

FRASER CHEAM REGIONAL DISTRICT

CHILLIWACK RIVER HAZARD MANAGEMENT STUDY
INTERIM REPORT

VOLUME 1 - TEXT

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HAY & COMPANY CONSULTANTS INC.

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GOLDER ASSOCIATES LTD.
D.B. LISTER & ASSOCIATES
URBAN SYSTEMS LTD.
ROBERT LAIRD
KEITH MOORE

CONTENTS

1	INTRODUCTION	1
1.1	Study Objectives	1
1.2	General Definition of Terms	1
1.3	Study Area	2
1.4	Mapping	3
1.5	Study Overview	5
2	BASIN RESOURCES	5
2.1	General	5
2.2	Residential	6
2.2.1	Future Growth	6
2.3	Agricultural	7
2.4	Institutional	7
2.5	Recreational	8
2.5.1	Recreational Facilities	8
2.5.2	Activity Levels	9
2.5.3	Future Recreational Uses	11
2.6	Fisheries	11
2.6.1	Salmonid Life Histories	11
2.6.2	Habitat Utilization	12
2.6.3	Magnitude of the Fishery Resource	13
2.6.4	Seasonal Constraints on Instream Construction Work	14
2.7	Forestry	14
2.7.1	The Forest Land Base	15
2.7.2	Past Commercial Forest Harvesting and Silviculture (1945-1990)	15
2.7.3	Current and Projected Commercial Forest Harvesting and Silviculture (1990-1995)	16
2.7.4	Value of Forest Harvesting and Silviculture	16
2.8	Infrastructure	17
2.9	Cultural	17
3	BASIN GEOGRAPHY	17
3.1	General Characterization of Features	17
3.2	Geology	19
3.2.1	Bedrock Geology	19
3.2.2	Surficial Geology	19

3.3	Groundwater	23
3.4	Hydrology	24
3.4.1	General	24
3.4.2	Factors Influencing Major Flood Events	24
3.4.3	Flood History and Analysis	25
3.4.4	Flood Frequency Analysis	26
3.4.5	Forest Harvesting and Runoff	27
3.5	Morphology	28
3.5.1	River Characteristics	29
3.5.2	Sediment Sources and Transport Rates	32
3.5.3	Recent Channel Changes	34
3.5.4	Summary of River Channel Dynamics	37
4	HAZARDS	38
4.1	Emergency Response Costs	38
4.2	Flood Hazards	40
4.3	Erosion Hazards	43
4.4	Geotechnical Hazards	47
4.4.1	Hazard Type	49
4.4.2	Hazard Distribution	50
4.4.3	Hazard Assessment	50
4.4.4	Slesse Park Area	51
4.4.5	Bell Acres Area	53
4.4.6	Baker Trails Area	55
4.5	Drainage	58
5	HAZARD MANAGEMENT	61
5.1	Existing Legislative Controls	61
5.2	Hazard Mitigation	63
5.3	General Mitigative Options	65
5.3.1	Non-Structural Options	65
5.3.2	Structural Options	67
6	HAZARD MITIGATION OPTIONS - SLESSE PARK TO BAKER TRAILS	72
6.1	General	72
6.2	Development Control Options	73
6.3	Source Control Options	75

6.3.1	Hazard Monitoring	75
6.3.2	Flow Detention	76
6.3.3	Sediment Control	79
6.3.4	Debris Control	83
6.4	Site-Specific Options - Slesse Park Area	85
6.4.1	Flooding and Erosion	86
6.4.2	Geotechnical Hazards	87
6.5	Site-specific Options - Bell Acres Area	88
6.5.1	Flooding and Erosion - Chilliwack River	88
6.5.2	Flooding - Ryder Creek	90
6.5.3	Geotechnical Hazards	91
6.6	Site-Specific Options - Baker Trails Area	92
6.6.1	Flooding and Erosion	92
6.6.2	Geotechnical Hazards	95
7	SELECTION OF HAZARD MANAGEMENT OPTIONS	95
8	IMPLEMENTATION FRAMEWORK	100
8.1	Existing Administrative Framework	100
8.2	Existing Financial Framework	104
8.2.1	An Administration and Financial Implementation Option	106
8.3	Technical Framework	110
8.4	Hazard Management Outline Plan	112
APPENDIX 1: Terms of Reference		
APPENDIX 2: Derivation of Chilliwack - Vedder River Salmon and Steelhead Trout Statistics		
APPENDIX 3: Summary of 'Clay Slide' Study		
APPENDIX 4: Structural Mitigation Cost Estimates for Flood and Erosion Hazards		

LIST OF TABLES

TABLE 1:	Chilliwack River Valley Property Categories
TABLE 2:	Fish Stocks
TABLE 3:	Forest and Logged Areas in the Chilliwack Watershed (pre 1965-1992)
TABLE 4:	Silvicultural Activities in the Chilliwack Watershed (1960 - 1990)
TABLE 5:	Proposed Logging in Tributary Watersheds of the Chilliwack River (1991 - 1995)
TABLE 6:	Estimated Dollar and Employment Value of Timber Removed from the Chilliwack Watershed, 1985 - 1989
TABLE 7:	Water Survey of Canada Gauging Stations
TABLE 8:	Unreported Floods
TABLE 9:	Flood Frequency Distributions - Chilliwack River at Vedder Crossing
TABLE 10:	Percent of Total Chilliwack River Watershed Harvested over 5-Year Periods
TABLE 11:	Percent of Chilliwack River Sub-Basin Areas Harvested over 5-Year Periods
TABLE 12:	River Bed Survey Comparisons 1976-1991, Slesse Park to Vedder Crossing
TABLE 13:	Bank Erosion, Slesse Park to Baker
TABLE 14:	Definition of Hazard Zones
TABLE 15:	Probability:Magnitude Relationships - Slesse Park
TABLE 16:	Probability:Magnitude Relationships - Ryder Creek to Slesse Park
TABLE 17:	Probability:Magnitude Relationships - Baker Trail Village

TABLE 18:	Potential for Debris Flow Events over next 50 Year Period at Baker Trail Village
TABLE 19:	Estimated 200 Year Flows for Ryder Creek and Wingfield Creek
TABLE 20:	Legislation Relevant to Hazard Management
TABLE 21:	Status of Existing Mitigative Works in the Slesse Park Area
TABLE 22:	Potential Options for Mitigation against Risks from Channelized Hazards - Slesse Park
TABLE 23:	Status of Existing Mitigative Works in the Bell Acres Area
TABLE 24:	Status of Existing Mitigative Works in the Baker Trails Area
TABLE 25:	Comparison of Capitalized Cost of Flood and Erosion Hazard Protection for Various Options. Chilliwack River - Slesse Park to Baker Trails
TABLE 26:	Potential Mitigative Options - Baker Trail Village
TABLE 27:	Comparison of Mitigative Options for Flood and Erosion Protection for Developed Properties
TABLE 28:	Comparison of Structural Mitigative Options for Flood and Erosion Control - Slesse Park
TABLE 29:	Comparison of Structural Mitigative Options for Flood and Erosion Control - Bell Acres
TABLE 30:	Comparison of Structural Mitigative Options for Flood and Erosion Control - Baker Trails
TABLE 31:	Activities of Government Agencies in the Chilliwack River Valley

LIST OF FIGURES

- FIGURE 1: Chilliwack River Watershed
- FIGURE 2: Study Area
- FIGURE 3: 1:5000 Scale Map Coverage
- FIGURE 4: Land Use
- FIGURE 5: Recreational Use
- FIGURE 6: Generalized Bedrock Geology
- FIGURE 7: Surficial Geology
- FIGURE 8: Valley Cross-Section: Bell Acres - Km 32.0
- FIGURE 9: Valley Cross-Section: Slesse Park - Km 28.5
- FIGURE 10: Valley Cross-Section: Km 25.5
- FIGURE 11: Valley Cross-Section: Slesse Creek - Km 21.5
- FIGURE 12: Historic Floods and Rainfall
- FIGURE 13: Long Term Climate Trends
- FIGURE 14: Flood Frequency
- FIGURE 15: River Bed Profile
- FIGURE 16: River Cross-Sections - Baker Trails Area
- FIGURE 17: River Cross-Sections - Edwards Road Area
- FIGURE 18: River Cross-Sections - Provincial Park Area
- FIGURE 19: River Cross-Sections - Bell Acres Area
- FIGURE 20: River Cross-Sections - Slesse Park Area
- FIGURE 21: Typical Stage Discharge Curve
- FIGURE 22: Bank Erosion Rates
- FIGURE 23: Typical Flood Proofing Options
- FIGURE 24: Typical Flood Protection Options

- FIGURE 25: Typical Bank Protection Options
- FIGURE 26: Slesse Park Flood and Erosion Hazards - Structural Mitigation Option 1
- FIGURE 27: Slesse Park Flood and Erosion Hazards - Structural Mitigation Option 2
- FIGURE 28: Slesse Park Flood and Erosion Hazards - Structural Mitigation Option 3
- FIGURE 29: Conceptual Design for Creek Channelling - Slesse Park Area
- FIGURE 30: Conceptual Mitigation for Debris Flow/Flood Hazards - Slesse Park
- FIGURE 31: Bell Acres Flood and Erosion Hazards - Structural Mitigation Option 1
- FIGURE 32: Bell Acres Flood and Erosion Hazards - Structural Mitigation Option 2
- FIGURE 33: Bell Acres Flood and Erosion Hazards - Structural Mitigation Option 3
- FIGURE 34: Bell Acres Flood and Erosion Hazards - Structural Mitigation Option 4
- FIGURE 35: Bell Acres Flood and Erosion Hazards - Structural Mitigation Option 5
- FIGURE 36: Ryder Creek Area Flood Hazard - Structural Mitigation Option
- FIGURE 37: Baker Trails Flood and Erosion Hazards - Structural Mitigation Option 1
- FIGURE 38: Baker Trails Flood and Erosion Hazards - Structural Mitigation Option 2
- FIGURE 39: Baker Trails Flood and Erosion Hazards - Structural Mitigation Option 3
- FIGURE 40: Baker Trails Flood and Erosion Hazards - Structural Mitigation Option 4
- FIGURE 41: Baker Trails Flood and Erosion Hazards - Structural Mitigation Option 5
- FIGURE 42: Baker Trails Flood and Erosion Hazards - Structural Mitigation Option 6
- FIGURE 43: Conceptual Mitigative Options for Containment Structures - Baker Trails Village
- FIGURE 44: Conceptual Outlet Details for Containment Structure at Base of Guy Creek
- FIGURE 45: Conceptual Mitigative Structures for Debris Flow/Flood Hazards - Baker Trails Village

LIST OF DRAWINGS

- DRAWING 1: Logging Chronology
- DRAWING 2: Geomorphic Features and Bankline Changes
- DRAWING 3: Flood and Erosion Hazards - Slesse Park Area
- DRAWING 4: Flood and Erosion Hazards - Bell Acres Area
- DRAWING 5: Flood and Erosion Hazards - Baker Trails Area
- DRAWING 6: Slope Hazards - Slesse Park Area
- DRAWING 7: Debris Flow Hazards - Slesse Park Area
- DRAWING 8: Debris Flood Hazards - Slesse Park Area
- DRAWING 9: Slope Hazards - Bell Acres Area
- DRAWING 10: Debris Flow Hazards - Bell Acres Area
- DRAWING 11: Debris Flood Hazards - Bell Acres Area
- DRAWING 12: Slope Hazards
- DRAWING 13: Debris Flow Hazards - Baker Trails Area
- DRAWING 14: Debris Flow Hazards - Baker Trails Area

1 INTRODUCTION

1.1 Study Objectives

This study is being undertaken in accordance with terms of reference included in a call for proposals issued by the Fraser Cheam Regional District and included in Appendix 1.

The purpose of the study, as extracted from the terms of reference is,

"To prepare a natural hazards management outline plan for the Chilliwack River Valley, focusing on the long term, to protect development in the study area against damage from river flooding and erosion, and from debris flooding and landslides associated with tributary streams."

The products from the study are to be:

- an interim report that contains all the background information and conceptual alternative mitigation schemes and is a reference volume, "to assist in evolving the management plan with the study participants";
- a final report that contains the valley hazard management outline plan.

As indicated in the purpose statement, this study is to develop a hazard management outline plan for the Chilliwack River Valley that takes a long term view of the valley. However, it is recognized that initiation of a plan is required in the short term. The challenge is to ensure that mitigative measures implemented in the short term are consistent with an overall plan so as to maintain livability in the valley in an economical and environmentally acceptable manner.

1.2 General Definition of Terms

The terms hazard and risk are often used interchangeably, yet in the context of this report, and in the context of hazard management generally, a differentiation is made between these terms.

The term hazard will be used in the sense of a situation or event which, threatens injury, loss of life, substantial damage to property, or disruption of valley access and communications. The specific hazards addressed in the plan are:

- floods;
- river bank erosion;
- landslides, or other non-channelized slope failures;
- debris flows;
- debris floods.

The latter three hazards, namely, slope failures, debris flows and debris floods, have been grouped together in this report and referred to as geotechnical hazards.

The characteristics of each of the hazards addressed in the plan are described in more detail in Section 4.

Risk is the exposure of an individual to loss of health, life or economic investment resulting from the hazard. This report does not deal with the risk to an individual, but deals rather with the probability of a particular hazardous event occurring, and the area impacted by the event.

Management of hazards, within the context of a river valley, involves the preparation and implementation of a plan that reduces the magnitude of the hazard, and/or reduces the hazard exposure to an acceptable level, to both the individual and the community as a whole.

The management of hazards involves a number of steps, including:

- identification of various hazards;
- assessment of the probability of occurrence of hazards;
- extent of impact of the hazard for a given probability of occurrence;
- identification of private and public properties exposed to hazards;
- identification of the acceptable level of exposure to various hazards (by a regulatory authority);
- identification of procedures or means to avoid unacceptable hazard exposure;
- identification of procedures or means to mitigate unacceptable exposures where they cannot be easily avoided;
- implementation of procedures or methods to provide protection to life and property to within acceptable levels of exposure.

1.3 Study Area

The terms of reference for the study defined the study area as the entire watershed of the Chilliwack River, Figure 1. Specifically, the entire watershed is addressed in the report only with respect to resource uses and the physical, hydrologic and geomorphic processes. The specific study areas examined relative to potential hazards were:

- eight slides located between Slesse Creek and Slesse Park, (Northwest, 1991), with respect to the potential of large slides occurring which could temporarily block the Chilliwack River;
- Slesse Park to Baker Trails, Figure 2, with respect to flood, bank erosion and geotechnical hazards.

The study does not include lands of the Soowahlie Indian Reserve.

1.4 Mapping

Mapping for the study was coordinated using Microstation CAD software with all levels of information referenced to UTM coordinates. This methodology facilitates cross-referencing of the various data types such as flooding and erosion limits, slope hazard zones, surficial geology and river channel changes, etc. The data is in a form suitable for translating to a Geophysical Information System database.

The coverage of various 1:5,000 scale maps is shown in Figure 3.

The base mapping was provided by McElhanney Geosurveys as a set of digital files which were translated and combined into a single Microstation file. BCGS sheets 92H.001.3.2, .4.1, .4.2 and .4.4 were prepared by McElhanney showing 2 m contours and planimetric features such as channel banks, bars, ponds, marshes, tributaries, roads, tracks, buildings, fences and vegetative cover. BCGS sheets 92H.001.3.4 and .4.3 were updated by McElhanney from 1989 Delta Aerial Surveys maps showing the 1991 river channel and planimetry. Contours were not updated and on sheet 92H.001.3.4 are at a 10 m interval on the valley walls.

The base maps prepared by McElhanney were developed from 1:19000 scale aerial photography. Eighteen surveyed control points were utilized with an RMS error of 0.2 m horizontally and 0.18 m vertically. The maximum vertical discrepancy at the control points was 0.38 m and pointing accuracy on the maps is considered better than 0.55 m both horizontally and vertically.

Additional plan information utilized in the study includes:

- Aerial photos 1957, 1979, 1984, 1986, 1989 and 1990. The 1986 photos are in colour, the other years in black and white;
- Orthophoto mosaics 1976, 1986 and 1991 at a scale of approximately 1:5000;
- 1940 air photo enlargements;

- LOIS maps produced by the Fraser Cheam Regional District for current land use existing in the valley;
- Cadastral and House Numbering plans at a scale of 1:5000, dated 1981. These map sheets are known to be distorted and do not register correctly with planimetric features;
- Legal survey plan of logged over areas Lot 439, Group 2, dated 1932.

Other information shown on plan mapping and photos includes:

- Terrain analysis of local areas by B.C. Ministry of Environment and surficial geology shown on a 1:20000 map;
- 1976, 1979, 1986, 1990 and 1991 Chilliwack River cross-section locations and Ministry of Environment survey monuments shown on orthophoto mosaics;
- 200 year floodplain limits together with 20 year and 200 year flood level isolines shown on the 1976 orthophoto mosaics and dated 1981;
- 1 m contour base mapping on the valley floor shown on 1976 orthophoto mosaics;
- Flood damage restoration, locations of executed works for 1984, 1989 and 1991 shown on 1991 orthophoto mosaics.

Information transcribed into CAD files from the above data and analysis of data includes:

- River channel changes from air photos, orthophoto mosaics and the 1932 survey plan using site features for registration;
- Flooding limits from the 1980 flood level isolines adjusted by applying increased flood levels, as presented in Section 4.2 of the report. Additional spot elevations were surveyed to ground truth the contours within the low-lying developed areas;
- The limit of unprotected 100 year bank erosion;
- Lot boundaries digitized from the cadastral plans with local adjustments made in registration to overcome the distortion in the cadastral plan data;
- Existing bank protection limits from field notes;
- Geomorphic features from field notes, topographic features and air photos.

1.5 Study Overview

The study has proceeded through the phases of data collection, data analysis, hazard definition, hazard mapping, assessment of mitigative options and consideration of optional administrative and financial frameworks to implement a hazard management plan.

Meetings held during the preparation of this interim report included:

- Five meetings with the Steering Committee for the study, comprised of representatives from the Fraser Cheam Regional District and Ministry of Environment;
- Four meetings with the Chilliwack River Valley Ratepayers' Environmental Management Committee;
- Two inter-agency meetings with representatives from Fisheries and Oceans Canada, Ministry of Environment, Ministry of Transportation and Highways, Ministry of Forests, Fraser Cheam Regional District, and the District of Chilliwack;
- Meetings with local residents.

The study has been focused on resource use of the valley, the physical processes at work, the hazards, and possible means to deal with these hazards. In so doing, the study tends to miss the human side of living in a well used and beautiful valley that is subject to events that are not only threatening, but frightening and damaging when they occur.

The report does not identify nor deal with the frustrations experienced by both residents and regulatory personnel as they seek to grapple with providing safety to residents, visitors, workers and properties within existing regulatory, policy and financial boundaries. However, it is hoped this interim report provides the springboard for development of a rational and implementable hazard management plan, capitalizing on the sincere interest of all study participants to see such a plan carried out.

This interim report does not include recommendations, but rather, as intended, serves as a basis for discussion for the formulation of the hazard management plan outline.

2 BASIN RESOURCES

2.1 General

The Chilliwack River Valley is a moderately broad, mostly forested valley bottom, containing a variety of natural resources, and scenic river and lake areas which have attracted settlement over the years, and

more recently, intensive development for recreational purposes. Settlement is clustered in four hamlets, where the residents live on semi-rural lots or in trailer parks, Figure 4.

The resources of the valley are used actively for a number of purposes including residential communities, commercial enterprises, agriculture, institutions, recreation, forestry and a fish hatchery. The valley includes archaeological resources.

Based on B.C. Assessment data, the number of properties in the valley employed for various uses is listed in Table 1.

2.2 Residential

Settlement in the Chilliwack River Valley is principally clustered in four nodes or hamlets, along the Valley Road from Vedder Crossing Bridge to Chilliwack Lake. The four residential hamlets are, from west to east, Baker Trails - McFaul Road, Edwards Road, Bell Acres and Slesse Park.

There is a recreational subdivision at Post Creek, near Chilliwack Lake.

According to Census data for 1986, the total population between Slesse Park and Baker Trails was 1106. Estimates by the Fraser Cheam Regional District (FCRD) place the 1991 population at about 1230, indicating a slow but steady growth over the last few years.

The annual growth rate for the period 1981 - 1986 was 1.7%, increasing to 2.1% for the period 1986 - 1991. FCRD building permits indicate that 38 houses were built since 1986, contributing approximately 124 new people to the area.

An Indian reserve is located near the junction of Sweltzer Creek and the Chilliwack River, just above Vedder Crossing. The Soowahlie Indian Band Reserve is some 461 ha in size, with 80 people living on it (1981 figure).

2.2.1 Future Growth

Continued growth will depend on the availability of land suitable for development, and this is generally felt to be in short supply because of slope conditions, hazards due to debris torrents and flooding and other factors. The Official Settlement Plan (FCRD 1982) further restricts the potential for growth by requiring that community water be provided for any lot under 1845 m². In the absence of community water, developments must be two hectares or greater in size.

The Official Settlement Plan (OSP) indicates that settlement other than institutional (which may locate in Natural Resource areas) is not permitted outside the four hamlets, for which the Regional District "has

a long term ...goal", which is "to maintain and improve these traditional settlement areas". Infilling and moderate expansion adjacent to the nodes are contemplated.

The OSP notes, "The Baker Trail/McFaul Road settlement area is essentially full, and the Edwards Road area is currently (1982) experiencing its last major expansion."

Taking these restrictions into account, the OSP concluded in 1982 that "today, apart from some potential for infill on the few lots in the Bell Acres area, and the odd vacant lot in other largely settled areas, the valley is essentially fully developed".

The Chilliwack River Recreation Corridor Study (FCRD 1987) indicated that the "potential for expansion of these hamlets is extremely limited (100 lots if community water supply is developed; 10 - 15 lots if there is no supply)".

While there has been a modest increase in the residential population over the last 10 years, it is not likely that a significant increase will take place over the next 10 to 50 years unless a community water supply is developed to service non-hazardous lands. This would indicate that the residential tax base is not likely to grow significantly in the valley.

2.3 Agricultural

Agriculture is of local significance, with some 800 ha designated within the Agricultural Land Reserve. There are two large farms and a number of small farming properties producing beef, dairy cattle, poultry and horses.

2.4 Institutional

A number of public uses are prominent in the valley. The military uses about 240 ha, located in three areas: a heavy equipment training area behind the Soowahlie Indian Reserve; a grenade and rocket range at Liumchen Creek; and a small arms facility in the Slesse Creek area. Exercises are undertaken on a regular basis at a number of locations throughout the valley, with activity both during the week and on weekends. The Department of National Defence also owns the Pierce Creek Camp which was previously used as a minimum security correctional facility.

A number of minimum security prison facilities (forest camps) have been established in the Provincial Forest, which itself extends over a large area. There are three camps: Mt. Thurston Correctional Centre with staff of 22 and 35 inmates; Ford Mountain Correctional Centre, with staff of 21 and 55 inmates; and Centre Creek Youth Custody Centre, with a staff of 34 and 36 inmates.

2.5 Recreational

The Chilliwack River Valley is located close to over half the population of British Columbia. Many thousands of recreationists have been drawn to the valley in ever increasing numbers to enjoy a wide range of outdoor activities and opportunities. These include:

- at least 20 km of the river offering one of the largest steelhead and salmon fisheries in the Province;
- white water boating;
- a large lake with boating and fishing opportunities;
- a large ecological reserve, with scenery, fresh air and lots of natural, relatively undeveloped landscape.

2.5.1 Recreational Facilities

Land has been set aside for park use, with approximately 360 ha in eight areas reserved for future recreational development.

There are two Provincial parks in the valley, Chilliwack Lake Provincial Park and Chilliwack River Foreshore Day Use Area.

The Ministry of Forests also operates recreational facilities, with fourteen sites available for public use, as shown on Figure 5. These are:

- Allison Pool
- Camp Foley
- Chipmunk
- Depot Creek
- Eagles Roost
- Foley Lake
- Paleface Creek
- Pierce Creek
- Post Creek
- Rapids
- Riverside
- Sappers Park
- Tamihi Creek
- Thurston Meadows

These sites are rustic and usually accommodate less than 10 vehicle units. They offer amenities such as basic sanitary facilities, fire rings, picnic tables and boat launch ramps (where appropriate).

The Ministry of Forests also manages eight recreation trails:

- Elk/Thurston
- Mt. Cheam
- Centennial
- Liumchen Lake
- Williams Creek
- Post - Greendrop
- Radium Lake
- Upper Chilliwack River

These trails are generally rough and unsurfaced but are maintained on a regular basis.

Discussions with the Ministry of Forests indicated that the 1990 flood resulted in road access to the Depot Creek site being severed. Alternative access options are being considered. The Upper Chilliwack River trail was also affected by this event, with access impeded by an eroding clay bank.

There are also other trails, not currently managed by Ministry of Forests, which provide access to the back country of the Chilliwack River drainage area. These are:

- Mt. McGuire
- Williamson Lake
- Mt. Mercer
- Mt. Laughington

2.5.2 Activity Levels

According to the Chilliwack River Recreation Corridor Study (FCRD 1987), no other small to medium sized river valley in British Columbia supports as great a volume of recreational activities as does the Chilliwack. The particular activities and their usage levels, as measured in 1986, are given below as the most recent statistics describing usage by particular activities.

- *Motorized 4 x 4 and ATV's:* 100 - 500 of each. Active period on peak weekends.
- *Snowmobiling:* Up to 500. Peak weekends.
- *Hiking:* Limited. Very few trails.

- *Camping and Park Use:* Several sites. Chilliwack Lake Provincial Park registered 4,700 camping parties in 1986, 10,500 day use. Chilliwack River Provincial Park registered 6,700 + day use vehicles in 1986. The Forest Service sites registered 34,400 vehicles in 1986.
- *Hunting:* 4,300 person days, for deer
- *Boating:* Lake boating, amount unknown. River canoeing, 1,000 person days, weekends mostly. River kayaking, 10,000 to 11,000 person hours a year, including racers, recreational and instructional kayakers, at 5 sites. Estimate some 400 paddlers. River rafting, both commercial and private, some 22,000 hours per year. There are at least 6 companies running white water trips.
- *Angling:* Steelhead, about 51,000 hours per year. Salmon, about 79,000 hours. Trout, in Chilliwack Lake, about 30,000 to 50,000 hours.

The Ministry of Forest's figures indicate a total of 49,558 user days at their sites in 1990. The number of users by each recreation site in 1990 was:

Allison Pool	9,266	Camp Foley	919
Chipmunk	1,958	Depot Creek	1,289
Eagles Roost	614	Foley Lake	1,694
Paleface Creek	1,567	Pierce Creek	1,045
Post Creek	5,879	Rapids	303
Riverside	922	Sappers Park	7,250
Tamihi Creek	10,044	Thurston Mountain	6,808

Provincial Parks figures for Chilliwack Lake Provincial Park and Chilliwack Provincial Park for 1990 were:

Chilliwack Lake	Campground	13,155 users
	Day Use	47,769 users
Chilliwack Provincial Park	Day Use	41,808 users

One user, identified as significant to the Chilliwack River Valley is "the Sunday drive/sightseer". The impact of this user has not been quantified and no figures are available.

2.5.3 Future Recreational Uses

The recreational opportunities in the Chilliwack River Valley currently serve the population of the Lower Mainland, estimated at 1.7 million. As growth continues unabated, the pressure on the valley and its facilities can be expected to increase. This trend is already occurring.

From 1979 to 1990, the users of the Forestry recreation sites increased in number from 26,000 a year, to over 49,000, an increase of some 88 percent.

The projected increase in the population of the Lower Mainland of one million, over the next twenty years, can be expected to create pressures which will result in even higher and more dramatic user volumes (Seelig and Artibise 1991). The Parks 1990 plan for the future indicates that societal changes in demographic structure, changing perceptions about health and increased concern for the environment will shape the type of recreation facility provided and the manner in which it is used. Changes in the age structure of the population, and a changing ethnic mix, will present challenges to the Ministry of Parks and other providers of recreational services.

The Chilliwack River Valley area has been identified in Park Plan 90 as an area where increased back country recreational opportunities should be studied.

Discussions with the Ministry of Forests (1991) revealed that there may be a change in policy regarding amenities offered by the Ministry to an increased sophistication in the level of amenities offered.

In summary, recreational use in the Chilliwack Valley is intense. Monitoring access to the valley and providing a level of security for recreationists against natural hazards should be a consideration of agencies and companies that encourage this use.

2.6 Fisheries

The Chilliwack River is an important producer of salmonid fish stocks to commercial, recreational and Indian food fisheries. It supports populations of pink, chum, chinook and coho salmon, as well as steelhead trout. Sockeye salmon migrate up the Chilliwack River to spawn and rear in Cultus Lake and Chilliwack Lake. Small numbers of Dolly Varden char and cutthroat trout also occur in the river system.

This section focuses on steelhead trout and the four major salmon species which spawn and rear in the Chilliwack River.

2.6.1 Salmonid Life Histories

Pink and chum salmon use the Chilliwack River main stem and side channels for spawning and egg incubation. The fry of each species migrate from the system immediately after emerging from the gravel,

proceeding directly to the ocean (pink salmon) or rearing for a short period in the lower Fraser River before entering the ocean (chum salmon).

Pink salmon spawn during September-October, principally in the main river channel and larger side channels fed directly from the river. Pinks spawn throughout the river, from Vedder Canal to Chilliwack Lake, but the majority (70%) use river sections upstream of Vedder Crossing.

Chum salmon spawn in the main river channel, in groundwater fed channels off the main river, and to a small extent in tributaries during November-December. About 25-30% of chum spawning occurs in the river section between Vedder Crossing and Allison Pool, just upstream of Slesse Park.

Chinook salmon stocks in the Chilliwack system include:

- a small, native summer-run population which spawns in the upper river between Slesse Creek and Chilliwack Lake; and,
- an introduced fall-run population which spawns downstream of Slesse Creek.

The heaviest fall-run chinook spawning occurs in the reach between Tamihi Creek and Allison Pool. Chinook spawn only in the main river channel. Chinook fry of the fall-run population migrate to rear in the Fraser River within a short period after emergence, whereas fry of the summer-run population rear in the Chilliwack River for one year before migrating seaward.

Coho salmon spawn in the Chilliwack River main stem between Vedder Canal and Chilliwack Lake, and in up to 20 tributary streams during November to January. In the main stem, heaviest coho spawning occurs in the upper reaches near Chilliwack Lake, while a minor portion (approximately 10-15%) spawns in the section between Vedder Crossing and Slesse Creek. Coho juveniles spend one year of rearing in the main river and tributaries.

Steelhead trout spawn in the river main stem during the spring, in side channels and in the lower reaches of some tributaries. The majority of juvenile steelhead rear in the river for two years, but a minor portion of the population spends three years of rearing before migrating to the ocean.

2.6.2 Habitat Utilization

All river salmonids require a stable gravel environment, generally in a riffle or the tail end of a pool, for successful spawning and egg incubation.

Extremes of river flow can cause significant mortality to salmonids during incubation, due to stream bed scouring, freezing during winter and deposition of sediment which tends to smother the incubating eggs. Pink and chinook salmon, which spawn almost solely in the main river channel, are most vulnerable to

extremes of river flow. A portion of the chum and coho salmon populations spawn in groundwater fed channels which are less exposed to flow extremes. Coho salmon spawners also gain a measure of protection from extreme flows through their use of the more stable upper reaches of the Chilliwack River, near Chilliwack Lake, and tributaries with groundwater influence.

The quality and quantity of the juvenile rearing environment is generally the factor limiting production of chinook and coho salmon and steelhead trout. Of particular importance to juvenile rearing capability is the amount and quality of pool habitat in a stream. In the Chilliwack River, the highest densities of rearing juvenile salmonids are found in pools with abundant log debris. Suitable rearing habitat also occurs along undercut natural banks with overhanging vegetation. Bouldery runs and pools formed along stable man-made banks of large, angular rock, known as riprap, are also attractive for steelhead and chinook juveniles.

Habitat preferences of juvenile salmonids are most pronounced in winter, when the fish seek protection from floods and periodic icing conditions. Deep pools with suitable cover, preferably log debris jams, are the preferred overwintering habitat. Side channels are also sought for protection during extreme high flows.

2.6.3 Magnitude of the Fishery Resource

Salmon spawning escapements to the Chilliwack River, in the most recent decade of available records (1981-1990), have averaged 300,000 annually, Table 2. In a pink salmon year, the average total stock resulting from natural production, including escapement and contributions to ocean and freshwater fisheries, is estimated at 700,000. These estimates of escapement and total stock are considered to be minimum estimates, as they are frequently based on visual counts of spawners which are known to underestimate the escapement. The spawner counts are considered to be a suitable index of fish abundance.

Runs of wild adult steelhead trout in the Chilliwack River are estimated to be in the range of 2,000 to 11,000 fish. An estimate of the average run is 4,000.

In addition to the natural production of anadromous salmonids noted above, significant numbers of salmon and steelhead are produced by the Chilliwack Hatchery, which reached full production in 1983. Estimated average annual production of adult salmonids from that facility is 320,000 fish. Coho salmon comprised a major portion (75%) of that contribution.

In a pink cycle salmon year, total production of anadromous salmonids from the Chilliwack-Vedder system is approximately one million fish.

2.6.4 Seasonal Constraints on Instream Construction Work

Fisheries is a vital and important resource in the Chilliwack River Valley. The resource is used locally and extensively by recreational fishermen, and the stocks derived from the system are harvested commercially by others outside of the valley. Preservation of the fishery resource is essential when considering hazard management in the valley, and is a factor considered in evaluation of options to mitigate hazards, Section 7.

Preservation of the stock is achieved by:

- selecting hazard mitigative options that do not adversely impact fish habitat;
- undertaking construction of any instream work during periods when fish habitats are least likely to be impacted; and,
- maintaining access to the existing fish hatchery.

The general practice of government fisheries agencies is to allow construction activity in the wetted stream channel in summer to avoid the period of fry emergence and adult spawning. Seasonal restrictions on instream work are designed to avoid sedimentation of spawning beds during the spawning and incubation periods.

The Chilliwack River has a diversity of anadromous salmonid populations which exhibit considerable variation in spawning time and length of the incubation period. Pink salmon, the earliest salmon spawners, commence spawning in late September, while coho are observed to spawn as late as January. The peak of salmon spawning occurs during October-December. Steelhead trout spawn in the spring, mainly during April-June. Salmon fry emerge from the gravel during March-May, while steelhead fry emergence does not take place until June-July.

Because of the diverse spawning and incubation periods of the various salmonid species, the instream construction "window" in the Chilliwack River is normally considered to run from July 15 to September 15. The window may be lengthened in odd-numbered years when pink salmon are not present.

2.7 Forestry

The Chilliwack River Valley's early development was in connection with the logging industry, being very active during the twenties and thirties. By the late 1930's, most of the easily accessible timber had been harvested, although shake and shingle operations continued sometime after this period. Logging then shifted into the major tributary drainage, moving higher up the slopes and further back into the watersheds, continuing to the present (1992) day.

2.7.1 The Forest Land Base

The Upper Chilliwack River and the headwaters of Slesse Creek, Tamihi Creek and Liumchen Creek are in the United States. Approximately 470 ha in the upper Liumchen was logged in the past but no further logging is likely in any of the American portion of the Chilliwack watershed in the near future. All of the upper Chilliwack, upper Slesse and most of the upper Tamihi are in either the North Cascade National Park or the Mt. Baker Wilderness Area where logging is not permitted. The remaining area of the Tamihi and the upper Liumchen are in the Mt. Baker - Snoqualmie National Forest where logging is not presently permitted because of the Supreme Court injunction protecting the Northern Spotted Owl.

In British Columbia, the Chilliwack watershed area (above Vedder Crossing) is in the Chilliwack Supply Block of the Fraser Timber Supply Area (TSA) and is administered by the Ministry of Forests from the Chilliwack Forest District. All forest inventory information is organized by Supply Block but calculations relating to allowable harvesting rates are made for the much larger TSA as a whole.

In 1982, a major review of the Chilliwack River Supply Block was undertaken by a Planning Task Force chaired by the Ministry of Forests (MOF, 1982). This body determined that the Chilliwack Supply Block included 81,000 ha of land, of which 37,000 ha was productive forest land potentially available for timber production. The area of mature forest available for harvest at that time was 17,800 ha.

At present, the Ministry of Forests is preparing to undertake a re-inventory of the Fraser TSA and may attempt to determine an allowable harvest rate for each of the Supply Blocks, including the Chilliwack.

2.7.2 Past Commercial Forest Harvesting and Silviculture (1945-1990)

Information from the Ministry of Forests provided a summary of all areas logged in the Chilliwack watershed, and the time periods in which the logging occurred, as shown on Drawing D101, and summarized in Table 3 (MOF, 1992).

In 1982 the Chilliwack Planning Task Force calculated that the available timber supply would support a sustainable annual harvest from the Chilliwack watershed of 182,800 m³. At an average of 560 m³/ha, this would have averaged 326 ha of logging per year. The Task Force estimated that, at that rate of harvest, 20 years of logging of old growth forest remained in the Chilliwack watershed. It was predicted that operations would then have to shift to second growth forest or would move to other supply blocks in the TSA.

In fact, the actual harvest in the 1980's in the Chilliwack watershed exceeded the sustainable rate projected by the Task Force by nearly 15%. The actual average annual harvest during the 1986-1992 period averaged 376 ha/yr. An additional 30 ha per year were cleared to establish commercial tree species in place of non commercial or low value species.

Extensive silvicultural activities have also been undertaken throughout the Chilliwack watershed as shown in Table 4 (MOF, 1990). Between 1960 and 1990, silvicultural projects were completed on a total of 11,035 ha. Trees were planted on 6,249 ha. Spacing, pruning, brushing and weeding, fertilization or site rehabilitation programs were completed on 4,786 ha. These figures include sites that were planted more than once and sites on which more than one silvicultural treatment has been carried out. Thus, the total number of hectares affected by silvicultural treatments is somewhat less.

