District of North Vancouver

Summary Report on Debris Flow Studies

Final Report
December 2003

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CONSULTING ENGINEERS

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EXECUTIVE SUMMARY

This report summarizes the results of detailed debris flow studies on the highest risk creeks in the District. The full study results are outlined in ten separately bound reports.

A debris flow is a damaging form of channelized landslide that may occur on a steep mountain creek during a wet weather period. The potential for debris flow damage in the District was underscored by a November 1995 event on Upper Mackay Creek that caused considerable damage in the Ranger Avenue area. Debris flows are the prime focus of this study, although debris floods are also considered where they are the dominant process. A debris flood is a flood that has an unusually high amount of sediment or wood debris.

For each creek, the debris flow and/or debris flood hazard is assessed in terms of probability and magnitude. This assessment arrives at 'design event' magnitudes that represent a 500-year return period, although on most of the creeks it must be recognized that there is the potential for damaging events to occur at much lower return periods.

For each creek, the potential consequence of a debris flow and/or debris flood is also assessed. The level of risk is then rated as a combination of hazard and consequence, recognizing that both factors are necessary to give rise to a significant risk. In the absence of an established standard for risk acceptability in B.C., a medium low or lower level of risk has been adopted as the target level of residual risk following the implementation of mitigative measures.

Where a significant risk is identified, a wide range of alternative mitigative measures is considered. These include land use planning, warning systems, watershed management actions, mitigation structures and creek management measures. Feasible measures are identified for possible consideration by the District. In most cases, effective hazard mitigation would require some form of mitigation structure.

The attached summary table documents the results of the study for each creek. The most promising mitigative measure is identified and a preliminary construction cost estimate is provided. The total cost of mitigation structures is estimated at roughly $27 million.

This report includes an implementation plan with the following initial District actions:

1. disseminate the study results to relevant stakeholders;
2. proceed directly with identified short-term actions that represent relatively low cost measures that provide some beneficial degree of risk mitigation; and
3. refine District programs to ensure comprehensive treatment of natural hazards issues.

Since construction of mitigation structures would be costly and complex, it would best be considered a long-term initiative. Following dissemination of the study results, it is suggested that the District develop a program for debris flow mitigation structures for Council's consideration. This would include stakeholder consultation, identification of preferable alternatives, identification of possible local and outside funding sources, development of an appropriate funding mechanism, resolution of administrative issues, and development of a system for ranking project priorities. If appropriate, the District could approve the program, with establishment of an annual level of District funding.

Summary of Creek Reports

Zone	Creek Name	Watershed Area (km²)	Dominant Process	Hazard Magnitude: Q_{200} Flood (m^3/s)	Hazard Magnitude: 500-Year Return Period Debris Flow / Debris Flood: Volume (m^3)	Hazard Magnitude: 500-Year Return Period Debris Flow / Debris Flood: Discharge (m^3/s)	Potential Consequences: Houses / Buildings	Potential Consequences: Roads	Potential Consequences: Other Infrastructure	Existing Risk Level	Most Promising Mitigative Alternative: Description	Most Promising Mitigative Alternative: Preliminary Cost Estimate
Mount Fromme Zone	Grouse Creek	0.3	Debris Flow	2.5	9,000	180	x		x	Med. High	Deflection berm.	$570,000
	Mackay Creek	0.45	Debris Flow	4.0	27,000	170	x	x	x	Med. High	Debris barrier, deflection berm, check dams, upgrade preliminary debris basin, and channel works.	$2.4 million
	Mosquito Creek	4.3	Debris Flood	22	10,000	250	x	x	x	High	Two debris barriers, channel works, and culvert daylighting.	$6 million
Deep Cove Zone	Panorama Creek	0.49	Debris Flood	4.2	200	10	x	x	x	Med. High	Debris barrier, channel works and berm.	$500,000
	Matthews Creek	0.51	Debris Flood	4.5	150	9	x	x	x	Med. High	Debris barrier and channel works.	$300,000
	Gavles Creek	0.37	Debris Flood	2.4	250	8	x	x	x	Med. High	Debris barrier and channel works.	$300,000
	Cove Creek	0.36	Debris Flood	4.0	250	10	x	x	x	Med. High	Debris barrier and channel works.	$300,000
	Cleopatra Creek	0.19	Debris Flood	1.5	100	4	x	x	x	Med. High	Debris barrier and channel works.	$300,000
	Martin Creek	0.19	Debris Flow	3.1	1,000	25	x	x	x	Medium	No works required provided that Francis Creek deflection berm is constructed.	$0
	Francis Creek	1.35	Debris Flow	9.0	1,000	25	x	x	x	High	Deflection berms, debris basin, culvert replacement and channel works.	$1.4 million
Indian Arm Zone	Ostler Creek	1.2	Debris Flood	10	200	24	x	x		Medium	Debris barrier, culvert replacement, channel works.	$600,000
	Allan Creek	1.0	Debris Flood	8	200	24	x	x		Medium	Gully stabilization, three debris barriers, culvert replacement (7) and channel works.	$2.5 million
	Allan Creek Gullies	-	Debris Flow	-	1,000	25	x	x		Med. High		
	Sunshine Creek	1.2	Debris Flood	9	1,000	25		x		Medium	Two debris barriers and culvert replacement.	$1.2 million
	Scott-Goldie Creek	1.7	Debris Flow	13	22,000	400	x	x		High	Remove existing house or protect it with a concrete wall and channelization. Also bridge upgrading.	$850,000
	Percy Creek	2.0	Debris Flow	15	25,000	450	x	x		High	Debris barrier, debris basin and channel works.	$3.8 million
	Vapour Creek	0.5	Debris Flood	5	400	25	x			Medium	Deflection berm and channelization.	$630,000
	Shone Creek	2.9	Debris Flood	20	10,000	90	x			High	Training berms, debris basin and channelization.	$2.9 million
	Underhill Creek	0.4	Debris Flow	3	5,000	100	x			Medium		
	Holmden Creek	2.1	Debris Flow	15	40,000	700	x			High	Remove the existing house and docks.	$125,000
	Coldwell Creek	4.7	Debris Flood	33	8,000	150	x			Med. High	Debris barrier, training berms and channelization.	$1.9 million
	Friar Creek	0.3	Debris Flow	2	4,000	90	x			High	Remove the existing house.	$300,000
	Clegg Creek	1.2	Debris Flow	9	30,000	500	x			High	Remove the existing cabin.	$50,000
											Total Cost (rounded)	**$27 million**

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Section 1

Introduction

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1. INTRODUCTION

1.1 BACKGROUND

PURPOSE OF REPORT

This report summarizes the results of a comprehensive debris flow study that has been performed for the District of North Vancouver. The study details are included in ten separately bound reports. For reference purposes, Figure 1-1 shows the location of the various creek systems that have been studied.

For the purpose of this study, a **debris flow** is defined as a form of channelized landslide that may occur during unusually wet weather on a steep mountain creek with abundant debris sources. A debris flow can reach a speed of 40 km/h, carry car-sized boulders, and have a volume of many thousand cubic metres. A debris flow may also have a peak discharge that may be up to 50 times higher than a peak flood event. Debris flows pose a significant hazard to development located near a creek channel or on a creek fan.

While debris flows are the primary focus of the study, debris floods are also considered. A **debris flood** is a water flood with an unusually large amount of sediment and/or wood debris. A debris flood may have a peak discharge that may be 2 to 10 times higher than a peak flood event. In general, debris floods are considered less hazardous than debris flows, but more hazardous than water floods.

Appendix A provides additional technical background information on debris flows and debris floods.

Where appropriate, the study also gives some consideration to floods (water floods). Compared to debris flows and debris floods, which occur infrequently, water floods occur frequently in response to heavy rainfall events.

1995 UPPER MACKAY CREEK DEBRIS FLOW

The District's current focus on debris flow hazards was triggered by a significant debris flow at Upper Mackay Creek on November 23, 1995. This event involved a surge of about 7,000 m^3 of debris (rocks, soil and organic matter) into the residential area of Ranger Avenue during a heavy rainstorm, resulting in considerable damage to homes, property and District infrastructure. While debris flows had been identified as a hazard on steep creeks in southwest BC since the late 1970's, the 1995 Upper Mackay Creek event was the first recorded debris flow affecting a developed area of the District.

DISTRICT'S DEBRIS FLOW PROGRAM

On the basis of engineering and legal advice, Council initiated a comprehensive debris flow program following the 1995 Upper Mackay Creek debris flow. As a first step this involved damage restoration at Upper Mackay Creek, followed by a detailed study and construction of a major debris basin in 1996/97 at a cost of almost $2 million.

With the debris flow risk mitigated at Upper Mackay Creek, the next step involved completion of an overview study of debris flow hazards to identify debris flow and debris flood risks on other steep creeks in the District that flow through developed areas. This study culminated in a presentation to Council and publication of the Overview Report on Debris Flow Hazards (Kerr Wood Leidal Associates and EBA Engineering Consultants) in April 1999. The Overview Report identified eight creek locations in the District having a very high risk and five more having high risk.

On the basis of the Overview Report, the third step in the program has involved completion of this detailed study of the highest risk creeks.

DETAILED DEBRIS FLOW STUDIES

The detailed debris flow studies received funding from two fiscal years. Funding from the District's 2000 budget provided for the following five studies:

- Percy Creek/Vapour Creek;
- Shone Creek/Underhill Creek;
- Mackay Creek/Grouse Creek;
- Mosquito Creek; and
- Coldwell Creek.

Funding from the District's 2001 budget provided for the following additional studies:

- Clegg Creek;
- Holmden Creek;
- Scott-Goldie Creek and Sunshine Creek;
- Deep Cove Area Creeks (Panorama Creek, Matthews Creek, Gavles Creek, Cove Creek, Cleopatra Creek, Frances Creek); and
- Ostler Creek and Allen Creek.

The detailed studies provide a comprehensive assessment of the hazards and potential consequences from debris flows and debris floods. This includes quantification of debris flow probability and magnitude (volume and peak discharge). Effective mitigative options are also identified, along with conceptual designs and preliminary construction cost estimates. Where appropriate, a preferred mitigative option is suggested for initial consideration. Recommendations for project implementation are also provided in the event that the District decides to proceed with a construction program.

Key excerpts from each of each of the reports are included in Appendices B to K. These excerpts include a copy of the hazard map and the summary and recommendations section of each report.

With the completion of the detailed studies, the District has sufficient information to understand the risks at each of the study locations and make informed decisions regarding implementation of mitigative measures.

The studies address debris flow and debris flood hazards on the major creek systems in the District that have physical characteristics indicative of such hazards. This does not imply that debris flow and/or debris flood hazards do not exist on other minor creeks that were not investigated. Flood and debris flood hazards associated with Seymour River and Lynn Creek are the subject of separate ongoing creek management studies.

While the identified mitigative measures for debris flows and debris floods would also reduce flood and erosion risks, it must be recognized that the studies are not comprehensive in their treatment of flood and erosion hazards.

1.2 ENGINEERING WORK PROGRAM

The typical work program for each of the detailed studies is summarized in Table 1-1.

Table 1-1: Typical Work Program for Detailed Debris Flow Studies

Major Activity		Work Tasks
1.	Air Photo Interpretation	▪ Obtain and review historical air photographs. ▪ Document changes over time. ▪ Identify unstable terrain.
2.	Watershed Mapping	▪ Create topographic maps of watershed and fan.
3.	Field Investigations	▪ Watershed overview by helicopter. ▪ Traverse accessible channel locations by foot. ▪ Assess sediment and debris supply sources. ▪ Identify watershed and creek management issues.
4.	Hazard Analysis	▪ Analyze field data. ▪ Assess debris flow probability and magnitude. ▪ Also consider debris floods.
5.	Hazard Mapping	▪ Complete topographic survey of fan area and run FLO-2D computer model (for selected creeks only). ▪ Prepare map to show hazard zones on fan.
6.	Risk Analysis	▪ Determine consequence on basis of elements at risk. ▪ Rate risk on basis of hazard and consequence.
7.	Mitigative Alternatives	▪ Consider and evaluate mitigative alternatives. ▪ Prepare conceptual drawings for selected alternatives. ▪ Prepare Class D construction cost estimates. ▪ Identify implementation issues.
8.	Draft Report	▪ Prepare draft report.
9.	Report Review	▪ Review by project team and District staff. ▪ Review by peer review consultant. ▪ Prepare final report, incorporating review of draft report.

The typical work program varied somewhat for each study in view of particular project issues.

1.3 PROJECT TEAM

This summary report was written by Mike V. Currie, M.Eng., P.Eng., and Matthias Jakob, Ph.D., P.Geo., of Kerr Wood Leidal Associates.

The KWL project team for the detailed debris flow studies is shown in Figure 1-2.

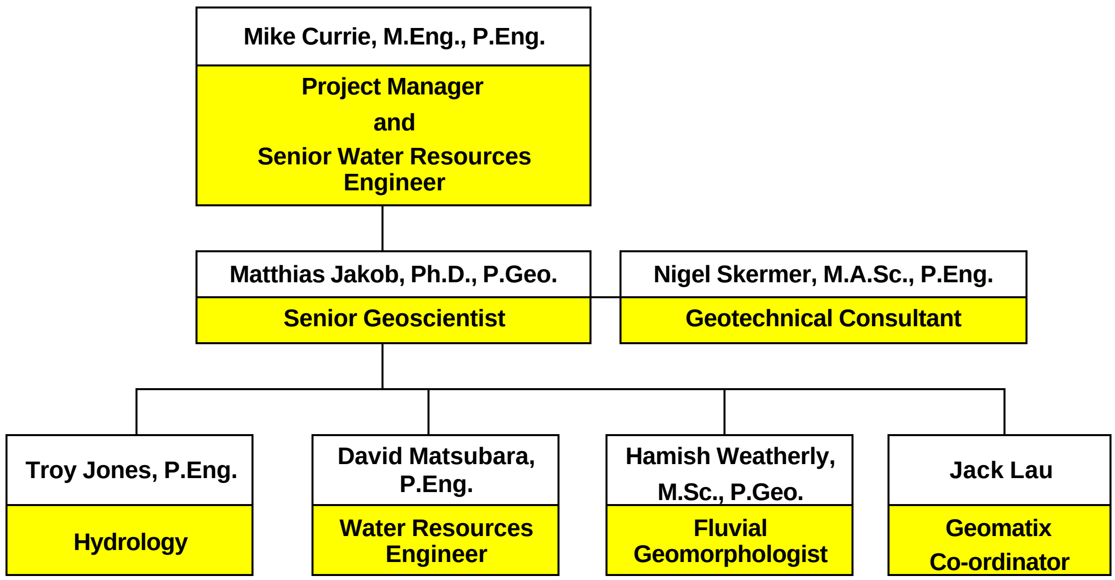
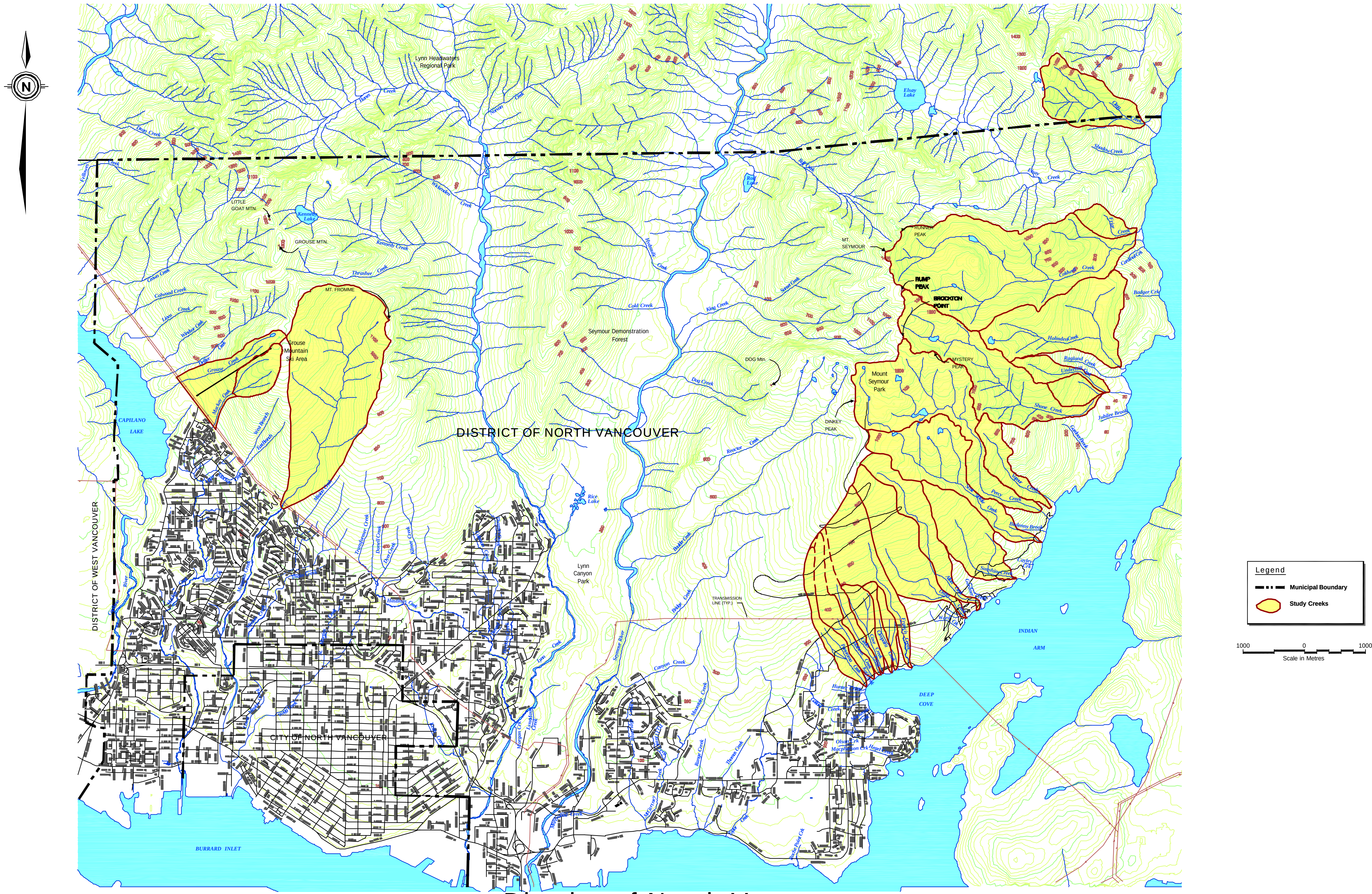


Figure 1-2: Project Team

Mr. Skermer was with EBA Engineering Consultants at the beginning of the study, but joined KWL near the end of the study.

Doug VanDine, P.Eng., P.Geo., of VanDine Geological Engineering assisted the project team in a peer review capacity for the studies on Percy Creek, Shone Creek, Mackay Creek, Mosquito Creek and Coldwell Creek.

Input to the study on behalf of the District of North Vancouver was coordinated by Len Jensen, A.Sc.T.



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Location of Study Creeks

Figure 1-1

Section 2

Risk Assessment Methodology

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2. RISK ASSESSMENT METHODOLOGY

This section provides a summary of the methodology used to assess the risk posed by debris flows and debris floods in the District. For the purpose of this study, **risk** is defined as the combination of hazard and consequence, where:

- **hazard** represents the occurrence of creek events, expressed in terms of probability and magnitude; and
- **consequence** represents the elements at risk and their vulnerability to damage during an event.

This definition reflects the fact that the generation of a risk of concern requires the presence of both a significant hazard and some degree of consequence (generally in the form of buildings or infrastructure). A severe hazard in an undeveloped area with minimal potential consequence will not give rise to a significant risk. Conversely, a less severe hazard occurring in a developed area will more likely result in a significant risk.

This section outlines the methodology used to assess hazard and consequence, and to combine these two components into a risk assessment. The acceptable level of risk is then defined and the general need for mitigative measures identified on this basis.

2.1 CREEK HAZARDS

Hazard assessment is based strictly on the capability of a particular creek to produce debris flow and debris flood events. This assessment does not consider whether the potential creek hazard will affect public safety, buildings or infrastructure. It is simply a reflection of how active the creek is.

Creek hazard is quantified in terms of probability and magnitude.

HAZARD PROBABILITY

The classification system for hazard probability used in this study is shown in Table 2-1. Hazard probability is most often expressed as a return period, which is the average number of years between event occurrences for an event of a particular magnitude. In other words, a 100-year return period event is an event so severe that it only occurs *on average* once every 100 years. Smaller events may occur more often, and larger events may occur less often. Hazard probability may be easier to visualize if expressed in terms of the percent chance of at least one event occurring in 50 years. Table 2-1 provides hazard classifications as both return periods and percent chance of occurrence in 50 years.

Table 2-1: Classification of Hazard Probability

Hazard Probability	Return Period	Percent Chance of at Least One Event in 50 Years
Very High	less than 20 years	more than 90%
High	20 to 100 years	40% to 90%
Medium	100 to 500 years	10% to 40%
Low	more than 500 years	less than 10%

In the absence of a risk analysis, mitigative works are sometimes designed for the upper range of the medium probability (i.e. 500-year return period). This is referred to as the 'design event' approach. The B.C. standard for flood hazard mitigation (200-year return period) also falls into the medium probability category. In practical terms, it is difficult to assess hazards at the low probability level, while the very low probability level is discounted for the purpose of this study.

HAZARD MAGNITUDE

Hazard magnitude reflects the size of the event in terms of volume and peak discharge. The event volume is the total quantity of sediment/debris material transported during the debris flow or debris flood, as measured in cubic metres. The peak discharge is the flow rate occurring at the peak of the event, as measured in cubic metres per second.

