FAIRMONT HOT SPRINGS RESORT AREA

TERRAIN HAZARD ASSESSMENT

DRAFT

Prepared for:

FAIRMONT HOT SPRINGS RESORT LTD.
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October 7, 1994

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Crowther

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October 7, 1994

Mr. Peter Mulyk, P. Eng.
Fairmont Hot Springs Resort Ltd.
#405, 1111 - 11 Avenue S.W.
Calgary, Alberta
T2R 0G5

RE: FAIRMONT HOT SPRINGS RESORT AREA
<u>TERRAIN HAZARD REVIEW</u>

Reid Crowther & Partners Ltd. is pleased to present this DRAFT report outlining the results of the Terrain Hazard Review for the Fairmont Area. The results of this assessment will allow you to specifically address the hazards within individual development phases on an as required basis. For a large part of your area, no hazards exist and development can proceed without detailed analysis.

In areas where hazards have been identified we have provided conceptual methods of dealing with the hazard and briefly outlined the works and analysis involved to deal with the type of hazard encountered.

If you have further questions do not hesitate to contact this office.

Reid Crowther & Partners Ltd.

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1.0 INTRODUCTION

JNMacKenzie Engineering Ltd. had originally been engaged to undertake a scoping study of terrain hazards on behalf of Fairmont Hot Springs Resort Ltd. Reid Crowther & Partners has acquired JNMacKenzie Engineering Ltd. and is continuing this project. The work program called for the identification of flooding and debris torrent concerns, formulation of conceptual solutions, definition of specific detailed analyses required for individual development areas, and conceptual works to address identified problems. The work program involved a comprehensive review of air photos, an aerial over flight, limited field inspections and literature review of terrain hazards in conjunction with Geo-Engineering (M.S.T.) Ltd. The geographic area covered by this assessment includes the property of Fairmont Hot Springs Resort Ltd. In the Columbia River Valley below Columbia Lake, see Figure 1.1.

The purpose of this assessment is an overview study to identify those lands which appear to be free from terrain hazards. By default those lands which appear to be potentially affected are also delineated along with type of potential hazard. The magnitude of any specific hazard is not quantified, rather that is left for more detailed planning and design phases during development. This assessment also provides an indication of some of the measures which might be employed to manage the hazards in other areas. An excellent description of the step by step process of assessment followed by more detailed work is included in Appendix A. This information titled Natural Hazards, Risk Assessment and Land Use Planning in British Columbia: Progress and Problems, was presented at the Geotechnique and Natural Hazards Symposium in Vancouver on May 6, 1992 by Peter W. Cave.

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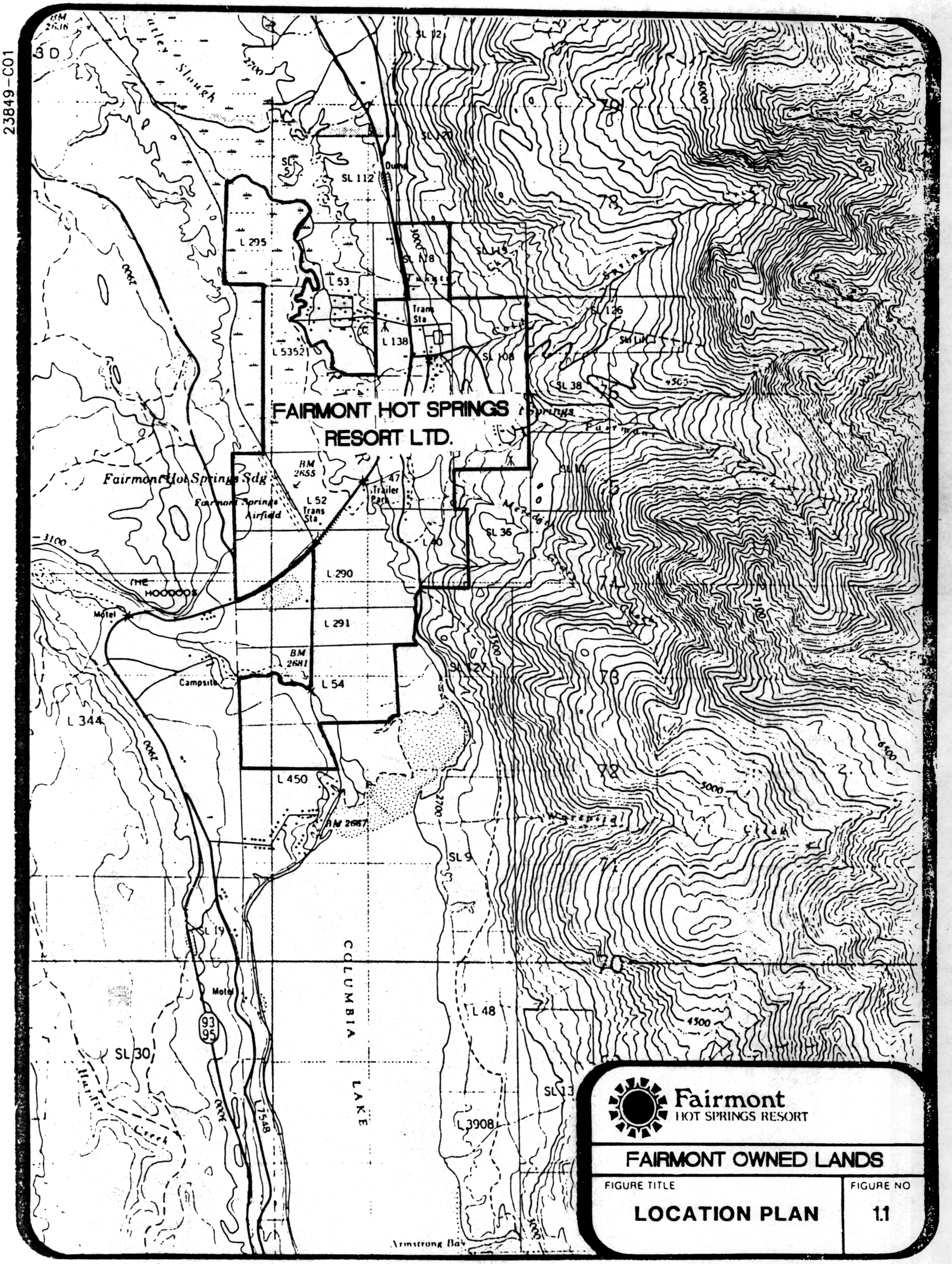


Fairmont
HOT SPRINGS RESORT

FAIRMONT OWNED LANDS

FIGURE TITLE	FIGURE NO
LOCATION PLAN	**1.1**

2.0 TERRAIN HAZARDS

In general there were five types of terrain hazard identified by Geo-Engineering. These being debris flows, flooding, erosion, silt liquefaction slides, and poor foundation conditions. The location of the terrain hazards along with an analysis of the surficial geology of the area are shown on Figure 2.1.

