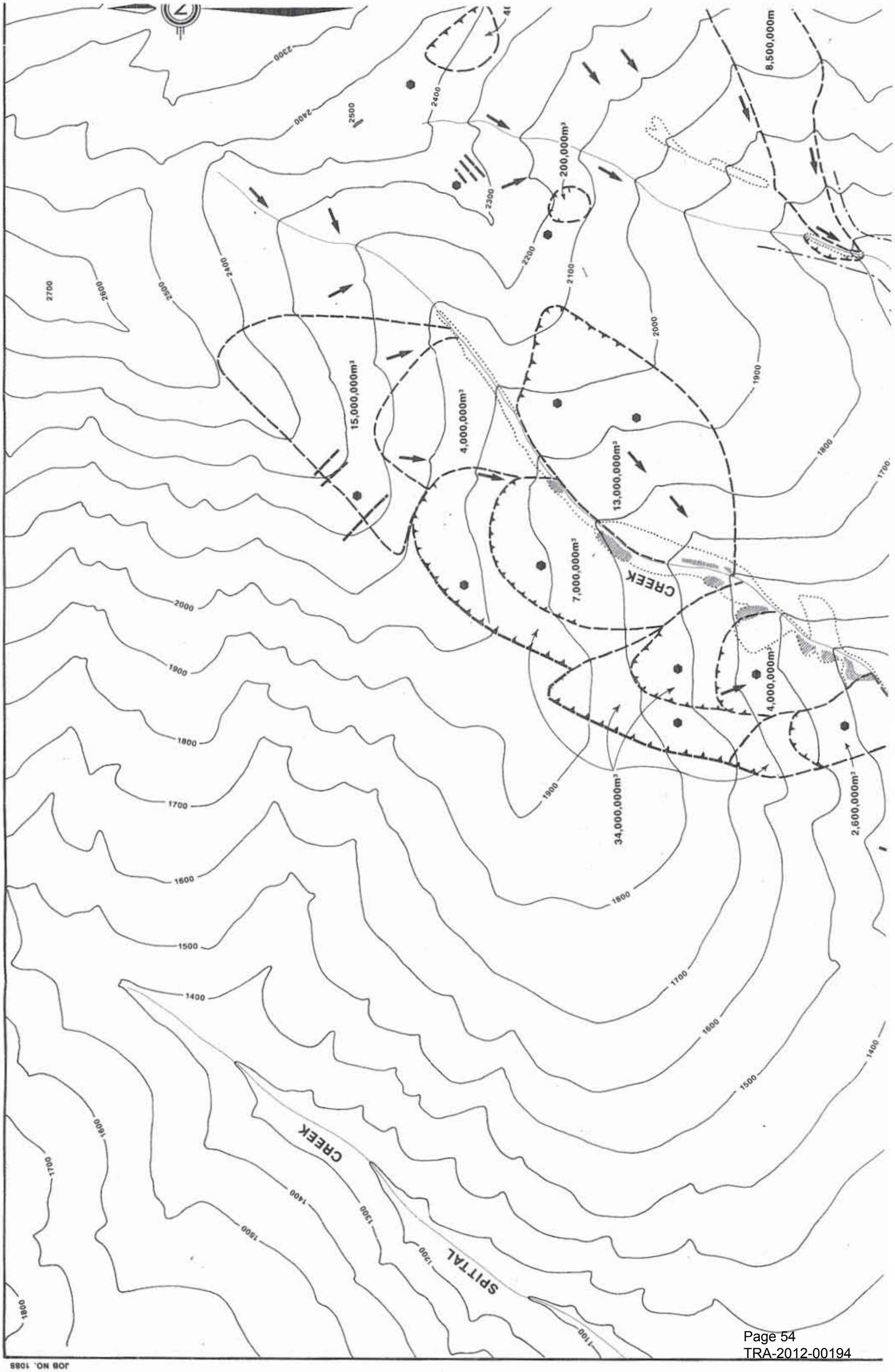
1. Information based on examination of aerial photographs and reconnaissance mapping in September 1993.
2. Base map derived from Government of British Columbia 1:20,000 Scale TRIM mapping.

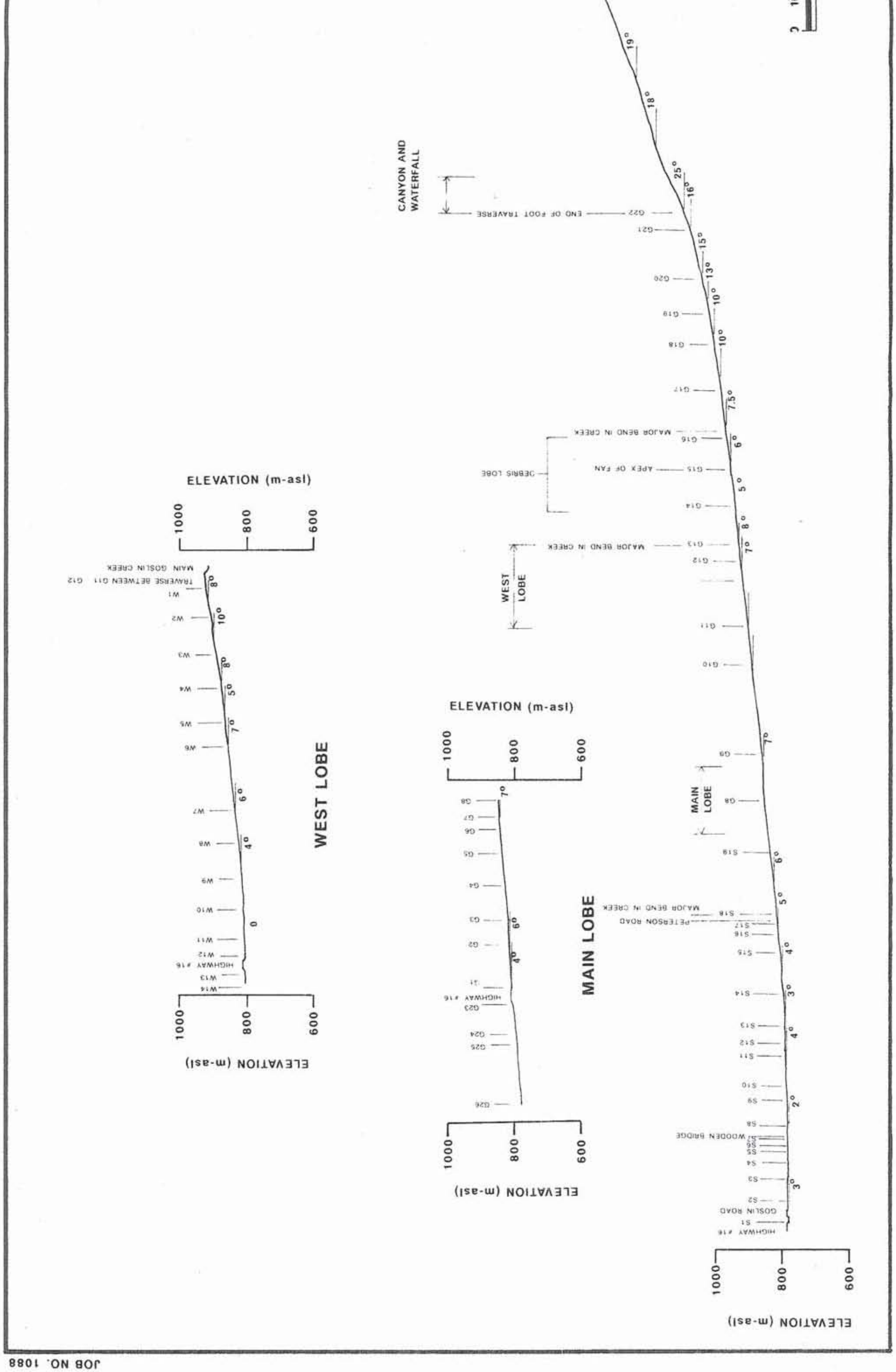
MINISTRY OF TRANSPORTATION AND HIGHWAYS
GOSLIN/L'HEUREUX CREEKS, TETE JAUNE CACHE, B.C.
GEOTECHNICAL ASSESSMENTS

ENGINEERING GEOLOGY AND TERRAIN ASSESSMENTS



8,500,000m³
CREEK
L'HEUREUX
GOSLIN
Estimated Limit of January 1989 Avalanche
BEDROCK CANYON AND WATERFALL
4,000,000m³
2,600,000m³
100,000m³
3,000m³
50,000m³
10,000m³
200,000m³
40,000m³
25,000m³
20,000m³
19,000m³
12,000m³
18,000m³
22,000m³
82,000m³
64,000m³
WEST LOBE
Limit of Debris from May 1993 Event
2500m


8,500,000m^3
200,000m^3
15,000,000m^3
4,000,000m^3
13,000,000m^3
7,000,000m^3
CREEK
4,000,000m^3
34,000,000m^3
2,600,000m^3
SPITTAL CREEK
JOB NO. 1088