In southwest B.C., debris flow volume is highly variable, ranging roughly from about 1,000 m^3 to over 100,000 m^3. Debris flood volume is not as well documented, but may be in the range of hundreds to tens of thousands of cubic metres. For a particular creek, a different hazard magnitude may be assessed for each probability classification.

HAZARD ASSESSMENT

Debris flow and debris flood hazard assessment is not an exact science, relying as much on judgement and experience as on textbooks and guidelines. Nevertheless, the science is sufficiently well developed that reasonable hazard estimates can be made. Given the uncertainties in hazard assessment, it is prudent to be conservative in making estimates.

Assessing hazard magnitude involves field investigations to identify unstable terrain and determine the quantity of available material that may become mobilized during an event. The assessment can benefit greatly where there are previous documented events on the creek or on a similar creek nearby. However, documented events are rare because the period of observation in B.C. seldom extends more than a few decades into the past.

For a debris flow of a particular magnitude, it is possible to illustrate the varying degrees of hazard in map form with a **hazard map**. Hazard delineation is based on topography and channel geometry, as well as roads and buildings that can influence flow behaviour. Preparation of a hazard map can involve computer modelling of debris flow runout.

2.2 POTENTIAL CONSEQUENCE

The potential consequence from a debris flow or debris flood depends on the degree of development located along the lower reaches of the creek. An area that is typically the most vulnerable is the **creek fan**, which is the cone-shaped depositional landform that forms where a creek undergoes an abrupt decrease in gradient or becomes laterally unconfined. Most of the study creeks in the District have an identifiable creek fan.

The system used to classify consequence in this study is shown in Table 2-2.

Table 2-2: Classification of Consequence

Consequence	Description
Very High	Direct debris impact with extensive structural damage.
High	Direct or indirect debris impact. Some potential for structural damage along with significant sediment deposition and flooding.
Medium	Indirect debris impact. No structural damage, but damage to houses and property from sediment deposition and flooding.
Low	Sediment deposition and flooding with property damage only.
Very Low	Virtually no damage.

While these classifications are based explicitly on property damage, it must be noted that the potential for injury and loss of life is implicit, particularly in the very high and high categories. It is relevant to recall that a series of debris flows along the Squamish Highway between 1981 and 1983 resulted in 12 casualties.

Many elements other than property may also be vulnerable to damage and should be considered in identifying potential consequence. These may include infrastructure such as roads, bridges, telecommunications lines, hydroelectric lines, water supply conduits, storm sewers, and wastewater pipes. Creek hazards may also result in damage to fish and wildlife habitat, but these are not easily factored into the analysis.

2.3 RISK ASSESSMENT

Following the assessment of hazard and consequence for a particular creek, a risk assessment can be performed to rate the overall level of risk. One significant benefit of a risk analysis is that it facilitates comparison of risk levels at various locations in a jurisdiction, allowing management attention to focus on the highest risk areas. A second significant benefit is that it allows the risk at any particular location to be compared with what would be considered an acceptable risk, thereby providing a quantitative assessment of the relative degree of risk.

For the purpose of this study, hazard and consequence are combined to define risk in accordance with the risk matrix shown in Table 2-3.

Table 2-3: Risk Matrix

Hazard Probability	Consequence				
	Very High	**High**	**Medium**	**Low**	**Very Low**
Very High	Very High	Very High	High	Medium High	Medium Low
High	Very High	High	Medium High	Medium	Low
Medium	High	Medium High	Medium	Medium Low	Low
Low	Medium	Medium	Medium Low	Low	Very Low

Based on the risk matrix, the risk at any location can be rated from very low to very high.

2.4 ACCEPTABLE LEVEL OF RISK

As noted in Section 2.3, comparing an existing risk to an acceptable level of risk serves to quantify the relative degree of risk. It also helps to determine the scale of mitigative measures that are necessary to reduce the risk to an acceptable level.

Ultimately, the acceptable level of risk is decided by regulatory authorities in consideration of technical evaluations and public expectations. As of this time, there is no established acceptable level of risk for creek hazards in B.C. Therefore, there is some latitude for the District to make a policy choice in this respect. It is possible that definition of an acceptable level of risk may change over time as societal values change.

Following the November 1995 debris flow, the risk at Upper Mackay Creek was established as medium to medium high. In discussions with District staff and Council, it was clearly established that such a risk was not acceptable. It was therefore decided to build a debris basin on Upper Mackay Creek to reduce the residual risk to medium low.

For the purposes of this study, a medium low or lower level of risk is also adopted as the target level of residual risk following the implementation of mitigative measures. This is subject to review in the future if the District adopts a policy in this respect. Acceptable risks (medium low and lower) are shaded in the risk matrix (Table 2-3).

Following the risk analysis and definition of an acceptable level of risk, the need for mitigative works can be determined, and a mitigative strategy developed. Alternative mitigative measures are the subject of Section 3.

Section 3

Mitigative Measures

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3. MITIGATIVE MEASURES

There are two general strategies for mitigation of debris flow risks:

- passive measures to avoid or warn against the hazard; or
- active measures to protect against event occurrences.

Active measures are generally needed where a debris flow risk affects a developed area. Passive measures can complement active measures to maximize safety in high hazard areas.

This section provides a brief review of the alternative mitigative measures that may be applied to mitigate the risk arising from debris flows and debris floods. For presentation purposes, these are categorized as follows:

- land use planning;
- warning systems;
- watershed management actions;
- mitigation structures; and
- creek management measures.

The section closes with a discussion of issues associated with implementation of mitigative measures.

3.1 LAND USE PLANNING

Land use planning measures are the primary form of passive measure for natural hazard mitigation. These measures can involve hazard mapping, zoning, and regulation of development activities.

In cases where a fan is already developed, land use planning measures are generally limited in application, and are best considered for implementation in conjunction with active measures to minimize future risks.

HAZARD MAPPING

Hazard areas can be mapped at three levels:

- simple delineation of primary hazard areas, such as creek fans;
- hazard mapping to identify different degrees of hazard within a hazard area; and
- detailed hazard mapping involving topographic surveys and computer modelling.

On the basis of hazard mapping (beyond simple delineation), in some cases it is possible to delineate a fan into zones of varying hazard, either with or without mitigative measures. This may result in portions of a fan being designated as:

- suitable for land development;
- suitable for land development, subject to conditions; or
- unsuitable for land development.

In the District, the Overview Report delineates known creek hazard areas. In the detailed studies, this is supplemented by hazard mapping for most of the creeks. Detailed hazard mapping has been completed for Percy Creek and Mackay Creek.

ZONING

Mapping of hazard areas, such as creek fans, allows for the hazard areas to be referenced in planning documents such as official community plans and zoning bylaws. This serves to disseminate information on the presence of hazard areas, and may go as far as to define regulatory requirements for development in the hazard areas.

Where a significant hazard exists, new development is generally not appropriate in the absence of mitigative works and should be discouraged in planning documents.

INFILL DEVELOPMENT

Where existing lots are located in a hazard area, there are often building permit applications for construction of new buildings or renovations to existing buildings. In Section 699 of the Local Government Act, building inspectors have a tool available to require mitigation of the creek hazard during the application process. This involves preparation of a report by a qualified professional engineer to specify how the property may be safely used for the intended purpose. In some cases, this may be supplemented by bylaw provisions that provide a more streamlined process for minor renovations (the District does not have such a bylaw).

OTHER CONSIDERATIONS

Some other relevant considerations in land use planning are:

- maintaining adequate building setbacks from creeks (for both safety of buildings and protection of the creek);

- ensuring that lands that are likely required for future mitigative works remain available for this purpose;

- ensuring that the ownership of any constructed creek works is vested in an ongoing maintenance authority; and

- ensuring that rights-of-way are obtained for all creek works and creek channels.

Finally, it should be recognized that there are some situations where it is more cost-effective to relocate existing development away from hazard areas than to construct costly mitigative works.

3.2 WARNING SYSTEMS

ADVANCE, EVENT AND POST-EVENT WARNING SYSTEMS

Systems can be installed to provide warning of an impending debris flow (advance warning system), a debris flow in progress (event warning system), or after a debris flow has occurred (post-event warning system).

An advance warning system involves real-time monitoring of precipitation data and creek flow data to determine when hydrologic conditions approach a threshold for regional landslide occurrence and debris flow activity. Activities in high risk areas may then be restricted and public notification considered. The period of notice may range from a few hours to a day or two. Warnings will typically apply to the creeks in a regional area as opposed to any specific creek. False warnings will occur relatively often. An advance warning system in the form of hydroclimatic threshold for landslide initiation has recently been developed for use by the GVRD at Grouse Mountain.

An event warning system may provide warning of an event in progress. Such a system would typically involve cables (tripwires) or sensors (geophones, ultrasonic devices) in a creek channel that emit a signal when displaced by a debris flow or triggered by vibration during a debris flow. Depending on the distance between the sensor and the facilities at risk, the period of warning could range from mere seconds to several minutes at best. A positive signal would likely lead to immediate evacuation, which carries the secondary risk of putting people in danger from debris impact. False warnings would likely occur at least occasionally and may erode public confidence in the warning system.

A post-event warning system may warn of disruption to critical infrastructure, such as bridges and power transmission lines. In the former case for example, a bridge collapse could trigger a stop light to come on, or a gate to close. Such a system could have prevented multiple deaths in 1981 at M Creek on the Squamish Highway, resulting from several vehicles driving unknowingly into a gorge after a bridge washout (a similar situation occurred on Rutherford Creek near Pemberton in October 2003).

In general, warning systems may be more useful for debris flows than for debris floods and floods. In addition to probable false warnings, concerns with such systems include:

- finding a recognized authority to accept management responsibility;
- protecting the authority from excessive liability exposure; and
- ensuring uninterrupted system operation.

Nevertheless, warning systems may be appropriate in some situations.

WARNING SIGNS

Trails are located in many of the District watersheds. Trail crossings of creek systems may be hazardous during floods, debris floods or debris flows. It is important that trails are constructed in a stable manner, with sufficient channel cross-section to pass the expected creek events.

In some situations, warning signs may be appropriate to warn trail users about potential creek hazards during wet weather periods. Warning signs may also be appropriate on some District roads where creek hazards are present.

3.3 WATERSHED MANAGEMENT ACTIONS

Watershed management actions refer to measures that can be implemented in the watershed upstream of the hazard area. The primary objectives are to address existing watershed instabilities and prevent new instabilities from occurring. In this manner, it is sometimes possible to reduce hazard probability and/or magnitude.

It should be noted that it is seldom possible to fully mitigate a debris flow hazard through watershed management actions alone. In most cases, they need to be supplemented with other mitigative measures to provide effective hazard mitigation.

Disturbances caused by human activities are often a primary target of watershed management actions. In the context of the District lands, these may include roads, historic logging areas, park developments and ski areas (Grouse Mountain and Mount Seymour). Watershed management actions may include the following physical works:

- deactivation of abandoned logging roads;
- slope stabilization;
- bridge upgrading;
- channel stabilization; and
- drainage improvements.

In the case of ski areas, it may be appropriate to prepare water management plans (especially where snow making systems exist) to ensure that there are no adverse downstream impacts.

In forested watersheds, implementation of watershed measures involving physical works is often impractical due to the difficulty and disturbance that is typically encountered in accessing unstable areas.

In order to ensure that future development activities in watershed headwater areas are not problematic, it is important that these be subject to an appropriate level of advance review and that the development incorporate appropriate mitigative measures.

3.4 MITIGATION STRUCTURES

Mitigation structures can be constructed on or above the fan area to protect development and infrastructure against debris flow damage. In general, there are four concepts that can be implemented individually, or in combination, to provide structural protection against debris flows:

- a **debris basin** on the creek fan to impound debris flow material;
- a **debris barrier** near the fan apex to stop and store large boulders and large organic debris, while allowing smaller particles to pass through;
- a **deflection berm** to divert a debris flow away from a critical area; or
- **channelization works** to "funnel" debris flows through a critical area.

A debris basin is a large structure that is designed to withstand the debris flow impact and contain most of the debris flow material. A debris basin is typically located on an upper fan area, above development.

A debris barrier consists of an open steel grillage or concrete slot structure that is anchored to bedrock in a confined section of the creek. Its function is to “filter” large boulders and trees, while allowing smaller debris to pass. A debris barrier may or may not be designed to contain the full design debris flow volume.

A deflection berm (or training berm) can be used to divert a debris flow from a development area and allow it to run out in an area where it will cause minimal damage. Application of a deflection berm depends on availability of a suitable runout area on the fan. In designing deflection berms, care must be taken not to transfer the debris flow risk from one developed area to another.

Channelization works can funnel a debris flow through a critical reach to a downstream area where deposition will result in minimal damage. Implementation of channelization works depends on such a downstream area being present.

3.5 CREEK MANAGEMENT MEASURES

Creek management measures may reduce debris flow risk in development areas. These may include:

- upgrading or replacement of bridges and culverts;
- debris racks upstream of culverts;
- bank protection works;
- channel stabilization works;
- flood protection works;
- floodproofing of developments; and
- drainage improvements.

Such measures are generally most applicable in conjunction with a mitigation structure.

Section 4

Summary of Creek Reports

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4. SUMMARY OF CREEK REPORTS

The ten sub-sections of this section summarize the results of the ten separately-bound detailed studies. Key excerpts from each report are provided in Appendices B to K.

Table 4-1 provides a summary of the design event magnitudes. By definition these have a medium probability, reflecting a return period of 500 years, or a 10% chance of occurrence in 50 years. Table 4-1 also provides consequence and risk ratings associated with the design event on each creek.

Table 4-1: Debris Flow and Debris Flood Risk Ratings for Design Events

Creek Name	Dominant Geomorphic Process	Hazard Magnitude		Consequence	Risk
		Volume (m^3)	Discharge (m^3/s)		
Mackay Creek	Debris Flow	27,000	170	High	Medium High
Grouse Creek	Debris Flow	9,000	180	High	Medium High
Mosquito Creek	Debris Flood	10,000	250	Very High	High
Panorama Creek	Debris Flood	200	10	High	Medium High
Mathews Creek	Debris Flood	150	9	High	Medium High
Gavles Creek	Debris Flood	250	8	High	Medium High
Cove Creek	Debris Flood	250	10	High	Medium High
Cleopatra Creek	Debris Flood	100	4	High	Medium High
Martin Creek	Debris Flow	1,000	25	Medium	Medium
Francis Creek	Debris Flow	1,000	25	Very High	High
Ostler Creek	Debris Flood	200	24	Medium	Medium
Allan Creek	Debris Flood	200	24	Medium	Medium
Allan Creek Gullies	Debris Flow	1,000	25	High	Medium High
Sunshine Creek	Debris Flood	1,000	25	Medium	Medium
Scott-Goldie Creek	Debris Flow	22,000	400	Very High	High
Percy Creek	Debris Flow	25,000	450	Very High	High
Vapour Creek	Debris Flood	400	25	Medium	Medium
Shone Creek	Debris Flood	10,000	90	Very High	High
Underhill Creek	Debris Flow	5,000	100	Medium	Medium
Holmden Creek	Debris Flow	40,000	700	Very High	High
Coldwell Creek	Debris Flood	8,000	150	High	Medium High
Friar Creek	Debris Flow	4,000	90	Very High	High
Clegg Creek	Debris Flow	30,000	500	Very High	High

The risk ratings of Table 4-1 can not be directly compared with those from the Overview Report. Whereas the Overview Report risks were generalized for all hazard probabilities, the detailed studies consider different magnitudes for each hazard probability.

4.1 MACKAY CREEK

BACKGROUND

Mackay Creek is located on the southwest slope of Grouse Mountain. The Grousewoods subdivision and Grouse Mountain base area are on the creek fan. Upper Mackay Creek, on which a debris basin was built in 1996/97, is a separate branch of Mackay Creek.

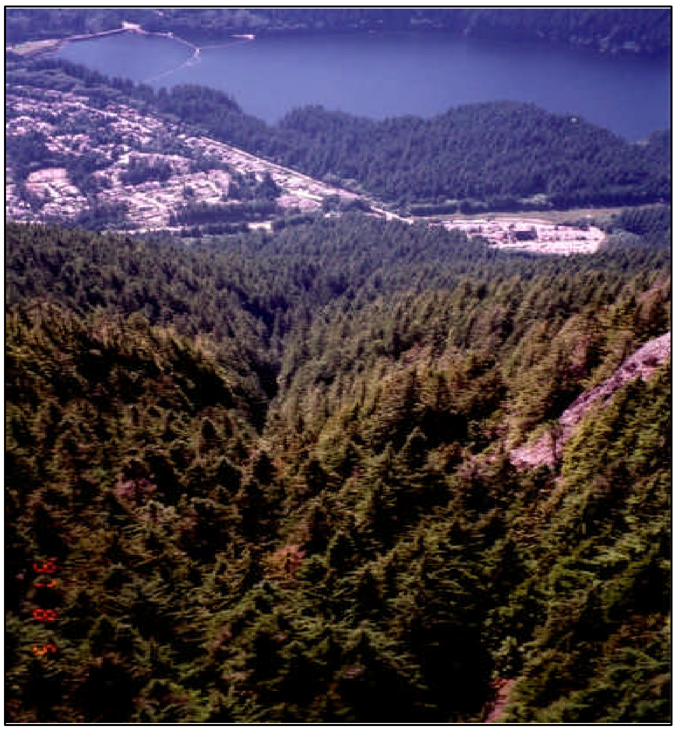

Photo 1
Aerial view of Mackay Creek looking downstream toward the developed area on the fan.

Grouse Creek is located immediately to the north of Mackay Creek and is within the Greater Vancouver water supply area, discharging into the Capilano reservoir. The two fans overlap in the Grouse Mountain base area parking lot, and accordingly the creeks have been investigated together.

RESULTS OF DETAILED STUDY

Excerpts from the detailed study for Mackay Creek are included in Appendix B.

There are two branches of Mackay Creek above the fan apex. The study concludes that both branches are subject to debris flows. The design debris flow volume at the fan apex is roughly 6,000 m^3 for each branch. There is also the potential for such debris flows to cause significant scour on the fan (due to a steep gradient and erodible fan materials). If deep scour occurs, it could increase the design debris flow volume to about 27,000 m^3 at the powerline. The associated peak discharge is estimated at 170 m^3/s.

Grouse Creek is also subject to debris flows, with a design volume of 9,000 m^3.

Without mitigative measures in place, a debris flow on Mackay Creek could cause considerable damage on the fan. Depending on whether a debris flow descends the east or west channel on the fan, either the Grousewoods subdivision (east channel) or the Grouse Mountain base area (west channel) could be damaged. The degree of damage would be dependant on how much deep scour occurs on the fan. The debris flow hazard on the fan has been delineated on the basis of a debris flow model.

On the basis of the detailed study, the existing level of risk is rated medium high at both Mackay Creek and Grouse Creek. The target level of risk is medium low. Significant mitigative measures would be required at Mackay Creek and Grouse Creek to achieve this level.

MITIGATIVE OPTIONS

While several mitigation structures are worthy of consideration at Mackay Creek, none are suitable on their own to fully mitigate the debris flow risk. The most promising option is a combination of:

- a combined debris barrier with a storage volume of 6,000 m^3 across both the east and west branch (immediately above the fan apex);
- check dams along the east and west channel on the fans;
- a large deflection berm spanning almost the entire width of the fan;
- upgrading of a preliminary debris basin to about 5,000 m^3 volume; and
- channel upgrading downstream of the debris basin.

The estimated cost of these measures is $2.4 million. There may be opportunities to phase the work over a number of years.

For Grouse Creek, a deflection berm at a cost of approximately $570,000 appears to be the most effective mitigation structure. The deflection berm would prevent debris flows on Grouse Creek from entering the Grouse Mountain base area.

4.2 MOSQUITO CREEK

BACKGROUND

The Mosquito Creek headwaters are between Grouse Mountain and Mount Fromme. Most of the watershed is located within the District, but the lower reaches pass through the City of North Vancouver and Mission I.R. 1.

The upper watershed is defined as the area upstream of the Baden-Powell footbridge. The watershed above the footbridge is forested, although there have been some disturbances from ski area development, roads and logging. Below the footbridge, the creek has been subject to extensive engineering works to stabilize the channel.

Mosquito Creek was culverted in the 1950's between Evergreen Basin and William Griffin Park. There is a blockage risk at Evergreen Basin, and this results in a flood overflow hazard downstream.

RESULTS OF DETAILED STUDY

Excerpts from the detailed study for Mosquito Creek are included in Appendix C.

Debris flows are not likely to occur on Mosquito Creek because the gradient is too low to allow mobilization of debris as a coherent mass. However, recorded events and dendrochronology suggest that there have been about 8 debris floods in the past century (1896, 1924, 1949, 1961, 1968, 1971, 1975 and 1981). These events were of sufficient magnitude to transport large boulders and/or large organic debris. These dates imply a recurrence interval of less than 20 years.

The estimated debris flood magnitude for design purposes (500-year return period) is a volume of 10,000 m^3 with a peak discharge of approximately 250 m^3/s (at the Baden-Powell footbridge). The debris flood magnitude would decrease downstream due to deposition and attenuation.

A large debris flood on Mosquito Creek would cause considerable damage. Property and infrastructure at risk includes the Baden-Powell footbridge, trails and park property, the Montroyal Boulevard Bridge, and residential buildings along the creek corridor. There is also a downstream risk in the event of Evergreen Basin overflowing.

On the basis of the detailed study, the existing level of risk is rated high at Mosquito Creek. The target level of risk is medium low. Significant mitigative measures would be required at Mosquito Creek to achieve this level.