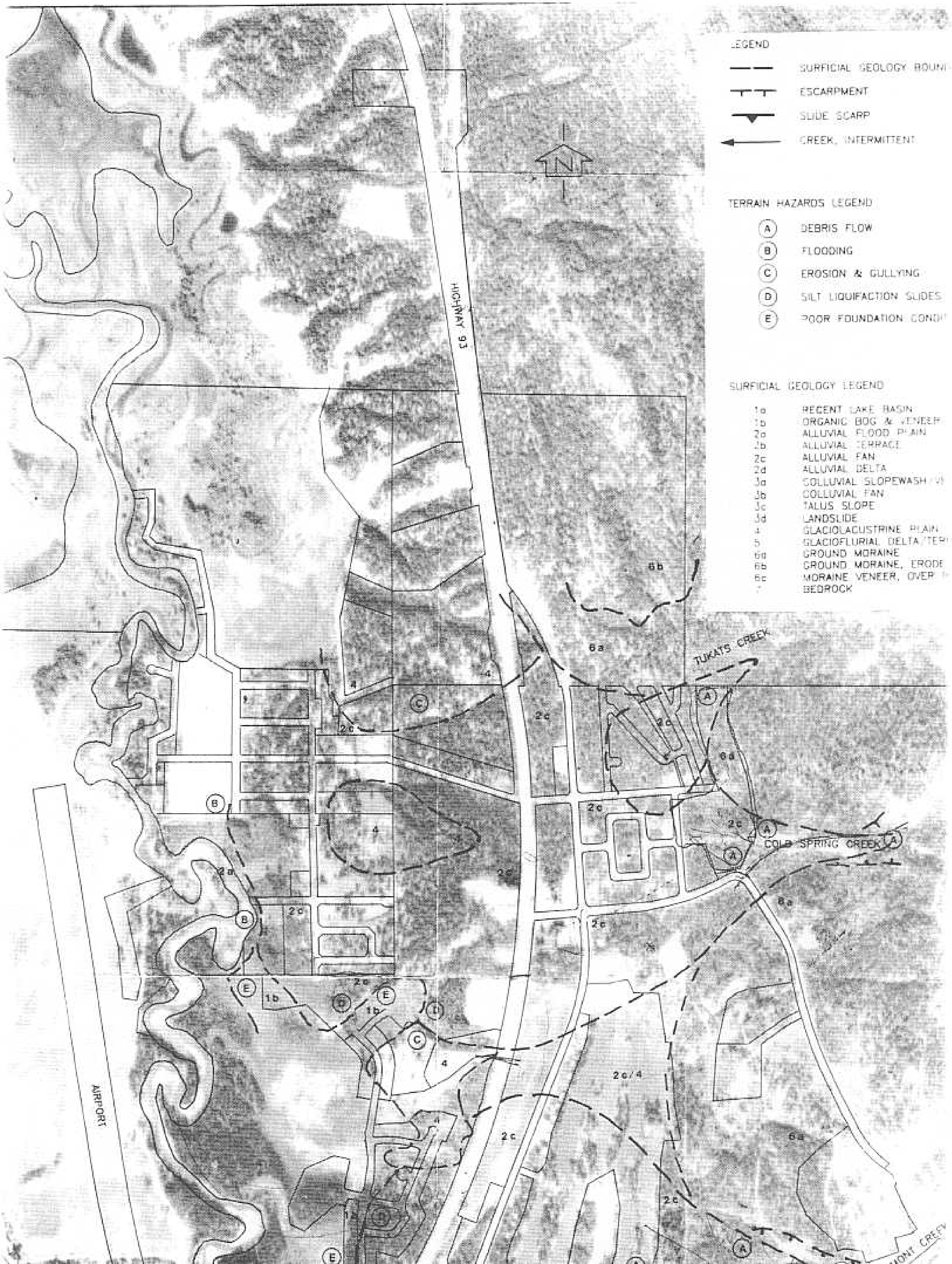
Each type of hazard has a unique cause and method of dealing with the hazard. The description of each type of hazard and possible methods of addressing each hazard can be determined at this time. **It is important to note that the application of any specific measure must follow a more detailed analysis of the magnitude of the risk and of the level of acceptable risk involved.**

2.1 DEBRIS FLOW

A debris flow (torrent) can be identified as a mass movement that involves water-charged, predominantly coarse grained inorganic and organic materials flowing down a steep, confined channel. Debris flows form in the headwaters or steep middle reaches of mountain creeks and are triggered by several different mechanisms. The most common appear to be slumping of over steep banks and spontaneous instability of loose creek bed deposits. A debris flow event typically consists of several surges of concentrated high discharge and high density flow separated and followed by more diluted after flow and water flooding. The flows usually occur in response to major rainstorms accompanied by rapid snow melt (Hungr, et al, 1987).

The profile of a creek that is subject to debris flow can be broadly divided into three zones; the initiation zone, the transportation and erosion zone, and the deposition zone. Initiation requires a gradient greater than 15°. The transportation and erosion zone must remain steep and confined enough for debris flow to maintain its velocity and usually requires slopes greater than 10°. The deposition zone begins where the flows are no longer confined allowing the formation of levies on a fan beginning on slopes less than 15° (VanDine, 1984).

Several defensive measures can be taken to deal with or control debris flows. Table 2.1 provides a list of such measures (Hungr, et al, 1987). Simple sketches of some possible structural measures are included in Figure 2.2 and Figure 2.3.


LEGEND
SURFICIAL GEOLOGY BOUN
ESCARPMENT
SLIDE SCARP
CREEK, INTERMITTENT
N
TERRAIN HAZARDS LEGEND
A DEBRIS FLOW
B FLOODING
C EROSION & GULLYING
D SILT LIQUIFACTION SLIDES
E POOR FOUNDATION COND
SURFICIAL GEOLOGY LEGEND
1a RECENT LAKE BASIN
1b ORGANIC BOG & VENEER
2a ALLUVIAL FLOOD PLAIN
2b ALLUVIAL TERRACE
2c ALLUVIAL FAN
2d ALLUVIAL DELTA
3a COLLUVIAL SLOPEWASH /V
3b COLLUVIAL FAN
3c TALUS SLOPE
3d LANDSLIDE
4 GLACIOLACUSTRINE PLAIN
5 GLACIOFLURIAL DELTA/TER
6a GROUND MORAINE
6b GROUND MORAINE, ERODE
6c MORAINE VENEER, OVER
7 BEDROCK
HIGHWAY 93
TUKATS CREEK
COLD SPRING CREEK
AIRPORT
MONT CREEK
6b
6a
4
C
2c
B
2a
E
1b
D
2c/4
6a
A
1a

