GEOLOGICAL SURVEY OF CANADA

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Field Trip – Guidebook
Some Geological Hazards in North Vancouver and along the Sea-to-Sky Highway British Columbia

R. Couture and D. VanDine

2004

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GUIDEBOOK

Compiled by

Dr. Réjean Couture
Geological Survey of Canada

and

Doug VanDine
VanDine Geological Engineering Limited

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November 2003

Cover page: Photograph of the 1990 rockfall near Loggers Creek.
(Photo credit: BC Ministry of Transportation)

ICL Workshop, Vancouver
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1. INTRODUCTION

This guidebook provides background information for a field trip dealing with a wide variety of landslide types along Highway 99 (the Sea-to-Sky Highway), between North Vancouver and Britannia Creek along the east shore of Howe Sound (Figure 1). The trip focuses on debris flows, rockfalls, rock slides and rock avalanches, which have resulted in damage and disruption to transportation facilities, damage to buildings, and the loss of life. Since 1915, 104 deaths, and millions of dollars of damage to private property and public infrastructure, have been related to landslides in the area.

This guidebook includes a description of each stop, numbered from 1 to 8, and additional information on other sites for which there is not enough time to stop. The description of the stops and sites proceeds from south to north although logistics may require visiting some in a different order. The information provided in this guidebook was compiled by Réjean Couture (organizer) and Doug VanDine (field trip leader) largely from previous guidebooks (e.g. Eisbacher 1983; Hungr and Skermer 1998; VanDine 2002; Clague and Turner 2003), excerpts from newspapers, papers published in scientific journals, reports from consulting firms, and personal knowledge.

Figure 1. Field trip route and stops.

2. BRIEF HISTORY OF DEVELOPMENT OF THE SEA-TO-SKY HIGHWAY

(modified from Hungr and Skermer 1998; Eisbacher 1983)

Prior to the arrival of the first European explorers (fur traders, miners and loggers), the southern Coast Mountains, valleys and coastal fans and deltas were inhabited by the peoples of the First Nations. During the 19th century, trails were first blazed across the mountains to provide access to the interior region.

About a hundred years ago, Dr. Forbes discovered copper deposits on Britannia Creek (Section 19) while deer hunting in the mountains north of Vancouver. At that time it was a remote area and few were interested in his discovery. Ten years later, trapper Oliver Furry (we will cross the creek bearing his name – Section 17) staked seven mining claims in the upper Britannia Creek watershed. In 1905, the Britannia Mining and Smelting Co Ltd, owned by Anaconda Copper, began to exploit this rich polymetallic deposit. The community of Britannia Beach, at the mouth of the creek, was established at that time. The community was serviced by boat until the mid-1950s, and thereafter by rail and road. The mine closed in 1974 and is now the BC Mining Museum.

Since 1914, a rail line has connected the harbour town of Squamish, north of Britannia Creek, with Lillooet on the Fraser River in British Columbia's interior, and until the 1950s Squamish was the major shipping port for resources from the Interior.

In 1920, to attract tourists and to protect the scenic volcanic peaks from the gradually expanding logging and mining exploration, Garibaldi Provincial Park was established along the eastern uplands of the Cheakamus River valley, between Squamish and (northwards to) what is now the Resort Municipality of Whistler.

In the mid 1950s, a rail bed and roadbeds were carved from the steep bedrock cliffs rising from the east side of Howe Sound, finally connecting Squamish with Vancouver by land. The Cheakamus Hydroelectric Dam was constructed in the Cheakamus Valley, north of Squamish, soon thereafter. Karl Terzaghi, the father of the soil mechanics, took part in its design. Transmission lines were located along the Squamish to Vancouver corridor to transmit power from Cheakamus and other generating plants farther north to Vancouver.

In 1965, Highway 99 was extended northwards from Squamish to Pemberton opening this area to tourists, principally skiers. In 1966, ski lift facilities were built at Whistler Mountain to serve the expanding recreational needs of Vancouver, and in the late 1970s the Resort Municipality of Whistler was established on the Fitzsimmons Creek fan. Subsequently the neighbouring Blackcomb Mountain was developed.

In the late 1970s, both logging and recreational activities advanced into the hitherto inaccessible mountain valleys. Real estate development, continued logging, a need for an expanded highway corridor, and intensified tourism continue to pose considerable challenges to resource managers and transportation engineers responsible for the Vancouver to Pemberton corridor.

The recent announcement of the 2010 Winter Olympics, to be held in Vancouver and Whistler, will generate important upgrading works along Highway 99, literally the Sea-to-Sky Highway.

3. PHYSIOGRAPHY AND GEOLOGY OF THE GENERAL AREA

(modified from Hungr and Skermer 1998; Eisbacher 1983)

3.1 Bedrock geology and geodynamic setting

The southern Coast Mountains are underlain mainly by rocks of the Coast Plutonic Complex: quartz diorite, granodiorite, and diorite (Figure 2). U-Pb ages of these plutonic rocks range from Jurassic to middle Cretaceous, broadly decreasing in age from southwest to northeast. The plutonic rocks (mKg, mKd, mKgsq, JKg, JKd in Figure 2) intrude Mesozoic island arc assemblages of Wrangellia terrane (JB in Figure 2) and sedimentary and volcanic rocks of the overlapping Gambier Assemblage (JKG, JKGA, in Figure 2). Remnants of these older sedimentary-volcanic assemblages are preserved as metamorphic septa and roof pendants between the intrusive complexes and juxtaposed along major northwest-trending faults of the southern Coast Belt Thrust System. Metamorphic foliation in these rocks (N in Figure 2) trends northwesterly, paralleling the overall topographic grain of the Coast Mountains. Younger fracture sets, shear zones, and mafic dikes are parallel to, but also discordant with older penetrative fabrics.

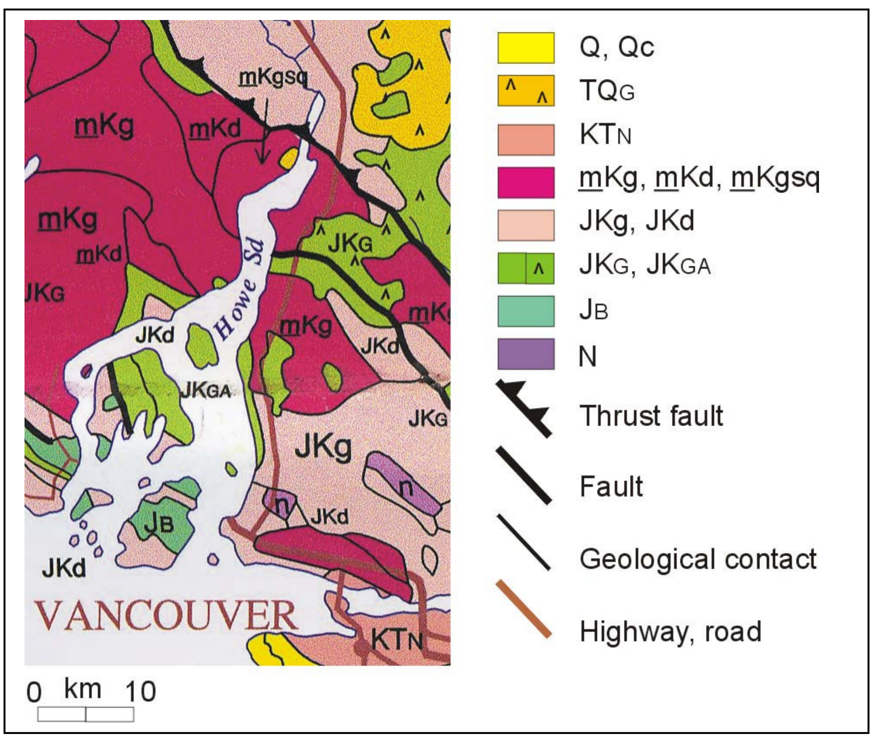


Figure 2. Tectonic assemblage map. Q,Qc: Quaternary; TQG: Tertiary and Quaternary, Garibaldi, volcanic rocks; KT_N: Upper Cretaceous-Oligocene, Nanaimo, volcanic rocks; mKg, mKd, mKgsq: Mid-Cretaceous, plutonic rocks; JKg, JKd: Late Jurassic-Early Cretaceous, plutonic rocks; JKG, JKGA: Upper Jurassic-Lower Cretaceous, Gambier, volcanic rocks; JB: Lower and Middle Jurassic, Bonanza, volcanic rocks; N: Lower and Middle Jurassic, metamorphic rocks, orthogneiss (after Journeay et al., 2000).

Near Vancouver, along the southwestern flank of the Coast Mountains, late Cretaceous to Eocene fluvial sediments (KTN) onlap the deeply eroded Coast Plutonic Complex. Along the northeastern flank of the mountains an Oligocene land surface is capped by late Miocene basaltic lava flows that range in age from 6 to 10 Ma (Parrish 1982). The present high position of these lavas and a young cooling history (revealed by fission track analysis of plutonic rocks) suggest that a low-lying gently rolling, mid-Cenozoic land surface in the area of the present southern Coast Mountains was elevated 2 - 3 km in Plio-Pleistocene time. This implies an average rate of uplift of up to 0.75 km/Ma (Parrish 1982).

During the last 2 Ma, several volcanic complexes, north of Squamish, along what is known as the Garibaldi Volcanic Belt, were superimposed onto the rising pedestal of the southern Coast Mountains: the Mt. Garibaldi, Mt. Cayley, and Meager Mountain complexes (Mathews 1958; Read 1978; Souther 1980). The eruptive centres within each complex trend north-northwest and appear to be controlled by Neogene fracture zones that dissect a physiographic landscape of possibly pre-Pleistocene age. The Garibaldi Volcanic Belt is part of a Pliocene-Recent volcanic province that extends from British Columbia southwards into the northwestern United States. The most recent eruptions along this northern segment of the volcanic chain occurred approximately 2,350 and 2,000 years ago in the Meager Mountain area (Souther 1977).

Neotectonic activity and seismicity of the southern Coast Mountains are broadly linked to northeastward underplating of oceanic crust (Juan de Fuca Plage) along the Cascadia subduction zone. Most historic seismicity has been localized along the subduction zone and benioff zones (Figure 3). The largest onshore earthquake in recent history had its epicentre on central Vancouver Island and occurred on June 23, 1946 (M 7.3). Shaking related to this seismic event caused a number of slope failures and extensive ground subsidence (Mathews 1979; Rogers 1980).

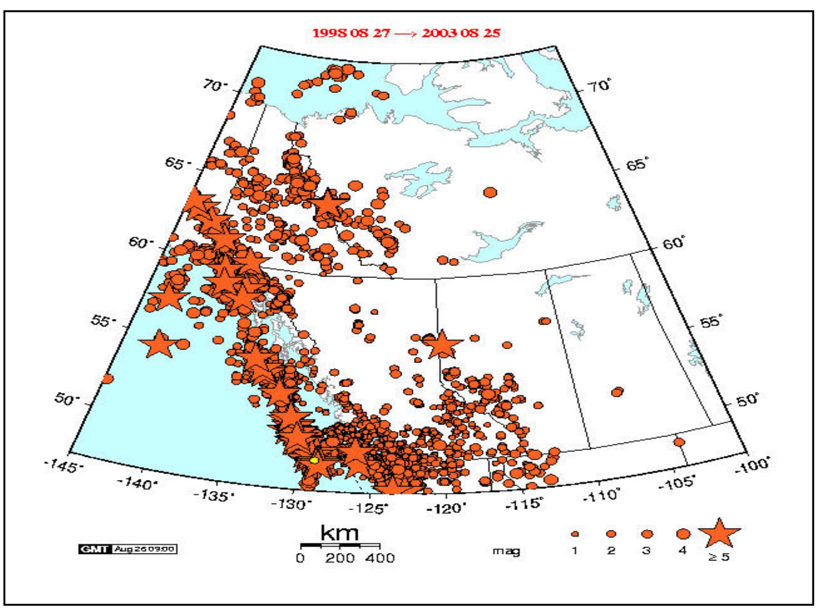


Figure 3. Seismicity of western Canada for the 5-year period August 1998 to August 2003. (source: http://www.pgc.nrcan.gc.ca/seismo/recent/wc.5yr.html)

3.2 Pleistocene glaciations and surficial deposits

The mountains, lowlands, and parts of the continental shelf of southwestern British Columbia were covered by glaciers repeatedly during the Pleistocene Period. At its maximum, the vast Cordilleran ice sheet extended more than 300 km south of the US-Canada border and reached an elevation of 2,000 m in the southern Coast Mountains.

Much of the unconsolidated deposits filling the valleys and lowlands of the region were laid down during the last major glaciation (Fraser Glaciation 26,000 to 10,000 years) and during the immediately preceding nonglacial period (Olympia Nonglacial Interval 65,000 to 26,000 years). The low-lying areas southwest of the mountains were sites of deposition of thick proglacial sand (Quadra Sand, between 25,000 and 18,000 years); they were subsequently covered by till and gravelly ice-contact sediments (Vashon Drift 18,000 to 13,000 years). During recession of the ice (between 13,500 and 10,000 years) complex successions of glaciomarine, diamictons, subaqueous outwash, sands, gravels, dropstone laminites, fan delta deposits, and marine clays were deposited on coastal lowlands depressed by the weight of the ice. Isostatic uplift, locally exceeding 200 m, was rapid and essentially complete in the Vancouver area about 11,000 years ago.

In the Coast Mountains, deglaciation was accompanied by resurgent volcanic activity, particularly in the Garibaldi Volcanic Belt. Volcanic cliffs, which had formed high above and at the contact with the glacier ice became unstable escarpments, and continue to fail by sporadic large mass movements, for example the Barrier (Moore and Mathews 1978; Clague and Souther 1982). After retreat of the glaciers and completion of isostatic adjustments, deltas, including that of the Fraser River, prograded both into the Strait of Georgia and into the narrow fjords, such as Howe Sound, of the mountainous Pacific coast.

Throughout postglacial time, creeks have discharged their bedload, in the form of debris flows, debris floods and water floods, from steep catchment basins onto adjacent valley floors and into fjords. Debris flows have been, and continue to be, a significant mechanism for debris transport. The ability of creeks to produce potentially destructive debris flows depends on the topographic-geological parameters illustrated in Figure 4: steep catchment areas, voluminous debris sources (surficial deposits and/or unstable bedrock slopes), and narrow channels or gorges. Depositional debris fans (or cones) are the result.

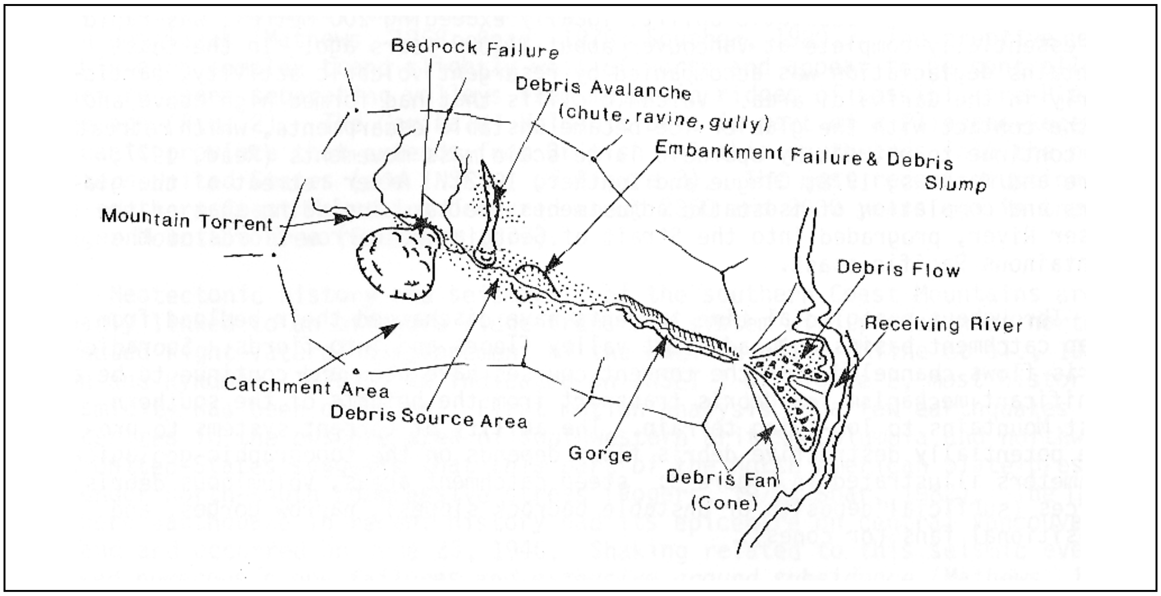


Figure 4. Principal features of a debris flow creek showing debris-generating mechanisms (after Eisbacher 1983).

In the last two decades, new technologies (e.g. high-resolution acoustic survey) have allowed the investigation of the submarine segments of coastal alluvial systems in fjord environments, such as Howe Sound in British Columbia. It has became apparent that *"gravity-driven sediment flows (turbidity currents and debris flows) and various types of sliding and avalanching (rockfall) are dominant processes in the underwater development of coarse-grained deltas"* (Prior and Bornhold 1988). As a typical example of a coarse-grained Gilbert-type delta (composite depositional prism with distinct subaerial and subaqueous components), the fan delta at Britiannia Beach involves gravitational sliding on the lower delta-slopes. However, there is no evidence of extensive runout of debris over the fjord bottom (Prior and Bornhold 1986).

3.3 Climate

The climate is significant in the context of geomorphological hazards in the field trip area. Moist air moving eastwards from the Pacific Ocean, and rising along the western slope of the Coast Mountains, is generally responsible for periods of heavy precipitation along coastal British Columbia. Most precipitation falls in autumn and winter, as summarized in the precipitation normals for several typical locations adjacent to Howe Sound, shown in Figure 5. Mean annual precipitation ranges from approximately 1,500 mm in Vancouver to 3,500 mm in the high mountains. Superimposed on the strong precipitation gradient is the temperature-sensitive control of the winter snow line along slopes facing the Pacific Ocean. Winter snowpacks of 300 to 400 cm can accumulate above 1,000 m, while at the same time no snow remains on the lowlands. Sudden rises of the freezing level, by as much as 2,000 m, accompanied by heavy precipitation, enhance torrential runoff. On such occasions, failure of saturated soil veneers and erosion along channels may combine into potentially destructive water floods, debris floods and/or debris flows.

Slide-triggering rainstorms often occur when a pronounced atmospheric depression is stalled in the northwest in the Gulf of Alaska and causes strong southwesterly gusts, rising air temperatures, and local storm cells. Failures in the upper watersheds and along gully walls tend to occur during such storms. Rainfall intensities are characteristically uneven, so that major runoff events in small drainages often occur during times when only moderate rainfalls are recorded at the nearest climatic stations. The period between 1981 and 1984 was characterized by unusually high annual precipitation, and was particularly influenced the creeks along Howe Sound.

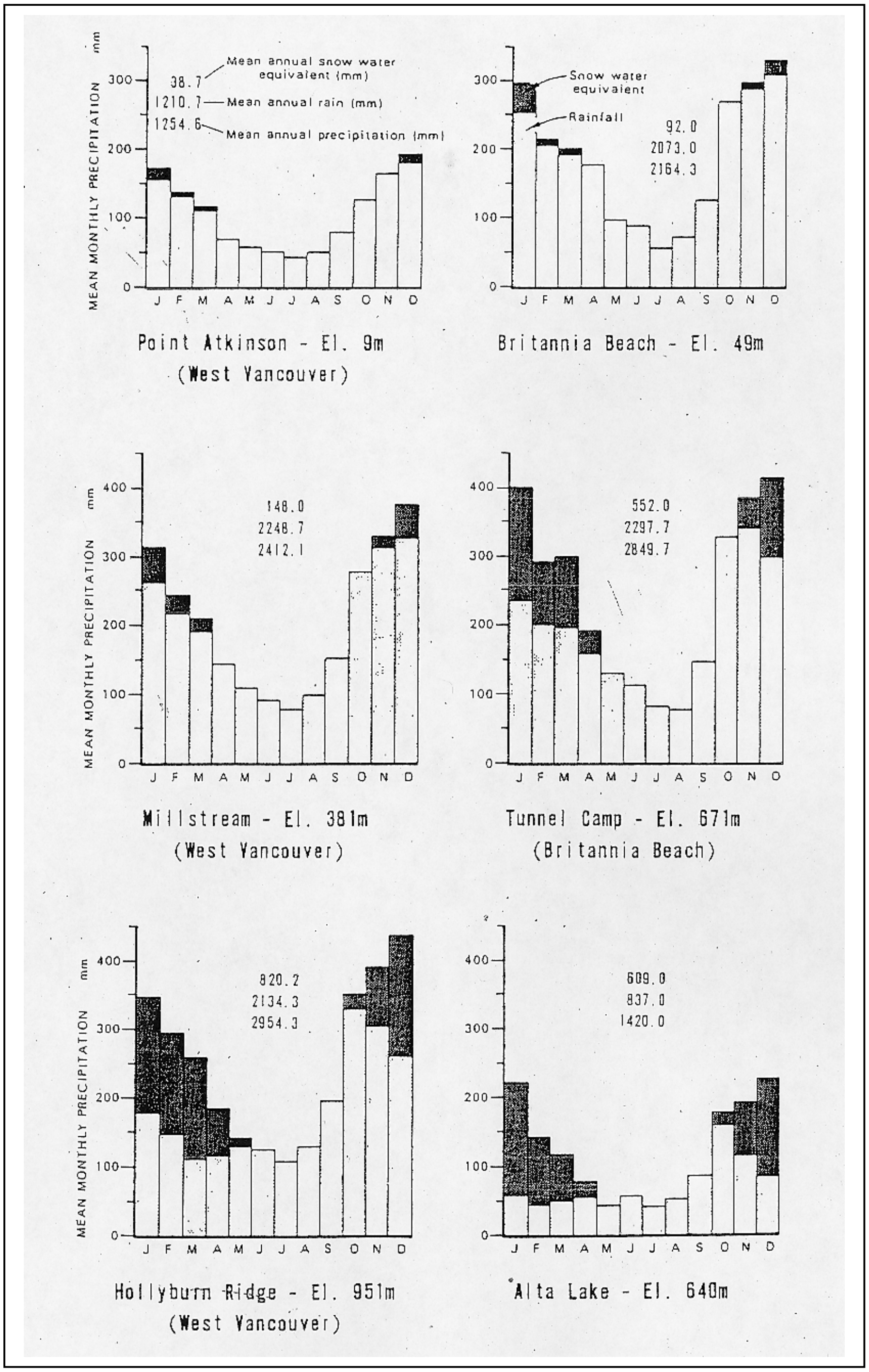


Figure 5. Monthly precipitation normals for the Howe Sound area. (after Thurber Consultants 1983)

4. GEOLOGICAL HAZARDS ALONG THE ROUTE – BACKGROUND INFORMATION

(modified from Hungr and Skermer 1998; Eisbacher 1983)

As discussed in Section 3.1, the mountains north of Vancouver consist mainly of fractured or massive plutonic rocks, intruded into northwest-trending foliated meta-sediments and volcanics. The Howe Sound fjord extends 50 km inland and is flanked by mountains rising steeply from the sea to elevations of about 2,000 m asl. During the Pleistocene Period, ice from both the Squamish and Cheakamus valleys to the north was channeled southward down Howe Sound. Geophysical investigations indicate the maximum depth of Howe Sound to be 300 m, and the depth to bedrock to be a further 500 m (Hungr and Skermer 1998).