MITIGATIVE OPTIONS

Based on a review of the identified alternatives, a multiple barrier approach (as commonly applied at many creeks in the European Alps) is favoured. This would include:

- a debris barrier in the canyon section above the Baden-Powell footbridge (with a storage volume of about 6,000 m^3);
- a second debris barrier above Montroyal Boulevard (also with a storage volume of about 5,000 m^3);
- some upgrading of channel works to Evergreen Basin; and
- daylighting of the 850 m long culvert below Evergreen Basin.

The cost of these works could exceed $6 million although there are good opportunities to partially mitigate the hazard by constructing one or both of the debris barriers as an initial phase of a long-term program. Daylighting of the culvert is the most expensive component ($3 to $4.6 million).

4.3 DEEP COVE CREEKS

BACKGROUND

The Deep Cove creeks include Panorama Creek, Mathews Creek, Gavles Creek, Cove Creek, Cleopatra Creek, Martin Creek and Francis Creek. Watershed areas range from 0.19 km^2 (Cleopatra and Martin Creek) to 1.35 km^2 (Francis Creek). The creeks flow across the south slope of Mount Seymour, and ultimately discharge to Indian Arm below Panorama Drive. The upper watersheds are within Mount Seymour Provincial Park. The watersheds are crossed by Mount Seymour Road and Indian River Drive.

The lower reaches and creek fan areas are extensively developed, with many creeks being channeled and culverted at Panorama Drive. The creek fans have been altered by construction and are difficult to delineate.

Photo 2
Overview of Panorama Drive at the lower reaches of the Deep Cove creeks.

RESULTS OF DETAILED STUDY

Excerpts from the detailed study for the Deep Cove creeks are included in Appendix D.

All creeks except Francis Creek are classified as debris flood creeks. Francis Creek is subject to debris flows, and there is a risk that a debris flow on Francis Creek could avulse into Martin Creek. In the vicinity of Panorama Drive, there are some existing engineering works to minimize flood damage.

The estimated debris flood and debris flow magnitudes for design purposes (500-year return period) range from a volume of 100 m^3 (Cleopatra Creek) to 1,000 m^3 (Francis Creek) with a corresponding peak discharge ranging between 4 m^3/s and 25 m^3/s.

Debris floods and debris flows on the Deep Cove creeks would cause considerable damage. Property and infrastructure at risk include numerous houses along the lower creek channels, culverts at Indian River Drive and Panorama Drive, trails, and park property.

On the basis of the detailed study, the existing level of risk is rated high for Francis Creek, medium high for Panorama Creek, Mathews Creek, Gavles Creek, Cove Creek and Cleopatra Creek, and medium for Martin Creek. The target level of risk is medium low. Significant mitigative measures would be required at most of the Deep Cove creeks to achieve this level.

Photo 3
Overview of Francis Creek and Deep Cove Marina.

MITIGATIVE OPTIONS

A wide range of alternative mitigative measures have been reviewed. For initial consideration, preferred alternatives have been identified for each of the creeks.

At Francis Creek risk mitigation could involve:

- construction of a deflection berm (to prevent an avulsion into Martin Creek);
- a smaller deflection berm to protect a house;
- a 2,000 m^3 debris basin above Indian River Drive;
- upgrading of the Indian River Drive crossing; and
- downstream channel works at the Deep Cove Marina.

The cost of these works at Francis Creek would be about $1.4 million.

With a deflection berm at Francis Creek, mitigative measures would not be required at Martin Creek.

Mitigation of the risk at Panorama Creek, Mathews Creek, Gavles Creek, Cove Creek, and Cleopatra Creek could involve:

- construction of debris barriers above the Panorama Drive development; and
- various channel works.

The cost of these works would range from $300,000 to $500,000 per creek. The combined cost of hazard mitigation for all the Deep Cove creeks would be roughly $3.1 million.

4.4 OSTLER CREEK AND ALLAN CREEK

BACKGROUND

Ostler Creek and Allan Creek are situated immediately north of Deep Cove in an area referred to as Woodlands. There are several secondary channels that provide interflow between the two creeks.

The Ostler Creek fan is relatively small with the creek flowing over a steep slope before reaching gentle terrain at Indian Arm and flowing between two houses. Ostler Creek is culverted at both Firelane 7 (the upper road) and Indian River Drive. The lower culvert (2,100 mm diameter) was replaced in 1996 following two flood incidents.

Allan Creek is north of Ostler Creek. In the lower reaches, Allan Creek flows past four road sections before reaching a 100 m long, low gradient fan at Indian Arm.

RESULTS OF DETAILED STUDY

Excerpts from the detailed study for Ostler Creek and Allan Creek are included in Appendix E.

The mainstem channels of Ostler Creek and Allan Creek are not considered to be prone to debris flows for return periods up to 500 years. However, they are subject to debris floods. The design event for each creek is a 200 m^3 debris flood with a peak discharge of 24 m^3/s at Firelane 7.

Photo 4
Overview of Ostler Creek and Allan Creek.

Allan Creek has two very active tributaries, which are referred to as the North Gully and South Gully. The two gullies are located above Firelane 7. In 1992 or 1993, a debris flow on the North Gully damaged Firelane 7. The design debris flow for each gully is a volume of up to 1,000 m^3 and a peak discharge of 25 m^3/s.

Without mitigation structures in place on either of the mainstem channels or the two gullies, a significant event would likely overwhelm the existing culverts on Firelane 7, causing damage to the road structure and downstream areas. Allan Creek has several undersized culverts at and below Indian River Drive.

On the basis of the detailed study, the existing level of risk is rated medium for the mainstem channels of Ostler Creek and Allan Creek, and medium high for the two Allan Creek gullies. The target level of risk is medium low. Significant mitigative measures would be required to achieve this level.

MITIGATIVE OPTIONS

The preferred approach for risk mitigation at Ostler Creek and Allan Creek is to build debris barriers at Firelane 7, combined with check dams, culvert upgrading (Allan Creek only) and minor channelization in the lower reaches. The total cost of risk mitigation is estimated at $3.1 million for the two watersheds.

4.5 SCOTT-GOLDIE CREEK AND SUNSHINE CREEK

BACKGROUND

The Scott-Goldie Creek watershed is located on the east slope of Mount Seymour. Firelane 8 provides road access to the Scott-Goldie creek fan, with a bridge across the creek channel. Only one home is located along the creek corridor (located adjacent to the creek mouth at Indian Arm). Unlike most of the Indian Arm creeks, a subaerial fan has not developed on Scott-Goldie Creek. Because the creek is largely confined within a bedrock canyon down to Indian Arm, sediment transported by the creek has accumulated under water, thereby forming a submarine fan.

Photo 5
Mouth of Scott-Goldie Creek at Indian Arm.

Sunshine Creek is a smaller watershed immediately south of Scott-Goldie Creek. Within 20 m of Indian Arm, the creek falls over a 20 m high bedrock waterfall. Houses are located on both sides of the waterfall, but are not risk from structural damage during creek events. Additional infrastructure along the creek corridor includes two road crossings (Firelanes 7 and 8) and water intakes.

Sunshine Creek was originally to have been included in a report on the Woodlands Drainage Area, which includes Sunshine Creek, Allan Creek, and Ostler Creek. However, an avulsion risk was discovered along a sharp bend of Scott-Goldie Creek where a debris flow could enter the drainage of Sunshine Creek. Therefore it was more appropriate to include Sunshine Creek in the Scott-Goldie Creek report.

RESULTS OF DETAILED STUDY

Excerpts from the detailed study for Scott-Goldie Creek and Sunshine Creek are included in Appendix F.

The study concludes that Scott-Goldie Creek is prone to infrequent large debris flows rather than more frequent smaller events. The design debris flow volume for Scott-Goldie Creek is estimated at 22,000 m^3, with an associated peak discharge of approximately 400 m^3/s.

Due to insufficient channel capacity at a sharp channel bend above Firelane 7, a portion of a debris flow event in Scott-Goldie Creek could avulse into the watershed of Sunshine Creek. Previous debris flow activity is evident along the avulsion route. Due to a low channel gradient, most of the debris would deposit above 200 m elevation. However, up to 1,000 m^3 of debris could continue down the channel as a debris flood and reach one of two culvert crossings. The corresponding peak discharge at Firelane 8 is estimated at 25 m^3/s.

Without mitigation structures at Scott-Goldie Creek, a significant event (even much smaller than the design event) could result in direct impact to the house at the creek mouth. In addition, the bridge is vulnerable to damage.

On Sunshine Creek, the design debris flood would overwhelm the Firelane 8 culverts, causing damage to the road structure. Damage could also be sustained to the lower crossing at Firelane 7.

On the basis of the detailed study, the existing level of risk is rated high at Scott-Goldie Creek and medium at Sunshine Creek. The target level of risk is medium low. Significant mitigative measures would be required to achieve this level.

MITIGATIVE OPTIONS

At Scott-Goldie Creek, the construction of mitigative works (channelization and concrete wall) to protect the house on the fan would cost about $450,000. This roughly equals the value of the house and property, therefore, it may be more appropriate to remove or relocate the house.

The Firelane 8 bridge at Scott-Goldie Creek would also require extensive blasting and excavation under the bridge to provide sufficient cross-section area to pass the design debris flow. This would cost about $400,000.

At Sunshine Creek, the only feasible alternative is the construction of two debris barriers, with capacities of 1,000 and 500 m^3 respectively, and culvert upgrading ($1.2 million).

4.6 PERCY CREEK AND VAPOUR CREEK

BACKGROUND

Percy Creek is located on the west side of Indian Arm within the community of Cascade. About 10 houses and several auxiliary buildings are located on the creek fan at Sasamat Lane. The community is the most northerly part of the District that has road access. This is a result of Firelane 8 being extended into the area in the 1990s.

Vapour Creek is located immediately north of Percy Creek and its fan overlaps the Percy Creek fan. Although Vapour Creek (0.5 km^2) is considered a less serious hazard than Percy Creek, the overlapping fans dictate that the two creeks be investigated together.

Photo 6
Overview of Percy Creek (middle left) and Vapour Creek.

RESULTS OF DETAILED STUDY

Excerpts from the detailed study for Percy Creek and Vapour Creek are included in Appendix G.

The study concludes that Percy Creek is subject to very large debris flows that occur infrequently, rather than smaller events that may occur more frequently. The estimated debris flow magnitude for design purposes (500-year return period) is a volume of 25,000 m^3 with a peak discharge of approximately 450 m^3/s. The debris flow hazard on the fan has been delineated on the basis of a debris flow model. Without debris flow mitigation structures, a significant debris flow (even much smaller than the design event) would cause considerable damage to houses, property, and infrastructure.

Vapour Creek is not considered subject to debris flows within the return period considered for design. However, it is considered subject to debris floods on the basis of field evidence and a documented event in November 1989. The estimated debris flood magnitude for design purposes is a volume of 400 m^3 and a peak discharge of 25 m^3/s.

On the basis of the detailed study, the existing level of risk is rated high at Percy Creek and medium at Vapour Creek. The target level of risk is medium low. Significant mitigative measures would be required at Percy Creek to achieve this level. Less extensive mitigative measures would be required at Vapour Creek.

MITIGATIVE OPTIONS

The most promising mitigation structure for Percy Creek appears to be a combination of a debris barrier and debris basin above the Sasamat Lane bridge (at a cost of roughly $3.8 million). It may be possible to partially mitigate the hazard by constructing a single structure as an initial phase of a long-term program.

At Vapour Creek, the most practical alternative is considered to be a combination of a deflection berm and channelization. These works would cost approximately $630,000.

4.7 SHONE CREEK

BACKGROUND

Shone Creek is located north of the District road system, and is therefore only accessible by boat. A children's camp (Camp Jubilee) and about six houses (Frames) are located on the creek fan.

Underhill Creek is a major tributary of Shone Creek. Because their fans overlap, the two watersheds have been investigated together.

Photo 7
Shone Creek fan with Camp Jubilee on the left.

RESULTS OF DETAILED STUDY

Excerpts from the detailed study for Shone Creek are included in Appendix H.

The study concludes that Shone Creek is subject to debris flows, but that a debris flow would likely transform into a debris flood before reaching the lower fan. The lower fan is subject to large debris floods and severe floods. Such events are known to have occurred in 1983, 1989, 1991, 1995 and 1998. The estimated debris flood magnitude for design purposes (500-year return period) is a volume of 10,000 m^3 with a peak discharge of approximately 90 m^3/s.

Underhill Creek is subject to debris flows, with an estimated volume for design purposes of 5,000 m^3 and a peak discharge of 100 m^3/s. Debris flows on Underhill Creek could potentially dam Shone Creek and cause an outbreak flood.

An additional hazard could arise if a debris flow from Shone Creek were to deposit a significant volume of sediment immediately downstream of the canyon at the upper fan apex. At this location, the creek is poorly confined and flow could avulse to the southeast into Gardner Brook. While debris flows would not reach the fan area of Gardner Brook, there is a debris flood and flood risk to the community of Brighton Beach.

Without debris mitigation structures, a significant event (even much smaller than the design event) could cause considerable damage to houses, property and infrastructure.

On the basis of the detailed study, the existing level of risk is rated high at Shone Creek and medium at Underhill Creek. The target level of risk is medium low. Significant mitigative measures would be required to achieve this level.

MITIGATIVE OPTIONS

The most promising alternative for Shone Creek appears to be training berms and channelization in conjunction with a small debris basin downstream of the lower fan apex. The training berms would be constructed along both sides of the mainstem channel with a setback of greater than 50 m on the north side. The channelization component would require an ongoing commitment to channel maintenance on the lower fan. To mitigate the risk from Underhill Creek, an overflow channel could be constructed at the confluence of the two creeks to redirect water into lower reaches of Shone Creek in the event of a temporary landslide dam from Underhill Creek.

These works could cost approximately $3.5 million.

4.8 HOLMDEN CREEK

BACKGROUND

Holmden Creek is situated immediately north of Shone Creek and there is minor overlapping of the two fans.

The Holmden Creek system is very active with two recorded debris flow events in the last decade. The first event occurred in the early 1990s, while the second occurred in 1998. The 1998 event damaged the only house on the fan, which was subsequently relocated and rebuilt. Damage was also sustained to two docks, including the dock on the a property to the north of the fan.

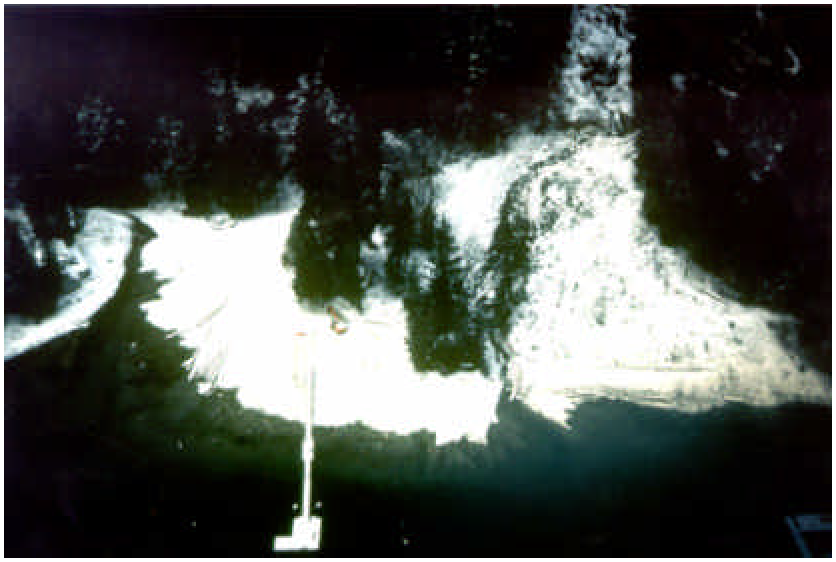

Photo 8
Aerial view of Holmden Creek fan. The house on the fan is located within the cluster of trees.

RESULTS OF DETAILED STUDY

Excerpts from the detailed study for Holmden Creek are included in Appendix I.

Holmden Creek is unique relative to other creeks along Indian Arm in that two debris flow fans have developed along the mainstem channel. The upper fan is a significant zone of deposition about 500 m upstream of Indian Arm. The lower fan is located at Indian Arm.

Given the almost unlimited supply of sediment to the channel and the incidence of two debris flows on the lower fan in the last decade, it is believed that Holmden Creek is prone to frequent small debris flows. However, Holmden Creek is also subject to infrequent large events. The estimated debris flow magnitude for design purposes (500-year return period) is a volume of 40,000 m^3 with a peak discharge of approximately 700 m^3/s.

Without mitigation structures in place, a significant event could result in direct impact to the only house on the fan. The two docks are also at risk.

On the basis of the detailed study, the existing level of risk is rated high at Holmden Creek. The target level of risk is medium low. Mitigative measures would be required to achieve this level.

MITIGATIVE OPTIONS

At Holmden Creek, the construction of mitigative works (deflection berm) to protect the house on the fan would cost about $250,000. This exceeds the value of the house and property, therefore, it may be more appropriate to remove or relocate the house (at a cost of roughly $125,000). Two docks would also need to be removed or relocated.

4.9 COLDWELL CREEK AND FRIAR CREEK

BACKGROUND

Coldwell Creek is located in the northern part of the Indian Arm portion of the District. The watershed is characterized by several tributaries that are prone to debris flows. The community of Coldwell Beach is located on the Coldwell Creek fan. Like many other creek fans along Indian Arm, the fan is densely populated with six houses and several docks. Coldwell Creek is only accessible by boat.

Friar Creek is a smaller watershed located to the north of Coldwell Creek. The fan complex at Coldwell Creek consists of debris delivered by both creeks, however, the sediment contribution of Friar Creek is estimated to be less than 10% of the total fan volume. One house and two small shacks are located on the Friar Creek fan.

Photo 9
Overview of Coldwell Creek.

RESULTS OF DETAILED STUDY

Excerpts from the detailed study for Coldwell Creek and Friar Creek are included in Appendix J.

While Coldwell Creek is characterized by several tributaries that are prone to debris flows, the average channel gradient is not steep enough to transport debris flows to the fan apex or beyond. However, the fan is considered to be prone to debris floods. The estimated debris flood magnitude for design purposes (500-year return period) is a volume of 8,000 m^3 with a peak discharge of approximately 150 m^3/s. Air photo and dendrochronological evidence suggests that Coldwell Creek has not witnessed a destructive debris flood for at least 55 years.

Conversely, Friar Creek is judged to be susceptible to debris flows, in part because of a steeper channel gradient. Fresh boulders located directly above the residence on the fan of Friar Creek indicate that small events (several tens to one hundred cubic metres) have occurred in the recent past (several decades). The design debris flow volume at Friar Creek is estimated at 4,000 m^3 with a peak discharge of approximately 90 m^3/s.

The design debris flood could directly impact several houses on the Coldwell Creek fan. The potential for damage is variable due to the topography. A debris flow on Friar Creek would likely cause significant damage to the only house on the fan.

On the basis of the detailed study, the existing level of risk is rated medium high at Coldwell Creek and high at Friar Creek. The target level of risk is medium low. Significant mitigative measures would be required to achieve this level.

MITIGATIVE OPTIONS

The preferred alternative to mitigate the debris flood risk at Coldwell Creek is a combination of a debris barrier above the fan apex, training berms along both sides of the creek, and channelization. The storage volume of the barrier could vary from one-third of the design volume to the full volume of 10,000 m^3. The greater the debris barrier storage volume, the less channel works required. The estimated cost of these works is $1.9 million.

At Friar Creek, the cost of construction of mitigative works to protect the house on the fan exceeds the value of the house and property (about $300,000). Therefore, it may be more appropriate to remove or relocate the house.

4.10 CLEGG CREEK

BACKGROUND

Clegg Creek lies at the northern boundary of the District. Clegg Creek is a typical debris flow basin characterized by very steep bedrock channels, a high drainage density and a steep fan (approximately 15^o).

More than two-thirds of the watershed is outside the District boundary, although virtually all of the fan is within the District. Only one cabin is located on the fan, to the south of the main channel.

Photo 10
Aerial view of Clegg Creek fan.

RESULTS OF DETAILED STUDY

Excerpts from the detailed study for Clegg Creek are included in Appendix K.

Based on the watershed characteristics and fresh debris lobes and boulder levees on the fan, Clegg Creek is considered prone to frequent debris flow activity. The estimated debris flow magnitude for design purposes (500-year return period) is a volume of 30,000 m^3 with a peak discharge of approximately 500 m^3/s.

Without mitigation structures in place, a significant event could result in direct impact to the cabin.

On the basis of the detailed study, the existing level of risk is rated high at Clegg Creek. The target level of risk is medium low. Mitigative works would be required to achieve this level.

MITIGATIVE OPTIONS

The cost of mitigative works at Clegg Creek would significantly exceed the value of the cabin on the fan (roughly $50,000). Therefore, the most practical alternative for risk mitigation at Clegg Creek is to remove or relocate the cabin.

Section 5

Implementation Plan

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5. IMPLEMENTATION PLAN

5.1 DISSEMINATION OF STUDY FINDINGS

This sub-section outlines some appropriate actions in terms of disseminating the study findings.

REFERRAL TO OTHERS

Reasons to refer the results of the detailed debris flow studies to others include the following:

1. to inform property owners and/or residents in identified hazard areas that land is subject to a potential hazard;
2. to inform land interests in key upper watershed areas that their activities may contribute to a downstream hazard;
3. to inform property owners in watershed areas that a hazard may originate on their property; and
4. to inform relevant organizations and agencies of the Districts actions and findings.

By informing property owners and/or residents in identified hazard areas, there will be an opportunity for any appropriate actions to be taken by individuals and/or local groups. There will also be an opportunity for local interest in mitigative measures to be put forward to the District.