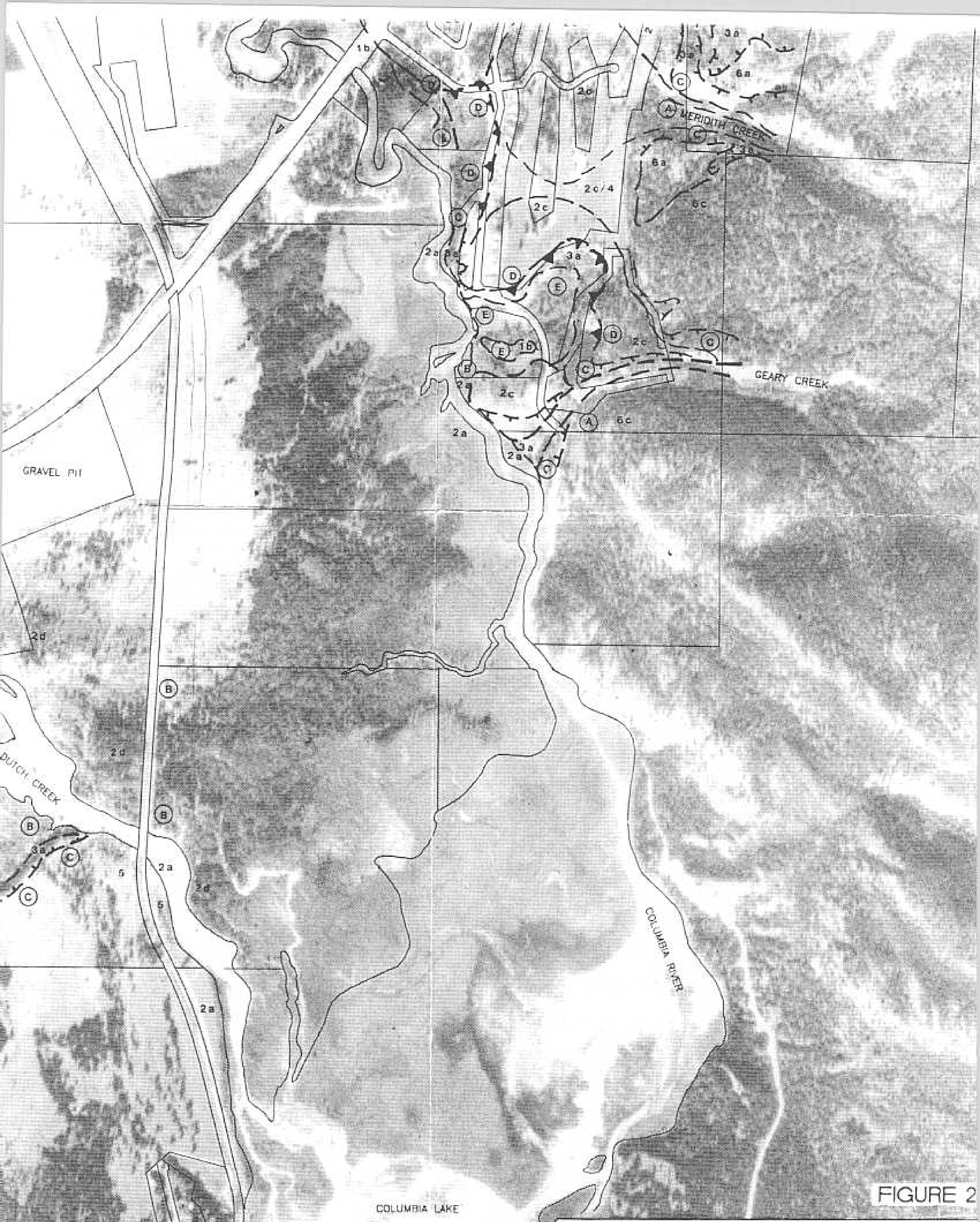


FIGURE 2

FAIRMONT HOT SPRINGS RESORT LT

TABLE 2.1
FAIRMONT HOT SPRINGS RESORT AREA
TERRAIN HAZARD ASSESSMENT
CLASSIFICATION OF DEFENSIVE MEASURES AGAINST DEBRIS FLOW

MEASURE	PURPOSE
Passive Measures	
• Hazard mapping and zoning	Restrict use of endangered areas
• Warning systems: advance, during event, or post-event	Facilitate evacuation at times of danger
Active Measures	
A. In initiation zone	
• Reforestation/controlled harvest	Reduce debris production due to logging or natural loss of forest cover
• Forest road construction control	Eliminate unstable cuts and fills that could act as debris sources or initiation points
• Stabilization of debris sources (channel linings or check dams)	Stabilize channel bed and side slopes in source reaches, Figure 2.1.
B. In transportation and erosion zone*	
• Training by chutes, channels, and deflecting walls or dikes	Ensure passage of debris surges down a predetermined path, without blockage or overflowing (branching) Figure 2.2
• Channel diversion	Change the path of debris flow away from endangered areas
• Bridges designed for passage	Protect traffic on bridge and prevent channel blockage due to bridge obstruction
• "Sacrificial" bridges or fords	Prevent channel blockage due to the obstruction of a bridge with inadequate clearance
• Bypass tunnels beneath creek bed	Protect transportation route without modifying stream channel
C. In deposition zone*	
• Open debris deposition basins; dikes or walls	Control the extent of a natural deposition area by shaping and diking
• Closed retention barriers and basins: full or partial volume	Create a controlled deposition space fronted by a straining structure and a spillway
• Bridges or other structures designed for burial	Prevent damage to structure during burial by debris flow
• Debris sheds (galleries) or cut-and-cover tunnels	Place transportation route beneath deposition area

* The limits of transportation and deposition zones are understood as those applicable after the defensive measures are in place. Channels and chutes will move the point of deposition downstream, barriers and basins upstream.

Although we provide these sketches as examples of the possible defensive measures the **specific measures must be determined during a more detailed and extensive analysis**. The magnitude of the problems and the risks must be assessed during these future work programs.

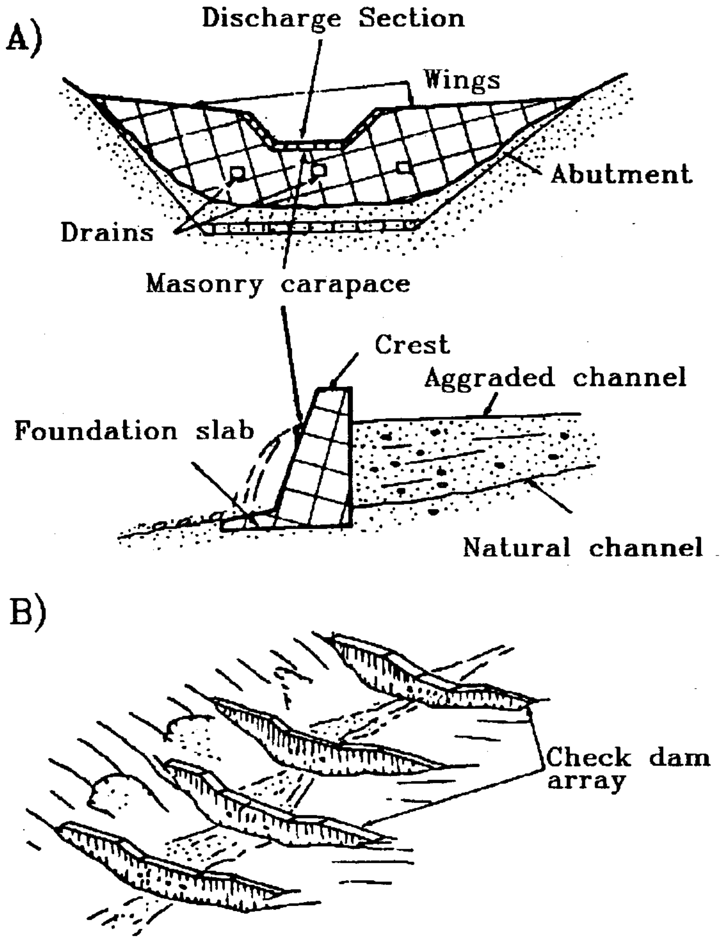


Figure 2.2 a) Diagrammatic views of the elements of an individual check dam; b) The arrangement of check dams in stacked arrays along torrent reaches bordered by erodible and unstable surficial deposits (Eisbacher).