The data indicates that nearly 50% of the logged area in the Chilliwack river watershed has been planted, and more than 75% has received some silvicultural treatment.

2.7.3 Current and Projected Commercial Forest Harvesting and Silviculture (1990-1995)

Timber harvesting in the Chilliwack watershed has been reduced from the levels of the 1980's. A re-inventory of the TSA and a Timber Supply Analysis to be initiated in 1992 by the Ministry of Forests may further reduce the amount of logging.

The Ministry of Forests estimates that the volume to be logged in the Chilliwack watershed for the five year period, 1991 to 1995, will drop to an annual average of 99,400 m³ equivalent to a harvested area of 203 ha per year.

The area and volume to be logged between 1991 and 1995 may actually be slightly lower than projected because one of the major licensees, Norvik Timber Inc., is not operating at the present time and may not cut the projected volume. Norvik cuts deciduous species, with a relatively low average volume of 175 m³/ha and if they did not operate, the average area harvested annually would drop to 183 ha.

Unfortunately, the projected reduction in the rate of harvest is not evenly distributed in the watershed. Data extracted from five year logging plans, given in Table 5, indicate that the Foley/Airplane and Chipmunk watersheds, which have been heavily harvested since 1976, will continue to provide a disproportionate amount of the proposed harvest with 210 ha to be logged in the Foley/Airplane and 108 ha in the Chipmunk. One hundred and sixty ha are planned to be logged in the Tamihi watershed.

2.7.4 Value of Forest Harvesting and Silviculture

Figures from a 1985 report by the Association of BC Professional Foresters (APFBC, 1985), which provide a rough yardstick of the economic activity generated by the rate of logging, estimated the end product value of logs removed between 1985 and 1989 from the Chilliwack watershed to have been approximately \$27 million per year, Table 6. The volume of timber removed in that period provided, on average, approximately 300 direct jobs.

The reduced level of harvest projected for the 1991 to 1995 period will reduce the end-product value to approximately \$11.4 million annually and provide approximately 124 direct jobs.

It is unclear what level of economic activities can be expected when the remaining old-growth timber in the Chilliwack watershed is exhausted in about eight years.

It is estimated that, in the 1991-1995 period, the number of jobs associated with silvicultural activities will exceed those associated with logging.

The current level of silvicultural activity is expected to continue at its recent rate of approximately 900 ha per year.

The forestry resource, like the recreational and fisheries resources, is a significant component of activity and income for residents in the valley, and elsewhere.

2.8 Infrastructure

The principal infrastructure component in the valley is the Chilliwack Lake Road, extending from Vedder Crossing to Chilliwack Lake. Valley residents have sought to have an alternative access into the valley developed, or improved. Until this is done, the present road is the sole access for the majority of resource use in the valley and serves as the only land means of providing access for emergency vehicles and emergency responses during hazardous events.

While no major utility corridors run through the valley, and are not likely to do so in the near future because of the predominant use of the Fraser River Valley as a corridor. Residents, commercial and institutional facilities in the valley rely on the supply of electric power and telephone lines via overhead lines. Electrical power extends up the valley to the Post Creek subdivision, about 1.5 km west of Chilliwack Lake. Telephone service presently extends to the Centre Creek correctional facility and will likely be extended to Post Creek when funding is in place. Gas service extends to the east end of the Slesse Park area.

2.9 Cultural

There are three known archaeological sites between Vedder Crossing and Bell Acres. Approximate locations of these sites are shown on Figure 5. The Archaeological Branch of the Ministry of Municipal Affairs, Recreation and Housing indicates the area has a high potential for unrecorded prehistoric sites (pers. comm.).

3 BASIN GEOGRAPHY

3.1 General Characterization of Features

The Chilliwack River empties into the southern side of the Fraser Valley Lowlands at Vedder Crossing, approximately 85 kilometres east of Vancouver. The upper reaches of the valley lie across the Canada -

U.S. border on the slopes of Mt. Shuksan and drain into Chilliwack Lake. The valley initially heads north along the lake then curves westwards, traversing approximately 40 km to the mouth at Vedder Crossing. The Chilliwack River is the only large drainage in the northwest Cascade Mountains, and has a total catchment area of 1,230 square kilometres.

The Chilliwack Valley has a glaciated U-shape, with a flat floor bounded by steeply sloping sides. The valley floor rises from an elevation of 40 metres above mean sea level at the mouth to 610 metres at Chilliwack Lake. The surrounding ridges range from 700 to 2,400 metres in height, giving a valley wall height of 660 to 1,200 metres. There are many tributary valleys situated along the length of the Chilliwack Valley. The principal streams along the south side when proceeding upstream in the Chilliwack Valley are Liumchen Creek, Tamihi Creek, Slesse Creek, Nesakwatch Creek and Centre Creek. On the north side the streams are Ryder Creek, Chipmunk Creek and Foley Creek, Figure 2.

The Chilliwack River meanders along the valley floor as it cuts through glacial and glaciolacustrine sediments, locally down to bedrock. The channel is narrow in the upstream reaches and widens downstream of Slesse Creek where it becomes well braided through reaches with coarse gravels and cobble bed materials. The majority of flood-induced channel changes have occurred within this downstream reach.

Bedrock outcrops are evident at several locations along the river channel. Several large bank slides are also apparent downstream of Slesse Creek where the stream is aggressively cutting into the glaciolacustrine sediments of the lower valley wall and relic terraces.

The hydrology of the Chilliwack Basin is primarily determined by the climate of the area. The basin lies in the transition between the maritime climate (warm, wet winters) and the continental climate (cold, snow-dominated winters).

In terms of annual discharge, snowmelt dominates the hydrograph with June the month of highest discharge. However, because of the maritime influence, the area is also subject to moist winter storms from November to February that produce short-term peak flows that usually exceed the snowmelt (nival) peak flows.

The high-intensity rain from multi-day winter storms is usually associated with existing snow and with already saturated soil. The steep high mountains of the border peaks further intensify precipitation. Mass erosion in the form of debris flows, debris torrents and slumps/earthflows is most likely to occur during high runoff periods associated with the rain-on-snow events.

The maritime influence is most strongly expressed below Chilliwack Lake. In 48 years of record, over half of the annual maximum daily discharges occurred during the winter at Vedder Crossing, whereas at Chilliwack Lake only about one-quarter occurred during the winter months.

Approximately one-third of the total drainage is buffered by lakes. Chilliwack Lake is an effective sediment trap and flow buffer for the upper one-quarter drainage. Foley Lake and Pierce Lakes control much smaller areas. Apart from the Chilliwack River itself, Slesse Creek is the only tributary with a significant floodplain and sediment storage.

In the tributaries that are not influenced by lakes, flow generation is therefore rapid, and sediment delivered to the tributaries moves relatively quickly into the Chilliwack River. Steep slopes, periods of high precipitation, and generally shallow young soils contribute to the natural mass erosion and transport of sediments.

3.2 Geology

An understanding of the geology of the area, including the impact of successive glaciations, distribution of surficial materials, and groundwater, is important as background to assessing the geotechnical hazards in the area and the morphological aspects of the river.

3.2.1 Bedrock Geology

The oldest rocks in the area correlate to the Yellow Aster Complex in Washington State, Figure 6. These are undated, but the amphibolites and diorite are probably early Palaeozoic age. The overlying Chilliwack Group comprises late Palaeozoic, highly deformed, metamorphosed marine sediments. Unconformably overlying the Chilliwack Group is the Cultus Formation. This series is composed of Triassic and Jurassic fine grained marine sediments, which again are highly deformed.

The eastern or upstream end of the valley is underlain by the Chilliwack and Mount Barr (granitic) Batholiths of mid-Tertiary age. Local occurrences of the Chuckanut Formation conglomerates, Custer gneiss, and Nooksack Group (Cretaceous/early Tertiary) greywacke and shales completes the bedrock geology.

3.2.2 Surficial Geology

History

An understanding of the history of the deposition of surficial materials is essential because all identified geotechnical hazards lie within glacial soils. Thus the relationship between the materials is of importance. Figure 7 shows the distribution of surficial soils within the valley from Chilliwack Lake to Vedder Crossing. Figures 8 to 11 show typical cross-sections along the length of the valley.

The main geological events occurred as follows:

- During the early Fraser Glaciation, proglacial outwash was deposited by glaciers advancing into the upper reaches of the Chilliwack River basin. Associated gravels are exposed at several sites between the Chilliwack River gravel pit and Slesse Park Slide, as illustrated by Unit 1, Figure 9, at the Slesse Park area.
- The Chilliwack Valley was then dammed by ice extending from the Fraser Lowland in the vicinity of Vedder Crossing, resulting in the development of an extensive lake in the valley. Thick glaciolacustrine sediments accumulated. This material is also exposed at many locations between the Chilliwack River gravel pit and Slesse Park Slide, as illustrated by Unit 2, Figure 9.
- Ice subsequently advanced down the valley from the east and outwash sands and gravels were deposited in front of the glaciers, developing a layer noted as Unit 3, Figure 9 in the Slesse Park area.
- This period represents the maximum advance of the Fraser Glaciation (Vashon Stade) when all the study area was ice-covered and the Vashon till was deposited. Thin Vashon till caps the sequence at the Chilliwack River gravel pit and till drapes over the upper valley sides, Figure 10. Vashon till has not been recognized in the vicinity of Slesse Park.
- Ice remained in the Fraser Lowland as the glacier in the Chilliwack Valley receded. Another glacial lake formed in the valley as the ice melted, depositing glaciolacustrine sediments (unit 5), and an extensive outwash plain developed in front of the Chilliwack Valley glacier in the Chilliwack Lake/Slesse Creek area, as represented by the glaciofluvial sands and gravels which are exposed in the vicinity of Slesse Creek (Unit 8, Figure 11) and fragments of a related terrace which are found downstream to within 3 km of Slesse Park (Figure 10).
- On two subsequent occasions, about 11500 and 11200 years B.P. (Saunders, et al. 1987), Fraser Lowland ice pushed upstream into the Chilliwack Valley (Sumas Stade) and covered the Ryder Upland as far east as Tamihi Slide, just west of Young Creek. A layer of till, about 100 m thick, was deposited on the Ryder Upland, (Unit 4 on Figure 9), particularly in the vicinity of Tamihi Slide. Sediments accumulated in the ice-dammed lake that persisted in the valley. During the last of these two re-advances, ice overrode the Unit 5 glaciolacustrine sediments as far upstream as Km 27.5 and caused disturbance of the sediments, as depicted in Figure 9.
- During the Sumas Stade, overflow from the glacial lake drained westward along the southern margin of the ice. At an early stage, this formed the Middle Terrace, which continues past Cultus Lake into the southward draining Columbia Valley. At a later

stage, the Lower Terrace was similarly formed; it terminates in a raised delta at Cultus Lake.

- Since deglaciation, low fluvial terraces have developed along the Chilliwack River, and fluvial and colluvial fans have formed where gullies debouch onto the flats, as indicated by Units 6 and 7, Figure 9. Landslides have probably occurred throughout postglacial time.

Glaciolacustrine Sediments

Most, if not all, slope movements in the study area (excluding bedrock failures high on the valley sides) appear to be related to the presence of glaciolacustrine sediments.

Two units of glaciolacustrine sediments have been identified during the course of previous work. Clague and Luternauer (1983) and Saunders et al. (1987) described glaciolacustrine materials at Slesse Creek that contained wood dated at 11900 years B.P. Clague et al. (1988) reported that three pieces of wood from the glaciolacustrine sediments at the Slesse Park landslide, dated between 15950 and 16100 years B.P. Thus glaciolacustrine materials appear to have been deposited both prior to the Fraser Glaciation maximum (considered to be 13000 to 15000 B.P.), and after this maximum, during the minor ice readvance of the Sumas Stade. These are referred to as the "older" and "younger" glaciolacustrine deposits.

Field work completed during this study suggests that, in the vicinity of Slesse Park and further downstream, the younger glaciolacustrine sediments were overridden by the Sumas ice as it advanced upstream to its maximum extent. In the vicinity east of Slesse Creek, the younger glaciolacustrine sediments were buried beneath outwash sands and gravels, and thus were not affected directly by the Sumas ice advance, and are rarely seen.

The detailed investigations carried out for the "clay-slides" hazard, Section 4.4, confirms the descriptions made by previous authors. The younger glaciolacustrine sediments were identified in the Slesse Creek (Km 20.6), Ranger Creek (Km 21.8), Correction Camp (Km 24.5), Anderson Run (Km 27.5), Allison Run (Km 28.2), Chilliwack Campground (Km 29.0) and Willow Run (Km 29.5). They may also underlie some of the recent river terraces downstream of Slesse Park but this is unproven. The older glaciolacustrine silts were found in the Slesse Park Slide (Km 27.8).

The younger silts show evidence of major glacial disturbance at Anderson Run, Allison Run, Chilliwack Campground and Willow Run, that is, downstream of Km 27.5.

At Slesse Creek the same sediments show disturbance considered to be unrelated to overriding by the ice and most likely due to loading by the overlying sediments, or even seismic activity. Generally they

consist of up to 25 m of laminated silt and clay containing isolated pebbles and cobbles and occasional lenses of coarse gravel.

These glacially overridden and severely modified glaciolacustrine sediments are present beneath the low, undulating benches in the vicinity of Slesse Park. Wood fragments from this unit are being dated. These sediments are mostly massive silts and clayey silts but some distorted remnants of the original bedding and some large tilted blocks of bedded silt are present. The massive silty material is criss-crossed by irregular fractures and the material breaks irregularly, rather than along bedding planes, and is described as "blocky-breaking". It shows a tendency to conchoidal fracture. Fracture planes are commonly coated with manganese dioxide.

The glaciolacustrine sediments contain irregular-shaped pods of till and glaciofluvial gravel and sand. In some sections, the silty sediments are capped by till, but elsewhere, they constitute the surface of the bench. The till that is associated with the overridden glaciolacustrine sediments appears to have been derived both from these sediments and fluvial gravel. It contains a high proportion of matrix of similar texture to the glaciolacustrine sediments, blocks of silt, and well rounded clasts.

The older glaciolacustrine sediments are best exposed in the Slesse Park Slide and are poorly exposed elsewhere on the hillside between Slesse Park and Vedder Crossing. They are generally horizontally bedded and the stratification is preserved.

The various categories of glaciolacustrine sediments referred to above cannot be distinguished by their textural or mineralogical characteristics because they were initially deposited under similar physical conditions and derived from similar parent materials. In general, they consist predominantly of silt and silty clay, but include minor fine sand. Dropstones, released by the melting of floating ice, are commonly present, and range from pebbles to boulders.

Where the original stratification of the glaciolacustrine sediments is preserved, they are horizontally bedded, with beds ranging in thickness from less than a millimetre to over 1 metre. In general, thinly bedded and laminated sequences are common, with considerable textural variation from bed to bed.

Distribution of Materials

In summary, the Chilliwack Valley can be divided up into four sections which are characterized by very different geological materials resulting from the geological history described above. Broadly the distribution is as described below and shown on Figure 7.

Km 0.0 to Km 20.6 (Chilliwack Lake to Slesse Creek)

To the east of Slesse Creek, the Chilliwack Valley is broad and U-shaped and choked with glaciofluvial sands and gravels which form extensive flat terraces. The river

channel is incised into these materials and recent alluvium forms shallow terraces in the valley bottom. The steep valley walls are formed by bedrock with thin overlying colluvium, and alluvial fans have been deposited from most drainages onto the glaciofluvial terraces. Glaciolacustrine sediments underlie the gravels but are not exposed in the valley slopes except close to Slesse Creek.

Km 20.6 - Km 26.0 (Slesse Creek to Allison Pool)

Over this stretch of the river glaciolacustrine silts are locally exposed below the glaciofluvial sands and gravels within the channel. Rock is exposed over some sections of the valley wall and locally down to river level. Alluvial/colluvial fans are present at the confluences of tributary creeks and the main valley.

Km 26.0 - Km 30.5 (Allison Pools to Tamihi Creek)

Over this stretch of the river, glaciolacustrine silts are exposed on both banks and for some considerable height up the valley walls. The silts are overlain by glaciofluvial sands and gravels and tills. The meanders of the river lie within exposures of fresh, and often unstable, younger and older silts. Recent alluvium is present within the river channel. Alluvial fans overlie terraces developed on the glaciolacustrine silts at various elevations where creeks flow from the valley slopes.

Km 30.5 - Km 40.0 (Tamihi Creek to Vedder Crossing)

Downstream of Km 30.5 the river meanders entirely within terraces formed of recent fluvial deposits. Rock is partially exposed on the south valley wall and glaciolacustrine silts/glaciofluvial sands and gravels/till are exposed on the north wall. Alluvial fans are typically present where the creeks flow out onto the floodplain terraces. It seems likely that the younger silts were not deposited within this section of the valley.

3.3 Groundwater

Many of the slope hazards in the Chilliwack Valley are dependent on groundwater conditions. The weak soils and steep slopes combine to produce adverse stability conditions which are exacerbated by groundwater pressures. Thick sequences of highly permeable glaciofluvial sands and gravels generally overlie the glaciolacustrine silts and silty clays and provide good opportunities for groundwater infiltration although they may be protected by the tills on the Ryder Uplands. In addition, many of the fine-grained glacial deposits contain sand or gravel interbeds causing springs and seepages from the exposed faces which in turn cause problems of erosion and debris flow/flood activity. In summary, groundwater conditions are generally complex with perched water tables and highly variable flow conditions.

Once failures develop in the glaciolacustrine silts, the slumped blocks create changed groundwater conditions with the opportunity for greater infiltration which could further affect the already weakened soils. In this way retrogressive failures develop in the slopes as support is progressively removed from the toes.

Groundwater conditions are highly seasonal and slope instability results from increased piezometric pressures, seepage or erosion due to surface flows particularly during the winter and spring melt.

3.4 Hydrology

3.4.1 General

The Chilliwack River, with its headwaters in the northern Cascade Mountains in Washington State, flows north to Chilliwack Lake on the Canadian side of the border and then in a westerly direction to the Fraser River.

The catchment area is 1,230 km² above Vedder Crossing and ranges in elevation from about 3 m (GSC) at the Fraser confluence to 2,400 m in the mountains. McLean (1980) reported that approximately half the basin was above an elevation of 1,130 m, with 25% above 1,370 m. About 27% of the catchment drains into Chilliwack Lake, whereas the remaining 63% is delivered by steep tributary creeks, Figures 1 and 2.

Stream flow data are collected at the Water Survey of Canada (WSC) stations, listed in Table 7.

In addition to the above, records are also available for many of the tributaries including Slesse, Tamihi, Liumchen and Sweltzer Creeks.

Floods on the Chilliwack River can be divided into spring/summer snowmelt events and fall/winter rainstorm generated events.

The snowmelt events generally occur between April and July whereas the rainfall events usually occur between October and February. The snowmelt events have longer durations but generally lower flood peaks than the rainstorm floods which tend to be rather "flashy" with durations of one to three days.

The most extreme floods on the Chilliwack River occur during the fall/winter period with heavy rain precipitating the sudden loss of some or all of the early snowpack. The total flood volumes associated with the rain events are usually considerably less than the snowmelt events.

3.4.2 Factors Influencing Major Flood Events

There are at least seven factors which influence the magnitude of flow events:

- snowpack and moisture content;
- rainfall;
- ground temperature;
- ground saturation;
- freezing level;
- air temperature;
- wind.

The factors which have the greatest influence on the magnitude of floods are the snowpack and rainfall components. The temperature and associated freezing level impact the rate and timing of the snowmelt and frozen ground from an antecedent cold spell can increase the flood level through a reduction of infiltration.

The magnitude of the flow depends on the amount of snowpack and rainfall, and the rate it is released to the system as influenced by the combined effect of the other factors. A large moist snowpack on saturated frozen ground, hit by a heavy, warm, windy, rainfall will undoubtedly cause flood conditions. The probability, or chance, of this occurring is the combined probability of each adverse factor developing.

3.4.3 Flood History and Analysis

The flood history on the Chilliwack River dates back to the 1800's although gauged records are only available since 1911. A chronology of the major floods at the Vedder Crossing gauge, both gauged and historical, is shown on Figure 12. Known floods have been restricted to those with mean daily discharges above 500 m³/s, a lower limit derived by McLean (1980) for damaging floods. The flood of record occurred December 30, 1917, although the Skagit River record, near Concrete in Washington State, indicates that larger floods may have occurred about 1815 and 1856.

The recent occurrences of large floods, 1975 to 1990, was matched by a similar period between 1906 and 1921. Jordan (1990) has attributed this pattern to the rainfall record noting that at Hope, 6 of the highest 7 one-day rainfalls in the last 51 years have occurred since 1974. A similar study by Church and Miles (1987), as reported by Jordan, found above average frequency of annual maximum one-day precipitation in the Agassiz record for the periods 1917-24, 1948-56 and 1971-84.

An attempt was made in this study to correlate the Agassiz and Chilliwack rainfall records to the observed floods on the Chilliwack River at Vedder Crossing. Both single and multi-day maximum annual rainfalls were extracted from the records and plotted against the corresponding floods on the Chilliwack River, Figure 12. While, as reported by others, there is a general correlation between periods of above average precipitation and above average floods, there is not a very good correlation between the rainfall data and the magnitude of the corresponding floods, indicating that other contributing factors, such as snowpack and freezing levels, play a significant part in the flood generation process.

Another factor which may contribute to a lack of good correlation between rainfall and flood peaks for specific events is that the orographic effect of the mountains often generates cells of high intensity rain in a storm, which may be missed by gauging stations but nonetheless have an important effect on the flood magnitude, especially for small tributaries or drainage catchments. Comparison between flow and rainfall records, and between adjacent rainfall gauging stations is affected by such orographic effects rendering correlation of data somewhat difficult.

A study of climatic trends also points to the likely increase in rainstorm frequency in the coastal area of Vancouver/Chilliwack. Rainfall analysis by Atmospheric Environment Services, Environment Canada, Figure 13, points to a steady increase in mean annual rainfall at Vancouver since about 1920, with the 10 year running mean increasing from approximately 800 mm to 1,200 mm over the last 70 years. Vancouver temperature data, Figure 13, also displays a slight upward trend, translating into increased precipitation, though the trend is almost non-existent over the last 50 years.

By comparison, an examination of temperature and precipitation data for the interior of British Columbia, as represented by data from Summerland, do not show the same increasing trends seen in the Vancouver data. The flow of the Fraser River, which depends on interior conditions, shows a cyclic variation, but not an increasing trend, Figure 13. As speculation, the data on Figure 13 would suggest that coastal weather conditions may be impacted by changes in ocean current patterns off the coast of the Province.

In summary, data indicates a general correlation between the trend of increasingly precipitation on the coast and the increased frequency of flooding events. However, the peak flow of a particular flood does not correlate well with rainfall intensity because of other contributing factors. The trend toward increasing precipitation would suggest that the traditional flood event analysis, as discussed below, may underestimate the magnitude of flood peaks associated with a particular return period.

3.4.4 Flood Frequency Analysis

The flood records on the Chilliwack River at Vedder Crossing were analyzed to assess changes to the frequency estimates since preparation of the floodplain mapping in 1981. The Consolidated Frequency Analysis program of Environment Canada (CFA 88) was used to prepare estimates for both fall/winter rain dominated events (September-March) and spring/summer snowmelt events (April-August). The September to December floods were tabulated with January to March data of the following year. The record included estimates for floods not reported by WSC, as given in Table 8.

Analysis of the 61 years of rain floods yielded the daily mean flood estimates given in Table 9. The Log Pearson Type III analysis, which gives a reasonable fit to the data, yields a 1 in 200 year flood flow estimate of 917 m³/s. The flood frequency distribution is plotted on Figure 14 for the rain dominated events (September-March).

Including the recent large floods significantly increases the flood estimates compared to the 1980 analysis. This is not surprising considering that 4 of the largest 9 floods (1980, 1984, 1989, 1990) were not included in the earlier analysis nor was the ungauged flood of 1951 (4th largest).

Although there is uncertainty in the magnitude of the recent large floods due to malfunctioning of gauges, the Log Pearson Type III (LP III) estimates would indicate increases of 13% and 16% for the 20 year and 200 year events respectively, compared to the 1980 analysis.

Analyses were not repeated for the other stations upstream, however, it would be prudent to increase the earlier 1980 estimates for these stations by at least 10% to reflect the recent large floods, pending a re-analysis of the upper station records.

A similar analysis of snowmelt floods yielded much lower flood estimates than the rain floods. The 20 year and 200 year Log Pearson Type III estimates were 359 m³/s and 427 m³/s respectively. The 200 year rain flood is therefore more than double the magnitude of the corresponding snowmelt event.

3.4.5 Forest Harvesting and Runoff

Considerable public concern has been expressed regarding the impact of forest harvesting on river flows and sediment production. A major study has been under way on Carnation Creek, Vancouver Island, to quantify the effects of clear-cut logging.

The Carnation Creek study (Hartman, 1990) provides some relevant and applicable scientific data because of the importance of the maritime influence on peak flows generated in some tributaries in the Chilliwack Basin.

Carnation Creek data indicate that 40% removal of forest cover over 5 years did not result in measurable changes in water yield or peak flow over the watershed as a whole. On a sub-basin that was 95% clear-cut, a 9 to 16% increase in yield was detected (Hartman, 1990). Such small increases are attributed to reduced evapotranspiration and interception. Since the majority of precipitation occurs during the winter months, when vegetation is relatively dormant, the effects of reduced evapotranspiration/interception are minimal at 40% removal.

Interception of subsurface flow by roads could be expected to speed the delivery of water to channel flow and possibly increase peak flows. However, this effect was not differentiated in the Carnation Creek study, and the small increases in yield in the sub-basin have become less in the post-logging period.

Another study in the Seymour Watershed showed a variable response to snow in clear-cuts compared to snow in the forested areas (Beaudry, 1984). During rain-on-snow conditions when snow was in a forest canopy, the forest produced higher runoff than the clear-cut. When snow in the forested area was on the ground, the clear-cut produced higher runoff, suggesting that a mix of forested and cut over areas would

provide a moderating influence on extremes of flow generated by rain-on-snow events through the winter.

Present research data indicates that no significant change in peak flows would be expected in watersheds if less than 40% of the watershed is harvested over a five year period.

Analysis of the areas harvested in the Chilliwack watershed is summarized in Table 10, indicating the percentage of the watershed logged over recent five-year periods is less than 5%. The total cumulative percent of the watershed area logged is 19.6%.

The breakdown in harvested areas for sub-basins is given in Table 11. Forest harvesting activities are not likely to have contributed to changes in runoff in the Chilliwack basin. Harvest rates in some tributaries may have affected flow regimes in those watersheds. In general, however, the spatial area in the Chilliwack watershed that is in a condition equivalent to a clear-cut is not considered large enough to have affected the overall flow regime.

3.5 Morphology

The modern Chilliwack River developed as glaciers melted and receded. Waters draining the valley began incising the pre-existing valley fill, carving channels into the glacial materials. This ongoing activity has reworked much of the glacial sediment prior to redepositing it as modern day alluvium. Evidence of this process is seen in the terraces lining previous river channels and channel scars throughout much of the present valley, as mentioned in Section 3.2.2.

The morphological form of the river is a product of the combined influence of river flows, sediment size and availability, and river slope. At some locations, such as near Chipmunk Creek, the river slope is controlled by bedrock outcrops, Figure 15. In other locations, the slope appears to be controlled by glacial outwash deposits of large boulders, such as downstream of the confluence of Tamihi Creek, or by tributary fans such as at Slesse Creek. In between these independent controls, the river slope, and the channel characteristics, respond to the amount of sediment delivered. Typically, when the river cannot degrade because of independent controls, the river responds by producing multiple, or braided, channels to transport a heavy delivery of sediment.

The braided sections of the river, such as upstream of Tamihi Creek, and between Ryder Creek and Vedder Crossing, are subject to rapid changes in channel locations, referred to as avulsions, during flood flows. A comparison of the river channel locations in 1976 and 1991, from Slesse Park to Vedder Crossing, Drawing 102, shows major shifts in the location of the river.

The morphological characteristics of the river are described below, followed by a discussion on sediment supply and transport.

3.5.1 River Characteristics

The Chilliwack River may be characterized by the following five reaches from Chilliwack Lake to Vedder Crossing (McLean 1980):

- Chilliwack Lake to Foley Creek
- Foley Creek to Slesse Creek
- Slesse Creek to Tamihi Creek
- Tamihi Creek to Ryder Creek
- Ryder Creek to Vedder Crossing.

Chilliwack Lake to Foley Creek

The upper reach of the river is a well incised sinuous channel which flows over the slope remaining after the last glaciation and reflects the moderating influence of Chilliwack Lake. The river pattern is irregular, wandering over the valley floor but running primarily along the south side. There are few developed mid-channel bars or islands except where local widening occurs. The extent of downcutting is controlled by a bedrock knickpoint near the confluence with Foley and Chipmunk Creeks.

Bed material is sub-angular boulders to rounded cobbles, showing rough gradation downstream from the lake. Bank material is virtually identical to the bed, comprised of boulders and cobbles, having been derived from glacial rather than fluvial processes. The coarseness of the bed material indicates armouring has developed with the fines washed out.

The reach is fast flowing, the nearly continuous rapids and white water reflecting the steep river gradient of 0.017. High velocities generally result from such steep gradients which provide a high capacity for sediment transport, but owing to the size of the substrate there is not a large amount of transportable material available. Significant sediment transport would be unlikely in this reach during normal floods but high flow events would see some mobilization of the bed.

This upper reach is not exposed to the 'flashy' floods experienced in the river downstream of Slesse Creek. Bank erosion is minor, being confined mostly to the outside of river bends, and debris seen in the system in 1991 was well weathered, indicating it has been in place for several years, and not washed out during the major flows in 1989 and 1990.

Foley Creek to Slesse Creek

This reach is similar to that upstream, with a wandering single channel. Although most of this section has a narrow sinuous form, a large meander has developed downstream of the Chipmunk Creek confluence and large sweeping bends are found locally further downstream. There are few mid-channel bars or islands. Downstream of the bedrock knickpoint, at Chipmunk Creek, there is a deep canyon cut into the valley floor leaving a distinct terrace along the southern side of the valley.

Bed material is boulder to cobble size with a smaller mean size than the upstream reach. Most of the banks also consist of boulder to cobble size material, while in some areas the banks comprise glaciolacustrine silts and clays. The banks are generally stable except in the fine grained sediment regions. In these areas erosion is concentrated on the outside of bends.

As the river gradient of 0.018 between Foley and Slesse Creeks is steeper than the upstream section, and the mean bed-material size smaller, bedload transport is greater. In order to move the substrate it is estimated a flood greater than the one in ten year event is necessary to generate sufficient flow velocities (McLean, 1980). The river is actively eroding the outside of the bends in areas with banks composed of glaciolacustrine sediment. Once the fine grained sediment enters the river, it is carried rapidly downstream.

Upstream of the confluence with Slesse Creek there is a short section of braided channel with well developed mid-channel and lateral bars. The local gradient is likely controlled by the Slesse Creek fan resulting in lower flow velocities and a braided depositional area.

Slesse Creek to Tamihi Creek

Slesse Creek is the first major tributary to join the Chilliwack River, increasing discharge in the river by approximately 15%. A considerable amount of sediment is also added especially under high flow conditions.

The Chilliwack River shows a marked change in morphology in response to the added water and sediment volume and the presence of glaciolacustrine silts. The average river width increases from 20 m - 27 m above Slesse Creek to 40 m - 47 m below the confluence. Alteration in river pattern and character also reflect the increased discharge, the river becoming much wider and slower. Both large scale meanders and wandering braided stretches, with frequent gravel bars and islands, are common. The entire reach has areas undergoing both deposition and erosion, often in close proximity.

The bed material ranges from large rounded boulders, near Slesse Creek, to rounded cobbles above Tamihi Creek. Boulders are found as far downstream as Slesse Park. Although the mean sediment size is much lower than upstream, there are no deposits of sand or gravel seen. The banks are highly variable, ranging from boulders and cobbles near Slesse Creek, silt and clay above Allison Pools, a bedrock section through Allison Pools and clay and silt from Allison Pools to near Tamihi Creek.

From Slesse Creek west for four kilometres (Km 21.5 to 24.5), erosion occurs along the outside of bends. The high banks on the north side of the valley usually consist of silt and clay which are easily undercut. The southern banks are more stable. Through Allison Pools, the banks are relatively stable, with only minor amounts of scour evident. Downstream of Allison Pools, the river meanders in looping bends over the valley floor. Medium to high relic terraces somewhat confine the river although undercutting of the glaciolacustrine banks results in slope failures along the river banks. From Slesse

Park to just upstream of Tamihi Bridge, the river is laterally unstable and assumes a braided wandering form with frequent mid-channel and lateral bars.

The reach of river from Slesse Park to about 700 m upstream of Tamihi Bridge is particularly prone to frequent channel changes. The river straightened its course dramatically in this area during the November 1990 flood, Drawing 102.

Tamihi Creek to Ryder Creek

Approximately 700 m upstream of the Tamihi Bridge, the Chilliwack River undergoes another change in morphology. The braided wandering river becomes narrow and sinuous dropping over a series of rapids. This narrow constricted channel has two large bends, widens downstream and runs virtually straight.

Numerous large boulders, one to three metres in size, line the bed and banks through the upper part of this incised reach and, together with the Tamihi Bridge crossing, offer some degree of lateral control. The boulders are probably of glacial origin as their size would preclude a fluvial source. The presence of the large boulders has armoured the bed against large scale downcutting in this area.

Bed and bank material is sub-angular to rounded boulders and cobbles which range in size from greater than four metres at the bridge to roughly 0.5 metres near Bell Acres. The bed material is probably stable near Tamihi Bridge but capable of being transported at locations further downstream. The banks consist of a thin mantle of soil over a coarse base fraction which is not easily eroded during normal flows, although local erosion does occur during extreme events. There is no evidence of the glaciolacustrine sediments along the active channel or in the lower valley walls.

The gradient of the river in this reach is quite high, averaging 0.0102, with local gradients as steep as 0.020. The sediment transport capability is correspondingly high, therefore any sediment introduced to this part of the river is rapidly carried downstream. A review of bankline changes since 1932 would indicate this reach is relatively stable, although there was a channel shift in 1975 and some bank erosion occurred during the floods of 1989 and 1990.

Ryder Creek to Vedder Crossing

Proceeding downstream from the Bell Acres hamlet near Ryder Creek, the Chilliwack River again changes morphology, once more assuming a wandering, braided pattern. This is most evident downstream of Ryder Creek as mid-channel and lateral bars become commonplace.

Bed material is cobble sized, with occasional boulders. Sediment deposited as mid-channel, lateral and point bars ranges in size from coarse sand to small boulders. This reach has the first occurrence of large scale sand deposits.

The present channel has exposed bedrock at the toe of the valley wall along some sections on the southern side of the valley whereas the northern banks are comprised of older glaciofluvial deposits, Figure 8. The banks are not erosion resistant and consequently the river channel is laterally unstable between the valley walls along the entire length of this reach.

The river gradient through this stretch is low, averaging 0.0050. Although sorting of bed substrate is likely to occur during mean annual floods, significant bedload transport is probably limited to floods with a return period of 1 in 10 years or greater. Thus, during quiet periods of minor flows, some aggradation will be evident followed by downcutting and channel shifts during major events.

Similar to the braided stretch near Slesse Park, this section of river is prone to frequent channel changes. Notable recent channel changes include a major avulsion to the south side of the valley upstream of Baker Trails, Drawing 102.

3.5.2 Sediment Sources and Transport Rates

The following three major sources of sediment supply have been identified (McLean 1980):

- bank erosion;
- landslides in terrace deposits;
- tributary creeks.

Bank erosion occurs both in recent alluvial deposits and in glaciolacustrine deposits. The numerous mid-channel bars that develop as islands during periods of moderate flows are subject to bank erosion during major events and the previously deposited sediments are reactivated in the system. This type of bank erosion occurs throughout the system downstream of Slesse Creek, being particularly evident between Liumchen Creek and Vedder Crossing. This bank erosion of contemporary alluvial deposits is often associated with the undermining of trees and contributes significant amounts of debris to the river. Analogous to this type of bank erosion is the sediment contribution reactivated when a channel avulsion, or cutoff, occurs. This phenomena is also associated with the infusion of woody debris. McLean (1980) estimated the volume of sediment produced by bank erosion upstream of Vedder Crossing during the 1975 flood to be about 500,000 m³.

The rate of erosion of glaciolacustrine deposits along the river edge depends upon the type of bank material and other factors, as discussed in Section 4.3. The volume of material contributed to the system may vary from small amounts, as is the case in the Tamih Creek area where the banks are comprised of boulders, to large amounts associated with landslides.

The significance of the contribution of sediments from landslides depends upon whether the material takes an active part in the formation of the river bed. The bulk of the landslide materials are silts and sands, whereas the bed materials in the study area to Vedder Crossing are predominantly gravel sizes. The

contribution of sediments from landslides is likely more significant to the river morphology downstream of Vedder Crossing, than upstream of the crossing.

The sediment contribution from tributary streams to the Chilliwack River is significant, as evidenced by the fans at the mouths of these creeks, notably Slesse, Tamihi, and Liumchen Creeks. Sediment delivered to these fans can remain in storage until flows in the Chilliwack River are capable of initiating transport.

The impacts of forest harvesting on sediment contributions to various watersheds have been under study for a number of years. It has been very difficult to quantify this contribution because of the complexities in measuring sediment yield and transport.

The Carnation Creek studies (Hartman, 1990) indicate that suspended sediment yield and bedload transport appears to have increased in this watershed after logging. However, the increases can be attributed to channel changes related to a severe streamside logging treatment since most sediments originated from bank erosion.