By informing land interests in upper watershed areas, there is an opportunity to communicate the District's findings in terms of specific concerns that should be addressed by such interests. There is also an opportunity to communicate general watershed management principles that may be applicable in order to avoid contributing to downstream hazards. Such interests include Grouse Mountain Resort, Greater Vancouver Regional District, Mount Seymour Park, Ministry of Transportation (re Mount Seymour Road), and BC Hydro.

By informing property owners in watershed areas, the District can pass on its knowledge about hazards potentially originating on private property. This will give property owners the opportunity to take any actions they deem appropriate.

By informing relevant organizations and agencies, the District can enhance coordination and understanding with respect to common interests in creek and watershed management. Such interests could include the City of North Vancouver, BC Ministry of Water, Land and Air Protection, Land and Water BC, the Squamish Nation, and the District of West Vancouver.

Finally, the District should advise the GVRD about the potential for debris flows on Grouse Creek and Mackay Creek to enter the Capilano Reservoir, potentially resulting in water quality impacts.

PUBLIC ADVISORY

The District could consider advising the general public about the overall results of the detailed studies. This would increase awareness about creek hazards and the need for some allocation of District funds for various mitigative measures.

5.2 SHORT-TERM ACTIONS

This sub-section outlines a number of relatively low cost actions that could be considered for short-term implementation to provide the District with some beneficial degree of risk mitigation.

WATERSHED MANAGEMENT

A number of watershed management concerns have been identified by the detailed studies. While these are not all within the jurisdiction of the District, the District has an interest in seeing that they are addressed. Some possible general actions are as follows:

- encourage or require Grouse Mountain Resort to develop a water management plan for the Grouse Mountain ski area;
- work with Grouse Mountain Resort to properly decommission an inactive logging road in the Mosquito Creek watershed;
- request the BC Ministry of Transportation to address undersized culverts and culvert blockage risks on Mount Seymour Road;
- work with BC Hydro to resolve drainage and stability issues along the powerline; and
- work with Mount Seymour Park to ensure that park activities do not aggravate creek hazards.

Proposed logging and/or road construction in any of the District watersheds may have the potential to exacerbate creek processes, especially where unstable terrain is encountered. Any such proposed activity should be carefully reviewed to ensure that creek processes are not exacerbated.

Some possible site-specific watershed management actions are noted in the various creek reports.

WARNING SIGNS

The District could consider placing warning signs on trails that are under the District's jurisdiction. The signs could warn trail users that trails are potentially subject to creek hazards during wet weather periods.

The District could also consider advising other agencies that have jurisdiction over trails that it may be appropriate for them to place warning signs.

The District could consider placing warning signs on District roads and bridges to warn that creeks could be hazardous during wet weather periods. Some priority locations would be:

- the Montroyal Boulevard bridge at Mosquito Creek;
- Indian River Drive; and
- Panorama Drive.

The District could also consider advising owners of private bridges and roads that it may be appropriate for them to place warning signs. The private firelanes in the Indian Arm area would be a priority in this respect.

ADVANCE WARNING SYSTEM

The District could consider developing a hydroclimatic threshold type of advance warning system for District-wide application. This could use real-time date from climate and hydrometric stations to determine when optimum conditions exist for debris flows and landslides. This could be used to issue a public warning, similar to the weather warnings (snowfall warning, heavy rainfall warning, etc.) issued by Environment Canada. Such warnings could be beneficial to trail users in the various parts of the District, road users (particularly in the Indian Arm area), and residents in hazard areas.

POST-EVENT WARNING SYSTEM

The District could consider installing a post-event warning system on the Montroyal Boulevard bridge at Mosquito Creek. Such a system could trigger a light to come on or a gate to close in the event of a bridge washout.

A similar post-event warning system could be installed on some of the private firelane bridges in the Indian Arm area.

Post-event warning systems are not considered to be as effective at culvert crossings as at bridges.

CAPITAL PROJECTS

Some of the detailed reports identify capital projects that would protect District infrastructure. These include mitigation structures, culvert upgrading, and creek works. As appropriate, these should be considered for inclusion in the District's public works program.

OPERATIONS

There should be continued emphasis on operation and maintenance issues associated with creek channels and creek works.

5.3 PROGRAM DELIVERY

This sub-section outlines some program delivery options that could provide some longer term risk mitigation, and avoid creation of additional future risks.

LAND USE PLANNING

The District could continue to improve the natural hazards components of its land use planning activities.

General information on natural hazards, map schedules on known hazard areas, and the need for mitigative measures could be incorporated into the District's Official Community Plan.

The District's Zoning Bylaw could also be reviewed with respect to known natural hazard areas, including those identified in the detailed debris flow studies.

DEVELOPMENT APPLICATIONS

Development applications near creeks and on creek fans should continue to be carefully reviewed with respect to the potential for damage from debris flows, debris floods, floods, and bank erosion. The creek fans and related hazard areas mapped during the detailed debris flow studies provide significant guidance for this ongoing activity.

Section 699 of the Local Government Act should continue to be used as a mechanism for addressing natural hazards issues for building permit applications. This statute allows the building inspector to require an applicant to obtain a report by a professional engineer. The engineer's report is to determine whether the land may be safely used for the intended use, and specify any conditions under which the land may be safely used. The report is to be the subject of a restrictive covenant registered against the land title.

Subdivisions in areas subject to flood, debris flood and debris flow hazards are no longer required to be referred to the BC Ministry of Water, Land and Air Protection for adjudication pursuant to Section 82 of the Land Title Act. The District is now responsible for such reviews, and should develop a set of guidelines. Conditions of approval would typically include construction of mitigative works prior to subdivision, floodproofing conditions for buildings, and registration of a restrictive covenant against the land title.

Within natural hazards areas, rezoning to higher densities should be avoided, with the possible exception of areas in which a comprehensive hazard mitigation measures are in place.

NATURAL HAZARDS BYLAW

Regulation of development applications within the District would be greatly facilitated by implementing a comprehensive natural hazards bylaw. This would identify standard mitigative measures (building elevations and setbacks) that can apply to most straight-forward applications. This would avoid applicants having to obtain engineer's reports in routine situations.

A natural hazards bylaw could include practical provisions for renovations that would avoid overly penalizing applicants for minor modifications to nonconforming buildings. For example, renovations up to a certain percentage of the original floor area could be exempted from floodproofing measures.

MONITORING AND INSPECTION

An appropriate level of monitoring should be undertaken for critical watershed areas and creek channels. The District could consider formalizing the level of monitoring that it accepts responsibility for in order to provide some defence against the possibility of future claims that its monitoring is not adequate.

In rugged terrain, periodic overflights by helicopter would be appropriate. Where instabilities are identified, further ground inspections could be undertaken.

For those creek channels that are obscured by dense forest cover, monitoring should entail periodic hikes of the creek channels.

District creek works should also be inspected regularly to identify any maintenance requirements. Where necessary, maintenance work should be undertaken promptly to ensure the continued integrity of the works.

EMERGENCY RESPONSE

The District's emergency response procedures could be reviewed with respect to the findings of the detailed debris flow studies.

5.4 MITIGATION STRUCTURES

Mitigative structures appear to be feasible in many of the identified hazard areas. However, these would involve significant costs in most cases. A number of administrative complexities would also need to be overcome. For these reasons, it is suggested that the District view construction of mitigative structures as a long-term term undertaking. This sub-section provides some suggestions regarding a possible implementation program.

PROGRAM DEVELOPMENT

As an initial step, it is suggested that the District develop an appropriate long-term program for construction of mitigative works. This could involve the following actions:

- consult with residents, property owners and other stakeholders in identified hazard areas to determine the level of local interest in a program of mitigative works;
- identify preferable mitigation alternatives and key local issues that would need to be addressed;
- identify possible local and outside sources for cost sharing;
- establish an effective funding mechanism for capital works;
- address administrative issues such as ownership and maintenance responsibility of capital works; and
- develop a method for ranking project priorities throughout the District.

If such a program is approved, it could provide a basis for establishing an annual level of District funding and proceeding with a long-term construction program.

FINANCIAL CONSIDERATIONS

The total cost to construct mitigative structures to address all of the identified debris flow and debris flood hazards in the District is estimated at roughly $27 million (2003 dollars), not including any land acquisition costs that may be incurred. This cost is based on what are considered the preferred mitigative alternatives, which may or may not be the ones that are ultimately selected. Therefore, the actual final cost could vary significantly.

In the event that the District decides to budget an amount per year toward mitigation structures, Table 5-1 provides an indication of the approximate number of years that it would take to complete a program of $27 million present value (assuming 3% annual inflation and 7% interest).

Table 5-1: Number of Years to Complete Program for Various Annual Funding Levels

Annual Funding Level	Number of Years to Complete Program
$100,000	97 years
$250,000	66 years
$500,000	44 years
$1,000,000	26 years
$2,000,000	14 years
$3,000,000	9 years
$4,000,000	7 years
$5,000,000	6 years

Previous legal advice obtained by the District suggests that Council may determine the timing and level of funding for mitigative measures. Failure to address the policy choices could be a basis for liability in the event of future damage. As long as the policy choice is reasonable, no liability should arise.

FUNDING MECHANISM

In order for mitigative works to be constructed, funding sources need to be identified for both the capital cost and future maintenance activities.

Alternative funding mechanisms are:

- District pays (using District-wide tax base);
- District pays, but recovers all or part of costs from benefiting property owners through annual assessment;
- District cost-shares with local interests (such as GVRD and/or Grouse Mountain Resorts) or:
- property owners or local interests pay.

There may be the possibility of some funding contribution from provincial government programs, but such programs have not been well-funded of late, so this is considered an unlikely possibility.

If a maintenance authority is established it will need to be funded. Again, this will need to be resolved between the District and local property owners. Funding for maintenance work needs to recognize two aspects:

- some degree of routine maintenance will be needed on an ongoing basis; and
- most significant maintenance will be needed after creek events, and this is episodic in nature.

Maintenance funding needs to consider the possibility of a major maintenance undertaking being required before an annually-funded maintenance fund would have significantly accumulated.

POLICY FOR OWNERSHIP OF MITIGATIVE WORKS

In considering the need for land acquisition, the District should consider formalizing a policy for ownership of any mitigative works that are constructed, as well as for maintenance responsibility. Following the precedent set for the Upper Mackay Creek debris basin and previous projects, the most likely scenario would be for the District to own, operate and maintain such works. This would be consistent with the previous requirement of MWLAP that such works be under the jurisdiction of a recognized local authority. However, within the District's umbrella, there may be an option for jurisdiction to be established through a utility or specified area.

The maintenance authority would require land tenure (ownership or easement) for all physical works constructed, as well as for maintenance access routes and the creek channel. This will generally require land acquisition.

IMPLEMENTATION PRIORITIES

If the District proceeds with a mitigative program, implementation priorities may be based on many considerations. Some considerations that could contribute to a high implementation priority include the following:

- protection of District-owned assets (roads, bridges and infrastructure);
- protection of assets for which the District previously issued an approval or permit;
- areas having a relatively high degree of risk;
- projects that would result in a high number or value of assets protected;
- projects that are cost-effective (high benefit relative to cost);
- projects that protect areas of year-round versus seasonal or part-time occupation;
- areas accessed by District roads versus areas only accessible by water;
- areas where residents support the proposed project;
- areas where funding contributions are forthcoming from other sources;
- projects having low environmental impact; and
- projects that are not subject to time-consuming implementation problems (land acquisition delays for example).

It would probably be appropriate for the District to formalize a method for prioritizing projects if it proceeds with a program of mitigation structures.

IMPLEMENTATION ISSUES

Some of the issues that would need to be resolved in the implementation of individual projects are as follows:

- the need for stakeholder consultation;
- selection of a preferred alternative for implementation;
- the need for land acquisition;
- financial arrangements;
- resolution of environmental issues;
- identification of specific issues to be addressed during the design phase; and
- operation and maintenance requirements.

The remaining sub-sections elaborate on some of these issues.

STAKEHOLDER CONSULTATION

For any given project, stakeholders should be consulted prior to selecting a specific project for implementation. This is particularly important where there are many project alternatives that could be considered. Prior to selecting a preferred alternative for implementation, it would be beneficial to consult with area residents with respect to issues such as the following:

- the nature of the creek hazard and the need for mitigative measures;
- the pros and cons of the various mitigative alternatives;
- the need for removal of some existing forest cover;
- visual impact (from the land and water);
- effect on roads and services in the area;
- environmental issues;
- possible encroachment of the works on private property;
- the need for land acquisition;
- alternative funding mechanisms (for construction and maintenance);
- maintenance responsibility for the works;
- anticipated temporary disturbances during construction (traffic, noise, etc.); and
- the need for fences to restrict access to the works.

In addition to area residents, stakeholders that should be consulted include the following:

- property owners and business interests in the area that would be protected;
- watershed interests;
- relevant provincial and federal government agencies; and
- non-governmental organizations (streamkeepers, etc.).

Input from the stakeholders will be valuable in identifying local issues that will assist in selecting the most effective alternative. Stakeholder consultation would also be useful in terms of advising the public and others about the nature of the creek hazards and the need for mitigative measures.

SELECTION OF ALTERNATIVE

Following the stakeholder consultations, the District should be well-positioned to select an alternative for implementation. In addition to the District's program objectives, this selection should consider stakeholder preferences, as well as project cost, the need for land acquisition, and environmental considerations.

ENVIRONMENTAL CONSIDERATIONS

Environmental issues need to be considered during alternative selection, design and maintenance. Typical environmental concerns associated with debris flow structures are as follows:

- interception of bedload material which may be required to replenish downstream spawning gravels;
- removal of riparian vegetation which provides fish and wildlife habitat;
- armouring of creek channels, resulting in loss of instream habitat; and
- the potential for water quality impacts during construction work.

The extent to which these concerns may apply to a particular project depends on the nature of the project. The extent to which the concerns may be significant depends on the relative value of the fish and wildlife resource values for that particular creek. In most cases, it is possible to satisfactorily mitigate the environmental effects associated with a project through sensitive design, good construction practices, revegetation, and other compensatory measures.

Avoiding water quality impacts during construction typically requires the following:

- construction during the summer fisheries window;
- construction in isolation of flowing water;
- erosion and sediment control measures;
- contingency planning for rainfall during construction; and
- providing an environmental monitor to oversee the work.

Further consideration of environmental issues should occur during the process of selecting an alternative for implementation. A detailed environmental review will be needed in order to prepare the design.

ENVIRONMENTAL APPROVALS

Construction of mitigative works would typically require at least two environmental approvals:

- approval from Land and Water BC under Section 9 of the Water Act; and
- approval under the District's Environmental Protection Bylaw.

The Section 9 approval process involves input from provincial and federal fisheries agencies. In some cases, this results in additional approval requirements.

There is an increasing tendency for environmental approvals to be co-ordinated through the District's Environmental Protection Department. This is accomplished through regular project review meetings with environmental agency representatives. It is possible that the Burrard Inlet Environmental Action Program will act as a lead agency in co-ordinating environmental approvals.

DESIGN ISSUES

It may be appropriate to prepare a preliminary design of one or more alternatives during the review of alternatives. Existing survey information is likely sufficient for preliminary design.

Once an alternative is selected for implementation, detailed design drawings would be prepared. The design phase would involve the following:

- a comprehensive topographic survey;
- assessment of fish and wildlife resource values;

- structural design for any concrete and steel structures;
- geotechnical review of foundations and any constructed slopes;
- consultation with local interests;
- incorporation of effective environmental protection and enhancement measures;
- landscape design regarding revegetation (for either environmental or aesthetic purposes;
- consideration of the need for security fences and signs;
- determination of appropriate right-of-way boundaries;
- resolution of land acquisition issues; and
- review of applicable utilities (water, sewer, electrical, etc.).

The design would be reflected in a set of drawings which can be used as a basis for proceeding with environmental approvals and construction.

CONSTRUCTION PROGRAM

Once detailed design drawings are completed to the satisfaction of the District, the project can be tendered for construction. The construction program would be subject to environmental approvals, and would include environmental monitoring by a biologist. Construction management would also involve engineering quality control inspections. Following the construction phase, an as-built survey should be performed and record drawings prepared.

OPERATION AND MAINTENANCE ISSUES

An operation and maintenance manual should be prepared to outline expected work items. These would cover both routine maintenance work and intermittent restoration following creek events.

PHASING OPPORTUNITIES

Some projects lend themselves to phasing in terms of different design components being constructed at different times.

The more complex projects will require multi-year implementation. In such cases, there is an opportunity to phase the work in terms of design being done one year, and construction the next.

Section 6

Summary and Recommendations

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6. SUMMARY AND RECOMMENDATIONS

6.1 SUMMARY

The findings of the detailed debris flow studies are summarized as follows:

APPROACH AND METHODOLOGY

1. The creeks that are subject to the highest debris flow and debris flood risks in the District have been subject to detailed investigation, and the results are outlined in ten separately bound reports.

2. For each creek, the debris flow and/or debris flood hazard is assessed in terms of probability and magnitude (total volume and peak discharge). This assessment provides 'design event' magnitudes that represent a 500-year return period, although on most of the creeks it must be recognized that there is the potential for damaging events to occur at much lower return periods.

3. For each creek, the potential consequence of a debris flow and/or debris flood is also assessed. This indicates the potential for damage to buildings, infrastructure and other assets.

4. The level of risk is rated as a combination of hazard and consequence, recognizing that both factors are necessary to give rise to a significant risk (i.e. a hazardous creek with no potential effect on homes or infrastructure is not considered a significant risk). In the absence of an established standard for risk acceptability in B.C., for the purposes of this Study, a medium low or lower level of risk has been adopted as the target level of residual risk following the implementation of mitigative measures. The District considers a risk of medium low to be an acceptable level of risk.

5. Where a significant risk is identified, a wide range of alternative mitigative measures are considered. These include land use planning, warning systems, watershed management actions, mitigation structures and creek management measures.

RESULTS OF HAZARD ASSESSMENT

6. Of the 20 creeks investigated, the dominant hazard is split about evenly between debris flows and debris floods.

7. Most of the creek hazards are natural in origin, although anthropogenic activities are contributing factors in some cases.

8. Many situations were discovered in the District where creeks may avulse (shift from one watershed to the next) due to natural processes.

9. The hazard magnitude for the design events varies widely as follows:

Process	Range in Volume	Range in Peak Discharge
Debris Flow	1,000 - 40,000 m^3	25 - 500 m^3/s
Debris Flood	100 - 10,000 m^3	4 - 250 m^3/s

POTENTIAL CONSEQUENCES AND RISK

10. The potential consequences of debris flows and debris floods primarily comprise assets on the creek fans. These include houses, other buildings, roads, bridges, culverts, and municipal infrastructure. These include both District and private assets.

11. Hazard maps have been prepared to define the extent and nature of hazard on the creek fans (except at Deep Cove where the fans have been significantly altered by development).

12. All of the creeks investigated have a risk greater than medium low, and therefore would require mitigative measures to achieve the target level of risk.

MITIGATIVE MEASURES

13. Land use planning should focus on avoiding additional development in hazard areas unless mitigative measures are implemented.

14. An advance warning system could be considered on a District-wide basis to provide a general warning of high risk periods. A post-event warning system may be appropriate at affected bridge crossings, such as Montroyal Boulevard at Mosquito Creek.

15. There are a number of opportunities to implement watershed management measures to address existing instabilities and prevent new instabilities. However, these will not fully mitigate the risk.

16. In some cases, creek management measures, such as culvert upgrading and bank protection works, will be effective.

17. Mitigation structures could be constructed on most of the creeks to provide an adequate degree of risk mitigation. Available alternatives include debris basins, debris barriers and deflection berms. For most creeks, there are a number of different alternatives that could be considered.

18. The total cost of mitigative measures would be roughly $27 million (2003 dollars) to mitigate all of the identified risks on all of the study creeks. This does not include land acquisition.

19. If the District decides to implement a program of mitigation structures, there are a number of methods that could be used to establish implementation priorities.

20. Implementation of specific projects should commence with stakeholder consultation prior to selection of a preferred alternative. A number of administrative issues also need to be addressed prior to construction. These include funding mechanism, ownership of the constructed works, maintenance responsibility, and right-of-way acquisition.

21. Following implementation of mitigative measures, it is important to recognize that a small level of residual risk would remain.

6.2 RECOMMENDATIONS

Further to the foregoing summary of findings, it is recommended that the District:

1. Disseminate the results of the study as follows:

   - inform property owners and residents in identified hazard areas;
   - inform property owners in watershed areas on which a hazard may originate;
   - refer the study findings to watershed interests and other agencies; and
   - issue an appropriate form of notification to the general public.

2. Proceed directly with implementation of the identified short-term actions that represent relatively low cost measures that could provide some beneficial degree of risk mitigation. These could include the following:

   - undertake watershed management actions in cooperation with local interests;
   - install warning signs at appropriate locations;
   - consider developing a District-wide advance warning system;
   - consider implementing a post-event warning system at key bridges;
   - implement capital projects to protect District infrastructure; and
   - place a continued emphasis on operation and maintenance.

3. Proceed with improvements to program delivery, possibly including the following:

   - continue to improve the natural hazards aspects of land use planning;
   - continue to closely scrutinize development applications in identified hazard areas;
   - consider adopting a comprehensive natural hazards bylaw;

- clarify the ownership and maintenance responsibility for existing and future creek works;
- implement an appropriate level of monitoring and inspection;
- perform an appropriate level of maintenance on creek channels and engineering works; and
- review emergency response procedures.