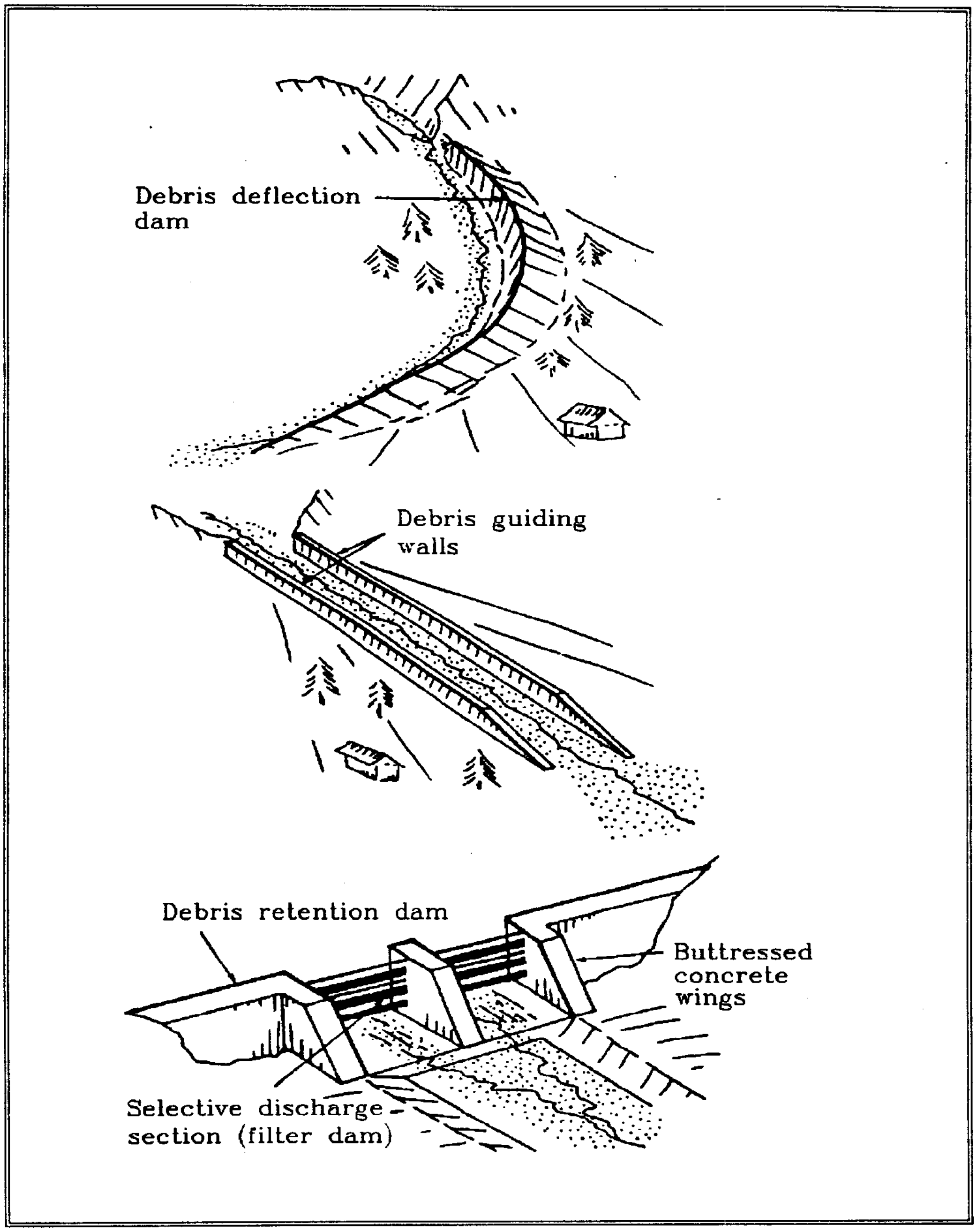


Figure 2.3 Schematic illustrations of the three principal types of protective engineering works against debris flows (Eisbacher)

In the vicinity of debris flow channels and fans, development should be proceeded by detailed and site-specific studies of debris flow potential, hazard and frequency of occurrence.

2.2 FLOODING

The flooding hazard should not be confused with debris flows. Floods are primarily composed of water with some associated alluvial materials. The method of approach in dealing with flooding concerns would be to quantify the flood discharges and flood plain limits while considering the alluvial material carried by the floodwaters. Setting building grades above and beyond flood limits, diversion of flows, bank stabilization or diking are all methods of dealing with a flood hazard. A detailed floodplain delineation for the Columbia River has been completed during the course of previous studies (JNM, 1989a). This study delineated the flood plain and determined the constraints placed upon development and the protective measures which must be in place to allow development with acceptable risk.

2.3 EROSION AND GULLYING

The occurrence of erosion and gullying occurs on steeply sloping terrain not normally considered for development. The process of erosion and gullying can affect adjacent developments with loss of areas at the top of steep slopes or with deposition of material at the slope bases. Top and bottom development set backs and slope stabilization are methods of dealing with this hazard. The surface of the slopes can be stabilized with the use of a vegetative cover provided the overall slope has stability. In areas where development of housing is to be undertaken the process of development will provide long term stability. The housing, roads and seeding of lots would provide surface protection following development.

2.4 SILT LIQUEFACTION SLIDES

Silt liquefaction slides result from the instability of the soil mass caused by liquid saturation. Site specific studies to determine the slope stability in the vicinity would be required to establish safe construction set back requirements. One possible option would be to intercept and divert or drain from the soil mass the water causing the soil mass to become unstable. In this case very specific geotechnical information regarding groundwater and recharge areas are required. The generally recommended approach would involve the definition and application of setback requirements.

2.5 POOR FOUNDATION CONDITIONS

The occurrence of poor foundation conditions does not preclude development. At the time of design and construction of any building the soil bearing capacity must be determined and appropriate foundations utilized.

3.0 CONCEPTUAL SOLUTIONS

We present here conceptual solutions to terrain hazards for the Fairmont Hot Springs Resort area. **In each of the basins one single and effective method of not increasing the hazard due to flooding and debris flows is to prevent timber harvesting in the upper reaches of the drainage basin. At the very least, logging should be planned in such a way as to minimize the effects on the drainage basins. Any logging activity should be preceded by a review process involving the downstream land owners which assesses risks associated with flooding and debris flow hazards.**

Shown on Figure 3.1 are the conceptual methods of reducing the hazards and the revised hazard mapping if these solutions prove to be required and feasible.