Other studies show an increase in suspended sediment production due to forest harvesting. Much of the increase is attributed to forest roads and their drainage systems. Roads intercept slow subsurface flow and convert it into rapid ditchline flow. Compacted road surfaces also redirect water as surface flow and provide a sediment source. Reid and Dunne, 1984, show sediment yields ranging from 0.51 tonnes/km/year on abandoned roads to 500 tonnes/km/year on heavily used roads. The Slim-Tumuch study (Brownlee, 1988) documents sediment increases of 4-12 times that of undeveloped areas. Haul roads were the major source, though sediment production returned to control levels in two creeks, one year after logging.

Acceleration of landslide activity after logging has been documented in many areas. A proportion of the increased landslide activity occurs from tree removal. Decay of root systems, damage from yarding, and increases in windfalls on exposed clear-cut boundaries are implicated in this acceleration. Roads are also responsible for accelerated mass erosion. Amaranthus et al., 1985, in a study in Oregon, show that while roads were only two percent of the inventory area, they accounted for over half of the number of landslides and 60% of the landslide volume. It is generally recognized that roads are the most significant factor in steep slope failures and that road drainage plays a major contributing role in road-related landslides.

Studies on the length of time that rivers are affected following the cessation of logging have been carried out on the Queen Charlotte Islands. Severe morphological changes in torrented channels appear to persist for a decade. Thirty years after disturbance, channel morphology resembled undisturbed channels (Hogan, 1990).

Rough estimates of sediment production from road washouts and failures during the November, 1989 storm in the Chilliwack River Valley are reported by Jordan, 1990. Volumes of 25,000 to 75,000 m³ of bedload material are suggested with caution expressed as to the accuracy of the estimates.

Forest road systems and some harvested areas are contributing small chronic inputs of suspended sediment and bedload to the Chilliwack River. Harvesting practices, particularly cross stream yarding and removal of riparian trees in the floodplain reaches of the main stem and some tributary reaches, are other possible mechanisms whereby forestry may have contributed to channel destabilization and accelerated bedload transport.

The actual increase in sediment contributions related to forest harvesting in the Chilliwack River basin cannot be quantified on the basis of available data. Based on observations within the valley, and the results of research referred to, there is little question that the activities have led to an increase in sediment production over that expected from an unlogged area. Favourable logging practices would reduce this contribution, as discussed in Section 6.3.3.

Several studies have estimated the amount of sediment transported annually through the Chilliwack River. Martin, 1991, undertook a sediment budget analysis downstream of the Vedder Crossing, where apart from her estimated annual throughput of 1,000 m³/yr, the area acts as a sediment trap for Chilliwack River sediments. Based on a review of surveys and sediment extraction records over the period 1981 to 1990, the study indicated the annual aggradation rate varied from 19,200 m³ to 109,000 m³. Based on the data given in the report, the average annual rate of aggradation over the study period was about 60,000 m³/yr. In independent studies, McLean (1980) estimated the average annual transport rate at Vedder Crossing at 77,000 m³/yr and Tamburi (1977) estimated the average annual rate to be between 56,000 to 68,000 m³/yr.

All studies make reference to the fact that the volume of sediment transported is very sensitive to the magnitude of the flow. Large flows, such as occurred in 1975, transported an estimated 200,000 m³ of bed sediments (Tempest, 1976). However, Martin notes that even during low flow years, such as 1981-1982, there is bedload transport even though it is at a greatly reduced rate.

3.5.3 Recent Channel Changes

Large scale changes such as avulsions and extensive in-channel erosion and braiding develop during major floods on the Chilliwack River. The 1989 and 1990 floods, both approximately 1 in 40 year events, provided evidence of such changes. The threshold velocity for transport of the bed gravels is exceeded throughout the river system during such major floods and large quantities of sediments are mobilized. Bars are formed and eroded during the flood in response to local velocity changes triggered by altered hydraulic conditions, bed character changes or debris jams. The channel in turn responds to the bar and debris development by shifting laterally into a new channel or re-activating relic side channels. The

major channel shift to the south side of the valley floor opposite Baker Trails is an example of these processes, Drawing 102.

As the major flood progresses, new sediments enter the system from tributary streams and from instream bank erosion. Deposition of these sediments occurs in low gradient reaches that can absorb lateral movement whereas degradation can result in previously overfull braided reaches. This localized downcutting and depositional process is evidenced at Slesse Park where a chute cutoff downcut through two previous meanders, depositing the sediments upstream of Tamihi Bridge. The deposition resulted in extensive braiding, lateral movement and further erosion into the Willow Run Slide.

The rain on snow events leading to these geomorphic changes are of short duration, in the order of days, so the changes that are triggered by the flood may not have a chance to fully develop into a new state of equilibrium. Subsequent minor floods do not have the stream power to dramatically alter the channel structure but instead consolidate the features triggered by the major flood into a new temporary equilibrium. Dormant reaches are progressively infilled and poorly incised braided channels become more definite as the stream attempts to equalize the bed gradient along the reach.

Large organic debris (LOD) studies in Carnation Creek showed woody material and streamside trees were important for channel stability. Particularly in small floodplains, channel form and sediment storage are regulated by LOD. Severe experimental treatments along the main channel floodplain in Carnation Creek contributed to decreased channel stability and increased bedload transport. A reduction in the volume of LOD of 30% in the areas logged to the streamside was considered a key factor in the channel changes. Bank damage from cross-stream yarding (dragging logs across the channel) breaks the integrity of the streamside zone.

Harvesting in the Chilliwack River Valley during the 1920-1950 period removed considerable numbers of streamside trees along the main stem, however, the period from 1921 to 1974 was a time with no successive major flow events, Figure 12. It may be that the period with large potential channel impacts from harvesting corresponded with relatively low discharge and frequency of floods.

River bed cross-sections were surveyed on the Chilliwack River between Slesse Park and Baker Trails in 1976, 1979, 1990 and 1991. The 1976, 1990 and 1991 surveys were taken after major flood events.

The available survey data permits a comparison of cross-sections from Vedder Crossing to the Edwards Road area for the years 1990-1991, covering the flood event of November 1990. Upstream from Edwards Road to Slesse Park, a comparison was made between the 1976 and 1991 surveys, covering a period in which there were 14 floods with mean daily flows exceeding 250 m³/s.

Data from the cross-sections was digitized into a computer in order to compare the cross-sectional changes between survey dates. Areas of deposition and scour were calculated and the average change in bed elevation was calculated from the net infill, or scour, over the width of the cross-section. The

locations of the cross-sections are shown on Drawing 102. Typical cross-sections for the Baker Trails to Slesse Park area are shown on Figures 16 to 20.

The results of the deposition and scour calculations are given in Table 12. In general, a review of the tabulated data indicates that even though the river has seen major floods, there is no overall general aggradation of the bed in the reach between Slesse Park and Vedder Crossing. This observation is consistent with the findings of Martin, 1991, for river cross-sections immediately downstream of Vedder Crossing.

From the survey data, and plotted cross-sections, it is evident that the river channel has shifted within the cross-sections at many locations, but generally the flow conveyance area has remained the same with infill at a cross-section being offset by scour elsewhere in the section.

There are some locations where net infill has taken place, for example cross-section 18, near the Way's farm, and others where net scour has taken place, such as section 14 near Wilson Road, or at Section 31, at Slesse Park. These changes, and the longitudinal variation in net scour or infill, may be indicative of the movement of large scale gravel bars.

Specific observations from the river bed cross-section plots include:

- at section 16, near the "Coutts" lease on I.R.4, there was no significant change in conveyance area, but there was scour up to 2.5 m deep on the outside of the bend in an area where road washouts have occurred;
- at section 9, Baker Trails area, there were considerable changes in the bed due to the braiding of the river during the 1990 flood, with bed elevation changes of ± 2 m, yet no significant change in conveyance area;
- at section 14, downstream of Wilson Road and the confluence with Liurnchen Creek, flows concentrated on the left bank during the 1990 flood causing scour up to 3 m deep;
- at section 16, in the Edwards Road Area, the channel shift of over 100 m, which lead to bank erosion at the "O'Hanley's" property during the 1990 flood, is evident;
- at section 18, near the "Way's farm", the braided character of the river is evident. Braiding of the river in this area, and attendant bank erosion, was likely exacerbated by the deposition in this area;
- at section 31, near Slesse Park, the more direct route taken by the river during the 1990 flood, called a 'chute cutoff', is evident, resulting in an overall decrease in the bed level at this cross-section.

3.5.4 Summary of River Channel Dynamics

The following, in point form, summarizes an opinion on the dynamics of the Chilliwack River channel from the lake to Vedder Crossing, based on a review of data and field observations:

- the river does not flow totally within its own alluvium, such that the river in certain reaches is controlled by bedrock, large glacial lag boulders or tributary fans. The bed gradient controls force the river to be braided in areas immediately upstream of these controls at Vedder Crossing, Tamihi and Slesse Creek;
- sediments build up in the tributary watersheds during periods with no major floods. The buildup is due to weathering of rock exposures, creep of slopes and accumulations of colluvium in tributary valleys;
- sediments delivered from high energy tributaries accumulate on the fans at the confluence of each with the Chilliwack River;
- vegetation grows on side and mid-channel bars during periods with minor floods;
- when a number of climatic conditions combine, a major flow occurs which mobilizes sediments accumulated in tributaries, on fans and within the bed of the river. The flow occupies the entire channel area and 'elbows' into previously deposited sediments, introducing both additional sediments and debris into the river;
- because of steep gradients, the silt and sand sized sediments move quickly through the system and do not play a significant role in the formation of the bed;
- when possible, the river in flood shortens its course and, in so doing, mobilizes additional sediments;
- the gravel and cobbles move quickly and very audibly through the steep, confined sections, such as the reach around the Tamihi Bridge, whereas they move more as gravel bars in the braided areas;
- because there is a wide range of gravel to cobble sized sediment mobilized in the system, the velocity at the river bed at any point is transporting the maximum size possible. When a tree, particularly a root wad, rests on the river bed, the flow velocity is reduced and gravels deposit in the lee of the debris forming a bar which encourages even more debris to collect;

- if a debris jam occurs, there is a temporary increase in the water level upstream of the jam which persists until the river finds and scours another channel. Where the river is unconfined, this bypassing of the jam occurs easily without any significant increase in upstream water level. However, if the river is confined, say at a bridge crossing, the jam will cause upstream water levels to increase perhaps to the point where the hydraulic force is sufficient to break up the jam, or the bridge piers are outflanked;
- as the river changes its course due to the movement of gravel bars, or because of logjams, additional debris and sediments are mobilized as relic channels are re-occupied or bank erosion occurs. Where the river is directed toward a natural or man-made rock bank, the concentration of flow results in scour of the river bed;
- as the flood flows decrease, the sediment transport also decreases and bar migration diminishes. Subsequent lower flows cut through these bars at a reduced rate.

The dynamics of the process are greatly influenced by the magnitude of the flow. An increase of flow velocity by a factor of two would lead to an increase of eight, or more, in sediment movement.

The significance of an increase in logging-related sedimentation should be viewed from the perspective of whether or not this increase leads to an increased exposure to bank erosion or flooding in the mainstream of the river. If the logging-related sedimentation was significant, its impact would be seen as a change in the morphological character of the river or, alternatively, as an increase in bed level elevations. The braided character of the river, which leads to bank erosion in developed areas between Slesse Park and Baker Trails, is largely dominated by independent river bed slope controls. Furthermore, as discussed earlier, there has not been any significant increase in average bed elevations of the river between Slesse Park and Baker Trails.

Available evidence would suggest that logging-generated sediments have not contributed to the flood and bank erosion hazards in the area between Slesse Park and Vedder Crossing.

4 HAZARDS

As discussed in Section 1 of this report, the Chilliwack River Valley is exposed to floods, bank erosion and geotechnical hazards. This section of the report briefly summarizes the funds spent during emergency responses to the 1989-90 floods and then estimates and maps the flood, bank erosion and geotechnical hazards on the north side of the valley from Slesse Park to Baker Trails.

4.1 Emergency Response Costs

Flooding and bank erosion occurred in the study area during the floods of 1984, 1989 and 1990. The 1989 and 1990 flows reached bankfull conditions throughout the valley and in local areas overtopped the

banks flooding the Chilliwack Lake Road and residences in the Bell Acres area. Bank erosion was severe in both the 1989 and 1990 events and resulted in the washout of the Chilliwack Lake Road between Vedder Crossing and Baker Trails. The relocation of one residence in the Edwards Road area was subsequently required.

The magnitude of recent flow events for which flooding and bank erosion occurred were not severe in comparison to the values which would normally be considered for hazard avoidance in the Province. The floods of 1989-90 had an estimated return period of 1 in 40 years, whereas the design criteria for floodplain management in British Columbia is based on a 1 in 200 year event.

Emergency work was undertaken in 1984, 1989 and 1990 to curtail flooding and bank erosion during the events. This was followed by remedial work after the events to replace and protect roads, repair bank protection and dykes, compensate for structural damage at some residences and to clean up debris both in the river channel and on the floodplain.

Funds expended by government and utilities for emergency response and restorative work following the floods of 1984, 1989 and 1990 are given in the table below, indicating a total of \$4.9 million was spent in direct costs. This amount does not include any costs expended by individual property owners, nor does it include any indirect costs associated with the flooding and bank erosion.

In addition to the above costs, restorative work undertaken by the Ministry of Environment following a 1980 storm totalled \$62,000 not including the cost of emergency bank protection placed by the Ministry of Highways during the same storm.

The Department of National Defence spent about \$27,000 in road and bridge repairs near Slesse Creek following the 1989 storm. Most of the expenditures by this Department following the 1990 storm involved work along the Vedder River.

There are no records of emergency response funds being applied to hazardous geotechnical events in the valley, apart from funds expended to construct a protective dyke along the base of the slide on the north bank upstream of Slesse Park.

Flood Damage Costs Associated with Floods of 1984, 1989 and 1990

Agency	Flood, Yr.		
	1984	1989	1990
B.C. Environment Supervised Work	\$277,000	\$770,000	\$2,000,000
Ministry of Highways	12,000	1,017,000	562,000
Department of National Defence	---	27,000	---
B.C. Hydro	---	40,000	25,000
B.C. Gas	---	25,000	---
B.C. Telephone	---	50,000	50,000
TOTALS	289,000	1,929,000	2,637,000

- Notes:
1. Amount for MOTH includes an estimate of costs incurred by a maintenance contractor of \$85,000 and \$110,000 for 1989 and 1990, respectively.
 2. Amount spent by B.C. Telephone was about \$100,000 following the floods of 1989-90.

4.2 Flood Hazards

Flood levels, often called flood stage, on a natural river are affected by numerous factors including river slope, channel roughness, constrictions, obstructions, bends and backwater effects from adjoining watercourses. These factors are in many cases interrelated with river slope having a dominant impact on river characteristics.

The relationship between river levels and river flow is often shown on a plot of a 'stage-discharge' curve. Rivers with mild slope tend to be slow moving, meandering and have fine grained bed materials. The stage discharge curve on such a river would exhibit a relatively large stage change for a given change in flow. Rivers of moderate slope would have larger bed material, less tendency for meandering and have faster flow velocities. Such rivers would exhibit somewhat flatter stage discharge curves with a smaller stage change required to produce a given flow change, assuming geometrically similar channels. Steep rivers are fast moving with large bed material and often have relatively straight reaches. The stage discharge curve for such a river would be flatter than the others described above with a small stage change required to produce a given flow change.

Channel roughness is related to the size of the bed material which, in turn is related to river slope as described above. Rivers dissipate energy by means of shear force interactions with the bed material as well as by turbulent mixing processes associated with bends, obstructions, contractions and expansions. Each of these factors results in energy losses which in turn impact on the flood stage at a given location on the river. Constrictions can be permanent in the form of bedrock control sections or temporary obstructions such as logjams, ice jams or landslides into the river. In either case, backwater effects from the constriction will cause higher flood stages in the river reach above the constriction than would occur in the absence of the constriction.

The ability of a natural channel to carry flow can be quantified in terms of channel conveyance, K , which when multiplied by the square root of the slope, equals discharge. When flow is described in terms of the Manning equation, conveyance may be described as:

$$K = 1/n AR^{2/3}$$

where:

n = Manning's roughness coefficient

A = channel area

R = hydraulic radius = area/wetted perimeter

For a natural channel with wide overbank areas, channel conveyance often increases rapidly once bankfull stage is exceeded due to the large increase in area contributed by the overbanks. This is shown graphically on Figure 21. For a unit stage change ΔH^A , the discharge increases by ΔQ^A for conditions below bankfull stage. Once the bankfull stage is exceeded, the river picks up a large increase in flow area and associated conveyance for the same unit stage change to ΔH^B . Consequently, the resulting incremental flow change ΔQ^B may be several times larger than the corresponding flow change below bankfull stage. The above conveyance change for overbank flow is somewhat offset by the increased roughness associated with overbank flow which is often accompanied by dense vegetation, and by reductions in the overall hydraulic radius for the cross section.

A return period or recurrence interval is generally used to describe the magnitude of an event for economic analysis and policy decisions. The return period is the average number of years within which a given event will be equalled or exceeded and it can be translated into a probability or level of risk for a designated event to occur within a selected time period. By example, there is a 0.5% chance of a 200 year event occurring in any one year, a 22% chance of the event occurring in a 50 year period and a 63% chance of the event occurring in a 200 year period.

The return period is only the average interval between events of a given or greater magnitude and while there may be a hundred 200 year flood events within a 20,000 year period, 90% of the recurrence intervals will range between 10 and 600 years.

McLean (1980) lists 500 m³/s, an 8 year return period flow at Vedder Crossing, as being an approximate threshold for damaging flood events on the Chilliwack River. Since 1974 there have been 5 years when winter flows have exceeded the threshold, December 1975, December 1980, January 1984, November 1989 and November 1990. The 1975, 1980 and 1984 events were determined to have return periods of 10 to 12 years, 1989 was a 34 year event and 1990 was a 42 year event. Also, both the 1989 and 1990 events had two successive peaks that effectively prolonged the flood duration allowing more erosion and channel changes to develop.

The frequency of these damaging floods, since 1974, is greater than for any period since 1914 to 1921, although the flow record is discontinuous between 1932 and 1951. The Hope rainfall station data is, however, continuous since 1938 and the majority of the highest one day rainfalls have occurred in the last 16 years of the 52 year record (Jordan 1990).

Based strictly on a statistical basis, the probability of 5 or more events, of a magnitude equalling or exceeding a 1 in 10 year flow, occurring in a 52 year period is 60% and the probability of 2 or more 40 year events occurring in the same period is 38%. Thus, rather than the recent floods being extraordinary events, there has been a concentration of large events in the last 16 years leaving the remainder of the past 52 year period as relatively benign.

The primary component in defining the flooding hazards is the 200 year floodplain limit. The Ministry of Environment defines the floodplain as being the still water level derived from the 200 year flow plus a factor of safety allowance (freeboard) to cover such items as surface waves, local disturbances and limitations of the analytical methods used to determine the water level. The Ministry undertook such an analysis in 1980 based on 1976 and 1979 cross-sections from Vedder Crossing upstream to Slesse Creek and prepared 1:5000 scale floodplain maps. The floodplain limits were generated by using water level isolines developed by the analysis and contours on a topographic base map.

The present hydrologic analysis, which includes additional significant flows not included in the 1980 analysis, indicates an increase in the assessed 200 year flow of 16% which in turn translates into a water level increase of 0.2 m. The 1980 floodplain map water level isolines were adjusted up by 0.2 m and applied to the 1989/91 base mapping contours which had been ground truthed by surveyed elevations at selected areas. The updated floodplain limits are delineated on Drawings 103, 104 and 105 for the Slesse Park, Bell Acres and Baker Trails areas, respectively.

As noted in Section 3.4.3, the trend for increasing amounts of precipitation in the Lower Mainland area is not factored into the estimates for the 1 in 200 year flood flow. If this trend continues, the 1 in 200 year daily mean flow of 917 m³/s at Vedder Crossing, used in updating the floodplain limits, could be underestimated. However, as noted earlier the floodplain limits include a freeboard allowance to cover the limitation of analytical methods available for flood flow predictions.

The floodplain mapping limits do not specifically consider some factors which may have a localized input on flood levels during an event such as changes to the channel and the bed or obstructions that may develop from ice, debris or logjams. The hydraulic characteristics of the stream cross-sections are often altered by such changes creating a local backwater effect leading to higher local water levels that will persist while the obstruction is present. The potential localized increase in water level is derived from the kinetic energy inherent in the water velocity. With typical flood velocities of 2 to 4 m/s local rises of 0.1 m to 0.5 m are possible.

A freeboard allowance of 0.6 m is included in the analysis used to derive the floodplain limits delineated on Drawings 103 to 105. This freeboard allowance should be increased if the width of the floodplain is so constricted that river flows cannot readily bypass local logjams.

The assessed value of properties and improvements exposed to the flood hazard totals about \$12 million, comprised of \$7.7 million in assessed property value and \$4.3 million in assessed property improvements. Market value of these affected properties is likely to be about \$16 million.

4.3 Erosion Hazards

The erosion hazard attendant to river systems is the threat that a river will migrate, cutting into banks or valley walls, creating a loss of property, damage to capital improvements, or danger to life.

The task for this study was to quantify the erosion hazard by estimating the limits to which the Chilliwack River would migrate, over a period of 100 years, unimpeded by bank protection or other river channel controls. In theory, a dwelling constructed beyond the limit would not be threatened by bank erosion over the next 100 years. In practice, as discussed later, while the general extent of potential channel migration may be delineated, site-specific conditions may prevail that cause the erosion to be more, or less, than the limit defined.

The erosion of river banks and valley walls is an integral part of the dynamics of river systems. River valley sediments, comprising the floodplain and banks of a river, are erosional products delivered by the combination of weathering and hydrological forces. In a general sense, the same processes that delivered sediments to the floodplain can act again to erode and rework the deposits.

Bank erosion leads to the migration of a river channel either laterally, in a direction perpendicular to the flow, or in a downstream direction. Most concerns and measurements of erosion rates are related to the lateral migration of river banks.

Banks erode by one, or a combination, of three principal mechanisms: direct extraction of the bank material by erosive forces; undercutting by erosive forces that leads to slumping of the bank; and the generally slower process of weathering where freeze-thaw cycles and/or seepage forces unravel the bank. Vegetation plays a more significant role in retarding erosion caused by weathering in comparison to

resisting aggressive hydraulic forces. Old growth stands of timber in the Nimpkish River Valley are progressively toppled by the river as it elbows its way across the valley floor.

There are numerous factors that affect the rate and extent of channel migration. Without attempting to separate the interdependence of variables, these include: catchment area (flow and width), slope, size of bed and bank material, rate of sediment transport, height of banks, and presence of bedrock. Some research has been undertaken to attempt to identify which are the principal factors controlling the rate of erosion. Hooke, 1990 measured bank erosion in rivers in Devon, Great Britain, over various time periods, using both field measurements and historical information. This analysis indicated the erosion rate was most closely related to catchment area, although the erosion resistance of bank material appeared also to be a major factor. Manson and Hickin, 1986 measured lateral migration rates on 18 rivers in Western Canada covering a period of 21 to 33 years. The rivers represented a wide range of river sizes with channel slopes varying from 0.00022 to 0.0019 and sediments ranging from sand to large cobbles. They compared their results with those obtained from some of their earlier work on the Beatton River, in British Columbia, which confirmed that the rate of erosion is affected by the radius of curvature in a bend, being greatest when the ratio of radius of curvature to channel width is between about 2 to 4. Taking the data within this range they demonstrated, on a statistical basis, that the rate of erosion was largely explained by the parameters of width and slope. These parameters are a measure of the size of the river system, as is catchment area.

Most of the research work on lateral river migration rates, including the studies mentioned above, has been undertaken for single channel meandering systems. This work has not addressed changes in channel alignment resulting from cutoffs between meander bends, or avulsions which are characteristic of braided systems. Nevertheless, the lateral migration data generated by others serves as a useful comparison for the bank erosion rates observed or measured on the Chilliwack River, as discussed below. The lateral migration potential of the Chilliwack River, from Slesse Park to Baker Trails, was estimated using the following steps:

- bankline locations extracted from aerial photographs and surveys were plotted to a common scale of 1:5000;
- the change in the position of the bankline at various locations was measured to represent the change in position over the interval between aerial photographs or surveys;
- the mechanism which resulted in the change in bank position was inferred and noted as being a lateral migration, chute cut-off, or an avulsion;
- the rates of lateral migration were compared to data from other rivers and to a regression relationship derived by Manson and Hickin;

- the area was examined using stereo photograph images and, together with the potential rates of lateral migration, a judgement was made as to the type of migration that could occur in an area over a 100 year period as well as the extent of the migration.

The river channel positions from Slesse Park to Baker Trails, for the period from 1932 to 1991 were used in the analysis, although only the changes from 1976 to 1992 are shown on Drawing 102. The distance the channel shifted at various locations is given in Table 13, together with the channel shifting mechanism and rate of lateral migration, expressed as metres per year.

Lateral migration immediately upstream of the Slesse Park area is typical of processes associated with a meander loop, recognizing, however, that the meander loop is forced by the impingement of river flow on the high post-glacial terrace forming the left bank. There is a tendency for the entire loop to move downstream, cutting into the valley walls, which has led to the occurrence of major slides in the area. The rate of erosion is affected by the height of the bank, or valley wall, as seen by comparing the rate of erosion at point 2, on the right bank upstream from Slesse Park, to the erosion rate at point 3, opposite Slesse Park, which has a higher bank than the former location. The lateral migration at point 2 was 80 m over a 15 year period as compared to a 15 m lateral migration over the same period at point 3, which has the higher bank.

A chute cut-off occurred during the 1990 floods in the river channel adjacent to Slesse Park, developing a straight channel some 50 m wide. The development of a cut-off during large flood flows is not an uncommon occurrence in single channel meandering systems. Once over top of its banks, a river in flood follows the general gradient of the valley, taking the shortest distance downstream.

The rate of channel migration in the Tamihi Creek area, from about Tamihi Bridge downstream to the Bell Acres area, is lower than other reaches, particularly along the right, or north, bank. The 1932 mapping shows the river was about 90 m south of its present location, point 7, Table 13, whereas the maximum lateral movement to the north, point 8, is about 20 m. The reason for the greater river stability in this latter reach is likely due to the predominance of large boulders, particularly on the right bank, which afford some resistance against direct erosion, or undermining of the banks.

The geomorphic character of the river commences to change, in the vicinity of Bell Acres, from a relatively stable single meandering channel to an unstable braided channel. From Bell Acres to Baker Trails, and downstream, large scale rapid changes in channel location can occur due to lateral migration or avulsions. Lateral migrations of up to 200 m have occurred during single large flood events. The porch of a home initially set back some 75 m from the river bank was undermined during the flood of - 1990, point 12, Table 13. Only the emergency placement of rip-rap curtailed the extent of lateral migration during the flood, limiting the extent of damage to the house. Further downstream, at Point 13, the channel shifted about 650 m to the south forming a single channel, which bears hard on an exposure of bedrock. These channel shifts occurred in a matter of hours.

Expressed as a rate per year, the range of lateral migration rates measured and tabulated in Table 13 varies from 0.3 my^{-1} (metres per year) to 13 my^{-1} , excluding bankline changes that may have been associated with an avulsion. An analysis of the Green River, Washington, which has about the same drainage area as the Chilliwack River, by Dunne and Dietrich, 1978 indicated lateral migration rates of about 0.05 my^{-1} to 9 my^{-1} .

Comparing lateral migration rates to other rivers, including the Tolt and Raging Rivers in Washington (Shannon and Wilson, 1991), indicates the values observed in the study area on the Chilliwack River are consistent with other data, Figure 22.

The rate of lateral migration equation derived by Manson and Hickin for radii of curvature/channel widths ratios (r/w) between 2 to 4, is as follows:

$$M = 0.301 \bar{W}^{0.895} S^{0.271}$$

where:

M = rate of lateral migration, my^{-1}

$\bar{W}$ = mean channel width, m

S = water surface slope.

Using a mean width of 60 m for the Chilliwack River and a slope of 0.007, which is typical of the Slesse Park area, would give a lateral migration rate of 3 my^{-1} , as compared to measured average values ranging from 1 to 5 my^{-1} , Table 13. The comparison would indicate there is reasonable agreement between the statistically derived predictive equation of Manson and Hickin and the observations on the Chilliwack River.

Given the results of the above analysis and comparisons with other river systems, the 100 year bank erosion limits, were estimated based on the following assumptions:

- there is no bank protection in place, other than the exposure of natural bedrock;
- the river would apply erosive stress to both left and right banks over a 100 year period;
- channel cut-offs could occur over the three point bars upstream of Slesse Park during a major flood event;
- the average rate of erosion into alluvial terraces from Slesse Park to Tamihi Bridge is 5 my^{-1} and into valley walls it is 0.3 my^{-1} . The maximum erosion is 250 m and 15 m into alluvial terraces and valley walls, respectively, unless geomorphic features suggest an increase. This is based on an equal chance of the erosion occurring on the left and right banks, that is, the equivalent of 50 years of erosion;

- the average rate of erosion into the right bank of the river from the vicinity of Tamihi Bridge to upstream of Bell Acres is 1 my^{-1} and the corresponding rate on the left bank is 5 my^{-1} . The maximum extent of erosion on the right and left banks over a 100 year period is 50 m and 250 m, respectively;
- commencing in the vicinity of Bell Acres and extending downstream to Baker Trails, an average lateral migration rate of 5 my^{-1} could readily occur, but more importantly, major avulsions could occur that over 100 years could result in the river migrating from valley wall to valley wall.

The bank erosion limits are shown on Drawings 103, 104 and 105 and need to be interpreted with some caution. The lines represent an opinion as to where the 100 year migration limits could be, based, in part, on historical evidence and, in part, on a subjective analysis. There are several factors that should be borne in mind in considering the magnitude and rate of the bank erosion hazard. These include:

- the use of an average rate of lateral migration is convenient for analysis but potentially misleading. Even though Hooke somewhat tentatively concluded that "most of the erosion appears to be achieved during or in association with events that occur several times a year", the evidence on the Chilliwack River is that aggressive bank erosion is associated with major flood events. Lateral migrations of up to 200 m, or a change in the course of the Chilliwack River by 650 m, or more, during a single event, is more descriptive of the bank erosion hazard than the average rates;
- large flood events will occur over a 100 year period. The probability of two or more floods equal to or greater than the 40 year flood occurring over a 100 year period is about 70 percent;
- the 100 year bank erosion limit shown is different than the 1 in 200 year flood limits shown. The flood limit is shown for a single flood event, whereas the bank erosion limit generally represents the accumulation of erosion from numerous floods;
- the bank erosion limits should be interpreted on the basis that, without protection, each point along the 100 year erosion limit has an equal probability of being reached over a 100 year period.

4.4 Geotechnical Hazards

In the Chilliwack Valley, three groups of geotechnical hazard can be identified:

- Channelized hazards: debris flows (or debris torrents)
debris floods

- Non-channelized hazards: slumps, slides
debris avalanches/earth flows
rock slides/rockfalls
- Erosion: Channel erosion

These are summarized in Table 14.

Two types of geotechnical maps can be produced: firstly, hazard maps which indicate the areal influence of geotechnical hazards; and secondly, risk maps which indicate zones of differing risk which result from the occurrence of a hazard of specified magnitude, or from a spectrum of hazards, of varied magnitudes. Risk mapping is currently in a state of evolution, and there is a progressive move towards showing risks in a quantitative, or semi-quantitative way to aid in planning decisions (Morgan, 1991).

Both hazard and risk maps require some engineering judgement. The ultimate objective of the process, however, must be to remove, as far as possible, the arbitrary selection of parameters, and to rationalize designation of probabilities of both hazard magnitude and risk.

Risks can be expressed in different ways depending on whether safety and health risks, or financial risks, are the prime considerations (Lind et al., 1991). Risk can be expressed as a "Probability of Death to the Individual" (PDI), or "Probability of Death to Populations" (PDP). Populations are considered as groups in excess of 10 people. Alternatively, where the hazard poses primarily an economic risk, an "Annual Risk Cost" (ARC) can be developed. In some areas, there may be both a safety and financial risk.

For PDI or PDP risk assessments, the "assigned" hazard probability is multiplied by the severity of the event which includes consideration of the exposure of the individual or population. The risks from a spectrum of hazards of different magnitudes can be integrated to determine a "total risk" of economic loss or death.

The ARC can be expressed as the annualized risk of damage, or total loss, as a percentage of the assessed value of the property, also on the basis of a spectrum of events, and may be compared with the cost of insuring against other hazards such as fire.

Previous systematic hazard assessments in the Chilliwack Valley have been developed on the basis of hazard maps (Thurber Consultants, 1988a and b). Currently, no risk maps have been produced. Zoning for different types of hazard has been carried out for the complete area between Vedder Crossing and Slesse Park on the north side of the river by Thurber Consultants (1988a). For consistency, and to aid in the planning process, detailed hazard maps have been produced during this study for the Slesse Park and Baker Trails areas. Data is available to extend the hazard maps into risk maps for comparative evaluation of risks should it be required.

Because of the rapid advances in risk assessment techniques, it is recommended that the results of this study should be reviewed periodically.

4.4.1 Hazard Type

Potentially destructive debris flows and debris floods develop from channels on the valley slopes, particularly in the area between Slesse Park and Vedder Crossing on the north side of the valley where the slopes are high and there is an abundance of erodible material within the creek channels. The highly unstable silts and fine sands in this area, Section 3.2, permit slumping of soils into the channels and blockage by organic debris. Debris flows also occur elsewhere in the basin as shown by the alluvial fans where tributary creeks flow into the Chilliwack Valley, but these are of less significance outside the Slesse Park - Vedder Crossing area since there is little habitation.

Debris floods may occur at the distal ends of the depositional zones of debris flows, or in flatter valleys, where they may deposit extensive volumes of material onto the alluvial terraces, or into the valley bottom.

Because of the localized distribution of channelized hazards, they generally only pose a risk of economic loss and a risk of death to individuals, but do not pose a risk of death to populations in the Chilliwack Valley.

Slumps and slides in glacial soils are widespread within the glaciolacustrine silts. Where the silts are undisturbed, they may fail partially on the horizontal bedding surfaces, as at the Slesse Park Slide, where the geological structure has been disturbed by overriding ice, the failures are likely to be independent of that structure, as at the Anderson Run Slide. The slumps are usually shallow and are considered to be up to 20 m deep, however, currently, there is no subsurface data to verify this assumption. They are often extensive in length.

Debris avalanches, or earth flows, may develop randomly at any location on the valley slopes within the glaciolacustrine sequence and they are independent of channel location. They may be precipitated by soil disturbance caused by slumping or by piping failures in fine sands, as at the Slesse Park Slide. They frequently mobilize the colluvium and contain a high proportion of organic material; they are invariably shallow. Like the channelized flows, they form fans on the alluvial terraces or in the valley bottom.

Rockslides and rockfalls are very localized and have not been identified as a problem.

Non-channelized hazards are poorly predictable (at this level of study) and should be considered as random events on the hillsides.

4.4.2 Hazard Distribution

Figures 6 and 7 show the distribution of geological materials throughout the main part of the Chilliwack Valley. The various materials and their properties are described in Section 3.2. The large clay slides have been the subject of a specific study which is summarized in Appendix 3. There is a concentration of 'clay slides' upstream and downstream of the Slesse Park area.

The distribution of geotechnical hazards is very much related to the presence of specific glacial or alluvial deposits within the valley as well as the steepness of the topography.

Slumps, debris flows/debris floods and earth flows are to be found where the older glaciolacustrine sediments (Unit #s 1, 2 and 3, Figures 8 to 11) are present between Slesse Park and Vedder Crossing. In this area, the slopes are high and are capped by till overlying glaciofluvial sands and gravels. Abundant springs and seeps are present on the slopes and cause non-channelized failures both by slumping and piping. These groundwater discharges coalesce in gullies which, together with the rapid runoff from heavy precipitation, create channelized flows and debris floods.

The 'clay slides' are characterized by chaotic slumps and earth flows primarily in the disturbed glaciolacustrine sediments (Unit #5), but occasionally also in the undisturbed (older) glaciolacustrine sediments (Unit #s 1, 2 and 3). These slides are generated primarily from erosion by the river causing oversteepening of the slopes, often aided by groundwater seepage.

Channel erosion is also causing instability in Slesse Creek near its confluence with the Chilliwack River, and it is a potential geotechnical hazard. Channel erosion also has local geotechnical significance throughout the lower stretches of the main valley.

Block falls and spalling from near-vertical cliff faces, developed in glaciofluvial sands and gravels, can be a hazard, particularly close to Vedder Crossing.

4.4.3 Hazard Assessment

For the purpose of hazard assessment, the area between Vedder Crossing and Slesse Park has been subdivided into separate areas according to the level of investigation carried out. These areas are shown on Drawings 106 to 114. The level of investigation carried out are designated as follows:

- Area 1: Terrain analysis was carried out supported by detailed ground reconnaissance and a review of previous work. Slope and channelized hazards were assessed, for zoning purposes, by Golder Associates based on probabilities assigned to a range of events. All zones are transitional and detailed site specific investigations and surveys are required to determine exact zonal boundaries and for permit approval.

Area 2: Terrain analysis was carried out supported by limited ground reconnaissance and a review of previous work. Slope and channelized hazards were assessed, for zoning purposes, by Golder Associates based on probabilities assigned to a range of events. All zones are transitional and detailed site specific investigations and surveys are required to determine exact zonal boundaries and for permit approval.

Area 3: Terrain analysis was carried out and previous work was reviewed. Zoning and assigned probabilities are those provided by Thurber Consultants (1988a), with minor modifications, based on the single maximum design event for channelized hazards. No probabilities have been assigned to slope hazards and zoning includes nominal setbacks from the crests or toes of slopes. Site specific investigations are required for permit approval.