4. Develop an appropriate long-term program for construction of mitigative works as follows:

   - consult with residents, property owners and other stakeholders in identified hazard areas to determine the level of local interest in a program of mitigative works;
   - identify preferable mitigation alternatives and key local issues that would need to be addressed;
   - identify possible local and outside sources for cost sharing;
   - establish an effective funding mechanism for capital works;
   - address administrative issues such as ownership and maintenance responsibility of capital works; and
   - develop a method for ranking project priorities.

5. If appropriate, approve the long-term program for construction of mitigative works, with establishment of an annual level of District funding.

6.3 REPORT SUBMISSION

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Appendix A

Background Information on Debris Flows and Debris Floods

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Appendix A

Background Information on Debris Flows and Debris Floods

DEFINITIONS

Steep mountain creeks are typically subject to a spectrum of events, ranging from clear water floods to debris flows as shown by Figure A-1. Slides and falls are not confined to stream channels but can follow channels for part of their descent.

Debris flows are a form of rapid water-saturated channelized landslide. Debris flow velocity typically ranges between 5 and 10 m/s, but some fine-grained debris flows have been known to travel up to 20 m/s. They are most likely to occur on small, steep creeks that have abundant sources of debris. Debris flows are sometimes alternatively referred to as *debris torrents* where they are particularly coarse in nature and carry large amounts of organic debris or *mudflows* where they are particularly fine in nature. Volcanic debris flows are referred to as *lahars*.

Debris floods are a very rapid, surging flow of water, heavily charged with debris, in a steep channel (Hungr et al., 2001). The sediment may, furthermore, be transported in the form of massive surges, leaving sheets of poorly sorted debris ranging from sand to cobbles or small boulders. Sediment surges in debris floods are propelled by the tractive forces of water overlying the debris, and flow velocities are comparable to those of water floods. The discharge of debris floods is commonly 2 to 5 times higher than that of 200-year return period water floods (Jakob and Jordan, 2001).

DEBRIS FLOOD OCCURRENCE

Debris floods are a poorly understood process because they are rarely directly observed. While they can be caused by a variety of processes, the most commonly observed processes are breaches of temporary stream blockages caused by tributary debris flows or other landslide types. In such scenarios, debris flood discharge depends strongly on the composition and geometry of the landslide dam and the geometry of the floodplain downstream. The latter will determine the degree to which the debris flood will attenuate before reaching the point of interest (i.e. development). Therefore, the typical range for debris flood discharge of 2 to 5 times the 200-year return period peak water flood (Q_{200}) should only be used as a preliminary guideline (Hungr et al. 2001, Jakob and Jordan, 2001). In extreme cases, debris flood discharge may be more than five times the Q_{200}.

DEBRIS FLOW OCCURRENCE

Occurrences of debris flows in the B.C. Coast Mountains have been well documented since the early 1980's following a number of high profile events along the Squamish Highway. Debris flows tend to occur in wet weather, but are not necessarily coincident with record rainfall or flood events. Debris flow occurrence can be described by three consecutive processes as follows:

- *Initiation* where a mass movement is triggered at the source area in the creek headwaters. Possible trigger mechanisms include debris slides, logjam release, flood surges, and creek bed instability.

- *Transport* of the debris flow down the creek channel. The transport zone is typically scoured as the debris flow grows in size. A straight and uniformly steep gradient channel represents the most favourable transport condition.

- *Deposition* where either the channel becomes laterally unconfined, or the creek gradient flattens to the point that there is insufficient energy for continued movement. Depositional landforms are known as creek fans. Damage in creek fan areas during debris flow deposition can be catastrophic. The nature of the deposited material is highly variable, but typically covers a wide range from mud to boulders, and usually also includes a significant wood debris component. Debris flow deposition may also result in flooding of adjacent areas as a result of subsequent relocation of the creek channel.

DEBRIS FLOW PROBABILITY

While significant floods occur virtually every year on a creek system, debris flows are usually an intermittent occurrence. Typical debris flow recurrence intervals range from 5 to 50 years; however, this is highly variable. Debris flow occurrence can be put into perspective by considering geomorphological processes since the most recent glaciation about 10,000 years ago. In the centuries following glaciation, the landscape was unforested and littered with glacial debris. Debris flow activity is believed to have been considerably higher than today during this period. As the landscape became forested and watersheds stabilized, debris production and debris flow activity gradually decreased on a regional basis. However, debris flow activity may increase for any particular watershed as a result of natural or anthropogenic watershed instability. There is also reason to believe that if the present trend of increasingly wetter conditions in coastal areas continues, debris flow occurrence will increase in frequency and possibly magnitude.

In general, the frequency of debris flows on a particular creek is a function of:

- availability of debris supply sources that contribute materials to the main creek channel and its tributaries (necessity to differentiate drainage basins between material supply-limited vs. material supply-unlimited);
- degree of instability and level of activity of the debris supply sources;
- characteristics of the debris supply source (fine vs. coarse material, consolidated vs. unconsolidated);
- existence of potential triggers of debris flows (debris slides, rockfall, avalanches);

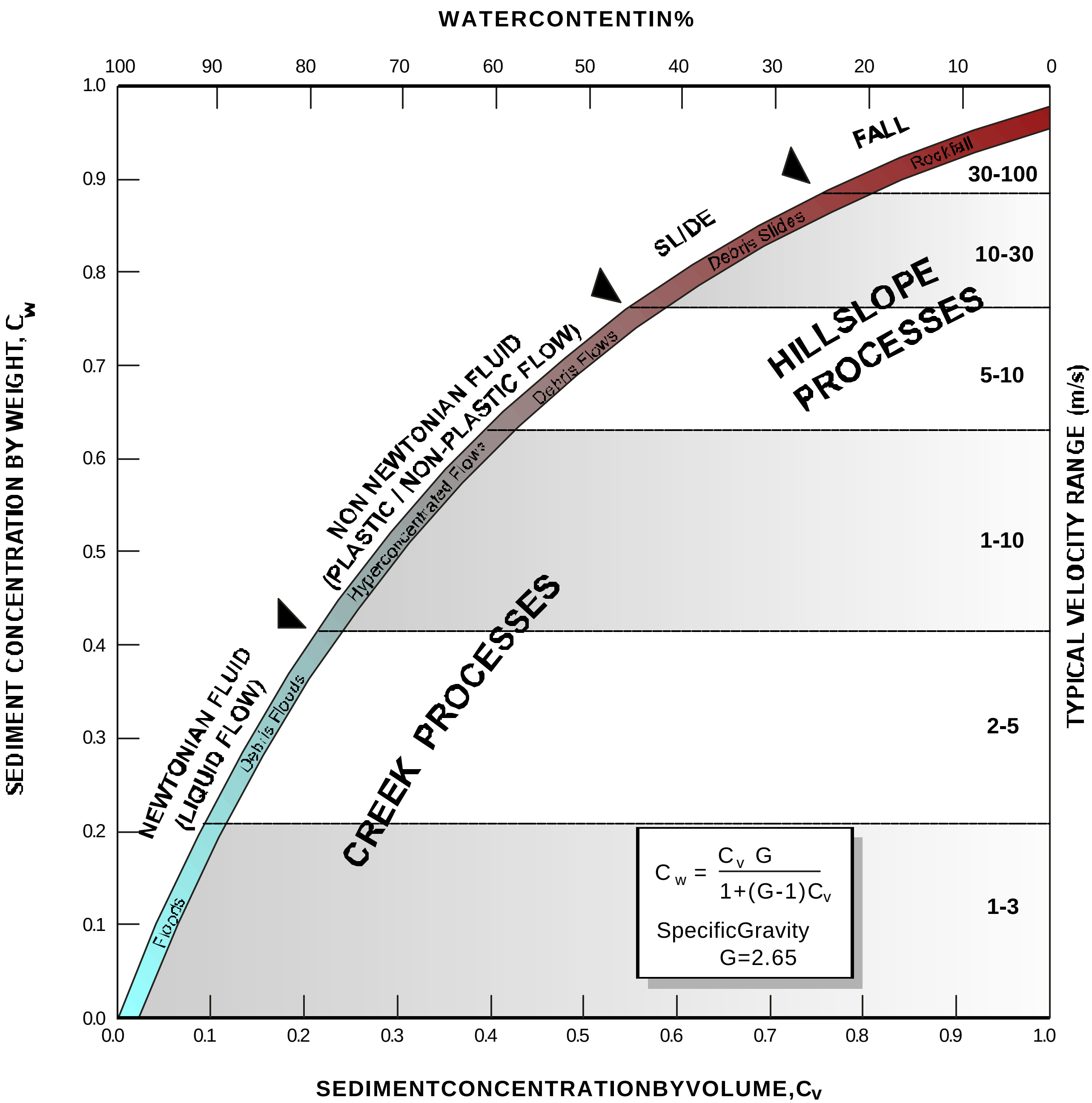
- capability of a creek channel to transport a debris flow (gradient, channel cross-section, longitudinal profile, channel roughness); and
- frequency of hydroclimatic events that have the capability of triggering debris flows.

As debris accumulates, a system gradually becomes "ripe" for a debris flow. The rate at which debris accumulates in a channel is a function of basin type.

BASIN TYPES

Recent research (Jakob, 1996) has identified two distinctly different basin types. One type, referred to as weathering-limited or supply-limited, is characterized by those basins that have a limited source of sediment and thus require recharge after a debris flow event for the next one to occur. In other words, even an exceptionally intensive storm will not trigger a debris flow if not enough sediment has accumulated to produce a debris flow. The other basin type is referred to as transport-limited or supply-unlimited. In those basins, there is a quasi-infinite amount of sediment available for transport and a debris flow can be triggered as soon as a critical climatic threshold (rainfall, rain-on-snow) is exceeded.

From the above description, it is clear that transport-limited basins experience a higher frequency of debris flows than weathering-limited basins. Examples for transport-limited basins are young volcanic complexes that rapidly shed material into the channel system, or basins with massive Quaternary deposits in the source area of debris flows. Weathering-limited basins are found primarily in slow weathering plutonic rock of the Coast Mountains.



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Classification of Mass Movement Processes

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Figure A-1

Appendix B

Report Excerpts for Mackay Creek

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EXECUTIVE SUMMARY

An Overview Report on Debris Flow Hazards was completed for the District of North Vancouver in April 1999 to identify the potential debris flow and debris flood hazards associated with the many creeks in the District. Following submission of the Overview Report, detailed debris flow and debris flood studies were initiated on several high risk creeks, including Mackay Creek which is the subject of this report. The risk at Mackay Creek is due to the combination of a significant debris flow hazard, and the presence of a large urban development and the Grouse Mountain base area. Reference is also made to Grouse Creek in this study in view of the fact that its fan overlaps the northern corner of Mackay Creek fan.

The study concludes that Mackay Creek is subject to frequent small debris flows and periodic large debris flows. The estimated debris flow magnitude for design purposes (a 500-year return period) is a volume of 27,000 m^3 with a peak discharge of approximately 170 m^3/s. Without debris flow mitigation structures, a debris flow of this size would cause considerable damage to houses and other infrastructure.

Grouse Creek is also considered subject to debris flows on the return periods established for design. A debris flow at Grouse Creek could avulse at the fan apex and follow an overflow channel towards the northwest corner of the Grouse Mountain base area. The estimated debris flow magnitude for preliminary design purposes is a volume of 9,000 m^3 and a peak discharge of 180 m^3/s.

The existing level of risk is rated medium high at both Mackay Creek and Grouse Creek. The target level of risk is medium low, and considerable mitigative measures are required to achieve this level.

A wide range of mitigative alternatives have been considered, including land use planning, warning systems, watershed management actions and debris flow mitigation structures. Mitigation of the hazard to any reasonable level will require the implementation of a debris flow mitigation strategy. Section 3 of this report provides concept drawings and cost estimates for several possible alternative structures. Effective mitigation of the debris flow risk could cost $2.4 million at Mackay Creek and $570,000 at Grouse Creek. There may be the possibility of partially mitigating the risk at Mackay Creek by constructing smaller structures at a lower cost as an initial phase of a long-term program.

Section 4 outlines an approach to implementation of hazard mitigation if the District wishes to proceed in this direction. As a first step, this would involve consultation with Grouse Mountain Resorts, the Greater Vancouver Regional District, BC Hydro, residents and other stakeholders prior to selecting an alternative for implementation.

5. SUMMARY AND RECOMMENDATIONS

5.1 SUMMARY

The key points in this report are summarized as follows:

MACKAY CREEK AND GROUSE CREEK

1. For the purpose of this report, Mackay Creek is defined as the watershed upstream of the fan apex. The total watershed areas is 0.45 km^2.

2. Although Mackay Creek is the primary focus of this report, Grouse Creek is also considered due to the fact that its fan overlaps the Mackay Creek fan. Grouse Creek has a watershed area of 0.3 km^2.

3. Both watersheds have very steep sections that actively shed rocks, along with steep slopes that are subject to debris slides that could trigger debris flows.

HAZARD ASSESSMENT

4. Appendix D provides a hydrologic analysis which results in the following 200-year return period peak instantaneous flood flow estimates:

Mackay Creek	4 m^3/s
Grouse Creek	2.5 m^3/s

5. A watershed investigation has been performed to identify potential debris flow trigger mechanisms and determine the amount of available debris. A detailed watershed map has been produced (Figure 2-1) to document geomorphological conditions.

6. Appendix E provides an analysis of debris floods and debris flows, resulting in the following 500-year return period (10% chance in 50 years) magnitude estimates:

	Event Type	Peak Discharge	Volume
Mackay Creek	Debris Flow	170 m^3/s	27,000 m^3
Grouse Creek	Debris Flow	180 m^3/s	9,000 m^3

7. Mackay Creek is considered subject to infrequent large debris flows with long runout distance, and smaller debris flows on a decadal time scale with short runout distance. The most significant hazard component arises from deep scour on the fan during a debris flow.

8. Grouse Creek is considered subject to infrequent debris flows of moderate size and small debris flows on a decadal time scale.

9. While the 500-year return period events provide a reasonable basis for design, the potential impact of smaller and larger events also needs to be considered.

RISK ASSESSMENT PROCEDURE

10. For the purpose of this report, risk is defined as the combination of hazard probability and potential consequence (i.e., vulnerability to damage should an event occur).

11. Hazard probability is classified as ranging from low to very high, and can be estimated in terms of magnitude and peak discharge for each classification.

12. The consequence of a debris flow depends on the size of the event and on conditions in the developed area. Consequence can be classified on a similar system as hazard probability (i.e. low to very high).

13. Debris flow runout modelling has been performed at Mackay Creek to develop a hazard map that allows the fan area to be classified in terms of potential debris impact, flow depth and flow velocity (Figure 2-2).

DEBRIS FLOW CONSEQUENCE AND RISK AT MACKAY CREEK

14. A major debris flow following the east channel of Mackay Creek is likely to cause damage in the Grousewoods Development. A major debris flow following the west channel of Mackay Creek is likely to cause structural damage to the Grouse Mountain base area. In either scenario, there is potential for loss of life.

15. Under existing conditions, the debris flow risk at Mackay Creek is rated as medium high for a 500-year return period debris flow.

DEBRIS FLOW CONSEQUENCE AND RISK AT GROUSE CREEK

16. A debris flow at Grouse Creek could avulse toward the upper parking lot of the Grouse Mountain base area and cause structural damage to existing buildings. There is potential for loss of life. Debris could also flow into Capilano Reservoir, adversely affecting water quality.

17. Under existing conditions at Grouse Creek, the debris flow risk is rated as medium high for a 500-year return period debris flow.

ALTERNATIVE STRATEGIES FOR HAZARD MITIGATION

18. A wide range of strategies for debris flow mitigation has been considered, including land use planning, warning systems, watershed management actions, and debris flow mitigation structures.

19. While land use planning, warning systems and watershed management actions may have some beneficial effect, effective mitigation of the Mackay Creek and Grouse Creek debris flow hazard will require construction of mitigation structures.

20. Alternative types of debris flow structures for consideration at Mackay Creek include debris basins, debris barriers, deflection berms, creek works and channelization. Section 3 provides a review of the applicability of each of these alternatives, along with concept plans and construction cost estimates.

21. The most promising alternative for mitigation of the debris flow risk at Mackay Creek appears to be a combination of debris barrier, deflection berm, debris basin, and creek works. The cost would be approximately $2.4 million, depending on the extent of supplemental works to protect the Grouse Mountain base area.

22. The debris flow risk at Grouse Creek can be mitigated by a deflection berm on the creek fan at a cost of approximately $570,000.

23. The objective in implementing debris flow mitigation measures would be to reduce the overall level of risk (i.e. the residual risk) to at least medium low. Regardless of the alternative chosen, there will always remain at least some level of residual risk.

24. The proposed mitigation of the debris flow hazard on Mackay Creek and Grouse Creek will also mitigate the 200-year return period floods on these creeks in the vicinity of the study area, but not to all downstream areas.

25. Consideration could be given to placing warning signs on hiking trails on the Mackay Creek fan.

26. It would be appropriate to perform periodic watershed monitoring to identify major watershed instabilities.

IMPLEMENTATION PLAN

27. Section 4 provides a basis for implementation of mitigative measures, should the District decide to proceed in this direction.

28. Consultation with residents and stakeholders should precede selection of an option for implementation.

29. For any option selected, land acquisition issues would need to be considered and alternative funding mechanisms reviewed. A policy for ownership of the constructed works (by the District or others) would also need to be developed.

30. Detailed design drawings and construction specifications would need to be prepared for the selected alternative. Environmental issues would need to be addressed under the environmental approval process.

31. Regular post-construction maintenance would need to be undertaken. Major maintenance work would be required after a debris flow event.

LAND USE PLANNING CONSIDERATIONS

32. In the absence of mitigative measures, changes in land use through rezoning and subdivision are not advisable until the risk is fully mitigated.

33. Following effective hazard mitigation, some further development on the fan may be possible.

5.2 RECOMMENDATIONS

It is recommended that the District disseminate the results of this study as follows:

1. Advise property owners and residents on the Mackay Creek / Grouse Creek fan regarding the contents of this report.

2. Submit copies of this report to the following organizations:

   - B.C. Ministry of Water, Land and Air Protection;
   - the Greater Vancouver Regional District;
   - Grouse Mountain Resorts;
   - BC Hydro; and
   - the City of North Vancouver.

It is also recommended that the District proceed directly with risk mitigation actions as follows:

3. Work with Grouse Mountain Resorts and the Greater Vancouver Regional District regarding watershed management issues, with a view to reducing the risk of future instabilities.

4. Work with Grouse Mountain Resorts, the Greater Vancouver Regional District and BC Hydro toward implementation of appropriate mitigative measures for the Grouse Mountain base area.

5. Ensure that site-specific mitigative measures are incorporated into any land development approvals (building permit, etc.) that are issued in the mapped creek hazard areas.

6. Consider the possibility of placing warnings signs at trail locations on the Mackay Creek fan as part of a broader initiative by the District.

If the District decides to implement debris flow structures at Mackay Creek and/or Grouse Creek, then it is further recommended that the District:

7. Consult with residents and stakeholders prior to selecting a preferred alternative for implementation.

8. Make arrangements for construction of mitigative measures, including:

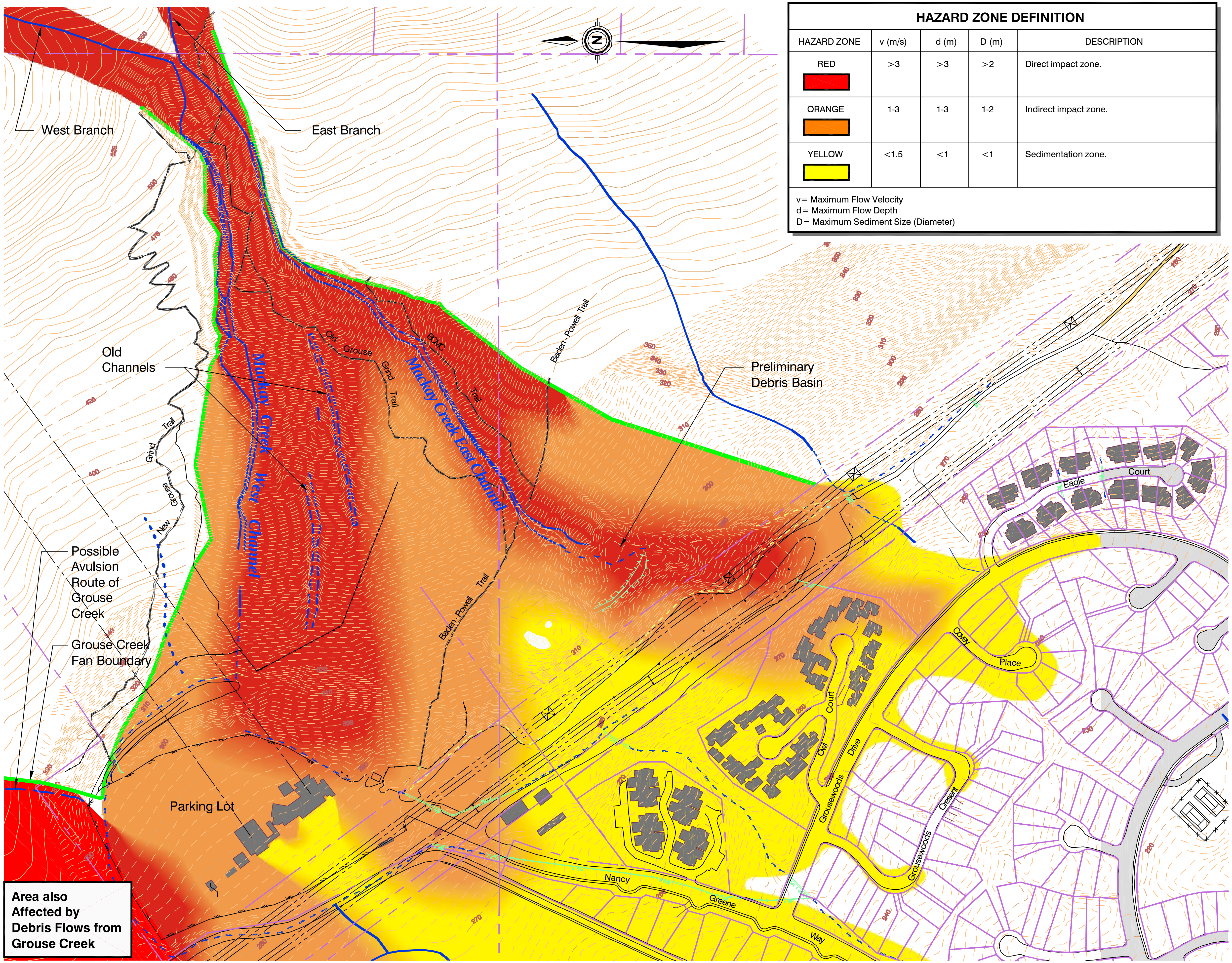
   - develop an appropriate funding mechanism;
   - determine future ownership of the works;
   - acquire any necessary property or right-of-way; and
   - establish maintenance requirements and responsibility.