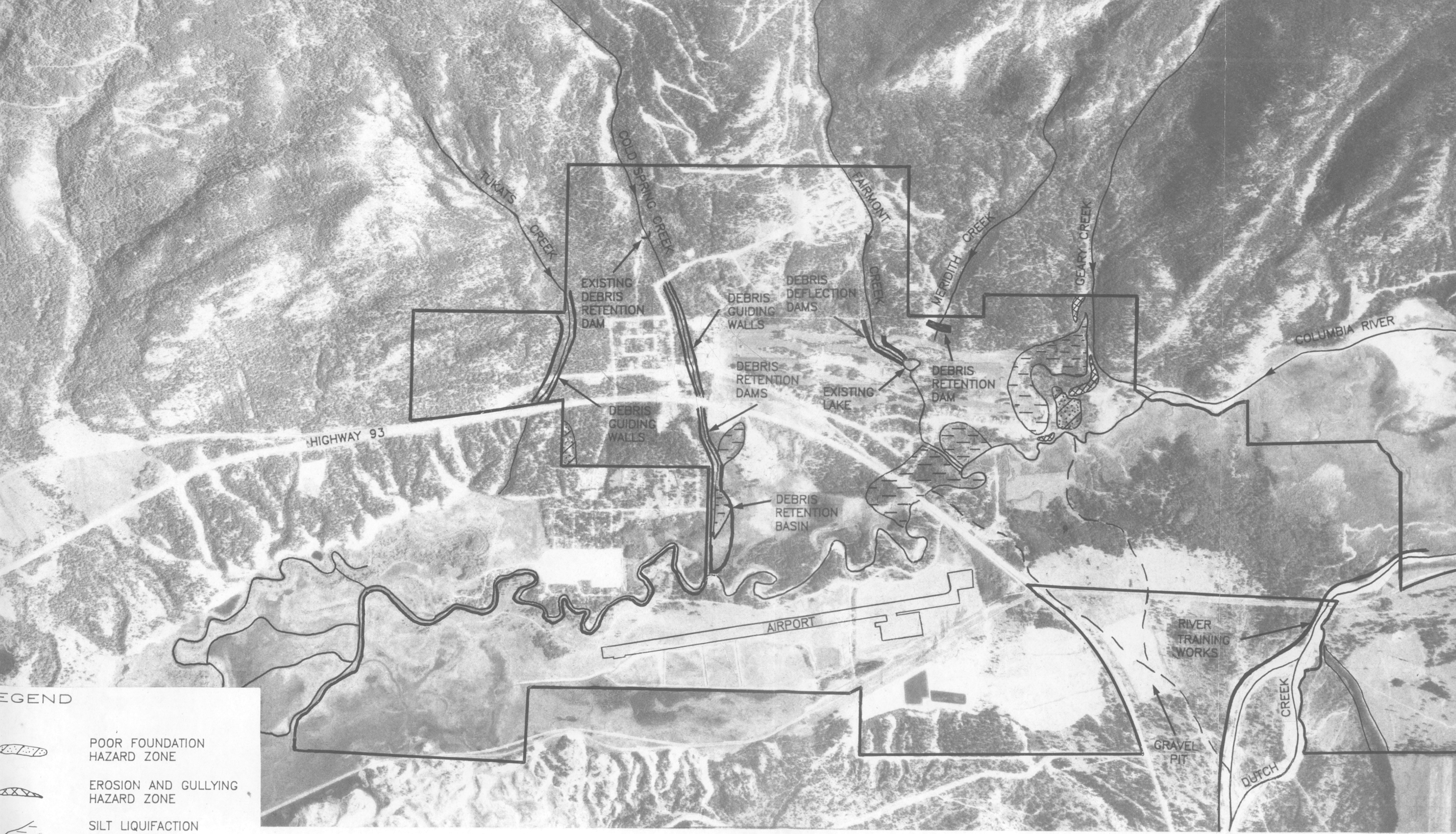
3.1 GEARY CREEK

The debris flow hazard zone of Geary Creek is well defined and limited to the confines of the deeply incised water course. No protection works are considered to be necessary to protect development from debris flows as the development would be along the deeply incised, transport zone of defined flow rather than in the deposition zone.

The flooding hazard along the Columbia River have previously been defined (JNM, 1989a). The flooding hazard is limited to a narrow fringe along the river. Any construction adjacent to the river could proceed as long as appropriate flood construction levels are utilized.

Erosion and gullying hazards occur on steep slopes in this area. Solutions to deal with this hazard include vegetative cover to prevent erosion and/or set backs from the edge of the slope. The setback requirement would be determined during the design phase of individual developments. In areas where development of housing is to be undertaken the process of development will provide long term stability. The housing, roads and seeding of lots would provide surface protection following development.

A silt liquefaction hazard zone exists in the area of a previous slide. The initial slide may have been caused by the erosion and formation of the creek channel. If the creek is still actively eroding, it will be necessary to establish development set backs to reflect



FAIRMONT HOT SPRINGS
TERRAIN HAZARD AS

potential future erosion induced slope failures or to stabilize the creek. If the initial slide was not affected by creek instability, but rather a localized slope instability, again development set backs will be required but in the case creek instability will not be a factor.

Poor foundation conditions are expected on the surface of the old slide area. Standard design procedures will establish safe bearing limits and appropriate footings would be constructed.

3.2 MERIDITH CREEK

Meridith Creek is unusual in that there is no evidence of a channel across the golf course. The upper reaches show evidence of debris flows in the past. A debris fan, upon which the golf course is constructed, is evidence of such activity. The flows in recent years must have been so low so as to spread out and flow in a wide and shallow fashion across the golf course. In such a way no erosion would occur on the golf course and with such small discharges no debris from the upper reaches would be transported to deposit on the golf course.

The debris hazard zone can be moved up the basin by incorporating one or more debris retention facilities on the upper reaches of the fan or in the lower reaches of the incised transport zone.

Erosion in the existing channel should present no hazard to development if the debris retention facilities are constructed and construction is set back from the steep slopes a sufficient distance. In areas where development of housing is to be undertaken the process of development will provide long term stability. The housing, roads and seeding of lots would provide surface protection following development.

The effects of silt liquefaction hazard can be minimized by providing an adequate setback along the top of the steep slope and/or by stabilizing the river along the base of the hazard zone.

3.3 FAIRMONT CREEK

The debris flow hazard along Fairmont Creek can be controlled in two ways. The first would be to stabilize the deeply incised transport reach between the resort complex and the golf course. Several debris retention dams would be required to reduce the channel slope and retain debris from farther up the basin. An extensive road access system would be required to provide access by service vehicles. A second option would be to provide debris deflection dams in the golf course to direct the debris flows and provide areas to control the location of debris deposit. **The exiting aesthetic lake acts as a debris trap and can continue to do so.**

agree but silt + water floods lots down slope during events. ie pond does not retain everthing

↑ should beef up channel from lake to Columbia. R.

The silt liquefaction hazard zone and the poor foundation hazards can be handled in the same manner as previously discussed.

3.4 COLD SPRING CREEK

The hazards within the drainage basin of Cold Spring creek are primarily due to debris flows. The deeply incised upper reaches are within the debris transport zone and control of the hazard involves the ongoing maintenance of the existing debris retention dam. Provision of debris guiding walls to extend the transport zone through the deposition zone will protect development. Construction of a debris retention basin immediately above the Columbia River will protect the river from sudden sediment loads (JNM, 1989b).

The erosion and gullying hazard can be controlled by regrading and revegetation which would be typical during a development project. In areas where development of housing is to be undertaken the process of development will provide long term stability. The housing, roads and seeding of lots would provide surface protection following development. The development of a golf course will necessitate the stabilization of the ground surface by reducing the potential of erosion with the use of dense grass cover associated with the golf course.

The silt liquefaction hazard should be further quantified prior to development to evaluate the effect of dewatering resulting from the construction of the retention basin and subsurface drainage in the golf course area.

3.5 TUKATS CREEK

The debris flow hazard on the Tukats Creek can be controlled by constructing debris guiding walls to prevent the flow from spreading and depositing (Figure 3.2). The flows can be directed to a deeply incised ravine west of Highway 93. The deposition can more readily be controlled on the flat area adjacent to the river.

Erosion and gullying hazards can be controlled with vegetation on the steep slopes or the establishment of development set backs. In areas where development of housing is to be undertaken the process of development will provide long term stability. The housing, roads and seeding of lots would provide surface protection following development.

3.6 DUTCH CREEK

The primary hazard along Dutch Creek is related to flooding (Figure 3.2). The drainage area is larger than that reported (Jackson, 1987) for mountain creeks producing debris torrent flows. However, a considerable amount of alluvial outwash material will be carried with the flows and this material must be considered. In this area there is a considerable accumulation of alluvial material deposited as the creek spreads out across the outwash fan. The present location of the creek has been the result of ongoing maintenance with heavy equipment. The equipment routinely pushes the alluvial material into guide dikes in an attempt to keep the flows in the existing well defined channels. The guide dikes are not protected from erosion and on occasion breach with flows going into an existing gravel pit and across the existing development area to the Columbia River. The most recent occurrence being during the summer of 1991.

Since existing developments are being threatened and occasionally damaged the province should become involved in providing adequate training works to protect the developments and direct the flows into Columbia Lake. Flooding and associated flood damages along the Columbia River would be greatly increased if the flows from Dutch Creek were not routed through the lake but were able to enter the river directly.

An area of steep slope causes an erosion and gullying hazard can be dealt with by utilizing appropriate setbacks. In areas where development of housing is to be undertaken the process of development will provide long term stability. The housing, roads and seeding of lots would provide surface protection following development.

4.0 CONCLUSIONS

- Specific terrain hazards as well as potential works or precautions to minimize the hazards have been identified on a conceptual basis for the Fairmont Hot Springs Resort area. One potential source of hazard has not been specifically addressed in that it is outside the scope of this report and control of Fairmont Hot Springs Ltd.; logging or timber harvesting in the upper reaches of the water courses must be controlled so as not to increase the existing flooding and debris flow hazards.

- The development of areas within the hazard zones identified or adjacent to the debris flow control works should be accompanied with the required engineering design to minimize the hazards. The debris flow control works including retention dams, guide channels and retention basins will require hydrologic assessment of flows and potential debris volumes. The configuration and component specification would be a part of the detailed design of the protective works during the planning and design of the affected developments.