At the climax of the Fraser Glaciation (14,000 to 14,500 years BP) the total isostatic depression of the coastal fringe of the southern Coast Mountains amounted to approximately 300 m (Clague 1981). During deglaciation of the Howe Sound area, a period of rapid isostatic rebound occurred, and stream delta and fan surfaces rose well above present sea level. The elevated, relic deltas and fans were deeply entrenched by the mountain creeks which continued to build new deltas and fans into the sea (Figure 6). The present-day creeks derive much of their sediment from eroding banks along these relic elevated delta and fan deposits, and from pockets of Pleistocene ice-contact debris and Holocene rockfall talus along the crests of steep catchment areas.

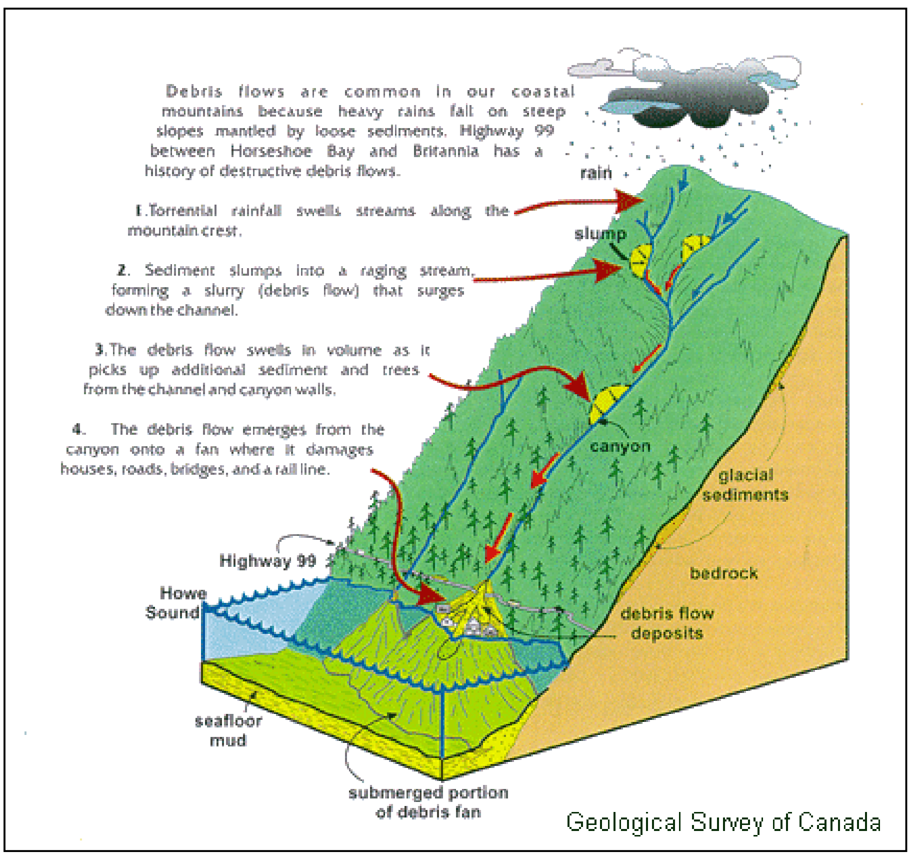


Figure 6. Geomorphological model of debris flows along the east shore of Howe Sound. (Source:http://sts.gsc.nrcan.gc.ca/geoscape/vancouver/sea.asp).

Along Howe Sound, the orientation of the major bedrock cliffs and creeks is generally controlled by north- or northeast-trending fracture zones, and northwest-trending metamorphic foliation. At the lower elevations, the watersheds are well forested, although some logging has occurred. In the upper elevations, tributary gullies are commonly well-scoured snow avalanche tracks. On north-facing slopes, snow avalanche tracks extend down to approximately 300 m asl.; in general, snow avalanches do not reach Highway 99. Recurrent destructive landslides along narrow Howe Sound include a) debris flows, debris floods and water floods along the creeks, b) rockfalls and rock slides from natural cliffs and artificial cuts, and c) submarine slope failures in unconsolidated deposits.

Along Howe Sound, debris flows mobilize coarse bouldery debris derived from plutonic and metamorphic rocks, and elevated relic deltas and fans. Almost completely devoid of fines (silt and clay grain sizes), the debris moves in a liquefied condition as a result of steep slopes and abundant water. Clast support is derived largely from turbulence and the debris tends to deposit when the surge flows reduce their speed on moderate slopes (<10° - 15°, see Hungr et al. 1984). Debris flows in this area often contain a high percentage of logs and other coarse woody debris, often as much as 40%.

Debris flow surges tend to be short in duration, but their peaks can attain discharges more than an order of magnitude greater than those of the largest water flood. Transitional events, containing heavy sediment loads but lacking the high discharge and peak flow depth are termed “debris floods”. While able to transport large amounts of moderately coarse debris and travel on flatter angles, debris floods tend to be much less destructive than debris flows, except where they occur on large streams such as the Britannia Creek (Section 19).

Over the past two decades, debris flows have been investigated and a variety of different types of mitigative control structures have been designed and constructed (VanDine et al. 1997). Some of these structures are described in the following sections.

5. STOP 1
UPPER MACKAY CREEK – DEBRIS FLOW

(modified from VanDine 2002)

More technical information is given in the paper by Murray *et al.* (1998) enclosed in the Appendix 1. The following table summarizes the principal information. Figures 7a and 7b show some of the completed mitigative work.

Table 1. Upper Mackay Creek – debris flow

Events	1995, 1998 (both debris flows)
Future debris flow probability	High
Elements at risk	Multiple residences and subdivision roads
Drainage area	1.0 km^2
Creek length	0.8 km
Debris control measure	Debris basin, barrier and channel stabilization completed in 1997
Design storage volume	13,000 m^3
Volume of concrete	670 m^3
Volume of grouted riprap	1,000 m^3
Cost	$2 million ($Can, 1997)
Owner	District of North Vancouver
Designers	Kerr Wood Liedal & Associates Ltd and EBA Engineering Consultants Ltd.

Figure 7a. Photograph of the Upper Mackay Creek debris basin and engineered outlet (photo by D. VanDine)

Figure 7b. Steel grillage of the oulet structure, looking upstream
(Photo by R. Couture)

6. WEST VANCOUVER – FLOODS AND DEBRIS FLOW

(modified from Eisbacher 1983)

The slopes above the north shore of Vancouver are densely populated and comprise the two municipalities of North Vancouver and West Vancouver. The Capilano River is the municipal boundary between the two, and its fan delta is a conspicuous gravel flat just west of Lions Gate Bridge. The Capilano River flows from the Capilano water reservoir which provides one third of Greater Vancouver's drinking water.

Several mountain creeks with gradients between 11° and 12° descend from forest-covered bedrock slopes that are mantled by only thin unconsolidated sediments (generally till). Below 200 m asl the creek channels are cut into late Pleistocene fan delta deposits. During severe storms unprotected channel embankments are subject to erosional scour. Bouldery debris has blocked road culverts and has caused serious flooding on the urbanized debris fans and shoreline flats below.

On July 12, 1972, during an unusual summer rainstorm, more than 95 mm of rain fell onto the slopes of West Vancouver in a few hours. Several creeks overflowed and debris, mobilized from a construction site, flowed down Rogers Creek causing considerable erosional damage to roads and properties. Several flood water retention basins have since been built in West Vancouver to delay flood runoff from storm sewers.

During the night of October 30/31, 1981, a regional rainstorm fell on the north shore mountains. A West Vancouver creek, Lawson Creek, locally undercut its bouldery embankments and plugged a road culvert with debris. Debris and flood water flowed over the road and onto the inconspicuous fan of the creek which is completely urbanized. Damage from this debris flood was estimated between $500,000 and $1,000,000 (1981 dollars).

7. HOWE SOUND – DEBRIS FLOWS

(modified from Hungr and Skermer 1998; Eisbacher 1983)

At Horseshoe Bay, Highway 99 turns sharply to the north and follows the east shore of Howe Sound. Figure 6 illustrates the hazards from landslides that are triggered at high elevation and are channellized down bedrock-controlled creeks through ravines or gorges, and onto small bedrock promontories, debris fans and fan deltas that have residential development.

The mountains have a relief of up to 1,400 m. The creek ravines can be seen on the mountain flanks, together with a number of the high elevation, unstable debris deposits. The creeks start at the base of bedrock cliffs or associated snow avalanche tracks. Their gradients generally exceed 15°, and often exceed 25°. Some of the lower slopes were logged in the 1960s, and enhanced debris movement resulting from logging has been demonstrated (O'Loughlin 1972).

8. SUNSET HIGHLANDS – ROCK AVALANCHE

(modified from Eisbacher 1983)

The development of Sunset Highlands straddles a bedrock spur that projects into Howe Sound. The upper part of this spur is covered by a conical rock avalanche deposit consisting of angular quartz diorite slabs. Since mature forest covers the blocky lobe, it is at least 300 years old. The total volume of the lobe is approximately 300,000 to 400,000 m^3. Its source is a fracture-controlled cliff face at an elevation of 600 m asl. Most of the surface of the bedrock spur, and the fringe of the rock avalanche deposit, have been subdivided and built over with residential buildings.

9. STOP 2
CHARLES CREEK – DEBRIS FLOW

(modified from VanDine 2002; Eisbacher 1983)

Charles Creek is a high-gradient creek (up to 52% or 27.5°) whose northern tributary includes a northeast-trending fracture-controlled rockfall chute at an elevation between 800 and 1,000 m asl. Mobilization of blocky debris from this rubble-filled ravine produces debris flows that gather momentum in the channelized creek downstream and subsequently, prior to the existence of the present debris flow basin, flowed onto the steep debris fan bordering Howe Sound.

On September 18, 1969, during a local rainstorm, a boulder flow of several thousand cubic metres swept away the original wooden trestle Highway 99 bridge and dislodged the BC Rail bridge (Table 2). Two vehicles plunged into the void in the highway, but the four occupants survived. Another car and its driver disappeared and presumably were carried into Howe Sound by the debris flow. The winter of 1968/69 had been characterized by an abnormal number of freeze-thaw cycles. Massive rockfalls into the upper ravine of Charles Creek may have provided the unstable granitic rubble that was mobilized during the September storm. A steel-reinforced concrete bridge was constructed across Charles Creek after the debris flow.

By 1981, a number of residences had been constructed on the debris fan below the highway and four subdivision bridges crossed the creek. On December 4, 1981, approximately 20 - 30 mm of rain fell in 5 hours and, coupled with rapid snowmelt at higher elevations mobilized approximately 30,000 to 40,000 m^3 of debris, including blocks up to 2 m in diameter, from the rubble-filled upper watershed. Fortunately, the new highway bridge withstood the pressure of the slow-moving boulder lobe and blocked its further advance onto the debris fan. Unfortunately, one person was killed.

The 1983 debris flow on Charles Creek had a peak discharge of 300 m^3/sec, as recorded by a video camera. The 80-tonne concrete deck of the BC Rail bridge was washed away into the bottom of Howe Sound by the event.

In 1985, to protect the highway bridge and the dozen or so expensive homes located on the fan below, a debris basin and barrier was constructed upstream of the highway

(Figure 8). The barrier was built as a zoned earthfill dam, capable of retaining water to full height, should the drainage openings be completely plugged. A reinforced concrete decant structure on the upstream face is intended to retain debris, while draining water through two precast concrete outlet conduits. A concrete spillway was constructed on the downstream face of the barrier, to protect the earthfill from erosion in the event of overtopping.

The barrier was dimensioned using principles of debris flow dynamics derived from observations of previous events on other creeks (Hungr *et al.* 1984 and 1987). For example, the height of the barrier shoulders is such that overtopping should only occur at the spillway. The retention volume was calculated by analyzing runout of debris on the surface of preceding deposits.

Further technical details (Price 1986) and a construction drawing of the basin are provided in Appendix 2.

Table 2. Charles Creek – debris flow

Events	1969, 1972 (2 events), 1981, 1983, 1986 to 2002 three small events (all debris flows)
Future debris flow probability	Very high
Element at risk	Highway, railway, multiple residences and subdivision road
Drainage area	1.8 km^2
Creek length	2.6 km
Design debris flow	29,000 m^3
Design debris discharge	350 m^3/sec
200-year flood	32.2 m^3/sec
Debris control measure	Debris basin and barrier constructed in 1985
Design storage volume	33,000 m^3
Spillway design capacity	700 m^3/sec
Structural impact	2 m diameter boulder traveling at 7m/sec
Volume of fill	43,000 m^3
Volume of concrete	1,500 m^3
Reinforcing steel	160,000 kg
Cost	$3.5 million (1985)
Owner	BC Ministry of Transportation
Designers	Thurber Engineering Limited and Ker Priestman & Associates

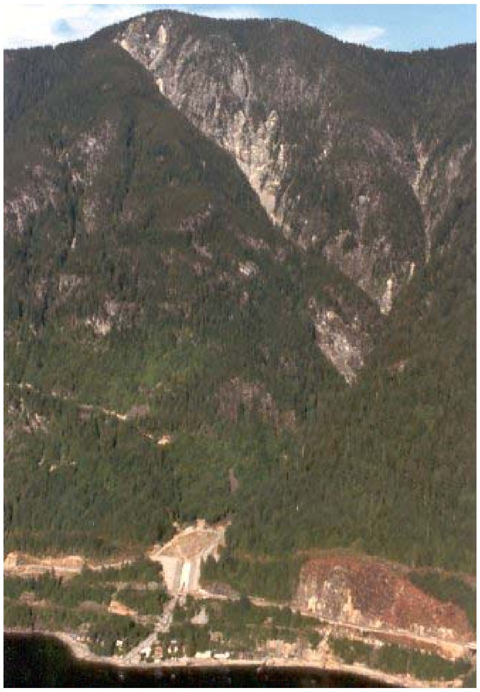


Figure 8a. Charles Creek and the community of Strachan Creek Charles Creek was previously called Strachan Creek).
Left: The upper drainage basin is characterized by very steep slopes and sparse vegetation. The houses are built on the debris fan. The BC Rail line is the lower linear line; Highway 99 is situated immediately below the debris basin.
Bottom: View from within the debris basin at Charles Creek.
(Source: http://www.mala.bc.ca/~earles/howesound/, photos provided by Lee Price)

Figure 8b. View of the debris spillway, looking downstream. The crest of the structure is about 30 m above the highway.
(photo by R. Couture)

10. STOP 3
NEWMAN CREEK – DEBRIS FLOW

(modified from VanDine 2002; Hungr and Skermer 1998)

Newman Creek also has a history of repeated debris torrent activity (Table 3). Extensive mitigative works were carried in 1986, although using different concept. Because there is little potential storage room upstream of the highway, the approach used in managing future debris flows is to keep the debris moving to Howe Sound in a smooth well-aligned channel. The channel is lined with steel-fibre reinforced shotcrete (Figure 9), and both the Highway 99 and BC Rail bridges were designed with sufficient clearance to allow debris to pass beneath them. By locating the channel on the northern margin of the fan (see plan in Appendix 3), bridge crossings for local traffic were eliminated. Since the debris flow hazard on the fan was reduced, it has been possible to develop the fan with an 18-home residential development.

Table 3. Newman Creek – debris flow

Events	1969 (debris flow), 1981 (debris flow), 1982 (flood), 1983 (debris flow), 1997 to 2002 (two small debris flows)
Future debris flow probability	Very high
Element at risk	Highway, railway, multiple residences and subdivision road
Drainage area	1.8 km^2
Creek length	2.4 km
Design debris flow	20,000 m^3
Design debris discharge	350 m^3/sec
200-year flood	32.2 m^3/sec
Debris control measure	Re-routing and channelization of lower channel, construction of new highway and railway bridges, completed in 1986; construction of lockblock wall in 1998
Spillway design capacity	375 m^3/sec
Cost	Re-routing and channelization: ??; lockblock wall: $30,000 (1998)
Owner	BC Ministry of Transportation
Designers	BC Ministry of Transportation

Figure 9. Photograph of the new Newman Creek channel lined with steel-fibre reinforced shotcrete, and the Highway 99 bridge (Photograph by D. VanDine).

11. THE VILLAGE OF LIONS BAY AND HARVEY CREEK – FLOOD, DEBRIS FLOOD AND DEBRIS FLOW *(modified from VanDine 2002; Hungr and Skermer 1998; Eisbacher 1983)*

The Village of Lions Bay is built on the coalescing fans of Harvey and Alberta creeks (Figure 10). The Harvey Creek fan, actually a large delta of glaciofluvial origin, contains dense cross-bedded deposits of sand and gravel many tens of metres thick. Only of the upper 10 to 20 m is coarse debris flow and flood deposits.

Harvey Creek has a drainage area of 7 km^2, extending from the sea level to the summit of the Lions at 1,646 m (Table 4). The main branch of the creek rises from the apex of the alluvial fan at 13º to 14º, and drains a large couloir at elevation 900 m. Four tributary branches drain steep headwall slopes, some of which were clearcut logged in the 1960s. Basin geology is mainly quartz diorite.

The creek has no known history of debris flows, although heavy flooding has occurred in 1969, 1972, 1973 and 1981. For instance, during the storm of September 18, 1969, when several other creeks along Howe Sound had debris flows, Harvey Creek (gradient 23% or 13°) was flowing at bankfull stage and carrying a substantial load of trees and boulders derived from a high-elevation point source in unconsolidated deposits. The peak of the debris flood, estimated at more than 100 m^3/sec (Russell 1972) damaged several homes on the fan. A large clearcut, stretching across most of the catchment area, may have intensified runoff that mobilized the main pulse of debris.

Older debris flow activity, however, is indicated by coarse bouldery deposits on the surface of the fan, by the steepness of both the fan and the channel upstream, and by the availability of debris sources on the slopes and in the channels. Based on such evidence, the creek's potential for producing a major debris flow event was estimated as "moderately high" (Thurber Consultants 1983), meaning that it could occur during the lifetime of a house. A major debris flow would have endangered approximately 30 residences on the fan, disrupt Highway 99 and could cause loss of life.

To prevent the above effects, a large debris basin and barrier was constructed on the upper portion of the fan in 1985 (Figures 11 and 12). It has a retention capacity of 70,000 m^3. The basin and barrier were designed similar to those described fro Charles Creek (Section 9). Further technical details (Price 1986) are provided in Appendix 2.

Downstream of the basin, the creek was provided with a smoothly curving boulder-lined channel to control flood flows, as well as debris flow discharges if the barrier was overtopped. Given the low estimated probability of the design debris flow event, the debris basin may never be tested to full capacity. If it is, however, it will serve to prevent a major natural disaster.

Table 4. Harvey Creek – flood, debris flood and debris flow

Events	1969 (debris flood?, flood?), 1972, 1973, 1981 (floods)
Future debris flow probability	Moderately high
Element at risk	Multiple residences, subdivision roads, highway and railway
Drainage area	7 km^2
Creek length	5.25 km
Design debris flow	62,500 m^3
Design debris discharge	500 m^3/sec
200-year flood	107 m^3/sec
Debris control measure	Debris basin, barrier and downstream channelization completed in 1985
Design storage volume	77,500 m^3
Spillway design capacity	1000 m^3/sec
Structural impact	2 m diameter boulder traveling at 7m/sec
Volume of fill	68,000 m^3
Volume of concrete	1,850 m^3
Reinforcing steel	215,000 kg
Cost	$4.4 million (1985)
Owner	BC Ministry of Transportation
Designers	Thurber Engineering Limited and Ker Priestman & Associates

Also refer to the paper by Thurber Consultants Ltd and Ker Priestman & Associates Ltd (1986) and several construction drawings in Appendix 4 for further technical details.

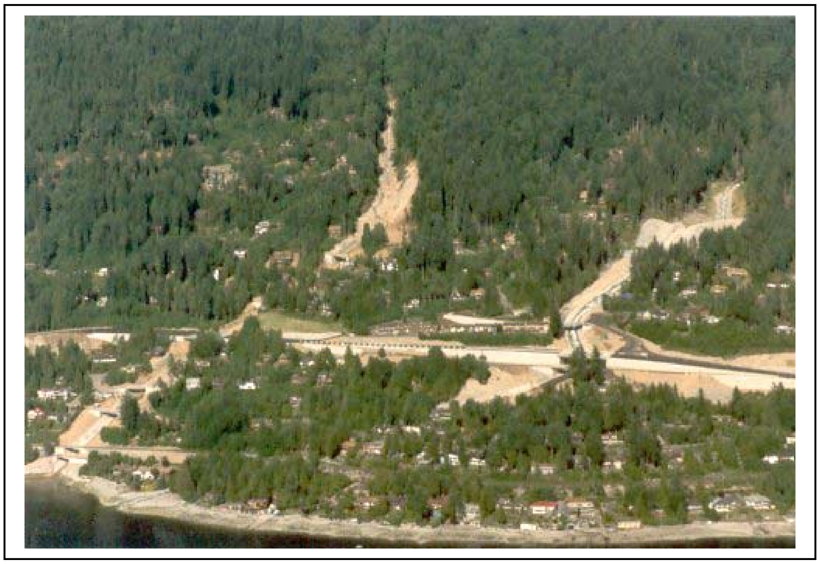


Figure 10. Aerial view of Lions Bay. The village has been built on the coalescing fans of Alberta Creek (left) and Harvey Creek (right). The BC Rail crosses the fans close to the water's edge. Highway 99 passes through the centre of the town. (Source: http://www.mala.bc.ca/~earles/howesound/, photos provided by Lee Price).

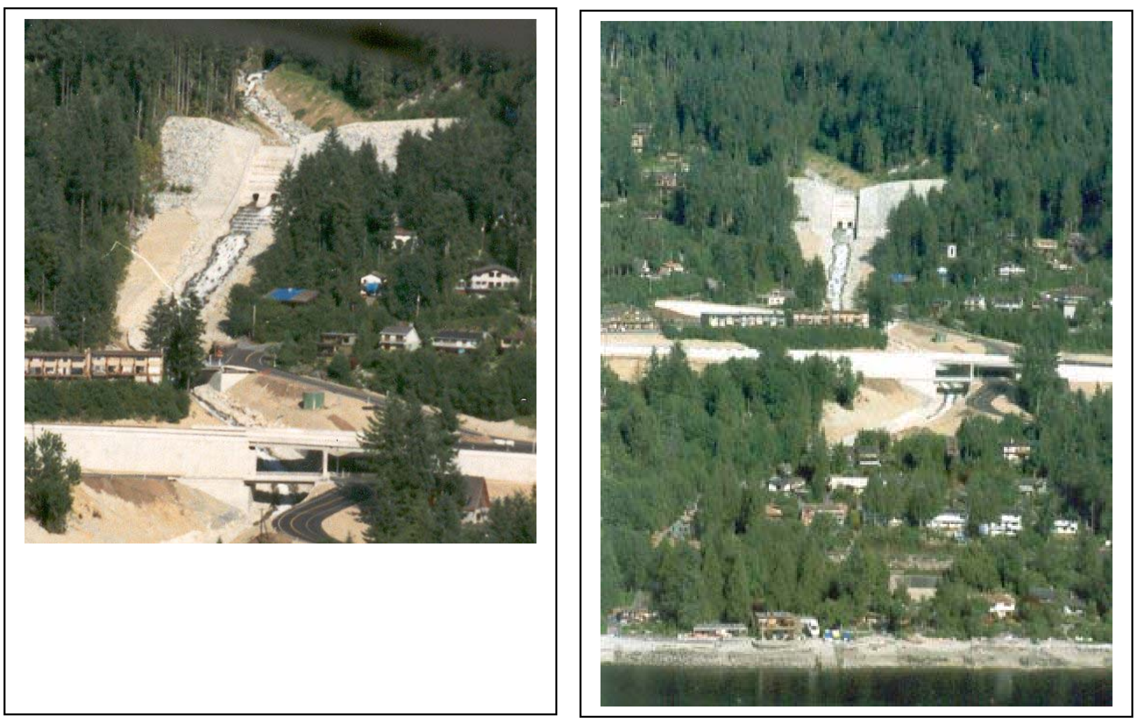


Figure 11. Harvey Creek.
Left: Harvey Creek debris basin. Highway 99 is in the central part of the photograph. Right: The creek has been channellized downstream of the debris basin. (Source: http://www.mala.bc.ca/~earles/howesound/, photos provided by Lee Price).