CANYON AND WATERFALL
WEST LOBE
MAIN LOBE
ELEVATION (m-asl)
1000
800
600
JOB NO. 1088

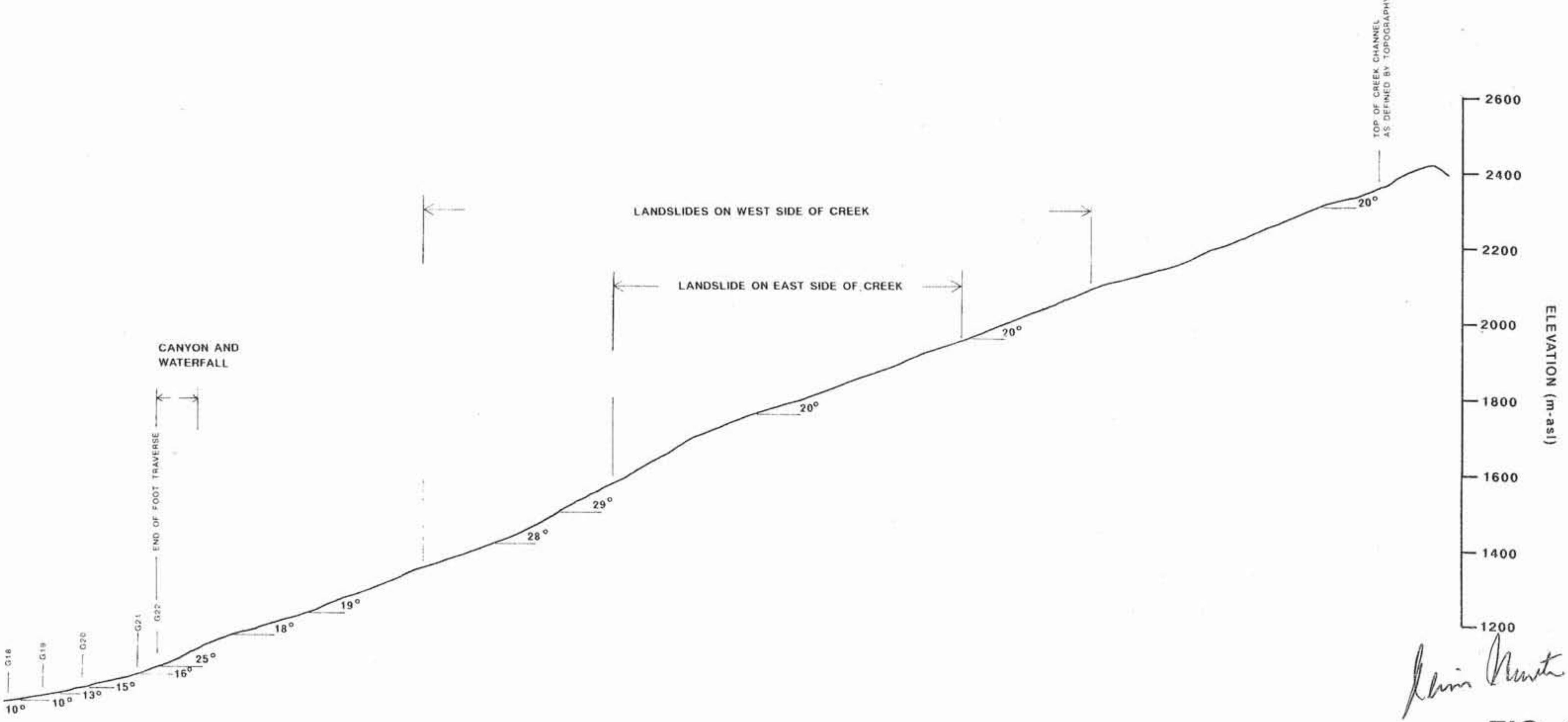


FIG. 3

0 100 200 400 600 800 1000m

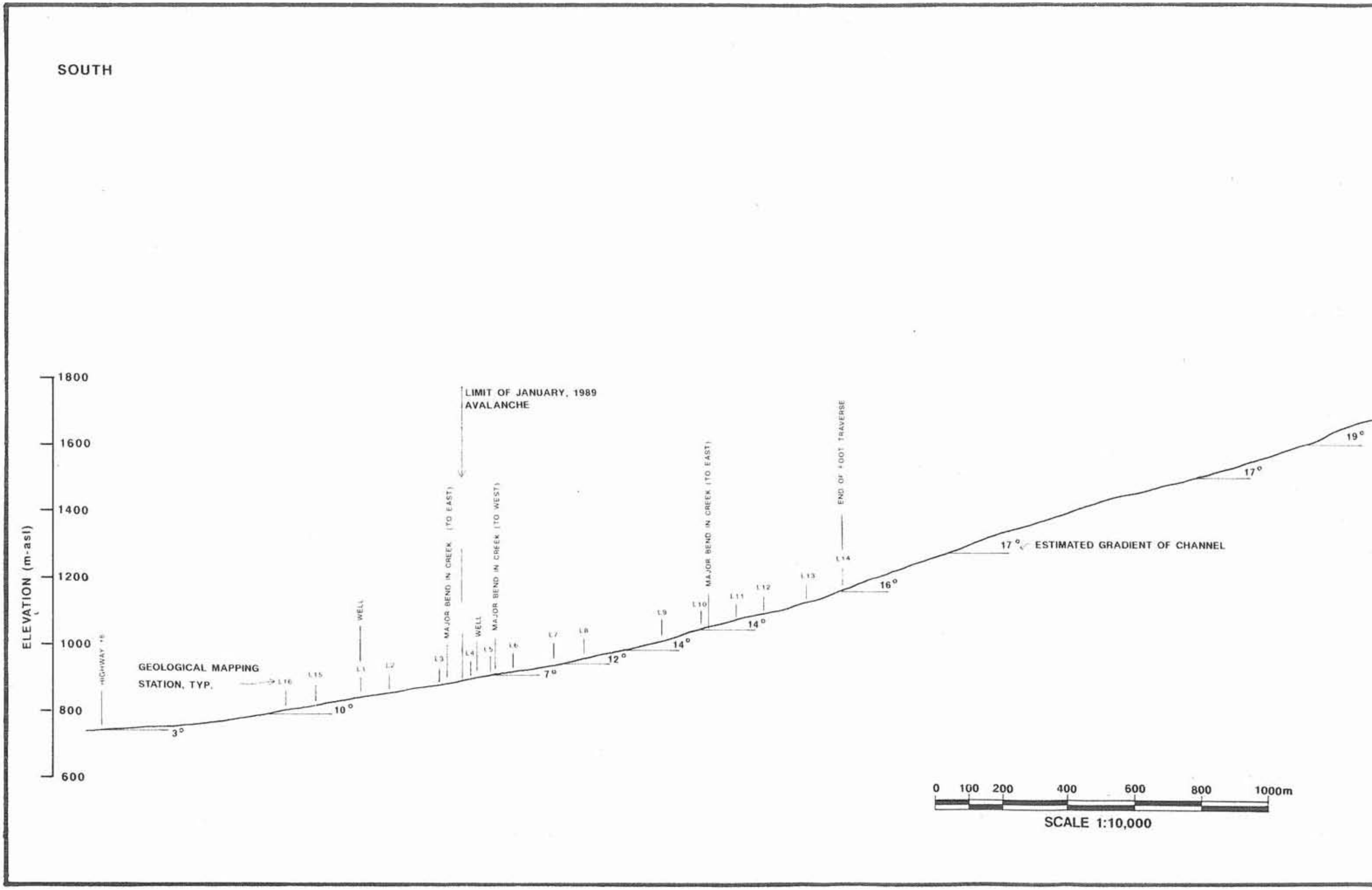
SCALE 1:10,000

MINISTRY OF TRANSPORTATION AND HIGHWAYS
GOSLIN/L'HEUREUX CREEKS, TETE JAUNE CACHE, B.C.
GEOTECHNICAL ASSESSMENTS

PITEAU ASSOCIATES
GEOTECHNICAL CONSULTANTS
VANCOUVER CALGARY

PROFILE ALONG CENTRELINE AND DEBRIS LOBES OF GOSLIN CREEK

BY	DATE
JC	OCT.93
APPROVED	DWG
	1088-3



SOUTH
ELEVATION (m-asl)
1800
1600
1400
1200
1000
800
600
HIGHWAY 16
3°
GEOLOGICAL MAPPING STATION, TYP.
L16
L15
10°
WELL
L1
L2
L3
MAJOR BEND IN CREEK (TO EAST)
LIMIT OF JANUARY, 1989 AVALANCHE
L4
WELL
L5
MAJOR BEND IN CREEK (TO WEST)
L6
7°
L7
L8
12°
L9
14°
L10
MAJOR BEND IN CREEK (TO EAST)
L11
14°
L12
L13
L14
END OF FOOT TRAVERSE
16°
17°
ESTIMATED GRADIENT OF CHANNEL
17°
19°
0
100
200
400
600
800
1000m
SCALE 1:10,000

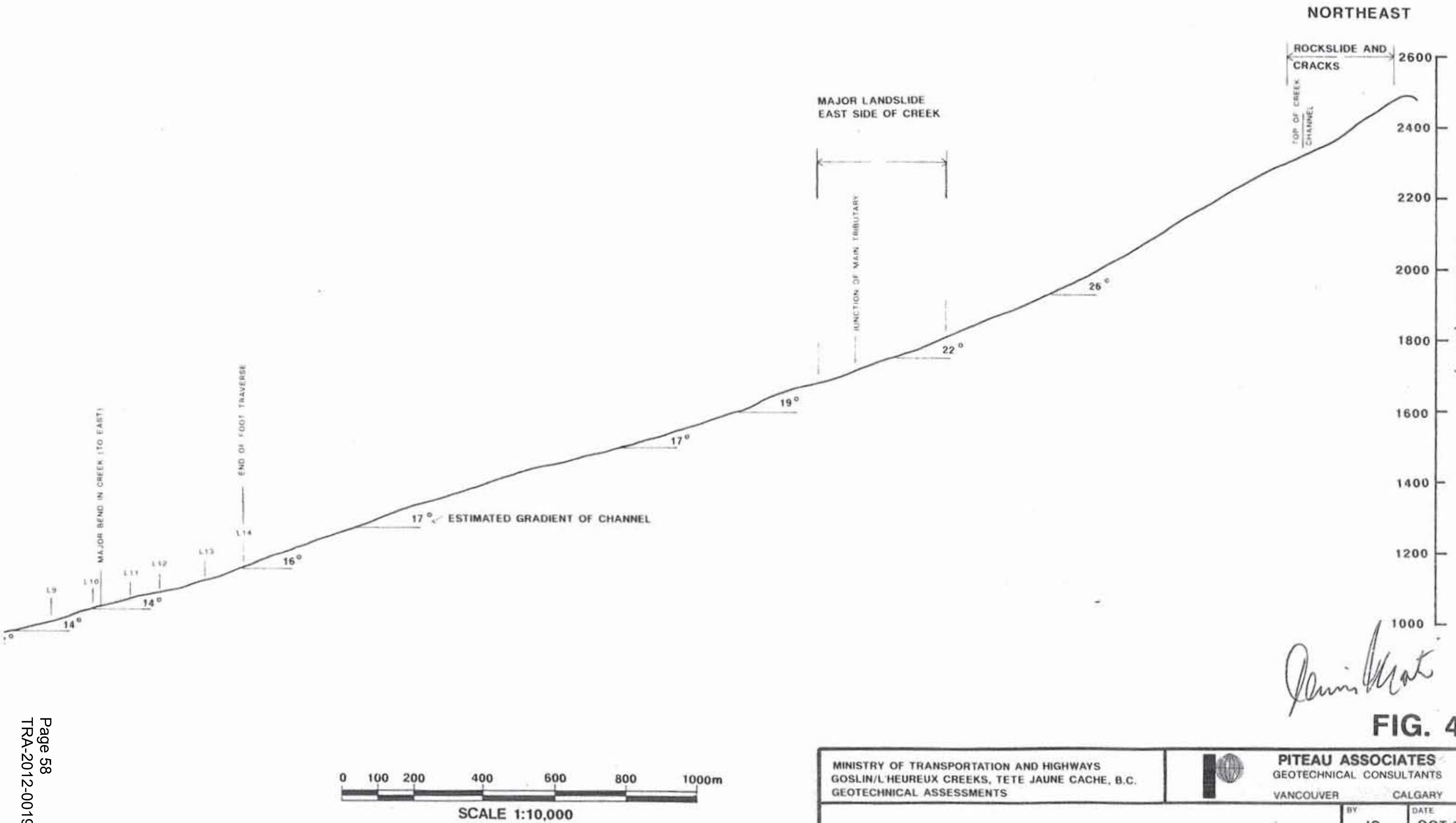


FIG. 4

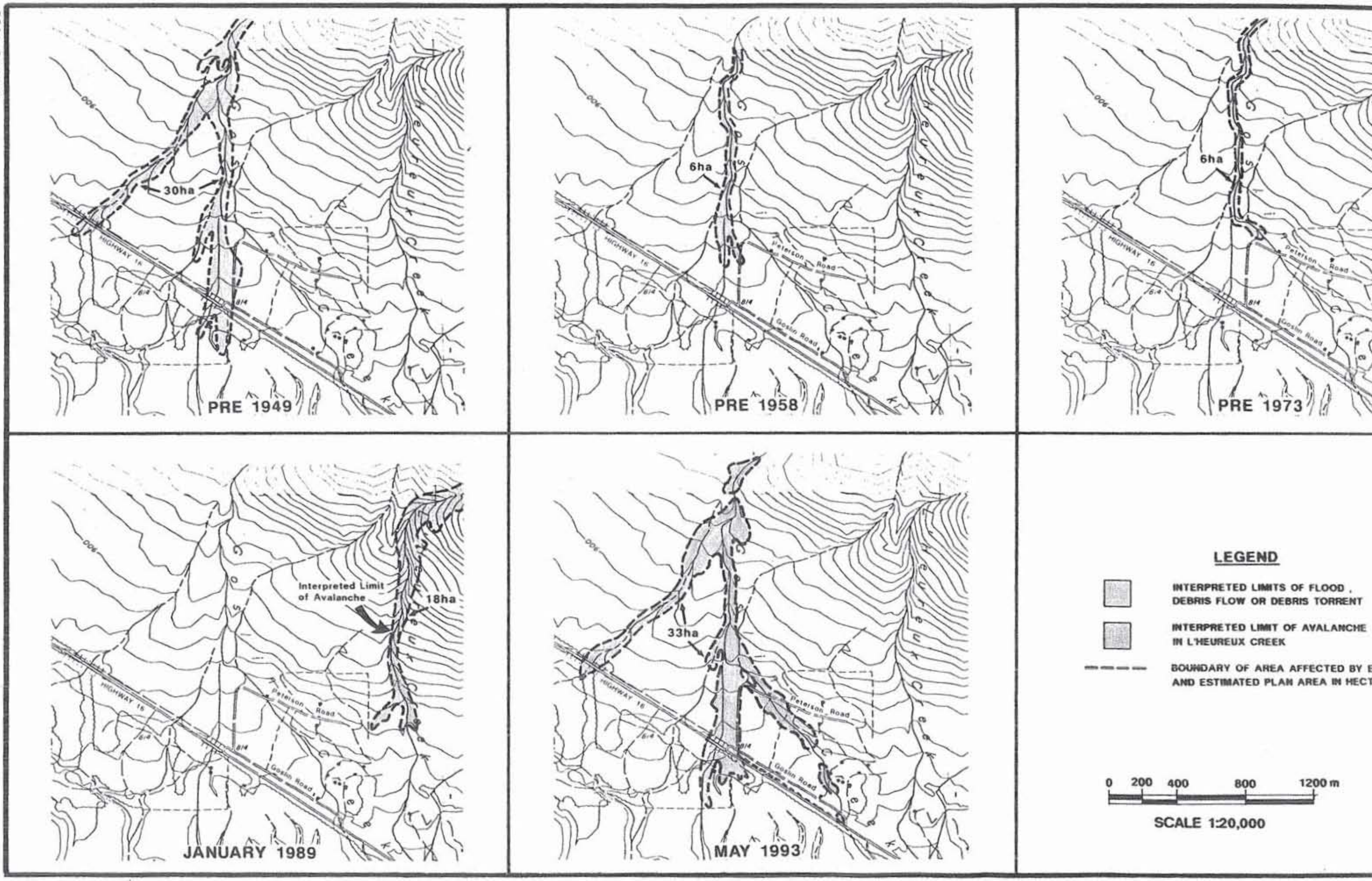
MINISTRY OF TRANSPORTATION AND HIGHWAYS
GOSLIN/L'HEUREUX CREEKS, TETE JAUNE CACHE, B.C.
GEOTECHNICAL ASSESSMENTS

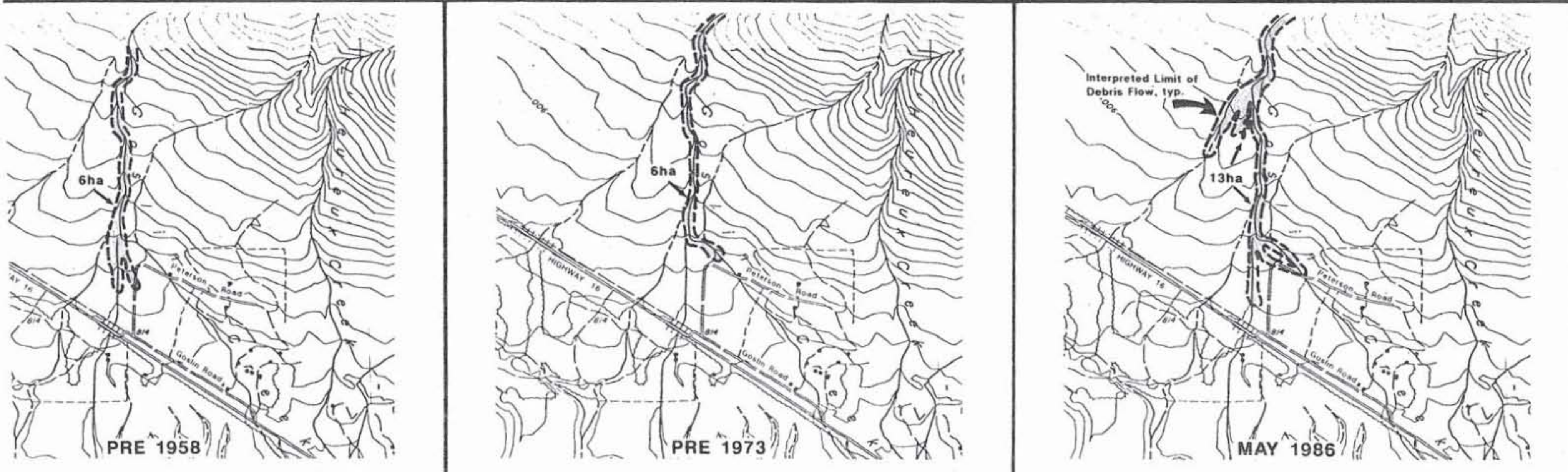
PITEAU ASSOCIATES
GEOTECHNICAL CONSULTANTS
VANCOUVER CALGARY

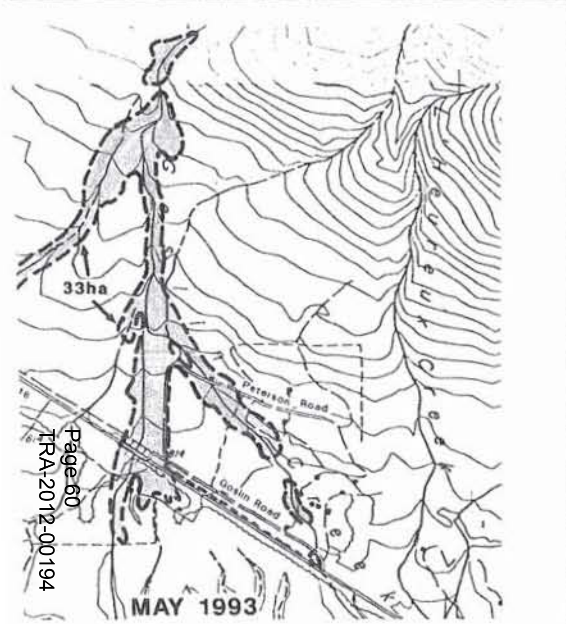
PROFILE ALONG CENTRELINE OF L'HEUREUX CREEK