- Flooding along the Columbia River has previously been addressed. The flooding along the creeks can be addressed at the time of development adjacent to the individual creeks.

- Erosion and gullying hazards can be addressed on an individual area basis with vegetative cover, regrading or development setbacks; the specific method to be determined during the development of the affected areas. In areas where development of housing is to be undertaken the process of development will provide long term stability. The housing, roads and seeding of lots would provide surface protection following development.

- Silt liquefaction is a hazard requiring site specific geotechnical evaluation. Specific items to resolve would be a definition of the specific bounds of the hazard zone, the cause of the potential instability and selection of the method to be utilized in minimizing the risks. Methods utilized will include but not be restricted to dewatering, setbacks and river stabilization at the base of the hazard zones.

- Poor foundation conditions will be evaluated during the design and construction of individual structures. As this is a standard requirement for any development no further specific consideration should be given to this hazard within the scope of further terrain hazard work.

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CORPORATE STUDY TEAM

The following staff of Reid Crowther & Partners Ltd. participated in the project:

Mr. Jim Dumont, P. Eng., P. Ag. - Project Engineer
Mr. Doug Reeder - Drafting
Mrs. Fran Boyko - Secretarial

APPENDIX A

Cave, P. W. Natural Hazards, Risk Assessment and Land Use Planning in British Columbia: Progress and Problems. Geotechnique and Natural Hazards, BiTech Publishers Ltd. 1992.

Natural Hazards, Risk Assessment and Land Use Planning in British Columbia:

Progress and Problems

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As scientists and policy makers confront increasing numbers of real world examples of development applications which hinge on geotechnical issues, they are becoming more aware of the complexities and subtleties involved in a land use planning program which tries to address effectively the risks associated with natural hazards. Many questions are involved, including statutory authority, property rights and values, insurance implications, mortgage security, perceptions of risk, the predictability of the hazard event, the degree of confidence in the state of scientific understanding and the extent of political fortitude to withstand criticism and to implement a consistent program. To codify these issues and to develop an integrated program requires patience, experience, and a willingness to accept the need to make decisions in an environment of uncertainty and incomplete knowledge.

In Fraser-Cheam Regional District such a program has been developed over the past eight years. Particularly since the amendments to the Municipal Act in 1985, which directly empowered and required local governments to address matters of geotechnical safety in planning and development approval, Fraser-Cheam has been amongst the most active jurisdictions in the Province in devising a program of hazard land management. This level of activity is not surprising because this region of southwestern B.C. is geomorphologically immature and unstable, with examples of virtually every kind of slope instability and river hazard which commonly threatens settlements and transportation. The steep mountain slopes of the Cascades are subject to snow avalanches, landslides, rockfall and debris flows, while the river valleys are prone to flooding, erosion and stream avulsion. Combined with strong development pressures 100-150 kms. away from Vancouver and a vigorous provincial program to protect flat agricultural land from development, these geotechnical conditions pose a real challenge to planners to devise a regulatory program which allows for safe, orderly development.

I. Progress

An idealized sequence describing this type of program is shown in Figure 1 which illustrates a four-step process from hazard identification to regulatory enforcement and remediation in the context of B.C. legislation. In its simplest form, program establishment would be linear with each

GOAL (PROGRAM COMPONENT)	OBJECTIVE (POLICY OR ISSUE)	METHOD (IMPLEMENTATION)
I. Hazard Identification and Evaluation	Hazard Mapping	*-Overview geotechnical study*
	Risk acceptability thresholds	*-Secondary geotechnical study*
II. Formulation of Policy and Regulation	OCP - general and special policies	*-MA Sect. 945(2)(d) policy statements in OCP Bylaw*
	- development permit areas	*-MA Sect. 945(4)(b) designation in Bylaw*
	Zoning regulations for land uses, buildings and structures	*-MA Sect. 963 Bylaw*
	Tree cutting regulations	*-MA Sect. 978 Bylaw*
	Floodproofing regulations	*-MA Sect. 969 Bylaw*
III. Development Approval	Rezoning	*-Site-specific geotechnical report, rezoning bylaw and LTA Sect. 215 covenant*
	Development Permit	*-Site-specific geotechnical report, permit under MA Sec. 976(5) and LTA Sect. 215 Covenant*
	Subdivision Approval	*-Site-specific geotechnical report, LTA Sects. 82 & 215 Covenants*
	Building Permit	*-Site-specific geotechnical report, MA Section 734(4) Covenant, letters of professional assurance and P.E. inspection reports.*
IV. Enforcement and Remediation	Enforce Covenant	*-Civil action for breach of contract*
	Enforce Permit and/or Bylaw	*-MA Sect. 750.1 Notice registered against title in Land Title Office* *-Information and Prosecution* *-Injunction*
	Enforce remediation	*-MA Sec. 735 Bylaw for demolition, removal or bringing up to standard a building or structure or infilling or covering an unsafe excavation* *-MA Sect. 936 for municipalities* *-Special powers re liability and cost recovery*

Figure 1. Hazard Land Management and Development Control: An Idealized Sequence

stage following the completion of the previous one. In practice, of course, all four components tend always to move ahead together with new information and experience in one area leading to revisions and improvements in others.

This paper summarizes the program developed in Fraser-Cheam, drawing attention to major substantive and methodological issues. Based upon this experience, it then makes recommendations for improvement and assistance directed at both the scientific and engineering community and at the provincial and other governments.

Hazard Identification

Hazard identification in Fraser-Cheam is essentially a two-step process, the rationale for which has been described in greater detail elsewhere[1]. Under the Community Planning budget, and in the context of section 945 of the Municipal Act, it begins with an **overview geotechnical study** which is commissioned to identify those areas of land which appear to be free from the types of hazards listed in the Act. These overview studies are quite preliminary and are based largely on air photo interpretation with supplementary field reconnaissance. Therefore, the geotechnical engineer must draw the "safe line" cautiously and well clear of natural hazards. This is the area on which development is normally allowed to proceed without further geotechnical investigation unless building foundation conditions on site require special attention.

Outside of this "safe" area is a more problematical "geotechnical study area" or "geologically sensitive area" within which exposure to risk may vary from virtually none to extremely high. Where portions of this "study area" are already developed, especially for residential uses, such that they may be exposed to existing hazards, Fraser-Cheam will normally proceed to the next investigative step which is the **secondary geotechnical study**. Typically, this will involve hip-chain and clinometer foot traverses, detailed geologic observations, topographic mapping, test pitting and specialist geotechnical skill in slope hazard investigation. Unlike the overview study, the secondary study will specifically identify those lands which are subject to hazards of various kinds and will assign return period probabilities to events of different magnitude. It tends to be the most elaborate and expensive phase of geotechnical investigation. Normally, the secondary study will increase the extent of the safe area as improved knowledge allows the geotechnical engineer to be more definitive.

Under B.C. statute, the onus falls upon the developer to undertake **site-specific geotechnical studies** prior to receiving development permits or building permits[2]. These studies are more limited and focused, but also much more numerous, with over 150 examples in Fraser-Cheam compared with 7 overview and 12 secondary studies. Generally, they contain recommendations respecting hazard avoidance or mitigation measures, some of which can be fully implemented during the construction phase while others relate to on-going maintenance or monitoring.

Evaluation

Evaluation of these hazards, once identified, is essentially a matter of determining the levels of risk which are acceptable for various types of development. These **hazard acceptability thresholds** will depend upon the specific nature of the hazard and upon the density of use of the land and hence upon the level of exposure or risk. Where risks exceed these thresholds, hazard mitigation measures have to be considered, including protective engineering and, under certain circumstances, legal devices designed to transfer liability. Because complete hazard avoidance (zero exposure) is less realistic in some areas than in others, acceptability thresholds have to be determined regionally, or perhaps provincially, and cannot yet be expected to be consistent from one geological and climatic zone to another.