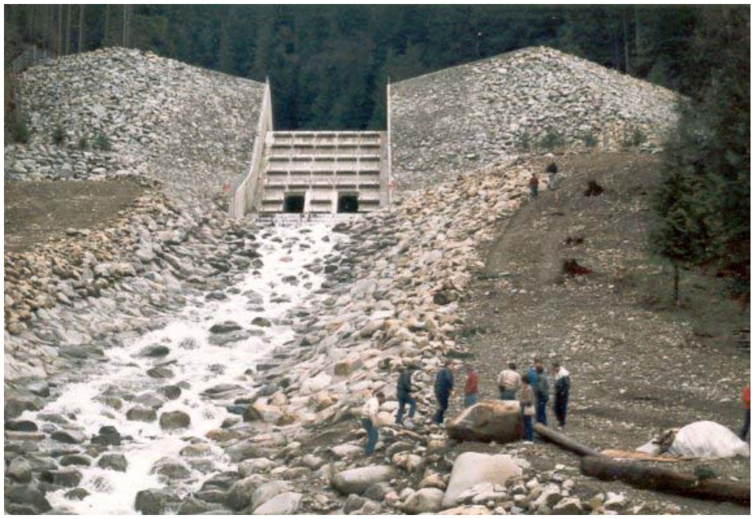


Figure 12. Harvey Creek.
Upper: The bed of Harvey Creek below the debris basin. Boulders have been set into the streambed with concrete.
Lower: Aerial view of the completed Harvey Creek debris basin.
(Source: http://www.mala.bc.ca/~earles/howesound/, photos provided by Lee Price)

12. STOP 4
ALBERTA CREEK – DEBRIS FLOW

(modified from VanDine 2002; Hungr and Skermer 1998)

Alberta Creek is a relatively small stream draining 1.2 km^2 of steep mountain slopes, underlain by sheared and fractured meta-volcanics of the Gambier Group. The creek channel has a relatively consistent gradient of 16º to 24º above the fan and is deeply incised into steep unstable banks. Airphotos show that the lower part of the creek was swept by a debris flow in the early 1930s. Lions Bay, Highway 99 and BC Rail did not exist at that time.

By 1980, an established community existed on the fan on both sides of Alberta Creek. Fifteen houses were built within 30 m of the creek. One house was only 3 m from the creek and 0.5 m above it. In addition to the wooden trestle Highway 99 bridge, the creek was crossed by a concrete BC Rail bridge and five subdivision road culverts. On February 11, 1983, a debris flow with an estimated magnitude of 20,000 m^3 descended the creek (Figure 13 upper left). The highway bridge, all the subdivision culverts and fills and three houses were completely destroyed. The railway bridge and another house were damaged. Two teenage residents lost their lives.

The event was likely started by a shallow slide of steep bedrock-derived colluvium undercut by the creek at elevation 700 m (an unlogged area). The initial failure probably contained less than 100 m^3 of soil and rock fragments. Most of the debris was derived by mobilization of channel infilling and undercutting of unstable banks over the 1.3 km length of channel between the initial slide and the fan. About 10 to 20% of the debris was logs and woody debris. The debris flow occurred in six surges spaced over a half-hour interval. The largest surge may have been as much as 4 m deep at its peak, with a maximum discharge of 250 to 350 m^3/sec. It was fortunate that the flow avoided spilling out of the established channel at an unprotected bend near the fan apex. Should this have happened, the damage may have been even more serious.

Due to steep slopes and the dense population, Alberta Creek offered no suitable site for a debris basin. Consequently, a 800 m long flume or "shooting channel" (from German "schussrinne") was constructed to deliver water flood and debris flow discharges to Howe Sound (Figure 13, see also drawings in Appendix 5). The design of the channel was based on semi-empirical formulas for debris flow hydraulics, developed by back-analysis of observed events (Hungr et al. 1984). Two main considerations in the design were a) to prevent spillover at bends by providing a uniform, gently curving channel and b) to prevent depositional plugging by ensuring secure confinement of the flow at a range of discharge rates. The lined channel was also used to stabilize steep eroding banks which threatened a number of houses upstream of the fan.

Table 5. Alberta Creek – debris flow

Events	1982, 1983 (debris flows)
Future debris flow probability	High
Element at risk	Multiple residences, subdivision roads, highway and railway
Drainage area	1.2 km^2
Creek length	2.6 km
Design debris flow	15,500 m^3
Design debris discharge	350 m^3/sec
200-year flood	22.7 m^3/sec
Debris control measure	Flume with sea basin storage completed in 1988
Length of flume	800 m
Volume of excavation	42,000 m^3 (land); 33,000 m^3 (marine)
Volume of fibre reinforced concrete lining	3,500 m^3
Area of pre-cast channel walls	1,100 m^2
Cost	$8.6 million (1988)
Owner	BC Ministry of Transportation
Designers	Thurber Engineering Limited and Ker Priestman & Associates

Figure 13 Alberta Creek.
Upper left: Aerial view (looking northwards) of the 1983 debris flow. Note damage to roads, the railway and to residences.
Upper right: Completed concrete flume with road crossings.
Lower left: Aerial view with the concrete flume under construction.
Lower right: Concrete flume and BC Rail crossing.
(Source: http://www.mala.bc.ca/~earles/howesound/, photos provided by Lee Price).

13. STOP 5
MAGNESIA CREEK – DEBRIS FLOW

(modified from VanDine 2002)

A plan of the general arrangement of the debris basin and barrier is provided in Appendix 6. Further technical details are provided in Appendix 2 (paper by Price 1986) and in Appendix 4 (paper by Thurber Consultants Ltd and Ker Priestman & Associates Ltd 1986). Table 6 summarizes the main characteristics.

Table 6. Magnesia Creek – debris flow

Events	1960 (flood), 1962, 1981 (debris flows)
Future debris flow probability	Very high
Element at risk	Multiple residences, access roads, highway and railway
Drainage area	4.7 km^2
Creek length	4.7 km
Design debris flow	44,500 m^3
Design debris discharge	400 m^3/sec
200-year flood	75.7 m^3/sec
Debris control measure	Debris basin and barrier completed in 1985
Design storage volume	51,500 m^3
Spillway design capacity	800 m^3/sec
Structural impact	2 m diameter boulder traveling at 7m/sec
Volume of excavation	100,000 m^3
Volume of concrete	750 m^3
Cost	$3.1 million (1985)
Owner	BC Ministry of Transportation
Designers	Thurber Engineering Limited and Ker Priestman & Associates

Figure 14a.
Upper: Photograph of the decant structure at Magnesia Creek (photograph by D. VanDine).
Right: Aerial view of Magnesia Creek debris basin (Source: http://www.mala.bc.ca/~earles/howesound/, photos provided by Lee Price)

Figure 14b. Close-up of the decant structure at Magnesia Creek.
(photo by R. Couture)

14. M CREEK – DEBRIS FLOW

(modified from VanDine 2002; Hungr and Skermer 1998; Eisbacher 1983)

M Creek is a high-gradient creek (gradient 48% or 25.6°) (Table 7). Flowing from an elevation of about 1,300 m asl. to a small fan on Howe Sound. M Creek was the scene of a disaster in 1981 (see attached paper by Skermer and Russell 1988 in Appendix 8).

During the night of October 27/28, 1981, a small debris/rock avalanche consisting of surficial debris and fractured bedrock failed along a steep tributary draw, along the margin of an old logging clearcut, at 1,150 m asl. The debris temporarily blocked the main rain-swollen bedrock channel, then descended to a logging-road crossing where it burst a log jam and flowed down into the gorge, growing to a volume of approximately 15,000 m^3. The bouldery front, having gained a velocity of several tens of metres per second, had sufficient momentum to knock out the central piers of the Highway 99 wooden trestle bridge, creating an 18-metre deep chasm (Figure 15). An unoccupied residential building on the fan was carried into Howe Sound. Several vehicles approaching the bridge in plunged into the chasm and disappeared in the debris flowing towards Howe Sound. The accident claimed 9 lives.

In 1982 and 1983 a new reinforced concrete clear span bridge was constructed (Figure 16) to replace the wooden trestle bridge.

Table 7. M Creek – debris flow

Events	1981 (debris flow)
Future debris flow probability	High
Element at risk	Highway, railway, and a residence and access road
Drainage area	3.8 km^2
Creek length	3.5 km
Design debris flow	41,500 m^3
200-year flood	62.3 m^3/sec
Debris control measure	Clear span bridge (steel girder with concrete deck) with 13 m clearance completed in 1983
Owner	BC Ministry of Transportation
Designers	BC Ministry of Transportation ??

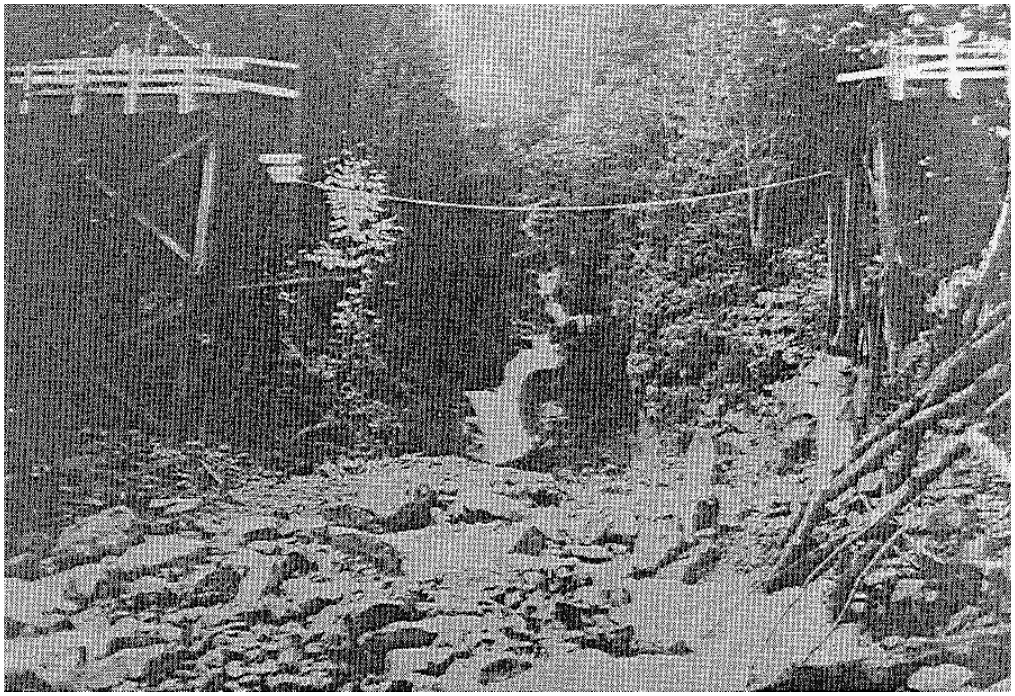


Figure 15. Highway 99 wooden trestle bridge over M Creek, shortly after its destruction by the October 1981 debris flow (from Hungr and Skermer, 1998).

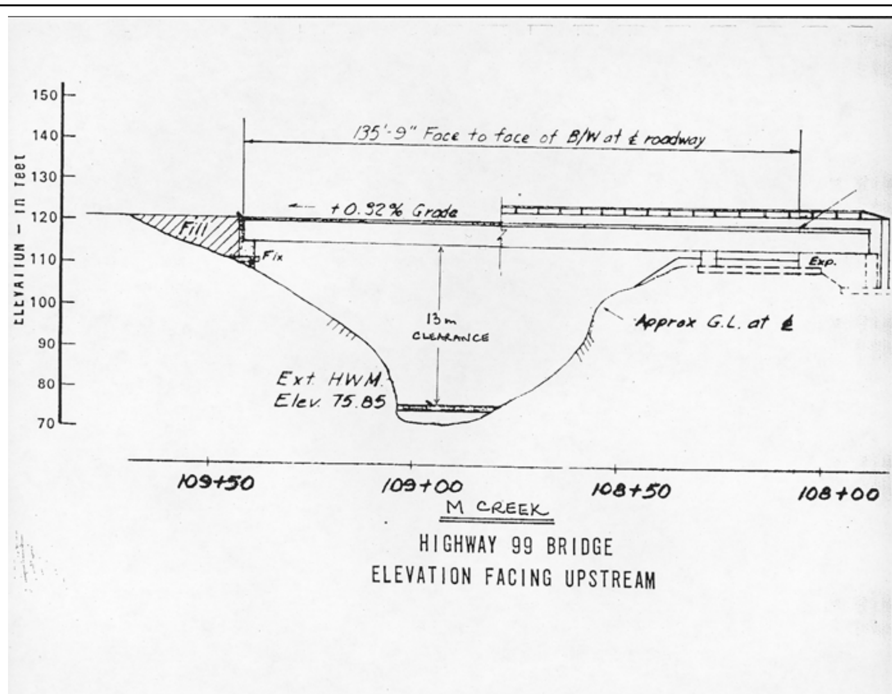


Figure 16. Elevation view facing upstream of the replacement Highway 99 bridge over M Creek, with 13 m of clearance (from Thurber Consultants 1983).

15. STOP 6
LOGGERS CREEK – ROCKFALL

(modified from Hungr and Skermer 1998, Clague and Turner 2003)

A short distance north of M Creek, Highway 99 crosses extremely steep slopes consisting of fractured meta-volcanic rocks. The largest rockfall recorded in the Gambier Group (10,000 m^3) occurred on October 20, 1990, when a natural slope above the highway failed near Loggers Creek (Clague and Turner 2003). This rockfall (Figure 17) blocked Highway 99 and the BC Rail, thus severing the land route between Squamish and Vancouver. Highway 99 was closed for 12 days, during which time vehicle movement between Squamish and Vancouver was only possible by a ferry between Horseshoe Bay and Darrell Bay (north of the rockfall). Clean-up, repairs and preventative scaling cost approximately $7 million (1990 dollars, Evans and Savigny 1994). A secondary, smaller rockfall, which occurred during the scaling operations, injured two workers. Following the rockfall, the BC Government designed and constructed an emergency port facility for large car ferries at the north end of the Howe Sound.

Figure 17. Rockfall near Loggers Creek. Looking north. (photo by BC Min. of Transportation).

16. STOP 7
BRUNSWICK POINT, PORTEAU COVE AND PORTEAU BLUFFS – ROCKFALLS AND ROCK SLIDES

(after Clague and Turner 2003; Hungr and Skermer 1998; Eisbacher 1983)

For approximately 5 km between Brunswick Point and the Porteau Bluffs to the north, Highway 99 passes through one of the most serious rockfall and rock slide zones in southwestern British Columbia. The bedrock consists of intensely fractured northwest-trending meta-sedimentary and volcanic rocks in the Brunswick Point area, and is characterized by surface-parallel fractures ("sheeting") at the Porteau Bluffs. Excavation for the BC Rail and Highway 99 in the mid-1950s resulted in vertical rock cuts which locally are more than 100 m high.

16.1 Brunswick and the Argillite Cut

At Brunswick Point and the Argillite Cut, where the rock is closely jointed volcanic or meta-argillite (Figure 18), rockfalls are relatively small, but relatively frequent. This area has experienced repeated rockfalls ranging from individual small blocks to large wedge failures. The large failures are generally preceded by the breakout of smaller rock fragments along pre-existing fracture zones.

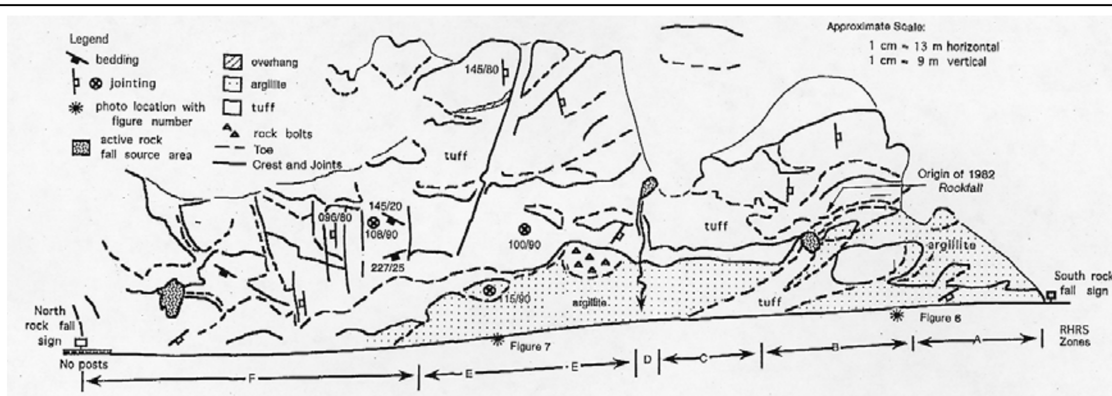


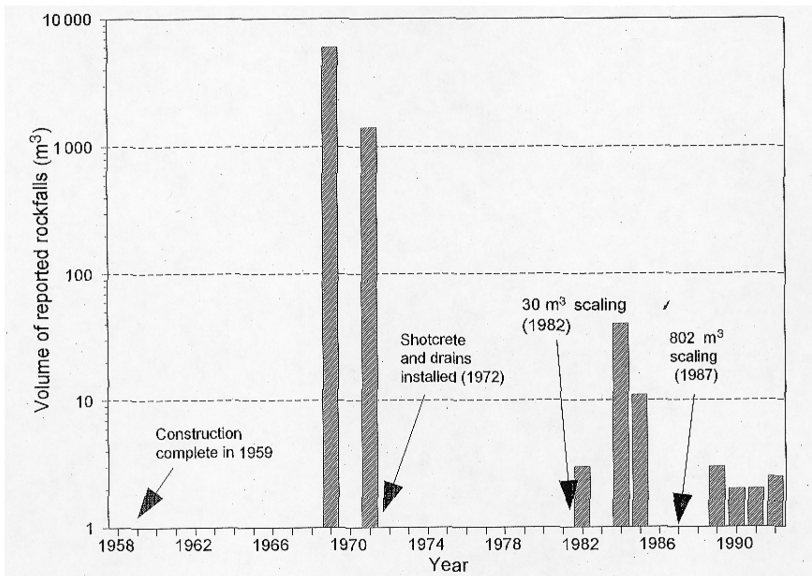
Figure 18. Geology of Argillite Cut (after Bunce et al. 1997).

On February 13, 1969, a rockfall of 6,000 m^3 closed the highway; on August 25, 1976, a rockfall of 1,500 m^3 closed the highway for two days and also caused the derailment of a BC Rail train; on January 16, 1982, when heavy snowfalls brought traffic on the road to a halt, a single large block fell from one of the cliffs, hit a stopped car, and killed one person and badly injured another.

In 1972 one of the most notorious cuts through in the Brunswick Point area was stabilized by the application of a blanket of wire mesh and shotcrete 5 to 10 cm thick. Effective scaling of this, and other meta-argillite cuts, has proven to be extremely difficult.

The hazard and risk associated with rockfalls in the Argillite Cut between 1958, when the road was opened, and 1992 has been studied in detailed by Bunce et al (1997). Figure 19 shows the annual volumes of recorded rockfalls and number of recorded rockfalls per year.

Bunce et al (1997) calculated the probability of an accident and the risk of death in the Argillite Cut for different scenarios: 1) a moving vehicle hitting a fallen rock and a falling rock; 2) a falling rock on a stationary vehicle; and 3) a falling rock on a moving vehicle.



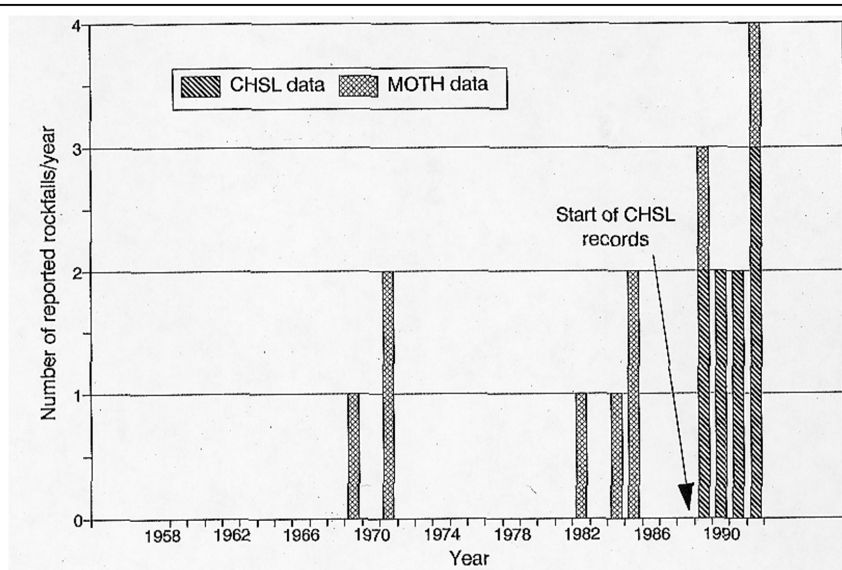


Figure 19.
Upper : Annual volumes of recorded rockfalls at the Argillite Cut.
Lower: Number of recorded rockfalls per year at the Argillite Cut.
(after Bunce et al. 1997).

With regard to the 1982 rockfall, the rock block seemed to have fallen from a point 40 m above the road level and above the highway cut. A fir tree with its roots in a crack between the intact face and the rock that fell, appeared to have toppled under the weight of heavy snow that was falling that morning. The tree pried two blocks loose. Both fell onto a bench below, and one slid off crashing onto the car. The other block was later pushed off the bench by highway maintenance personnel. The blocks would have been ready to fall for a long time, and critical conditions just happened to arise that particular morning. The point from where the blocks fell is a natural rock face covered with clearly defined glacial striae. The rockfall was the first from this particular segment of rock slope in the time since deglaciation.

Hungr and Evans (1988) have analyzed the trajectory of the rockfall (Figure 20). The analysis uses impact parameters typical of small fragments. This is justified, not so much by the size of the block, but by the limited velocities developed in such a short path. A small initial drop is specified, to account for the velocity gained in toppling failure. As would be expected, the path is dominated by the bouncing mode and free flight. The simulation indicates that the block struck the car with a velocity of approximately 28 m/s (101 km/hr).

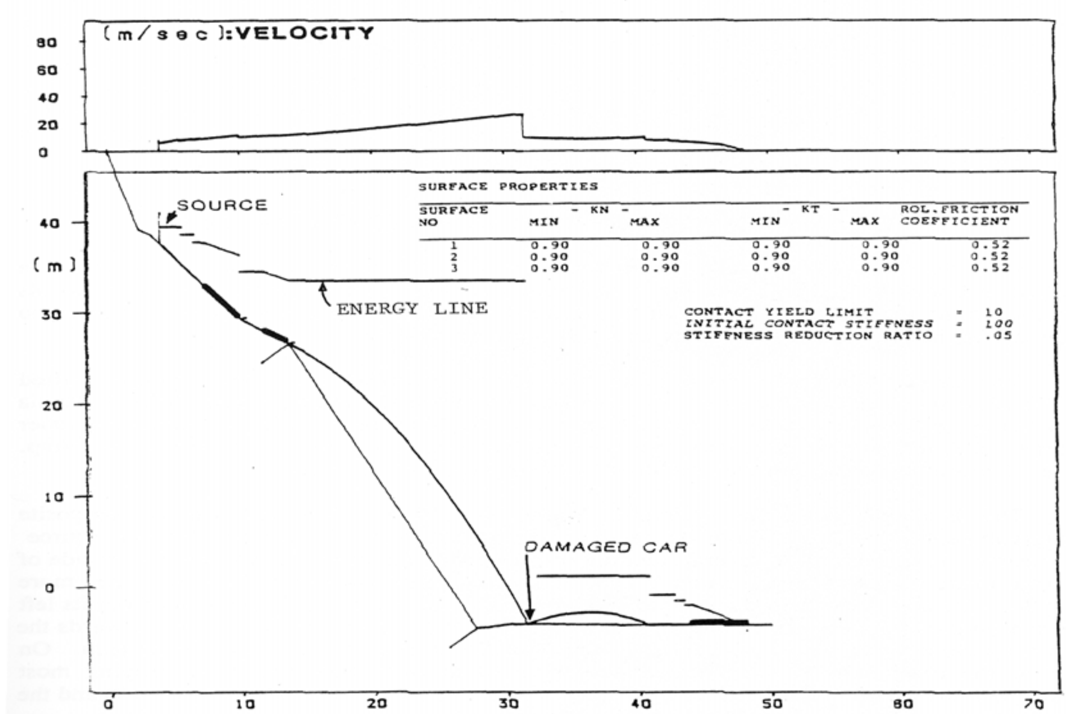


Figure 20. Dynamic analysis of the trajectory of the 1982 rockfall accident at the Argillite Cut(after Hungr and Evans 1988).