4.4.4 Slesse Park Area

Geology

The development at Slesse Park is located entirely on surficial deposits of Pleistocene and Recent age. The higher slopes are developed on till and glacial outwash sands and gravels overlying overconsolidated, glaciolacustrine silts with interbedded silts and sands, and occasional till-like materials, all partially masked by colluvium and slide deposits. Disturbed "younger" glaciolacustrine silts are present in the lower part of the valley where they are considered to have been overridden by late glacial ice. The lowest terrace and valley bottom show Chilliwack River alluvium comprising coarse sands and gravels.

Other than on the near-horizontal terraces, most slopes lie in the range 20°-30°. Instability, although widespread, is considered to be only shallow (say 10-20 m), and developed mostly in the silts and has resulted from the presence of a combination of high and steep slopes, high groundwater pressures and weak materials. Internal erosion (piping) is common at some horizons in the interbedded sands and results in the flow slides/mudflows described by Munshaw (1976) and Golder Associates (1990). The area has been logged in the past, probably some 50 - 60 years ago, and some of the instability is considered to have developed, or been reactivated, by forest harvesting activities.

Instability on the slopes is indicated by irregular topography, distorted trees, ponded or poorly drained areas and weak remoulded soils. Development in the area, particularly changed drainage patterns, clearing of slopes and excavation, has locally exacerbated the existing post-glacial instability.

Hazard Assessment

The Slesse Park area is designated as Area 1. The creeks draining the area are shown on Drawing 106. Most creeks were fully traversed during this study, and the following characteristics are considered to be noteworthy in respect of the hazard assessment:

- Young and Nonie Creeks have the largest catchment areas;
- Creek channel gradients vary between 6° and 32° ;
- All creek channels have steep slopes in the upper catchment (25° - 30°) with intermediate slopes of between 6° and 15° over most of the channel lengths;
- All creeks show active shallow slumping of side slopes in the glaciolacustrine silts. Accumulations of soil and organic debris in the creek channels has dammed the creeks at a number of locations resulting in small-scale steps in the channel profiles;
- In all creek channels, the upper limit of the glaciolacustrine silt was encountered approximately at El. 250 m;
- Man-made modifications to creek channel profiles due to road construction across creek alignments are evident on Creek #2;
- Road construction across the alluvial fans at the base of Creek #s 1 and 3 and Young Creek have necessitated culverting of creek flows beneath the roads;
- Springs and seeps are well developed at the junction between the sands and gravels, and underlying silts;
- Creek #1 originates at El. 230 m and exhibits the shortest channel length;
- Some deep channelling (up to 3 m) within the sands and gravels overlying the silts was evident in Creek #2.

Specific identifiable potential hazards in the Slesse Park area are predominantly channelized and comprise debris flows and debris floods. Hazard severity is reduced by the topography, particularly the presence of terraces at different elevations which result in grade reductions and deposition of material. Thus, the effective length of some of the creeks over which debris flow/flood material can be mobilized is much reduced. Debris flow hazards are restricted to zones close to the creek channels.

Non-specific hazards in the Slesse Park area include slumps and debris slides resulting from non-channelized instability which may occur randomly on slopes.

Hazard Maps

Based on Golder Associates' field assessments, the relationships shown on Table 15 have been allocated in producing hazard maps for planning purposes at Slesse Park.

In deriving Table 15, the following considerations on past and future potential activity have been taken into account:

- Creek activity on the lower slopes is dependent on the conditions at the higher terraces (El. 160 m); avulsions could occur on Creek #s 1, 2 and 3.
- Probabilities:
 - extent of side slope instability;
 - size and slope of existing fans.
- Magnitudes:
 - availability of debris;
 - length of confined channel > 60;
 - opportunity for storage in channels or on terraces;
 - side slope instability.

Slope hazard boundaries are shown on Drawing 106. Runout zones for debris flows and debris floods have been assumed for each magnitude event, and the composite hazard maps are shown on Drawings 107 and 108.

4.4.5 Bell Acres Area

Geology

As with the slopes north of Slesse Park, the high slopes between Auchenway Road to Slesse Park are developed on till and glacial outwash sands and gravels overlying overconsolidated, glaciolacustrine silts with interbedded silts and sands, all masked by colluvium and slide deposits. The valley bottom consists of Chilliwack River alluvium comprised of coarse sands and gravels which are overlain in areas by debris flow/flood and debris slide deposits, particularly along the base of the slope. Instability on the slopes is indicated by irregular topography, distorted trees and poorly drained areas.

Hazard Assessment

Specific identifiable potential hazards in this area are predominantly channelized and comprise debris flows and debris floods associated with the creeks draining the high slopes to the north of Chilliwack Lake Road. These creeks are shown on Drawing 109. The creeks in this area were not traversed during this study, however, several creeks were inspected at their outlets at the base of the slope.

The area on the north side of the Chilliwack River, between Bell Acres and Young Creek, is particularly exposed to these hazards due to the high and steep slopes (25° to 40°) and the constricted valley bottom. There is a history of small mudflow/debris avalanche events in this area. A small mudflow occurred in 1975 from a small gully on the slopes to the north of Bourne Road and was described by Munshaw (1976). The mudflow which originated from the headwall of the gully through surficial instability and/or seepage erosion, flowed downslope through a narrow gap and deposited a lobe of fine grained slurry across Chilliwack Lake Road and to a distance of 225 m from the base of the gully. A similar event occurred some 65 years ago (Thurber Consultants 1987) about 300 m east of the 1975 event.

Recent mudflows have also occurred on the steep slopes to the north of Auchenway Road (Golder 1991). Creeks issuing from these slopes show evidence of repeated debris flow activity and the steep coarse fans along the base of the slope indicate other small debris flow or debris slide activity.

Non-specific hazards in this area include slumps and debris slides resulting from non-channelized instability which may occur randomly on slopes. Piping erosion from the uniform glacial sand deposits is a common mechanism in the initiation of debris avalanches and mudflows.

Hazard Maps

The area between Auchenway Road to Tamahi Bridge is designated as Area 2. Golder Associates reviewed previous work conducted in this area and carried out terrain analyses supported by limited ground reconnaissance. Slope and channelized hazards were assessed for zoning purposes. The zoning is based on probabilities assigned to a range of events as indicated in Table 16. In deriving this table, the following considerations on past and future potential activity have been taken into account:

- Probabilities:
 - extent of side slope instability;
 - size and slope of existing fans.
- Magnitudes:
 - availability of debris;
 - length of confined channel $> 6^{\circ}$

- opportunity for storage in channels or on terraces;
- side slope instability.

The scale of this study did not permit a detailed assessment of this area and site specific geotechnical investigations are essential to confirm the hazard boundaries and to determine if, and how, development is possible.

As in Area 1, conditions on the slopes are highly variable and stability is locally dependent on slope angle and height, geological materials present and groundwater conditions. This area has been assigned a hazard probability within the range 1:50 to 1:200.

Slope hazard boundaries are shown on Drawing 109. Runout zones for debris flows and debris floods have been assumed for each magnitude event, and the composite hazard maps are shown on Drawings 110 and 111.

4.4.6 Baker Trails Area

Geology

The high slopes between Baker Trails Village and Auchenway Road are developed on similar geological materials to those found on the slopes in the Bell Acres and Slesse Park areas. Till and glacial outwash sands and gravels overlie overconsolidated glaciolacustrine silts with interbedded silts and sands. These deposits are masked by colluvium and slide deposits. The valley bottom comprises Chilliwack River alluvium composed of coarse sands and gravels which are overlain in areas by debris flow/flood and debris slide deposits, particularly along the base of the slope.

Hazard Assessment

For the area between Baker Trails Village and Auchenway Road, terrain analysis was carried out and previous hazard zoning (Thurber, 1988a) was reviewed. The creeks in this area were not traversed during this study. This area is designated as Area 3 on Drawings 112, 113 and 114.

The area is subject to channelized hazards from the many creeks which drain the high slopes to the north of Chilliwack Lake Road as well as non-specific hazards including debris slides and slumps resulting from non-channelized instability which may occur randomly on the slopes. Specific examples of these include a debris flow which occurred in the Lyardon Road area in 1984 (Thurber, 1984) and a shallow failure observed on the slopes in the Edwards Road area (Golder, 1985).

A more detailed geotechnical hazard assessment was carried out during this study for the slopes behind Baker Trails Village. Terrain analysis was carried out supported by ground reconnaissance. Wash and Guy Creeks were traversed on the ground and all five creeks were inspected at their outlets at the base

of the slope in the village. Discussions were held with the Chairman of the Strata Council (Mr. Harold Crassweller).

In addition, a review of previous work at Baker Trails Village (Thurber, 1988b) was carried out for the purposes of this study to determine mitigative options. The existing mitigative measures in the village were inspected. Confirmation of Thurber's work by means of inventories on each creek would be required prior to the detailed design and implementation of any potential mitigative measures.

This area is designated as Area 1 on Drawings 112, 113 and 114; these drawings also show the creeks draining the slopes behind the village.

The following characteristics of the creeks draining the slopes behind Baker Trails Village are considered to be noteworthy in respect of the hazard assessment:

- Wash and Briar Creeks originate on a terrace at El. 125 m and are thus short.
- Midgely Creek has the greatest catchment area of all the creeks, but shows no channelling across the terrace at El. 125 m so that its effective length for debris flow assessment is less than its total length.
- Guy Creek rises at El. 150-175 m but is not affected by the terrace at El. 125 m.
- Guy and Tank Creeks have pronounced fans which have been partially excavated, or modified, during site development.
- Materials forming Guy and Tank Creek fans are apparently structureless silty gravels.
- Wash Creek has a steep 18° fan.
- Creek channels have grades varying between 7° and 45°.
- Most creeks show slumping from the side slopes in the glaciolacustrine silts.
- Springs and seeps are well developed at the base of the sands and gravels where they overlie the silts.

Considering the nature and availability of material within the creeks and the characteristics of the gullies, it is anticipated that fine grained debris flows could occur. This appears to have been the mechanism which formed the observed fans except for Wash Creek where its steepness shows that it is likely to have been produced by frequent, but low volume, alluvial flows from the coarse glaciofluvial deposits. The high proportion of fines derived from the bedded silts can produce mudflows which would run out to

form slopes as flat as 5-6°. Where channelized, these mudflows can reach speeds in excess of 5 m/s, but if they are not contained they are slow-moving and can be easily diverted. Debris floods are less destructive and in their unchannelized state may deposit on slopes as flat as 3°.

Non-specific hazards could also include slumps and debris slides resulting from non-channelized instability which might occur randomly on the slopes.

Hazard Maps

Based on the Thurber data, and with modifications from Golder Associates' field observations, the relationships shown in Table 17 have been allocated in producing hazard zoning for planning purposes for Baker Trails Village. In deriving these relationships, the following considerations on past and potential future activity have been taken into account:

Probabilities:

- extent of side slope instability;
- size and slope of the existing fan.

Magnitudes:

- availability of debris;
- length of confined channel > 6°;
- opportunity for storage within channel;
- side slope instability.

Consideration must be given to a spectrum of events of varying probabilities. In an existing development where weak potentially-damageable structures (such as mobile homes) are present, it is considered that small but frequent events could be of importance.

An estimate (compatible with the above relationships) of the total quantities of material which could be brought down over the next 50-year period is shown on Table 18.

Slope hazard boundaries are shown on Drawing 112. Runout zones for debris flows and debris floods have been assessed for each magnitude event and the composite maps are shown on Drawings 113 and 114.

For the area between Baker Trails Village and Auchenway Road (Area 3), the hazard maps presented are those produced by Thurber, 1988a, with minor modifications from Golder Associates' terrain analyses. More detailed site specific investigations are required for permit approvals.

Slope hazard boundaries, including nominal setbacks from the crest or toe of slopes, are shown in Drawing 112. No probabilities have been assigned to slope hazards in Area 3.

Runout zones and assigned probabilities for debris flows and debris floods in Area 3 are based on the single maximum design event and are shown on Drawings 113 and 114. Thurber estimated that, for a creek of average rating, the return period for a design debris flow event is 200 years and for a design debris flood event is 50 years.

4.5 Drainage

Drainage issues are related to small valley wall streams tributary to the Chilliwack River, watercourses across the floodplain, and road and boundary ditches. These drainage courses typically have a narrow poorly incised profile which is occasionally confined and culverted. Potential local flooding may occur due to blocked culverts, heavy vegetation, diverted or combined watercourses and other construction activities that affect runoff or catchment size.

There is considerable concern about drainage in the area between Slesse Park and Baker Trails. Many of the issues raised by residents during discussions, and specific problem areas listed and forwarded by residents, dealt with drainage problems. A few of those identified include:

- Tank, Guy, Briar, Wash and Midgely Creeks drain into a perimeter ditch around Baker Trails Village. Cleaning and maintenance is presently undertaken by local residents on a regular basis. The perimeter ditch has overtopped in the past and drained through the village.
- Valley wall drainage has affected properties along Lyardon Road and culvert blockage causes overflow along Chilliwack Lake Road.
- Rexford Creek causes flooding along Chilliwack Lake Road and is impacted by the size of culverts on Chilliwack Lake Road and Edwards Road.
- Siltation in the lower reaches of Ryder Creek, combined with an ill-defined channel through the marsh area north of the Chilliwack Lake Provincial Park and debris and gravel deposited by the Chilliwack River at the mouth of Ryder Creek, have resulted in some backwater flooding effects.
- Wingfield Creek, which was diverted across the floodplain to discharge into Ryder Creek, is poorly incised and subject to overflowing.

- Poor channelling of Nonie, Christine and Currence Creeks, across the valley floor in Slesse Park, results in local surface flooding. Uphill development and road drainage has exacerbated the problem by increasing runoff into the low gradient reaches across the floodplain.

It is difficult to separate drainage problems, which can lead to local nuisance flooding, from tributary flows that are hazardous. The geotechnical hazards analysis, addresses this issue for debris flows and debris floods, however, definition of the 1:200 year flood limits for each tributary was beyond the original scope of this study. An amendment to the terms of reference requested an analysis be undertaken for the 1:200 year flood limits of Ryder Creek, as discussed below.

Many of the problems associated with local drainage and associated flooding are avoided through maintenance. The Ministry of Transportation and Highways is responsible for maintaining the passage of tributary waters under some Provincial roads. The Ministry of Forests looks after others. However, there is no formal drainage plan for the area and no organization responsible for maintaining drainage other than in the immediate vicinity of Provincial roads.

Ryder Creek

Stream configurations in the Ryder Creek area, Drawing 104, have been changed in recent years. Wingfield Creek used to directly enter the Chilliwack River, prior to 1976, and now joins Ryder Creek near the Chilliwack Fish and Game Club (CFG). At the junction, Ryder Creek has also been diverted to the west to enter the Chilliwack River further downstream. In both instances, the stream gradients have been reduced resulting in sedimentation and a reduction in flow capacity. Local flooding presently occurs in the lower reaches of Ryder Creek, in the vicinity of Auchenway Road.

Field surveys were undertaken to establish cross-sections for Ryder and Wingfield Creeks for use in a flow model, HEC-2.

Neither Ryder Creek nor Wingfield Creek is gauged so a regional analysis was required to determine design flood flows. A multiple regression analysis was used to relate flood estimates derived from gauged stream records to the following catchment parameters:

- drainage area;
- median basin elevation;
- basin length.

There were no small catchments with suitable maximum instantaneous flow records in the immediate vicinity so stations near the coast were used. The catchment parameters and estimated flood flows from the regression analysis are given in Table 19.

The capacity of the bridge at the Fish and Game Club was analyzed and found to have a capacity of 8.2 m³/s at the incipient overtopping elevation of 85.0 m. The adjacent culvert (36 inch CMP) has a capacity of 1 m³/s for a combined capacity of 9.2 m³/s. This capacity was reached during the November 1990 storm which nearly overflowed into the parking area. Wingfield Creek is known to have exceeded its channel capacity and flowed across the fields and roads during this storm.

The present bridge capacity is only about 25% of the combined 200 year instantaneous flow for the combined catchment.

Upstream of the confluence with Wingfield Creek, Ryder Creek was shifted to the east to provide additional room for the rifle range at the CFG Club. The main channel has a capacity of approximately 20 m³/s before overtopping. Much of this capacity is due to containment dykes which are non-existent further upstream. The 200-year flood would spread out over the fan and the possibility exists for a channel avulsion at the apex of the fan sending Ryder Creek on a new course across the rifle range or even across to the Wingfield Creek side. In the analysis of lower Ryder Creek, it was assumed that the entire upper Ryder Creek flow could enter the channel by by-passing the bridge.

Wingfield Creek has a low gradient, of 0.0072, and low channel capacity due to siltation problems. One of the property owners has constructed a dyke along the left bank upstream of the Ryder confluence from dredged bed material. This dyke is only 0.2 m above the overflow level at the CFG bridge as measured at a surveyed section some 88 m upstream of the bridge. The derived channel capacity is approximately 4 m³/s before overtopping occurs. Therefore, the present channel can accommodate only 25% of the estimated 200 year flood flow. Once overtopped the present dyke would fail sending Wingfield Creek across the fields and by-passing the CFG bridge.

Lower Ryder Creek was investigated from the Auchenway Bridge to the CFG bridge, a distance of approximately 540 m, by means of 9 surveyed sections including the two bridges. The analysis indicates that in some locations the existing channel has a capacity of only 3 m³/s before overtopping the banks. The Auchenway Bridge has a capacity of approximately 13 m³/s before overtopping the road.

It is clear the low capacity of Ryder Creek, of 3 m³/s, leads to local flooding in this area. Because of the combined effect of limited channel capacity, and limited culvert capacity, residences in the area are exposed to floods from both the Chilliwack River and Ryder/Wingfield Creeks. The 200 year flood limits of Ryder Creek were joined to the 200 year flood limits of the Chilliwack River to delineate the 200 year flood hazard limits in the area, Drawing 104.

5 HAZARD MANAGEMENT

5.1 Existing Legislative Controls

Legislative Framework

Legislation in the Province of British Columbia requires consideration of hazards in the administration and regulation of public and private lands. In general, the legislation listed in Table 20 presently forms the mosaic for addressing flood and geotechnical hazards in the Province.

Flooding hazards are presently managed by application of Section 82 of the Land Title Act and by Section 969 of the Municipal Act. Under Section 82 of the Land Title Act, the Subdivision Approving Officer cannot approve a subdivision in a flood hazard area without the consent of the Minister of Environment, Lands and Parks. The Water Management Branch reviews the hazard on behalf of the Minister, and if appropriate, can consent to the subdivision subject to conditions. The conditions can be stated in a covenant and registered on title of the new lots created. The Ministry of Transportation and Highways assumes the responsibility of the Subdivision Approving Officer in the Chilliwack River Valley.

Amendments to the British Columbia Municipal Act were introduced in 1985 to ensure that all new development would be safe from various geotechnical hazards. The legislation addresses the policy and regulatory framework for dealing with geotechnical hazards. The Act requires local governments to include in their community plans "...statements and map designations... respecting restrictions on the use of land that is subject to hazardous conditions...".

At the policy level, the Act requires local governments to include in their community plans "...statements and map designations... respecting restrictions on the use of land that is subject to hazardous conditions..." (Section 945 2d). For this purpose it allows the plan to "...designate development permit areas for the protection of development from hazardous conditions..." (Section 945 4b). In areas so designated, a development permit must be obtained before any construction or subdivision can be undertaken. The permit "...may specify areas of land that may be subject to flooding, mud flows, torrents of debris, erosion, land slip, rock falls, subsidence, tsunami or avalanche and that must remain free of development..." (Section 976 5a).

Furthermore, Section 734 of the Municipal Act states that:

"...where a building inspector considers that construction would be on land that is subject to or is likely to be subject to flooding, mud flows, debris flows, debris torrents, erosion, land slip, subsidence or avalanche, he may require the owner of the land to provide him with a report certified by a professional engineer with experience in geotechnical engineering that the land may be used safely for the use intended. This section further requires that "...where a professional engineer with experience in geotechnical

engineering determines that the land may not be used safely for the use intended, the building inspector shall refuse to issue the building permit".

However, the Act also provides the opportunity for the land to be deemed safe if works or means are undertaken and maintained consistent with the advice contained in a report prepared by a qualified engineer. The building inspector may issue a building permit on the basis of the engineer's report, given assurance by a registered covenant against the land that the owner will comply with the recommendations contained in the engineer's report.

Section 969 of the Municipal Act authorizes local government to adopt a building bylaw to regulate river setbacks and floor elevations of new buildings. The bylaw is jointly developed and administered by the local government and the Water Management Branch.

Section 930(d) of the Municipal Act (1979), or amendments, provide authority to regulate or prohibit the deposit (or removal) of soil or other material on land and allows differing regulations for differing areas.

Section 588 provides that bylaw(s) may be established to prescribe the conditions which must be met by any person doing work to maintain the proper flow of water in a stream as defined by the Water Act, ditch, drain or sewer in the Municipality, as well as work to reclaim or protect part of the land in the Municipality from erosion by action of the sea, a lake or stream as defined by the Water Act.

Section 611(5)(a) provides that bylaw(s) may regulate the design and installation of drainage and sewerage works provided by persons other than the municipality.

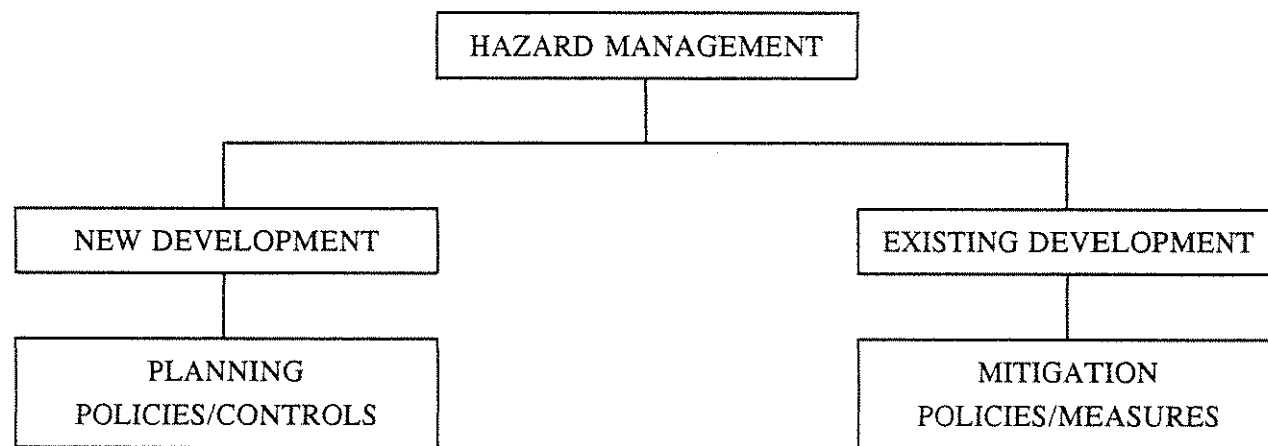
Other authority to control or maintain the proper flow of water, including the right of appropriation without compensation, is provided in Sections 596, 587(c) and 589(2).

Although not known to be previously utilized, in other geotechnical hazard control guidelines, Section 978 now provides a means of protecting against natural hazards resulting from loss of vegetation cover and exposure of slopes or drainage channels to detrimental changes in erosion, runoff flows and infiltration.

Application of Legislation

As illustrated in the schematic below, the body of existing legislation, although fragmented and targeted more specifically to geotechnical than hydrotechnical hazards, encourages hazard management policies for lands under consideration for new developments which may be exposed to natural hazards, and also for existing developments on lands known, or shown, to be hazardous. For new developments, planning policies can be proactive, undertaking measures to preclude unacceptable levels of exposure to hazards. The thrust of hazard management for new development is to permit development only when hazards are avoided. Existing developments on hazardous lands rely on mitigative measures to reduce hazard exposure to an acceptable level.

The hazard mapping undertaken for this study augments and consolidates information used as a basis for regulating new development in the Regional District of Fraser Cheam. It also forms the basis for identifying existing developments exposed to hazards of a given probability of occurrence, and in so doing leads to consideration of available means of mitigating the hazards these properties are exposed to.



5.2 Hazard Mitigation

As the term implies, the objective of hazard mitigation is to alleviate the exposure to a hazard. It is important to recognize, however, that while mitigation can lessen the exposure, it does not remove, or eliminate, the hazard. The owner of property exposed to erosion can reduce the probability of losing land by constructing protective works along the river bank, however, the erosive forces of the river remain. Similarly, a level of protection may be provided against geotechnical or flooding hazards without necessarily preventing debris flows or floods from occurring. A residual exposure may remain after the implementation of a mitigative measure.

Guidelines, or government policies, that establish acceptable levels of exposure for developments in potentially hazardous lands, or what is "safe", have not been established on a comprehensive, or consistent, basis throughout the Province. Flood hazard management policy is the most advanced, largely due to the implementation of the Federal-Provincial floodplain mapping program. This program generally maps the limit of the 1 in 200 year flood level, which, together with a freeboard allowance, is usually incorporated in local bylaws to establish the elevation required for the lowest habitable floor in residential, commercial, or industrial developments on floodplains. An exception is the Fraser River floodplain where water levels associated with the flood of record (1894) are used by the Province to regulate floodplain development. The 1 in 200 year return period, which has a probability of occurrence of 0.005 in any given year, is also used by the Province to regulate development on coastal lands exposed to tidal flooding.

Some legal and policy precedents for levels of acceptable exposure have been established for hazards which could impact a larger community. The National Building Code recommends buildings be designed

for accelerations associated with a 1:475 year earthquake event. In other instances, where widespread loss of life could occur from a major landslide or a dam break, a much lower probability of annual exposure of about 1:10,000 is deemed acceptable.

The attitude of individuals in a community to an acceptable level of exposure may vary widely, being dependent upon a number of factors which include:

- perception of the exposure and consequences of a hazardous event;
- general philosophical outlook as it relates to hazards of any type, but particularly natural hazards;
- life style, as it relates to the choice of accepting a level of exposure in return for some benefit;
- level of investment in a property and the consequences of losing all or a portion of the investment.

As is the case for other matters regulated by government, it is a challenge to establish both acceptable levels of exposure and appropriate means of mitigating against unacceptable levels of exposure, given the diversity of individual attitudes in a community. Nevertheless, policies are necessary to establish a basis for advising the public of hazardous areas and to provide protection to the property owners and the general taxpayer.

The factors considered by government in establishing acceptable levels of exposure may include:

- the likelihood of providing advance warning of the hazardous event;
- the nature and extent of the damage caused by the event, as it relates to the types and density of development;
- the likelihood that loss of life would be associated with the hazard; and,
- the degree to which the hazard can be avoided, or damage minimized.

In consideration of some of the above factors, and in recognition of the need to establish policies for development in hazardous areas, the Regional District of Fraser Cheam developed guidelines for the building inspector and approving officer that inter-relates levels of risks deemed to be acceptable to the type of hazard and type of development (Cave, 1991). Built into these guidelines are a range of regulatory responses to a particular hazard of a given probability of occurrence. The responses range

from an approval without restrictions, where the probabilities of hazardous occurrences are very small, through approvals with conditions, to 'not approvable' where probabilities of hazardous events are high.

As discussed in Section 5.1, an approval to proceed with a development may be granted subject to the property owner undertaking protective works, or other means, to mitigate the hazard. As discussed below there are a number of approaches or means which can be taken to mitigate hazards and reduce the level or exposure to an acceptable level.

5.3 General Mitigative Options

Mitigative options available generally fall into the category of structural or non-structural options.

5.3.1 Non-Structural Options

The non-structural options include:

- relocation
- acquisition
- development restriction
- indemnifications
- covenants
- monitoring

Relocation refers to physically moving buildings, or other property improvements, outside of the hazardous area. This option has been employed in the study area. Three homes in the Slesse Park area were moved to higher ground following the 1984 floods. Another home threatened by bank erosion in the Edwards Road area was moved following the 1990 floods. These relocations were carried out under the Provincial Emergency Program (PEP) because Provincial government policy did not permit a purchase of the homes, and presumably relocation of the homes was considered to be more economical than providing structural protection.

The potential advantage of the relocation option is that property improvements are placed outside of the zone deemed hazardous. In essence the relocation is to avoid the hazard. The potential disadvantages are that not all buildings can be relocated for structural reasons; or, there may not be a safe site on the property, requiring other property be purchased for the relocation; or, the potential relocation sites on the property are considered inferior by the owner with respect to utilization of the property.

Economics, or other factors, may also suggest that it is more expedient for regulatory agencies to purchase properties and improvements in a hazardous zone for the purpose of rezoning the property and restricting its use. This could be by an outright purchase of the property where the owners are required

to vacate because of the risk of loss of life, or it could be by a lease-back arrangement where the purchase is made and the owner leases back the property under certain terms and conditions.

The advantage of the property acquisition option is that it presents the opportunity to impose zoning restrictions on land that is in a hazardous area with less public resistance than rezoning the property without first acquiring it. The property, likely without improvements, could be resold under the revised zoning or kept as public property.

The property acquisition option may be advantageous to the property owner by way of relieving the anxiety associated with living in a hazardous area, and also by way of providing the funds to relocate.

Disadvantages associated with the outright purchase of hazardous properties include a potential adverse public perception that a financial benefit is being bestowed on the property owner at taxpayers' expense. It is also possible that the value of the property is not sufficient to enable the home owner to purchase equivalent facilities elsewhere. This latter disadvantage is offset by a lease-back arrangement where the home-owner may utilize the property until the decision is made to move from the premises for health, or other, reasons.

A potential disadvantage of the lease-back arrangement for the regulatory agency is the potential liability associated with risk to health or life associated with the hazard the property is exposed to. The lease-back arrangement is not appropriate for hazards for which there is little warning of the event, such as the geotechnical hazards, but may be appropriate for the flooding and bank erosion hazard where homes are set back from the river bank and some warning for evacuation is possible.

The non-structural mitigative option of 'development restriction' is aimed primarily at ensuring that additional improvements are not added to a property exposed to potential damage from a hazardous event. This option does not alleviate the exposure to the hazard, but rather alleviates the amount of damage and financial loss that could occur as a result of a hazardous event. The advantages of this option are that implementation can be carried out within the existing regulatory building permit process, and that there are no capital or maintenance costs to be borne by the non-affected taxpayer.

The disadvantage of the development restriction option is that the property owner who was initially permitted to improve property in a hazardous area may be curtailed in the improvement, and perhaps enjoyment, of the property because it is later deemed to be in a hazard zone.

Indemnification, sometimes referred to as 'save-harmless', is an option to mitigate liability to regulatory agencies, or their staff, in the event damage or loss of life was incurred as a result of a hazardous event. Theoretically, a property owner could, by legal agreement, commit to assuming full responsibility for being permitted to improve or live on land in a hazardous area. This would have the advantage of giving individuals the choice as to whether they are prepared to live with the exposure to the hazard and bear the consequences of a hazardous event. However, the disadvantages are that the indemnification would

not cover third parties, such as visitors to the property, nor is the validity of an indemnification often really known until tested in a court of law. Also, local governments are not empowered to delegate a responsibility given by statute.

Covenants, as a mitigative option, are similar to indemnification except they are placed against title to the property. The covenant would seek to restrict use of the property, or impose other restrictions, that would minimize the damage costs should a hazardous event occur. The advantages and disadvantages are similar to the indemnification option when applied for the purpose of reducing risk of exposure. A covenant on title which serves solely as a notice that all or a portion of the property is in a hazardous zone would, quite apart from reducing risk, provide a valuable public service to an otherwise uninformed prospective purchaser.

Insurance programs are another form of non-structural mitigative measures to alleviate the financial loss suffered as a result of a natural hazard. However, flood, erosion, and geotechnical hazard insurance (apart from earthquakes) is not available to the individual home owner and this form of mitigative measure is not considered further other than to note that an emergency response program could be considered as an insurance program. For any given flood flow, an estimate of potential damage could be made, where the damage cost is comprised of both emergency response and restoration costs. Given the probability distribution for flood flows, similar to Figure 14, an annual 'insurance premium' could be calculated based on the sum of the products of probability of occurrence times associated damage costs. This insurance premium could be proactively placed in an emergency response fund, from which funds are drawn when required, or as is the existing practice, funds are drawn when emergencies occur and the general taxpayers cover the 'insurance premium'.

'Monitoring' is a mitigative option directed at providing an early warning of a potentially hazardous event so as to initiate a preparedness program and reduce the potential for damage and injury. Monitoring programs have been used successfully in the Province for geotechnical and flood hazard warnings. The 'Downie' slide near Revelstoke is monitored by B.C. Hydro with respect to any potential for a large displacement of water in the reservoir. A flood warning system has been successfully implemented by the Ministry of Environment in the Squamish River valley and for the Fraser River system. The advantage of a monitoring system is that the installation and monitoring expense is modest in comparison to the potential savings of reduced damage costs.

5.3.2 Structural Options

There are a wide range of structural options available to deal with flood, erosion and geotechnical hazards. Some options deal with alleviating the probability of occurrence of the hazard, while others provide protection against the hazard. Several options are discussed below, starting first with 'Emergency Response' followed by a discussion of other options under the appropriate heading for each hazard.

Emergency Response

One mitigative strategy common to all hazards is the 'emergency response' option where equipment and manpower resources are mobilized to respond to a particular hazard. While perhaps not strictly a structural option, the emergency response to a hazard often utilizes structural methods, such as sand bagging, riprap replacement, debris removal, and berm or road construction, to reduce the extent of damage afflicted by the hazardous event.

Emergency response, which to a large degree is a damage control measure, is more applicable to the flooding and erosion hazards which tend to develop more slowly than geotechnical hazards which may occur rapidly. That is, the emergency response option has its principal mitigative value if there is the opportunity to act before and during the event, rather than after the event. A distinction is made, of course, between emergency response as a management option for the mitigation of hazards, and emergency response to the post-disaster needs of the community.

Under the Provincial Emergency response program, administered by the Ministry of the Solicitor General, there may be action taken during a hazardous event to control floodwaters, prevent erosion or maintain communication. There is a similar provision under the Disaster Financial Assistance Program for cabinet to approve disaster relief funds. In agreement with Emergency Planning Canada, one stipulation is that funds may only be applied to restoration work, rather than the construction of any new mitigative measures.

A weakness in the existing Provincial Emergency Response program is that emergency work is undertaken after damage has occurred, and present policy does not permit work to be undertaken on a pre-emptive basis.

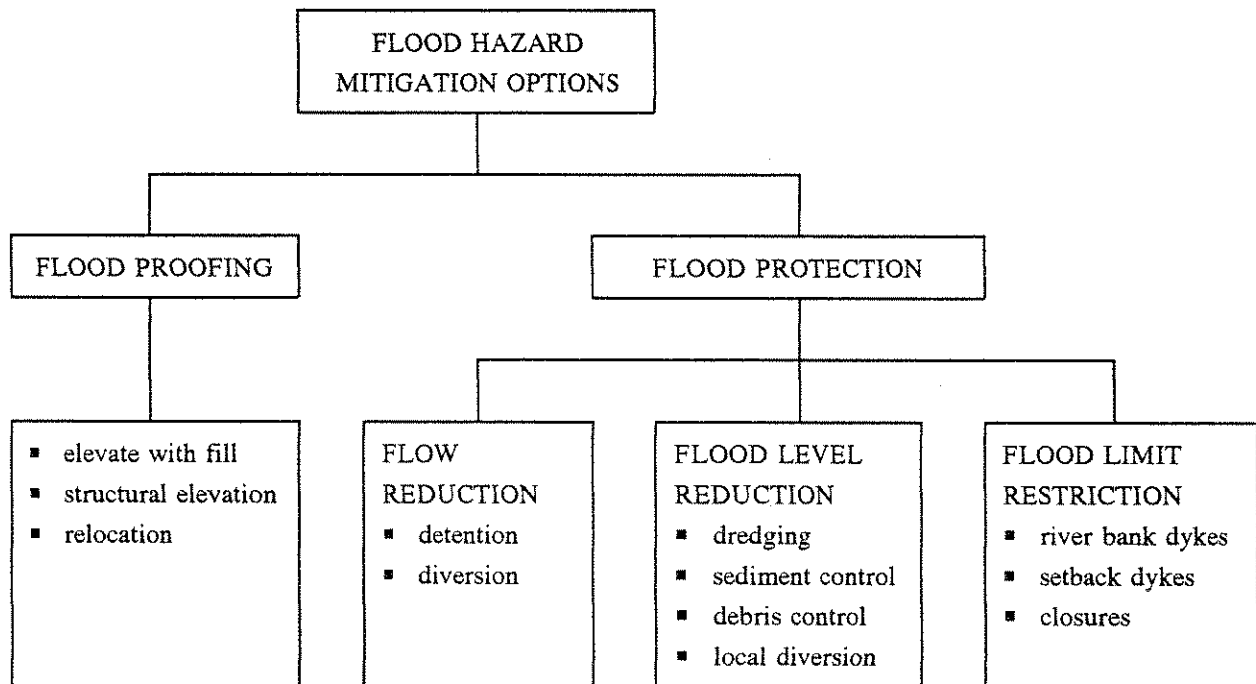
Emergency response as a mitigative measure is an essential component of any hazard management plan as, if for no other reason, a hazardous event may occur which exceeds the magnitude of the design event an area is protected against. An effective preparatory measure to an emergency response is to have quick access to materials normally required during a hazardous event. Residents in the Chilliwack Valley have suggested that some riprap be stockpiled in the valley for this purpose. The cost of a riprap stockpile would be small compared to the overall cost of mitigative measures and should be incorporated in the hazard management plan.

A combination of an emergency response plan and structural mitigation measures, coupled with post-disaster relief, may be the most cost-effective means of dealing with existing developments on hazardous lands. In essence, emergency response replaces the optional measure of the government purchasing or underwriting insurance for natural hazard relief and takes advantage of the economics associated with deferred payments.