9. Complete engineering design of mitigative works, with attention to environmental protection requirements, and with input from both residents and stakeholders.

10. Proceed with construction and follow up with post-construction monitoring.

In the event that the District does not proceed with implementation of mitigative measures at Mackay Creek or Grouse Creek in the short-term, as a minimum it is recommended that the District:

11. Perform periodic monitoring of both watersheds to identify future instabilities, which may warrant further public advisory or reconsideration of debris flow structures.



HAZARD ZONE DEFINITION

HAZARD ZONE	v (m/s)	d (m)	D (m)	DESCRIPTION
RED	>3	>3	>2	Direct impact zone.
ORANGE	1-3	1-3	1-2	Indirect impact zone.
YELLOW	<1.5	<1	<1	Sedimentation zone.

v= Maximum Flow Velocity
d= Maximum Flow Depth
D= Maximum Sediment Size (Diameter)

District of North Vancouver
Debris Flow Study and
Risk Mitigation Alternatives for
Mackay Creek

Legend

- Building
- Property Boundary
- Approximate Fan Boundary
- Contour Line
- Hydro Tower

Notes:

1. Topography on the Mackay Creek fan above the power transmission line is from a KWL ground survey.
2. 5 m contours outside the fan area are based on photogrammetry and are approximate only.
3. 1 m contours elsewhere are provided by the District.
4. Property lines are based on cadastral information provided by the District.
5. No buildings are indicated on lots south of Grousewoods Drive and west of Nancy Greene Way.
6. The model is calibrated for the November 25, 1995 debris flow at Upper Mackay Creek.
7. The hazard map is based on the medium probability debris flow events (500 - year return period) on Mackay Creek and Grouse Creek.

KERR WOOD LEIDAL associates limited CONSULTING ENGINEERS

100 0 100
Scale in Metres

Project No.	Date
31.265	December 2003

Debris Flow Hazard Map for Mackay Creek

Figure 2-2

Dec. 10/03
031-265\Drawings\Fig2-2.dwg

Appendix C

Report Excerpts for Mosquito Creek

KERR WOOD LEIDAL
associates limited
CONSULTING ENGINEERS

EXECUTIVE SUMMARY

An Overview Report on Debris Flow Hazards was completed for the District of North Vancouver in April 1999 to identify the potential debris flow and debris flood hazards associated with the many creeks in the District. Following submission of the Overview Report, detailed debris flow and debris flood studies were initiated on several high risk creeks, including Mosquito Creek which is the subject of this report. The risk at Mosquito Creek is due to the combination of a significant hazard and the presence of numerous houses along the creek corridor.

The study concludes that the upper reaches of Mosquito Creek are not subject to debris flows on the return periods established for design. While debris flows may reach the Mosquito Creek channel and even travel some distance downstream, they are not likely to reach the fan area. However, Mosquito Creek is subject to periodic large debris flood events. The estimated debris flood magnitude for design purposes (a 500-year return period) is a volume of 10,000 m^3 with a peak discharge of approximately 250 m^3/s. Without debris flood mitigation structures, a debris flood of this size could cause considerable damage to houses and other infrastructure.

The existing level of risk at Mosquito Creek is rated high. The target level of risk is medium low, and considerable mitigative measures would be required to achieve this level.

A wide range of mitigative alternatives have been considered, including land use planning, warning systems, watershed management actions, debris flood mitigation structures (debris basin, debris barrier, channelization and deflection berms), and creek management measures. While land use planning, warning systems, watershed actions, and creek management measures may have some positive effects, mitigation of the hazard to any reasonable level will require the construction of one or more mitigation structures. Section 3 of this report provides concept drawings and cost estimates for several possible alternative structures. A preferred alternative is suggested (a combination of debris barriers, channel works, and culvert daylighting) at a cost of roughly $6 million (or more if a new bridge is constructed at Queens Avenue).

Section 4 outlines an approach to implementation of hazard mitigation if the District wishes to proceed in this direction. As a first step, this would involve consultation with residents and stakeholders prior to selecting an alternative for implementation.

5. SUMMARY AND RECOMMENDATIONS

5.1 SUMMARY

The key points in this report are summarized as follows:

MOSQUITO CREEK SYSTEM

1. Upper Mosquito Creek is defined as the watershed upstream of the fan apex (near the Baden-Powell footbridge). The upper watershed area is 4.3 km^2. However, the report does consider reaches of Mosquito Creek down to West Queens Road.

2. Key features in the upper watershed are convex slopes on both sides of Mosquito Creek that are incised by gullies that actively shed debris into the channel, the ski area of Grouse Mountain, and steep slopes with thin soils susceptible to debris slides.

HAZARD ASSESSMENT

3. Appendix D provides a hydrologic analysis which results in the following 200-year return period peak instantaneous flood flow estimates:

Mosquito Creek	22 m^3/s

4. A watershed investigation has been performed to identify potential debris flood trigger mechanisms and determine the amount of available debris. A detailed watershed map has been produced (Figure 2-1) to document geomorphological conditions.

5. Appendix E provides an analysis of debris floods and debris flows, resulting in the following 500-year return period (10% chance in 50 years) magnitude estimates:

	Event Type	Peak Discharge	Volume
Mosquito Creek	Debris Flood	250 m^3/s	10,000 m^3

6. Mosquito Creek is considered subject to infrequent large debris floods, and more frequent floods. Debris flows are possible in the upper watershed but are unlikely to reach the fan area.

7. While the 500-year return period event provides a reasonable basis for design, the potential impact of smaller and larger events also needs to be considered.

RISK ASSESSMENT PROCEDURE

8. For the purpose of this report, risk is defined as the combination of hazard probability and potential consequence (i.e. vulnerability to damage should an event occur).

9. Hazard probability is classified as ranging from low to very high, and can be estimated in terms of magnitude and peak discharge for each classification.

10. The consequence of a debris flood depends on the size of the event and on conditions in the developed area. Consequence can be classified on a similar system as hazard probability (i.e. low to very high).

11. A hazard map has been developed for the Mosquito Creek fan that allows the fan area to be classified in terms of potential debris impact, flow depth, and flow velocity (Figure 2-2).

DEBRIS FLOOD CONSEQUENCE AND RISK AT MOSQUITO CREEK

12. A major debris flood at Mosquito Creek is likely to damage the Baden-Powell trail footbridge and the Montroyal Boulevard bridge. The design debris flood is likely to spill out of the channel at several locations and cause severe bank erosion. The diversion culvert inlet at Evergreen Basin is likely to become obstructed, resulting in an uncontrolled flood overflow.

13. Under existing conditions at Mosquito Creek, the debris flood risk is rated as high for a 500-year return period event.

ALTERNATIVE STRATEGIES FOR HAZARD MITIGATION

14. A wide range of strategies for debris flood mitigation has been considered, including land use planning, warning systems, watershed management actions, and debris flood mitigation structures.

15. While land use planning, warning systems, and watershed management actions may have some beneficial effect, effective mitigation of the hazard will require construction of a debris flood mitigation structure.

16. Alternative debris flood structures considered at Mosquito Creek include debris basins, debris barriers, deflection berms, channelization, and daylighting of the culverted creek section. Section 3 provides a review of the applicability of each of these alternatives, along with concept plans and construction cost estimates for some possible configurations. A combination of two debris barriers with channel works and culvert daylighting appears to be the most promising debris flood mitigation measure at Mosquito Creek.

17. The objective in implementing debris flood mitigation measures would be to reduce the overall level of risk (i.e. the residual risk) to at least medium low. Regardless of the alternative chosen, there will always remain at least some level of residual risk.

18. The proposed mitigation of the debris flood hazard on Mosquito Creek will also mitigate the 200-year return period flood.

19. Consideration could be given to implementing a post-event warning system and possibly warning signs at Montroyal Boulevard bridge.

20. It would be appropriate to perform periodic watershed monitoring to identify major watershed instabilities.

IMPLEMENTATION PLAN

21. Section 4 provides a basis for implementation of mitigative measures, should the District decide to proceed in this direction.

22. Consultation with residents and stakeholders should precede selection of an option for implementation.

23. For any option selected, land acquisition issues would need to be considered and alternative funding mechanisms reviewed. A policy for ownership of the constructed works (by the District or others) would also need to be developed.

24. Detailed design drawings and construction specifications would need to be prepared for the selected alternative. Environmental issues would need to be addressed under the environmental approval process.

25. Regular post-construction maintenance would need to be undertaken. Major maintenance work would be required after a debris flood event.

LAND USE PLANNING CONSIDERATIONS

26. In the absence of mitigative measures, changes in land use through rezoning and subdivision are not advisable until the risk is fully mitigated.

27. Following effective hazard mitigation, some further development on the fan may be possible.

5.2 RECOMMENDATIONS

It is recommended that the District disseminate the results of this report as follows:

1. Advise property owners and residents along Mosquito Creek hazard regarding the contents of this report.

2. Submit copies of this report to the following organizations:

    - B.C. Ministry of Water, Land and Air Protection;
    - City of North Vancouver; and
    - Grouse Mountain Resorts.

It is also recommended that the District proceed directly with risk mitigation actions as follows:

3. Work with Grouse Mountain Resorts regarding watershed management issues, with a view to mitigating existing instabilities and reducing the risk of future instabilities.

4. Ensure that site-specific mitigative measures are incorporated into any land development approvals (building permit, etc.) that are issued in the mapped creek hazard area.

5. Consider the installation of warning signs and a post-event warning system at Montroyal Boulevard bridge.

6. Continue the current level of channel maintenance work as a minimum, and consider further upgrading of the channel works to reflect the debris flood hazard.

7. Consider the possiblity of placing warning signs at the Mosquito Creek trail crossings as part of a broader initiative by the District.

8. Work with the North Vancouver Fire Department to review the existing mitigative works and assess the need for additional works.

If the District decides to implement debris flood structures at Mosquito Creek, then it is further recommended that the District:

9. Consult with residents and stakeholders prior to selecting a preferred alternative for implementation.

10. Make arrangements for construction of mitigative measures, including:

    - develop an appropriate funding mechanism;
    - determine future ownership of the works;
    - acquire any necessary property or right-of-way; and
    - establish maintenance requirements and responsibility.

11. Acquire adequate right-of-way through the diversion culvert area to facilitate a future channel daylighting project.

12. Complete engineering design of mitigative works, with attention to environmental protection requirements, and with input from both residents and stakeholders.

13. Proceed with construction and follow up with post-construction monitoring.

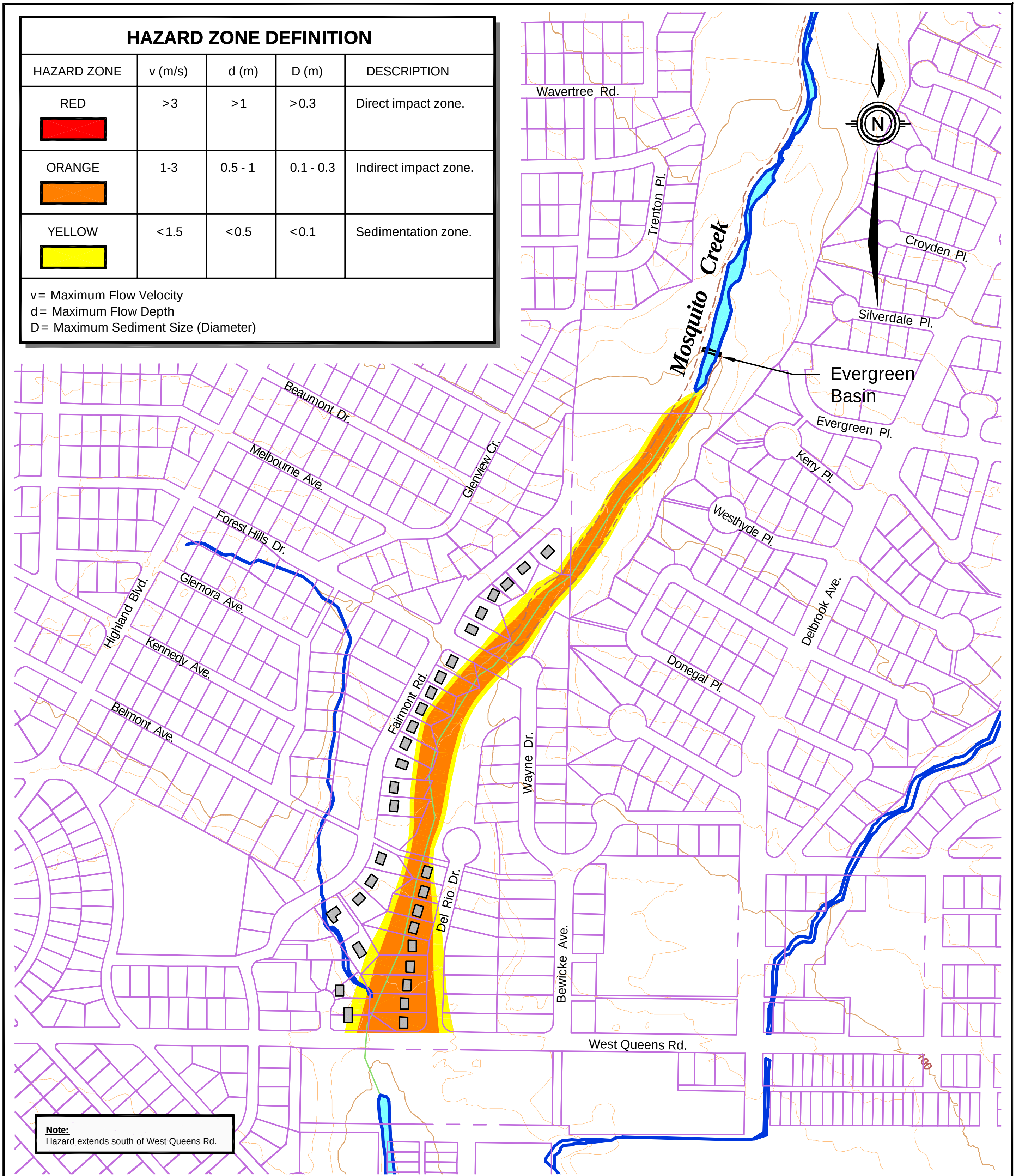
In the event that the District does not proceed with implementation of mitigative measures at Mosquito Creek in the short term, as a minimum it is recommended that the District:

14. Perform periodic monitoring of the Mosquito Creek watershed to identify future instabilities, which may warrant further public advisory or reconsideration of debris flood structures.

HAZARD ZONE DEFINITION

HAZARD ZONE	v (m/s)	d (m)	D (m)	DESCRIPTION
RED	>3	>1	>0.3	Direct impact zone.
ORANGE	1-3	0.5 - 1	0.1 - 0.3	Indirect impact zone.
YELLOW	<1.5	<0.5	<0.1	Sedimentation zone.

v = Maximum Flow Velocity
d = Maximum Flow Depth
D = Maximum Sediment Size (Diameter)



KERR WOOD LEIDAL associates limited CONSULTING ENGINEERS

District of North Vancouver
Debris Flood Study and Risk Mitigation Alternatives for Mosquito Creek

Project No.	Date
31.264	December 2003

150 0 150
Scale in Metres

Flood Hazard Map for Mosquito Creek

Figure 2-2

Dec. 9/03
\031-264\Drawings\Fig2-2.dwg

Appendix D

Report Excerpts for Deep Cove Creeks

KERR WOOD LEIDAL
associates limited
CONSULTING ENGINEERS

EXECUTIVE SUMMARY

An Overview Report on Debris Flow Hazards was completed for the District of North Vancouver in April 1999 to identify the potential debris flow and debris flood hazards associated with the many creeks in the District. Following submission of the Overview Report, detailed debris flow and debris flood studies were initiated on several high risk creeks, including the Deep Cove creeks that are the subject of this report. The Deep Cove creeks include Panorama Creek, Mathews Creek, Gavles Creek, Cove Creek, Cleopatra Creek, Martin Creek and Francis Creek. The risks at these creeks are due to a debris flow or debris flood hazard and the presence of dense development along Panorama Drive.

The study concludes that the Deep Cove creeks are typically subject to periodic debris floods. The estimated debris flood magnitudes for design purposes (a 500-year return period) are a volume ranging from 100 m^3 to 250 m^3 with a peak discharge ranging from 3 m^3/s to 10 m^3/s. Exceptions are Martin Creek and Francis Creek which can produce debris flows at the 500-year return period. The estimated design debris flow magnitude on Francis Creek is a volume of 1,000 m^3 and a peak discharge of 25 m^3/s. Debris flows on Francis Creek can also overflow into Martin Creek, therefore Martin Creek is considered subject to debris flows of about the same magnitude as Francis Creek. Without mitigation structures, debris floods and debris flows on the study creeks could cause damage to houses, road crossings and other infrastructure.

The existing level of risk is rated medium high for Panorama Creek, Mathews Creek, Gavles Creek, Cove Creek and Cleopatra Creek, high for Francis Creek, and medium for Martin Creek. The target level of risk is moderately low, and mitigative measures would be required at the Deep Cove creeks to achieve this level.

A wide range of mitigative alternatives have been considered, including land use planning, watershed actions, debris flow mitigation structures (debris basin, debris barrier, channelization and deflection berms), and creek management measures.

At Francis Creek, risk mitigation would likely involve construction of a deflection berm (to prevent an avulsion into Martin Creek), a second smaller deflection berm to protect a house, a 2,000 m^3 debris basin above Indian River Drive, upgrading of the Indian River Drive culvert, and downstream channel works at the Deep Cove Marina. The combined cost of the works at Francis Creek would be about $1.4 million.

With the Francis Creek deflection berm, no migitative measures would be needed at Martin Creek. Mitigation of the risk at Panorama Creek, Mathews Creek, Gavles Creek, Cove Creek and Cleopatra Creek would involve debris barriers above the Panorama Drive development, along with various channel works. The cost of the mitigative works at these creeks would range from $300,000 to $500,000 per creek.

The combined cost of hazard mitigation for all the Deep Cove creeks would be roughly $3.1 million.

4. SUMMARY AND RECOMMENDATIONS

4.1 SUMMARY

The key points in this report are summarized as follows:

DEEP COVE CREEKS

1. For the purposes of this report, the Deep Cove creeks refer to Panorama Creek, Mathews Creek, Gavles Creek, Cove Creek, Cleopatra Creek, Martin Creek and Francis Creek.

2. Key features in the watersheds are Mount Seymour Road, Indian River Drive, and dense housing development along Panorama Drive.

HAZARD ASSESSMENT

3. There are several locations where interflow may occur between the various creek systems. These represent both natural and anthropogenic conditions where the creek channels may shift as a result of erosion or deposition.

4. Appendix D provides a hydrologic analysis that results in the following 200-year return period peak instantaneous flood flow estimates:

Creek	Peak Flow
Panorama Creek	4.2 m^3/s
Mathews Creek	4.5 m^3/s
Gavles Creek	2.4 m^3/s
Cove Creek	4.0 m^3/s
Cleopatra Creek	1.5 m^3/s
Martin Creek	3.1 m^3/s
Francis Creek	9.0 m^3/s

The above peak flow estimates provide some allowance for interflow between watersheds where this is considered to be likely.

5. A watershed investigation has been performed to identify potential debris flow and debris flood trigger mechanisms and determine the amount of available debris. A detailed watershed map has been produced (Figure 2-1) to document geomorphological conditions.

6. Appendix E provides an analysis of debris floods and debris flows, resulting in the following 500-year return period (10% chance in 50 years) magnitude estimates:

Creek	Event Type	Peak Discharge	Volume
Panorama Creek	Debris Flood	10 m^3/s	200 m^3
Mathews Creek	Debris Flood	9 m^3/s	150 m^3
Gavles Creek	Debris Flood	8 m^3/s	250 m^3
Cove Creek	Debris Flood	10 m^3/s	250 m^3
Cleopatra Creek	Debris Flood	4 m^3/s	100 m^3
Martin Creek	Debris Flow	25 m^3/s	1,000 m^3
Francis Creek	Debris Flow	25 m^3/s	1,000 m^3

7. While the 500-year return period events provide a reasonable basis for design, the potential impact of smaller and larger events also needs to be considered.

RISK ASSESSMENT PROCEDURE

8. For the purpose of this report, risk is defined as the combination of hazard probability and potential consequence (i.e. vulnerability to damage should an event occur).

9. Hazard probability is classified as ranging from low to very high, and can be estimated in terms of magnitude and peak discharge for each classification.