BY: JC
DATE: OCT.93
APPROVED:
DWG: 1088-4

JOB NO 1088


PRE 1949
30ha
PRE 1958
6ha
PRE 1973
6ha
JANUARY 1989
Interpreted Limit of Avalanche
18ha
MAY 1993
33ha
HIGHWAY 16
Peterson Road
Goslin Road
L'Heureux Creek
LEGEND
INTERPRETED LIMITS OF FLOOD, DEBRIS FLOW OR DEBRIS TORRENT
INTERPRETED LIMIT OF AVALANCHE IN L'HEUREUX CREEK
BOUNDARY OF AREA AFFECTED BY EV
AND ESTIMATED PLAN AREA IN HECTA
0 200 400 800 1200 m
SCALE 1:20,000





LEGEND

- (shaded) INTERPRETED LIMITS OF FLOOD, DEBRIS FLOW OR DEBRIS TORRENT
- (shaded) INTERPRETED LIMIT OF AVALANCHE IN L'HEUREUX CREEK
- (dashed line) BOUNDARY OF AREA AFFECTED BY EVENT AND ESTIMATED PLAN AREA IN HECTARES

0 200 400 800 1200 m

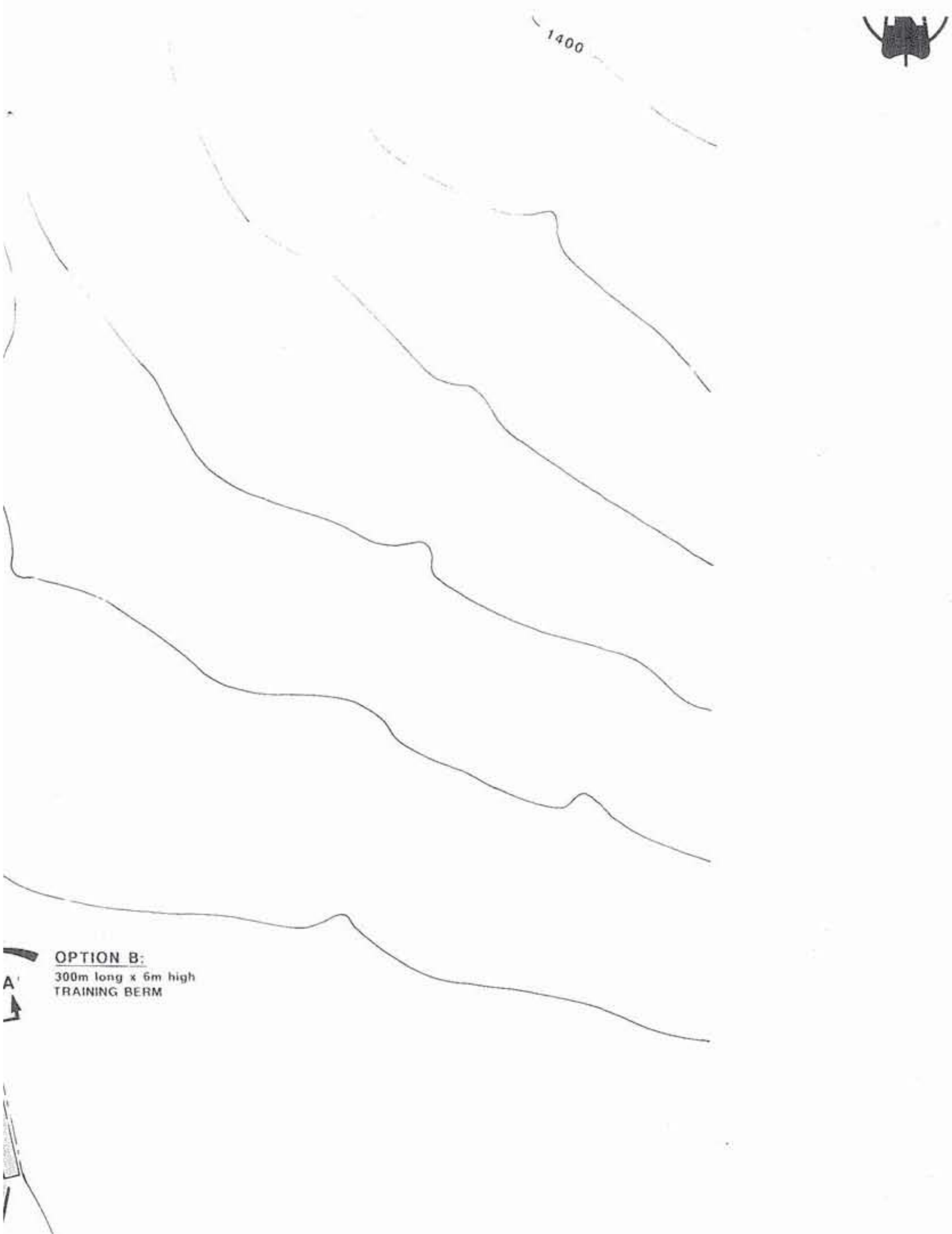
SCALE 1:20,000

NOTES

1. Based on ground reconnaissance and discussions with local residents in September 1993 and examination of Government of British Columbia aerial photographs taken in 1949, 1958, 1973, 1986 and 1991.
2. Event in L'Heureux Creek has been described as an avalanche, all other events are interpreted as floods, debris flows and/or debris torrents.

FIG. 5

MINISTRY OF TRANSPORTATION AND HIGHWAYS GOSLIN/L'HEUREUX CREEKS, TETE JAUNE CACHE, B.C. GEOTECHNICAL ASSESSMENTS	PITEAU ASSOCIATES GEOTECHNICAL CONSULTANTS VANCOUVER CALGARY	
EXTENT OF DEBRIS FLOW AND AVALANCHE EVENTS INDICATED FROM GROUND RECONNAISSANCE HISTORICAL RECORDS AND EXAMINATION OF AERIAL POTOGRAPHS (1949 to 1993)	BY: JC/BL APPROVED: [signature]	DATE: OCT.93 DWG: 1088-5



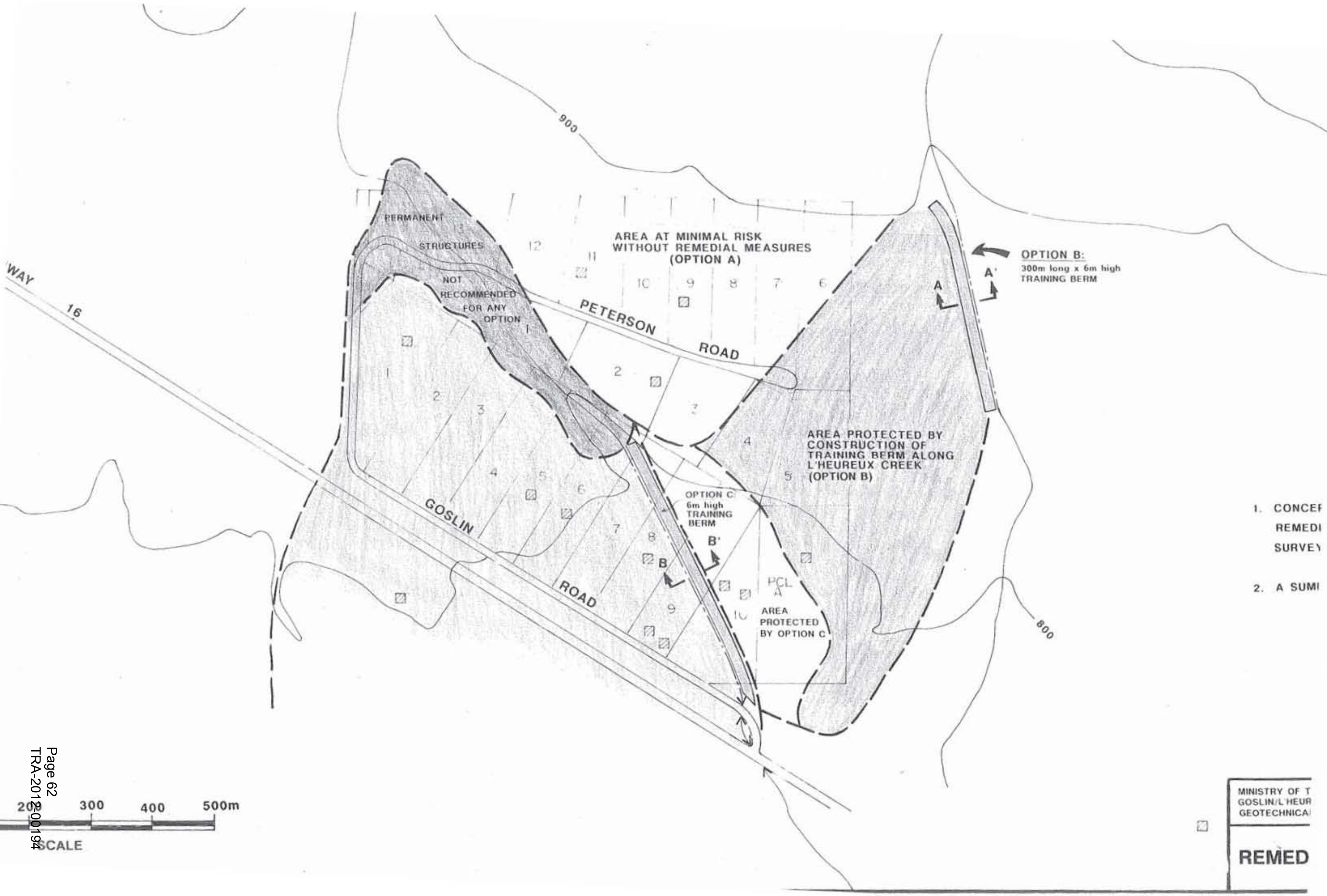
NOTES

1. CONCEPTUAL LAYOUTS ONLY. DETAILED DESIGN OF SELECTED REMEDIAL MEASURES WILL REQUIRE ACCURATE TOPOGRAPHIC SURVEYS AND ENGINEERING DESIGN.

2. A SUMMARY OF EACH OPTION IS PRESENTED IN TABLE V.

FIG.6a

MINISTRY OF TRANSPORTATION AND HIGHWAYS GOSLIN/L'HEUREUX CREEKS, TETE JAUNE CACHE, B.C. GEOTECHNICAL ASSESSMENTS	PITEAU ASSOCIATES GEOTECHNICAL CONSULTANTS VANCOUVER CALGARY	
REMEDIAL MEASURES OPTIONS A,B AND C	BY GFB/BL	DATE OCT.93
	APPROVED	DWG

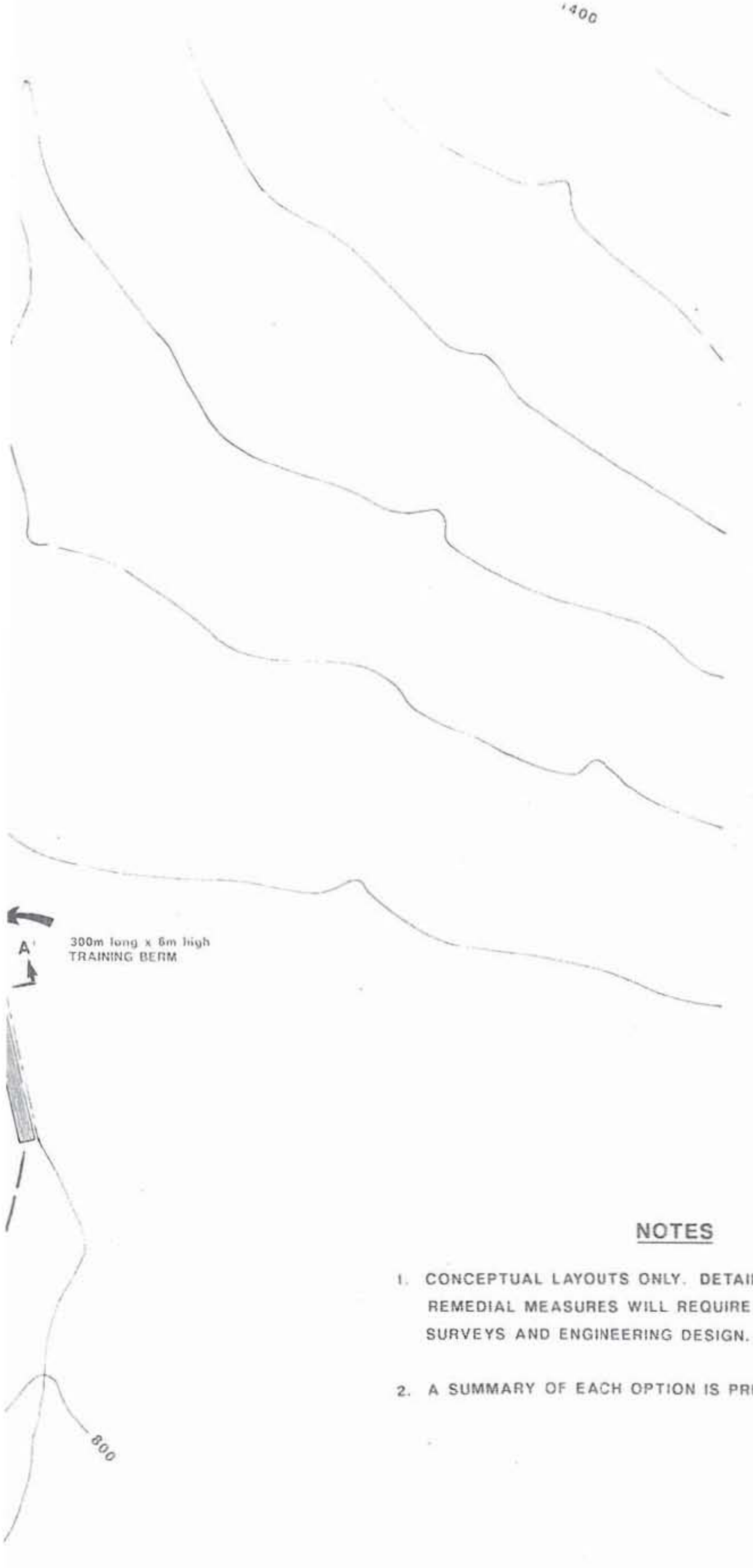


1. CONCE
REMEDI
SURVEY

2. A SUM

MINISTRY OF T
GOSLIN/L'HEUR
GEOTECHNICA

REMED



NOTES

1. CONCEPTUAL LAYOUTS ONLY. DETAILED DESIGN OF SELECTED REMEDIAL MEASURES WILL REQUIRE ACCURATE TOPOGRAPHIC SURVEYS AND ENGINEERING DESIGN.