As a result of the 1982 rockfall, the driver of the car sued the BC Ministry of Transportation for damages. The first action was brought in 1985 in the BC Supreme Court, but was dismissed by the judge on the grounds that the decision by the BCMOT not to scale the slope above the cut was a policy decision for which they cannot be held liable in a court of law. The law states they can only be held liable for operational functions if negligence is established. The policy decision not to scale the loose blocks was said to involve "ordering of priorities" based on province-wide allocation of limited resources.

The decision was appealed to the BC Court of Appeal in 1986, but was dismissed by all three appeal judges. They said that the danger of the rock becoming dislodged was not apparent from the highway, and therefore the BCMOT personnel responsible for inspection were not negligent. Finally, however, on appeal to the Supreme Court of Canada, a retrial was ordered on the grounds that the BCMOT personnel failed to meet the standard of care by not conducting a climbing inspection. The Court awarded more than $1 million to the plaintiff in November 1991.

16.2 Porteau Bluffs

For a half of kilometer distance north of Porteau Cove, the Highway 99 and BC Rail have undercut a quartz diorite cliff (the Porteau Bluffs). The cliff has widely spaced (1 - 5 m) surface-parallel joints that dip approximately 50° to the west (towards the south) and "daylight" in the excavated railway and highway cut. Blasting during construction probably opened several incipient joints in the weakly foliated, but otherwise massive, rock mass (Figures 21 and 22). The fact that rock is internally stressed is inferred by a set of blasting fractures along the bottom of the Porteau Bluff. These fractures are roughly perpendicular to the weak foliation and parallel to the “sheet” joints.

The rock slides are usually triggered by repeated freeze-thaw cycles during winter months, with sliding occurring on pre-existing planar surfaces. The wide spacing of the joints adds to the severity of the slides, because large rock blocks are involved.

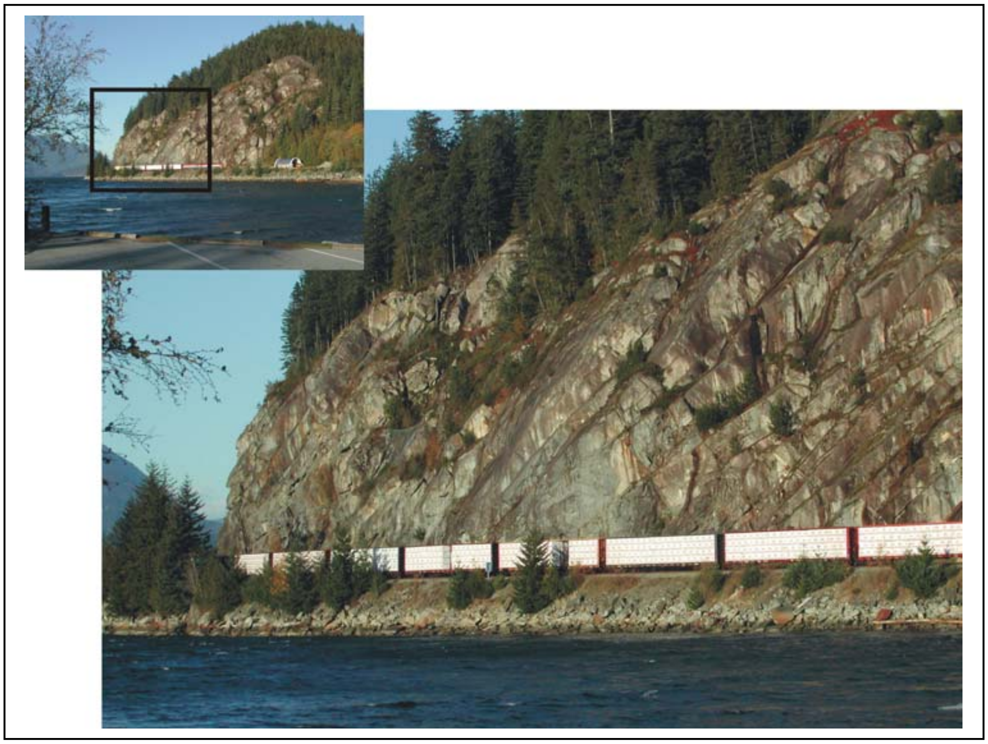


Figure 21. View of the sheeted structure in weakly foliated quartz diorite along Highway 99 at Porteau Bluffs. Note that there are two sets of joint sets, both roughly parallel to the surface. (photos by R. Couture).

On November 26, 1964, several thousand cubic metres of rock slid from the Porteau Bluffs onto Highway 99 (Figure 23). On this occasion both the highway and the railway were blocked. On February 9, 1969, a slab of rock landed on a car moving along the highway, killing three people; on February 17 and March 4, 1969, other rock slides were triggered due to repeated freeze-thaw cycles. On July 25, 1970, a house-sized block landed on the highway.

Rock bolts, scaling, and drainage have since improved the stability of the slope. During the extremely variable and wet winter of 1981 and 1982 individual blocks again came loose near the toe of the highway cut. The most recent rock slide fatality here occurred in the spring of 1991.

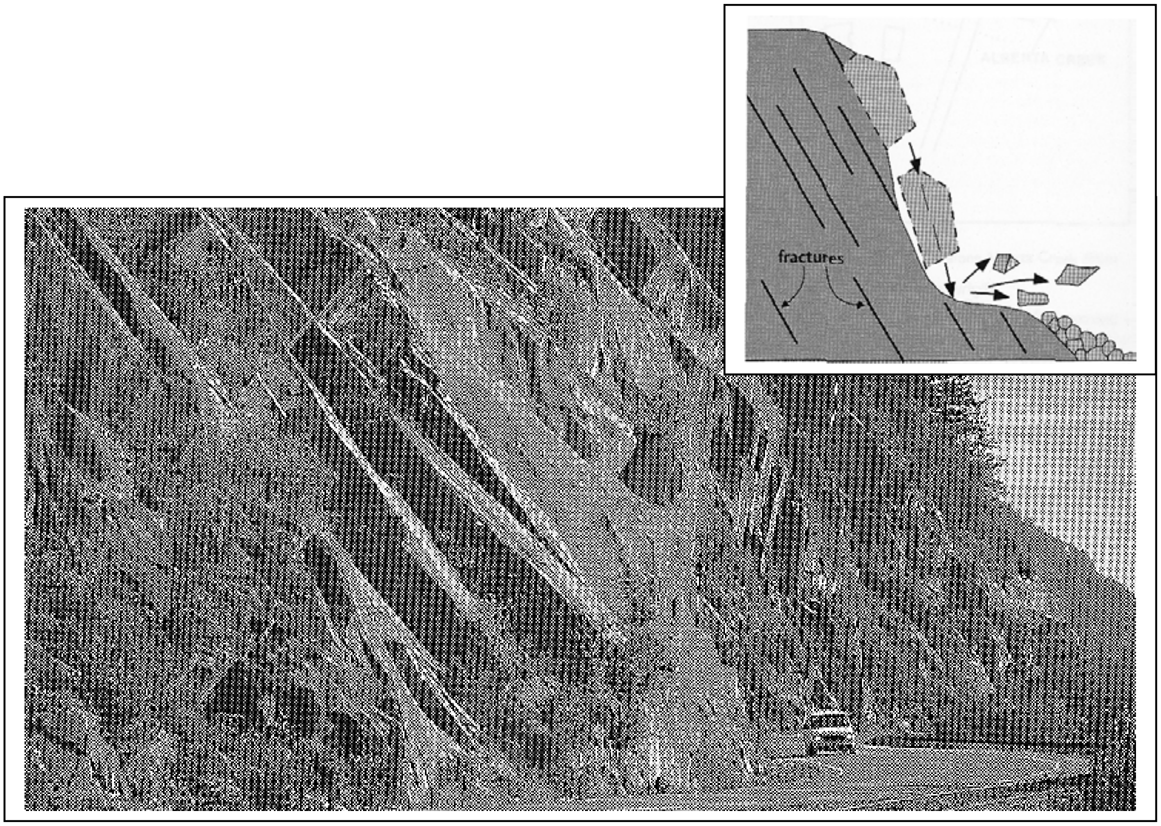
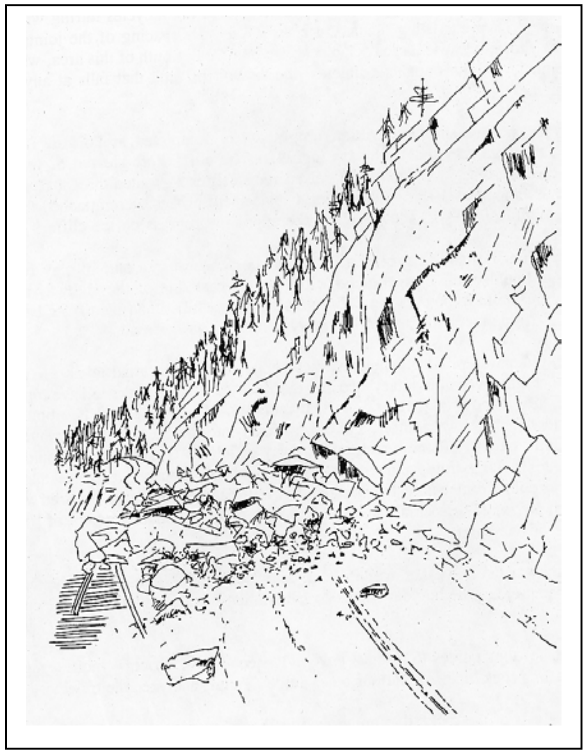


Figure 22. Fractures in bedrock along Highway 99 at Porteau Bluffs. The rock slope was undercut during construction of the BC Rail and Highway 99 in the 1950s. (after Clague and Turner 2003).

A major scaling and stabilization program was completed at Porteau Bluffs by the BC Ministry of Transportation in 1991. The cliffs were cleared of vegetation and thoroughly scaled. Some 3,000 m of galvanized steel resin grouted threadbar anchors were installed, some up to 10 m in length. Permanent displacement prisms were attached for long term monitoring (see also figures from Hungr and Skermer (1998) enclosed in Appendix 7).

The Porteau Bluffs is such a classic case of “daylighted” fractures, that Hoek and Bray (1981) used a picture of this area for the front cover of their text book, *Rock Slope Engineering.*

Figure 23. The 1964 rockfall at Porteau Bluffs (drawing by N. Skermer, Hungr and Skermer 1998)



17. FURRY CREEK – DEBRIS FLOOD

(after Eisbacher 1983)

Furry Creek, named after fur trapper Oliver Furry, is incised into a relic fan delta which for years has been mined for aggregate and therefore has almost disappeared along Highway 99. Deposits farther upstream provide a steady source of debris to the channel of the creek. During intense rainstorms, such as those of the winter of 1982, pulses of blocky-bouldery debris use to threatened to the low Highway 99 bridge crossing Furry Creek. The original bridge has been replaced. The new bridge has been provided with more clearance.

18. BRITANNIA CREEK – JANE CAMP ROCK SLIDE

(after Clague and Turner 2003; Evans 2000; Hungr and Skermer 1998; Eisbacher 1983)

Britannia Creek is 8.5 km long with a drainage area of 28.5 km^2 and creek gradients between 3° to 11°. In 1905, in the upper portion of this watershed, Britannia Mining and Smelting Co Ltd began its mining operations. Over its active life from 1905 to 1974, the Britannia Mine produced in excess of one billion pounds (454 million tonnes) of copper as well as lead, zinc, gold and silver. The ore bodies extended along the 3 km long northwest-trending, and steeply southwest-dipping, Britannia shear zone composed mainly of volcaniclastics of the lower Cretaceous Gambier Group rock. The mine is presently the site of the BC Mining Museum.

Among other things, the exploitation of ore has resulted in acid rock drainage, in which rainwater and snowmelt react with pyrite and other sulphide minerals. The transported metals in the surface and groundwater reach levels that are toxic to aquatic life. The solution, adopted by the BC Government has been to treat the runoff from the mine operations by addition of lime.

The original mining camp, Jane Camp, was established at elevation 1,000 m asl on a bench on the south side of the Britannia Creek valley within a cirque-like bowl on the northern side on the Britannia Mountain. In the early days of the mining, although some of the mine staff was housed on the fan at the mouth of Britannia Creek on Howe Sound, camps were also scattered throughout the upland basin of the creek. An aerial tramline was used to connect the upper watershed with the beach community. During initial mine exploration and development activities, most of the timber was removed from the Britannia Creek watershed, and logs and debris from unstable embankments clogged the channel at narrow passages.

Just after midnight on March 22, 1915, a landslide of rock, mud, and snow suddenly overwhelmed Jane Camp. The landslide smashed into a cluster of closely spaced mine buildings demolishing the mine office, cook house and dining room, store, rock crusher, candle house and tramway terminus, together with six houses and a large bunkhouse. The camp was buried with up to 15 m of debris. With 56 fatalities, the Jane Camp rock slide is the second most destructive landslide in Canadian history (after the Frank Slide of

1903). Unfortunately, very few details exist concerning the technical aspects of the disaster. Even the site of the rock slide source no longer exists, having been removed by subsequent open pit mining.

An anonymous composite photograph, kept in the BC Mining Museum, only shows a hint of the source. It appears to be 150 m above the camp, on the southeast side of the large niche surrounding the camp bench. The detachment mechanism is unknown, but the sheared rock has a schistosity dipping steeply to the southwest (into the mountain), creating conditions favorable for toppling on the northeast facing slopes. Tunneling may have contributed to a progressive deterioration of the bedrock ridge. A near-vertical crack on the ridge crest above Jane Camp was observed, photographed, and inspected by company geologists two days prior to failure (Ramsay 1967), but the danger was not recognized.

Evans (2000) has reconstructed the landslide from: historical photographs taken before and after the event, from Geological Survey Map 199A (James 1929) for which the topography was surveyed in 1918 and 1919; and from contemporary newspaper accounts.

The initial rock slide path appears to have been not more than 50 m wide and very steep. The slide entered a gully and ran up the opposite wall of the gully, then redescended towards the camp on a slope of less than 30°, incorporating talus and rock waste in its path. The slide debris then traveled a distance of about 1.5 km down the creek to Jane Camp. On reaching the camp, the slide widened to over 100 m, destroying most buildings on the bench. The slide volume at the camp is estimated to have been about 50,000 m^3 (Ramsay 1967). The remainder of the slide debris continued to flow down Jane Creek tearing a great rut 15 m deep to Britannia Creek. If it is assumed that some 50,000 m^3 travelled down Jane Creek to its confluence with Britannia Creek, then a total volume of 100,000 m^3 for the event is indicated. This should be taken as an upper limit for the volume of the event which appears to have consisted of about half surficial deposits and half rock. The landslide also incorporated a significant volume of snow which was estimated to be about 1.3 m deep at the site at the time.

As cited in Evans (2000), a newspaper account describes the post-slide scene at Jane Camp scene as

> "*a great pile of mud and snow - or rather two piles, for the avalanche resembled the work of a great plow, which had furrowed through the camp throwing up, on each side a great pile of boulders, mud and broken timber, snow and ice"*

These features may have been levees formed when the flow changed direction 90° to the west as it turned to follow Jane Creek after damaging the camp. Although the landslide contained large rock blocks, photographs of the debris also indicate that it contained a significant volume of finer grained material, referred to as "mud" by eyewitnesses. The mud was probably incorporated into the slide from the slope immediately above the camp and the valley floor which was described as being a little marshy. The mud was quite fluid as indicated by the fact that the interior of one of the bunkhouses was plugged with mud, resulting in four of the deaths.

The mobility of the rock slide appears excessive, given its moderate magnitude and coarse dry material. It may have been mobilized by snow accumulated in the gully leading to the camp. In the *Annual Report of the Minister of Mines for the Year 1915* the event is described as a "disastrous snowslide". Snow was certainly incorporated into the moving mass of rock and mud, and may have contributed to the mobility of the landslide, but it was not the main constituent of the slide mass (Evans 2000).

In the 1920s, the mining company developed another upper watershed town site below Jane Camp. Although this town site only lasted a few years, it is disturbing to note that a large debris avalanche swept over the site in 1990, knocking out the abandoned basement walls of what would have been several miners' cottages.

The mountainside on the west side of the Jane Camp bench, opposite the source of the 1915 rock slide is traversed by a series of large scarps and open cracks, suggesting displacements of over 10 m. These displacements are likely partially due to subsidence caused by underground ore drawing operations approximately 50 years ago. Given the steepness of the slopes below the disturbed area, however, another major rock slide is a possibility. The disturbed area is presently being monitored by means of permanent survey prisms, observed from a fixed instrument base in what was Jane Camp.

19. STOP 8
BRITANNIA CREEK – MULTI-HAZARDS

(after Clague and Turner 2003; Evans 2000; Hungr and Skermer 1998; Eisbacher 1983)

After the rock slide disaster of 1915, a new town site, Britannia Beach, was established on the fan at the mouth of Britannia Creek. It too had its problems.

A sudden outburst debris flood occurred on 28 October 1921, and struck Britannia Beach. A wall of water, reported to be 20 m high, swept through the village and more than 50 of the 110 houses in the community were destroyed either directly by the flood or by being swept out to sea (Figure 24 and Figure 13 from Hungr and Skermer 1998 in Appendix 8). Two swaths of destruction were cut by the floodwaters as it swept through the community leaving an island of dislodged but not destroyed houses in between. The narrower northern swath followed the immediate pre-flood stream course and the wider southern swath swept directly through a densely settled part of the settlement adjacent to the department store. Thirty-five families, a total of 100 people, were made homeless by the disaster. The debris flood killed 37 people.

The debris flood occurred after 6 days of heavy rain culminating in a cloudburst that yielded 146 mm in the 24-hour period immediately prior to the flood. Conditions were made worse because "a warm Chinook wind was blowing, which melted the snow in the mountains, adding their quota of water to the already swollen stream." (Coroner's inquest *in* Hungr and Skermer 1998). At first it was believed to be the result of the collapse of a natural dam of timber and soil debris that had slid from the banks of the creek creating a landslide dam. Later at the inquest civil engineers testified that, rather than a natural dam, the cause lay in the collapse of a culverted fill that carried the mine's railway across the creek. The 2.5 m wooden culvert became plugged with debris, ponding 60,000 m^3 of water before it failed. The coroner's inquest found the mining company criminally negligent and declared that "*it was criminal neglect on the part of the Britannia Mining and Smelting Co. Ltd…for deliberately allowing the blocking of…Britannia Creek causing a menace to persons living at Britannia Beach.*". Further details are given in Skermer and Russell (1988) (Appendix 8).

The next incident in the area occurred in 1955 at Woodfibre, 6 km to the northwest of Britannia Beach on the west shore of Howe Sound. A submarine landslide, apparently triggered by an extremely low tide, damaged a dock and warehouse facilities (Terzaghi 1956 and Prior et al. 1981b cited in Clague and Turner 2003).

In 1957, a submarine landslide occurred on the edge of the Britannia Creek fan and removed a portion of the newly constructed BC Rail embankment. The slide left the rails hanging over a 150 m wide chasm.

The latest acts in the Britannia Creek drama were in 1990 and 1991. The first was a "controlled flood" in 1990 when an old wooden dam in the upper portion of the watershed was purposely breached for safety reasons. The resulting, but unplanned flood swept a large volume of logs and boulders down the channel and into Howe Sound. Fortunately, the debris remained in the creek channel and little damage occurred. An interesting video recording of this event was taken from a helicopter, and it is available for viewing through the BC Ministry of Water Land and Air Protection.

A completely uncontrolled natural event occurred a year later, in August 1991, when an unusually high summer rainfall struck the southwestern BC. The resulting water flood yielded large quantities of sand, gravel, cobble and boulder debris and a large portion of the fan was overrun. Highway 99 was over topped by debris, and the elevated BC Rail embankment then acted as a dyke, with the result that the fan was flooded with up to a metre of water. Sand and silt settled out over the fan covering the residential yards, gardens and services areas and the highway.

The events in the environs of Britannia Creek indicate the disaster potential of resource development and residential development of a steep mountain Coast Mountain watershed, where facilities are built in close proximity to steep unstable slopes and on fans at the mouths of steep creeks. Some of the disasters may have been avoided or reduced by careful engineering design and a pre-development hazard assessment. The disasters were the result of combined geologic and climatic conditions and human activities, and highlight the difficulty in isolating the role of “natural” causes in some so-called natural disasters.

Figure 24. The mining community of Britannia Beach before and after the catastrophic flood of October 1921 (courtesy of BC Mining Museum). Thirty-seven people were killed and about half the 110 houses in the town were destroyed by the flood (Source: http://sts.gsc.nrcan.gc.ca/geoscape/vancouver/sea.asp).

20. ACKNOWLEDGEMENTS

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The photographs in Figures 8, 10, 11, 12, 13 and 14 (right) were taken from http://www.mala.bc.ca/~earles/howesound/. The photos were provided to the web site by Lee Price. The photographs were taken by a number of individuals, but almost all for the BC Ministry of Transportation.

BC Ministry of Transportation has reviewed a draft of this document and has approved its publication by the Geological Survey of Canada.

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Appendix 1

Design and Construction of the Upper Mackay Creek Debris Basin in North Vancouver District

by

D.N. Murray, M.V. Currie, N.A. Skermer, and B.K. Henry

in

Proceedings, Canadian Water Resources Association, BC Chapter, Vancouver, BC, 1998: 225-230.

Design and Construction of the Upper Mackay Creek Debris Basin in North Vancouver District

David N. Murray[1], Mike V. Currie[1], Nigel A. Skermer[2], and Bill K. Henry[3]

Abstract

This paper describes key aspects of the design and construction of a 13 000-m³ debris basin on Upper Mackay Creek, which is on the south flank of Grouse Mountain in the District of North Vancouver. On November 23, 1995, without warning, a debris flow occurred on Upper Mackay Creek and impacted a downstream residential neighbourhood. After the debris flow event, emergency channel restoration work was undertaken and a comprehensive mitigation strategy was developed. The key mitigative measure was the construction of a debris basin immediately upstream from the residential area. Construction of the basin commenced in summer 1996 and was completed in fall 1997.

Résumé

Cet article décrit les aspects principaux de la conception et de l'aménagement d'un bassin de débris de 13 000 m³ dans le tronçon supérieur du ruisseau Mackay, située sur le flanc sud de Grouse Mountain dans le district de North Vancouver. Le 23 novembre 1995, sans signes préalables, un écoulement de débris s'est produit dans le tronçon supérieur du ruisseau Mackay, perturbant un quartier résidentiel en aval. Après l'occurrence de l'écoulement de débris, des réparations d'urgence ont été entreprises dans le canal et une stratégie détaillée d'atténuation des dommages fut mise en oeuvre. La mesure d'atténuation principale a été l'aménagement d'un bassin de débris immédiatement en amont de la zone résidentielle. L'aménagement du bassin a débuté pendant l'été 1996 et fut complété à l'automne 1997.