The disadvantages of adopting emergency response as a hazard mitigation option are as follows: there is likely no net reduction in the exposure to the hazard achieved for subsequent events; there is no assurance that a response will be timely and effective; and the response does not preclude damage from occurring, it only contains or reduces it. Finally, emergency response cannot mitigate a hazard to a predetermined acceptable level of exposure.

Flood Hazard Mitigative Options

In general, alleviating the flood hazard involves either floodproofing or flood protection. Floodproofing elevates development improvements above the flood level, whereas flood protection reduces the flood level by structural means. Examples of floodproofing and flood protection options are tabulated below and some are illustrated on Figures 23 and 24.



The advantages of floodproofing are that improvements are physically removed from flood threat and there is very little, if any, reliance on procedures or structures that are expected to be in place and work during the flood.

Conversely, the flood protection options all rely on an activity or structure functioning as intended during the event. Since a probability exists that this will not be the case, the flood protection options have less reliability than the floodproofing options. The choice of either floodproofing or flood protection is affected by other factors, as discussed in Section 7, and also, as discussed previously, it is influenced by the type of development and whether it is new or existing. Provincial policy is that new developments

be floodproofed, by either being located outside of the designated flood hazard area, or by having habitable floors and services elevated above the designated flood construction level.

For existing developments, flood protection may be achieved by reducing the flood flows, reducing the flood levels or by restricting the floodplain limits.

The maximum flow during a flood, often referred to as the flood peak, may be reduced for a given event if some of the runoff is detained by storage, through the creation of detention ponds, as is frequently employed in urban areas, or by means of reservoirs behind dams. A reduction in the flood peak may also be achieved on a valley wide basis by diverting some flow to another drainage basin.

As discussed in Section 4.2, and illustrated on Figure 21, the flood level in an area is established by the magnitude of the flood flow and the channel conveyance available. In some cases, the flood level may be lowered by increasing the conveyance capacity of the channel. This may be accomplished by deepening and/or widening the channel through dredging or by reducing the resistance to flow in the channel by removing obstructions such as log debris.

Where a river bed is rising as a result of the deposition of sediments, then the reduction of sediments entering the system may result in a lowering of the river bed and reduction in flood levels.

A local reduction in flood levels may also be achieved by diverting all, or a portion, of flow into another shorter channel which has an effect similar to that of reducing flow resistance.

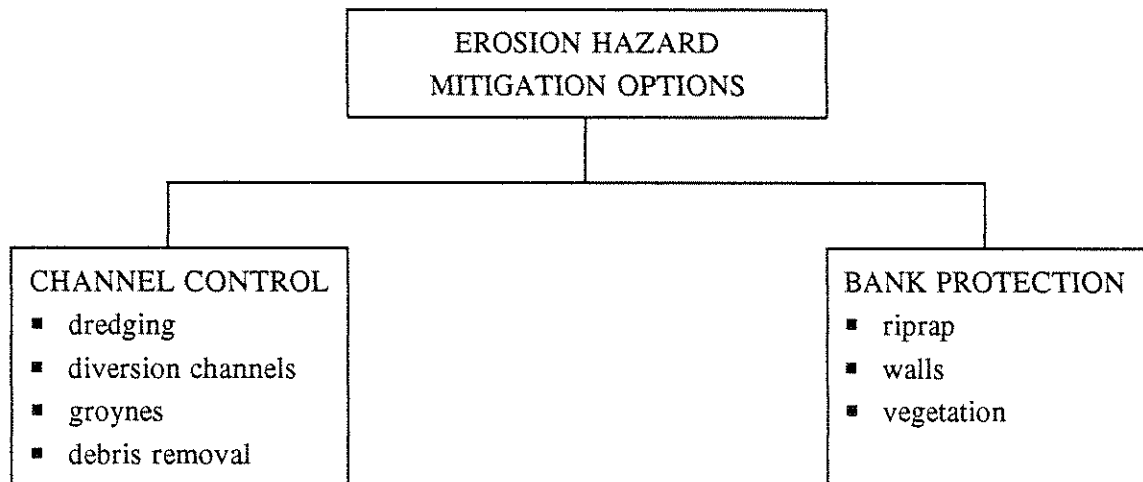
The third set of flood protection options involves measures to restrict the excursion of floodwaters on the floodplain into developed areas. This structural option usually involves the construction of dykes or floodwalls using impermeable materials capable of withstanding the pressure of flood waters. Dykes may be constructed along the river banks, confining the flow to only the low flow channel of the river, or they may be set back from the river banks to allow some flow to occupy the floodplain. Setback dykes have hydraulic and geomorphic advantages in terms of larger flow conveyance and scope for the river to migrate in response to local blockages and gravel bar migrations.

Site-specific flood protection may be given to a single home by way of closing any apertures through which floodwaters may enter the dwelling, or by constructing a flood wall around the property. The feasibility of this mitigative option is very site-specific depending on the nature of the dwelling; the potential flood level relative to the habitable floor of the dwelling; the potential for uplift problems; the exposure of the dwelling to high flow velocities; and the cost of implementing a protective closure.

The design and implementation of any dyking system requires the consideration of drainage of runoff behind the dykes and the prevention of outflanking of the dykes by floodwaters.

Erosion Hazard Mitigation Options

As indicated below the options available for mitigating erosion fall into one of two general categories: channel control or bank protection.

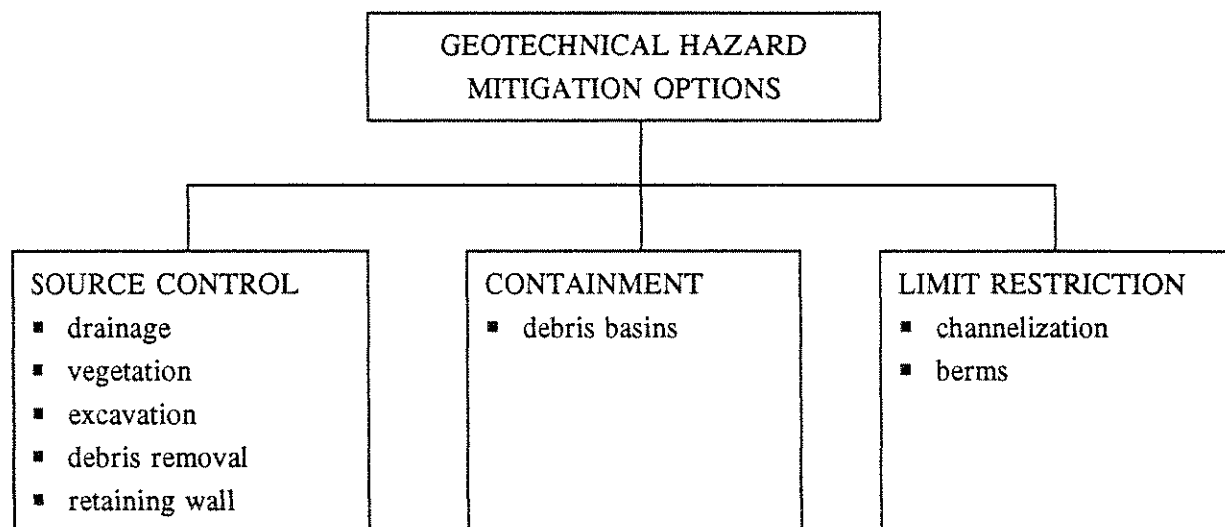


The objective of the channel control options is to reduce the erosive stress of flows on the bank. This may involve channel dredging or diversions to straighten the river, or the construction of groynes, or rock spurs, to divert flow away from the river banks. Changing the geomorphic character of a river from a braided system, that is subject to avulsions and rapid bankline changes, to that of a single channel system, requires a major change in one of the parameters affecting the character of the system, such as the slope of the river bed or sediment supply. In general, these options would be less practical than alternative measures such as using groynes to direct the flow away from the bank or removing obstructions such as logjams which direct the flow toward the bank. However, obstruction removal during a flood is often hampered by lack of access and any bank erosion attributable to the obstruction has often taken place before the obstruction can be removed.

The most widespread form of bank protection in the Province is the placement of riprap which consists of fractured rock. Other forms of bank protection include the construction of concrete, masonry or timber walls, or the use of vegetation to encourage the growth of root wads to stabilize the bank, Figure 25. The choice of bank protection and the design and construction procedures for any choice is influenced by a number of factors including river flow velocity, potential for undermining by scour, durability, appearance and cost.

Geotechnical Hazard Mitigation Options

The mitigative options for slides, debris flows, and debris floods fall into one of three categories: source control, containment, or limit restriction, as tabulated below.



In certain instances, particularly where the hazard is limited in size, it may be possible to undertake measures to directly reduce the hazard through implementing specific measures at the hazard source. The instability of a slope, for instance, may be due primarily to surface runoff or groundwater seepage and, in this case, drainage control may reduce the exposure to slides. In other cases where vegetative cover has been removed, slope stability may be re-established by a revegetation program. In situations where the accumulation of debris in steep valleys leads to a debris flow hazard, a debris removal program may reduce this hazard.

Where a debris removal program is impractical because of difficult access to the valley floor, it may be feasible to construct a basin that traps debris at an accessible location. This basin would be cleared out on a regular basis, being available during a debris flow event to reduce or eliminate the amount of debris swept downstream.

In certain situations, the practical means of mitigating the exposure of existing developments to debris flow and debris flood hazards is to restrict the areal extent of the hazard through the construction of berms to deflect the flows, or channels to direct the flows.

The choice of a mitigative measure to reduce the exposure to geotechnical hazards is very site-specific and depends upon factors such as ground slope, drainage area, topography, soil types and location of dwellings.

6 HAZARD MITIGATION OPTIONS - SLESSE PARK TO BAKER TRAILS

6.1 General

This section of the report examines the application of various hazard mitigation options to the section of the Chilliwack River from Slesse Park to Baker Trails.

The options are presented as a basis for comparison and discussion by regulatory agencies and the public. The options are presented in order to facilitate the selection of mitigative measures to incorporate in a specific hazard management plan. Factors involved in the selection of the most appropriate options are discussed in Section 7.

In general, mitigative options fall into one of the following three categories:

- *development control* options which apply valley-wide to new developments, including major repairs and/or renovations;
- *source control* options which deal with the source of the hazard; and,
- *site-specific* options which deal with providing protection against the hazard.

The site-specific options are discussed under the headings of three hamlet areas; Slesse Park, Bell Acres, and Baker Trails, yet cover the river continuously as shown on the hazard mapping discussed previously, Drawings 103 to 114.

6.2 Development Control Options

Existing legislation encourages the restriction of developments in hazardous areas, therefore the primary and preferred control option for new developments is avoidance of the hazard.

However, even this avoidance option requires definition by policy in areas related to land use and degree of safety.

Zoning policies may specify that certain uses may be made of hazardous lands and exclude other uses which should avoid the hazard. The type of use suitable for hazardous lands needs to reflect the hazard type and potential economic loss should a hazardous event occur. Typically areas exposed to flooding in which there is ample opportunity for a flood warning may be designated as parks, or as sites storage for goods not damageable by floodwaters.

It is beyond the scope of this study to suggest appropriate land use policies for the Chilliwack River Valley. The levels of risk acceptable for new developments in the valley have been defined as policy by the Fraser Cheam Regional District (Cave, 1991).

New developments in hazardous areas should have covenants attached to the property title for the purpose of identifying that the property is located in a hazardous area and securing the mitigative works recommended by the engineer. This is the present regulatory practice for the Fraser Cheam Regional District.

Although not presently required by law, consideration by legislators should be given to requiring that existing properties in hazardous areas have covenants on title identifying the hazardous nature of the site.

New development permits should include provisions to ensure that work undertaken during a development does not create a hazard or increase the risk of exposure to a hazard. This would include factors such as excavation near the toe of slopes; removal of vegetation; diversion of watercourses; and groundwater drawdown.

Development control from Slesse Creek to Baker Trails will be based on the hazard mapping given on Drawings 106 to 114, when adopted by the Fraser Cheam Regional District and B.C. Environment. This mapping should be updated from time to time, recognizing also that site-specific hazard assessments may be required for individual development proposals.

New development "avoids" the flood hazard by:

- taking place outside the designated 1:200 year flood level; or,
- filling or elevating buildings above the 1:200 year flood level; and,
- taking precautions with respect to nuisance flooding due to inadequate local drainage.

Floodplain management policy may reflect different types of building uses when establishing floor elevations required for development in the floodplain. The present MOE policy is:

- for residential and commercial developments the underside of floor joists, or top of concrete slabs, is to be at or above a 1:200 year mean daily flood level that includes a freeboard allowance of 600 mm, or above a 1:200 year instantaneous flood level that includes a freeboard allowance of 300 mm, whichever combination results in the higher level;
- for industrial developments the top of the floor is to be at or above the 1:200 year flood water level, without freeboard;
- the freeboard amounts of 600 mm or 300 mm should be considered as minimum values which should be increased if, in the opinion of a qualified engineer, these values are deemed insufficient.

New development "avoids" the bank erosion hazard by being set back from the existing river bank. The existing setback requirement adopted by Fraser Cheam Regional District is 30 m. Alternative or updated policies could be as follows:

- For areas in which there is no effective bank protection, buildings shall be set at or behind the 1:100 year designated erosion limit;
- For areas in which there is effective bank protection, as defined below, buildings and all building appendages, shall be set back from the top of the bank a minimum distance of 10 m to permit access for bank protection maintenance;
- Effective bank protection is defined as bank protection designed by a qualified engineer for the purpose of providing bank erosion protection during the 1 in 200 year flood flow. Effective bank protection shall be inspected on an annual basis and repaired, or maintained, as required by a designated authority. Furthermore, although bank protection may be overtopped during flood events, effective bank protection precludes the possibility of flow outflanking the protection and causing failure of the protection.

Geotechnical hazards are 'avoided' by permitting new developments only outside of the designated hazard boundary, where the boundary designation is established by regulatory policy which defines an acceptable level of exposure for a particular type of development.

The mapping of the geotechnical hazards included in the report are intended as a guide for hazard management of the study area as a whole. Site-specific investigations should be undertaken by a qualified engineer for individual properties.

6.3 Source Control Options

6.3.1 Hazard Monitoring

Monitoring hazards in the valley does not influence or control the level of hazard per se, however, it does provide the opportunity to reduce the level of exposure by providing the opportunity to evacuate or initiate emergency responses.

The Ministry of Environment, and Water Survey Canada, are installing data collection platforms (DCP's) that will assist in obtaining an early warning of potential floods.

A Ministry of Environment station was installed in the Slesse Creek drainage in 1991 to monitor temperature, precipitation and snow pack. Some difficulty was experienced during the winter of 1991-92 due to wind exposure and the site is to be relocated to a more protected location prior to the fall of 1992.

Water Survey of Canada will have DCP's to measure river flow in Slesse Creek and in the Chilliwack River, upstream of Slesse Creek. DCP's provide real time data to a data bank in the United States via satellite. This data bank is accessible in Canada.

Data from the DCP's will be monitored by the flood forecasting section of the Ministry of Environment in Victoria. These data, plus additional information from Atmospheric Environment Service, will be interpreted to assess flood potential. Should conditions indicate the potential exists for flood flows, the Ministry of Environment will notify the Regional Office who, in turn, will notify valley residents in accordance with its flood response plan (MOE, 1991).

The potential for bank erosion may also be evident prior to the event. As discussed in Section 3.4.3, the blockage of distributary channels may lead to a shift in the concentrations of flow and subsequent bank erosion. Management of debris will assist in alleviating this threat. The inspection of existing bank protection may indicate that failure of the protection by undermining, outflanking, or other causes may occur during the next flood. Bank and dyke inspections are part of an early warning hazard monitoring and should be incorporated in an on-going hazard management program for the valley.

Some geotechnical hazards may also be monitored effectively to obtain an early warning of an event. Monitoring programs for these hazards may include the installation of monitors to measure any soil creep or change in inclination of the slope; change in groundwater flows; accumulation of debris; or slides in the upper watersheds of tributary streams. Geotechnical monitoring programs are very site-specific and generally are limited to areas where there is a potential of widespread damage or loss of life associated with the event. Specific monitoring programs of geotechnical hazards in the study area have not been addressed. However, a general inspection of the study area, from Slesse Park to Baker Trails, should be undertaken on an annual basis to ascertain the following:

- whether any debris floods or flows have occurred;
- whether any unmapped geotechnical hazards have become evident;
- whether there are any geotechnical situations evident that require an emergency response.

6.3.2 Flow Detention

Peak flows associated with floods may be reduced by detaining (regulating) some of the runoff for later release. The amount the flood peak may be reduced depends upon the following factors:

- amount of detention storage available;
- relative timing of the inflows from various sources; and
- the contribution of the regulated catchment relative to the total catchment.

Flow detention has potential benefits in terms of reduced bank erosion and flood levels. The reduction in flood levels achieved through flow detention depends on the magnitude of the flow reduction and the

water level versus discharge relationship for the area of interest, whereas the reduction in erosion depends on the amount flow velocities are reduced.

Opportunities for significant detention storage in tributary streams are limited because of the steepness of the valleys. However, Chilliwack Lake was investigated to ascertain whether some flood and erosion control benefits could be derived by controlling the outlet of the lake and detaining flood inflows. The methodology applied in the analysis was as follows:

- flow records for mean annual flows, and peak instantaneous flows were used to calculate the contribution of outflows from Chilliwack Lake as a percentage of the flow at Vedder Crossing;
- the watershed area contribution to Chilliwack Lake was calculated as a percentage of the total watershed area contribution downstream to Slesse Creek, to Tamihi Creek and to the Vedder Crossing;
- the contribution of flows from Chilliwack Lake as a percentage of the flow above Tamihi Creek was estimated based on a ratio of watershed area contributions and the percentage contributions above Slesse Creek and at Vedder Crossing;
- an analysis of specific winter rain floods was undertaken to ascertain when flood peaks occurred at the outlet of Chilliwack Lake and at Vedder Crossing to ascertain the influence of outflow timing on the percent contribution of Chilliwack Lake outflows to peak flows in the study area;
- an estimate was made of the maximum reduction in winter flood peak flows which could be expected upstream of Tamihi Creek and at Vedder Crossing, assuming all the inflow into Chilliwack Lake is detained by storage and released after the flood peak passed the study area;
- potential flood level bank erosion benefits associated with eliminating the Chilliwack Lake contribution to the flood peak were assessed.

From the concurrent discharge records for the years 1964-79, it was found that the mean annual outflow from Chilliwack Lake was 19.6 m³/s compared to 35.8 m³/s at Chilliwack River above Slesse Creek and 67.5 m³/s at Vedder Crossing. The average lake outflow therefore represents 55% and 29% respectively of the discharge at Chilliwack/Slesse and Chilliwack/Vedder compared to corresponding drainage area ratios of 0.51 and 0.27 respectively. The corresponding flow percentages for four years of snowmelt instantaneous flood peaks (averaged) were 48% and 23% and, for four rain flood events, it was found that the peak lake outflow represented 33% and 13%.

These percentages are given in the table below together with the estimate of the percentage of the Chilliwack Lake contribution to the Chilliwack River above Tamihi Creek, assuming flood peaks at the outlet of Chilliwack Lake and upstream of Tamihi occur at about the same time.

**Percent Contributions of
Chilliwack Lake Drainage to Points Downstream**

Factor	LOCATION - CHILLIWACK RIVER ABOVE		
	Slesse Creek %	Tamihi Creek %	Vedder Crossing %
Watershed Area	51	35	27
Mean Annual Flow	55	---	29
Snowmelt Peak Flows	48	---	23
Rainfall Peak Flows	33	20	13

From the percentages given in the table, it can be seen that the mean annual flow contribution and the peak flows associated with snowmelts correspond within four percent to the watershed area contribution of drainage into Chilliwack Lake. However, during rainfall events, which lead to the largest peak flows in the study area, the percent contribution of flows from Chilliwack Lake to peak flows downstream is less than the watershed area contribution and less than the peak flow contribution during snowmelt events.

Existing natural lake storage is relatively more effective in reducing the flood peaks for rain events compared to snow events due to the shorter time period of the rain event and smaller total runoff volume. Given a constant inflow over a long period of time, the outflow from the lake would equal the inflow. Conversely, the shorter the time period of the inflow, the greater is the difference between the peak of the inflow to the lake and the outflow from the lake because of storage or flow detention in the lake, often referred to as routing effects.

The percentages given in the table are based on a comparison of flood peaks at the lake outlet, above Slesse Creek, and at Vedder Crossing. An examination of specific rain event flood flows for 1975, 1979, 1980 and 1989 showed that the peak of the outflow from Chilliwack lake was later than the peak of the flow at Vedder Crossing. For the December 26, 1980 flood, the maximum outflow from Chilliwack Lake was a day after the peak at Vedder Crossing. This delay in the flood peaks for rain events would further reduce the percent contribution of Chilliwack Lake flows to the total flow in the study area. Considering this, it is estimated that the percent contribution of Chilliwack Lake outflows to the rain event flood peaks in the study area would be about 8 to 15%.

Considering now the potential benefits of lake regulation on reducing flood and bank erosion hazards assume that 100% lake regulation was developed such that the 1 in 200 year flood peak could be reduced by 8 to 15%, resulting in an estimated 1 in 200 year flood peak of 781 m³/s at Vedder Crossing. A reduction of the peak flow from 917 m³/s to 781 m³/s would reduce water levels associated with the 1 in 200 year flood event by 0.15 to 0.20 m.

As discussed in Section 4.3, the principle causes of bank erosion in the study area are channel avulsions and/or direct extraction of bank material by erosive forces. Although channel avulsions may occur as a result of flow momentum, which is a direct function of discharge and velocity, it is more likely both erosion mechanisms are more directly related to flow depth. The reason for this is that erosive forces (shear stress) are a function of flow depth and river slope, and any increase in water level due to a blockage which could lead to a channel avulsion is related to velocity, which itself is related to flow depth, river bed roughness, and river gradient. Since the river bed roughness and river bed gradients could be assumed to be the same with and without regulation, the principle parameter affecting changes in the erosive character of the river will be flow depth.

The average midstream water depth in the study area during a major flood is about 5 m. Reducing the water level by 0.2 m as a result of 100% lake regulation during the 1 in 200 year flood event would result in a four percent reduction in water depth and a two percent reduction in average flow velocity. There would not be a significant reduction in bank erosion associated with this reduction in flow depth, or flow velocity.

A potential adverse impact associated with regulating the outlet from Chilliwack Lake would be the aggradation of river bed levels downstream. Flow from the Chilliwack Lake does not deliver a sediment load to the system, however this flow is available to transport sediments delivered to the system by tributaries. This effect would be most noticeable at the confluence of Slesse Creek where the relative contribution of Chilliwack Lake flows to the total flow is higher than it is further downstream in the study area.

6.3.3 Sediment Control

The geomorphic aspects of the river, including sediment transport, were discussed in Section 3.4 in which it was noted that approximately 60,000 to 77,000 m³ of sediment move through the study area in an average year. The volume is much higher in years with major floods.

Since the water level for a particular flood flow is influenced, in part, by the elevation of the river bed, there are three basic sediment related options to consider relative to flood mitigation:

- excavate the sediments to lower the river bed, or to maintain existing river bed elevations;

- reduce the influx of sediment; or
- maximize the opportunity for the river to transport sediment through the study area in order to preclude deposition.

To lower water levels associated with the 1 in 200 year flood below existing banks would require the excavation of about two million cubic metres from the Slesse Park to Vedder Crossing reach, at a cost in the order of six million dollars.

In order to maintain an excavated channel in anticipation of the 1 in 200 year event, it would be necessary to annually remove any net deposition in the river channels. Since the initial excavation would establish non-regime (unbalanced) bed elevations, the excavated area would act as a sediment trap. It is likely that an average of 40-60,000 m³ of gravel would have to be excavated annually to maintain the flood protection. The deposition would likely take place throughout the study area unless a large sediment trap was excavated at the upstream end.

Although water levels could be lowered by extensive excavation, potential adverse factors include downstream scour and undermining of river banks; loss of fish habitat; and, shortage of accessible gravel disposal areas.

Excavation and removal of gravel to maintain river bed elevations is undertaken in systems where river bed aggradation is occurring. As noted in Section 3.5.3, although there has been a shifting of channels and migration of gravel bars through the study area, there has not been a net loss of channel flow capacity in the study area due to river bed aggradation. There is no evidence to suggest that gravel removal is necessary in the study area to maintain channel conveyance at historical levels. High water levels seen in recent years have resulted from higher than average river flows. The increase in the 1 in 200 year flood level over that established in 1980 results from the prediction of a higher 1 in 200 year flood flow, not from changes in the river bed.

In certain instances the formation of a gravel bar may lead to flow concentrations along an unprotected river bank. A post-flood assessment may lead to the conclusion that removal or 'scalping' of this bar is desirable to train the river away from the bank. However, this exercise is more associated with a site-specific river management initiative to reduce or eliminate a nuisance, rather than seriously address the hazard. In a major flood new gravel bars are formed and an unprotected bank will be vulnerable to erosion irrespective of any bar scalping.

River bed aggradation is generally caused by one or a combination of factors including:

- flow reduction;
- flattening of the bed slope; or,
- confining the width of the river.

The flattening of the bed slope may result from the influx of excessive sediment via a landslide, debris flow, or river diversion. It may also occur due to progradation upstream from a delta, sill, or downstream constriction. River bed slopes in the study area appear to be established by natural controls and not influenced, to date, by major slides or man-made structures.

The confinement of a river may lead to aggradation of the river bed by either restricting the area available for deposition, resulting in an increased rate of aggradation, or by forcing a change in the geomorphic character of the river such that a steeper bed gradient is required to transport the sediment load. Two examples in British Columbia of river bed aggradation resulting from confinement of the river are the Vedder River and the Bear River near Stewart.

Gravels are removed from the Vedder River for the purpose of flood control; the only other options being to remove the dykes and let the river have access to a wider floodplain, or raise the dykes. If removal of gravels from the Vedder is not continued it is possible that increased bed levels could prograde upstream past Vedder Crossing to the Bell Acres area. Evidence to date is that this is not occurring (Martin, 1991).

River bed aggradation may occur as a result of an increase in sediment supply resulting from natural slides or poor logging practice. Although there is no evidence of river bed aggradation in the study area, it is suggested that management of the Chilliwack River Valley should include the following actions related to forest harvesting in order to minimize the possibility of any significant increase in logging-related sediment production:

- Planning for future forest harvesting in the Chilliwack Valley should include the determination and implementation of a sustainable rate of harvest for the Chilliwack watershed as a whole. It should be based on a proper inventory of the remaining old-growth timber and the advancing second growth.

Forest harvesting in the Chilliwack Valley should be well distributed throughout the watershed so that individual tributaries are not overharvested. Reference should be made to the past level of harvest in each watershed and consideration should be given to the "clear-cut equivalent" area before new logging blocks are approved.

In the immediate future, it is recommended that the amount of logging planned in the Foley/Airplane and Chipmunk watersheds in the 1991-1995 period should be reduced.

Planning guidelines which limit block size to a maximum of 30 ha, leave 400 m between openings and require crown closure on cutblocks before adjacent areas are logged, have been applied by the Ministry of Forests to one licensee. They should be applied to all areas and licensees in the Chilliwack Valley, including the Small Business Forest Enterprise Program.

Prompt regeneration of logged sites, with planting if necessary, will reduce the length of time cutblocks take to reach canopy closure.

- A major program is required to rehabilitate and retire old roads and landings throughout the watershed. These programs should include:
 - retrieving sidecast material on the oversteepened sideslopes or roads and landings;
 - removing culverts and bridges;
 - re-establishing natural drainage patterns;
 - revegetating disturbed sites.

The Centre Creek watershed, the Chipmunk/Foley/Airplane watersheds and Liumchen watershed are suggested as priorities.

- A program should be initiated to improve forest harvesting and road construction practices throughout the watershed. This program should focus specifically on:
 - reducing cross-stream yarding and greater attention to protecting in-stream natural debris and riparian vegetation, particularly on steep headwater stream channels;
 - reducing the amount of sidecasting on steep sideslopes during road and landing construction. Endhauling of material should be required;
 - avoiding construction of roads alongside stream channels and on floodplains to avoid the need of river training works to protect the roads;
 - placing emphasis on installing maintenance free features in road and culvert design. These include fords, permanent dips in road surfaces, outsloped roads, stable cutbank slopes and other features which reduce the need for road maintenance;
 - avoiding the use of log cribs to hold road fill in place on steep sideslopes.
- A program should be initiated to greatly improve road maintenance practices. This program should focus specifically on:

- avoiding grader berms along roadsides;
 - avoiding the wasting of material, which has ravelled onto roads, over the edge of the slope;
 - maintaining ditches and natural hillside drainage patterns to avoid water running down the road surface.
- Proper procedures to respond to flooding damage and soil mass movements should be developed. These would avoid the past pattern of ad-hoc, and often, inadequate emergency repairs to roads and bridges. Expert advice should be sought prior to the rebuilding of roads and bridges and the training of streams with berms.
 - The extensive areas of gravel pits, river training works and disturbed sites around bridges and culverts should be revegetated. These include the disturbed area near the mouth of Slesse Creek, the bridge works on Tamihi Creek and the gravel pits on Lower Liumchen Creek and near Slesse Creek.

The third flood hazard management option, with respect to sediment control, is to maximize the opportunities for the river to transport sediment within the system. This may be achieved by adopting the following principles:

- Chilliwack Lake outflows will not be reduced;
- constriction of the floodplain will be minimized.

The floodplain of a river acts not only as a conveyance zone for flood flows but also as an area for sediment storage and braided channel development. Confinement of the floodplain by the construction of dykes or bank protection reduces the efficiency of the river to convey both water and sediment.

6.3.4 Debris Control

Debris in the river consists primarily of trees, in whole or in part. During floods, new debris is generated from undercut banks, or mobilized from banks in the main stem and tributaries.

Debris in the system raises two main concerns during floods:

- large trees swept against the banks may erode the banks or dislodge bank protection materials; and

- debris jams that develop throughout the study area may lead to a re-direction of the flow resulting in bank erosion or they may lead to increased water levels due to channel blockage.

Debris control as a hazard mitigation option requires an assessment of the effectiveness of the control measures in reducing the hazard.

Most surface debris is swept to the outside of a river bend due to a spiralling action initiated by momentum effects which results in higher flow velocities and shear stresses at the outside of the bend. The degree to which debris either initiates or exacerbates erosion of unprotected banks is unknown. Unlike coastal situations where debris continuously batters against the shoreline during a storm, river debris is much more transient and erosion would more likely be due to the cumulative effect of many pieces of debris passing a site, rather than an individual element.

Erosion tends to be continuous over a length of the river bank and not just confined near the flow surface which suggests that the primary cause of erosion is shear stress and not debris. Nevertheless, the design and construction of bank protection should take the presence of debris into account. This requires that bank protection material be interlocked and well trimmed so as to minimize the possibility of the bank protection unravelling as a result of a single piece of material being dislodged by debris.

Since, even if desired, it will be impossible to prevent all debris from entering the system during a flood, property improvements should be set back from the top of the bank to preclude damage by debris that is being swept downstream.

Debris jams that lead to an increase in water levels and consequent increase in the flood threat are generally those that occur in a single channel, or at a constriction such as a bridge opening, where the river has no scope for bypassing the jam. Therefore jams that block the flow capacity of the river channel may contribute to the flood hazard.

Where there is the opportunity for the river to bypass the jam, the flood threat may be relieved but bank erosion may develop as occurred in the Edwards Road area in 1990. An area without bank protection is therefore vulnerable to erosion initiated or exacerbated by a logjam. An area given bank protection is less vulnerable to erosive stresses initiated by a logjam, however, for areas provided with bank protection, the design and/or maintenance of this protection should recognize that the full flow of the river may at some time impinge on the bank.

Complete removal of all debris in the system and prevention, if possible, of additional debris from entering the system are not, by themselves, hazard management options since bank erosion would still occur and the 1 in 200 year flood limits depicted on the hazard mapping would remain unchanged.

However, recognizing there are situations where the erosion and flood hazards are exacerbated by debris, the following debris control options are available:

- where possible, reduce the amount of new debris introduced to the system by extensive bank protection works; or
- following annual floods, remove all logjams in the study area irrespective of whether they are located in channels or not; or,
- following annual floods, remove logjams that block any low-flow channels, or any secondary distributary channels; or,
- following annual floods, remove logjams that occupy only low-flow channels, for example in the Tamihi area, or are located at or immediately upstream of bridge crossings.

Debris in the river provides an important contribution to fish by providing habitat for foraging, cover and refuge. As such, any removal of debris must receive the approval of the Ministry of Environment and Fisheries and Oceans Canada in accordance with habitat protection policies.

Finally, some debris jams, such as in a small side channel near O'Byrne Road, block river flows and lessen the bank erosion threat. Removal of these should be contingent on bank protection being in place prior to removal.

6.4 Site-Specific Options - Slesse Park Area

Site-specific options for mitigating against the flooding, erosion and geotechnical hazards in the Slesse Park area are considered in this section of the report, followed by similar sections covering the Bell Acres and Baker Trails areas.

The report does not attempt to draw conclusions on levels of acceptability for the hazards it covers. The mitigative options and alternatives summarized are based on the acceptability thresholds employed by the Provincial Government and the Regional District of Fraser Cheam.

Designs are given at the conceptual level and costs are for estimates derived without site-specific information. The basis for estimating costs associated with the flood and erosion hazard mitigative options is given in Appendix 4. It should be noted that no allowance has been made in the cost estimates for land acquisition required for dykes or bank protection. A summary of the estimated costs for various flood and erosion mitigation options is given in Table 25.

It should be noted that the only the initial capital costs are given in the text below, whereas Table 25 includes the capitalized maintenance cost, the capitalized emergency response cost and the total present day cost of each option.

6.4.1 Flooding and Erosion

The flooding and erosion hazards in the Slesse Park area are discussed in Sections 4.2 and 4.3 and shown on Drawing 103. The improved properties exposed to the flood hazards are shown as sub-areas 1, 2 and 3 on Drawing 103. There are properties outside of sub-areas 1, 2 and 3 subject to either the loss of land due to bank erosion or to inundation by floods. However, based on available mapping, there are no property improvements exposed to flooding other than those included in the sub-areas.

Some mitigative protection has been constructed in the Slesse Park area in response to specific hazardous events. The mitigative works implemented and the level of protection presently afforded are summarized in Table 21.

In addition to the protective works for existing developed properties, approximately 300 m of rock berm has been placed to protect the toe of the slide area on the right bank upstream of sub-area 1. This work was undertaken primarily to curtail the influx of silt into the system and to mitigate potentially adverse impacts on fisheries.

Bank and bridge pier protection was placed at the Tamihi Bridge following the 1990 floods as an emergency response to the bank erosion and bridge washout that occurred. These protective works should be inspected after each major flood as part of an on-going monitoring program and repairs undertaken as required to maintain the integrity of the bridge.

A number of site-specific hazard mitigation options are presented and briefly discussed below, recognizing any one, or a combination of these options, would be combined with development and source controls in the hazard management plan.

Option 1 - Bank Protection and River Dykes - Figure 26

Elements

- 1,300 m of riprap bank protection on left bank along base of valley wall;
- 1,435 m of riprap bank protection on the right bank, including a spur upstream of sub-area 1;
- minor raising of the existing dyking for sub-area 1;

- raise river bank protection as flood protection dyking for sub-areas 2 and 3;
- reinforcement of existing bank protection.

Estimated Capital Cost - \$2,988,000

Option 2 - Bank Protection and River Dykes - Figure 27

Elements

- outflanking protection of sub-area 1;
- 650 m additional right bank protection for sub-areas 1, 2 and 3;
- minor raising of the existing dyking for sub-area 1;
- raise river bank protection as flood protection dyking for sub-areas 2 and 3;
- reinforcement of existing bank protection.

Estimated Capital Cost - \$1,102,000

Option 3 - Bank Protection and Elevated Houses - Figure 28

- bank protection as for Option 2;
- elevate permanent homes above the 200 year flood construction level, in lieu of dyking.

Estimated Capital Cost - \$1,554,000

6.4.2 Geotechnical Hazards

The geotechnical hazards in the Slesse Park area are discussed in Section 4.4 and shown on Drawings 106, 107 and 108.

Recommended mitigative options are shown in Table 22 with approximate costs for the implementation of the active measures.

It will be noted that few houses are currently impacted by channelized hazards and that the cost of protective measures is relatively small. By contrast, many more houses lie within the high hazard setback zones at the crest and toes of the lower escarpment. Two houses within this zone on O'Byrne Road

currently have stability problems and are the subject of geotechnical remediation. Many other houses within these zones are at risk from potential geotechnical slope failures which will require other planning solutions such as buy-out/lease back.

Conditions on the slopes above Slesse Park Road are highly variable and stability is locally dependent on slope angle and height, geological materials present and groundwater conditions. The scale of this study does not permit detailed assessment of this area. It is flagged as a zone with a hazard probability within the range 1:50 to 1:200, and site-specific surveys are essential to determine if, and how, development is possible. If the current RDFC guidelines on development (Cave, 1991) are implemented, mitigative works and legal covenants would be required for many properties in this area.

Conceptual designs for mitigation of the channelized hazards are shown on Figures 29 and 30.

6.5 Site-specific Options - Bell Acres Area

6.5.1 Flooding and Erosion - Chilliwack River

The flooding and erosion hazards in the Bell Acres area are shown on Drawing 104. Properties with improvements subject to the flood hazard are shown as sub-areas 4, 5 and 6. Other improved properties are subject to land loss from bank erosion. The Provincial Park and other unimproved properties are subject to inundation by floods.

Existing structural mitigation measures for flood and erosion control in the area are summarized in Table 23 together with a comment on the level of protection afforded.