2. A SUMMARY OF EACH OPTION IS PRESENTED IN TABLE V.

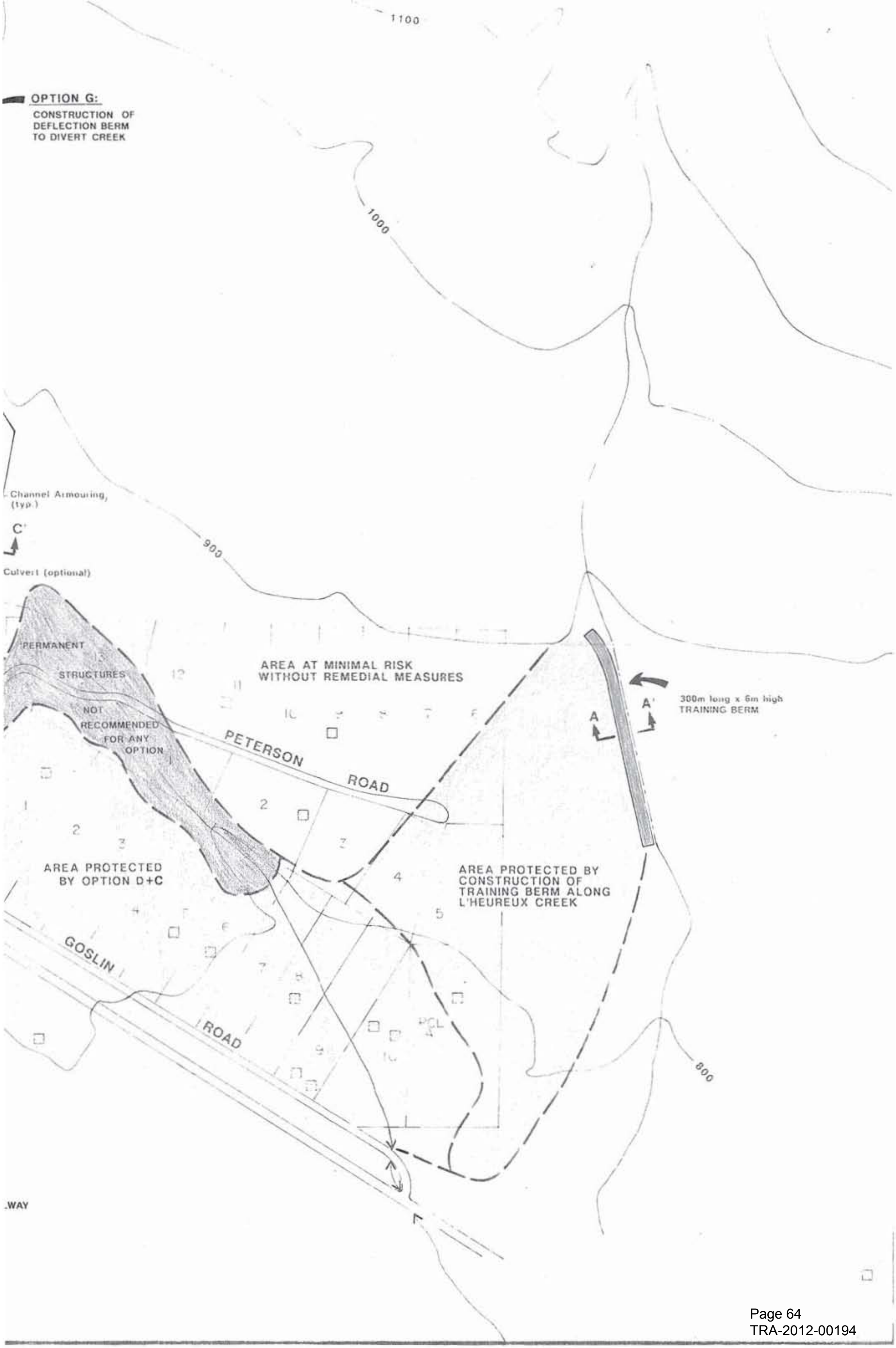
FIG.6c

MINISTRY OF TRANSPORTATION AND HIGHWAYS
GOSLIN/L'HEUREUX CREEKS, TETE JAUNE CACHE, B.C.
GEOTECHNICAL ASSESSMENTS

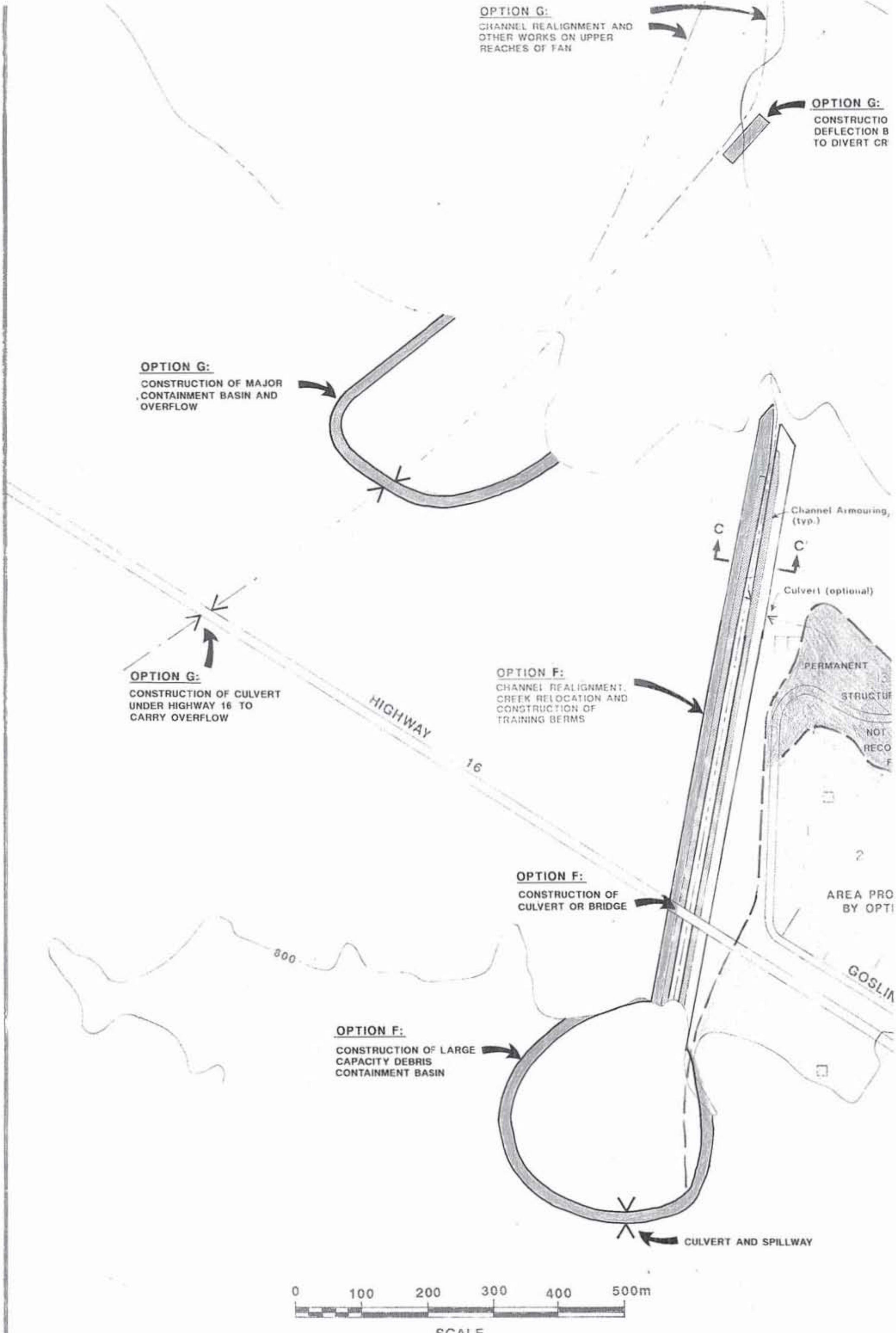
PITEAU ASSOCIATES
GEOTECHNICAL CONSULTANTS
VANCOUVER CALGARY

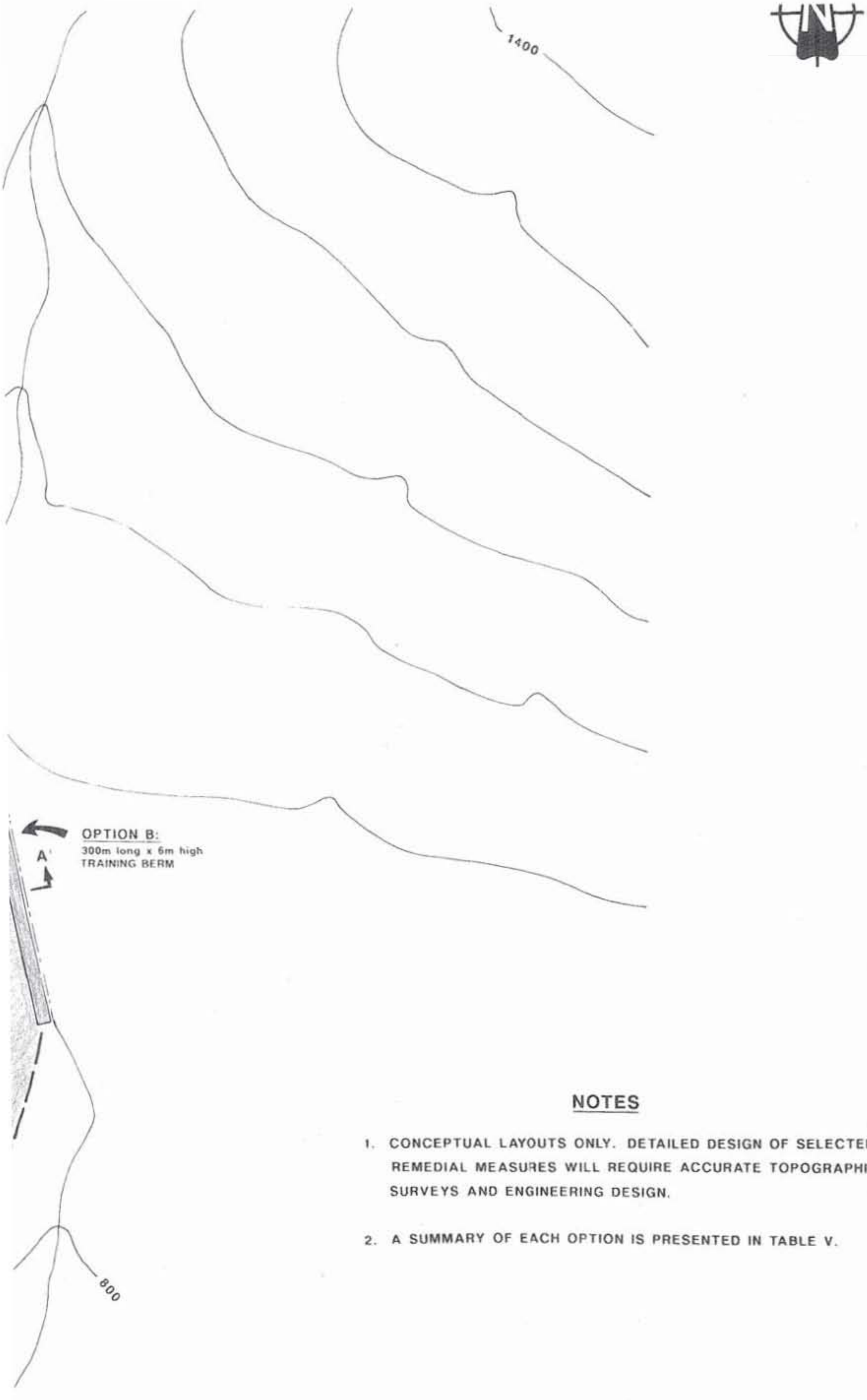
REMEDIAL MEASURES OPTIONS F AND G

BY	GFB/BL	DATE OCT.93
APPROVED		DWG 1088-6



1100
OPTION G:
CONSTRUCTION OF DEFLECTION BERM TO DIVERT CREEK
1000
Channel Armouring, (typ.)
C'
900
Culvert (optional)
PERMANENT STRUCTURES NOT RECOMMENDED FOR ANY OPTION
AREA AT MINIMAL RISK WITHOUT REMEDIAL MEASURES
300m long x 6m high TRAINING BERM
A
A'
PETERSON ROAD
AREA PROTECTED BY OPTION D+C
AREA PROTECTED BY CONSTRUCTION OF TRAINING BERM ALONG L'HEUREUX CREEK
GOSLIN ROAD
800
.WAY


OPTION G:
CHANNEL REALIGNMENT AND OTHER WORKS ON UPPER REACHES OF FAN
OPTION G:
CONSTRUCTIO
DEFLECTION B
TO DIVERT CR
OPTION G:
CONSTRUCTION OF MAJOR CONTAINMENT BASIN AND OVERFLOW
Channel Armouring, (typ.)
C
C'
Culvert (optional)
OPTION G:
CONSTRUCTION OF CULVERT UNDER HIGHWAY 16 TO CARRY OVERFLOW
HIGHWAY 16
OPTION F:
CHANNEL REALIGNMENT, CREEK RELOCATION AND CONSTRUCTION OF TRAINING BERMS
PERMANENT
STRUCTUR
NOT
RECO
2
AREA PRO
BY OPTI
OPTION F:
CONSTRUCTION OF CULVERT OR BRIDGE
800
GOSLIN
OPTION F:
CONSTRUCTION OF LARGE CAPACITY DEBRIS CONTAINMENT BASIN
CULVERT AND SPILLWAY
0 100 200 300 400 500m
SCALE



NOTES

1. CONCEPTUAL LAYOUTS ONLY. DETAILED DESIGN OF SELECTED REMEDIAL MEASURES WILL REQUIRE ACCURATE TOPOGRAPHIC SURVEYS AND ENGINEERING DESIGN.