Introduction

Background

A debris flow is a type of rapidly moving channelized landslide. This flood-related event occurs on steep mountain creeks and includes both hydrological and geological elements. On November 23, 1995, a debris flow of about 7000 m³ hurtled down the East Branch of Upper Mackay Creek within the District of North Vancouver. The debris flow caused considerable damage to infrastructure and private property, including infilling of the creek channel and the blockage of a culvert at Ranger Avenue.

Public safety was paramount, therefore, extensive channel restoration work was undertaken in the weeks following the event. This included removal of debris flow material and armouring the channel with rock riprap. Heavy steel cable nets were placed across the creek, upstream of the developed area, as a temporary debris flow mitigation measure.

Extensive engineering was undertaken to determine the frequency and magnitude of debris flow. Terrain mapping identified surficial materials and bedrock, and determined key areas of instability that could trigger future debris flows. A comprehensive mitigation strategy was developed which included watershed actions, creek management measures, land-use planning, and construction of a debris basin immediately upstream of the residential area to contain future debris flows. Following adoption of this plan by the District, construction of the project commenced on a fast-tracked basis.

Mackay Creek is situated immediately below the Grouse Mountain ski area on the south flank of the North Shore Mountains within the District of North Vancouver. The creek winds its way through both park and residential lands within the District and City of North Vancouver and eventually discharges into Burrard Inlet (Figure 1).

Watershed Description

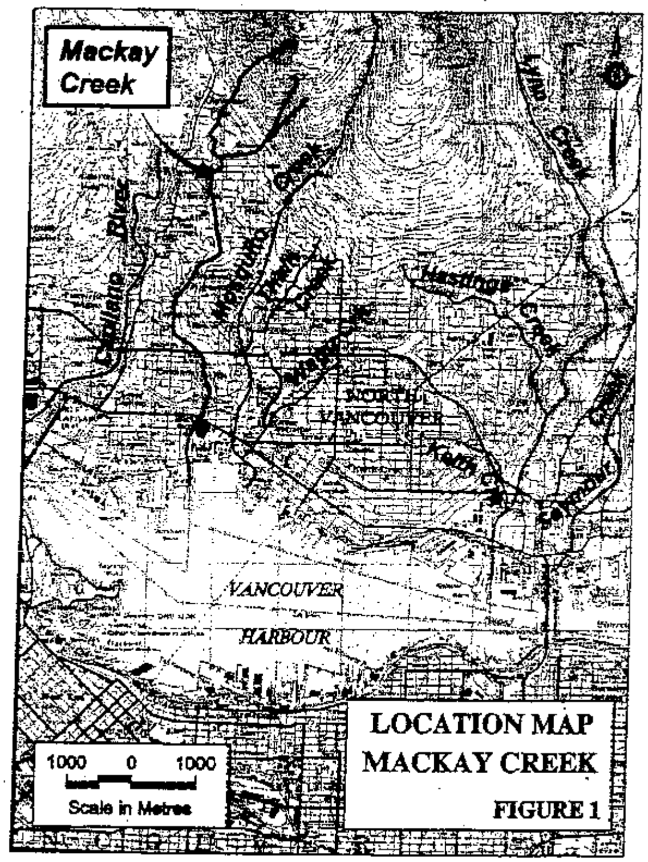
Total drainage area is 7.8 km² with 1.0 km² above the project site. The watershed headwaters are within the ski area at approximately 1015 m elevation. A BC Hydro transmission corridor (heavily used as a public pathway) crosses the watershed at elevation ~300 m near the confluence of the East and West Branches of Upper Mackay Creek. The channel gradient ranges from 35° near the headwaters to about 13° at the BC Hydro corridor. Lower Mackay Creek is considered one of the most productive watercourses on the North Shore from a fisheries perspective.

Design Event

The November 23, 1995 event ranked second in peak flow magnitude for the year of record. A debris flow is roughly a 10-year event; however, it is not always the case that flood frequency and debris flow frequency correspond. The 200-year return period peak flow was estimated at 4.7 m³ /s based on rainfall-runoff modeling of the upper watershed.

The objective of the debris basin is to reduce the public risk to the "moderately low" event class, which accepts that some property damage and minor flooding occurs during the design event. Following a risk analysis, the basin volume was set at 13,000 m³ which amounts to 65% of estimated available debris including landslide point sources (Kerr Wood Leidal 1996).

[1] Kerr Wood Leidal Associates Ltd., Consulting Engineers, 139 West 16th Street, North Vancouver, BC, Canada, V7M 1T3. [2] EBA Engineering Consultants Ltd., Suite 550, 1100 Melville Street, Vancouver, BC, Canada, V6E 4AG. [3] District of North Vancouver, 1370 Crown Street, North Vancouver, BC, Canada, V7L 4K1.



LOCATION MAP
MACKAY CREEK
FIGURE 1

Conceptual Design

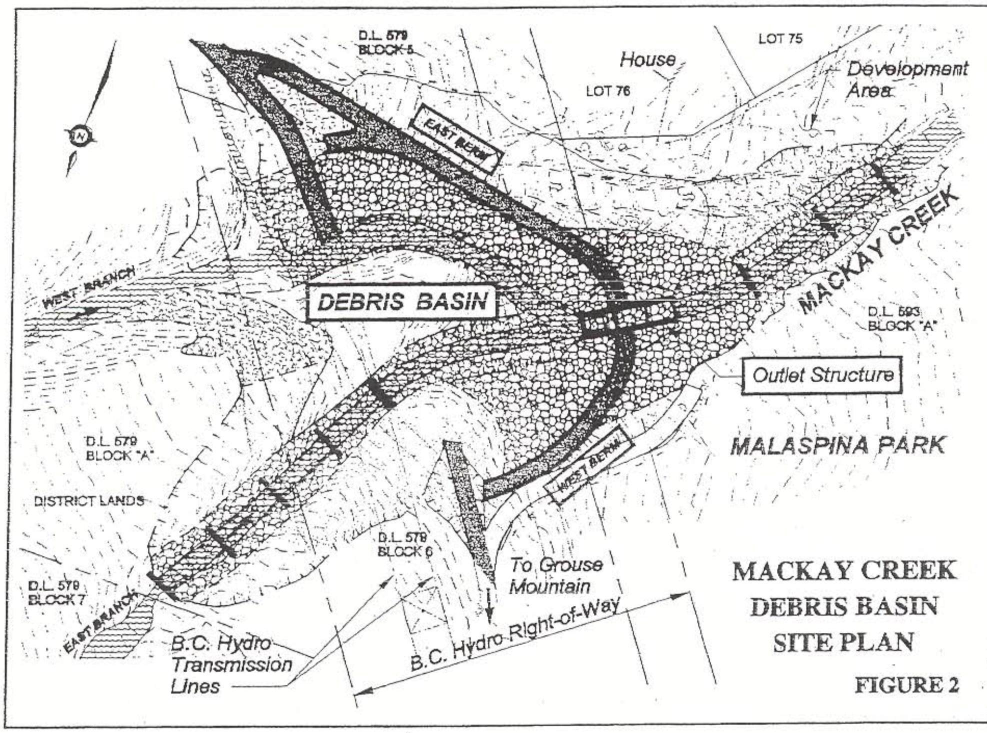
The basin site is located upstream of the residential area, on District lands within a BC Hydro right-of-way, at the confluence of the east and west creek branches (Figure 2).

The basin concept included a 12-m high "Austrian Style" reinforced concrete outlet structure as shown in Figures 3 and 4, with a structural steel grillage designed to withstand debris flow impact loading, while passing creek flows and retaining debris. The proposed outlet structure was then flanked by two 8 to 12-m high rock-armoured earthen berms which would connect the structure with the existing landscape to form a basin (Currie et. al. 1996). After reviewing existing debris mitigation structures along the Squamish highway, assessing of the proposed site with respect to cost reduction and material availability, and consulting with Austrian technical experts, key design objectives were identified:

- minimize the use of concrete
- maximize the use of native material
- facilitate passage of normal bedload
- facilitate emergency operation and maintenance
- minimize disturbance to vegetation and the surrounding landscape

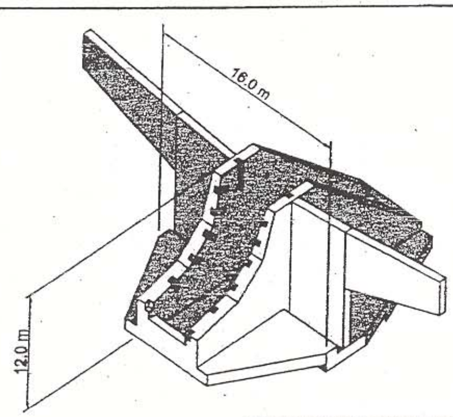
Minimizing the use of concrete would not only lower the project cost, but would also reduce the risk to the fisheries resource during construction, and improve aesthetic impacts. Construction of earthen berms would allow extensive use of native materials while reducing off-site hauling costs. The main fisheries issues which arose during the Water Act approval process were: possible disruption of bedload movement (needed to replenish downstream gravel beds), and the loss of riparian vegetation resulting from basin construction. Bedload passage concerns were addressed by designing the outlet structure grillage to allow passage of normal bedload movement. The loss of riparian vegetation and forested parkland were minimized by locating the basin as far north into the BC Hydro right-of-way as possible, thus reducing tree loss in Malaspina Park to the south.

Under the design concept, debris from either creek branch would enter the basin and fan out, thus energy would be dissipated and impact forces reduced. The



MACKAY CREEK DEBRIS BASIN SITE PLAN

FIGURE 2



OUTLET STRUCTURE

FIGURE 3

following design criteria were developed:

Storage Volume

- debris basin capacity of 13,000 m^3 of debris
- basin freeboard of 1 m (volume to 15,000 m^3)
- upper debris deposition surface of 10%

Creek Channel

- designed to pass the 200-year peak flow
- basin to contain both creek branches
- locate outlet to direct creek flows along existing
- downstream creek alignment

Containment Berms

- berm slopes > 2:1 outside 1.5:1 inside
- safety factor for sliding >2.0
- erosion protected interior slopes

Outlet Works

- factor of safety for sliding >1.5
- factor of safety for overturning >3.0
- impact loading equivalent to 3 times hydrostatic pressure equivalent to a 1.0 m f boulder at 3.0 m/s

After considerable input from environmental agencies and the public, the District directed that the detailed design be expedited to allow construction to start in summer 1996.

Detailed Design

Approach

The design team used a "Peer Review" design approach. Conceptual design objectives and criteria were developed into the detailed design specifications (Table1). The design optimized debris storage within tight site constraints. Basin geometry, berm configuration, and outlet structure details were integrated with a new creek alignment to produce an economical design that satisfied the design criteria. This required considerable engineering judgement because BC has no standards for this type of project.

Debris Basin Configuration and Geometry

Malaspina Park is to the west of the basin site, and the nearest residential area is to the south. An existing District watermain runs along the northern portion of the area, and two BC Hydro overhead transmission lines cross the site. Location of the outlet structure was optimized in the north-south direction thus maximizing basin volume and minimizing disturbance to the park. The steep channel gradient through the project area (18-25%) necessitated that berm elevations be as high as possible without overly encroaching on clearance requirements for overhead transmission lines. The gradient of the incoming West Branch was steepened

Table 1. Design data.

General	
Basin Area	5000 m^2
Access Ramp Grades	East 20 %, West 25%
Watermain	70 m of 300 mm D.I.
Quantity of Rock Armour	4800 m^3
Creek Channel	
Channel Width	4.0 m
Side Slopes	2:1 minimum
Gradients	18-40%
Channel Stabilizers	7
Outlet Structure	
Concrete Volume	670 m^3
Footprint	20 m x 16 m
Height at crest	12 m (4 stories)
Wall Thickness	750-1100 mm
Channel Width	3.5 m
Grillage Spacing	400-500 mm
Cross Member Size	200 mm x 600 mm
Containment Berms	
Crest Width	4.0 m
Fill Height	2-12 m
Exterior/ Interior Slope	2:1/ 1.5:1(locally steeper adjacent to outlet structure)
Rock Armour Size	900 mm minus
Grouted Riprap	1100 m^2

to 40% to allow for a relatively flat basin bottom at 10% in the north-south direction, and thus provide a deep enough basin to meet the volume requirement. To provide sufficient basin capacity, the 300-mm diameter watermain through the northern part of the basin was relocated.

Outlet Structure and Berms

The outlet structure was designed to be self-cleaning during minor flood events. This was achieved by designing the grillage spacing to allow small boulders to pass during flow up to about 0.5 m in depth (Figure 4); however, the grillage would block when struck by large boulders and/or log debris during a major event. The outlet structure and flanking containment berms were designed for impact loading. The approach taken was to apply an impact load equal to three times hydrostatic pressure, assuming full basin conditions. This was considered conservative but less severe than applying full boulder impact using the Hertz equation. This approach was economical and accounted for two practical considerations: that large timber in typical Coastal debris flows could soften the impact, and the structure could tolerate some damage without failure.

To avoid debris flow run-up and overflow, the frontal slopes were designed to be steep and faced with grouted angular rock. This technique was thought to be an improvement over the smooth concrete facing at flatter angles used on some of the earlier structures built in BC.

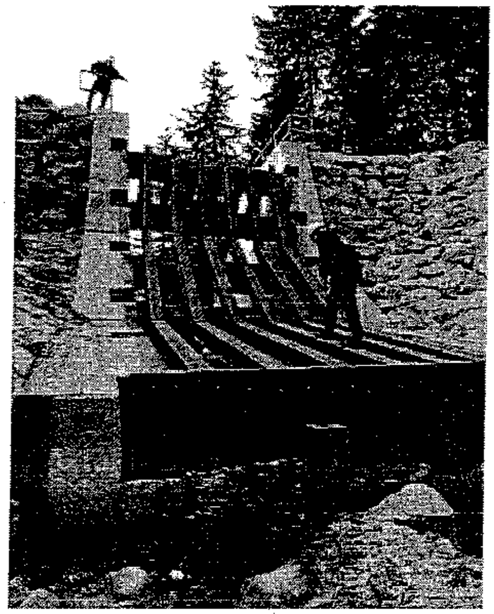


Figure 4. Steel grillage, looking south.

Containment berms were designed as free-draining embankments and no attempt was made to treat the basin as a water-retaining dam. No impermeable zones were incorporated into the earthen containment berms. The berm design is akin to a tailings dam with the addition of free-draining outlet works.

Creek Channel Realignment and Reconstruction

Confluence of both creek branches was relocated to an area immediately upstream of the outlet structure, requiring that both branches be realigned and rebuilt. Channels were designed to handle 200-year peak instantaneous flood flows and velocities. This required rock armouring and channel bottom stabilizers on steeper sections.

Maintenance Access

Heavy equipment access to the basin is required for both routine and emergency maintenance. The site configuration allowed for a permanent access ramp from the east along the existing BC Hydro service road. A high-level ramp was also designed for the west side to provide emergency access should the basin be filled significantly. A low-level west access road was also provided for access to the outlet structure area.

Environmental Approvals

The debris basin works required approval from BC Environment under Section 9 of the *Water Act* and authorization from Fisheries and Oceans Canada. Because the conceptual design process had involved extensive consultation with environmental agencies the approval process was somewhat streamlined — a critical asset given the project's "fast track" timeline.

To reduce the environmental impact of the project, substantial re-vegetation planting was incorporated. This included hydroseeding or fibrebonding of all disturbed areas and riparian planting, including live wattle staking, within pockets and benches on the basin slopes. A sizable area downstream of the basin was replanted after blowing a bark and compost mixture to provide organic content to the planting surface. In addition, a net positive habitat balance was achieved by constructing an off-channel fish habitat on Lower Mackay Creek.

Construction

The debris basin design was completed, approved, and tendered in early July 1996. Because this project was not included in the District budget, several other District capital works had to be delayed to allow this project to proceed. After carefully reviewing the project for all possible savings, the project was awarded to GCL Contracting and Engineering Inc. of Langley, BC.

1996 Construction

Construction commenced in August 1996 with clearing and grubbing of the site and installation of the outlet structure. The site constraints allowed very little flexibility in scheduling. The outlet structure was on the critical path and required significant completion prior to commencing portions of the earthwork . Elaborate water and sediment control plans had to be integrated with the work schedule to divert creek flows back and forth from east to west ahead of the next project phase. The outlet works were completed by mid October 1996, but construction was affected by the wettest winter on record and environmental constraints. Work had to be suspended in November 1996; however, the project was sufficiently complete to achieve a reasonable level of debris flow protection over the winter. The winter decommissioning of the site required close consultation with environmental personnel to satisfy environmental protection concerns. A detailed project sequence was developed that included proposed environmental mitigation measures for each remaining project task. The site was decommissioned by early December 1996.

1997 Construction

The 1997 construction proceeded according to schedule, and the debris basin was complete by September 30, 1997 (Figure 5). Construction began in early August; the east and west containment berms were completed first. Next, creek channels were finalized and finally the watermain was relocated. Riparian landscaping began immediately after final basin grading and was completed in early November.

Problems and Solutions

Construction of the debris basin had its share of difficulties. Water control was a constant concern and a co-operative approach was used to schedule certain work for dry periods. Wet weather seriously hampered fill placement on several occasions. To aid the contractor in berm construction, a portion of imported free-draining fill was trucked in during fall 1996.

Extreme care by a skilled equipment operator was required to complete the rock armour at the top of the containment berms adjacent to the structure. Special attention was given to grouting of approximately 1100 m^2 of rock riprap slope protection adjacent to the outlet works. Rock riprap adjacent to the structure was grouted using an in-line, slow-rate pump, which provided good flow control and protected the creek channel during construction.

Public access was maintained through most of the project; after the basin was complete, footbridges and a permanent trail were constructed through the basin to re-establish the trail link along the BC Hydro corridor. The perimeter of the basin was fenced to direct the public away from higher basin slopes and onto the trail system.

Project Cost

The capital cost was about $1.9 million for the debris basin and mitigation works. The cost of other mitigation measures to date are in the order of $200,000.

Conclusion

The debris basin is the centerpiece of a comprehensive strategy for debris flow mitigation at Upper Mackay Creek. The basin protects the downstream residential area, leaving only a moderately low level of residual risk. The project required innovative approaches to engineering, environmental protection, and aesthetics. Immediate concern for public safety was the driving factor of this project which resulted in the "fast track" design and construction of the basin in less than two years.

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Figure 5. Overall view of completed debris basin (looking south).

Appendix 2

Debris Torrent Control Facilities (Vancouver, BC, Canada)

by

J. Price

in

IABSE Periodica 3/1986, IABSE Structure C-38/86, 1986: 60-61.

and

General arrangement of Charles Creek debris basin

from

B.C. Ministry of Transportation

CHARLES CREEK
HARVEY CREEK
MAGNESIA CREEK

4. Debris Torrent Control Facilities (Vancouver, BC, Canada)

Owner:	*Ministry of Transportation and Highways, Province of British Columbia*
Consulting Engineers:	*Thurber Consultants Ker, Priestman & Assoc. Ltd.*
Construction Period:	*1984 to 1987*

General

The British Columbia Railway mainline and Highway 99 follow the coastline of Howe Sound north from Vancouver. The steep mountain slopes above these corridors experience a mean annual runoff in excess of 3000 mm. Since the B.C.R. was opened in 1956, six bridges and a number of residences have been destroyed by natural phenomena known as debris torrents. In the vicinity of Howe Sound a debris torrent is a rapid mass movement of water-charged inorganic and organic material down steep, confined creek channels. The material in a torrent ranges from gravel to very boulders entrained with forest debris from mulch to intact trees. The torrent can be initiated during periods of high runoff by a small slide that temporarily dams a creek. When the dam breaks the resulting flow is very erosive and the torrent grows by mining substantial volumes of material from the channel bed. The torrent moves at about 7 to 10 m/s in teardrop-shapes pulses with a steep-fronted accumulation of the larger fragments at the leading edge. The after-flow behind the accumulation is both finer and more dilute. Yields of 20,000 m^3 have been recorded in the most recent events on these creeks.

Control Facilities

In 1983 design work commenced on measures to mitigate the effects of the torrents. Design discharges are typically in the order of 350 to 500 m^3/s with flow depths of about 4.5 m in lined channels with truncated V shapes.

For creeks without housing or other development on their banks it was only necessary to provide new bridges with properly proportioned openings which safety permit passage of the torrent flows. A 3-m air draft is provided above the calculated flow depth to prevent blockage at the upstream edge of bridge openings.

For three high hazard creeks with development on the deposition fan, barriers have been constructed above Highway 99. The function of the barriers is to impound a design debris flow and to decant the accompanying water flow. Debris storage requirements ranged from 33,000 to 60,000 m^3 depending on the creek. The capital cost of a barrier divided by the design storage capacity varies from $ 30 to $ 65/m^3 (CDN.) depending on the amount stored and the difficulty of the site. The barriers are typically 12 to 15 m high to the crest of the spillway with another 8 or 9 m provided for run-up freeboard. Permanent access roads were constructed into all basins to facilitate their cleanout.

At one location, a barrier was not feasible and a 800-m long channel with an average grade of 31 % was designed to convey the torrent through the residential community to the sea. The 5.6 m by 13 m concrete channel cost approximately $ 3,500/m (CDN.) and the integral earthworks, secondary retaining walls, and eight

Fig. 1 Fill type debris barrier

bridge crossings increased the cost by a factor of two. The concrete in the channel invert area is a 60 MPa silica fume mix with a 200 mm wear allowance.

Barriers

Two types of barrier were developed. The simplest is a 15 to 25 meter deep hole excavated in bedrock with a decant structure at the outled. The grillage beams for the basin decant are supported by a central buttress and abutments post-tensioned into the rock. The 15 m high decant tapers from 20 m wide at the top to 6 m at the bottom to reduce the total hydrostatic sliding force acting on the buttress. The design case for the buttress was hydrodynamic impact of a wave of debris transiting a partially full basin at 10 m/s. The front of the decant is sloped to reduce the force of the impact and to generate a stabilizing vertical reaction at the toe of the buttress. A small concrete faced wing dam is provided on one side of the decant to provide the necessary run up freeboard to redirect the overtopping debris flow.

At the two other sites where rock was not available, sliding on the steep original ground governed the barrier design resulting in the selection of concrete-faced, zoned fill, structures. The material in the fill barriers was typically obtained by mining the creek above the barrier site to help form storage basin. Each fill barrier features a service spillway for the basin full situation and a decant structure to prevent significant accumulations of water behind the barrier when the basin is only partially full. To control seepage in the zoned fills, a network of relief wells was drilled prior to constructing each barrier and a shotcrete facing and apron was applied to the front of the barrier.

The most important design criteria for the barriers was that the new structures must not exacerbate conditions which prevailed prior to barrier construction. If the estimates of required storage were incorrect or if the barriers could not be emptied in a timely manner, the barriers had to be capable of withstanding repeated overtoppings without failing and thereby adding material to the debris aleady being carried by the torrent. In one case a 400-m long channel was built downstream of the barrier to conduct a flood flow of over 100 m^3 safely past three downstream bridges. The channel gradient is in excess of 20% and the formation of shock waves was a concern, so a rough bed was produced by setting 1000 mm diameter boulders in a steel fibre reinforced concrete bed.

With the basin full, a subsequent flow entering the storage basin would not necessarily spread out and decelerate on the plane of the previously stored debris. Material at the edges of the flow comes to rest and may form levies which have the ability to contain the flow. If the subsequent flow transits the basin without losing much energy, the shape of the barriers above the spillway will direct the overtopping flow into the creek channel below the barrier.