Site-specific structural options for flood and erosion mitigation related to the Chilliwack River are outlined below. Mitigative options related to the Ryder Creek flood hazard are discussed in the next section of the report.

Option 1 - Bank Protection and River Dykes - Figure 31

Elements

- 2,700 m of new bank protection on the right bank;
- 575 m of new bank protection on the left bank;
- 150 m of dyking on the left bank;
- raise river bank protection, as flood protection dyking;
- reinforcement of existing bank protection.

Estimated Capital Cost - \$3,761,000

Option 2 - Bank Protection and Dyking - Figure 32

Elements

- 2,600 m of new bank protection on the right bank, including riprap protection of the existing gravel berm at the Provincial Park;
- 575 m of new bank protection on the left bank;
- 150 m of dyking;
- raise river bank protection, as flood protection dyking;
- reinforcement of existing bank protection.

Estimated Capital Cost - \$3,679,000

Option 3 - Bank Protection, Setback Dyking and Relocations - Figure 33

Elements

- 400 m of new bank protection on the right bank;
- raise 2,450 m of existing road to act as dyking;
- relocate, purchase or lease-back 40 homes;
- emergency response, as required, to provide erosion protection for roads acting as dykes;

Estimated Capital Cost - \$4,156,000

Option 4 - Bank Protection, Setback Dyking and Relocations - Figure 34

Elements

- 985 m of new bank protection on the right bank;
- 450 m of setback dyking;
- 650 m of raised road to act as dyking;
- relocate, purchase, or lease-back 4 homes;
- raise river bank protection, as flood protection dyking;
- emergency response, as required, for erosion protection of raised road;
- reinforcement of existing bank protection.

Estimated Capital Cost - \$2,371,000

Option 5 - Bank Protection and Setback Dyking - Figure 35

Elements

- 985 m of new bank protection on the right bank;
- 800 m of dyking with rock spurs for river channel control;
- 450 m of dyking with slope protection;
- raise river bank protection, as flood protection dyking;
- reinforcement of existing bank protection.

Estimated Capital Cost - \$2,168,000

6.5.2 Flooding - Ryder Creek

The flood hazards associated with Ryder Creek are discussed in Section 4.2. Options considered to mitigate the flood hazard of Ryder Creek assume that mitigation for the Chilliwack River flooding would be in place.

Option 1 - Elevate Improvements

Elements

- elevate 22 homes in the floodplain areas affected by Ryder and/or Wingfield Creeks, leaving the creeks in their present condition.

Estimated Capital Cost - \$550,000

Option 2 - Confine Flood Flows to Ryder Creek

Elements

- excavate and widen Ryder and Wingfield Creeks;
- dyke Ryder and Wingfield Creeks;
- enlarge culvert capacity at bridge crossings;
- relocate one home to accommodate creek enlargement.

Estimated Capital Cost - \$600,000

Option 3 - Re-establish Historic Courses for Ryder and Wingfield Creeks

Elements

- excavate and dyke new channels for Ryder Creek and Wingfield Creek following a more direct route to the Chilliwack River;
- dyke the banks of the new channels;
- install culverts under the road.

Estimated Capital Cost - \$430,000

Option 4 - Limit Capacity of Ryder Creek and Construct a Flood Bypass Channel

Elements

- undertake slight improvements to Ryder Creek to develop a flow capacity of 4 m³/s;
- install floodbox at outlet to Ryder Creek, or dyke the lower section;
- install a control to Ryder Creek flows to limit flows to 4 m³/s downstream of the bypass channel;
- excavate a bypass channel to the Chilliwack River;
- place culverts under Chilliwack Lake Road;
- construct dykes on Ryder and Wingfield Creeks;
- bank protection for bypass channel.

Estimated Capital Cost - \$340,000

The configuration of Option 4 is shown on Figure 36, which also indicates the dyking alignment to contain Chilliwack River floods would be slightly different than options shown under Section 6.5.1.

6.5.3 Geotechnical Hazards

The geotechnical hazards in the Bell Acres area are discussed in Section 4.4 and shown on Drawings 109, 110 and 111.

The assessment of mitigative options for channelized hazards in this area was not required as this was beyond the scope of the present study. Site specific hazard studies for several properties have been carried out by various engineering firms and some mitigative measures have been constructed. There are a number of homes, however, which are presently considered to be at risk from exposure to debris flow and/or debris flood hazards, particularly in the area between Wingfield Creek and Bourne Road. Based on current RDFC guidelines for development, it is unlikely that these properties would be approved or would be approved only with engineering works to control debris flow/flood deposition. Further studies are required to be carried out.

The scale of this study did not permit detailed assessment of the high slopes to the north of Chilliwack Lake Road. Conditions on these slopes are highly variable and stability is locally dependent on such factors as slope angle and height, geological materials present and groundwater conditions and are considered to be similar to those north of Slesse Park. The slopes are flagged as a zone with a hazard probability within the range 1:50 to 1:200, and site specific surveys are required to determine if, and how, development is possible.

A few homes lie within the recommended setback zones at the crest or toe of these slopes and are at risk from potential geotechnical slope failures.

6.6 Site-Specific Options - Baker Trails Area

6.6.1 Flooding and Erosion

The flooding and erosion hazards in the Baker Trails area are discussed in Sections 4.2 and 4.3 and shown on Drawing 105. The improved properties exposed to the flood hazard are shown on sub-areas 7, 8 and 9. There are other improved properties exposed to the hazard of bank erosion plus additional unimproved properties which are subject to flooding.

Existing structural mitigation measures for flood and erosion control in the area are summarized in Table 24 together with a comment on the level of protection afforded.

In addition to the existing mitigative measures listed in Table 24, approximately one-half of the 2,000 m of Chilliwack Lake Road between Baker Trails Village and Vedder Crossing has riprap bank protection in place. A portion of the road passes through the Soowahlie Reserve.

Six site-specific structural options for mitigating the flood and erosion hazards in the Baker Trails area are presented below.

In addition to the options outlined below, common to all options should be the provision to extend the bank protection for Chilliwack Lake Road between Baker Trails Village and Vedder Crossing. An

estimated \$375,000 is required to extend existing bank protection by 100 m and to reinforce existing bank protection.

Option 1 - Bank Protection, River Dykes and Setback Dykes - Figure 37

Elements

- 3,200 m of new bank protection on the right bank;
- 575 m of setback dyking;
- raise river bank protection, except for agricultural lands, to act as flood protection dyking;
- emergency response, as required, to protect setback dykes against erosion.
- reinforcement of existing bank protection.

Estimated Capital Cost - \$3,630,000

Option 2 - Bank Protection, River Dykes and Setback Dykes - Figure 38

Elements

- same as Option 1, except bank protection for agricultural lands comprised of gravel berm.

Estimated Capital Cost - \$2,893,000

Option 3 - Bank Protection, River Dykes and Setback Dykes - Figure 39

Elements

- 1,900 m of new bank protection on the right bank;
- 575 m of setback dyking;
- raise river bank protection to act as dyking;
- emergency response, as required, to protect setback dykes against erosion;
- reinforcement of existing bank protection.

Estimated Capital Cost - \$2,581,000

Option 4 - Bank Protection, River Dykes, Setback Dykes, Relocation of Homes and Liumchen Creek Mouth - Figure 40

Elements

- 1,050 m of new bank protection on right bank;
- 1,550 m of setback dykes;
- raise river bank protection to act as dyking;
- relocate, or purchase, two homes;
- relocate the mouth of Liumchen Creek;
- emergency response, as required, to protect setback dykes against erosion;
- reinforcement of existing bank protection.

Estimated Capital Cost - \$2,075,000

Option 5 - Bank Protection and Setback Dykes - Figure 41

Elements

- 1,300 m of new bank protection on the right bank;
- 1,175 m of setback dyking;
- raise bank protection to act as flood protection dyking;
- emergency response, as required, to protect setback dykes against erosion;
- reinforcement of existing bank protection.

Estimated Capital Cost - \$2,160,000

Option 6 - Bank Protection, Setback Dykes and Cut-Off Channel - Figure 42

Elements

- 1,300 m of new bank protection on the right bank;
- 175 m of setback dyke;
- 1,500 m cut-off channel through Liumchen Creek fan;
- raise bank protection to act as flood protection dyking;
- emergency response, as required, to protect setback dyke against erosion;
- reinforcement of existing bank protection.

Estimated Capital Cost - \$2,569,000

6.6.2 Geotechnical Hazards

Drawings 112, 113 and 114 show the boundaries of the hazard zones for the anticipated magnitudes of debris flow, debris flood and slope failures in the Baker Trails area. Original boundaries were identified by Thurber (1988a and b), and have been checked by Golder Associates. For Baker Trails Village, whilst the extent of the Thurber boundaries is agreed with minor modifications, higher magnitude events than indicated by Thurber are considered possible, and this will affect the size of the catch-basins required.

Recommended mitigative options are shown in Table 26 with approximate costs for implementation of the active measures.

Sedimentation basins are considered to be required on Midgely, Guy and Tank creeks. These should be sized, as a minimum, to accept the maximum anticipated event (Table 17). The volumes of debris anticipated over a 50-year period for 50% and 75% probability levels are shown in Table 18. For the 50% probability, all basins, except for Wash and Briar Creeks, would be seriously undersized without maintenance. It is recommended that the basins should be sized for the maximum event, but that maintenance is essential to ensure that the maximum event, when it does occur, is capable of being stored.

Conceptual designs for the three basins are shown on Figures 43, 44 and 45.

For the area between Baker Trails Village and Auchenway Road, the assessment of mitigative options for channelized hazards was not required for this study. Several houses in the Lyardon Road and Edwards Road areas are considered to be exposed to channelized hazards, particularly debris flood hazards. Under current RDFC guidelines on development, it is unlikely that a number of these sites would be approved or would be approved only with engineering works to control debris flow/flood deposition. Further studies are required to be carried out.

The high slopes to the north of Chilliwack Lake Road have been flagged as a zone with a hazard probability within the range 1:50 to 1:200, and site-specific investigations and surveys are essential to determine if, and how, development is possible. A few houses lie within the recommended setback zones at the toe of these slopes and are at risk from potential geotechnical slope failures.

7 SELECTION OF HAZARD MANAGEMENT OPTIONS

This section of the report summarizes factors involved in making a selection from the various options presented and discussed earlier in the report.

Since the number of options available for mitigating the geotechnical hazards is limited, this section deals primarily with the selection of options to mitigate the flood and erosion hazard.

A general comparison of mitigative options is presented first, followed by a summary of the advantages and disadvantages of site-specific options.

Factors bearing on the selection of appropriate hazard mitigation for developed properties have been grouped together under the following main headings, and tabulated in Table 27 as part of a general qualitative assessment of various mitigative options for flood and erosion controls discussed in Section 5:

- Management
- Economic
- Environmental
- Public
- Technical

Across the top of Table 27 are the various mitigative options described and discussed either in general terms in Section 5, or in more detail in Section 6.

Factors involved with the management, or administration, of a plan deal largely with whether there is existing legislation or policies to enable various mitigative options to be implemented. For example, the granting of 'save harmless' indemnifications of the government without protective works is generally not consistent with existing law. Another administrative consideration is whether there is a requirement for constant, and perhaps considerable, on-going administrative input, as would be the case for an annual gravel removal program.

Ease of implementation and ease of funding are other factors, recognizing it is relatively easier to implement remedial measures on public land than on private land, and it is often relatively easier to obtain disaster relief funding than it is to obtain funding for proactive mitigation programs.

The economic considerations include capital cost and maintenance costs. Actual costs, of course, are site-specific, yet in general terms it is known that non-structural bank protection, such as a gravel berm, is less expensive than a riprap berm, yet is more costly to maintain. Furthermore, a mitigative option such as diverting a portion of the river may have a localized benefit in comparison to upstream retention of flood flows which could give flood benefits to a larger area. Therefore the areal extent of a benefit should be considered, together with whether a mitigative measure may provide a reduction in exposure to more than one hazard. For example, riprapped riverbank dykes can afford protection against both flooding and bank erosion.

Existing legislation is in place to protect fish and wildlife resources. The Federal Fisheries Act (RSC 1985, C.F-14), which is administered by Fisheries and Oceans Canada (DFO), prohibits any work, "that results in the harmful alteration, disruption, or destruction of fish habitat". DFO administers the Act with a 'no net loss' policy in which the productive capacity of the habitat is to be maintained through avoidance or mitigative measures. Some of the mitigative options for flood and erosion control, such as

development restriction, have less impact on fish and wildlife than others, such as removal of organic debris from the river which is used by fish as part of their habitat. Mitigative options which require regular instream work for maintenance, such as a non-structural bank protection option, would have potentially more impact on fish habitat than structural bank protection.

Specific comments on the environmental impacts of various options are as follows:

Construction of New Dykes

Setback dykes would generally have less impact on fish and wildlife habitat than riverbank dykes, because they would allow greater opportunity for the river to develop side channels and thereby create a more complex, diverse channel pattern. Side channels, among the most important habitat for salmonid fish spawning and juvenile rearing, have already been reduced in the Chilliwack River by past dyking projects. Though setback dykes would have relatively low impact on stream habitat, they could alienate wetlands and side channels in certain areas by infilling, altering drainage patterns, and cutting off fish access.

River bank dykes can also affect wetland and side channel habitats, mainly by cutting off flows from the main river and by eliminating fish access. Such dykes also affect the habitat suitability of the river bank, mainly for juvenile salmonid rearing, through elimination of bank vegetation and wood debris. The fallen trees, overhanging vegetation and undercut sections along vegetated natural banks are important juvenile salmon and steelhead trout rearing habitat features.

Raising Existing Dykes

The raising of existing dykes would generally have only a small incremental effect on fish habitat values because the riverbank has already been altered by the initial dyke construction. As raising the dyke will necessitate widening at the base, there is a chance that side channel habitat behind the dyke could be infilled in some cases.

New Bank Protection

Armouring of natural, unaltered banks by riprap placement eliminates most bank vegetation and associated habitat features. Relatively deep sections of stream channel along the outside of river bends, the areas generally requiring erosion protection, are especially valuable as salmonid juvenile rearing and adult holding habitat. Research has shown that the loss of habitat features associated with natural banks is especially critical for juvenile coho salmon. For juvenile steelhead trout, which have an affinity for bolder habitat, the change from a natural bank to a riprap bank need not have an adverse effect

on rearing capability. Riprap banks of relatively large material, placed to create a rough, irregular profile, can have significant rearing value, particularly for juvenile steelhead and chinook salmon. However, the best natural habitats, such as logjam pools, carry significantly higher densities of these species than well designed riprap banks.

Other environmental factors include whether a mitigative option is compatible with natural physical processes on the river, and whether potential impacts on the forestry and recreational resources of the valley are associated with a particular option.

Three subjective factors were identified and assessed with respect to the impact of various mitigative options on residents in the valley: level of disruption as it relates to inconvenience during or after implementation of the mitigative measure; level of equity, as it relates to whether the mitigative option provides a widespread benefit to residents and on whether either a few or many are advantaged or disadvantaged as a result of implementing the option; and, level of security as related to confidence in the mitigative option being in place when needed during the hazardous event.

Finally, the comparison on Table 27, includes four factors included under the heading 'Technical'. As for other factors, it is important to bear in mind the assessment of the option is for performance during a major event, such as the 1:200 year flood. A differentiation is made in the assessment between effectiveness and reliability. Options such as emergency response may be effective when in place, however they depend upon a timely response to an emergency during a hazardous event and are therefore less reliable than protective measures which are already in place before the event.

Table 27 was compiled by giving each factor a value of between 1 and 5 based on the general evaluation scale shown on the right side of the table. The individual values were totalled, without giving weight to any particular factor, in order to obtain an indication of the relative ranking of the options based on the factors listed. The number of factors scoring greater than 3 was also totalled as another measure of ranking.

Even though the general assessment of various options listed in Table 27 is subjective, the comparison suggests the following:

For *development control* options:

- development restrictions to avoid the hazard or reduce the level of exposure to the hazard ranks best (lowest score), in spite of the fact that restrictions are often unpopular to corporations and individuals because they are disruptive to development or improvement plans;

- indemnifications are least attractive because they are not compatible with existing law or government policy, nor do they reduce the exposure of the property owner, or public, to the hazard.

For *source control* options:

- monitoring of hazardous events to give an advanced warning is attractive, even though the monitoring by itself does not provide protection to property and improvements during a major flow event on the river;
- flow control by detention or damming does not achieve a significant reduction in water levels and therefore suffers from a lack of effectiveness relative to cost;
- similarly, gravel removal as a measure to mitigate against flooding during a major event suffers in comparison to other options due to high capital and maintenance costs, and potential adverse environmental impacts;
- debris control ranks slightly better than sediment control or flow diversions, but lacks in comparison to site-specific structural options because debris control, by itself, will not preclude flooding or bank erosion during a major event.

For *site-specific* options:

- elevating a habitable dwelling to provide floodproofing ranks best, in spite of the fact the cost could be high. This is likely to be most attractive for an individual, somewhat isolated, dwelling exposed to flooding, rather than a group of dwellings. It should also be noted that elevating a dwelling does not provide protection against erosion;
- setback dykes rank better, on the whole, than river bank dykes, largely due to lower costs and potentially less environmental impact;
- non-structural bank protection; as seen for providing protection for property improvements, does not fair well in the comparison largely because of potentially high maintenance cost and lack of effectiveness, reliability and durability during a major flood flow;
- emergency response, as a singular means of mitigating flood and erosion hazards, does not rank well in comparison to other structural options.

The selection of the site-specific mitigative structural options for the study area does not lend itself to applying a numerical score matrix to evaluate the options. But rather Tables 28, 29 and 30 have been

prepared as a comparative matrix to summarize the advantages and disadvantages of each option for Slesse Park, Bell Acres and Baker Trails, respectively.

The purpose of this interim report is not to recommend specific non-structural or structural options, but rather to present the options and the factors which bear on the selection of options which will be included in an implementation plan.

8 IMPLEMENTATION FRAMEWORK

An hazard management plan should incorporate three basic components:

- *administrative* - who is going to initiate, implement, monitor, and maintain the hazard mitigation measures?
- *financial* - how are the capital, operating and maintenance costs going to be funded?
- *technical* - which mitigative options are to be employed and on what basis are they selected?

This section of the report presents the existing administrative and financial framework for hazard management; offers an option for administering and financing hazard mitigation in the valley; and makes some suggestions as to the basis for selecting appropriate mitigative options.

8.1 Existing Administrative Framework

The government agencies that manage or control land and resources in the Chilliwack River Valley are tabulated in Table 31.

Not all of the agencies in Table 31 have a direct involvement in hazard management, but all, to some degree, are involved in the formulation of policies or the granting of approvals which are relevant to the planning or implementation of a hazard management plan. The number of agencies involved and the diversity of mandates renders the development, financing, and implementation of a hazard management plan a cumbersome process under present policy and legislation.

As noted in Section 5.1, legislation governing hazard management is also diverse. The majority of legislation is regulatory in nature, rather than enabling. That is, there is strong legislation with respect to regulating new developments in potentially hazardous areas, and strong legislation regulating environmental protection, but no coherent legislation that enables a community located in a hazardous area to develop and implement a hazard management plan.

The major change made to the Provincial statutory or legislative framework for hazard management over the last 10 years has been to delegate authority for hazard management to local governments. In turn, many municipalities are reluctant to become involved in hazard management, even in a reactive mode during a hazardous event, because of the concern their involvement may lead to liability issues. This reluctance is even greater in dealing with existing developments, as compared to proposed new developments, because of the difficulty in funding and managing any mitigative measure incorporated in a hazard mitigation plan.

The existing statutory and regulatory framework, and current Provincial policy, tends to deal with individual developments and property owners rather than a collective community. The onus is placed on individual proponents to comply with regulations, pay for mitigative measures, and obtain necessary permits to implement the measures. This is more appropriate for dealing with new, rather than existing, developments.

Options for assuming administrative responsibility for a hazard management plan for the valley essentially fall into one of the following three categories:

- lead is taken by a Provincial Ministry;
- lead is taken by the Regional District;
- lead is taken by a local authority.

In assessing the options, it is recognized that administration of a plan involves both the capital improvements and ongoing monitoring and maintenance. These two functions could be completely separate, or initially separate in establishing an administrative authority.

Lead by Provincial Ministry

There are a number of precedents for Provincial Ministries to take the lead in managing and administering the construction of mitigative works, but fewer in which a Ministry has an on-going responsibility for maintenance of the works. The Ministry of Environment has taken the lead on numerous projects under the joint Federal-Provincial Fraser River dyking program. However, responsibility for local drainage and dyke maintenance is left with local governments.

Similarly the Ministry of Transportation and Highways took the lead in planning and constructing debris basins along the Squamish Highway, and routinely designs and constructs bank protection for highways and roads. This Ministry also manages maintenance for highways, including bank protection where roads are threatened by ocean waves or river currents.

The advantages of the administrative lead being taken by a Ministry include:

- experience in the area of undertaking capital construction programs;

- familiarity with government policies and standards;
- ability to cover administrative expenses and salaries from the general tax base funding the Ministry; and,
- ability to enter into Federal-Provincial funding agreements.

The disadvantages of a Ministry taking the administrative lead include:

- Provincial Ministries are generally not staffed adequately to administer site-specific programs;
- Ministries have relatively narrow mandates, whereas the issues involved in the hazard management plan for the valley are numerous;
- Ministries deal on a Province-wide basis, although there are often District Offices, and may be concerned during decision making about establishing precedents in one area of the Province that are deemed to be inequitable to other areas;
- less accountability for decisions and action than for more local levels of administration.

Lead by the Regional District

There are no known precedents for a Regional District in the Province of British Columbia undertaking the implementation and administration of a site-specific hazard management plan. The mandate of Regional Districts, to date, has been to plan for development on a regional basis, regulate development in unincorporated areas, and be a vehicle for the provision of some community services to a region.

Advantages of the Regional District of Fraser Cheam taking the administrative lead include:

- the organizational infrastructure such as personnel, financial reporting, and record keeping procedures are in place;
- there is some diversity and depth of support capability for various aspects of a program, whereby work associated with the program is shared and incorporated in other functions of the District;
- the Regional District is closely linked to the Provincial Government, providing an established vehicle for the political process; and,

- the Regional District can apply for and receive grants, or funds, earmarked for specific purposes.

The disadvantages of the Regional District taking the administrative lead include:

- the involvement focuses resources of the Regional District on one specific area within the region, rather than providing a more uniform level of support for all areas within the region;
- additional staff and office support space would likely be required to undertake administration of the program;
- as presently organized, the role of the District in dealing with some issues such as local drainage, emergency response, fish habitat, and technical reviews of mitigative measures, and liability, are either not clearly defined, or the interface with other agencies is inefficient; and,
- enabling legislation for the Regional District to assume this role and responsibility is inadequate.

Lead by a Local Authority

There are precedents in the Province for Local Improvements Districts to be established for the purpose of implementing a specific program such as a water supply, irrigation, drainage, or sewerage system.

Also, a recent revision to the Municipal Act allows for the formation of a Local Community Commission which can operate with four elected commissioners plus the director for the electoral area in which the Local Community is located. A bylaw is required to establish the name and boundaries of the Local Community, including other details, and may include the terms, conditions and restrictions on activities of the Commission.

Another form of local authority, other than a Local Improvement District or Local Community Commission, could possibly be developed that would include representation from the community and all three levels of government. However, this would likely require enabling legislation, and senior governments may not wish to delegate regulatory authority to the local group.

The advantages of a local authority implementing and administering a hazard management plan include:

- site-specific knowledge of area;

- access to the residents affected by hazardous conditions in order to establish priorities for action;
- local accountability for decisions and actions of the authority; and ,
- funds to support the program are generated from a local tax base.

The disadvantages associated with a local authority taking the lead in administering a hazard management plan for the valley include:

- a political decision, legislation, time and funds would be required to establish a local authority;
- the existing tax base is likely too small to fund the capital, maintenance, and administrative costs of the program;
- the local authority may be perceived adversely by the public as another layer of government;
- public support, or funds, for the continuity of the local authority is not guaranteed; and,
- the local authority may not be capable of assuming liability for decisions and actions taken.

8.2 Existing Financial Framework

At present there is no comprehensive or integrated means of financing hazard mitigation in the Province, particularly for existing developments on hazardous lands.

Traditionally funding related to hazard management has fallen into one of the categories listed below, with funding coming from various sources depending on the category:

- Hazard management planning;
- Emergency response;
- Hazard mitigation.

Funds for *planning studies* have come from a number of sources, including:

Ministry of Municipal Affairs, Recreation and Culture - Planning grants have been made available for the development of plans, including hazard management plans, but the funding is very limited and would not cover on-going management of a plan once it is developed.

Provincial Emergency Program - Funds have been made available for studies, particularly for extremely hazardous situations with a high degree of imminence where a development could be affected.

Ministry of Environment - This Ministry has undertaken studies internally or provided grants for hazard management studies. The Ministry, in concert with the Federal government, has an annual allocation of funds for floodplain mapping.

Ministry of Transportation and Highways - This Ministry funds studies related to the definition and/or mitigation of hazards which threaten highway systems.

Ministry of Forests - To a lesser degree than the Ministry of Transportation and Highways, this Ministry would fund studies related to hazard management within the forest industry.

Individual Proponents - Private funds are used by proponents of new developments to meet regulatory requirements related to hazard management.

Funds for *emergency response* to a hazard come from the following five sources, where emergency response is considered to cover work undertaken both during and after the hazardous event:

Provincial Emergency Program - Provincial funds are allocated annually for emergency preparedness for the purpose of co-ordinating a response to a hazardous situation involving flood and landslide hazards. Funds are made available to respond to a situation only after it is declared as an emergency. Post-event disaster relief funds are made available through Federal and Provincial governments on a site-specific basis. Over the years there have been several funding sources and means of dealing with disaster relief (Smith, 1991).

Department of National Defence - The Base Commander of CFB Chilliwack can, on his own initiative, provide a limited response to a critical local situation under the heading of "assistance to Civil Authority". Any major response under this same heading can only be authorized by the Area Commander in Victoria following a request by the Province and a commitment by the Province to pay for wages of military personnel and utilization of military equipment.

Regional District Program - The Regional District of Fraser Cheam has the ability to allocate up to \$10,000 in funds annually for "Programs in Preparation for an Emergency". The funds are to be used for the production of plans, the acquisition of communication equipment and the pre-positioning of stores of materials for (primarily) a flood emergency. Funds have been used by residents of the Chilliwack River Valley to develop an emergency operating procedure in case of a flood event.

Private Insurance - Some geotechnical hazards, such as earthquakes, can be covered by insurance, whereas others such as floods and bank erosion, cannot be covered by insurance.

Private Property Owners - Either during or after a hazardous event, property owners draw on personal funds to protect, repair or replace property.

Funds for *hazard mitigation* have historically been made available on a project specific basis, typically as follows:

Federal-Provincial Programs - By far the largest contributions of funds to dyking and bank protection in the Province has been by joint Federal-Provincial programs such as the Fraser River Flood Protection Program which is given limited funding to 1997 for projects on the Fraser River and its tributaries with a cost benefit ratio of 1, or greater. In the Pemberton Valley, a program of bank protection was undertaken between 1979 and 1984 under the Canada/British Columbia Agri-Regional Development Subsidiary Agreement.

Ministry of Environment - The Ministry has relied on joint Federal-Provincial programs for funding major mitigative projects, or its own flood protection program funds. There are no funds presently budgeted in this Ministry for the construction of mitigative measures, outside of existing Federal/Provincial programs.

Ministry of Transportation and Highways - Capital funding is budgeted on a project by project basis within this Ministry. A component of a project may include mitigative works to protect a highway against avalanche, debris flow, flood, or erosion hazards. This Ministry also funded the construction of some dykes in the Kamloops area.

Ministry of Forests - As for the Ministry of Transportation and Highways, this Ministry may budget funds to afford hazard protection for access roads and bridges associated with forestry operations.

Local Authorities - Often, by agreement, local authorities such as Municipalities, or Regional Districts, are required to contribute funds to a program, as was the case in the Squamish River Valley where 25% of the funds were from the District. Local authorities are normally required to cover maintenance costs associated with protective works.

Private Funding - Private corporations, including crown agencies such as B.C. Hydro and Power Authority, and individual developers are usually required to provide the capital funds to mitigate against known hazards for any new development. The cost of works borne by the owner may vary widely from the stabilization of a large potential landslide to placing a few inches of fill on the footprint of a dwelling.

8.2.1 An Administration and Financial Implementation Option

Significant administrative and financial impediments to the implementation of a hazard management plan for the valley include:

- a lack of existing Provincial legislation targeted specifically at enabling the implementation, administration and funding of a hazard management plan;
- establishing the level of government, or base of taxpayers, responsible for the capital funding required for hazard mitigative measures for existing development on hazardous lands;
- as above, for the on-going operation and maintenance costs associated with mitigative measures.

The following is suggested for discussion:

Capital Funding

The allocation of capital funding depends to a large extent on the mitigative options included in a hazard management plan. The mitigative options required should be established prior to examining the capital funding options. However, with this mind the following factors should be noted with respect to the source from which capital funding is drawn to provide hazard mitigative for existing improvements in hazardous areas.

- precedent of funding similar mitigative needs;
- implementing mitigative measures will reduce the exposure to Federal/Provincial disaster relief funding;
- the resources of the valley are utilized extensively by organizations and individuals from outside the valley;
- protection of the Chilliwack Lake Road is vital to all interests utilizing the valley, during both hazardous and non-hazardous times;
- residents living in hazardous areas were permitted to locate in these areas in the prior absence of hazard avoidance policies; however,
- those who stand to gain financially as a result of receiving direct benefits from mitigative measures should share in the cost of hazard management program.

The allocation of capital costs may be established in a number of ways, including:

- a unilateral decision of a senior level of government to provide sole source funding;

- an apportionment between senior levels of government, drawing on funds from existing, or budgeted, government programs;
- an apportionment between senior levels of government and the local community drawing on existing, or budgeted funds and local funds raised through taxation or levies.

The River Bank Protection Act offers an approach to funding allocation whereby the engineer designated by MOH proposes an assessment scheme for the apportionment of cost between the Province and the owners of land to be benefited.

The capital cost associated with mitigating against hazards for new developments should be borne by the proponent, including the cost of floodproofing within dyked areas.

Operation and Maintenance Funding

The operation and maintenance funding associated with flood monitoring should be borne by the Provincial government since this program has downstream benefits and monitors for events that may exceed a 1:200 year value.

The operation and maintenance funding associated with administrative costs and maintenance of mitigative works should be borne by property owners within the watershed of the Chilliwack River Valley, including, but not necessarily restricted to:

- private residential and commercial property owners;
- Ministry of Environment, Lands and Parks;
- Ministry of Transportation and Highways;
- Ministry of Attorney General;
- Fisheries and Oceans Canada;
- Department of National Defence;
- Timber lessees, through the Ministry of Forests.

Annual rates for property owners would be established on the basis of assessed property and improvements values. The cost of any mitigative works included in new development could be incorporated in the assessed value of the property as improvements. Annual levies would be collected by the Regional District or a local authority.

The allocation of maintenance costs between private properties and government departments is not addressed in this interim report, nor is the mechanism for applying the levy.

The arguments in favour of this approach to covering operation and maintenance costs are:

- the incentive for prudent use of maintenance funds, and establishing the priorities for applying maintenance funds will be directly through principle valley users;
- any capital or operational benefit derived to principle valley users from application of tax funds derived from outside the valley are offset by the obligation to maintain the mitigative works;
- precedents of requiring local governments to maintain mitigative measures.

Administration

It is suggested that implementation of the capital works associated with a hazard management plan for the valley be undertaken by the Ministry of Environment, for the following reasons:

- existing legislation and administrative systems and personnel are in place that would be able to undertake management of the work;
- if Federal funds are involved, there are precedents and working relationships between the Ministry of Environment and general agreement on the standard of construction for dyking and bank protection works;
- technical expertise to deal with environmental issues is available within the Ministry;
- the Ministry has knowledge on the exposure to hazards in the valley, and the issues involved;
- the Ministry has access to powers of expropriation, if necessary, to obtain right-of-way required for mitigative works,.
- time will be required to establish any alternative administrative body, other than a Provincial Ministry.

It is suggested a local authority be established to undertake the following:

- receive, possibly in trust, the ownership of mitigative works;
- raise, or receive, funds for the maintenance of mitigative works and administrative expenses;
- establish, carry out and report on an annual maintenance program;

- receive information from the Ministry of Environment flood monitoring program;
- carry out and report on an annual hazard inspection of the valley;
- inform the Regional District and any potentially affected property owners of any previously undefined and unmapped hazards;
- report on hazardous events which occurred in the valley;
- provide a co-ordinating role in the valley during an emergency response;
- maintain a supply of materials suitable for use in an emergency situation, including riprap, concrete blocks, and sand bags; and,
- interface with DFO on fisheries issues and MOTM on road drainage issues.

The maintenance of local drainage could also be a function of this local authority.

It is suggested the annual inspection for hazard management be carried by a committee comprised of a representative from the local authority, a qualified biologist, and a qualified engineer. This team should also undertake an inspection after the occurrence of any hazardous events in the valley associated with geotechnical, flood or erosion hazards. The team would report on maintenance requirements, priorities and methods.

8.3 Technical Framework

The selection of the technical components of a hazard management plan should be guided by a set of principles and priorities. The following are suggested for discussion:

Principles

1. A hazard management plan, like a watershed management plan, or a logging plan, is only a part of an overall river valley management plan. The hazard management plan should focus on issues related to the definition, avoidance and mitigation of natural hazards.
2. Decisions associated with developing the hazard management plan should view the long term utilization of the valley (50+ years), giving consideration to the next generation which seeks to redevelop properties in existing hazardous areas.
3. The implementation of structural mitigation measures should avoid, or minimize, exacerbating the level of exposure to any natural hazards in both the short and long term.

4. The river should be given as much freedom for movement as possible. Therefore bank protection should be limited to:
 - transportation links;
 - developed areas; and,
 - valley walls.
5. It is necessary to designate the areas to be provided with hazard mitigation, as part of the hazard management plan.
6. It is necessary to differentiate between a hazard and a nuisance. A natural hazard should be considered as a potential significant threat from a process or event of considerable force. A nuisance should be considered as a disruption or aggravation due to a process involving less force and severity.
7. The most effective hazard management strategy for new developments is hazard avoidance, handled through the existing regulatory process and the mapping of hazardous areas.
8. The purpose of a hazard mitigation in existing developed areas is to reduce the level of hazard exposure to levels acceptable to regulatory agencies so property improvements, sub-divisions, and financing of improvements, or development, can proceed.
9. It is necessary to have assurance through the use of proven technology, or qualified professional opinion, that the mitigative measure to be relied on during a hazardous event will be in place, and effective, during the event.
10. Floodproofing is preferable to flood protection. New developments behind flood protection dykes should be elevated to provide floodproofing in the event of dyke failure.
11. Structures for flood, erosion, debris flow and debris flood protection should be protected against outflanking or breaching.
12. Environmental impacts associated with mitigative measures should be avoided or mitigated. Mitigative measures should avoid adverse impacts on other properties.
13. Limited emergency response is an appropriate mitigative strategy.
14. Monitoring and maintenance is an essential mitigative strategy

15. Implementation of mitigative measures should be phased based on a prioritization of needs.

Priorities

Priorities in implementing the plan should be established on the following basis:

- equalizing the risk of exposure to natural hazards of those residents living in hazardous areas; that is, giving priority to those residents most exposed to a hazardous event;
- addressing hazards for which there is a widespread risk such as the flooding hazard, as compared to the bank erosion hazard of properties presently set back from the river edge;
- maximizing the amount of mitigation provided for the funds expended; for example, filling in gaps in existing dyking;
- protecting Chilliwack Lake Road, and its bridges.

8.4 Hazard Management Outline Plan

As required in the terms of reference, following discussion of the information, options, and suggestions included in this report, a hazard management outline plan will be prepared. The outline plan is expected to be relatively brief, addressing the following topics in point and/or drawing form:

A. Principles of Hazard Management Plan

B. Area Designations

- designation of areas of known hazards, type and exposure;
- designation of existing developed areas to receive and maintain structural mitigation measures;
- designation of areas not receiving structural mitigation measures;

C. Hazard Mitigation for New Developments

- within areas designated to receive structural mitigative measures;
- outside areas designated to receive structural mitigative measures.

D. Structural Hazard Mitigation

- Protective Works
- Scope and Phasing
- Environmental Mitigation
- Capital and Maintenance Costs
- Design Requirements
- Flow and Debris Control Measures
 - scope, basis and method;
 - capital and maintenance cost.
- Emergency Response Measures
- Monitoring Measures

E. Administrative Organization

- Regulatory
- Implementation of Capital Works
- Monitoring and Maintenance
- Emergency Response

F. Financing

- Capital Works
- Monitoring and Maintenance

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TABLES

Table 1: Chilliwack River Valley Property Categories

Single Family Dwellings	246	43.2%
Mobile Home and Strata	185	32.4%
Seasonal Dwellings	26	4.6%
Vacant Residential	44	7.7%
Farms	29	5.1%
Commercial	3	0.5%
Industrial	2	0.4%
Transport/Communication	1	0.2%
Civic/Recreational/Institutional	11	1.9%
Other (Mostly Vacant)	23	4.0%
TOTAL	570	100.0%

Table 2: Fish Stocks^a

Species	Natural Production			Hatchery Production			Total Stock
	Spawning Escapement	Catch	Total	Spawning Escapement	Catch	Total	
Pink salmon ^b	139,600	266,400	406,000	---	---	---	406,000
Chum salmon	152,900	133,200	286,100	30,000	26,100	56,100	342,200
Chinook salmon	50	150	200	7,600	13,500	21,100	21,300
Coho salmon	7,200	19,700	26,900	64,700	177,900	242,600	269,500
Steelhead trouts ^c	4,000	5,800	4,000	--- ^d	4,200	1,500 ^d	5,500
TOTALS	303,750	425,250	723,200	102,300	221,700	321,300	1,044,500

- a Data sources and methodologies used to derive these estimates are described in Appendix 2.
- b Pink salmon spawn in the Fraser River system only in odd-numbered years. The 1981-1990 period therefore includes only 5 cycles of production.
- c As angling regulations require that all wild steelhead be released, wild steelhead catch can exceed the total number in the population because some steelhead are caught and released more than once. Although hatchery steelhead can be retained, a substantial percentage are also released and may therefore be caught more than once.
- d Hatchery steelhead spawners have not been enumerated. Estimated total stock of hatchery steelhead (1,500) is a minimum value, i.e. the average kill of hatchery fish. It does not include fish that escaped to spawn.