2. A SUMMARY OF EACH OPTION IS PRESENTED IN TABLE V.

FIG. 6b

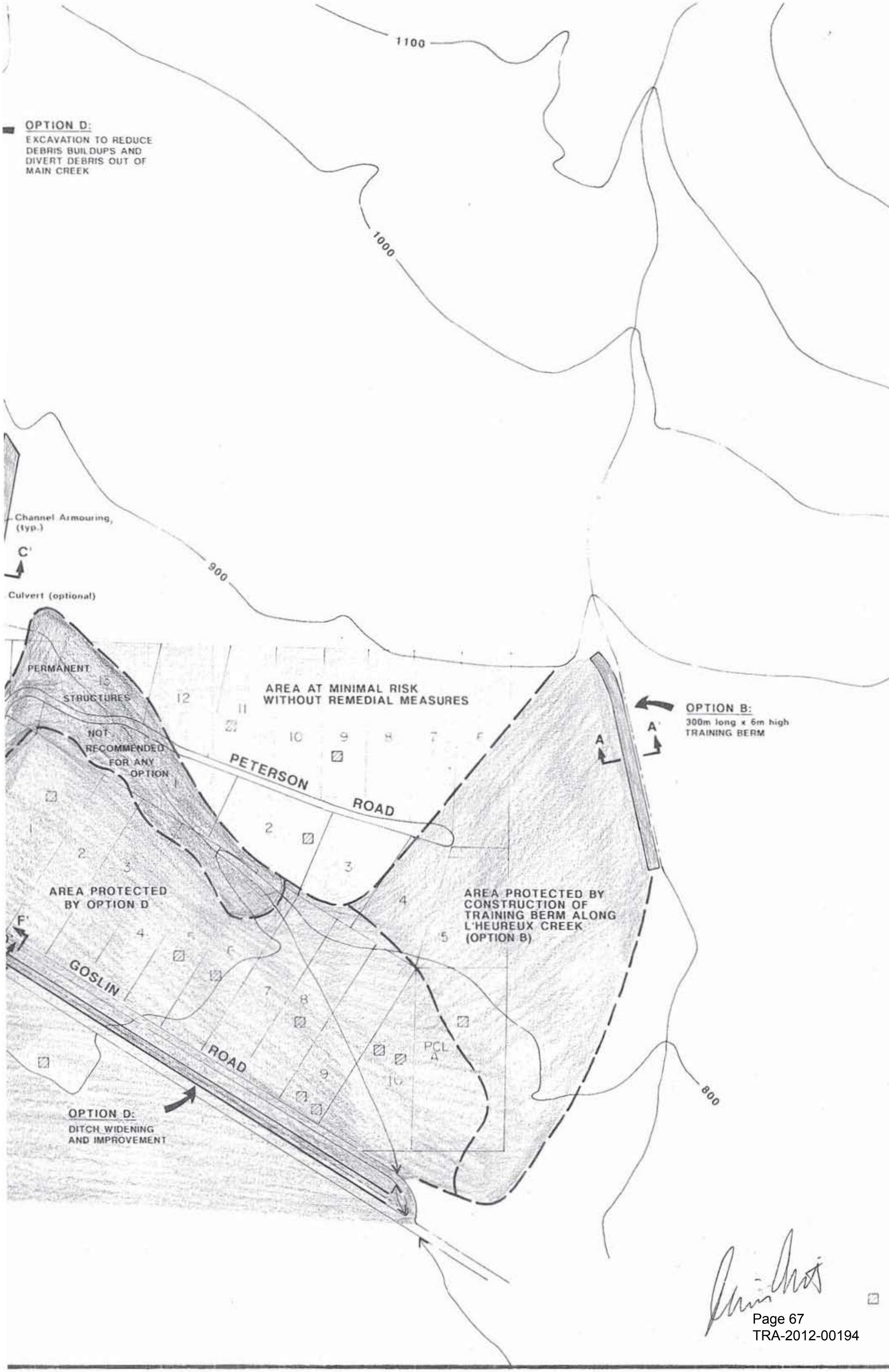
MINISTRY OF TRANSPORTATION AND HIGHWAYS
GOSLIN/L'HEUREUX CREEKS, TETE JAUNE CACHE, B.C.
GEOTECHNICAL ASSESSMENTS

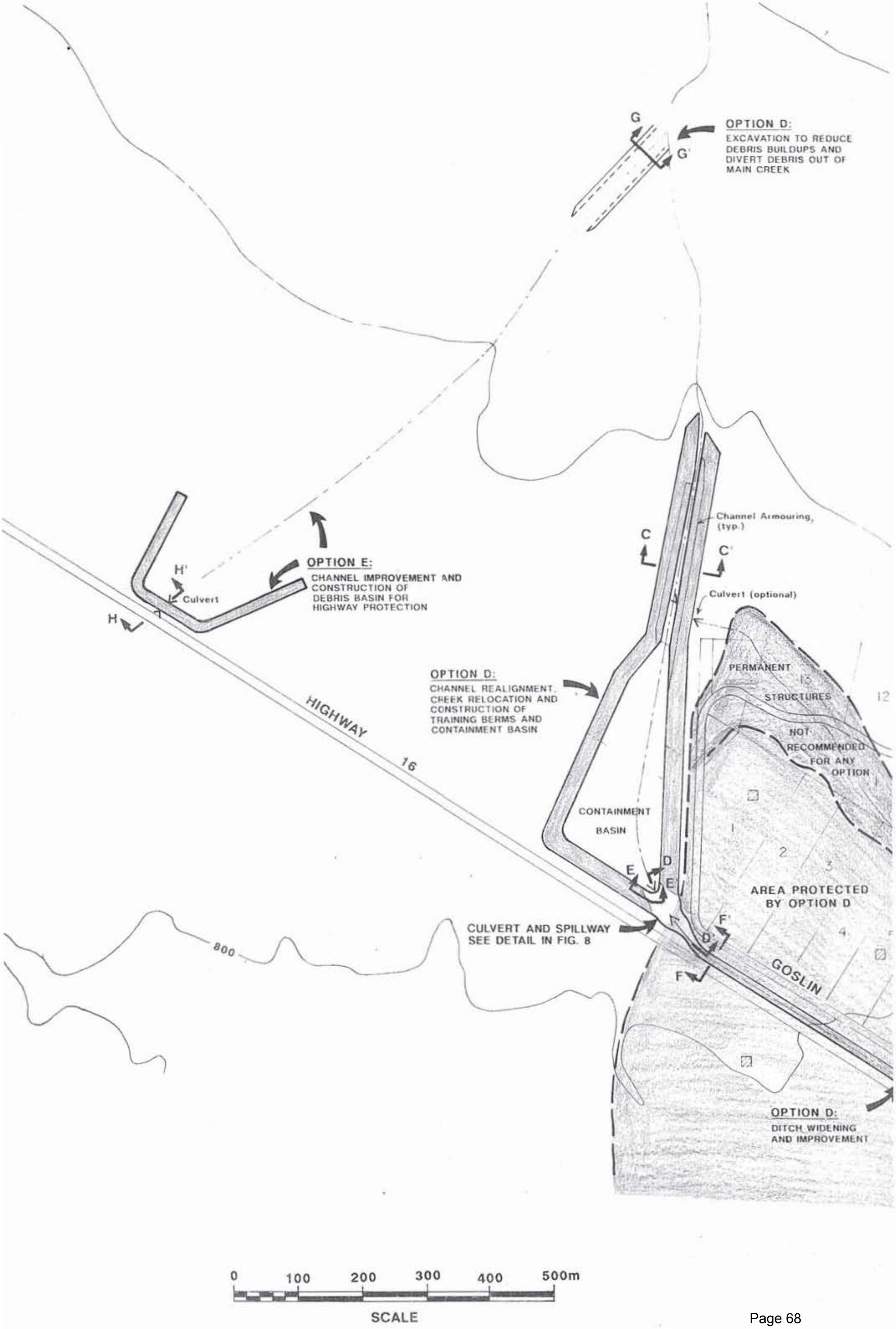
PITEAU ASSOCIATES
GEOTECHNICAL CONSULTANTS
VANCOUVER CALGARY

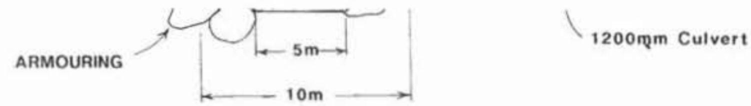
REMEDIAL MEASURES OPTIONS D AND E

DATE OCT.93

1088-6


1100
1000
900
800
OPTION D:
EXCAVATION TO REDUCE DEBRIS BUILDUPS AND DIVERT DEBRIS OUT OF MAIN CREEK
Channel Armouring (typ.)
C'
Culvert (optional)
PERMANENT STRUCTURES NOT RECOMMENDED FOR ANY OPTION
AREA AT MINIMAL RISK WITHOUT REMEDIAL MEASURES
PETERSON ROAD
OPTION B:
300m long x 6m high TRAINING BERM
A'
A
AREA PROTECTED BY OPTION D
AREA PROTECTED BY CONSTRUCTION OF TRAINING BERM ALONG L'HEUREUX CREEK (OPTION B)
F'
GOSLIN ROAD
PCL A
OPTION D:
DITCH WIDENING AND IMPROVEMENT


OPTION D:
EXCAVATION TO REDUCE DEBRIS BUILDUPS AND DIVERT DEBRIS OUT OF MAIN CREEK
G
G'
OPTION E:
CHANNEL IMPROVEMENT AND CONSTRUCTION OF DEBRIS BASIN FOR HIGHWAY PROTECTION
H'
H
Culvert
Channel Armouring, (typ.)
C
C'
Culvert (optional)
OPTION D:
CHANNEL REALIGNMENT, CREEK RELOCATION AND CONSTRUCTION OF TRAINING BERMS AND CONTAINMENT BASIN
HIGHWAY 16
PERMANENT STRUCTURES NOT RECOMMENDED FOR ANY OPTION
CONTAINMENT BASIN
AREA PROTECTED BY OPTION D
CULVERT AND SPILLWAY SEE DETAIL IN FIG. 8
800
GOSLIN
OPTION D:
DITCH WIDENING AND IMPROVEMENT
0 100 200 300 400 500m
SCALE



SECTION H-H'

OUND SURFACE
LOBE)

NOTES

1. SECTION LOCATION GIVEN IN FIG. 6.
2. ALL SECTIONS AND CONSTRUCTION DETAILS BASED ON ESTIMATED TOPOGRAPHY AND 1:5000 SCALE PLANS. DETAILED TOPOGRAPHIC SURVEYING REQUIRED TO ENABLE PREPARATION OF DETAILED DESIGNS.

0 5 10 15 20 25m

SCALE (Approximate)

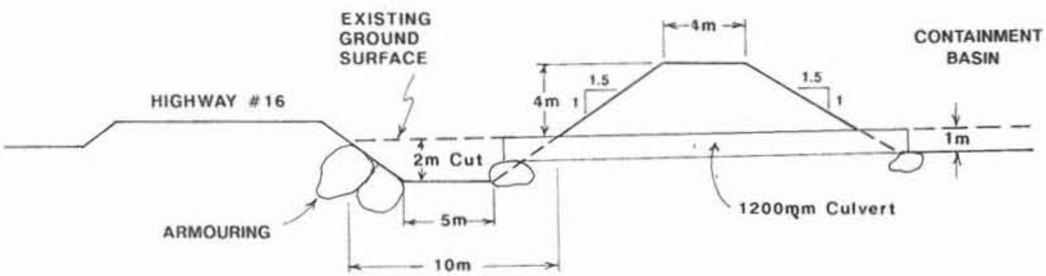
FIG. 7

ON AND HIGHWAYS
TETE JAUNE CACHE, B.C.
TS

PITEAU ASSOCIATES
GEOTECHNICAL CONSULTANTS
VANCOUVER CALGARY

SURES - TYPICAL SECTIONS

BY:	DATE:
DCM/GFB	OCT.93
APPROVED:	DWG:
	1088-7



SECTION H-H'

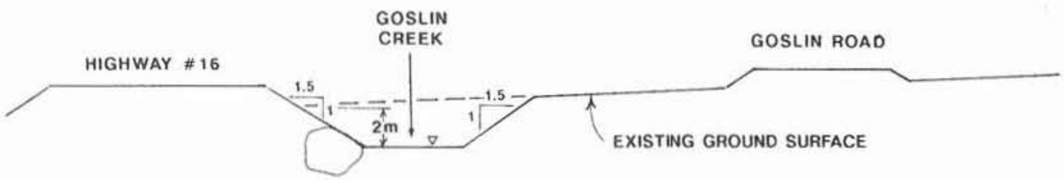
ROUND SURFACE
T LOBE)

NOTES

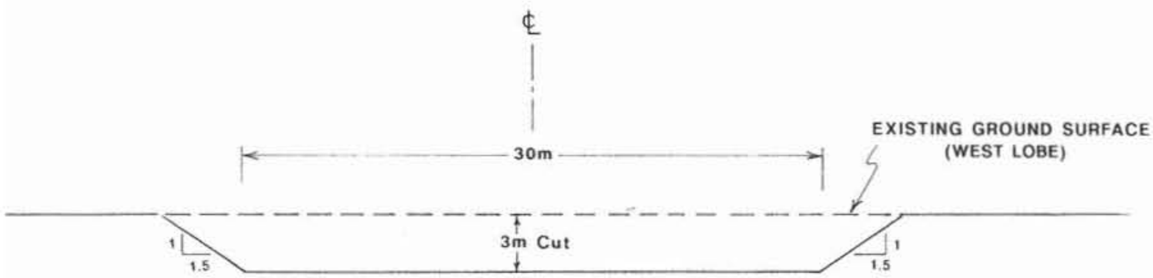
1. SECTION LOCATION GIVEN IN FIG. 6.
2. ALL SECTIONS AND CONSTRUCTION DETAILS BASED ON ESTIMATED TOPOGRAPHY AND 1:5000 SCALE PLANS. DETAILED TOPOGRAPHIC SURVEYING REQUIRED TO ENABLE PREPARATION OF DETAILED DESIGNS.