In Fraser-Cheam, acceptability thresholds have been defined in some detail for eight different types of natural hazard[3]. They represent a codified summary of the many previous decisions of the elected Regional Board which in turn were based partly on limited provincial guidelines (respecting flood hazards and subdivision approvals), partly upon legal precedent[4], and particularly upon advice from engineers and staff. Typical examples are shown in Figure 2, which describes the regulatory response to various types of applications for residential development in the face of rockfall, debris flood, catastrophic landslide, and Fraser River flood hazards. Other thresholds are applied to stream avulsion, debris flow, minor landslip and snow avalanche hazards. Thresholds are higher for those applications which involve higher densities of use, and therefore greater risk (i.e. higher overall exposure to the hazard), and for those hazards which pose a greater threat to life. Note also that a spectrum of conditions may be attached to any given approval to reflect strategies of hazard prevention, avoidance, mitigation, protection and liability transfer, as appropriate to the situation.

Policy, Regulation, Approval and Enforcement

Five separate sections of the Municipal Act empower local governments to develop policies and regulations to implement these hazard acceptability thresholds[5]. Each must be adopted by a bylaw as opposed to a resolution, permit, agreement, contract or administrative procedure. Public and provincial government input into the process, including a public hearing where necessary, is specified in Part 29 of the Act. Community plans, development permit areas, zoning bylaws, flood-plain and tree-cutting bylaws all form part of an integrated policy and regulatory program. Its components should be clearly spelled out in the bylaws and should be made understandable to the public through appropriate brochures and information packages directed at those who may be affected. Otherwise, consistent implementation of the program and public support or compliance is almost impossible to achieve.

Development approval through rezonings, development permits, subdivision approvals, building permits and agreements is a complex technical field involving the use of a whole array of legal

Type of Project	Rockfall: Small-Scale Detachment					Debris Flood			
	Annual Return Frequencies					Annual Return Frequencies			
	1:100	1:100-1:500	1:500-1:1000	1:1000-1:10000	<1:10000	1:50	1:50-1:200	1:200-1:500	1:500-1:10000
Minor Repair (<25%)	5	2	1	1	1	2	2	1	1
Major Repair (>25%)	5	4	2	1	1	4	4	1	1
Reconstruction	5	4	2	1	1	4	4	3	1
Extension	5	5	4	1	1	4	4	3	1
New Building	5	5	4	1	1	4	4	3	1
Subdivision (infill/extend)	5	5	5	4	1	5	5	4	2
Rezoning (for new community)	5	5	5	5	1	5	5	5	3

Type of Project	Major Catastrophic Landslide					Inundation by Fraser River			
	Annual Return Frequencies					Annual Return Frequencies			
	1:200	1:200-1:500	1:500-1:1000	1:1000-1:10000	<1:10000	1:40	1:40-1:200	1:200-1:500	1:500-1:10000
Minor Repair (<25%)	5	2	1	1	1	2	1	1	1
Major Repair (>25%)	5	5	2	1	1	4	3	3	1
Reconstruction	5	5	5	1	1	4	3	3	1
Extension	5	5	5	1	1	4	3	3	1
New Building	5	5	5	1	1	4	3	3	1
Subdivision (infill/extend)	5	5	5	5	1	5	4	4	1
Rezoning (for new community)	5	5	5	5	5	5	5	5	1

1. Approval without conditions relating to hazards.
2. Approval, without siting conditions or protective works conditions, but with a covenant including 'save harmless' conditions.
3. Approval, but with siting requirements to avoid the hazard, or with requirements for protective works to mitigate the hazard.
4. Approval as (3) above, but with a covenant including 'save harmless' conditions as well as siting conditions, protective works or both.
5. Not approvable.

Figure 2. Hazard-related Responses to Development Approval Applications.

instruments. For the most part, final approval is an administrative process, as opposed to a political one, such that the applicant is required to satisfy the concerns and meet the standards identified in the policies, and relatively little discretion is involved.

Having issued a development approval, enforcement proceedings or remediation measures must be taken if the project deviates from the geotechnical safety conditions imposed in the permit. Unfortunately, this is an area of statute in which there remain some gaps in B.C., particularly with respect to hazardous situations induced by unsound earth-moving or similar activity and with respect to the locus of liability following public sector intervention. Perhaps these gaps are more apparent than real and reflect only the recency of the statutes. As case law develops, the extent of local government's duty of care for geotechnical hazards will become better defined and only then will the full implications of the amendments enacted in the 1980's become clear.

II. Problems

Based on experience with integrated programs such as the one in Fraser-Cheam, it is possible to identify those aspects of the system which remain inadequate. The analysis and recommendations which follow are grouped in terms of the improvements which are necessary in data collection, data distribution, interpretation, program design and implementation. Overall, this review of the strengths and weaknesses of the system suggests that the regulatory framework is somewhat ahead of the science and its institutional support system.

Data Collection

Academic research in the field of natural hazards tends to focus on process, rather than on place, in the hope of developing an understanding which would have general applicability in other situations. As a result, there are many examples of potentially hazardous situations which have not been subject to intensive study despite their significance from a public safety point of view. Moreover, there is no agency with a clear mandate and funding to remedy this deficiency and systematically review the extent to which each area may be exposed to hazards.

A case in point was the research conducted into the possibility that Mt. Breakenridge, on the shores of Harrison Lake in Fraser-Cheam, could perhaps be the source area for a future catastrophic landslide and resultant tsunami-type wave which could devastate the shoreline[6]. Helicopter reconnaissance seemed to suggest that the threat may be real; but there was no institutionalized system for assessing the need for action and in any case the costs of a meaningful investigation were far beyond the local government's resources. To its credit the provincial government provided special funding under the Provincial Emergency Program and, fortunately, the study found the mountain to be more benign than first feared. Despite good science and responsible actions by the Province, however, the exercise revealed serious flaws in the system.

First, the linkage between PEP and geotechnical research is not a good one from a public relations perspective, at least until the existence of a serious hazard is proven, because it only lends weight to the many sceptics who doubt the value of any such work on the predictability of natural hazards. The positive findings, rather than prompting critical review and feelings of relief, tended to be disparaged and the whole study cited as an example of bureaucratic over-anxiety. Furthermore, once the prospect of an emergency was dispelled, it was very nearly impossible to obtain the funding necessary to return to the site and take readings from the extensometers which had been installed to monitor the tension cracks.

Secondly, the lack of any routine, objective, scientific, comparative review process necessarily forced an *ad hoc* decision on whether to devote scarce resources to research this one particular problem, as opposed to any one of several dozens of other potentially hazardous situations in the Province. Matters of liability and political credibility inevitably factor into such decisions, but there is no doubt that the system would be served better if there existed a standing committee of qualified professionals whose role it was to review the merits of, and assign priorities to research directed at public safety.

These problems could be remedied by the establishment of a structured and on-going program of research, with objectively defined priorities, under the auspices of the B.C. Ministry of Environment. This is not to argue that local government's existing mandate for geotechnical study in official community plans should be changed, or that developers should not be required to undertake site-specific studies when there is a known problem. Rather, the analogy is drawn to seismic and geophysical hazards, and to meteorological hazards, for which it is generally agreed that the public sector has the primary responsibility to identify zones of risk. The B.C. government has accepted this position with respect to flood hazards and has taken a lead role in regulation, but responsibility for other geotechnical hazards has been delegated to local government without the benefit of systematic research having been undertaken.