The decant structure which conveys normal (non-overtopping) flood flows is composed of two parts, the grillage beams and their supporting works, and the outlet conduit. The face of the decant is sloped to deflect the impact of the torrent's boulder front. The reinforced concrete grillage beams are proportioned to dissipate the kinetic energy of a 2000 mm diameter boulder by plastic hinging and compression of unreinforced rubber bearing pads. The beams must survive the boulder impact and continue to span under hydrostatic loads generated during basin infilling and barrier overtopping. The pressures on the beams can be equivalent to a head of water in excess of 30 m.

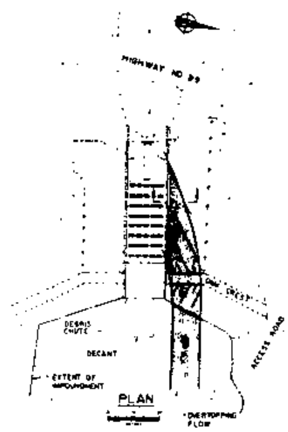


Fig. 2

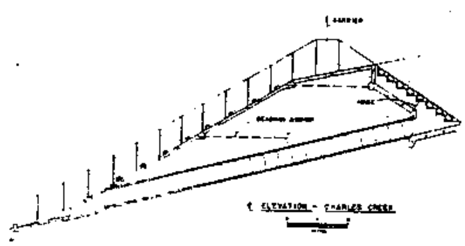
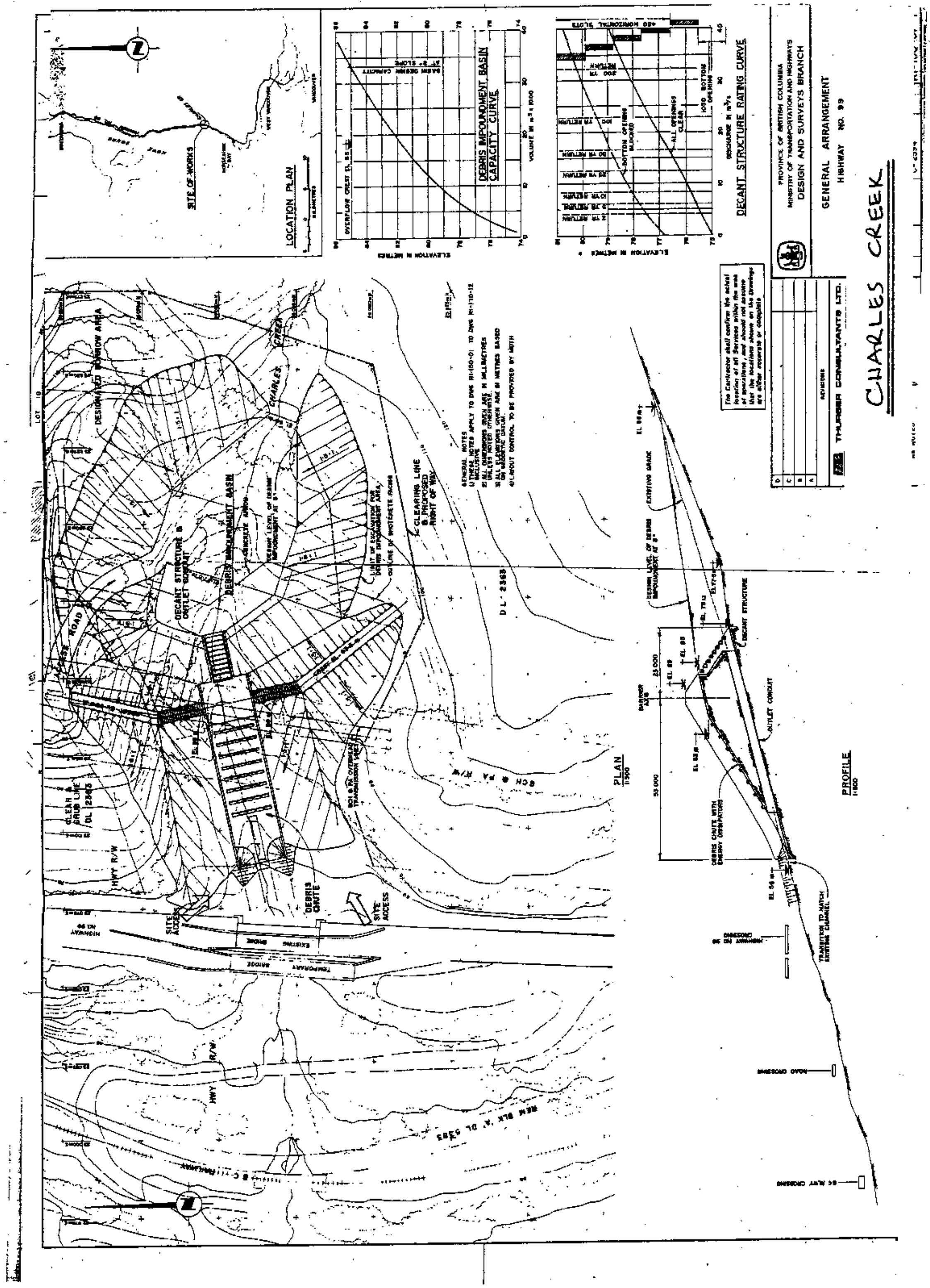


Fig. 3

The possibility of structural failure of the outlet conduit which passes through the fill barriers was unacceptable. The reinforced concrete box sections were designed to withstand the full weight of the column of soil supported by them with no arching and no side wall support.

The spillways constructed on the downstream faces of the fill barriers have slopes of approximately 60%. The tendency for sections of the spillways, when full of debris, to slide downhill is resisted by deadmen anchors with a combined capacity of over 6000 kN per spillway segment. The walls of the spillway are proportioned to withstand a 4-m deep redirected overtopping flow at it plunges into the spillway. The floor of the spillway is inclined and only receives glancing blows from the redirected overtopping flow. The floor is also proportioned to resist punching shears while holding the spillway walls apart.

(John Price)

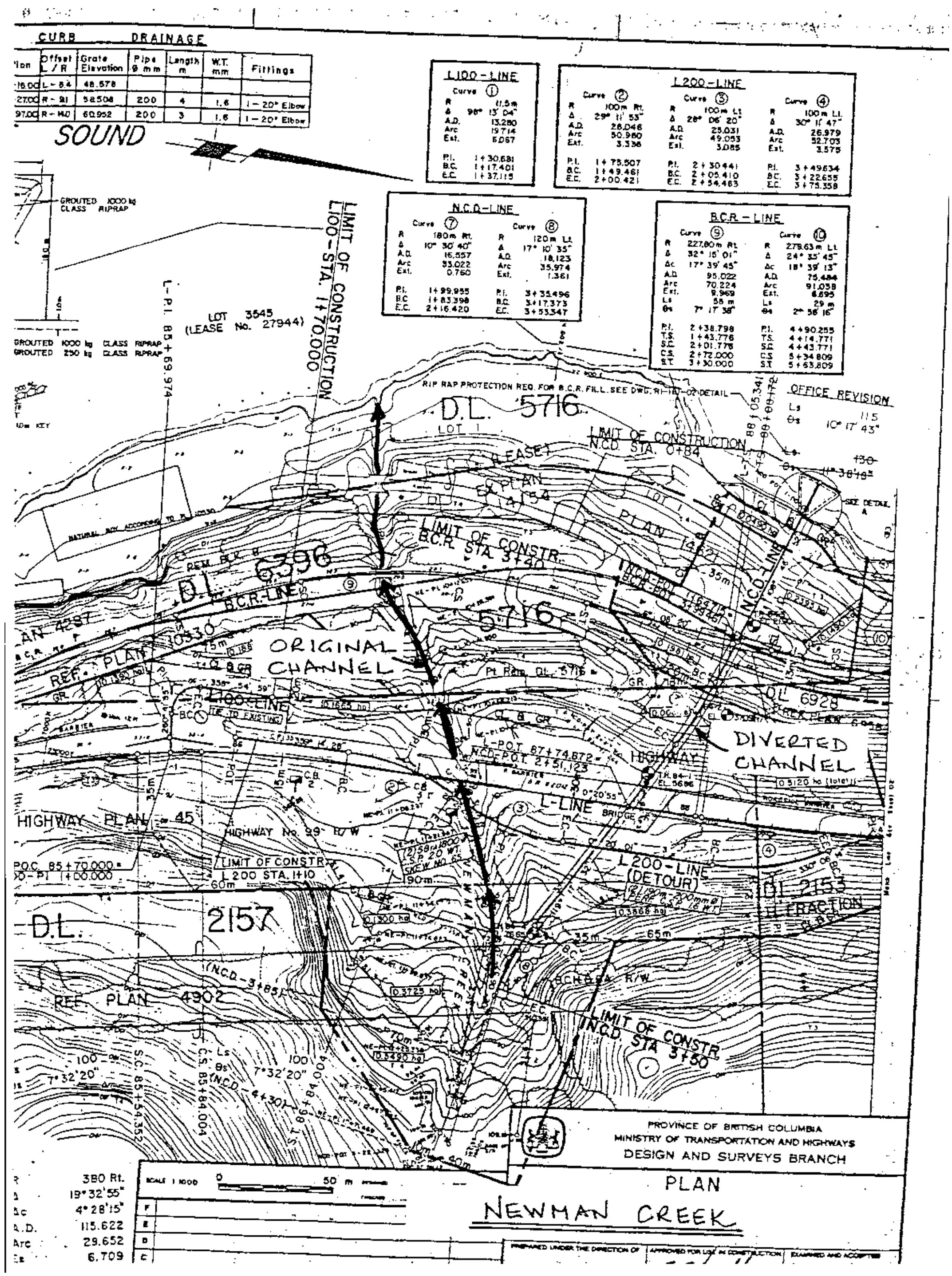

CHARLES CREEK
GENERAL ARRANGEMENT
HIGHWAY NO. 99
DESIGN AND SURVEYS BRANCH
LOCATION PLAN
DEBRIS IMPOUNDMENT BASIN CAPACITY CURVE
DECANT STRUCTURE RATING CURVE
PLAN
PROFILE
DEBRIS IMPOUNDMENT BASIN
DECANT STRUCTURE & OUTLET CONDUIT
DEBRIS CHUTE
SITE ACCESS
THURBER CONSULTANTS LTD.

Appendix 3

Plan of the diverted Newman Creek channel

from

BC Ministry of Transportation


CURB DRAINAGE
SOUND
L100-LINE
L200-LINE
N.C.D-LINE
B.C.R.-LINE
LIMIT OF CONSTRUCTION L100-STA. 1+70.000
LOT 3545 (LEASE No. 27944)
D.L. 5716
LIMIT OF CONSTRUCTION N.C.D. STA. 0+84
OFFICE REVISION
D.L. 6396
LIMIT OF CONSTR. B.C.R. STA. 3+40
ORIGINAL CHANNEL
DIVERTED CHANNEL
L-LINE
HIGHWAY
HIGHWAY PLAN 45
HIGHWAY No. 99 R/W
LIMIT OF CONSTR. L 200 STA. 1+10
L 200-LINE (DETOUR)
D.L. 2157
REF. PLAN 4902
D.L. 2153
LIMIT OF CONSTR. N.C.D. STA 3+50
NEWMAN CREEK
PROVINCE OF BRITISH COLUMBIA
MINISTRY OF TRANSPORTATION AND HIGHWAYS
DESIGN AND SURVEYS BRANCH
PLAN
NEWMAN CREEK

Appendix 4

Debris-torrent structures, Harvey & Magnesia Creek, BC

by

Thurber Consultants Ltd and Ker Priestman & Associates Ltd

in

Canadian Consulting Engineer, September/October 1986: 51-52.

and

Plans and drawings of the Harvey Creek mitigation

from

BC Ministry of Transportation

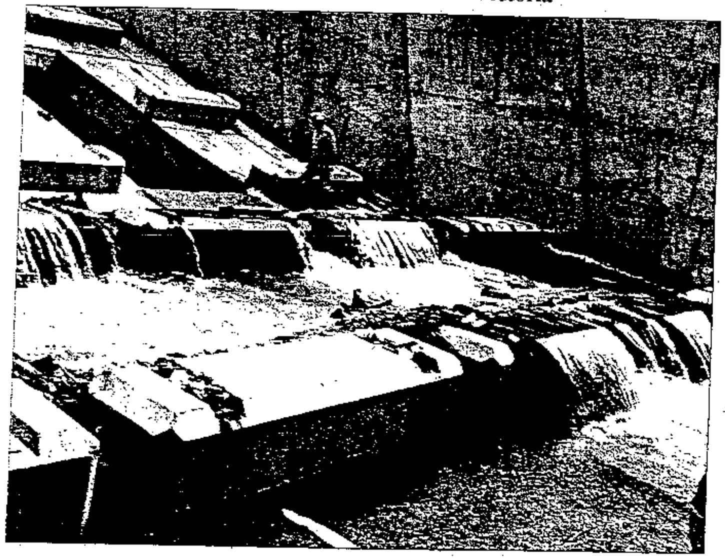
Award of Merit – Civil

Debris-torrent structures Harvey & Magnesia Creek, B.C.

Thurber Consultants Ltd./Ker Priestman & Associates Ltd. – Victoria

By the end of 1984, 43 debris-torrent events were documented in Western Canada; over half of these occurred between 1980 and 1984. These torrents, comprised of coarse bouldery material, fine-grained material, and forest debris, occur mainly in the Coast Mountains of British Columbia in regions having high annual precipitation intensity. Over 50 bridges and many buildings have been damaged or destroyed by these torrents. A conservative estimate of the structural and property damage they have caused in B.C. over the last 20 years exceeds $100 million. As well, debris torrents have resulted in 17 deaths.

B.C. Highway 99 follows the coastline of Howe Sound, north of Vancouver, along the foot of steep mountain slopes and crosses 26 creeks, most of which are subject to debris torrents. Four of these creeks, located at or near the Village of Lions Bay, are high-hazard creeks with return periods of between 10 and 50 years. Protective works on these creeks, i.e., large debris barriers and extensive channelization, have been completed or are under construction by the B.C. Ministry of Transportation and Highways and are unprecedented in North America. Other active creeks flowing through undeveloped areas along the highway are being dealt with by providing bridge openings large enough to pass the torrents.



Harvey Creek emergency spillway energy dissipators.

Design criteria

In 1982 the B.C. Ministry of Transportation and Highways awarded a contract to Thurber Consultants Ltd. to advise on the probable frequency, magnitude, velocity and duration of the future debris torrents and to prepare hazard-zone maps covering the creeks on Highway 99. The firm was subsequently retained by the ministry to design debris torrent facilities on four high hazard creeks. Ker, Priestman & Associates Ltd. were awarded a contract to assist in conceptual design and carry out detailed design of the facilities.

Current techniques for forecasting debris-torrent magnitudes are not as well-developed as for water-flood flows. The debris-torrent barriers had to be designed to withstand repeated overtoppings and to prevent the barriers' material or the stored debris from contributing to debris torrents. The emergency spillway capacity was designed to safely pass 200 percent of the peak-design debris-torrent flow and the 15-metre high structures were provided with nine metres of freeboard to protect against run-up during basin-full conditions. Vehicular access was provided to all barriers for removal of accumulated debris.

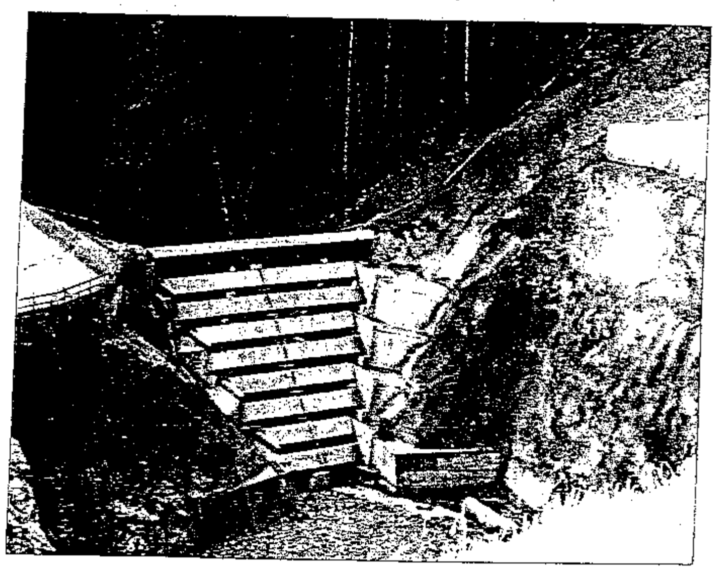
Harvey Creek

The Harvey Creek structure consists of an earth barrier across the channel with a storage basin excavated immediately upstream, to contain a design event of 75,000 m³. The design is unique in that there was little precedent for structures of this magnitude. Numerous concepts were considered but because of the difficulty of constructing a barrier on the steep slopes many designs were unsuitable, the main reason being their inability to resist sliding.

The material used for the concrete-faced, earth-fill structure was obtained by processing creek material from the upstream storage basin excavation. The barrier features an emergency spillway for the basin-full situation and a decant structure to permit passage of creek flood flows. The earth-fill section of the structure is zoned to control seepage and relief wells were installed at the toe. The height of the spillway above the original creek bed is 15 m.

The decant structure consists of large, reinforced concrete grillage beams and two large box-outlet conduits. The upstream face of the decant beams is sloped to deflect the impact of the torrent's boulder front. The concrete grillage beams are designed to dissipate the kinetic energy of a large boulder by plastic hinging. Because any failure is unacceptable, the special box-culvert outlets are designed to withstand the full weight of the column of soil supported by them with no arching and no sidewall support. The spillway on the downstream face of the structures has a slope of about 60 percent and can withstand a redirected overtopping flow. Deadman anchors are used to resist the tendency for the spillway sections to slide down these slopes.

Magnesia Creek nearing completion.



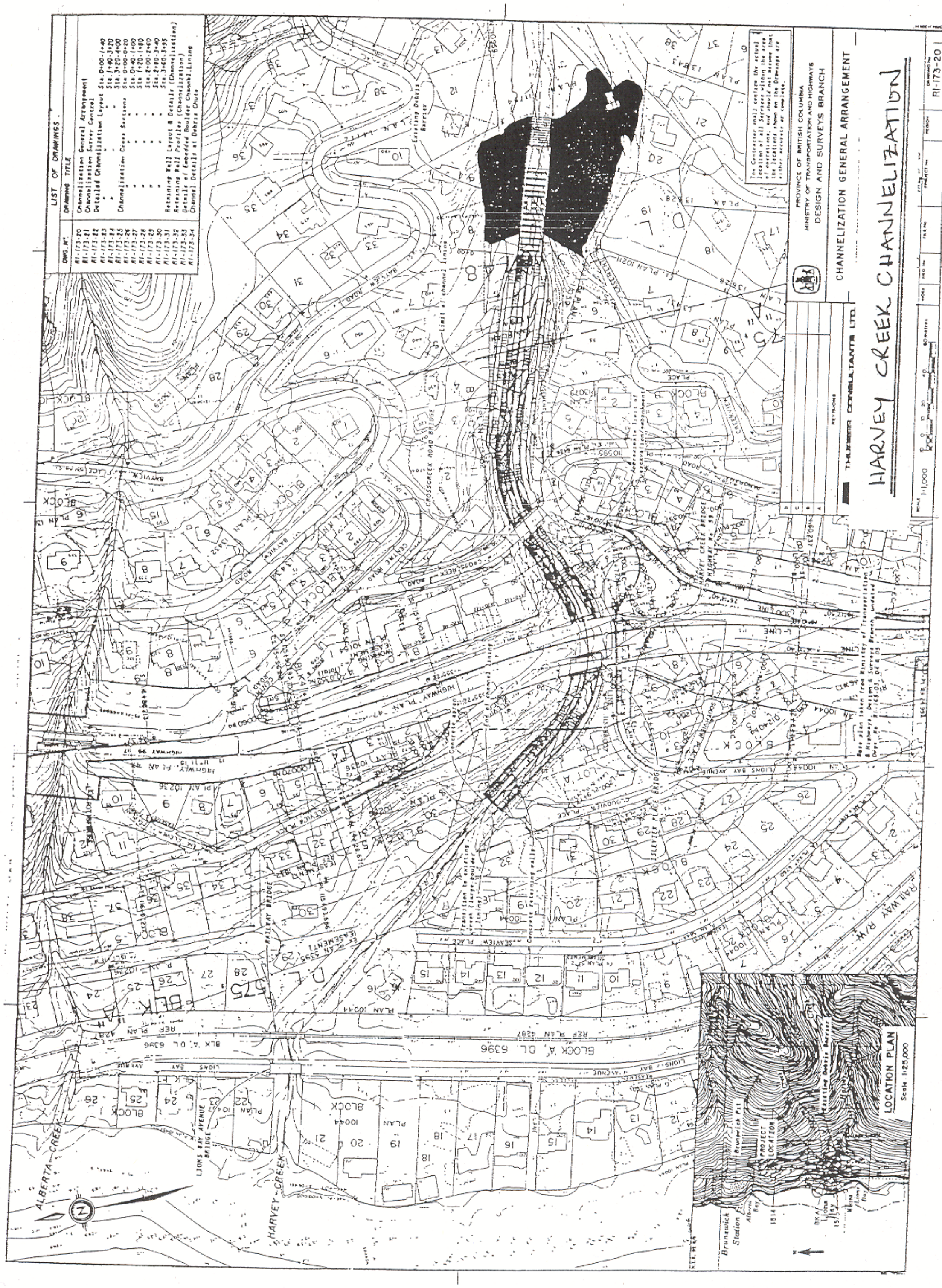
Magnesia Creek debris torrent barrier.