0 5 10 15 20 25m

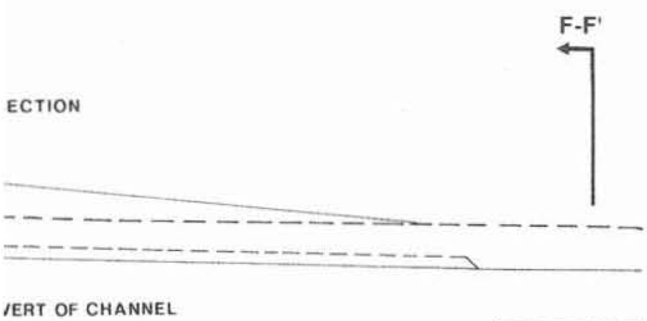
SECTION E-E'

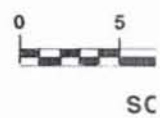


SECTION F-F'



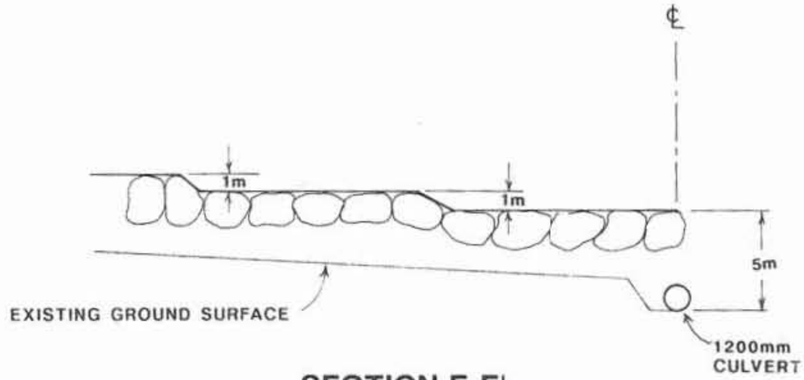
SECTION G-G'



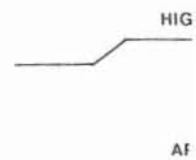


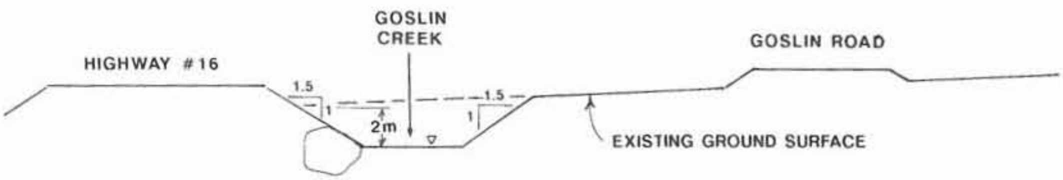
MINISTRY OF TRANSPORTATION AND HIGHWAYS
GOSLIN/L'HEUREUX CREEKS, TETE JAUNE CACHE, B.
GEOTECHNICAL ASSESSMENTS

REMEDIAL MEASURES - TYP

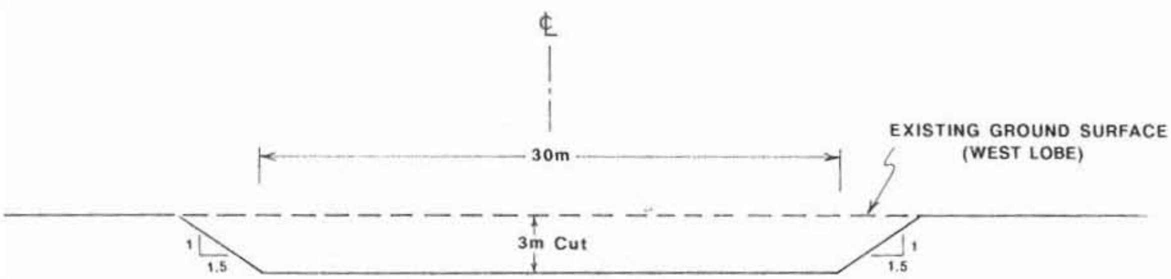


SECTION E-E'





SECTION F-F'



SECTION G-G'

F-F'

0 5

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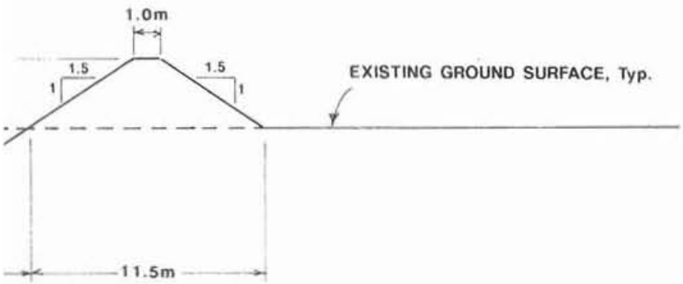
EXISTING GROUI



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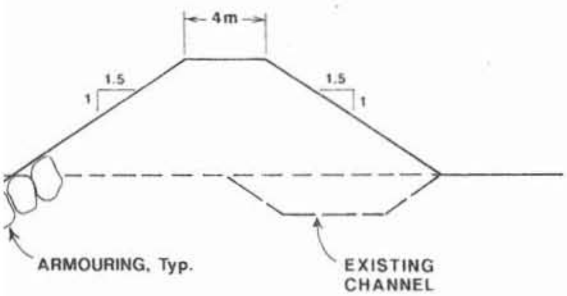
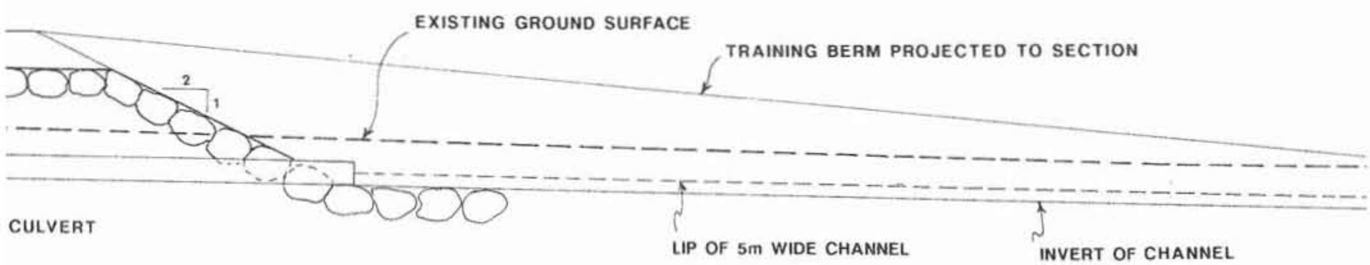
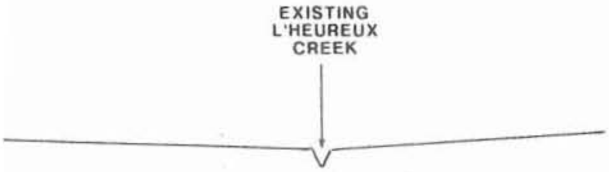
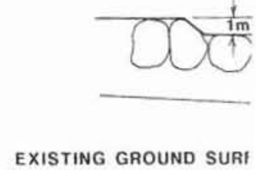


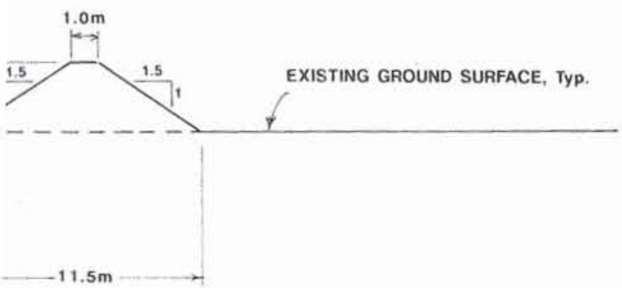
-C'

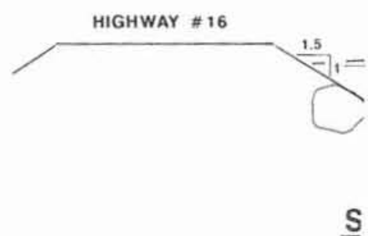


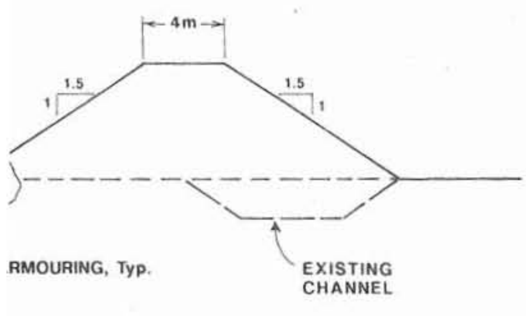
SECTION D-D'


EXISTING
L'HEUREUX
CREEK


1m
EXISTING GROUND SURF


1.0m
1.5
1.5
1
EXISTING GROUND SURFACE, Typ.
11.5m

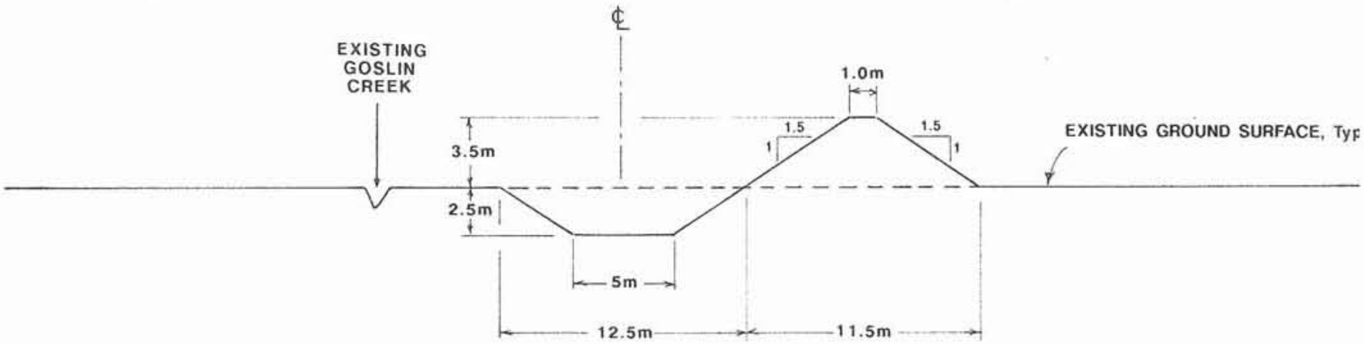

HIGHWAY #16
1.5
1
S


4m
1
1.5
1.5
1
RMOURING, Typ.
EXISTING
CHANNEL

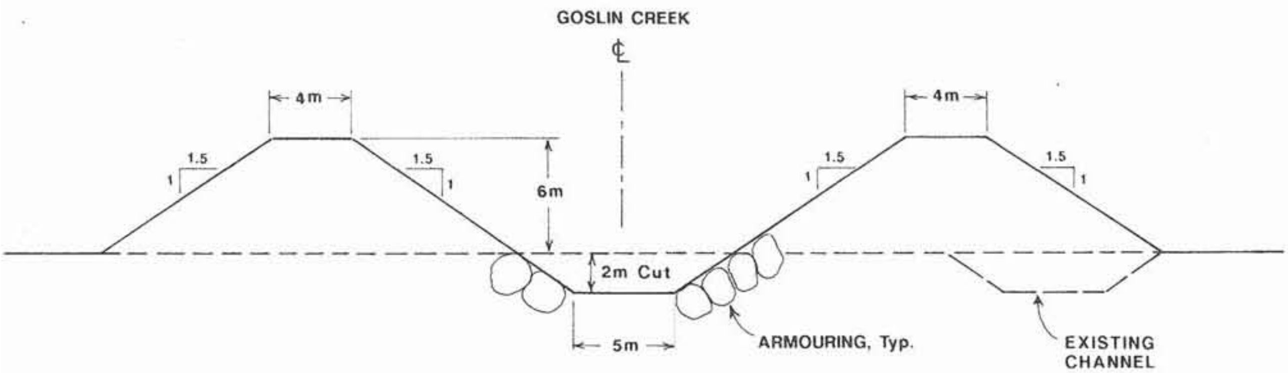

1
1.5


EXISTING GROUND SURFACE

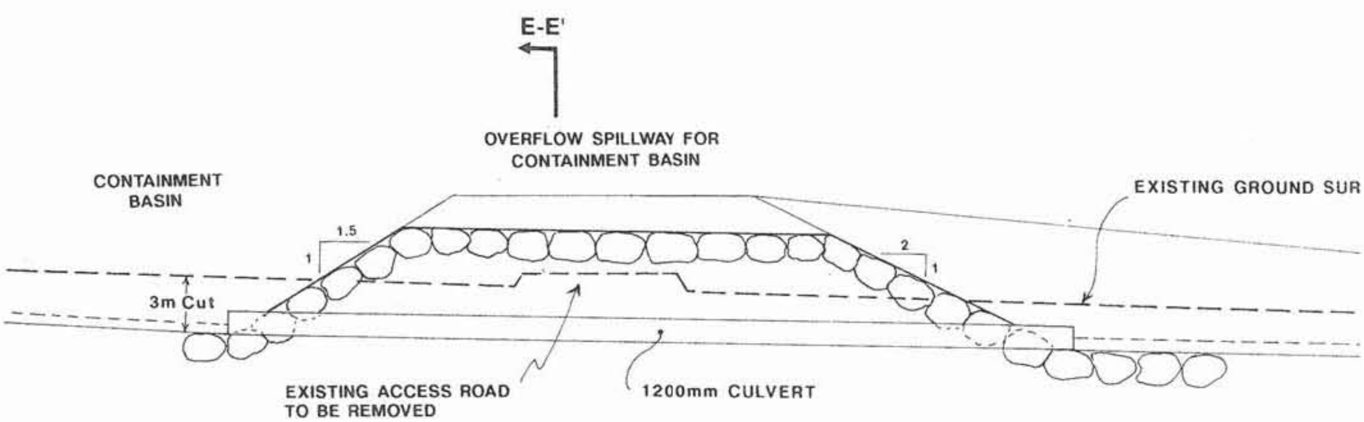
SECTION A-A'



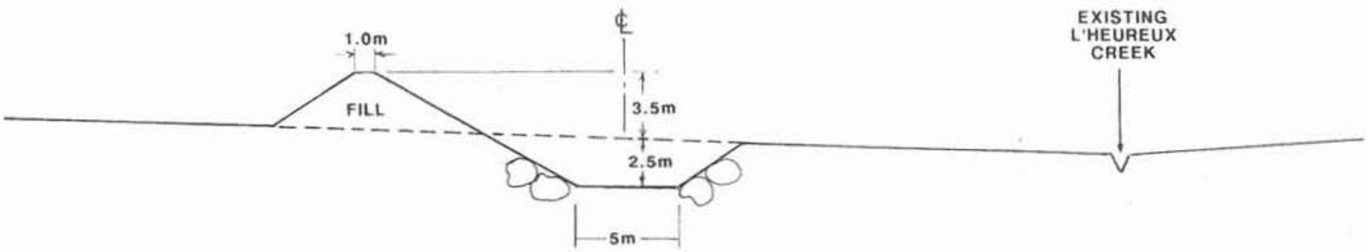
SECTION B-B'



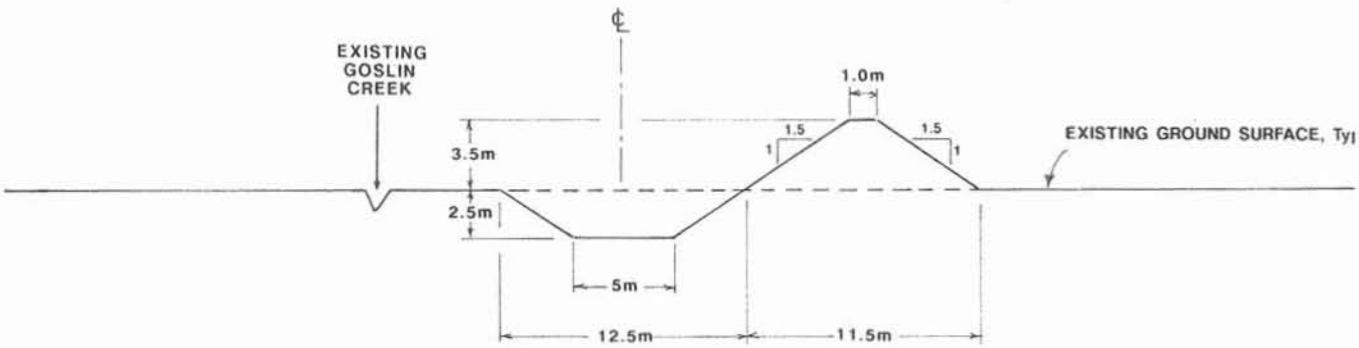
SECTION C-C'