Table 3: Forest and Logged Areas in the Chilliwack Watershed (pre 1945-1992)

Total Area (ha)	Total Forest (ha)	Total Operable Mature (ha)	Total Operable Immature (ha)	Total Natural Immature (ha)	'45-65 Logging (ha)	'66-75 Logging (ha)	'76-85 Logging (ha)	'86-92 Logging (ha)
67700.46	42886.11	8617.72	25341.31	9011.69	4648.34	3104.01	2814.74	2636.38

- Notes:
1. Total Natural - Defined as all polygons coded as disturbed by wildfire
 2. Logging Years are based on first year of disturbance
 3. Includes all ownerships

Table 4: Silvicultural Activities in the Chilliwack Watershed (1960 - 1990)

Watershed	Planting (ha)	Non-planting (ha)	Total (ha)
Liumchen	364	227	591
L. Tamihi	180	13	193
Tamihi	885	491	1,376
Slesse	431	495	926
Borden	319	24	343
Nesakwatch	156	31	187
Center	260	37	297
Depot	437	194	631
Paleface	350	51	401
Foley	283	284	567
Airplane	81		81
Chipmunk	1,005	87	1,092
Chilliwack	1,116	2,581	3,697
Deer	205	239	444
Clayburn	81	24	105
Other Areas	96	8	104
Total	6,249	4,786	11,035

Table 5: Proposed Logging in Tributary Watersheds of the Chilliwack River (1991 - 1995)

Watershed	Licensee	1991	1992	1993	1994	1995	Total (ha)
Liumchen	SBFEP		22.1				
	Norvik		60.0	10.0			92.1
L. Tamihi							0
Tamihi	Tamihi	18.4	50.5	45.3	23.8	28.6	166.6
Slesse	Herman	8.9	19.4	18.0			46.3
Borden	Herman			28.3*	28.3*		56.6
Nesakwatch	SBFEP			28			
				37			65
Center							0
Paleface	SBFEP	24.3	34.1	49.2	23.0		130.6
Radium	SBFEP					34.0	34
Foley/Airplane	Tamihi	11.4	5.8	5.6	5.6	8.0	
	Herman		51.1*	38.8	6.5		
	SBFEP	1.0			40.0	37.0	209.8
Chipmunk	Herman	26.0	47.0*				
	SBFEP	35.4					108.4
Chilliwack	SBFEP	6.1					6.1
Other		20.0	20.0	20.0	20.0	20.0	100.0
Total		151.5	310.0	280.2	147.2	127.6	1016.5
Average							203.3

- Notes:
1. Block areas are shown only for the year in which logging is proposed to commence. *blocks have not been approved by Ministry of Forests.
 2. "Other" includes the 7 small quota holders for which no definite operating areas are assigned.
 3. Norvik Timber may not log the areas projected in Liumchen Creek.

**Table 6: Estimated Dollar and Employment Value of Timber
Removed from the Chilliwack Watershed, 1985 - 1989**

Year	Volume m ³	Log Value \$	End Product Value \$	Direct Jobs
1985	151,186	8,315,230	17,386,390	181
1986	263,648	14,500,640	30,319,520	330
1987	205,124	11,281,820	23,589,260	256
1988	298,408	16,412,440	34,316,920	373
1989	270,570	14,881,350	31,115,550	338
Total	1,188,936	65,391,480	136,727,640	
Average	237,782	13,078,296	27,345,528	297

- Notes:
1. Log Value based on \$55/m³
 2. End Product Value based on \$115/m³
 3. Direct jobs based on 800 m³/job
 4. Information provided by Ministry of Forests, Chilliwack District office.

Table 7: Water Survey of Canada Gauging Stations

Station No.	Name	Drainage Area km ²	Record Period
08MH001	Chilliwack River at Vedder Crossing	1,230	1911-31, 51-date
09MH103	Chilliwack River above Slesse Creek	645	1963-date
08MH016	Chilliwack River at Outlet of Chilliwack Lake	329	1923-date

Table 8: Unreported Floods

Date	Daily Flood (m ³ /s)	Max. Stage (m)	Source
February 10, 1951	566	4.11	McLean
January 5, 1984	544 (925 i)	4.50	McNeil, MOE
November 9, 1989	684 (816 i)	4.251	Jordan
November 10, 1990	715 (912 i)	4.116	Coulson, MOE

- Notes:
1. instantaneous peak flows shown in brackets
 2. The daily flood peak for November 10, 1990 was estimated from the hourly hydrograph derived by Coulson (1991).

Table 9: Flood Frequency Distributions (Daily Mean Flows) - Chilliwack River at Vedder Crossing

Return Period (years)	Frequency Method (CFA 88)				MOE (1980) m ³ /s
	GEV m ³ /s	3 PLN m ³ /s	LP III m ³ /s	WAKEBY m ³ /s	
20	620	630	615	634	544
50	760	769	736	747	
100	873	877	827	825	
200	991	989	917	895	790

- Notes:
1. GEV, 3 PLN, LP III and WAKEBY refer to different frequency plotting routines.
 2. MOE (1980) refers to values derived by the Ministry of Environment, based on the data available at that time.

Table 10: Percent of Total Chilliwack River Watershed Harvested over 5-Year Periods

Date	Area Logged (ha)	% of Watershed	Cumulative % of Watershed
1950-1965	4,648	6.9	6.9
1966-1975	3,104	4.6	11.5
1976-1985	2,814	4.2	15.7
1986-1992	2,636	3.9	19.6

- Notes:
1. Area in U.S.A. not included
 2. Source (MOF, 1992)

Table 11: Percent of Chilliwack River Sub-Basin Areas Harvested over 5-Year Periods

Drainage	Area (ha)	% of Sub-Basin Area				% of Drainage in Clear-cut Equivalent
		Years				
		Pre 1965	66-75	76-85	86-92	
Liumchen	4408*	15	.9	1.5	5.3	5.6
L. Tamihi	1595	35	8.8	10	12	16.0
Tamihi	5114*	15	9.7	8.2	3.7	7.5
Slesse	7414*	8.4	3.2	2	4.3	5.3
Borden	4497	11	5.2	8.5	5	8.7
Nesakwatch	5482*	.4	3.9	3.9	3.5	5.1
Center	5088*	7.9	5.1	.4	11.6	5.3
Bench	3918	2.3	0	4.2	0	2.1
Radium	938	0	0	0	0	0
Post	2326	0	0	0	0	0
Ford Mtn	3419	1.1	.5	1.4	.9	1.2
Chipmunk	4646	20	9.7	10.6	7.8	12.3
Foley	7887	1.1	1.4	7.2	6.6	9.5
Paleface	5075	0	9.1	.4	.9	1.0
Depot	2781	0	16.1	3.7	.5	2.2

- Notes:
1. *Area in U.S.A. not included. For these drainages clear-cut equivalents will be significantly less.
 2. Clear-cut equivalency based on canopy at 25 years acting hydrologically as a mature stand. Factor for calculating clear-cut equivalency based on median age.
 3. Source (MOF, 1992)

Table 12: River Bed Survey Comparisons 1976-1991, Slesse Park to Vedder Crossing

SECTION NO.	COMPARISON OF		FLOODS	CHANGE m ²		AVE. BED ELEV. m		CHANGE IN ELEV. m	
	BASE YR	COMP YR		INFILL	SCOUR	BASE YR	COMP YR	INFILL	SCOUR
1	1990	1991	1	31.8	14.9	29.3	29.6	0.4	
2	1990	1991	1	118.0	97.9	31.8	31.9	0.1	
3	1990	1991	1	52.8	55.7	34.2	34.2		
4	1990	1991	1	116.8	112.7	37.3	37.3		
5	1990	1991	1	157.9	143.0	39.9	40.0	0.1	
6	1990	1991	1	87.9	51.3	41.5	41.7	0.1	
7	1990	1991	1	75.3	124.8	43.6	43.4		0.1
8	1990	1991	1	104.8	81.5	44.1	44.2	0.1	
9	1990	1991	1	206.9	157.9	46.3	46.4	0.1	
10	1990	1991	1	214.9	159.4	48.1	48.2	0.1	
11	1990	1991	1	104.7	197.0	51.3	51.3		0.1
12	1990	1991	1	130.3	89.9	52.8	52.9	0.1	
13	1990	1991	1	32.7	62.2	53.2	53.1		0.1
14	1976	1991	14	20.0	83.4	53.8	53.1		0.7
15	1976	1991	14	41.1	121.8	59.1	58.8		0.4
16	1976	1991	14	130.6	186.0	62.7	62.4		0.3
17	1976	1991	14	99.8	16.1	65.4	65.9	0.5	
18	1976	1991	14	353.9	37.6	70.0	71.0	1.0	
19	1976	1991	14	74.0	271.2	74.9	74.4		0.5
20	1976	1991	14	110.1	178.3	79.0	78.5		0.4
21	1976	1991	14	34.8	75.0	82.6	82.0		0.6
22	NONE	1991							
23	1976	1991	14	21.7	0.0	88.3	88.6	0.3	
24	1976	1991	14	14.1	27.7	91.6	91.3		0.2
25	1976	1991	14	8.4	20.5	97.3	97.0		0.2
26	1976	1991	14	44.5	9.8	102.2	102.8	0.7	
27		1991							
28		1991							
29	1979	1991	13	95.3	72.6	122.8	122.9	0.2	
30		1991							
31	1979	1991	13	95.5	234.6	130.6	130.0		0.6
32	1979	1991	13	27.6	44.3	134.7	134.6		0.1
33		1991							
34	1979	1991	13	128.9	82.2	150.1	150.4	0.2	
35	1979	1991	13	33.8	22.6	155.3	155.4	0.1	
TOTALS				2,768.9	2,831.9				

Table 13: Bank Erosion, Slesse Park to Baker

	Location	Type of Bank Erosion	Bank Erosion (m)	Period	Rate m y^{-1}
1	U/S of Slesse Park Slide R/B	Accretion	-10	76 - 91	0.7
1	U/S of Slesse Park Slide R/B	Lateral	30	56 - 76	1.5
2	D/S of Slesse Park Slide R/B	Lateral	80	76 - 91	5.3
3	Opposite Slesse Park L/B	Lateral	15	76 - 91	1.0
4	Slesse Park	Lateral	70	76 - 91	4.7
5	Slesse Park	Cut-Off Chute	Width Approx. 50 m		
6	U/S Tamihi R/B	Lateral	10	76 - 91	0.7
7	800 m D/S of Tamihi L/B		13	76 - 91	0.9
7	800 m D/S of Tamihi L/B	Lateral(?)	90	32 - 91	1.5
8	Opposite Bell Acres Road R/B	Lateral	20	32 - 91	0.3
8	Opposite Bell Acres Road R/B	Lateral	6	76 - 91	0.4
9	Ryder Creek	Avulsion	Single Channel Width 60 - 100 m Braided Channel Width 110 - to 150 m		
10	Way Farm Area L/B	Lateral(?)	160	32 - 40	20
10	Way Farm Area L/B	Lateral(?)	70	40 - 56	4.4
10	Way Farm Area L/B	Lateral(?)	1	56 - 76	0.1
10	Way Farm Area L/B	Lateral(?) Accretion	150	76 - 91	10
11	D/S Way Farm L/B	Lateral	200	76 - 91	13
12	O'Hanley's Property	Lateral	75	76 - 91	5
13	DND Firing Range	Avulsion	Single Channel 50 - 60 m Shift in Channel 1976-91 by 650 m		
14	D/S Baker Trail	Avulsion(?)	Shift in Two Braided Channels 1956-91 by 350 - 400 m Combined Width of Channels 45 to 80 m		

Notes: U/S = Upstream L/B = Left Bank
 D/S = Downstream R/B = Right Bank
 ? = Mechanism Uncertain

Table 14: Definition of Hazard Zones

	Slope Characteristics	Existing Slope Stability	Potential Activity
Non-Channelized			
1. Upper Slopes	a. Steep slopes in till or outwash materials	<ul style="list-style-type: none"> ▪ Generally stable ▪ Some sloughing 	Piping in uniform sands
	b. Steep slopes in glaciolacustrine silts	Widespread slumping	<ul style="list-style-type: none"> ▪ Continued slumping ▪ Debris avalanche
	c. Flatter slopes in glacial material	Stable	Creep
2. Lower Slopes	a. Terrace and floodplain	Instability at crests and toes of escarpments	Slumping and erosion
	b. Escarpment slopes	Widespread slumping in glaciolacustrine sediments	Slumping
Channelized			
3. Drainage	a. Erosion areas (gullies)	Locally unstable	Local sloughing, debris flow and debris flood erosion and deposition
	b. Depositional areas (fan)	Stable	Debris flow and debris flood deposition

Table 15: Probability:Magnitude Relationships - Slesse Park

A. Channelized Hazards

Annual Probability of Occurrence	Debris Flow/Debris Flood Magnitude (m ³)							
	Nonie Creek	Creek #1 (El. 160 m)	Creek #1 (El. 140 m)	Creek #2 (El. 160 m)	Creek #2 (El. 140 m)	Creek #3 (El. 160 m)	Creek #3 (El. 140 m)	Young Creek
1:10 - 1:50	500	100		200		300		500
1:50 - 1:200	2,000	500	200	500	200	1,000	250	1,000
1:200 - 1:500	3,500	1,000	400	1,000	500	1,500	750	2,500
< 1:500	7,500	1,500	700	2,000	1,000	3,000	1,750	5,000

B. Non-Channelized Hazards

Slopes: 1:50 - 1:200

Setback zones - Crests and toes above and below slopes: 1:200 - 1:500

Table 16: Probability:Magnitude Relationships - Bell Acres Area

Annual Probability of Occurrence	Debris Flow/Debris Flood Magnitude (m³)											
	Creek #20	Creek #21	Wingfield Creek	Creek #25	Creek #26	Creek #27	Creek #28	Creek #29	Creek #30	Creek #31	Creek #32	Creek #33
> 1:50	200	200	500	500	300	250	100	300	300	300	300	300
1:50 - 1:200	400	750	2,000	1,000	1,000	750	300	1,000	750	750	750	750
1:200 - 1:500	800	1,200	3,500	2,000	2,000	1,500	750	2,000	1,500	1,500	1,200	1,200
< 1:500	1,500	2,500	7,500	4,500	3,500	3,000	1,200	3,500	3,000	3,000	2,000	2,400

Note: Creek numbers as designated in Thurber Consultants 1988a report.

Table 17: Probability:Magnitude Relationships - Bakers Trail Village

A. Channelized Hazards

Annual Probability of Occurrence	Debris Flow/Debris Flood Magnitude (m ³)				
	Midgely	Wash	Briar	Guy	Tank
1:20 - 1:50	200	50	50	750	500
1:50 - 1:200	1,000	500	500	2,000	2,500
1:200 - 1:500	2,000	1,000	1,000	4,000	5,000
< 1:500	2,000	1,500	1,500	4,000	5,000

B. Non-Channelized Hazards

Slopes: 1:50 - 1:200
 Setback zones - Crests and toes above and below slopes: 1:200 - 1:500

Table 18: Potential for Debris Flow Events over next 50-Year Period at Baker Trails Village

Creek	50% Chance	75% Chance (greater than or equal to)	Max. Single Event Exposure (probability)
Midgely			
events	3 ≥ 200 m ³ to a max. of 1,400 m ³	2 ≥ 200 m ³ to a max. of 600 m ³	2,000 (22%)
deposition (m ³)	2,250	1,000	
Wash and Briar (each)			
events	3 ≥ 50 m ³ to a max. of 600 m ³	2 ≥ 50 m ³ to a max. of 400 m ³	1,500 (10%)
deposition (m ³)	1,000	500	
Guy			
events	3 ≥ 750 m ³ to a max. of 2,500 m ³	2 ≥ 750 m ³ to a max. of 1,500 m ³	4,000 (22%)
deposition (m ³)	5,000	2,750	
Tank			
events	3 ≥ 500 m ³ to a max. of 3,500 m ³	2 ≥ 500 m ³ to a max. of 1,750 m ³	5,000 (22%)
deposition (m ³)	5,500	3,000	

- Notes:
1. All values are approximate;
 2. Based on the annual probabilities given in Table 16 assuming a Poisson distribution;
 3. The potential for events of smaller volume than indicated has not been included, although the figures for total 50-year deposition do include the small events;
 4. Reference: Morgan, Rawlings and Sobkowics, 1992.

Table 19: Estimated 200 Year Flows for Ryder Creek and Wingfield Creek

Catchment	Drainage Area (km ²)	200 Year Instantaneous Flood Estimate (m ³ /s)
Ryder Creek	7.7	31
Wingfield Creek	3.2	16
Combined	10.9	40

Table 20: Legislation and Programs Relevant to Hazard Management in the Chilliwack River Valley

AREA ADDRESSED	LEGISLATION/PROGRAM	AGENCY
Identification	Agreement Respecting Floodplain Mapping in B.C.	BCE
Management	Section 82 Land Title Act Sections 85/215 Land Title Act Section 86 Land Title Act Municipal Act, Section 945, Community Plans Municipal Act, Section 952, Rural Land Use Municipal Act, Section 970, Non Conforming Municipal Act, Section 976, Development Permit Municipal Act, Section 978, Tree Cutting Municipal Act, Section 969, Floodplain Elevation Municipal Act, Section 734, Geotechnical Report Land Act Section 8 (Inter-Agency Referral) Section 7, Fisheries Act Drainage, Ditch and Dyke Act Dyke Maintenance Act	BCE MOTH MOTH MARC MARC MARC MARC MARC BCE MARC MCL DFO BCE BCE
Mitigation	Dyke Maintenance Act Flood Protection Program River Bank Protection Act Flood Relief Act	BCE BCE MOTH MOTH
Response/ Recovery	Disaster Financial Assistance Program Environmental Management Act	PEP BCE

KEY

BCE - Ministry of Environment, Lands and Parks

MOTH - Ministry of Transportation and Highways

MARC - Ministry of Municipal Affairs, Recreation and Culture

BCL - B.C. Lands, Ministry of Lands, Parks and Housing

PEP - Provincial Emergency Program, Ministry of the Solicitor General together
with Federal Government Participation

DFO - Federal Department of Fisheries and Oceans

Table 21: Status of Existing Mitigative Works in the Slesse Park Area

SUB-AREA	MITIGATIVE WORKS	STATUS RELATIVE TO DEFINED HAZARDS
1	Setback dyke and deflection berm for seven properties	<ul style="list-style-type: none"> ▪ setback dyke elevation set at previous flood design level. Presently about 0.2 m low; ▪ bank protection exposed to outflanking by river flows.
2	Approximately 300 m of bank protection installed, which also provides some flood protection	<ul style="list-style-type: none"> ▪ existing bank protection may require some reinforcement or additional toe protection; ▪ existing bank protection is exposed to outflanking; ▪ existing bank protection would be overtopped during a 1:200 year flood.
3	Approximately 250 m of bank protection installed, which also provides some flood protection.	<ul style="list-style-type: none"> ▪ existing bank protection is exposed to outflanking; ▪ existing bank protection would be overtopped at downstream end during the 1:200 year flood; ▪ existing bank protection may require some reinforcement or additional toe protection

Table 22: Potential Options for Mitigation against Risks from Channelized Hazards - Slesse Park

		Options Recommended by this Study	Comments	Estimated Cost (\$)
A. Channelized				
Creek #1				
El. 160 m	Channelization, dykes, minimum setbacks	Requires channelling beneath Winona Road	100,000	
El. 140 m	Channelization, dykes, minimum setbacks			
Creek #2				
El. 160 m	Channelization, dykes, minimum setbacks	Requires channelling beneath Slesse Park Road and O'Byrne Road	165,000	
El. 140 m	Channelization, dykes, minimum setbacks			
Above El. 160 m		Further channelization and dyking above the 160 m level may be required - needs further study	(200,000)	
Creek #3				
El. 160 m	Channelization, dykes, minimum setbacks	Requires channelling beneath Slesse Park Road and O'Byrne Road	110,000	
El. 140 m	Channelization, dykes, minimum setbacks			
Young Creek	Channelization, dykes, minimum setbacks	Requires channelling beneath Slesse Park Road	160,000	
Nonie Creek	Channelization, dykes, minimum setbacks		110,000	
B. Non-Channelized				
Crests and toes above and below slopes	Minimum setbacks. Control of drainage, dumping and vegetation removal. Site-specific remedial works as appropriate.	Bylaw regulations to be established. Remedial/preventive works as recommended by detailed surveys	N/A	
Slopes	Land use zoning after area-specific surveys.	High hazard probabilities unlikely to result in issuing of building permits without detailed geotechnical surveys. Bylaw regulations to be established.	N/A	

- Notes:
1. With the implementation of the mitigative measures outlined above, partial protection from the hazards shown in Table 15 would result. Some residual risks from extreme hazard events would still remain however.
 2. Minimum setbacks of 10 m for slopes between 20° and 30°, and 15 m for slopes > 30° are recommended; however, actual setbacks should be determined on a site specific basis.
 3. Estimated costs do not include any costs associated with property acquisition.
 4. Cost includes engineering fees and contingency of 20% of estimated construction costs.

Table 23: Status of Existing Mitigative Works in the Bell Acres Area

SUB-AREA	MITIGATIVE WORKS	STATUS RELATIVE TO DEFINED HAZARDS
4	Approximately 100 m of bank protection	<ul style="list-style-type: none"> ▪ bank protection limited in length and exposed to outflanking; ▪ bank protection may require reinforcement and/or toe protection.
5	<p>Approximately 850 m of bank protection, raised in sections as dykes for flood protection.</p> <p>Floodgate for internal drainage installed at Osborne Road.</p>	<ul style="list-style-type: none"> ▪ bank protection is not continuous nor extended sufficiently far downstream to preclude outflanking; ▪ dyking is not complete, permitting overtopping or flow through openings; ▪ bank protection may require some reinforcement and/or toe protection.
6	A gravel berm, approximately 900 m in length, was constructed with gravels pushed from the river after the 1990 floods.	<ul style="list-style-type: none"> ▪ the berm has no sideslope protection and is subject to erosion; ▪ flood backwater could inundate properties with access from behind the downstream limit of the berm.

Table 24: Status of Existing Mitigative Works in the Baker Trails Area

SUB-AREA	MITIGATIVE WORKS	STATUS RELATIVE TO DEFINED HAZARDS
7	Approximately 350 m of bank protection	<ul style="list-style-type: none"> ■ existing bank protection exposed to outflanking, particularly at downstream end; ■ bank protection overtopped during 1:200 year flood; ■ bank protection may require some reinforcement or toe protection.
8	Approximately 850 m of combined dyking and bank protection	<ul style="list-style-type: none"> ■ minor increase in dyke elevation likely required for 1:200 year flood protection, unless freeboard allowance relaxed; ■ dyking and bank protection exposed to outflanking at downstream end; ■ bank protection may require some reinforcement and/or toe protection.
9	Approximately 300 m of bank protection	<ul style="list-style-type: none"> ■ small area exposed to 1:200 year flood hazard requires dyke protection; ■ existing bank protection needs to be extended upstream and downstream to give protection against erosion hazard; ■ existing bank protection may require some reinforcement and/or toe protection.

TABLE 25
COMPARISON OF CAPITALIZED COST OF FLOOD AND EROSION HAZARD PROTECTION FOR VARIOUS OPTIONS
CHILLIWACK RIVER - SLESSE PARK TO BAKER TRAILS

	SLESSE PARK			BELL ACRES					BAKER TRAILS					
	OPTION			OPTION					OPTION					
	1	2	3	1	2	3	4	5	1	2	3	4	5	6
SITE PREPARATION	18,000	14,000	6,000	23,000	22,000	3,000	17,000	39,000	36,000	36,000	28,000	56,000	45,000	127,000
NEW RIPRAP BANK PROTECTION	2,121,000	553,000	459,000	2,700,000	2,633,000	218,000	607,000	607,000	2,383,000	1,519,000	1,519,000	823,000	1,048,000	1,048,000
REINFORCEMENT OF EXISTING BANK PROTECTION	301,000	301,000	301,000	300,000	300,000	—	300,000	300,000	378,000	378,000	378,000	336,000	378,000	98,000
BERM BANK PROTECTION	—	—	—	—	—	—	—	—	—	250,000	—	—	—	—
SETBACK DYKES	—	—	—	25,000	25,000	—	76,000	775,000	121,000	121,000	121,000	296,000	222,000	54,000
RAISING EXISTING DYKING OR BANK PROTECTION	50,000	50,000	—	86,000	86,000	—	86,000	86,000	107,000	107,000	107,000	95,000	107,000	19,000
RAISING EXISTING ROADS AS DYKES	—	—	—	—	—	1,030,000	273,000	—	—	—	—	—	—	—
RELOCATE OCCUPIED BUILDINGS	—	—	—	—	—	2,655,000	400,000	—	—	—	—	69,000	—	—
ELEVATE OCCUPIED BUILDINGS	—	—	550,000	—	—	—	—	—	—	—	—	—	—	—
CHANNEL EXCAVATIONS	—	—	—	—	—	—	—	—	—	—	—	66,000	—	795,000
PERMITS, ENGINEERING AND CONTINGENCY	498,000	184,000	238,000	627,000	613,000	250,000	612,000	361,000	605,000	482,000	428,000	334,000	360,000	428,000
ESTIMATED TOTAL INITIAL CAPITAL COST	\$2,988,000	\$1,102,000	\$1,534,000	\$3,761,000	\$3,679,000	\$4,156,000	\$2,371,000	\$2,168,000	\$3,630,000	\$2,893,000	\$2,581,000	\$2,075,000	\$2,160,000	\$2,569,000
CAPITALIZED MAINTENANCE COST	1,108,000	391,000	348,000	1,379,000	1,379,000	100,000	432,000	592,000	1,291,000	1,468,000	896,000	748,000	697,000	2,356,000
CAPITALIZED EMERGENCY RESPONSE	—	—	—	—	—	76,000	68,000	—	13,000	13,000	13,000	42,000	28,000	6,000
ESTIMATED TOTAL PRESENT DAY COST	\$4,096,000	\$1,493,000	\$1,902,000	\$5,140,000	\$5,058,000	\$4,332,000	\$2,871,000	\$2,760,000	\$4,934,000	\$4,374,000	\$3,490,000	\$2,865,000	\$2,885,000	\$4,931,000

Table 26: Potential Mitigative Options - Baker Trails Village

	Thurber Recommendations (1988b)	Options Recommended by this Study	Additional Comments	Estimated Cost (\$)
A. Channelized				
1.0 Midgely Creek <i>Dotzler Creek on TWD maps</i>	<ul style="list-style-type: none"> ▪ Dyke to control 200 year flood at rear of lots 100 to 108. ▪ Sedimentation basin east of dyke and lots 102 and 109. 	<ul style="list-style-type: none"> ▪ Dyke to control debris flow at rear of lots 101 and 102. ▪ Sedimentation basin east of dyke and lots 102, 103 and 104 to create storage. 	<ul style="list-style-type: none"> ▪ Would require acquisition of a portion of the neighbouring property to the east to permit construction of dyke and basin. ▪ Basin sized to capture debris from 1:500 year event (2000 m³), plus an additional 1,000 m³ of debris from simultaneous events on Briar and Wash Creeks. Maintenance required. 	130,000
2.0 Wash and Briar Creeks	<ul style="list-style-type: none"> ▪ Deepen and widen ditch which drains Wash Creek into Midgely Creek at rear of lots 97 to 100. ▪ Homes 28 and 93 to 97 to be built on specially reinforced and raised concrete foundations. ▪ Homes 144 to 148 (south of Baker Way) to be built on raised concrete foundations. 	<ul style="list-style-type: none"> ▪ Deepen and widen ditch behind lots 27 to 101. Ditch lined with shotcrete. ▪ Construct barrier behind lots 27, 28 and 93 to 99 to deflect flow along ditch line. Barrier height will vary along ditch and will be highest at mouth of Briar and Wash Creeks. 		120,000

* ALL LOTS REQUIRING SAME FUNDING COORDINATE

Table 26 - continued

	Thurber Recommendations (1988b)	Options Recommended by this Study	Additional Comments	Estimated Cost (\$)
3.0 Guy Creek	<ul style="list-style-type: none"> ▪ <u>Option 1</u> - move homes No. 23 to 27 (5) and build a sediment basin on the site. Also nine homes (Nos. 29, 30 and 63 to 69) on west side of Baker Way to be placed on raised concrete foundations to avoid flood damage. ▪ <u>Option 2</u> - construct a trash rack on lower Guy Creek. 5 homes (No. 23 to 27) to be placed on specially reinforced concrete foundations. 9 homes west of Baker Way (Nos. 29, 30 and 63 to 69) to be placed on raised concrete foundations. Temporary removal of one trailer north of Baker Way may be required for access. 	<ul style="list-style-type: none"> ▪ Remove 3 to 5 homes at base of Guy Creek fan for sedimentation basin. Channelize flow through fan area. Construct barrier on east side of Baker Way to create sedimentation basin and protect west and south side homes. 	<ul style="list-style-type: none"> ▪ Basin sized to capture debris from 1:500 year event (4000 m³). Maintenance required. ▪ Trash rack option not considered to be practical for potential debris flows of allocated magnitudes. ▪ Stabilization of creek channel by means of drop structures not practical. 	115,000
4.0 Tank Creek	<ul style="list-style-type: none"> ▪ Construct dykes on fan of Tank Creek to prevent a jump to old channel. Construct sediment basin north of lots 7 to 12. May require some importing of soil and riprap materials. 	<ul style="list-style-type: none"> ▪ Same as Thurber's 	<ul style="list-style-type: none"> ▪ Basin sized to capture debris from 1:500 year event (5000 m³). Maintenance required. Would likely impact Indian Reserve. 	85,000

Table 26 - continued

	Thurber Recommendations (1988b)	Options Recommended by this Study	Additional Comments	Estimated Cost (\$)
B. Non-Channelized				
Toe Area at Base of Slope	<ul style="list-style-type: none"> Homes 19 through 22 to be raised on specially reinforced concrete foundations. 	<u>Option 1</u> <ul style="list-style-type: none"> Relocate homes 19 through 21 on existing lots so they are outside the minimum setback requirements. 	Bylaw regulations to be established	15,000
		<u>Option 2</u> <ul style="list-style-type: none"> Homes 19 through 21 to be raised on specially reinforced concrete foundations. 		75,000
Slopes		<ul style="list-style-type: none"> Control of drainage, dumping, excavation and vegetation removal. <p>Land use zoning after site specific surveys. Control of drainage, dumping, excavation and vegetation removal.</p>	Bylaw regulations to be established	N/A

- Notes:
1. With the implementation of the mitigative measures outlined above, partial protection from the hazards shown in Table 17 would result. Some residual risks from extreme hazard events would still remain however.
 2. Minimum setbacks of 10 m for slopes between 20° and 30°, and 15 m for slopes > 30° are recommended; however, actual setbacks should be determined on a site specific basis.
 3. Estimated costs do not include any costs associated with property acquisition.
 4. Costs include engineering fees and contingency of 20% of estimated construction costs.

TABLE 27
COMPARISON OF MITIGATIVE OPTIONS FOR FLOOD AND EROSION PROTECTION FOR DEVELOPED PROPERTIES

FACTORS	MITIGATIVE OPTIONS																		EVALUATION SCALE		
	NON-STRUCTURAL						STRUCTURAL														
	RELOCATION	ACQUISITION	DEVELOPMENT RESTRICTION	INDEMNIFI- CATIONS	COVENANTS	MONITORING	FLOW CONTROL		SEDIMENT CONTROL		DEBRIS CONTROL	PROTECTIVE WORKS									
							DETENTION	DIVERSION	GRAVEL REMOVAL	SOURCE CONTROL		IMPROVEMENT ELEVATION	IMPROVEMENT CLOSURE	SETBACK DYKES	RIVER BANK DYKES	STRUCTURAL BANK PROTECTION	NON-STRUCTURAL BANK PROTECTION	GROYNES			EMERGENCY RESPONSE
MANAGEMENT																					
Compatibility with existing government policies	1	4	1	5	4	1	2	2	1	4	1	1	2	1	3	1	3	2	1	1 - Compatible	5 - Incompatible
Compatibility with existing legislation	1	2	1	5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1 - Compatible	5 - Incompatible
Requirement for on-going management	1	2	3	4	2	4	2	4	5	4	4	1	3	2	3	3	4	3	5	1 - Minimum	5 - Significant
Implementation	4	4	3	4	4	2	2	2	2	3	2	3	3	2	3	3	2	2	2	1 - Easy	5 - Difficult
Ease of funding	4	4	1	1	1	1	3	3	3	3	3	4	4	3	3	3	3	3	2	1 - Existing programs	5 - New funding source required
ECONOMIC																					
Capital cost	3	4	1	1	1	1	3	4	4	3	2	5	5	2	3	3	2	3	3	1 - Low	5 - High
Maintenance cost	1	1	1	1	1	3	2	4	4	3	3	1	2	2	3	2	4	2	3	1 - Low	5 - High
Areal extent of benefits	4	4	1	1	1	1	2	3	2	1	2	5	5	2	2	2	2	3	2	1 - Large	5 - Small
Protection benefit for more than one hazard	2	2	1	1	1	2	3	3	3	3	3	3	3	5	2	5	5	5	2	1 - Multiple	5 - Singular
ENVIRONMENTAL																					
Compatibility with physical processes	1	1	1	1	1	1	4	4	3	3	3	1	1	1	3	3	2	3	4	1 - Compatible	5 - Incompatible
Impact on fish and wildlife resource	2	1	1	1	1	1	4	4	4	2	4	1	1	2	4	3	4	3	4	1 - None	5 - Significant
Impact on forestry resource	1	1	1	1	1	1	1	1	1	2	2	1	1	2	1	1	1	1	2	1 - None	5 - Significant
Impact on recreational resource	1	1	2	2	2	1	3	3	2	2	1	1	1	1	2	2	2	3	2	1 - None	5 - Significant
PUBLIC																					
Level of disruption	5	4	4	4	4	1	2	2	2	2	2	5	4	3	3	3	3	3	4	1 - Low	5 - High
Level of equity	4	4	1	4	4	1	1	2	2	1	2	3	3	4	2	2	2	2	3	1 - High	5 - Low
Level of security	2	1	3	5	5	4	3	3	4	3	3	1	3	2	3	2	4	3	4	1 - High	5 - Low
TECHNICAL																					
Proven technology/method	2	1	2	4	4	1	1	3	3	4	4	1	1	1	1	1	4	2	2	1 - Proven	5 - Unproven
Effectiveness	2	1	3	4	4	5	4	3	4	4	4	1	2	2	2	2	4	3	2	1 - Effective	5 - Ineffective
Reliability	3	1	3	4	4	4	2	3	4	4	4	1	1	2	3	2	5	3	4	1 - Reliable	5 - Unreliable
Durability	1	1	1	1	1	3	2	3	3	2	3	1	1	2	3	2	4	2	3	1 - Durable	5 - Not durable
NUMERICAL SCORE	45	44	35	54	47	39	47	57	57	54	53	41	47	42	50	46	61	52	55		
NUMBER OF FACTORS SCORING > 3	5	7	1	10	8	4	3	5	7	5	5	4	4	2	1	1	9	1	6		

TABLE 28
COMPARISON OF STRUCTURAL MITIGATIVE OPTIONS
FOR FLOOD AND EROSION CONTROL
SLESSE PARK

FACTOR	OPTION		
	1	2	3
MANAGEMENT	<ul style="list-style-type: none"> ▪ Bank protection afforded to property improvements on left bank outside of 100 year erosion limit ▪ Upstream right bank protection affords protection for a single property owner 	<ul style="list-style-type: none"> ▪ Protection proposed is minimum considered necessary to afford reliable protection to the hamlet area 	<ul style="list-style-type: none"> ▪ Implementation more cumbersome than providing flood protection by dyking ▪ Trailer park (commercial) area designated differently than other dwellings since funding structural elevations for this type of dwelling would generally be outside of present government policy
ECONOMIC Initial Capital Cost Capitalized Maintenance Cost Total Present Value Cost	\$2,988,000 1,108,000 4,096,000 <ul style="list-style-type: none"> ▪ Bank and flood protection combined ▪ Cost of left bank and upstream right bank protection is high for property and improvements protected 	\$1,102,000 391,000 1,493,000 <ul style="list-style-type: none"> ▪ Bank and flood protection combined ▪ Increase in elevation of existing bank protection, or dyking, is small, giving a lower cost than Option 3 	\$1,554,000 348,000 1,902,000
ENVIRONMENTAL	<ul style="list-style-type: none"> ▪ Considerable instream bank protection work, particularly on left bank ▪ Left bank protection reduces amount of silt contributed to the river 	<ul style="list-style-type: none"> ▪ Very limited instream work required 	<ul style="list-style-type: none"> ▪ As per Option 2