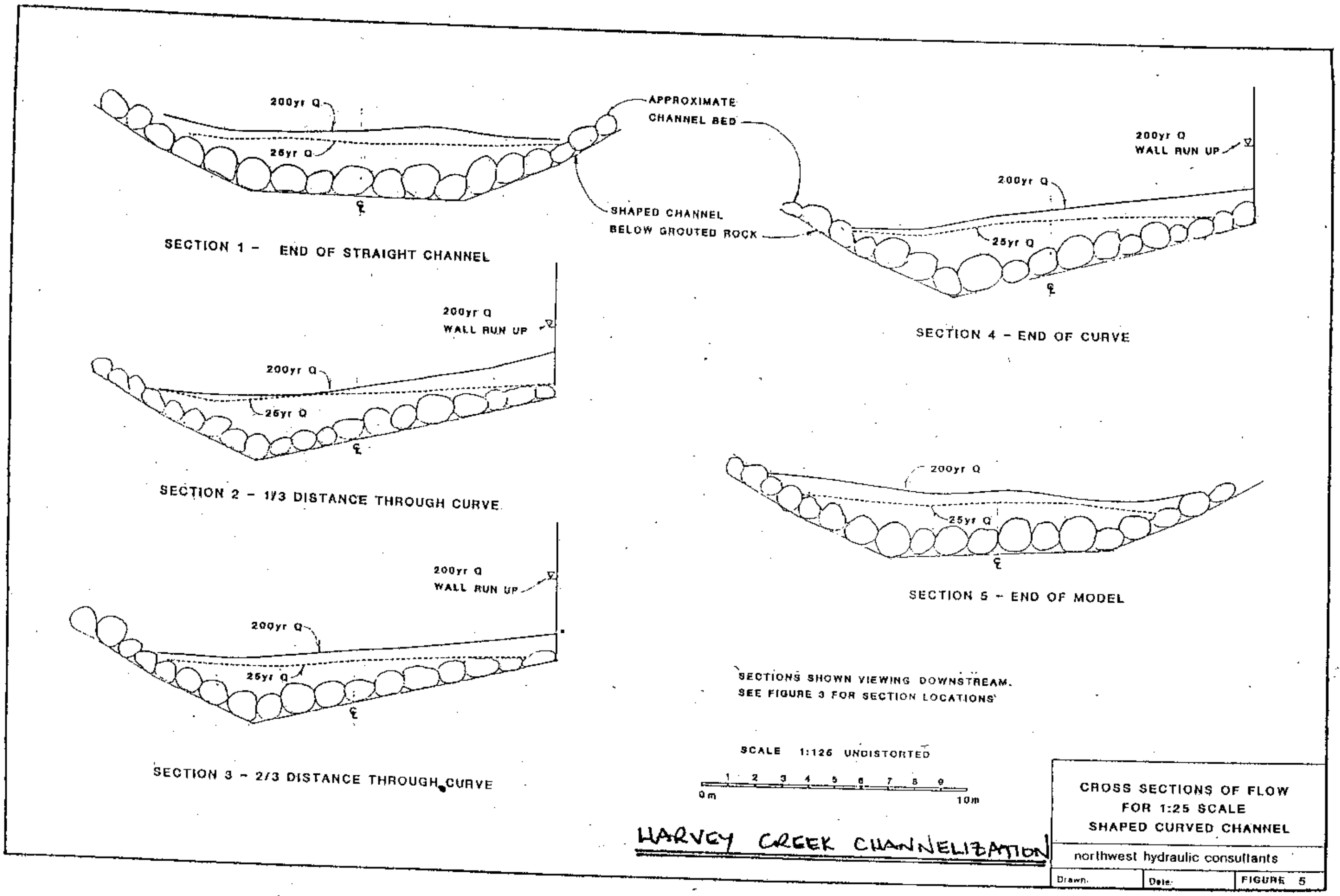
Magnesia Creek

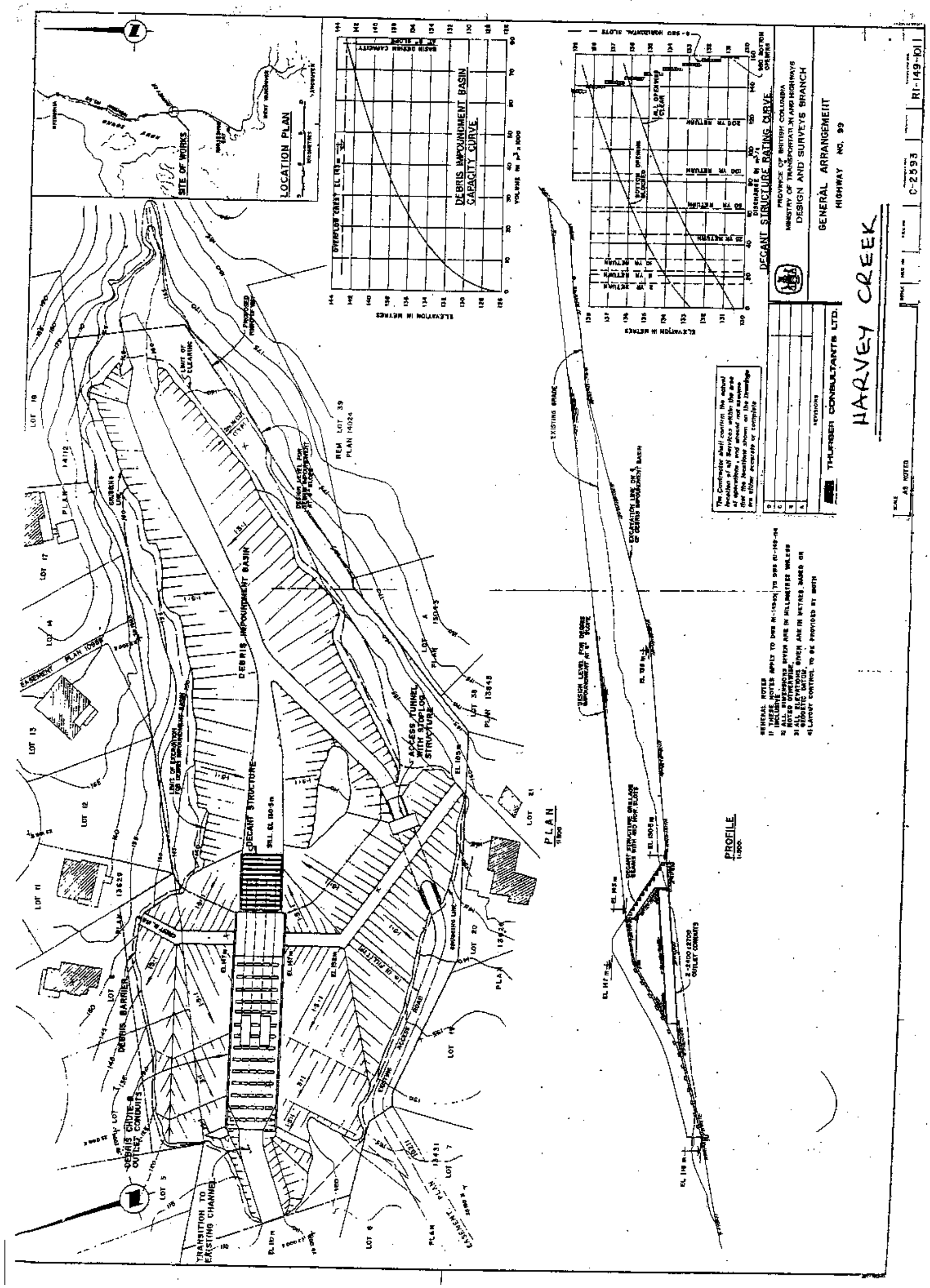
The topography of Magnesia Creek permitted a simpler design. An existing waterfall in a narrow canyon was replaced with a 15-metre high decant structure similar to the Harvey design. Storage of the debris material was then provided by excavation in bedrock upstream of the decant structure to provide the design storage of 37,500 m^3. The excavation continued up the creek for about 85 m to the foot of the next waterfall.

The decant grillage beams are supported by a central reinforced concrete buttress and concrete abutments post-tensioned to the rock. The design case for the buttress has a 16,000 kN (1600 Tonne) hydrodynamic impact of a wave of debris transiting a partially-full basin. The front of the decant is sloped to reduce the force of the impact and to generate a stabilizing vertical reaction at the toe of the buttress. A small, concrete-faced wing dam on the south abutment provides the necessary run-up freeboard and directs any overtopping debris flow.

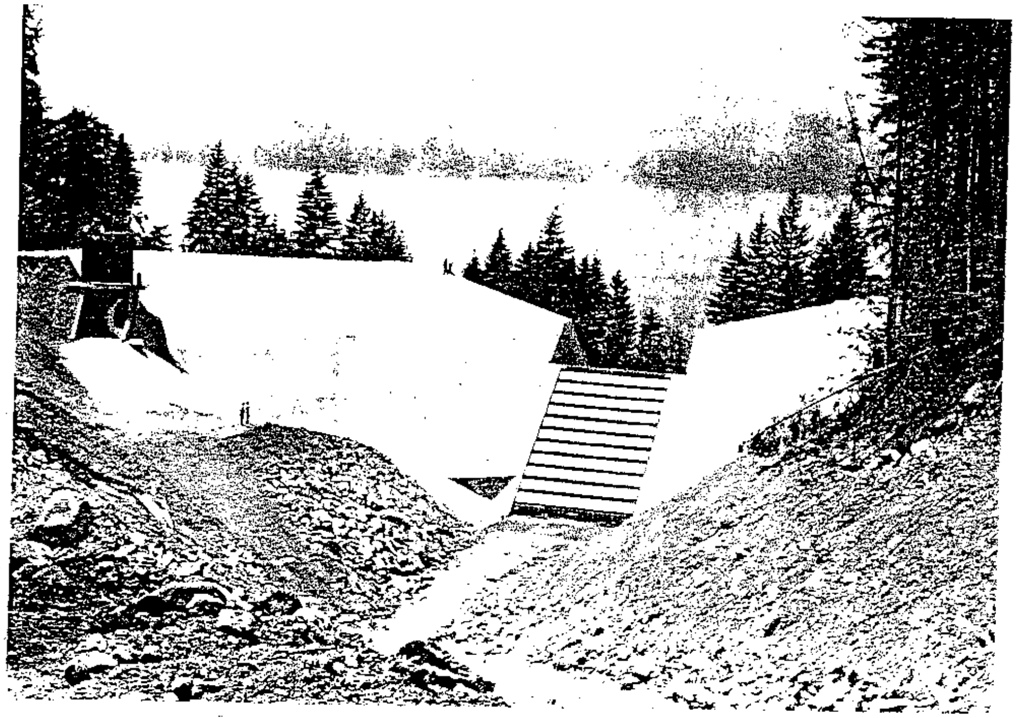
The design of the Harvey and Magnesia Creek debris torrent structures is unique. Although debris torrents are experienced in Switzerland and Japan, control structures in these countries are typically built on the fans where the torrents have begun to deposit on the flatter slopes and the velocities considerably reduced. In Lions Bay, however, extensive development on the fan areas, eliminates this possibility. Construction of such facilities on such steep slopes is also believed to be unprecedented. □


HARVEY CREEK CHANNELIZATION
CHANNELIZATION GENERAL ARRANGEMENT
PROVINCE OF BRITISH COLUMBIA
MINISTRY OF TRANSPORTATION AND HIGHWAYS
DESIGN AND SURVEYS BRANCH
LOCATION PLAN
LIST OF DRAWINGS
RI-173-20

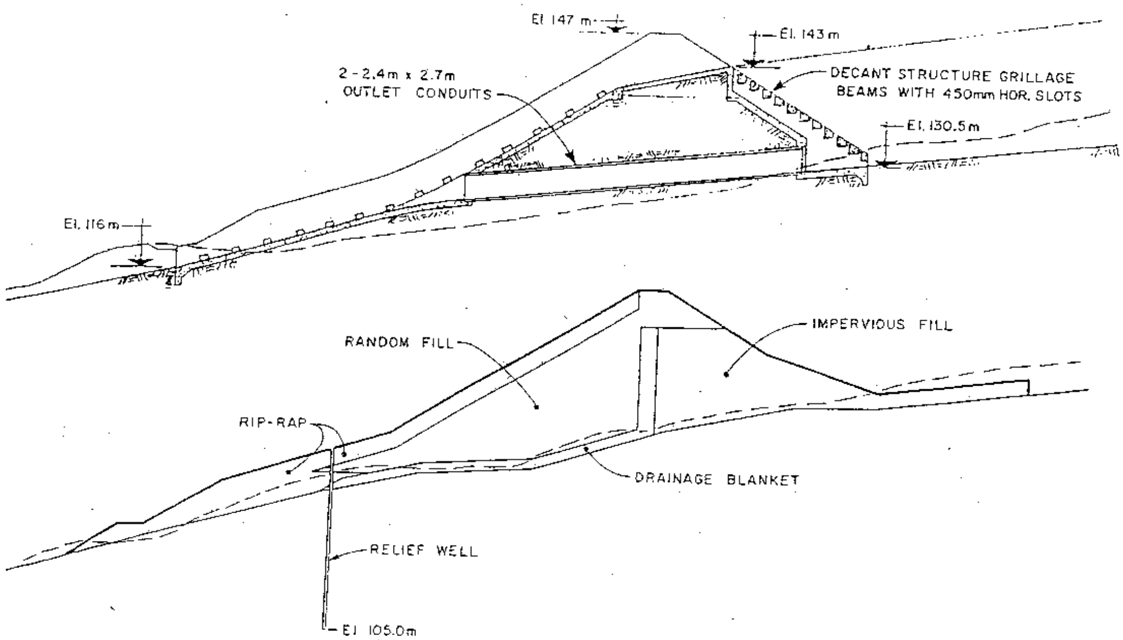

200yr Q
25yr Q
SECTION 1 - END OF STRAIGHT CHANNEL
APPROXIMATE CHANNEL BED
SHAPED CHANNEL BELOW GROUTED ROCK
200yr Q WALL RUN UP
200yr Q
25yr Q
SECTION 2 - 1/3 DISTANCE THROUGH CURVE
200yr Q WALL RUN UP
200yr Q
25yr Q
SECTION 3 - 2/3 DISTANCE THROUGH CURVE
200yr Q WALL RUN UP
200yr Q
25yr Q
SECTION 4 - END OF CURVE
200yr Q
25yr Q
SECTION 5 - END OF MODEL
SECTIONS SHOWN VIEWING DOWNSTREAM.
SEE FIGURE 3 FOR SECTION LOCATIONS
SCALE 1:126 UNDISTORTED
0m 1 2 3 4 5 6 7 8 9 10m
HARVEY CREEK CHANNELIZATION
CROSS SECTIONS OF FLOW FOR 1:25 SCALE SHAPED CURVED CHANNEL
northwest hydraulic consultants
Drawn.
Date.
FIGURE 5



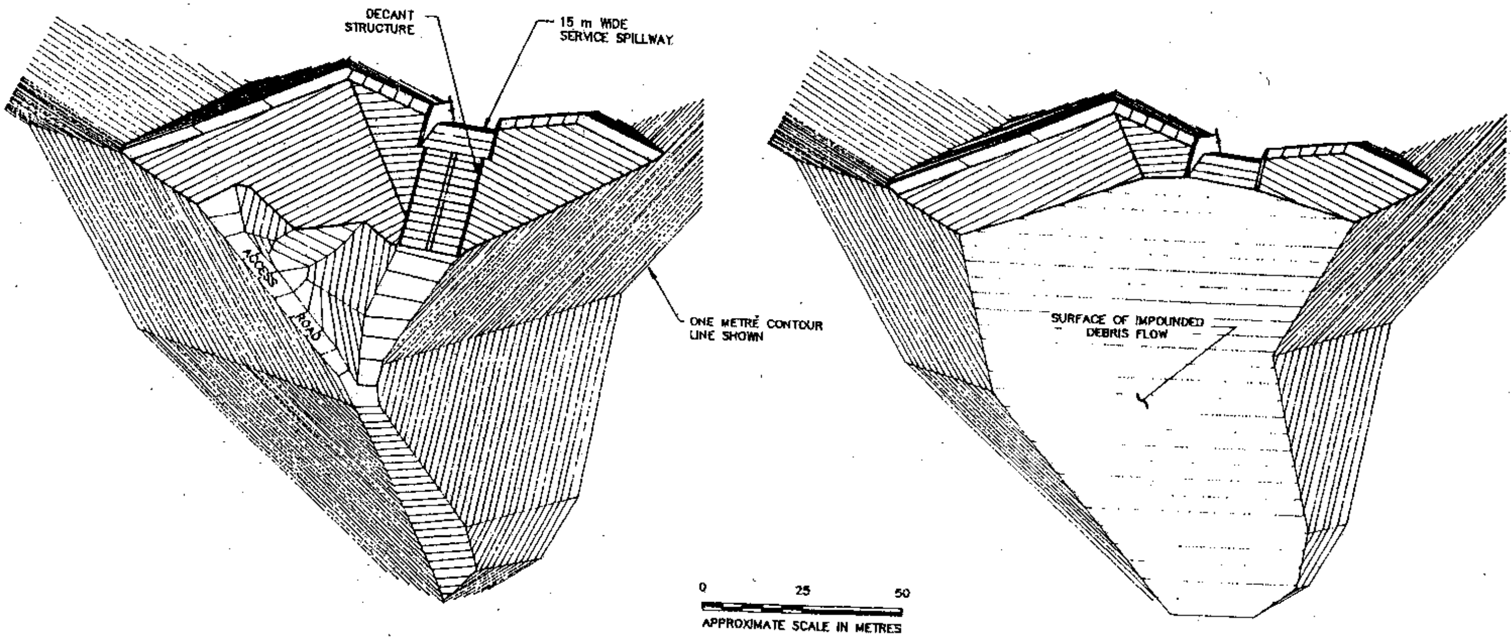
LOCATION PLAN
SITE OF WORKS
DEBRIS IMPOUNDMENT BASIN CAPACITY CURVE
DECANT STRUCTURE RATING CURVE
DEBRIS IMPOUNDMENT BASIN
DECANT STRUCTURE
DEBRIS BARRIER
ACCESS TUNNEL WITH STOPLOG STRUCTURE
TRANSITION TO EXISTING CHANNEL
PLAN
PROFILE
THURBER CONSULTANTS LTD.
DESIGN AND SURVEYS BRANCH
GENERAL ARRANGEMENT
HIGHWAY NO. 99
HARVEY CREEK
C-2593
RI-149-101



Upstream Face



Harvey Creek Debris Barrier.



BASIN EMPTY CONDITION

NOTE:
A DIGITAL MODEL OF THE DEBRIS BARRIER WAS PROCESSED BY A CUSTOM WRITTEN PERSPECTIVE DRAWING PROGRAM. THE AUTOCAD DRAFTING SOFTWARE PACKAGE EDITED THE IMAGES AND ASSEMBLED THEM INTO FINISHED DRAWINGS.

DESIGN CONDITION
STORAGE BASIN FULL

DESIGN CAPACITY 80000 CUBIC METRES
SLOPE OF THE SURFACE OF THE DEBRIS 8°
FREEBOARD FOR SUBSEQUENT FLOWS 8.5 METRES

HARVEY CREEK DEBRIS TORRENT CONTROL FACILITY

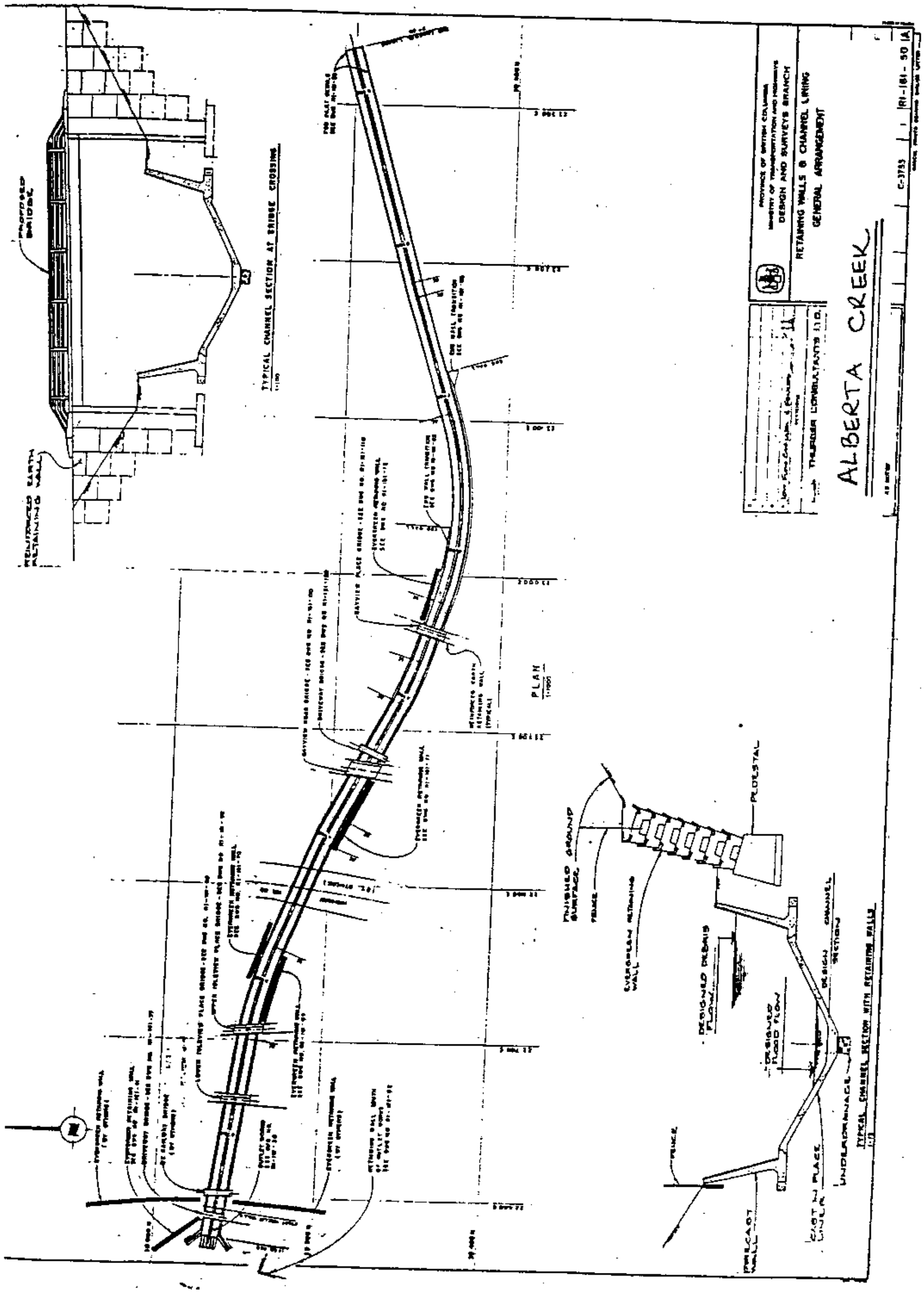
KER, PRIESTMAN & ASSOCIATES LTD

Appendix 5

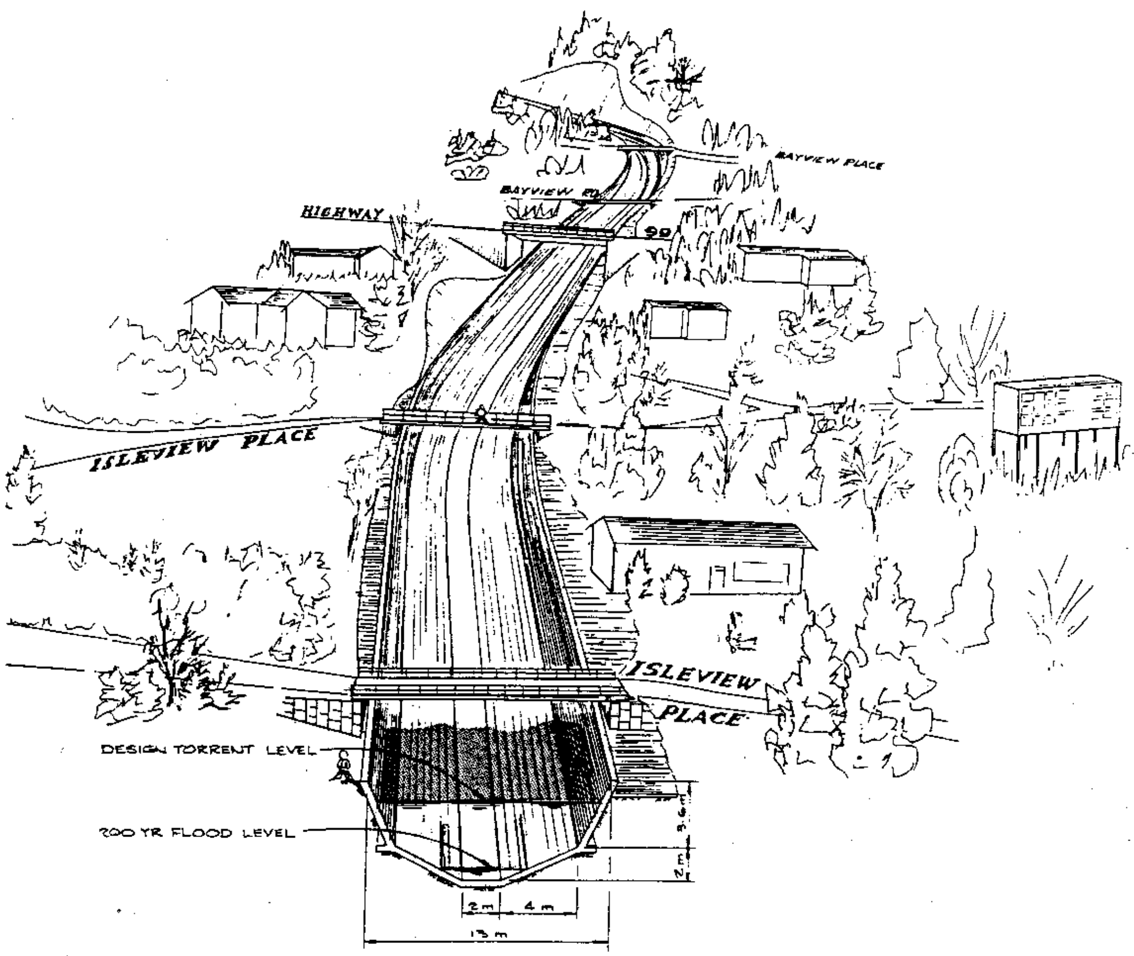
Drawings of the channelization at Alberta Creek

from

BC Ministry of Transportation


PROPOSED BRIDGE
REINFORCED EARTH RETAINING WALL
TYPICAL CHANNEL SECTION AT BRIDGE CROSSING
PLAN
PEDESTAL
FINISHED GROUND SURFACE
FENCE
EVERGREEN RETAINING WALL
DESIGNED DEBRIS FLOW
DESIGNED FLOOD FLOW
DESIGN CHANNEL SECTION
UNDERDRAINAGE
CAST IN PLACE LINER
PRECAST WALL
TYPICAL CHANNEL SECTION WITH RETAINING WALLS
DESIGN AND SURVEYS BRANCH
RETAINING WALLS & CHANNEL LINING
GENERAL ARRANGEMENT
THURBER CONSULTANTS LTD.
ALBERTA CREEK