10. The consequence of a debris flow or debris flood depends on the size of the event and on conditions in the developed area. Consequence can be classified on a similar system as hazard probability (i.e. low to very high).

DEBRIS FLOOD CONSEQUENCE AND RISK AT PANORAMA CREEK, MATHEWS CREEK, GAVLES CREEK, COVE CREEK AND CLEOPATRA CREEK

11. A major debris flood on any of the Deep Cove creeks could result in direct or indirect debris impact to houses on Panorama Drive.

12. Under existing conditions, the debris flood risk is rated as medium high for a 500-year return period debris flood.

DEBRIS FLOW CONSEQUENCE AND RISK AT FRANCIS CREEK AND MARTIN CREEK

13. A major debris flow at Francis Creek could cause structural damage to buildings at the Deep Cove Marina and indirect debris impact to a house located upstream of Indian River Drive. A debris flow is also likely to cause damage to Indian River Drive. There is potential for loss of life.

14. A debris flow avulsion from Francis Creek to Martin Creek could result in direct or indirect damage to houses on Panorama Dive. There is potential for loss of life.

15. Under existing conditions, the debris flow risk is rated as high at Francis Creek and medium at Martin Creek for a 500-year return period debris flow.

ALTERNATIVE STRATEGIES FOR HAZARD MITIGATION

16. A wide range of strategies for debris flood and debris flow mitigation have been considered, including land use planning, warning systems, watershed management actions, and mitigative structures.

17. Watershed stabilization activities, incorporating bioengineering methods would be appropriate for some watershed areas.

18. Further development on Panorama Drive near creek channels should be subject to site-specific investigations to determine the need for mitigative measures, followed by implementation of any necessary measures.

19. A comprehensive culvert assessment should be undertaken for Mount Seymour Road, with a view to reducing the risk of culvert blockage and flood interflow between watersheds.

20. For the debris flood creeks (Panorama Creek, Mathews Creek, Gavles Creek, Cove Creek and Cleopatra Creek), risk mitigation would involve debris barriers above the Panorama Drive development and various channel works. These measures would cost between $300,000 and $500,000 per creek.

21. The debris flow risk at Francis Creek could be mitigated by construction of a 2,000 m^3 debris basin upstream of Indian River Drive. Additional works may include a deflection berm to prevent avulsion to Martin Creek, a second minor deflection berm to protect a house near Indian River Drive, upgrading the Indian River Drive culvert, and channel works at the Deep Cove Marina. The combined cost of these works at Francis Creek would be about $1.4 million.

22. With construction of the Francis Creek deflection berm, no mitigative measures would be required at Martin Creek.

23. The combined cost for risk mitigation at all the Deep Cove creeks would be about $3.1 million, not including any culvert upgrading that may be considered necessary on Mount Seymour Road.

24. The objective in implementing debris flow mitigation measures would be to reduce the overall level of risk (i.e. the residual risk) to at least medium low. Regardless of the alternative chosen, there will always remain at least some level of residual risk.

25. It would be appropriate to perform periodic watershed monitoring to identify major watershed instabilities.

4.2 RECOMMENDATIONS

It is recommended that the District disseminate the results of this study as follows:

1. Advise property owners and area residents regarding the contents of this report.

2. Submit copies of this report to the following agencies:

   - BC Ministry of Water, Land, and Air Protection;
   - BC Parks (with respect to operations at Mount Seymour Park); and
   - BC Ministry of Transportation (with respect to operation of Mount Seymour Road).

It is also recommended that the District proceed directly with risk mitigation actions as follows:

3. Restrict further development above the existing Panorama Drive development, unless detailed engineering studies conclude that such development can safely occur.

4. Ensure that appropriate site-specific mitigative measures are incorporated into any land development approvals (building permits, etc.) that are issued in the vicinity of the Deep Cove creeks.

5. Work with owners of the following key properties toward the implementation of on-site mitigative measures in the absence of comprehensive mitigative works: Panorama Creek (#2525), Mathews Creek (#2603), Gavles Creek (#2681, #2679), Cove Creek (#2735), and Cleopatra Creek (#2755). These properties are all situated above Panorama Drive and are at risk in the event of a medium probability debris flood.

6. Investigate alternative means for establishing an unobstructed channel on Gavles Creek at #2679 Panorama Drive.

7. Work with the BC Ministry of Transportation regarding completion of a comprehensive culvert assessment for Mount Seymour Road, followed by culvert upgrading as appropriate.

8. Consider posting warning signs on Indian River Drive to warn road users about the potential for creek hazards.

9. Consider the possibility of placing warning signs at the trail crossing as part of a broader initiative by the District.

If it is decided to implement mitigative measures at the Deep Cove creeks, then it is further recommended that the District:

10. Consult with residents and stakeholders prior to selecting a preferred alternative for implementation.

11. Make arrangements for construction of mitigative measures, including:

    - develop an appropriate funding mechanism;
    - determine future ownership of the works;
    - acquire any necessary property or right-of-way; and
    - establish maintenance requirements and responsibility.

12. Complete engineering design of mitigative works, with attention to environmental protection requirements, and with input from both residents and stakeholders.

13. Proceed with construction and follow up with post-construction monitoring.

In the event that mitigative measures are not implemented at the Deep Cove creeks in the short term, as a minimum it is recommended that the District:

14. Perform periodic monitoring of the watersheds to identify future instabilities that may warrant further public advisory or reconsideration of mitigative measures.

15. Consider the possible stabilization of key watershed areas.

Appendix E

Report Excerpts for
Ostler Creek and Allan Creek

KERR WOOD LEIDAL
associates limited
CONSULTING ENGINEERS

EXECUTIVE SUMMARY

An Overview Report on Debris Flow Hazards was completed for the District of North Vancouver in April 1999 to identify the potential debris flow and debris flood hazards associated with the many creeks in the District. Following submission of the Overview Report, detailed debris flow and debris flood studies were initiated on several high risk creeks, including Ostler Creek and Allan Creek that are the subject of this report. The risk at Ostler Creek and Allan Creek is a result of debris flow and debris flood hazards, coupled with development along the lower creek reaches.

The mainstem channels of Ostler Creek and Allan Creek are not considered prone to debris flows for return periods up to 500 years. However, both creeks are subject to debris floods. The design debris flood volume is estimated at 200 m^3, with an associated peak discharge of up to 24 m^3/s.

Allan Creek has two active tributaries (South Gully and North Gully) that are prone to debris flows. These gullies have developed in glacial materials and are actively eroding. In 1992 or 1993, a debris flow originated at the headwall of the North Gully and flowed across Firelane 7 eroding its fill slope. For the 500-year return period, larger debris flows may occur on these gullies, yielding volumes of up to 1,000 m^3 and peak discharges of 25 m^3/s. Indian River Drive and other downstream development would also be subject to damage during the design events.

Field investigations showed that there is a possibility of Allan Creek avulsing into Ostler Creek in the upper watershed and vice versa. Such avulsions would substantially increase the discharge in the receiving creek, increasing the downstream hazard. In addition, the South Gully (which is tributary to Allan Creek) could further entrench headward and eventually intercept Ostler Creek.

The hazard at Ostler Creek can be mitigated by constructing a debris barrier upstream of Firelane 7 and replacing the Firelane 7 culvert. Check dams downstream of Firelane 7 could also be constructed to stabilize the channel.

Mitigation of the risk at Allan Creek would involve building debris barriers above Firelane 7 at the mainstem channel and the two gully crossings, installing check dams below Firelane 7, replacing culverts at Indian River Drive and other road crossings, and performing minor channelization in the lower reaches. Some other alternatives could also be considered.

The total cost of risk mitigation is estimated at roughly \$0.6 million for Ostler Creek and \$2.5 million at Allan Creek, for a total of about \$3.1 million.

4. SUMMARY AND RECOMMENDATIONS

4.1 SUMMARY

The key points in this report are summarized as follows:

OSTLER CREEK

1. For the purpose of this report, Ostler Creek is defined as the watershed upstream of Indian Arm. The total watershed area is 1.2 km^2.

2. Key features in the watershed are Mount Seymour Park and Mount Seymour Road in the upper watershed, and two road crossings in the lower reaches.

ALLAN CREEK

3. For the purpose of this report, Allan Creek is defined as the watershed upstream of Indian Arm. The total watershed area is 1.0 km^2.

4. Key features in the watershed are Mount Seymour Park and Mount Seymour Road in the upper watershed and several culvert crossings in the lower reaches. There are also two unstable, actively eroding tributary gullies (South Gully and North Gully) that are prone to debris flows.

HAZARD ASSESSMENT

5. There are several locations where interflow may occur between the Ostler Creek and Allan Creek watersheds. These typically represent natural conditions where the creek channels may shift as a result of erosion or deposition.

6. Appendix D provides a hydrologic analysis which results in the following 200-year return period peak instantaneous flood flow estimates:

Ostler Creek	8 to 10 m^3/s
Allan Creek	6.5 to 8 m^3/s

A range of discharges is provided due to the possibility of interflow between the watersheds during storm events. The higher values should be used for design purposes.

7. A watershed investigation has been performed to identify potential debris flow and debris flood trigger mechanisms and determine the amount of available debris. A detailed watershed map has been produced (Figure 2-1) to document geomorphological conditions.

8. Appendix E provides an analysis of debris flows and debris floods, resulting in the following 500-year return period (10% chance in 50 years) magnitude estimates:

	Event Type	Peak Discharge	Volume
Ostler Creek and Allan Creek mainstem channels	Debris Flood	24 m^3/s	200 m^3
North and South Gully – Allan Creek	Debris Flow	25 m^3/s	1,000 m^3

9. Continued head scarp progression of the South Gully could result in the eventual interception of Ostler Creek.

10. While the 500-year return period event provides a reasonable basis for design, the potential impact of smaller and larger events also needs to be considered.

RISK ASSESSMENT PROCEDURE

11. For the purpose of this report, risk is defined as the combination of hazard probability and potential consequence (i.e. vulnerability to damage should an event occur).

12. Hazard probability is classified as ranging from low to very high, and can be estimated in terms of magnitude and peak discharge for each classification.

13. The consequence of a debris flow or debris flood depends on the size of the event and on conditions in the developed area. Consequence can be classified on a similar system as hazard probability (i.e. low to very high).

14. A hazard map has been developed for the lower fan of Ostler Creek and Allan Creek fan that allows the fan area to be classified in terms of potential debris impact, flow depth, and flow velocity (Figure 2-2).

DEBRIS FLOOD CONSEQUENCE AND RISK AT OSTLER CREEK

15. A debris flood at Ostler Creek is likely to obstruct and damage the culvert at Firelane 7, and possibly the crossing at Indian River Drive.

16. Under existing conditions at Ostler Creek, the debris flood risk is rated as medium for a 500-year return period event.

DEBRIS FLOW AND DEBRIS FLOOD CONSEQUENCE AND RISK AT ALLAN CREEK

17. A debris flood on the mainstem channel of Allan Creek is likely to obstruct and damage the culvert at Firelane 7 and may erode the road surface and fill. It could also impact Indian River Drive, several properties on the fan, and the other lower road crossings.

18. The two Allan Creek gullies (South Gully and North Gully) are susceptible to debris flows that could severely damage Firelane 7. A debris flow in either gully could also impact several downstream properties on the fan and lower road crossings.

19. Under existing conditions at Allan Creek, the debris flow risk is rated as medium high for a 500-year return period, and the debris flood risk is rated medium.

ALTERNATIVE STRATEGIES FOR HAZARD MITIGATION

20. A wide range of strategies for debris flow and debris flood mitigation has been considered, including land use planning, warning systems, watershed management actions, and debris flow mitigation structures.

21. The hazard at Ostler Creek can be mitigated by constructing a debris barrier upstream of Firelane 7 and replacing the Firelane 7 culvert. Check dams downstream of Firelane7 should also be constructed to stabilize the channel.

22. Full mitigation of the debris flow and debris flood risk at Allan Creek would involve stabilizing the North Gully and South Gully, building debris barriers above Firelane 7 at the mainstem channel and the two gully crossings, installing check dams below Firelane 7, replacing culverts at Indian River Drive and other crossings, and performing minor channelization in the lower reaches.

23. The total cost of risk mitigation is estimated at $2.5 million at Allan Creek and $0.6 million at Ostler Creek, for a total of $3.1 million.

24. The objective in implementing debris flow and debris flood mitigation measures would be to reduce the overall level of risk (i.e. the residual risk) to at least medium low. Regardless of the alternative chosen, there will always remain at least some level of residual risk.

25. Consideration could be given to placing signs on Firelane 7 and Indian River Drive to warn against creek hazards during wet weather.

26. It would be appropriate to perform periodic watershed monitoring to identify major watershed instabilities.

4.2 RECOMMENDATIONS

It is recommended that the District disseminate the results of this study as follows:

1. Advise property owners and users of Firelane 7 and Indian River Drive regarding the contents of this report.

2. Submit copies of this report to the following agencies:

   - BC Ministry of Water, Land and Air Protection;
   - BC Parks (with respect to operations at Mount Seymour Park); and
   - BC Ministry of Transportation (with respect to operation of Mount Seymour Road).

It is also recommended that the District proceed directly with risk mitigation actions as follows:

3. Ensure that appropriate site-specific mitigative measures are incorporated into any land development approvals (building permit, etc.) that are issued in the mapped creek hazard areas.

4. Mitigate the risks at Indian River Drive by replacing the culvert on Indian River Drive, stabilizing the creek channels between Firelane 7 and Indian River Drive, and possibly installing warning signs.

5. Work with the owners of Firelane 7, and other area residents toward the following:

   - installing debris barriers upstream of Firelane 7;
   - replacing the four culvert crossings of Firelane7;
   - installing warning signs; and
   - replacing the lower culverts on Allan Creek.

6. Work with the BC Ministry of Transportation regarding completion of a comprehensive culvert assessment for Mount Seymour Road, followed by culvert upgrading as appropriate.

If it is decided to implement mitigative measures at Ostler Creek and/or Allan Creek, then it is further recommended that the District:

7. Make arrangements for construction of mitigative measures, including:

   - develop an appropriate funding mechanism;
   - determine future ownership of the works;

- acquire any necessary property or right-of-way; and
- establish maintenance requirements and responsibility.

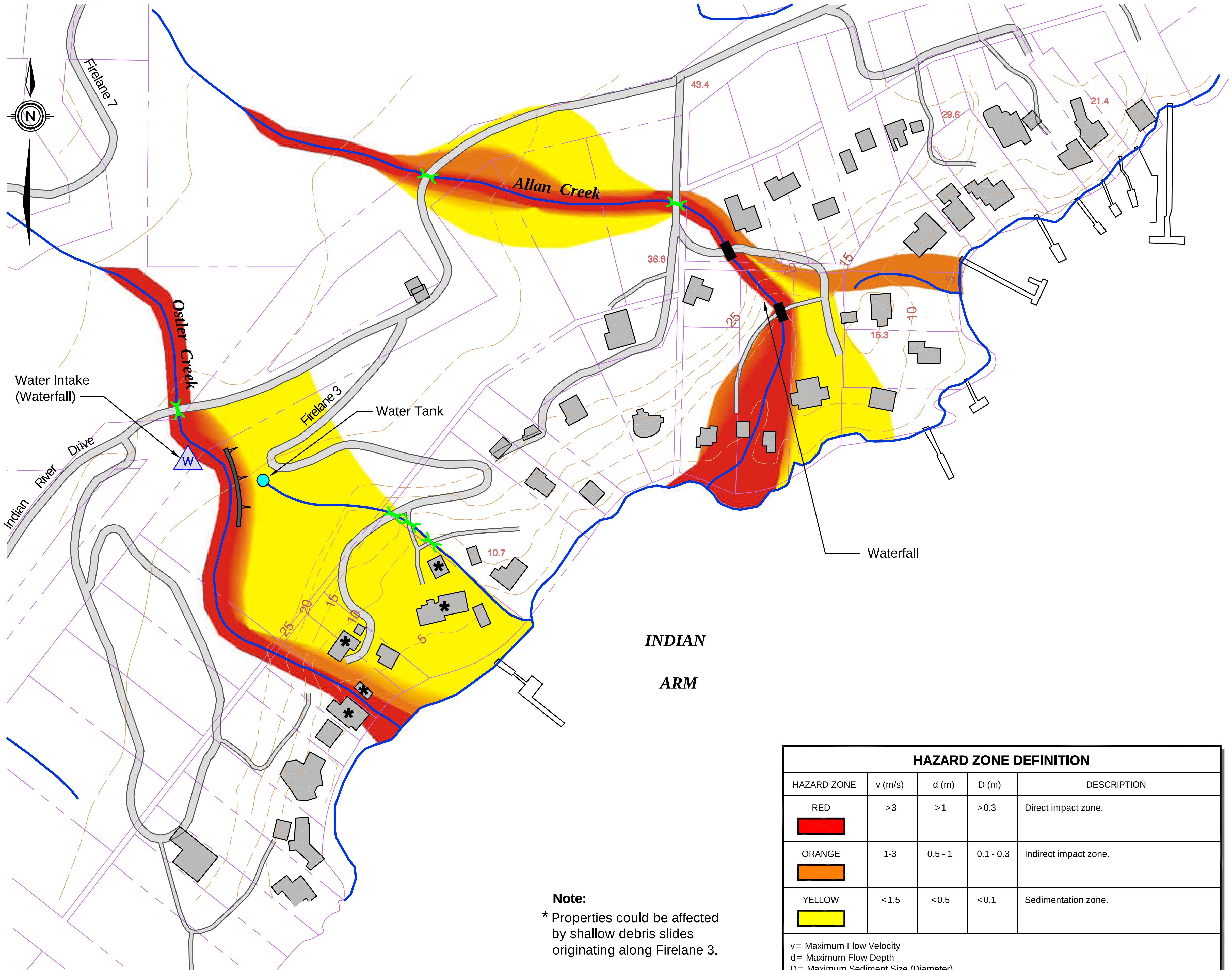
8. Complete engineering design of mitigative works, with attention to environmental protection requirements, and with input from both residents and stakeholders.

9. Proceed with construction and follow up with post-construction monitoring.

In the event that mitigative measures are not implemented at Ostler Creek and Allan Creek in the short term, as a minimum it is recommended that the District:

10. Perform periodic monitoring of both watersheds (particularly the Allan Creek erosional gullys) to identify future instabilities that may warrant further public advisory or reconsideration of mitigative measures.

District of North Vancouver
Debris Flood Study and
Risk Mitigation Alternatives
for Ostler Creek and Allan Creek



Note:
* Properties could be affected by shallow debris slides originating along Firelane 3.

Legend

- Building
- Property Line
- Culvert
- Bridge

Notes:

1. Contours are based on photogrammetry and are approximate only.
2. The dimensions and location of mapping features are approximate and are based on 1996 colour air photos.
3. Property lines are based on cadastral information provided by the District of North Vancouver.
4. Hazard boundaries refer to creek hazard only. Debris slides from road related failures are not included.
5. The hazard map is based on the medium probability debris flood events. (500 year return period)

HAZARD ZONE DEFINITION

HAZARD ZONE	v (m/s)	d (m)	D (m)	DESCRIPTION
RED	>3	>1	>0.3	Direct impact zone.
ORANGE	1-3	0.5 - 1	0.1 - 0.3	Indirect impact zone.
YELLOW	<1.5	<0.5	<0.1	Sedimentation zone.

v = Maximum Flow Velocity
d = Maximum Flow Depth
D = Maximum Sediment Size (Diameter)

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Scale in Metres

Project No.	Date
31.292	December 2003

Flood Hazard Map for Ostler Creek and Allan Creek

Figure 2-2

Dec.8/03

31-292\Drawings\31292Fig2-2.DWG

Appendix F

Report Excerpts for Scott-Goldie Creek and Sunshine Creek

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EXECUTIVE SUMMARY

An Overview Report on Debris Flow Hazards was completed for the District of North Vancouver in April 1999 to identify the potential debris flow and debris flood hazards associated with the many creeks in the District. Following submission of the Overview Report, detailed debris flow and debris flood studies were initiated on several high risk creeks, including Scott-Goldie and Sunshine Creek which are the subject of this report. The risk at Scott-Goldie Creek is due to a significant debris flow hazard and the presence of one house adjacent to the creek channel, as well as a private road crossing.

Sunshine Creek was originally to have been included in a report on the Woodland Drainage Area, which includes Sunshine Creek, Allan Creek, and Ostler Creek. However, an avulsion risk has been identified along a sharp bend of Scott-Goldie Creek where a debris flow could enter the Sunshine Creek watershed. Therefore, Sunshine Creek has been included in this report.

The study concludes that Scott-Goldie Creek is subject to periodic large debris flow events. The estimated debris flow magnitude for design purposes (a 500-year return period) is a volume of 22,000 m^3 with a peak discharge of approximately 400 m^3/s. Without mitigation, a debris flow of this size would cause considerable damage to the existing house and the bridge on Firelane 8.

A 500-year return period debris flow on Scott-Goldie Creek could avulse up to 14,000 m^3 of sediment into the watershed of Sunshine Creek. The avulsion point is located at an elevation of 290 m where the creek makes a sharp 90^o turn. Evidence of previous debris flow activity is apparent along the avulsion route. Due to low channel gradient, the design debris flow toward Sunshine Creek would deposit mainly above an elevation of 200 m. However, the design event would transform into a debris flood and impact the Sunshine Creek culvert crossings at Firelanes 7 and 8. The design debris flood magnitude on Sunshine Creek is a volume of 1,000 m^3 and a peak discharge of 25 m^3/s. The design event would not impact houses adjacent to the creek mouth at Indian Arm.