SECTION D-D'



SECTION A-A'



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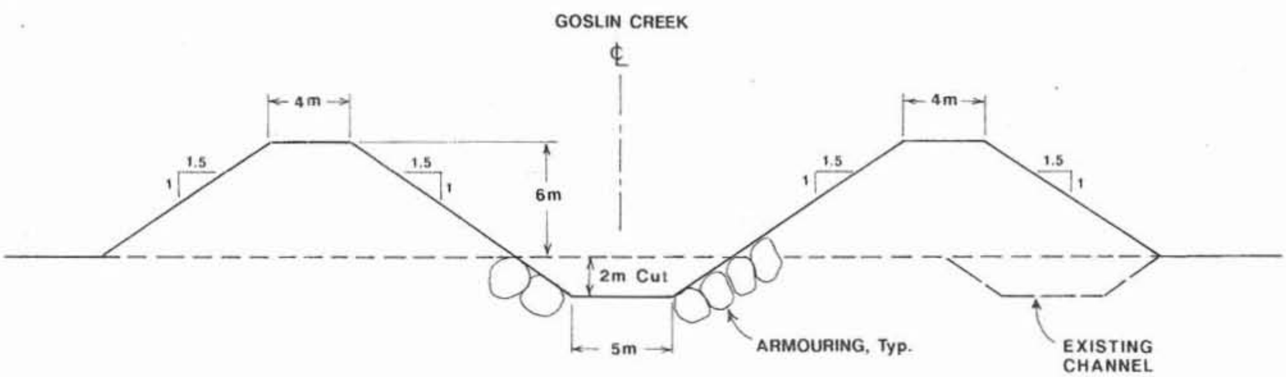
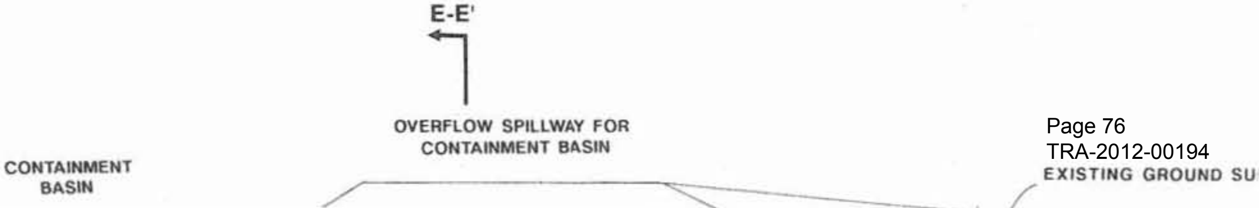


SECTION C-C'



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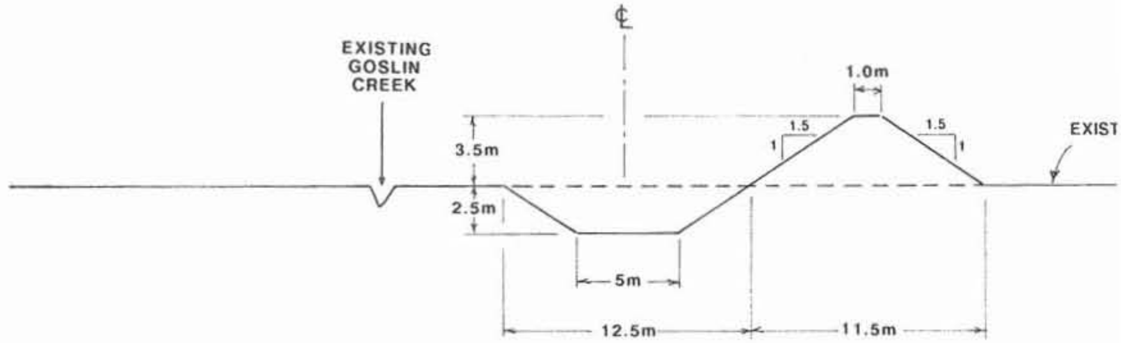
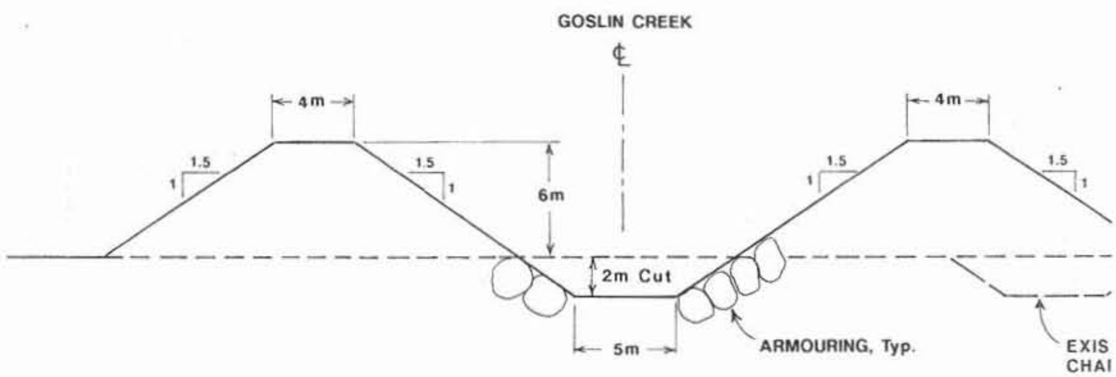
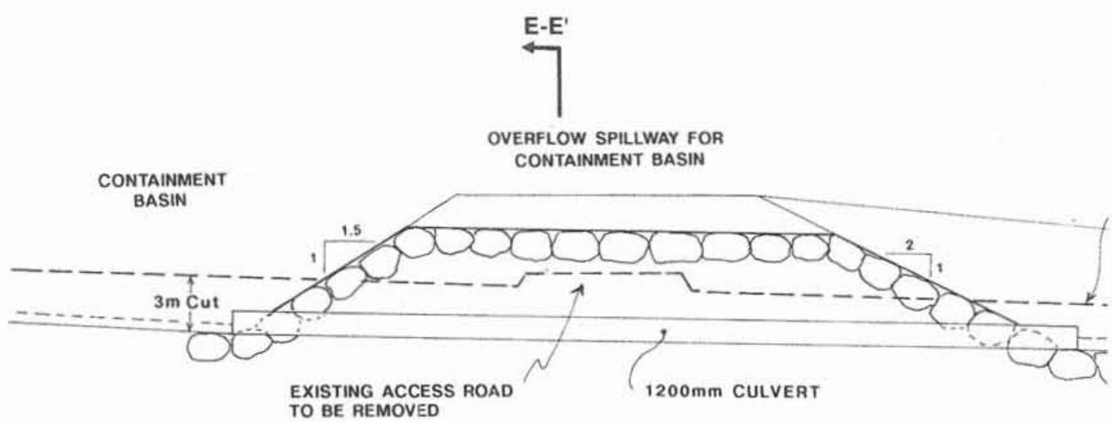
SECTION A-A'



SECTION B-B'

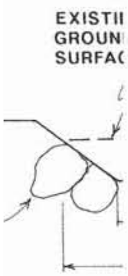


SECTION C-C'



SECTION

JOB NO. 1088



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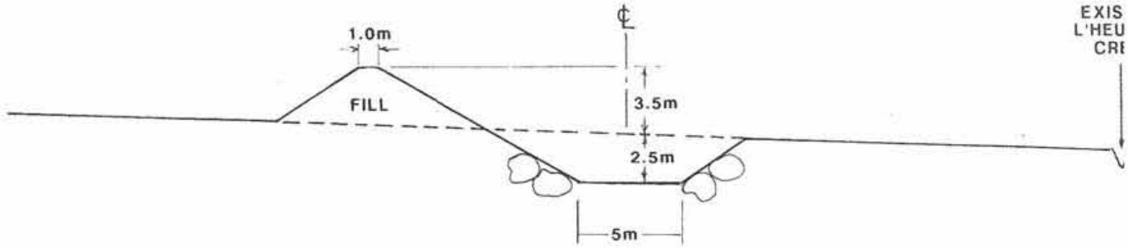
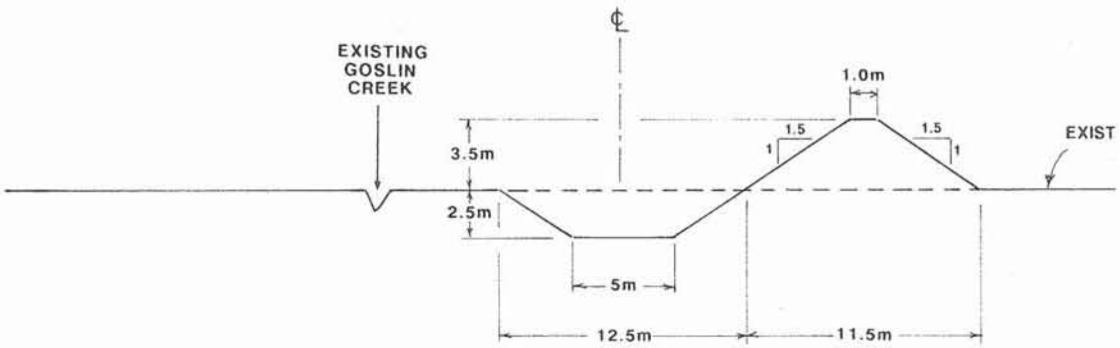
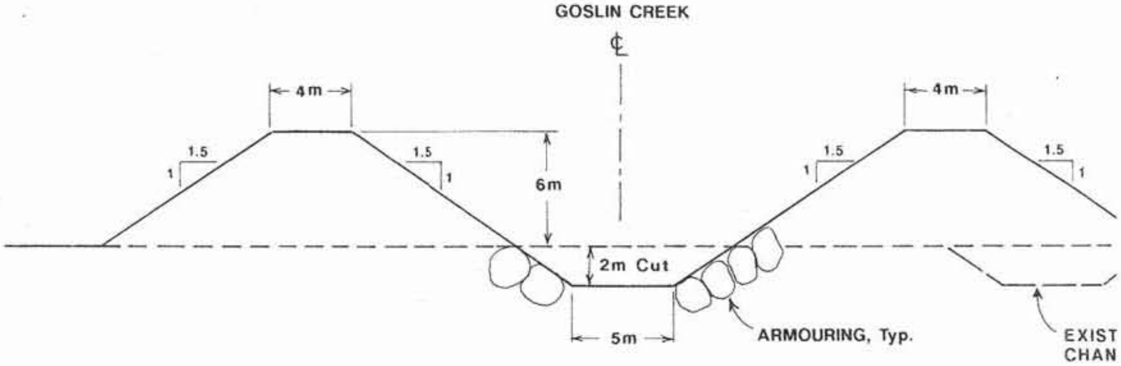


SECTION A-A'



SECTION B-B'



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SECTION C-C'

E-E'

OVERFLOW SPILLWAY FOR

NOTES

1. LAYOUTS AND CONSTRUCTION DETAILS ARE CONCEPTUAL ONLY AND ARE BASED ON ESTIMATED TOPOGRAPHY AND 1:5000 SCALE PLANS. DETAILED TOPOGRAPHIC SURVEY REQUIRED TO PREPARE DETAILED DESIGN.
2. ARMOURING ON DITCH ALONG HIGHWAY 16 EXTENDS TO GOSLIN CREEK CULVERT AT EAST END OF SUBDIVISION.

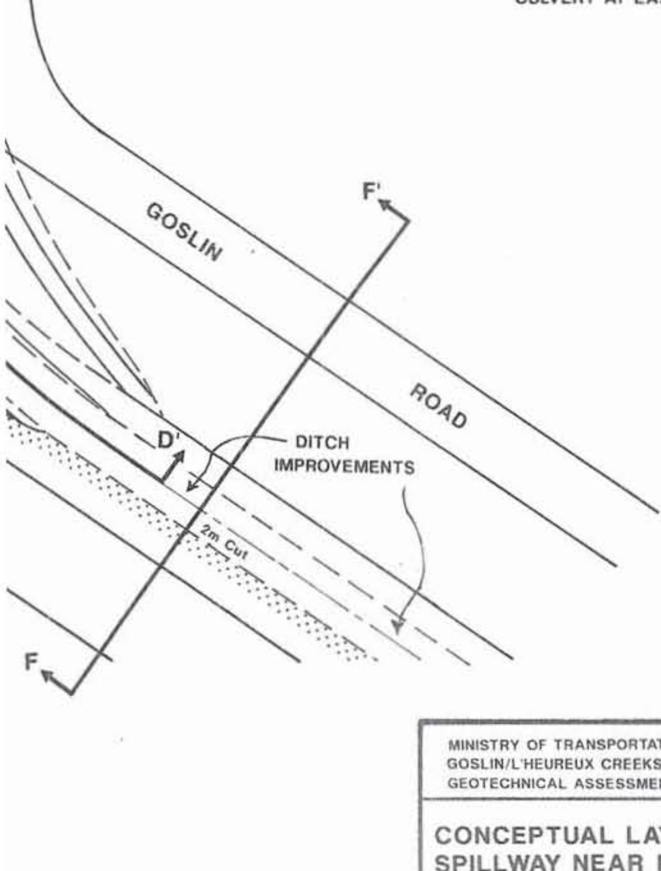
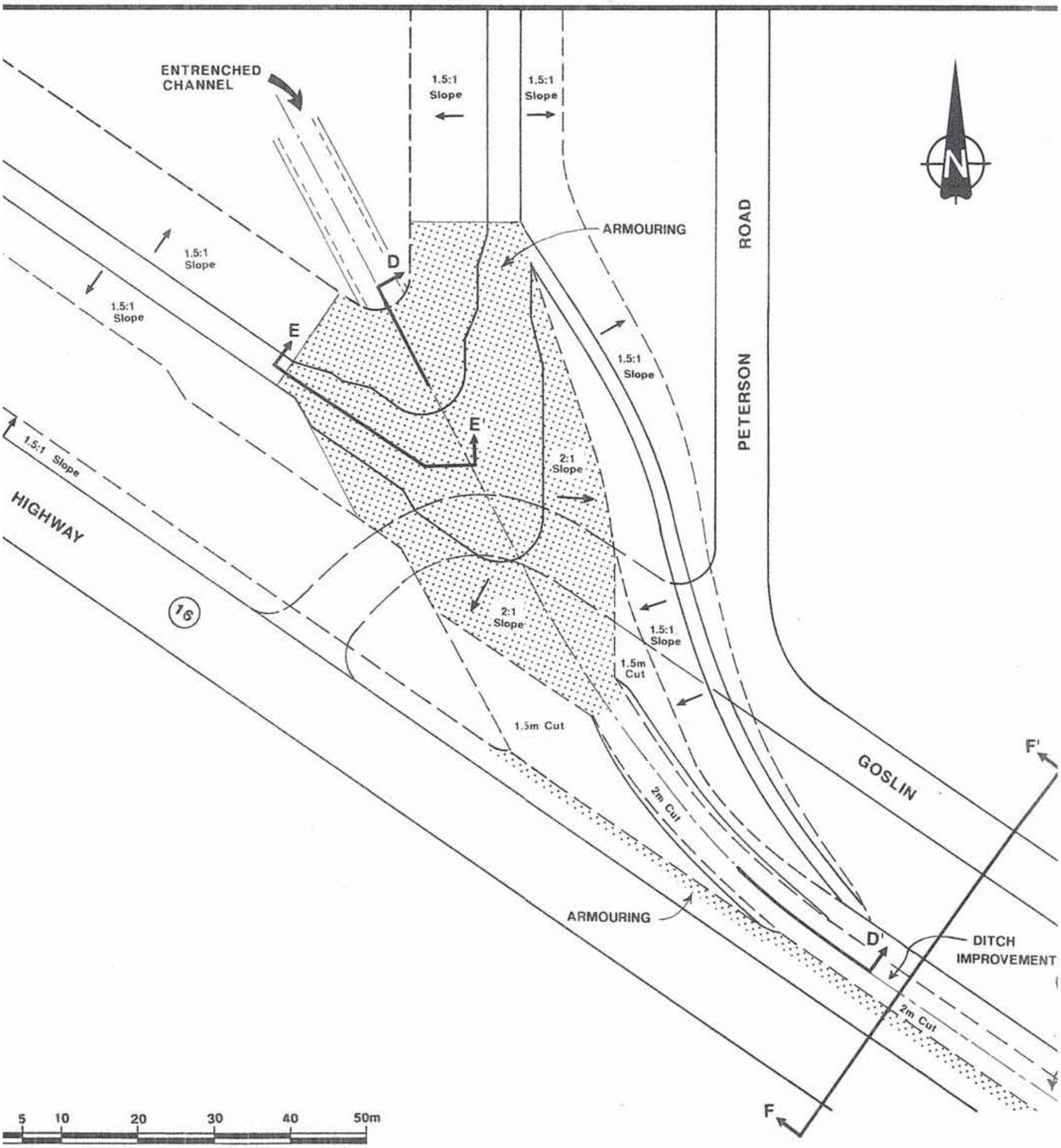