ALBERTA CREEK

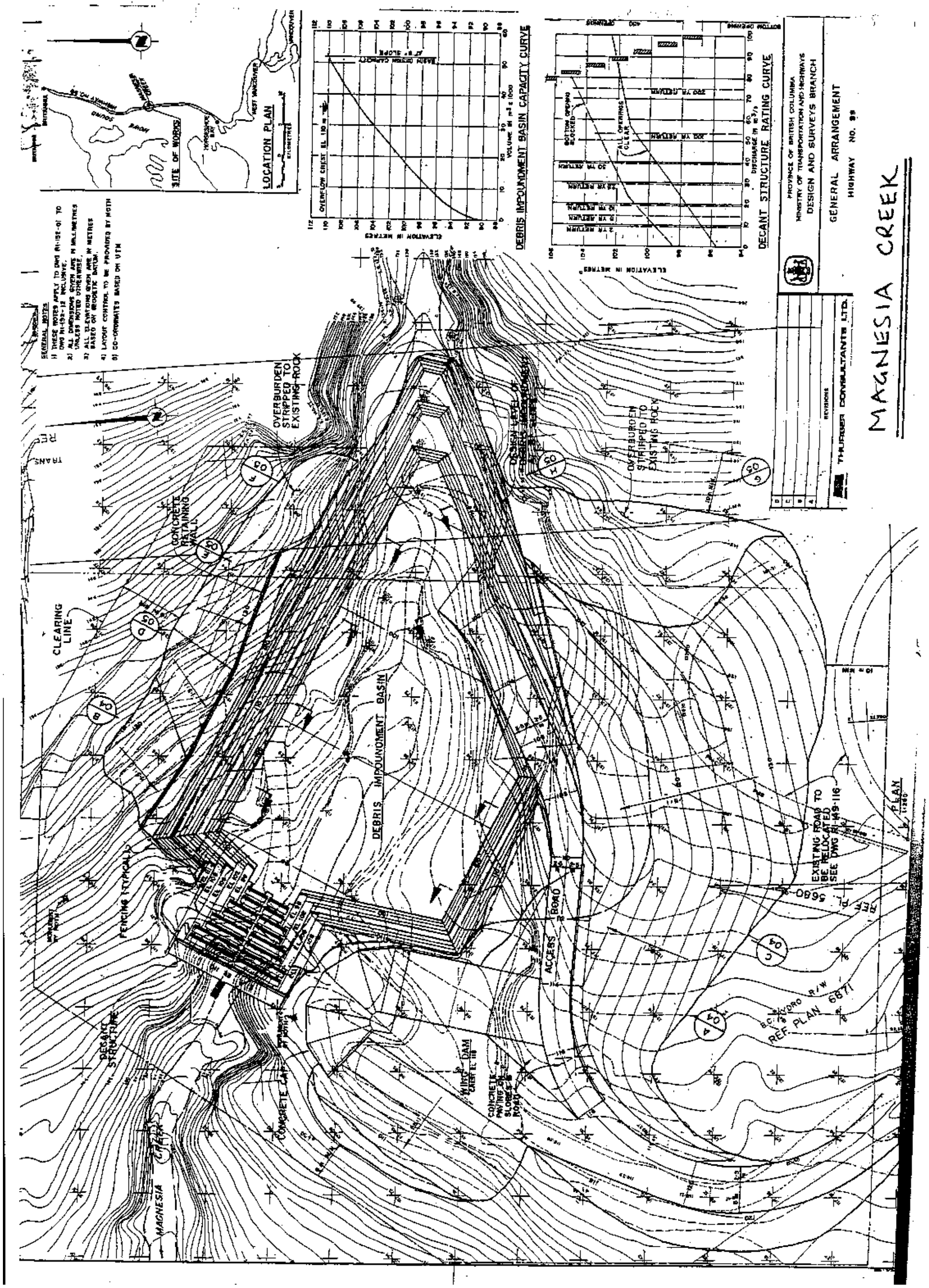


Appendix 6

General arrangement of Magnesia Creek debris basin

from

BC Ministry of Transportation



LOCATION PLAN
DEBRIS IMPOUNDMENT BASIN CAPACITY CURVE
DECANT STRUCTURE RATING CURVE
DESIGN AND SURVEYS BRANCH
GENERAL ARRANGEMENT
HIGHWAY NO. 99
THURBER CONSULTANTS LTD.
MAGNESIA CREEK
OVERBURDEN STRIPPED TO EXISTING ROCK
CONCRETE RETAINING WALL
CLEARING LINE
DEBRIS IMPOUNDMENT BASIN
DECANT STRUCTURE
ACCESS ROAD
PLAN

Appendix 7

Photograph of Porteau Bluffs during scaling operations
(photo courtesy BC Ministry of Transportation)

Rock bolting with a bencher drill at Porteau Bluffs
(photo courtesy BC Ministry of Transportation)

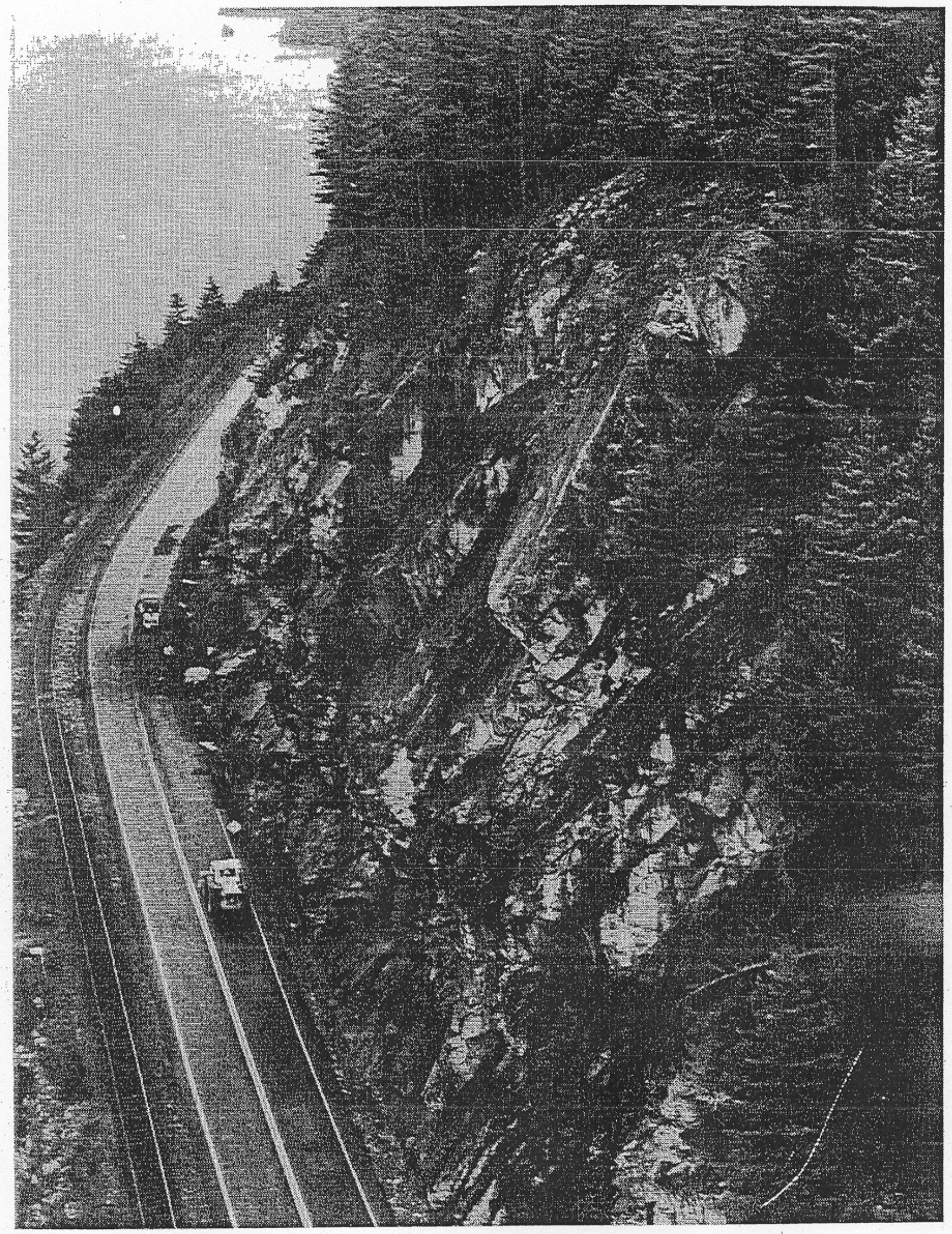


Figure 9 Porteau Bluffs during scaling operations (Photo courtesy B.C. Ministry of Transportation and Highways).

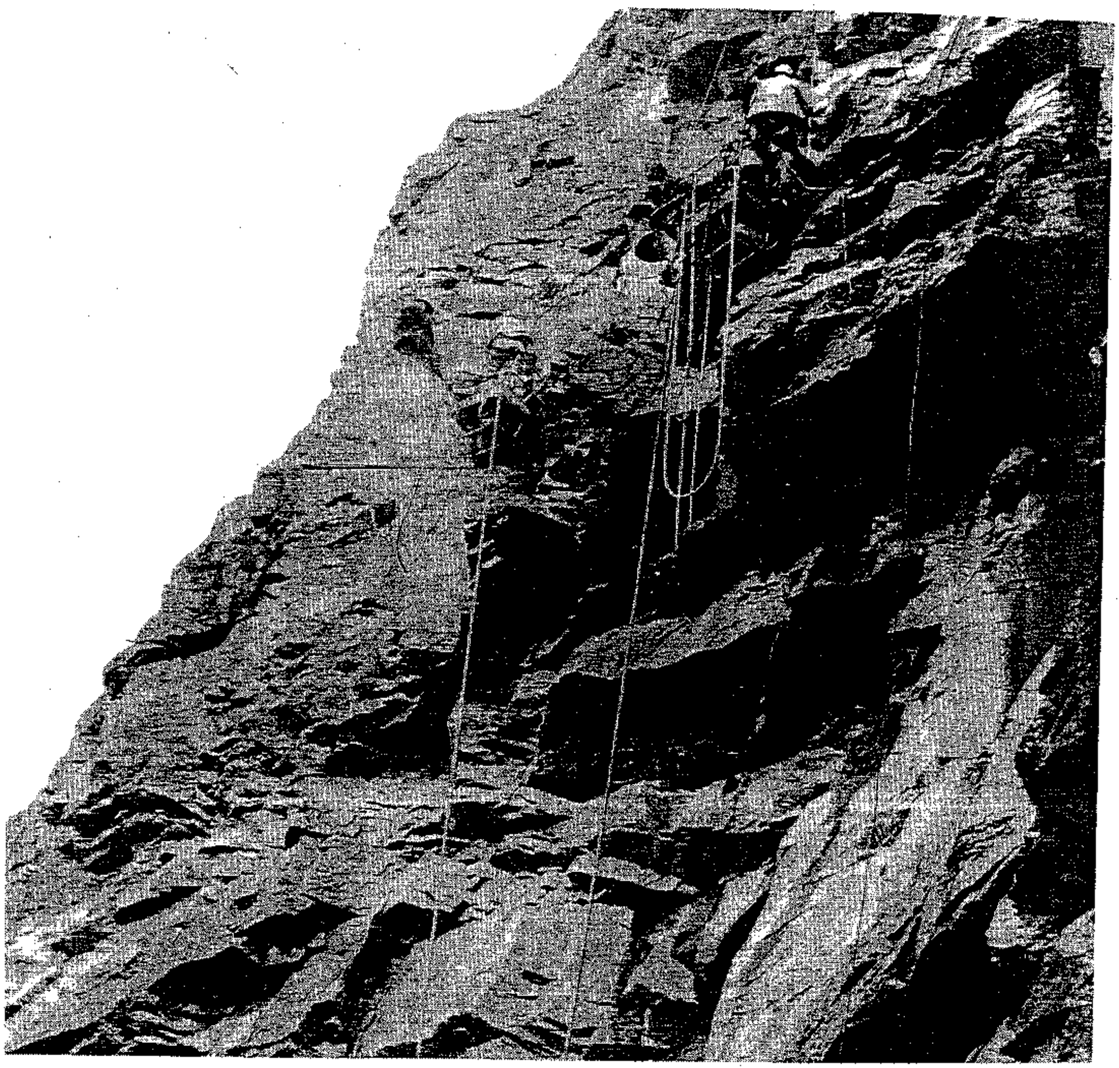


Figure 10 Rock bolting with a bencher drill on the Squamish Highway (Photo courtesy B.C. Ministry of Transportation and Highways).

Appendix 8

28th of October.

by

Skermer N.A. and Russell D.

in

The BC Professional Engineer, May 1988

and

Photograph of the 1921 flood damage on the fan of Britannia Creek (photo courtesy Vancouver public Library)

from

Hungr and Skermer 1998

28th of October

Nigel Skermer PEng and Denis Russell PEng

The twenty-eighth of October. A day of coincidence for floods on Howe Sound.

28 OCTOBER 1921 — The atmosphere in Britannia Beach had been tense all week since October 19, 1921, when there had been a cave-in at the portal of a new shaft at Britannia Mine. Two men had been trapped there and rescue workers had been working night and day in a desperate effort to rescue them. Conditions were appalling. The rainy season had begun, bringing with it heavy rainstorms which were causing widespread flooding all over southwestern BC.

At Britannia, the miners in the rescue teams had to work soaked to the skin, knee deep in a liquid mass of debris turned to muck by the cold October rain. But they kept at it and on the 28th they reached the trapped men, cold and hungry, but otherwise little the worse from their ordeal. That night, there was great rejoicing in the town and at the Tunnel Camp, where some of the miners were staying.

But while the prayers of Thanksgiving were being said and the rescue was being celebrated, a much greater disaster was in the making. A few miles above the town, where the mine railway crossed a narrow gorge, the culvert had plugged, and Britannia Creek waters were ponding and forming a lake perched precariously above the town.

The railway crossing had been built on fill, about 200 feet long and up to 100 feet high, with an eight foot square, wooden culvert at the bottom, to carry the creek under the fill. The rain was pouring down harder than ever and the unusually high flow in the creek was carrying logs, trees and floating debris.

During the daylight hours, men from the mine had been detailed to pull out logs, that twice had jammed at the entrance to the culvert. But after dark, when they could no longer see, they left for the town and the celebrations.

During the early evening, another log jam formed at the culvert entrance, cutting the water flow to a trickle. The railway embankment acted as a dam and 14 million gallons of icy cold Britannia Creek water ponded behind it before the "dam" broke, releasing a surge of water. The wave front rushed down the valley straight towards the town, where it struck in the dark at 9:30 in the evening, as a "wall of water", destroying everything in its path.

There was chaos and confusion everywhere, and the screams of the victims mingled with the rushing of the waters and the crash of buildings being torn apart. But as always in a disaster, people rose to the occasion and there were many tales of heroism from that awful night. When news of the disaster reached the Tunnel Camp, 50 miners came down to help. They had to cross the creek and the only way was over the railway crossing.

The fill had gone, but the steel railway line still hung suspended over the rushing waters of the creek. In ones

1. The destruction was overwhelming when Britannia Creek debris came crashing down on the mining town, just 30 miles north of Vancouver, in 1921. (Courtesy — Vancouver Public Library No 15287)

2. Less than 15 miles south of the site of the old Britannia Beach disaster and on the same day in 1981, M Creek's debris flow destroyed this highway bridge. (Courtesy — Wayne Leidenfrost, The Province)

and twos, the miners made the crossing swaying precariously in the dark above the creek far below. All made it safely and they rushed to do what they could to help in the stricken town.

Later reports put the height of the wave that struck the town at between 3 and 70 feet. But there was no doubt about the damage. Thirty-seven people lost their lives and almost half of the 110 homes in the settlement were destroyed. Daylight next day revealed the full extent of the devastation. (See Photo 1) Much of the centre of the town was under a 10 foot deep mass of matted and tangled cables, poles and parts of damaged or destroyed buildings, as well as mud, rocks, logs and trees up to 5 feet in diameter, which had been brought down by the raging torrent.

The creek, now much reduced in size was flowing through the centre of town and several homes, some almost intact, were floating peacefully in Howe Sound. Later that morning a relief boat from Vancouver arrived with medical and emergency supplies. The slow process of rebuilding the town and the lives of the survivors began. Later, there were the rituals of burial and inquiry. The coroner's jury found that the company had been criminally negligent in constructing a crossing with an opening so small that it could be blocked by debris.

SIXTY YEARS LATER

On the 28th of October 1981, exactly 60 years later, a terrifying deluge of rocks, mud and timber tore down M Creek around midnight. It was dark and pouring buckets. Unsuspecting motorists negotiated the twisting Highway 99. Suddenly they rounded the bend at M Creek, where most had scarcely ever noticed the bridge or creek before, and found a gaping canyon through the highway.

Brakes were applied but not in time. Five cars plunged over the gap into the milling torrent. Nine motorists died. At the mouth of the torrent on the fan at the shoreline, terrified occupants of a house scrambled clear as it was dozed off its foundation by the madly surging debris. Within a short time, the pulses of debris subsided, and the flow in the torrent returned to a harmless stream of muddy water.

This debris flow phenomenon is fairly common on steep alpine creeks, but not common enough to be an everyday event. For years, such creeks may yield no more than high water flows. Now and again, usually during a cloudburst, the flow of water is sufficient to clear accumulated debris out of the creek bed. Aided by sideslips from the creek banks, the load moves in pulses down the channel. On flatter sections it may halt. It may remain there, and, if this section of the creek is thickly wooded, the threatening behaviour of the creek may pass unnoticed.

If it continues on its course, eventually it reaches the fan at the mouth of the creek where most of the debris spreads out and halts. Thus, the fan has been developed by repeated channel clearouts, dumping the debris to form the cone-shaped deposit at the terminus. It is a repeating geological process, at perhaps 30-100 year intervals, common on geological time scales — over centuries.

Where people have dwelt in mountains for many generations, they are well aware of what such creeks can do. Hence the French word for alpine creeks — torrents — from the Latin torrente — meaning impetuous flow. Or the German word — wildbach — which pretty well speaks for itself. Austrians give the debris flow a curious word all to itself — mure. In the Himalayas they call it a swa. The Bolivians excel with the word mazamorra — meaning porridge.

The *Vancouver Sun* called the M Creek event a mudflow. The accepted word in North American technical usage is debris flow, or debris torrent in the Pacific Northwest. Call it what we will, the swirling mass of mud, boulders and logs left a pretty desolate scene on the fan of M Creek, appearing at daybreak. (Photo 2) The bridge had gone, the railway was overwhelmed and the house of Mr. J.C. Stainsby PEng, was almost launched into Howe Sound.

The drainage basin of M Creek is about 3 sq km and the creek is about 3 km long. It has an average gradient of 50 percent. The size of the debris flow was about that of a BC Rail freight train — about 20,000 m^3. It is believed to have been all over within about 5 minutes. Most of the debris came from the accumulated load in the creek channel. However, this had been fed constantly by a rockfall and talus slope, high in the watershed at about 1000 m elevation.

The rockfall is still active. It can be seen as a long strip on the hillside next to the clearcut. It is clearly visible from the Horseshoe Bay ferries. A Sketch of the M Creek — mure — mazamorra — mudflow is shown.

MORAL

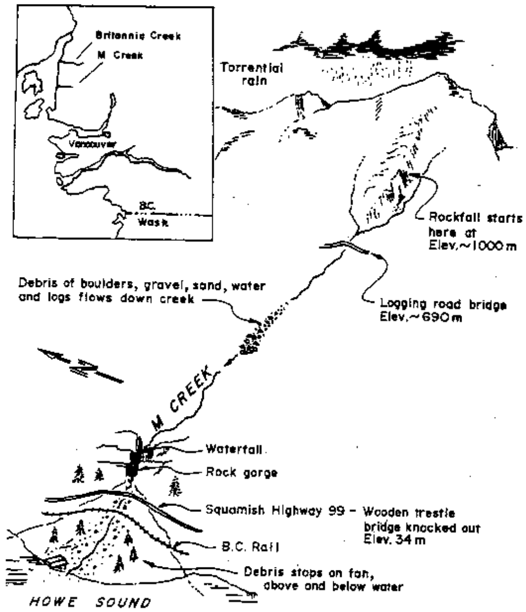
Great care should be taken in crossing torrential creeks with culverts and bridges.

William Edwards, Bridge Builder

. . . when any work of more than ordinary difficulty was proposed, application was usually made to William Edwards. Hence in 1746, when it was proposed to throw a bridge over the river Taff, he was employed to build it; and although he was only

twenty-seven years old, and had not yet built any bridge, he had the courage at once to undertake the work. The bridge was built of three arches, in a style superior to anything of the kind that had been erected in the neighbourhood; the stones were excellently dressed and closely jointed; the arches were light and elegant, and supposed to be sufficiently substantial for the duty they had to perform; and as a whole the erection was much admired, and greatly added to the fame of its builder. It would appear, however, that Edwards had not sufficiently provided for the passage of the floods, which in certain seasons rush down from the Brecknock Beacon mountains with great impetuosity. Above Newbridge several rivers of considerable capacity, such as the Crue, the Bargold Taff, and the Cynon, besides numberless brooks descending rapidly from the high grounds, contribute to swell the torrent so as to render it almost irresistible. The piers of Edward's new bridge unfortunately proved a serious obstruction in the way of a heavy flood which swept down the valley about two years and a half after the bridge had been completed. Trees were torn up by the roots and carried down the stream, lodging athwart the piers, where brushwood, haystacks, and field-gates, becoming firmly stuck amongst their branches, choked up the arches and fairly damned the torrent. The waters rapidly accumulated above the bridge and rose to the parapets; the sides of the valley being steep, left no room for their escape, and the tremendous force finally swept away arches and piers together, carrying the materials far down the river.

From *"Lives of the Engineers"*, Vol 1 by Samuel Smiles, London, 1862. o



Both disasters (top left) were close in location and caused loss of life and extensive property damage. The M Creek tragedy is detailed here, with the same scenario repeated at Brittania exactly 60 years before.

Figure 13 The 1921 flood damage on the fan of Britannia Creek (photo courtesy Vancouver Public Library).