Data Distribution

The need to establish some form of central registry for geotechnical reports was one of the principal recommendations to flow from the provincial Geologic Hazards Workshop in 1991 which brought together more than 130 experts on various aspects of geologic hazards and public safety from B.C, Yukon, Alberta and Washington State for a meeting at the University of Victoria[7]. The workshop reviewed existing knowledge, on-going research, current legislation and implementation techniques and concluded that the B.C. Geological Survey should establish and operate the registry as a central data-base for this vital information. For its own area, Fraser-Cheam already maintains such a data-base, but there is no doubt that ready access to a more comprehensive reference source would enhance the quality of site-specific studies while limiting their cost. Indeed, one of the principal shortcomings of these limited-budget private commissions is their failure to consult previous relevant work on a consistent basis.

Professional Standards

Recognition of the professional significance of the 1985 legislation has been rather slow to develop within the engineering community. It remains an alarming fact that some professionals are still not fully aware of the statutes, and of the implications of the requirement for "certification"[8]. Amongst the great preponderance of good reports, for example, Fraser-Cheam has received too many which are either substantively incompetent, prematurely presented (with inadequate evidence) or otherwise fatally flawed. The results are almost always difficult and embarrassing both for the client and the regulator. Examples include a study which denied the possibility of an erosion hazard at a proposed building site on the active soft alluvial floodplain of a fast flowing mountain river, a study which identified a serious landslide hazard affecting private land which later proved to be false, and reports insensitive to the regional geotechnical context of their subject because of failure to consult previous work. Even the method and timing of reporting, not simply the matter of substance, is critically important in the light of present legislation. The guiding principles for any report affecting public safety must be prudence and caution, but premature announcements of negative findings, unless supported by irrefutable evidence, can be almost as destructive as unwarranted optimism and can easily attract liability.

This is not the place to recommend any specific actions which should be taken by professional associations to remedy these problems. However, there is clearly a need for these organizations to increase the level of awareness of the legislation and to define some standards for geotechnical reports to meet. In their absence, Fraser-Cheam has compiled a preliminary list of criteria against which to evaluate the acceptability of geotechnical reports[9], including the requirement that the engineer show evidence that previous work has been consulted. This does not, however, provide a proper substitute for guidelines from a professional association.

Methodology

Given the rapidly developing state of knowledge in the science, it is perhaps inevitable that geotechnical reports display an inconsistency of methodology which makes them difficult to compare and to implement. This diversity may be creative rather than negative; convergence cannot be anticipated until a consensus has developed within the scientific community. Nevertheless, there are certain methodological principles which could be agreed upon immediately if professional leadership were present.

One source of confusion, for example, is the distinction for subdivisions between those geotechnical reports which detail "hazard free" or "safe building areas" and those which identify "safe building sites". The one type of study will review geotechnical conditions over the entire parcel to be subdivided and will demarcate a "safe line" which is then locked in by means of a covenant against further re-subdivision or future development of the lands beyond the surveyed safe line. The simpler and cheaper, "safe building site" study is more suitable for one- or two-lot subdivisions particularly in areas where future re-subdivision is unlikely. In these studies, the engineer restricts his report and certification to the future proposed building site, and the geotechnical conditions which may affect it, leaving remaining areas to be studied at some date in the future. In this case, the covenant will require that the new building occur only within the approved site and will commit a future owner to undertake additional geotechnical study before any other portion of the land can be developed.

A second and more profound source of confusion concerns the use of probability statements to express the uncertainty inherent in predicting natural hazards. From a regulatory perspective there is a clear need to distinguish between those probability statements which describe uncertainty as to the **timing** of an event which is considered to be virtually inevitable to occur in the long run and those in which the probability statement expresses uncertainty as to whether the event will **ever** occur. The latter has scientific value and may accurately describe the (uncertain) state of knowledge, but it provides no credible basis for land use regulation. Too often are these types of statement presented as equivalent when in reality they are fundamentally different.

Finally, in terms of specific methodology, professional engineers and geoscientists should make a particular effort to incorporate Quaternary geologic and geomorphologic evidence and, where necessary, they should provide the same level of detailed support mapping for these surficial features as is normal for structural elements. Reports should be set in a regional geomorphological context and should contain lines of reasoning and judgement in sufficient detail to allow an independent professional review, where necessary, by the approving authority.

Interpretation

Despite the success in applying the acceptability thresholds adopted locally by Fraser-Cheam Regional District, there is no doubt that thresholds defined provincially would be preferable and easier to administer. Already the provincial government has provided guidance in the context of flooding and subdivision. A more complete set of guidelines would make it easier for local authorities to obtain compliance and would assist the professional community in standardising the content of reports. It would also help to clarify such matters as liability and the effect of hazards on property values in relation to insurance and mortgage equity. Given all the other problems in the geotechnical field, it may still be somewhat premature to expect definitive guidelines from the Province. In the long run, however, acceptability thresholds will not be set by local government. They will be defined at the provincial level either by the government or by the courts, and the latter would involve a much longer and more painful process.

Program Design

Amongst the shortcomings of the hazard land management and development control program illustrated in Figure 1 is the fact that it is conceived as a linear and a "one time" decision process. This limitation is not surprising because it reflects the statutory basis of the program in regulating new development. Inherently this fails to recognise that hazards do not exist only at one point in time. Their probabilities are not static; they are dynamic and will change along with geotechnical conditions (such as the quantity of debris in a stream channel) and with science's ability to predict.

Although most geotechnical engineers will recommend some form of monitoring as an integral part of their certification, few agencies at the local level are able to commit to such a program over the long term. Noteworthy is the fact that the Ministry of Environment, which oversees the flood protection program, routinely monitors the snow-pack prior to the spring freshet, and the Ministry of Highways monitors and scales unstable rock slopes and potential snow avalanches which pose a threat to provincial roads. Techniques are becoming increasingly sophisticated and reliable and there is no doubt that monitoring is a valuable adjunct to hazard avoidance and protection. Local governments, on the other hand, do not have the resources to do the same kind of monitoring even of those slopes which may have been given only conditional safety certification prior to development.

This deficiency must be corrected if the hazard land management program in the Province is ever to become reliable, consistent and fully accepted by the population. An established monitoring program will permit a more flexible, sensitive and "common sense" response to development applications. As an aid to its establishment, it would be useful if geotechnical reports would be more specific as to the nature, frequency and cost of the monitoring which is recommended. Local governments might then be able to seek an endowment fund at the time of development, or might introduce a tax levy against the new development sufficient to pay the costs of the required monitoring.

Implementation

The recent review of geotechnical programs completed for the Ministry of Municipal Affairs identified surprisingly few gaps and inconsistencies in the statutory framework[10]. A hazard land management program would certainly be easier to implement if there were clear authority to intervene in situations where earth-moving (for driveway construction or any other reason) was creating a condition of instability which did not previously exist. Such activity rarely requires a permit, and in its absence intervention and remediation is not mandated. Implementation would be easier, too, in difficult cases where things have gone wrong, if local government were empowered to recover the costs of enforcement and remediation on the taxes against the property and if there were protection from liability in the event that the best efforts of the municipality to effect a solution prove ultimately to be unsuccessful. Perhaps the statutes could help, too, by making explicit reference to the funding and liability issues of long-term monitoring activities.

Nevertheless, these are not the primary difficulties in regulating development in the context of risk from natural hazards. Much more problematical is the relatively primitive state of geotechnical science today, the lack of funding to permit adequate research and the lack of agreement as to methodology and as to hazard acceptability thresholds. Certainly some of the work being undertaken in B.C. is exemplary and some geotechnical reports are penetrating and profound. However, given the inconsistent quality of reports, the number of differing opinions and the variable state of knowledge available to the decision-maker at the critical time, it is sometimes easy to believe that the geotechnical community as a whole is not yet ready to have its advice form the basis for statutory regulation. For those planners and politicians who dread the alternative, and for the sake of public safety as a whole, the hope must be that these problems will be rapidly overcome.

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