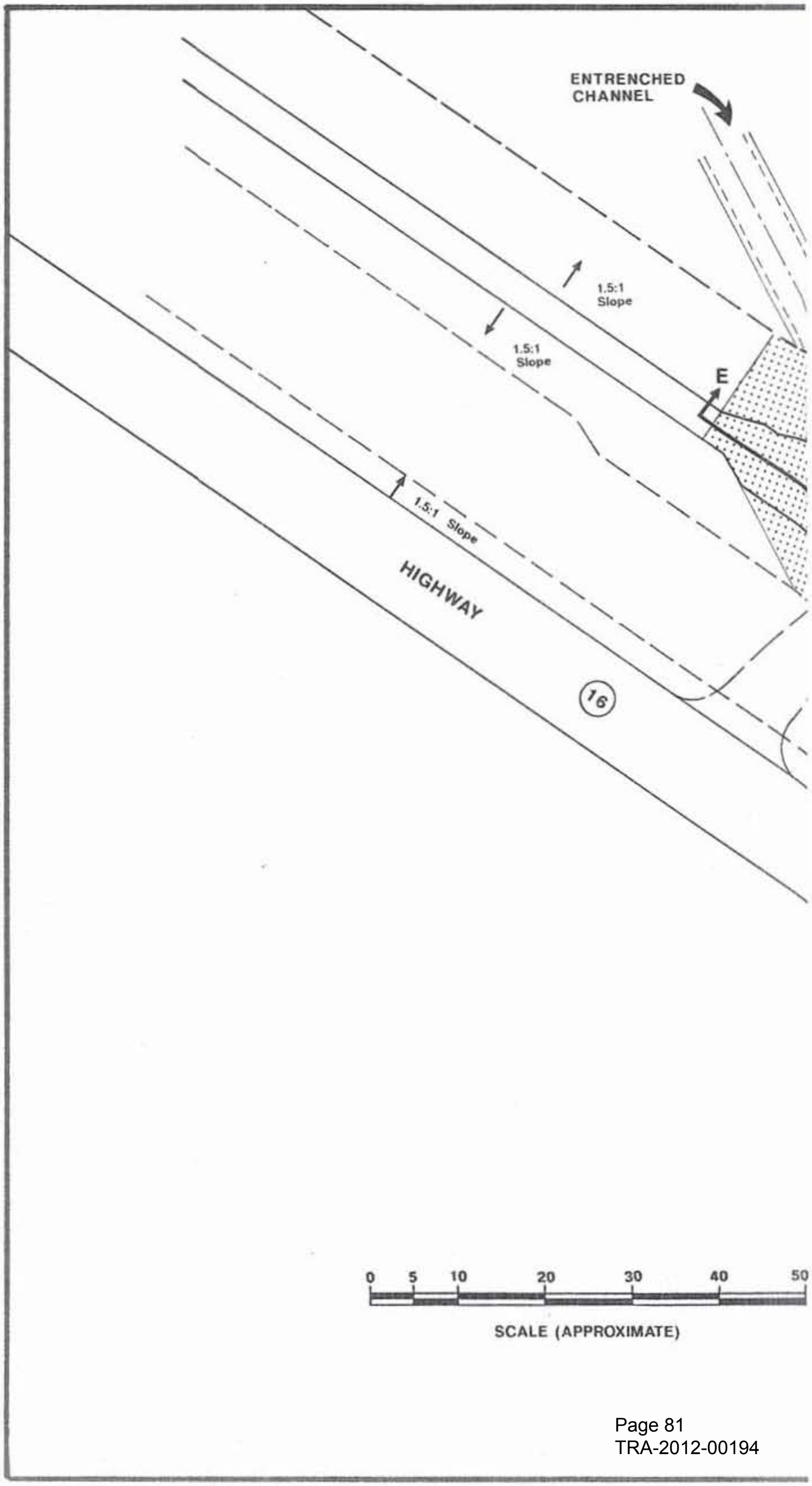
FIG. 8

MINISTRY OF TRANSPORTATION AND HIGHWAYS GOSLIN/L'HEUREUX CREEKS, TETE JAUNE CACHE, B.C. GEOTECHNICAL ASSESSMENTS	PITEAU ASSOCIATES GEOTECHNICAL CONSULTANTS VANCOUVER CALGARY	
CONCEPTUAL LAYOUT OF DEBRIS BASIN AND SPILLWAY NEAR PETERSON ROAD AND HIGHWAY 16	BY GFB/BL APPROVED	DATE OCT.93 DWG. 1088-8

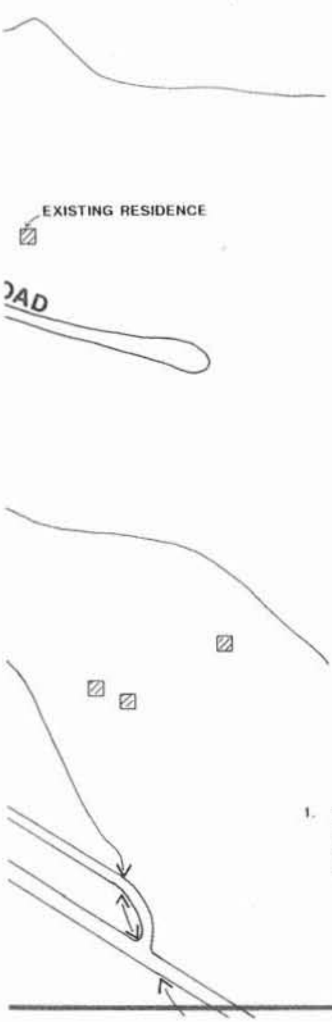


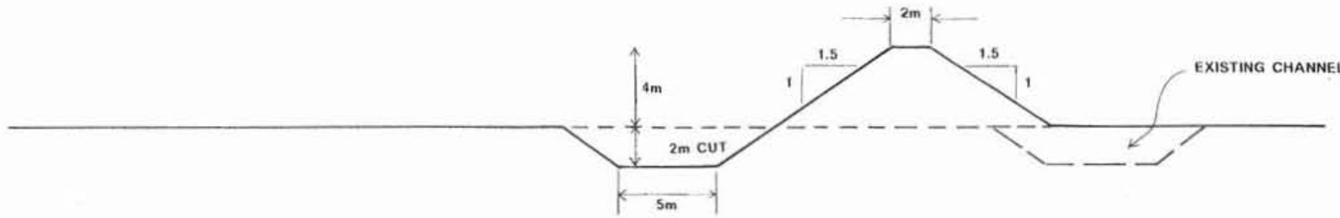
SCALE (APPROXIMATE)

JOB NO. 1088



ENTRENCHED
CHANNEL
1.5:1
Slope
1.5:1
Slope
E
1.5:1 Slope
HIGHWAY
16
0 5 10 20 30 40 50
SCALE (APPROXIMATE)

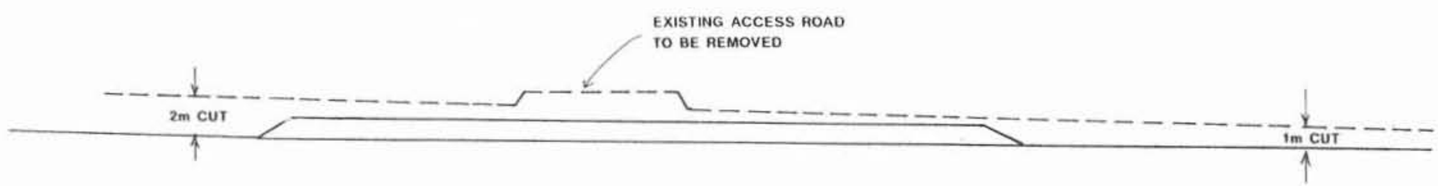




0 2.5 5 10 15

SCALE 1:250

SECTION C'- C'



0 2.5 5 10 15

SCALE 1:250

SECTION D'- D'

FIG. 9

NOTES

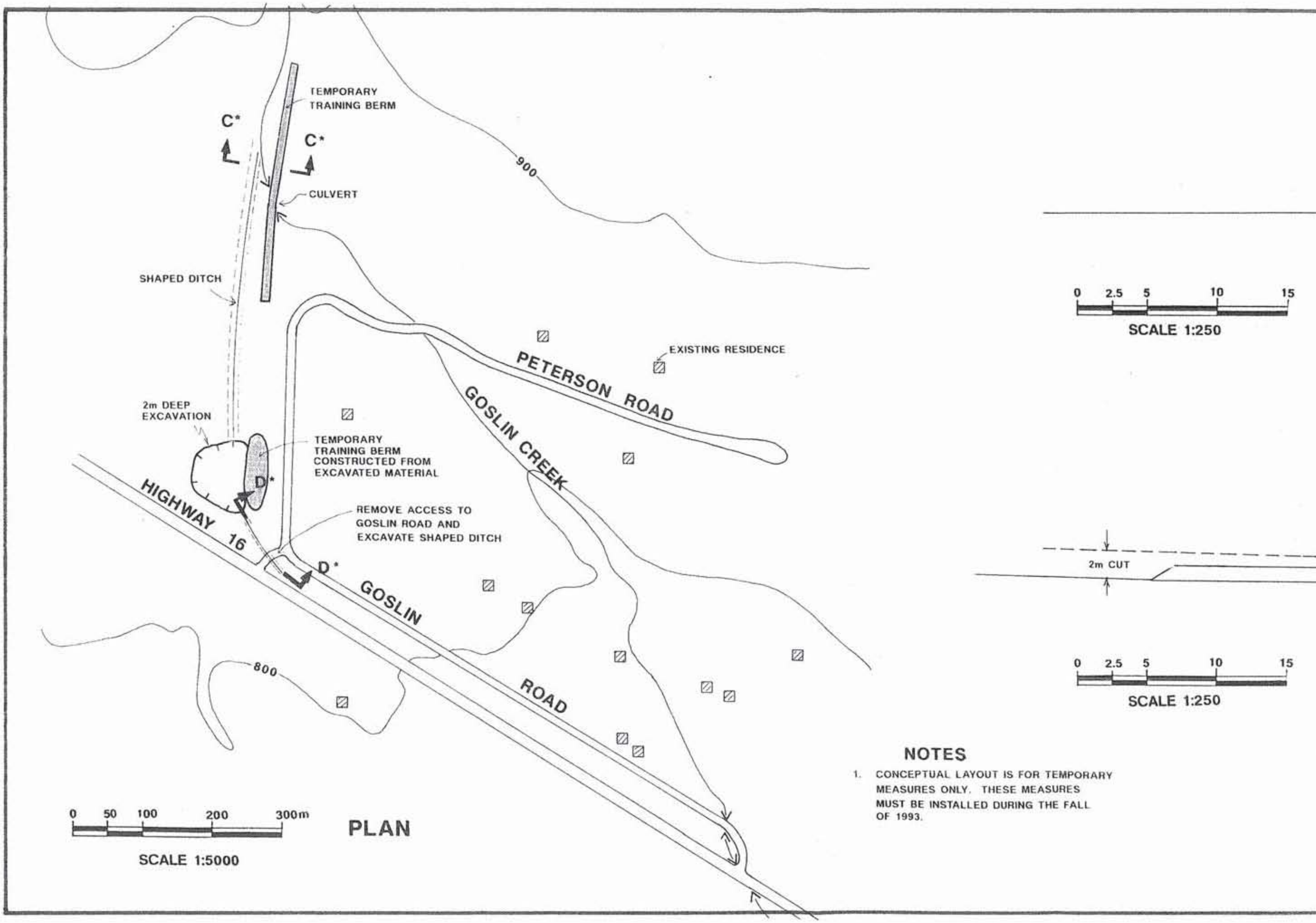
1. CONCEPTUAL LAYOUT IS FOR TEMPORARY MEASURES ONLY. THESE MEASURES MUST BE INSTALLED DURING THE FALL OF 1993.

MINISTRY OF TRANSPORTATION AND HIGHWAYS
GOSLIN/L'HEUREUX CREEKS TETE JAUNE CACHE, B.C.
GEOTECHNICAL ASSESSMENTS

PITEAU ASSOCIATES
GEOTECHNICAL CONSULTANTS
VANCOUVER CALGARY

RECOMMENDED INTERIM REMEDIAL MEASURES	JC	OCT 93
		1088-9

JOB NO. 1088



PLAN

NOTES

1. CONCEPTUAL LAYOUT IS FOR TEMPORARY MEASURES ONLY. THESE MEASURES MUST BE INSTALLED DURING THE FALL OF 1993.