TABLE 28 - CONTINUED

FACTOR	OPTION		
	1	2	3
PUBLIC	<ul style="list-style-type: none"> ▪ For perception of security the log jam in the side channel downstream of O'Byrne Road should be left in place until bank protection installed ▪ Providing outflanking protection for upstream properties (7) on O'Byrne Road and flood protection for the hamlet considered to be a high priority 	<ul style="list-style-type: none"> ▪ As per Option 1 ▪ As per Option 1 	<ul style="list-style-type: none"> ▪ As per Option 1 ▪ Level of disruption to individual home owners is high ▪ As per Option 1
TECHNICAL	<ul style="list-style-type: none"> ▪ Uses proven technology ▪ Costs include reinforcement of existing bank protection 	<ul style="list-style-type: none"> ▪ As per Option 1 ▪ As per Option 1 	<ul style="list-style-type: none"> ▪ As per Option 1 ▪ As per Option 1

TABLE 29
COMPARISON OF STRUCTURAL MITIGATIVE OPTIONS
FOR FLOOD AND EROSION CONTROL
BELL ACRES

FACTOR	OPTION				
	1	2	3	4	5
MANAGEMENT	<ul style="list-style-type: none"> Left bank protection affords protection to a single unimproved property Right bank protection upstream of Bourne Road not strictly required because of existing improvement setbacks. Protection reduces potential loss of land 	<ul style="list-style-type: none"> As per Option 1 As per Option 1 	<ul style="list-style-type: none"> Outright purchase of properties, or lease-back arrangements, less preferable than other options under present government policies 	<ul style="list-style-type: none"> As per Option 3 Unprotected setback dykes require monitoring during flood events in case of emergency response requirement 	<ul style="list-style-type: none"> Easiest option to implement under existing government policies
ECONOMIC Initial Capital Cost Capitalized Maintenance Cost Total Present Value Cost	\$3,761,000 1,379,000 5,140,000	\$3,679,000 1,379,000 5,140,000	\$4,156,000 176,000 4,332,000	\$2,371,000 500,000 2,871,000	\$2,168,000 592,000 2,760,000
	<ul style="list-style-type: none"> Cost of protecting single unimproved property on left bank is high in comparison to number of improved properties protected on right bank, as is relative cost/benefit for extending bank protection upstream of Bourne Road Cost of Ryder Creek flood protection not included 	<ul style="list-style-type: none"> As per Option 1 As per Option 1 	<ul style="list-style-type: none"> Purchase of 40 properties included in cost estimate As per Option 1 	<ul style="list-style-type: none"> Purchase of 3 properties and 4 dwellings included in cost estimate As per Option 1 	<ul style="list-style-type: none"> Initial capital cost would be reduced by \$565,000 if setback dyke through park and around 3 properties left without bank protection until under threat of erosion. Present day value of providing emergency response for bank protection is \$68,000 for a total present day value of \$2,263,000 for setback dyke without bank protection As per Option 1
ENVIRONMENTAL	<ul style="list-style-type: none"> Considerable instream bank protection work, most in deep water areas except through provincial park Dyking and/or bank protection on riverside edge of park impacts the natural appearance of the water edge and inhibits easy access to the water 	<ul style="list-style-type: none"> As per Option 1 As per Option 1 	<ul style="list-style-type: none"> Minimum amount of instream work of options considered Relocation of existing homes would open up the river edge for public recreational use 	<ul style="list-style-type: none"> Setback dykes minimize impacts of fish habitat and allow river scope for lateral migration Has minimal impact on recreational use of the park. Setback dyke could be developed as a pathway within the park 	<ul style="list-style-type: none"> As per Option 4

TABLE 29 - CONTINUED

FACTOR	OPTION				
	1	2	3	4	5
PUBLIC	<ul style="list-style-type: none"> ▪ Infilling or extension of existing riprap bank protection requires has been resisted by some property owners ▪ Providing flood protection by infilling gaps in the existing dyke and bank protection from Neville Road downstream, plus flood protection for 3 properties immediately west of the park is considered to be a high priority 	<ul style="list-style-type: none"> ▪ As per Option 1 ▪ As per Option 1 	<ul style="list-style-type: none"> ▪ Level of disruption to home owners is very high for this option ▪ Option not equitable to all since replacement of scenic setting for dislocated home owners not likely to be achievable for all ▪ As per Option 1 	<ul style="list-style-type: none"> ▪ As per Option 1 ▪ Disruption of home owners required to relocate ▪ As per Option 3 ▪ As per Option 1 	<ul style="list-style-type: none"> ▪ As per Option 1 ▪ As per Option 1
TECHNICAL	<ul style="list-style-type: none"> ▪ Uses proven and reliable technology ▪ Flood protection for Ryder/Wingfield Creek required as part of flood hazard management ▪ Costs include reinforcement of existing bank protection 	<ul style="list-style-type: none"> ▪ As per Option 1 ▪ As per Option 1 ▪ As per Option 1 	<ul style="list-style-type: none"> ▪ Relies heavily on bank protection for road on an emergency response basis over an extended length of the hamlet bankline ▪ As per Option 1 ▪ As per Option 1 	<ul style="list-style-type: none"> ▪ Minimizes length of dyke without bank protection to an area presently well set back from the river ▪ As per Option 1 ▪ As per Option 1 	<ul style="list-style-type: none"> ▪ As per Option 1, although rock spurs not as reliable as continuous riprap bank protection ▪ As per Option 1 ▪ As per Option 1

Note: Cost estimates included in the table do not include costs associated with mitigative works on Ryder Creek, Section 6.5.2

TABLE 30
COMPARISON OF STRUCTURAL MITIGATIVE OPTIONS
FOR FLOOD AND EROSION CONTROL
BAKER TRAILS

FACTOR	OPTION					
	1	2	3	4	5	6
MANAGEMENT	<ul style="list-style-type: none"> ▪ Providing federal or provincial funds for bank protection of agricultural land, as included in this option for land in the Edward Road area, generally more difficult to obtain than funds for residential/commercial properties 	<ul style="list-style-type: none"> ▪ As per Option 1 and Option 4 ▪ Soft berm protection of agricultural lands requires more on-going management than Option 1 	<ul style="list-style-type: none"> ▪ Unprotected setback dykes require monitoring in case of emergency response requirement 	<ul style="list-style-type: none"> ▪ Capital funds from the federal or provincial governments for works requiring substantial subsequent maintenance are more difficult to obtain than funds for permanent works ▪ Relocation of existing dwellings on existing properties more consistent with existing government policies than purchase or lease-back ▪ Relocation of outlet channel for Liumchen Creek requires additional management due to on-going maintenance ▪ As per Option 3 	<ul style="list-style-type: none"> ▪ As per Option 3 	<ul style="list-style-type: none"> ▪ As per Option 4 ▪ Maintenance of diversion channel requires additional management due to on-going maintenance
ECONOMIC						
Initial Capital Cost	\$3,630,000	\$2,893,000	\$2,581,000	\$2,075,000	\$2,160,000	\$2,569,000
Capitalized Maintenance Cost	1,304,000	1,481,000	909,000	790,000	725,000	2,362,000
Total Present Value Cost	4,934,000	4,374,000	3,490,000	2,865,000	2,885,000	4,931,000
				<ul style="list-style-type: none"> ▪ Relocation of 2 dwellings included in estimate 	<ul style="list-style-type: none"> ▪ Reduction in cost compared to Option 3 is solely due to lower cost of using a setback dyke in Edwards Road area and relying on emergency response for bank protection 	<ul style="list-style-type: none"> ▪ Large increase in total present value cost over Options 3 and 5 to eliminate dyking in Edwards Road area

TABLE 30 - CONTINUED

FACTOR	OPTION					
	1	2	3	4	5	6
ENVIRONMENTAL	<ul style="list-style-type: none"> Substantial instream bank protection 	<ul style="list-style-type: none"> As per Option 1 	<ul style="list-style-type: none"> Considerable instream bank protection work 	<ul style="list-style-type: none"> As per Option 1 On-going instream maintenance work to maintain channel 	<ul style="list-style-type: none"> Minimum amount of combined initial and subsequent instream bank protection work 	<ul style="list-style-type: none"> Minimum amount of initial instream bank protection work As per Option 4
PUBLIC	<ul style="list-style-type: none"> Local interest in providing protection for agricultural land Protection of agricultural land raises issue of equity for other owners of unprotected property Providing flood protection and bank protection against washout of the Chilliwack Lake Road considered to be a high priority 	<ul style="list-style-type: none"> As per Option 1 As per Option 1 As per Option 1 	<ul style="list-style-type: none"> As per Option 1 	<ul style="list-style-type: none"> Some disruption of property owners to relocate existing seasonal dwellings. Potential relocation areas north of present locations less attractive to owners for recreational and/or permanent use As per Option 1 	<ul style="list-style-type: none"> Level of security against bank erosion in setback dyke area not as great as for protected bank, as in Option 3 As per Option 1 	<ul style="list-style-type: none"> As per Option 1
TECHNICAL	<ul style="list-style-type: none"> Uses proven technology Costs include reinforcement of existing bank protection 	<ul style="list-style-type: none"> Soft berm protection less reliable during major flows As per Option 1 	<ul style="list-style-type: none"> As per Option 1 As per Option 1 	<ul style="list-style-type: none"> Relocation of Liumchen Creek mouth is redundant protection if riprap bank protection extended and reinforced in Wilson Road area Dwellings likely difficult to relocate due to condition As per Option 1 	<ul style="list-style-type: none"> As per Option 1 As per Option 1 	<ul style="list-style-type: none"> Diversion channel less reliable than dyking as flood control method As per Option 1

Table 31: Activities of Government Agencies in the Chilliwack River Valley

AGENCY	LEGISLATION	OPERATIONS
Ministry of Forests	<ul style="list-style-type: none"> Forest Act 	Provides for land tenures and designations for harvesting, recreation, etc., on crown land
Ministry of Environment, Lands and Parks	<ul style="list-style-type: none"> Land Act Water Act (Water Management Division) Land Title Act Wildlife Act Park Act Ecological Reserves Act 	<p>Provides for land reservations for variety of uses, private and public</p> <p>Water allocation, flood control and bank protection works</p> <p>Regulates subdivisions in flood hazard areas</p> <p>Fishing and hunting</p> <p>Recreational and scenic features</p> <p>Natural features</p>
Ministry of Energy, Mines and Petroleum Resources	<ul style="list-style-type: none"> Mineral Act Placer Act 	Controls mining
Ministry of Attorney General (Corrections Branch)		Operates four facilities
Ministry of Transportation and Highways	<ul style="list-style-type: none"> Highways Act River Bank Protection Act 	<p>Road system and road drainage</p> <p>Provides for a report on bank protection requirements and allocation of costs of protection</p>
Department of Fisheries and Oceans	<ul style="list-style-type: none"> Fisheries Act 	<p>Operation of a fish hatchery</p> <p>Protection of fish habitat</p>
Department of National Defence		Operates on three areas within the valley
Department of Northern Affairs Canada		Works with the Soowahlie Indian Band
Fraser Cheam Regional District	<ul style="list-style-type: none"> Municipal Act 	<p>Plans and controls settlement activities</p> <p>Programs in preparation for emergency can regulate tree cutting on private land</p>

APPENDIX 4

STRUCTURAL MITIGATION COST ESTIMATES FOR FLOOD AND EROSION HAZARDS

APPENDIX 4

STRUCTURAL MITIGATION COST ESTIMATES FOR FLOOD AND EROSION HAZARDS

The breakdown of the estimated cost of various options to mitigate flood and erosion hazards associated with the Chilliwack River are given in the table below.

The basis for the cost estimates are outlined below.

1. Unit Rates

Unit rates given below embody the following assumptions:

- site preparation includes clearing and grubbing plus provision for accommodating some local drainage through the dykes, but not tributary channel control, such as Ryder Creek;
- rock riprap would be available from a local quarry;
- core material for dyking would be imported;
- riprap would be machine placed;
- channel excavation would be disposed of locally.

SITE PREPARATION	UNIT	RATE
Site preparation	ha	\$15,000.00
Supply and Placement of riprap and underlayer	m ³	\$35.00
Dyke core fill	m ³	\$12.00
Local fill by truck	m ³	\$8.00
Local fill pushed from river	m ³	\$4.00
Channel excavation	m ³	\$5.00

2. Home Relocations

The cost estimate attached to home relocations, property purchase, or lease-back arrangements were all established at 30 percent above the tax assessment value.

3. Home Evaluations

The cost of raising a house, will vary depending on the dwelling type, location, size and method of elevating.

For the purpose of cost estimating it was assumed houses would be elevated on fill or on raised foundations. Each house would take approximately three weeks to elevate at an average cost of \$25,000 per home.

4. Riprap Bank Protection

It was assumed the combined thickness of riprap and underlayer would be 1.5 m and a 1.5 m deep by 3 m wide toe apron would be constructed.

5. Existing Riprap Reinforcement

It was assumed that the riprap required for reinforcement of existing riprap slopes would be 8 m³/m, which is about 50% more than the volume of the toe protection trench incorporated in the cost estimate for new riprap bank protection.

6. Berm Bank Protection

It was assumed that 'soft' bank protection comprised of available gravels and wood debris would consist of a berm with slopes of 3 horizontal to 1 vertical and a 4 m wide crest.

7. Dykes

Dyke crests would be at the flood construction level (1 in 200 year flood level plus 600 mm). Dyke crests would be 4 m wide.

8. Emergency Response

Emergency response costs to give erosion protection for initially unprotected setback dykes and roads were estimated on the basis that bank protection would be required over the next 100 years in areas inside the 100 year erosion limit. It was assumed that 50 percent of the length would require protection 25 years after construction and the remaining 50 percent 75 years after construction. Costs were reduced to present day value using an interest rate of 10 percent and an inflation rate of 5 percent.

9. Permits, Engineering and Contingency

An allowance of 20 percent is included in the capital cost to cover the cost of permits, engineering and contingencies.

10. Land Purchase

No allowance was made for the purchase of properties for the construction of bank protection, dykes, or channels. It was assumed right-of-ways would be granted through private properties.

11. Maintenance

Maintenance costs were reduced to present day values for a 100 year period using an interest rate of 10 percent and an inflation rate of 5 percent. Annual maintenance costs were assumed as the following percent of initial capital cost:

Riprap bank protection	2%
Soft berm bank protection	10%
Setback dyking	1%

Annual maintenance costs associated with maintaining channels excavated for flood or bank erosion control were based on assuming that, on average, 10 percent of the initial excavation volume would require removal every year.

APPENDIX 1

TERMS OF REFERENCE

SCHEDULE A

Services

1.
 - a. Describe the history of the flooding/erosion hazard problems on the Chilliwack River and its tributaries. The description should include existing flood and erosion control works on the river, log debris and jams, debris flows and drainage from the escarpment tributaries. Describe current land use in the Valley and anticipated trends.
 - b. Carry out a hydrological investigation of the Chilliwack River. Describe the factors which influence major flooding events. Assess (give an opinion on) what influence, if any, forest management practices are having on the runoff and sediment regime.
 - c. Describe the morphology (bar migration and thalweg changes) of the Chilliwack River using air photos, river cross sections and any other sources of information.

Identify factors contributing to channel instability. Estimate the 1:100 year probable erosion limit (defined as the extend to which the active channel may progress to over a period of 100 years assuming no works were constructed).
 - d. Assess whether or not there is a significant risk of a damaging flood surge caused by a massive slope failure and temporary blockage of the Chilliwack River. The investigation should particularly review the slide at Slesse Park, but include examination of the entire reach from Tamihi Creek to Chipmunk Creek. Describe the significance of the "clay slides" in contributing to downstream bedload deposition and channel instability.
 - e. Describe the timber resource of the Chilliwack River watershed: area to timber lands, chronology of areas logged, rate of logging on a surface area per year basis and the estimated value of the resource.
 - f. Describe the fisheries resource of the Chilliwack River: species, number, rearing and spawning habitats, life cycles, period of year wetted perimeter of river would be off limits to various construction activities and estimated value of resource.
 - g. Describe the recreational resource of the Chilliwack River, in addition to sports fishing (white water rafting, etc.).
 - h. Develop/propose various means which may be available for implementing, financing and operating/maintaining any structural measures in the management plan including a possible inter-agency dispute resolution procedure.

SCHEDULE A

(continued)

Services

2. Prepare an interim report. This interim report would contain all the background information (e.g., hydrology, morphology, resources of the river, etc.). The report would contain conceptual alternative mitigation schemes and an assessment of what impact or enhancement opportunities each scheme would have on fisheries habitat, forest management practices and recreational users of the river. Each scheme should be evaluated in the context of Section 82 of the Land Title Act and Section 734 of the Municipal Act. The interim report would be considered a reference volume, to assist in evolving the management plan with the study participants.
3. Prepare a final report. This report would contain the valley hazard management outline plan. It would describe whatever means and measures appear appropriate to minimize future property damage and hardship in the study area. Order of magnitude costs would be attached to all recommended engineering works, property purchases and maintenance obligations. Engineering works could include, but not be restricted to: river training works, dredging, discharge containment structures, setback dyking, debris control devices, upgrading primary and secondary road accesses, drainage, etc. The final report would describe possible enhancement opportunities and measures available to mitigate any impact of the outline plan on fisheries habitat and recreational users of the river. In short, the final report would outline what needs to be done.
4. Liaise with the Ministry of Environment on the emergency remedial measures being carried out, as a consequence of last year's flooding, to mitigate the river hazard at specific areas of concern. This would include clay bank control measures/works.
5. Recommend an appropriate data collection monitoring system for the Chilliwack River Valley that would provide a warning of a potential flooding situation (such a data collection system was installed recently for the Squamish River Valley. In that installation "real-time" information is generated every three hours from strategic locations in the watershed. This information is on temperature, precipitation, snow depth, snow water equivalent and stream flow.)
6. Make interim progress reports and submit claims for services rendered to the Regional District on a monthly basis.

The progress reports would be in the form of a meeting with staff of the Regional District and Ministry of Environment and whomever else they believe appropriate to attend.
7. For budgeting purposes, the consultant shall assume that 30 copies of each report will be required.

APPENDIX 2

DERIVATION OF CHILLIWACK-VEDDER RIVER SALMON AND STEELHEAD TROUT STATISTICS

APPENDIX 2

DERIVATION OF CHILLIWACK-VEDDER RIVER SALMON AND TROUT STATISTICS

Data sources and methods used to produce estimates of Chilliwack-Vedder River salmon and steelhead populations and fishery contributions (Table 2) are briefly described in this appendix. Natural production and hatchery production are treated separately.

Natural Production

Pink Salmon

pink salmon escapement information for the 5 cycles between 1981 and 1989 was obtained from recent annual reports of the Pacific Salmon Commission (PSC, 1988 and 1990). The average catch of Chilliwack-Vedder pinks in the commercial fishery during that period was estimated from a mean catch:escapement ratio (1.91:1) derived from catch and escapement data for the total Fraser River pink stock (Appendix Table 7 of PSC, 1990). As information on exploitation rates for the Chilliwack-Vedder stock was not available, it was assumed that the mean overall exploitation rate for Fraser River pinks during 1981-1989 could be applied to the Chilliwack-Vedder population.

Chum Salmon

Escapement estimates for wild chum salmon were obtained from 2 sources:

- Department of Fisheries and Oceans stream catalogue (DFO, 1990) for 1981-1984;
- Chilliwack Hatchery data for 1985-1990 (D. Buxton, pers. comm.).

The latter source was considered to provide the most reliable estimates after 1984, as the estimates are based on a systematic carcass enumeration program. Catches of Chilliwack-Vedder chums in the commercial fishery were estimated from the average escapement and an average catch:escapement ratio (0.87:1) for tagged 1981-1985 brood chum production from Chilliwack Hatchery. These unpublished catch and escapement data were from the Salmonid Enhancement Program (SEP) office in Vancouver.

Chinook Salmon

Chinook salmon escapements to the Chilliwack River are presently comprised of 2 stocks:

- a small, native summer run;
- an imported (Harrison River) hatchery stock of fall run fish.

The imported hatchery stock dominates the present escapements. As there is no information on reproductive success of the imported stock in the Chilliwack River, it was assumed for this analysis that natural production of chinook is confined to the native summer run. Since significant returns of hatchery-produced chinook started in 1985, escapement records (DFO, 1990) have include an estimate for the 2 stocks combined. Escapements for the 10 year period immediately preceding hatchery production of fall chinook (1975-1984) were therefore used to indicate the probable magnitude of the naturally-producing native chinook stock. Catch of native chinook in ocean sport and commercial fisheries was estimated from an assumed catch:escapement ratio of 3:1.

Coho Salmon

Estimates of wild coho escapement to the Chilliwack-Vedder system were from published records (DFO, 1990) for the 1981-1987 period, and unpublished data for 1988 and 1989 (G. Serbik, pers. comm.). Extreme high flows in the fall of 1990 precluded coho escapement estimation in that year. The estimated contribution of wild coho to ocean commercial fisheries and ocean and river sport fisheries was derived from a catch:escapement ratio (2.71:1) measured for Chilliwack Hatchery coho production in the 1983-1990 catch years (unpublished SEP data).

Steelhead Trout

Spawning escapements of steelhead have not been enumerated. Natural production of Chilliwack-Vedder steelhead has been estimated at 3,000 to 11,000 adults, depending on the methodology employed (Caverhill, 1989). A conservative estimate of the average urn in recent years is 4-5,000 fish (Caverhill, pers. comm.). Steelhead Harvest Analysis data, based on angler questionnaire returns, indicates an average wild steelhead catch of 13,000 fish in the 1981-82 to 1989-90 harvest years. When the large positive bias in that catch estimate is removed, using an average correction factor (0.445) from creel surveys (Clark and Facchin, 1986; Scott and Lewynsky, 1985) the estimated average catch for that period is reduced by 55.5% to 7,600 fish. As a "wild steelhead release" regulation is in force, the spawning escapement of wild steelhead was assumed to equal total stock size. In reality, an unknown amount of adult steelhead mortality results from the catch-and-release sport fishery.

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APPENDIX 3

SUMMARY OF 'CLAY SLIDE' STUDY

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SUMMARY OF GEOTECHNICAL INVESTIGATION OF 'CLAY SLIDES'

Golder Associates undertook a detailed investigation of eight active slide areas to assess whether slides in these areas could be of sufficient size to temporarily block the Chilliwack River creating a hazard associated with the release of impounded water. The slide locations are shown on Figure 2.

Conclusions from the Golder Associates investigation for each of the eight slides are as follows:

Slesse Creek Landslide

- The instability of the Slesse Creek Slide is the result of undercutting and oversteepening of the slope and is related to the presence of glaciolacustrine materials within the lower portion of the slope.
- At present, the landslide is mainly dormant due to re-alignment of the river away from the toe of the slope. Some ravelling and sloughing of materials from the slope will continue, mainly due to runoff and groundwater seepage but these are not expected to be large scale. There appears to be no apparent danger of a major slide from this area which could block the river.

Ranger Creek Landslide

- Recent slope instability has been the result of undercutting of the weak glaciolacustrine deposits by the Chilliwack River at the toe of pre-existing slide.
- Further erosion of the toe of the slope should be prevented due to recent construction of a berm.
- Heavier riprap should be placed on the front of the berm prior to the next wet season.
- There is little apparent danger of a major deep-seated slide which could block the river.
- Small scale, localized sloughing and erosion of the glaciolacustrine deposits will continue due to seepage from within the slope and from surface runoff. This will be a slow process and should not contribute significant quantities of fines into the river.
- Construction of the diversion ditch to control surface runoff should assist in reducing gullyng and erosion of the terrace upstream of the slide.

Correction Camp Landslide

- Instability of the slope is primarily the result of undercutting and oversteepening of the slope by the Chilliwack River and the presence of weak glaciolacustrine sediments in the lower portion of the slope. These instabilities are generally shallow.
- A spur or berm could be constructed to divert river flow away from the toe of the slide. Bedrock in the lower part of the slope provides some protection for the downstream end of the slide.
- No tension cracks were observed behind the crest of the slide. There is little apparent danger of a major deep-seated slide which could block the river.

Anderson Run Landslide

- The instability has resulted from the oversteepening of slopes cut in disturbed glaciolacustrine silts/clays under saturated conditions.
- The slope will continue to retrogress into the terrace and the extent of the slide is likely to increase, particularly during the wet season, if no mitigative measures are taken.
- If the Chilliwack River is not diverted away from toe of the slope further undercutting of the bank will occur. Even if the river is re-aligned, the slope will continue to experience shallow slumping together with surface (runoff) erosion during periods of heavy rain. It is likely that some silt would still enter the river during these times but at a significantly slower rate than at present.
- The role which the beaver ponds play in the overall stability of the slope requires further review. Plans for draining the ponds should be considered.
- The present instability involves shallow slumps and mudslides in the fine grained materials but there are no signs of potential deep seated failures which would block the river.

Slesse Park Slide

- Slope instability is on-going but generally shallow and is related to the presence of weak glaciolacustrine deposits. There appears to be some reactivation of pre-existing slides. However, movement of individual blocks within the lower portion of the slope of loss of support through downcutting and erosion by either the river channel or tributary streams can be expected to induce retrogressive movements upslope and possible expansion of slide activity.

APPENDIX 1

TERMS OF REFERENCE

SCHEDULE A

Services

1.
 - a. Describe the history of the flooding/erosion hazard problems on the Chilliwack River and its tributaries. The description should include existing flood and erosion control works on the river, log debris and jams, debris flows and drainage from the escarpment tributaries. Describe current land use in the Valley and anticipated trends.
 - b. Carry out a hydrological investigation of the Chilliwack River. Describe the factors which influence major flooding events. Assess (give an opinion on) what influence, if any, forest management practices are having on the runoff and sediment regime.
 - c. Describe the morphology (bar migration and thalweg changes) of the Chilliwack River using air photos, river cross sections and any other sources of information.

Identify factors contributing to channel instability. Estimate the 1:100 year probable erosion limit (defined as the extend to which the active channel may progress to over a period of 100 years assuming no works were constructed).
 - d. Assess whether or not there is a significant risk of a damaging flood surge caused by a massive slope failure and temporary blockage of the Chilliwack River. The investigation should particularly review the slide at Slesse Park, but include examination of the entire reach from Tamihi Creek to Chipmunk Creek. Describe the significance of the "clay slides" in contributing to downstream bedload deposition and channel instability.
 - e. Describe the timber resource of the Chilliwack River watershed: area to timber lands, chronology of areas logged, rate of logging on a surface area per year basis and the estimated value of the resource.
 - f. Describe the fisheries resource of the Chilliwack River: species, number, rearing and spawning habitats, life cycles, period of year wetted perimeter of river would be off limits to various construction activities and estimated value of resource.
 - g. Describe the recreational resource of the Chilliwack River, in addition to sports fishing (white water rafting, etc.).
 - h. Develop/propose various means which may be available for implementing, financing and operating/maintaining any structural measures in the management plan including a possible inter-agency dispute resolution procedure.

SCHEDULE A

(continued)

Services

2. Prepare an interim report. This interim report would contain all the background information (e.g., hydrology, morphology, resources of the river, etc.). The report would contain conceptual alternative mitigation schemes and an assessment of what impact or enhancement opportunities each scheme would have on fisheries habitat, forest management practices and recreational users of the river. Each scheme should be evaluated in the context of Section 82 of the Land Title Act and Section 734 of the Municipal Act. The interim report would be considered a reference volume, to assist in evolving the management plan with the study participants.
3. Prepare a final report. This report would contain the valley hazard management outline plan. It would describe whatever means and measures appear appropriate to minimize future property damage and hardship in the study area. Order of magnitude costs would be attached to all recommended engineering works, property purchases and maintenance obligations. Engineering works could include, but not be restricted to: river training works, dredging, discharge containment structures, setback dyking, debris control devices, upgrading primary and secondary road accesses, drainage, etc. The final report would describe possible enhancement opportunities and measures available to mitigate any impact of the outline plan on fisheries habitat and recreational users of the river. In short, the final report would outline what needs to be done.
4. Liaise with the Ministry of Environment on the emergency remedial measures being carried out, as a consequence of last year's flooding, to mitigate the river hazard at specific areas of concern. This would include clay bank control measures/works.
5. Recommend an appropriate data collection monitoring system for the Chilliwack River Valley that would provide a warning of a potential flooding situation (such a data collection system was installed recently for the Squamish River Valley. In that installation "real-time" information is generated every three hours from strategic locations in the watershed. This information is on temperature, precipitation, snow depth, snow water equivalent and stream flow.)
6. Make interim progress reports and submit claims for services rendered to the Regional District on a monthly basis.

The progress reports would be in the form of a meeting with staff of the Regional District and Ministry of Environment and whomever else they believe appropriate to attend.
7. For budgeting purposes, the consultant shall assume that 30 copies of each report will be required.

APPENDIX 2

DERIVATION OF CHILLIWACK-VEDDER RIVER SALMON AND STEELHEAD TROUT STATISTICS

APPENDIX 2

DERIVATION OF CHILLIWACK-VEDDER RIVER SALMON AND TROUT STATISTICS

Data sources and methods used to produce estimates of Chilliwack-Vedder River salmon and steelhead populations and fishery contributions (Table 2) are briefly described in this appendix. Natural production and hatchery production are treated separately.

Natural Production

Pink Salmon

pink salmon escapement information for the 5 cycles between 1981 and 1989 was obtained from recent annual reports of the Pacific Salmon Commission (PSC, 1988 and 1990). The average catch of Chilliwack-Vedder pinks in the commercial fishery during that period was estimated from a mean catch:escapement ratio (1.91:1) derived from catch and escapement data for the total Fraser River pink stock (Appendix Table 7 of PSC, 1990). As information on exploitation rates for the Chilliwack-Vedder stock was not available, it was assumed that the mean overall exploitation rate for Fraser River pinks during 1981-1989 could be applied to the Chilliwack-Vedder population.

Chum Salmon

Escapement estimates for wild chum salmon were obtained from 2 sources:

- Department of Fisheries and Oceans stream catalogue (DFO, 1990) for 1981-1984;
- Chilliwack Hatchery data for 1985-1990 (D. Buxton, pers. comm.).

The latter source was considered to provide the most reliable estimates after 1984, as the estimates are based on a systematic carcass enumeration program. Catches of Chilliwack-Vedder chums in the commercial fishery were estimated from the average escapement and an average catch:escapement ratio (0.87:1) for tagged 1981-1985 brood chum production from Chilliwack Hatchery. These unpublished catch and escapement data were from the Salmonid Enhancement Program (SEP) office in Vancouver.

Chinook Salmon

Chinook salmon escapements to the Chilliwack River are presently comprised of 2 stocks:

- a small, native summer run;
- an imported (Harrison River) hatchery stock of fall run fish.

The imported hatchery stock dominates the present escapements. As there is no information on reproductive success of the imported stock in the Chilliwack River, it was assumed for this analysis that natural production of chinook is confined to the native summer run. Since significant returns of hatchery-produced chinook started in 1985, escapement records (DFO, 1990) have include an estimate for the 2 stocks combined. Escapements for the 10 year period immediately preceding hatchery production of fall chinook (1975-1984) were therefore used to indicate the probable magnitude of the naturally-producing native chinook stock. Catch of native chinook in ocean sport and commercial fisheries was estimated from an assumed catch:escapement ratio of 3:1.

Coho Salmon

Estimates of wild coho escapement to the Chilliwack-Vedder system were from published records (DFO, 1990) for the 1981-1987 period, and unpublished data for 1988 and 1989 (G. Serbik, pers. comm.). Extreme high flows in the fall of 1990 precluded coho escapement estimation in that year. The estimated contribution of wild coho to ocean commercial fisheries and ocean and river sport fisheries was derived from a catch:escapement ratio (2.71:1) measured for Chilliwack Hatchery coho production in the 1983-1990 catch years (unpublished SEP data).

Steelhead Trout

Spawning escapements of steelhead have not been enumerated. Natural production of Chilliwack-Vedder steelhead has been estimated at 3,000 to 11,000 adults, depending on the methodology employed (Caverhill, 1989). A conservative estimate of the average urn in recent years is 4-5,000 fish (Caverhill, pers. comm.). Steelhead Harvest Analysis data, based on angler questionnaire returns, indicates an average wild steelhead catch of 13,000 fish in the 1981-82 to 1989-90 harvest years. When the large positive bias in that catch estimate is removed, using an average correction factor (0.445) from creel surveys (Clark and Facchin, 1986; Scott and Lewynsky, 1985) the estimated average catch for that period is reduced by 55.5% to 7,600 fish. As a "wild steelhead release" regulation is in force, the spawning escapement of wild steelhead was assumed to equal total stock size. In reality, an unknown amount of adult steelhead mortality results from the catch-and-release sport fishery.

References

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Conclusions from the Golder Associates investigation for each of the eight slides are as follows:

Slesse Creek Landslide

- The instability of the Slesse Creek Slide is the result of undercutting and oversteepening of the slope and is related to the presence of glaciolacustrine materials within the lower portion of the slope.
- At present, the landslide is mainly dormant due to re-alignment of the river away from the toe of the slope. Some ravelling and sloughing of materials from the slope will continue, mainly due to runoff and groundwater seepage but these are not expected to be large scale. There appears to be no apparent danger of a major slide from this area which could block the river.

Ranger Creek Landslide

- Recent slope instability has been the result of undercutting of the weak glaciolacustrine deposits by the Chilliwack River at the toe of pre-existing slide.
- Further erosion of the toe of the slope should be prevented due to recent construction of a berm.
- Heavier riprap should be placed on the front of the berm prior to the next wet season.
- There is little apparent danger of a major deep-seated slide which could block the river.
- Small scale, localized sloughing and erosion of the glaciolacustrine deposits will continue due to seepage from within the slope and from surface runoff. This will be a slow process and should not contribute significant quantities of fines into the river.
- Construction of the diversion ditch to control surface runoff should assist in reducing gullying and erosion of the terrace upstream of the slide.

Correction Camp Landslide

- Instability of the slope is primarily the result of undercutting and oversteepening of the slope by the Chilliwack River and the presence of weak glaciolacustrine sediments in the lower portion of the slope. These instabilities are generally shallow.
- A spur or berm could be constructed to divert river flow away from the toe of the slide. Bedrock in the lower part of the slope provides some protection for the downstream end of the slide.
- No tension cracks were observed behind the crest of the slide. There is little apparent danger of a major deep-seated slide which could block the river.

Anderson Run Landslide

- The instability has resulted from the oversteepening of slopes cut in disturbed glaciolacustrine silts/clays under saturated conditions.
- The slope will continue to retrogress into the terrace and the extent of the slide is likely to increase, particularly during the wet season, if no mitigative measures are taken.
- If the Chilliwack River is not diverted away from toe of the slope further undercutting of the bank will occur. Even if the river is re-aligned, the slope will continue to experience shallow slumping together with surface (runoff) erosion during periods of heavy rain. It is likely that some silt would still enter the river during these times but at a significantly slower rate than at present.
- The role which the beaver ponds play in the overall stability of the slope requires further review. Plans for draining the ponds should be considered.
- The present instability involves shallow slumps and mudslides in the fine grained materials but there are no signs of potential deep seated failures which would block the river.

Slesse Park Slide

- Slope instability is on-going but generally shallow and is related to the presence of weak glaciolacustrine deposits. There appears to be some reactivation of pre-existing slides. However, movement of individual blocks within the lower portion of the slope of loss of support through downcutting and erosion by either the river channel or tributary streams can be expected to induce retrogressive movements upslope and possible expansion of slide activity.

- Further erosion of the toe of the cliff should be prevented by completion of the berm.
- Even with the berm in place the slope will continue to recede and mudslides will develop periodically.
- There is little apparent danger of a major deep-seated slide which could block the river.
- Mudslides have filled up the area behind the berm and overtopped the structure.
- Culverts will be poorly effective in draining the mudslide debris behind the berm.
- An "apron" of colluvial material will build up at the toe of the cliff and will in due course provide some support to the cliff. However, the prime cause of instability is higher in the face and thus will not be assisted.
- Re-routing of the drainage from above the cliff to further downstream might place other areas in jeopardy unless such drainage control can either be carried out effectively while remaining above the zone of instability or, alternatively, can be safely developed to accommodate possible slide or slump movements without adverse effects. The long term viability of any surface drainage structures on the unstable slopes should not be assumed.

Allison Run Landslide

- Instability of the slope is shallow and related to weak glaciolacustrine deposits, river erosion and groundwater seepage. Continued river erosion will likely cause retrogressive failures upslope and may increase the extent of the slide.
- The Chilliwack River should be diverted away from slope to prevent further undercutting of the banks. Protective measures such as those presented by Northwest Hydraulics in their March 1991 report should be undertaken.
- Even after the river is re-directed away from toe of slope, small sloughs due to seepage together with runoff erosion will continue until the slope has reached a stable angle and has been revegetated. Some silt may still be introduced into the river through these processes but at a significantly slower rate than at present.
- There is little apparent danger of a deep-seated failure which could block the river.
- Beaver ponds probably contribute to local groundwater recharge. The extent to which these ponds affect the overall stability of the slope requires further review. Plans for draining ponds should be considered.

Chilliwack Campground Landslide

- Instability of the slope is on-going but shallow and is primarily related to the presence of weak glaciolacustrine deposits and undercutting/oversteepening of the slope by the river.
- Until the river is diverted away from the toe of the slope, failures into the river will be on-going and the slope will continue to retrogress upslope and possibly expand slide activity. Even if the river is diverted, small scale failures and runoff erosion will continue to introduce silt into the river but at a significantly slower rate than at present. This process would continue until the slope has attained a stable angle and vegetation cover has taken hold.
- There is little apparent danger of a deep-seated failure which could block the river.

Willow Run Landslide

- Instability of the slope is primarily the result of undercutting by the Chilliwack River and related to the presence of weak disturbed glaciolacustrine deposits.
- These failures are generally shallow and there is little apparent danger of a major deep-seated slide which could block the river.
- Retrogressive movements into the bank and possible expansion of the slide activity can be expected if the river is allowed to continue undercutting the slope.
- Further erosion of the bank should be prevented through protective measures such as construction of a spur to deflect the river away from the toe of the slope as suggested in the Northwest Hydraulics Report (March, 1991).