The existing level of risk is rated high at Scott-Goldie Creek and medium at Sunshine Creek. The target level of risk is medium low, and mitigation measures would be required at both creeks to achieve this level.

A wide range of mitigation alternatives has been considered, including land use planning, warning systems, watershed actions, and debris flow mitigation structures (debris basin, debris barrier, channelization and deflection berms). The existing house at Scott-Goldie Creek could be protected by a concrete wall and channelization works at a cost of roughly $450,000. Given the high relative cost of mitigation, removal of the house could also be considered. In either event, channelization work would still be necessary at Firelane 8 to provide sufficient cross-section area for the design debris flow (at a cost of roughly $400,000). At Sunshine Creek, culvert upgrading and debris barrier installation could be undertaken at the firelane crossings (at a total cost of up to $1.2 million).

4. SUMMARY AND RECOMMENDATIONS

4.1 SUMMARY

The key points in this report are summarized as follows:

SCOTT-GOLDIE CREEK

1. For the purpose of this report, Scott-Goldie Creek is defined as the watershed upstream of Indian Arm. The total watershed area is 1.7 km^2.

2. Key features in the watershed are the Firelane 8 at 65 m elevation, a house on the north side of the creek mouth, and the general absence of a fan above the low water line.

SUNSHINE CREEK

3. For the purpose of this report, Sunshine Creek is defined as the watershed upstream of Indian Arm. The total watershed area is 1.2 km^2.

4. Key features in the watershed are several culverted road crossings, a 20 m waterfall upstream of a small fan at Indian Arm, and the potential for debris flow avulsion from Scott-Goldie Creek.

HAZARD ASSESSMENT

5. Appendix D provides a hydrologic analysis which results in the following 200-year return period peak instantaneous flood flow estimates:

Scott-Goldie Creek	13 m^3/s
Sunshine Creek	9 m^3/s

6. A watershed investigation has been performed to identify potential debris flow trigger mechanisms and determine the amount of available debris. A detailed watershed map has been produced (Figure 2-1) to document geomorphological conditions.

7. Appendix E provides an analysis of debris floods and debris flows, resulting in the following 500-year return period (10% chance in 50 years) magnitude estimates:

	Event Type	Peak Discharge	Volume
Scott-Goldie Creek	Debris Flow	400 m^3/s	22,000 m^3
Sunshine Creek	Debris Flood	25 m^3/s	1,000 m^3

8. Scott-Goldie Creek is considered subject to infrequent large debris flows, as opposed to more frequent smaller events.

9. The design event at Sunshine Creek results from a large debris flow on Scott-Goldie Creek partially avulsing into the Sunshine Creek watershed at an elevation of 290 m. Most of the debris associated with such an event would deposit above the 200 m elevation due to the low channel gradient, but the event would transform into a debris flood and impact the road crossings.

10. While the 500-year return period event provides a reasonable basis for design, the potential impact of smaller and larger events also needs to be considered.

RISK ASSESSMENT PROCEDURE

11. For the purpose of this report, risk is defined as the combination of hazard probability and potential consequence (i.e. vulnerability to damage should an event occur).

12. Hazard probability is classified as ranging from low to very high, and can be estimated in terms of magnitude and peak discharge for each classification.

13. The consequence of a debris flow or debris flood depends on the size of the event and on conditions in the developed area. Consequence can be classified on a similar system as hazard probability (i.e. low to very high).

14. A hazard map has been developed for the Scott-Goldie Creek and Sunshine Creek fans that allows the fan area to be classified in terms of potential debris impact, flow depth, and flow velocity (Figure 2-2).

DEBRIS FLOW CONSEQUENCE AND RISK AT SCOTT-GOLDIE CREEK

15. A major debris flow at Scott-Goldie Creek is likely to destroy the Firelane 8 bridge and cause structural damage to the existing house. There is potential for loss of life.

16. Under existing conditions at Scott-Goldie Creek, the debris flow risk is rated as high for a 500-year return period debris flow.

DEBRIS FLOOD CONSEQUENCE AND RISK AT SUNSHINE CREEK

17. A debris flood at Sunshine Creek is likely to damage culvert crossings on Firelanes 7 and 8.

18. Under existing conditions at Sunshine Creek, the debris flood risk is rated as medium for a 500-year return period debris flood.

ALTERNATIVE STRATEGIES FOR HAZARD MITIGATION

19. A range of strategies for debris flow and debris flood mitigation has been considered, including land use planning, warning systems, watershed actions, and mitigation structures.

20. The objective in implementing mitigative measures would be to reduce the overall level of risk (i.e. the residual risk) to at least medium low. Regardless of the alternative chosen, there will always remain at least some level of residual risk.

21. The existing house at Scott-Goldie Creek could be protected by constructing a concrete wall and channelizing the creek at a cost of roughly $450,000. Given the high cost, removal of the house could also be considered (the value is roughly $400,000).

22. Channelization would be required at the Firelane 8 bridge on Scott-Goldie Creek to provide sufficient cross-sectional area for the design debris flow (at a cost of roughly $400,000).

23. The hazard at Sunshine Creek can be mitigated by construction of two debris barriers (1,000 m^3 and 500 m^3 capacity) above Firelane 8, along with upgraded culverts on Firelanes 7 and 8. These works could cost a total of roughly $1.2 million.

24. Consideration could be given to placing a sign to warn users of the trail crossing about potential hazards.

25. Consideration could be given to placing signs on Firelanes 7 and 8 to warn against creek hazards during wet weather.

26. It would be appropriate to perform periodic watershed monitoring to identify major watershed instabilities.

4.2 RECOMMENDATIONS

It is recommended that the District disseminate the results of this study as follows:

1. Advise property owners and users of Firelanes 7 and 8 regarding the contents of this report.

2. Submit copies of this report to the following organizations:

   - BC Ministry of Water, Land and Air Protection; and
   - BC Parks (with respect to operations at Mount Seymour Provincial Park).

It is also recommended that the District proceed directly with risk mitigation actions as follows:

3. Ensure that site-specific mitigative measures are incorporated into any land development approvals (Building Permit, etc.) that are issued in the mapped creek hazard area for Scott-Goldie Creek or adjacent to Sunshine Creek.

4. Consider the possibility of acquiring the property at the mouth of Scott-Goldie Creek.

5. Work with the owners of Firelanes 7 and 8, and other area residents, toward the following:

   - upgrading the Scott-Goldie Creek bridge to pass the design debris flow discharge;
   - construction of debris barriers on the two Sunshine Creek crossings of Firelane 8;
   - upgrading the four culvert crossings of Sunshine Creek; and
   - installing warning signs.

If it is decided to implement mitigative measures at Scott-Goldie Creek and/or Sunshine Creek, then it is further recommended that the District:

6. Make arrangements for construction of mitigative measures, including:

   - develop an appropriate funding mechanism;
   - determine future ownership of the works;
   - acquire any necessary property or right-of-way; and
   - establish maintenance requirements and responsibility.

7. Complete engineering design of mitigative works, with attention to environmental protection requirements, and with input from both residents and stakeholders.

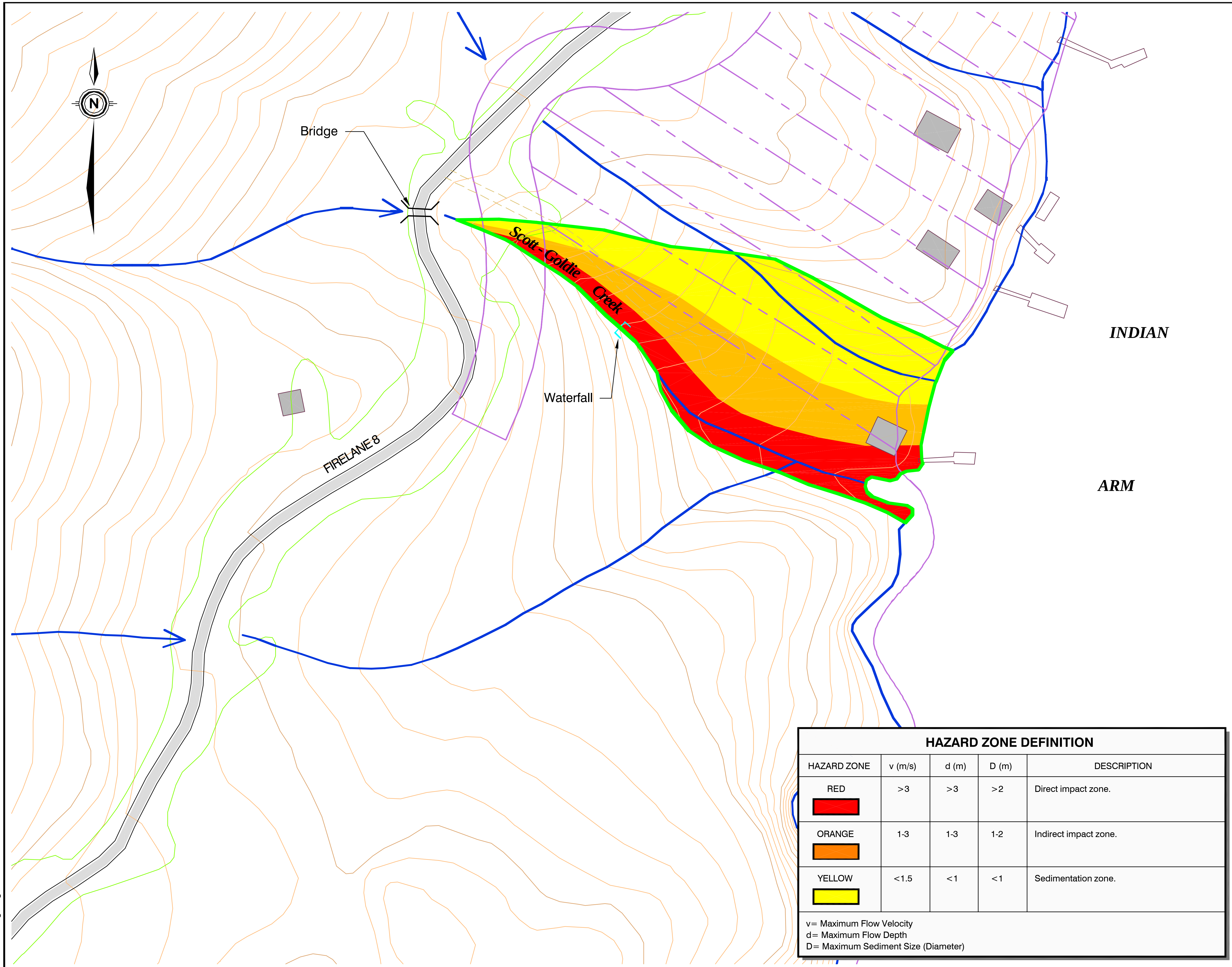
8. Proceed with construction and follow up with post-construction monitoring.

In the event that mitigative measures are not implemented at Scott-Goldie Creek and Sunshine Creek in the short term, as a minimum it is recommended that the District:

9. Perform periodic monitoring of the Scott-Goldie Creek watershed to identify future instabilities, which may warrant further public advisory or reconsideration of structural mitigative measures.

10. Work with the owners of Firelane 8 toward installation of a post-event warning system at the bridge crossing of Scott-Goldie Creek.

11. Consider the possibility of placing warning signs at the trail crossing as part of a broader initiative by the District.



HAZARD ZONE DEFINITION

HAZARD ZONE	v (m/s)	d (m)	D (m)	DESCRIPTION
RED	>3	>3	>2	Direct impact zone.
ORANGE	1-3	1-3	1-2	Indirect impact zone.
YELLOW	<1.5	<1	<1	Sedimentation zone.

v= Maximum Flow Velocity
d= Maximum Flow Depth
D= Maximum Sediment Size (Diameter)

District of North Vancouver
Debris Flow Study and
Risk Mitigation Alternatives for
Scott-Goldie Creek and Sunshine Creek

Legend

- Existing Building
- Dock
- Property Line
- Approximate Fan Boundary

Notes:

1. Contours are based on photogrammetry and are approximate only.
2. The dimensions and location of mapping features are approximate and are based on 1996 colour air photos.
3. Property lines are based on cadastral information provided by the District of North Vancouver.
4. The hazard map is based on the medium probability debris flow event (500-year return period)

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25 0 25
Scale in Metres

Project No.	Date
31.288	December 2003

Debris Flow Hazard Map for Scott-Goldie Creek

Figure 2-2

31-288\Drawings\Fig2-2.DWG Dec.05/03

Appendix G

Report Excerpts for Percy Creek and Vapour Creek

KERR WOOD LEIDAL
associates limited
CONSULTING ENGINEERS

EXECUTIVE SUMMARY

An Overview Report on Debris Flow Hazards was completed for the District of North Vancouver in April 1999 to identify the potential debris flow and debris flood hazards associated with the many creeks in the District. Following submission of the Overview Report, detailed debris flow and debris flood studies were initiated on several high risk creeks, including Percy Creek the subject of this report. The risk at Percy Creek is due to the combination of a significant debris flow hazard and the presence of about 12 houses at the community of Cascade at Indian Arm. Vapour Creek is also included in this study in view of the fact that its fan overlaps the Percy Creek fan.

The study concludes that Percy Creek is subject to periodic large debris flow events. The estimated debris flow magnitude for design purposes (a 500-year return period) is a volume of 25,000 m^3 with a peak discharge of approximately 450 m^3/s. Without debris flow mitigation structures, a debris flow of this size would cause considerable damage to houses and other infrastructure.

Vapour Creek is not subject to debris flows on the return periods established for design. However, Vapour Creek is subject to debris floods on the basis of field evidence and a documented event in November 1989. The estimated debris flood magnitude for design purposes is a volume of 400 m^3 and a peak discharge of 25 m^3/s.

The existing level of risk is rated high at Percy Creek and medium at Vapour Creek. The target level of risk is medium low, and mitigation measures would be required at both Percy Creek and Vapour Creek to achieve this level.

A wide range of mitigation alternatives have been considered, including land use planning, warning systems, watershed management actions, debris flow mitigation structures (debris basin, debris barrier, channelization and deflection berms), and creek management measures. While land use planning, warning systems, watershed management actions, and creek management measures may have some positive effects, mitigation of the hazard to any reasonable level will require the construction of a debris flow mitigation structure. Section 3 of this report provides concept drawings and costs of several possible alternative structures. The cost of effective mitigation of the debris flow hazard at Percy Creek is estimated at $2 million to $3.8 million, depending on which alternative is selected. The cost of mitigating the debris flood hazard at Vapour Creek is approximately $630,000. At Vapour Creek, there may be the possibility of partially mitigating the hazard by constructing a smaller structure at a lower cost as an initial phase of a long-term program.

Section 4 outlines an approach to implementation of hazard mitigation if the District wishes to proceed in this direction. As a first step, this would involve consultation with residents and stakeholders prior to selecting an alternative for implementation.

5. SUMMARY AND RECOMMENDATIONS

5.1 SUMMARY

The key points in this report are summarized as follows:

PERCY CREEK

1. For the purpose of this report, Percy Creek is defined as the watershed upstream of Indian Arm. The total watershed area is 2.0 km^2.

2. Key features in the watershed are the Mount Seymour ski area in the watershed headwaters, the Sasamat Lane road crossing at about 30 m elevation, and dense development at the lower fringe of the fan along the shoreline of Indian Arm.

VAPOUR CREEK

3. For the purpose of this report, Vapour Creek is defined as the watershed upstream of Indian Arm. The total watershed area is 0.5 km^2.

4. Key features in the watershed are a 30 m high waterfall immediately upstream of the fan apex, and several properties at the lower fringe of the fan along the shoreline of Indian Arm.

HAZARD ASSESSMENT

5. Appendix D provides a hydrologic analysis which results in the following 200-year return period peak instantaneous flood flow estimates:

Percy Creek	15 m^3/s
Vapour Creek	5 m^3/s

6. A watershed investigation has been performed to identify potential debris flow trigger mechanisms and determine the amount of available debris. A detailed watershed map has been produced (Figure 2-1) to document geomorphological conditions.

7. Appendix E provides an analysis of debris floods and debris flows, resulting in the following 500-year return period (10% chance in 50 years) magnitude estimates:

	Event Type	Peak Discharge	Volume
Percy Creek	Debris Flow	450 m^3/s	25,000 m^3
Vapour Creek	Debris Flood	25 m^3/s	400 m^3

8. Percy Creek is considered subject to infrequent large debris flows, as opposed to more frequent smaller events.

9. Vapour Creek is not considered subject to debris flows within the probability considered for design purposes (up to the 500-year return period), but is considered subject to periodic debris floods.

10. While the 500-year return period events provide a reasonable basis for design, the potential impact of smaller and larger events also needs to be considered.

RISK ASSESSMENT PROCEDURE

11. For the purpose of this report, risk is defined as the combination of hazard probability and potential consequence (i.e. vulnerability to damage should an event occur).

12. Hazard probability is classified as ranging from low to very high, and can be estimated in terms of magnitude and peak discharge for each classification.

13. The consequence of a debris flow or debris flood depends on the size of the event and on conditions in the developed area. Consequence can be classified on a similar system as hazard probability (i.e. low to very high).

14. Debris flow runout modelling has been performed at Percy Creek to develop a hazard map that allows the fan area to be classified in terms of potential debris impact, flow depth, and flow velocity (Figure 2-2).

DEBRIS FLOW CONSEQUENCE AND RISK AT PERCY CREEK

15. A major debris flow at Percy Creek is likely to destroy the Sasamat Lane bridge and cause structural damage to existing houses. There is potential for loss of life.

16. Under existing conditions at Percy Creek, the debris flow risk is rated as high for a 500-year return period debris flow.

DEBRIS FLOOD CONSEQUENCE AND RISK AT VAPOUR CREEK

17. A design debris flood at Vapour Creek is likely to cause damage to at least three houses.

18. Under existing conditions at Vapour Creek, the debris flood risk is rated as medium for a 500-year return period debris flood.

ALTERNATIVE STRATEGIES FOR HAZARD MITIGATION

19. A wide range of strategies for debris flow mitigation has been considered, including land use planning, warning systems, watershed management actions, debris flow mitigation structures, and creek management measures.

20. While land use planning, warning systems, watershed management actions, and creek management measures may have some beneficial effect, effective mitigation of the hazard will require construction of a debris flow mitigation structure.

21. Alternative types of debris flow structures for consideration at Percy Creek include a debris basin, debris barrier, deflection berm, and channelization. Section 3 provides a review of the applicability of each of these alternatives, along with concept plans and construction cost estimates for some possible configurations. A combination of a barrier and a debris basin on the upper fan (at a cost of roughly $3.8 million) appears to be the most promising debris flow mitigation measure at Percy Creek.

22. The hazard at Vapour Creek can be mitigated in conjunction with the hazard from Percy Creek, or independently. Channelization in combination with berming represents the most practical mitigation measure at Vapour Creek (approximate cost of $630,000).

23. The objective in implementing debris flow mitigation measures would be to reduce the overall level of risk (i.e. the residual risk) to at least medium low. Regardless of the alternative chosen, there will always remain at least some level of residual risk.

24. The proposed mitigation of the debris flow hazard on Percy Creek and the debris flood hazard on Vapour Creek will also mitigate the 200-year return period floods on these creeks.

25. Consideration could be given to implementing an advance warning system as part of a broader initiative by the District.

26. Consideration could be given to implementing a post-event warning system at Sasamat Lane bridge.

27. Consideration could be given to placing signs on Sasamat Lane to warn against creek hazards during wet weather.

28. It would be appropriate to perform periodic watershed monitoring to identify major watershed instabilities.

IMPLEMENTATION PLAN

29. Section 4 provides a basis for implementation of mitigation structures, should the District decide to proceed in this direction.

30. Consultation with residents and stakeholders should precede selection of an option for implementation.

31. For any option selected, land acquisition issues would need to be considered and alternative funding mechanisms reviewed. A policy for ownership of the constructed works (by the District or others) would also need to be developed.

32. Detailed design drawings and construction specifications would need to be prepared for the selected alternative. Environmental issues would need to be addressed under the environmental approval process.

33. Regular post-construction maintenance would need to be undertaken. Major maintenance work would be required after a debris flow event.

LAND USE PLANNING CONSIDERATIONS

34. In the absence of mitigation measures, changes in land use through rezoning and subdivision are not advisable until the risk is fully mitigated.

35. Following effective hazard mitigation, some further development on the fan may be possible.

5.2 RECOMMENDATIONS

It is recommended that the District disseminate the results of this study as follows:

1. Advise property owners and residents on the Percy Creek / Vapour Creek fan regarding the contents of this report.

2. Submit copies of this report to the following agencies:

   - BC Ministry of Water, Land and Air Protection; and
   - BC Parks (with respect to operations at the ski area and Mount Seymour Provincial Park).

It is also recommended that the District proceed directly with risk mitigation actions as follows:

3. Ensure that site-specific mitigative measures are incorporated into any land development approvals (building permit, etc.) that are issued in the mapped creek hazard area.

4. Work with the owners of Sasamat Lane toward possible installation of warning signs and possibly a post-event warning system.

5. Work with the owners of the existing Percy Creek channel works toward establishing a program for maintaining, and possibly upgrading, the channel works.

6. Work with B.C. Parks regarding attention to water management and drainage issues in Mount Seymour Provincial Park, as well as repair of the bridge at Goldie Lake.

7. Consider the possibility of placing warning signs at the Percy and Vapour Creek trail crossings as part of a broader initiative by the District.

If the District decides to implement debris flow structures at Percy Creek or Vapour Creek, then it is further recommended that the District:

8. Consult with residents and stakeholders prior to selecting a preferred alternative for implementation.

9. Make arrangements for construction of mitigative measures, including:

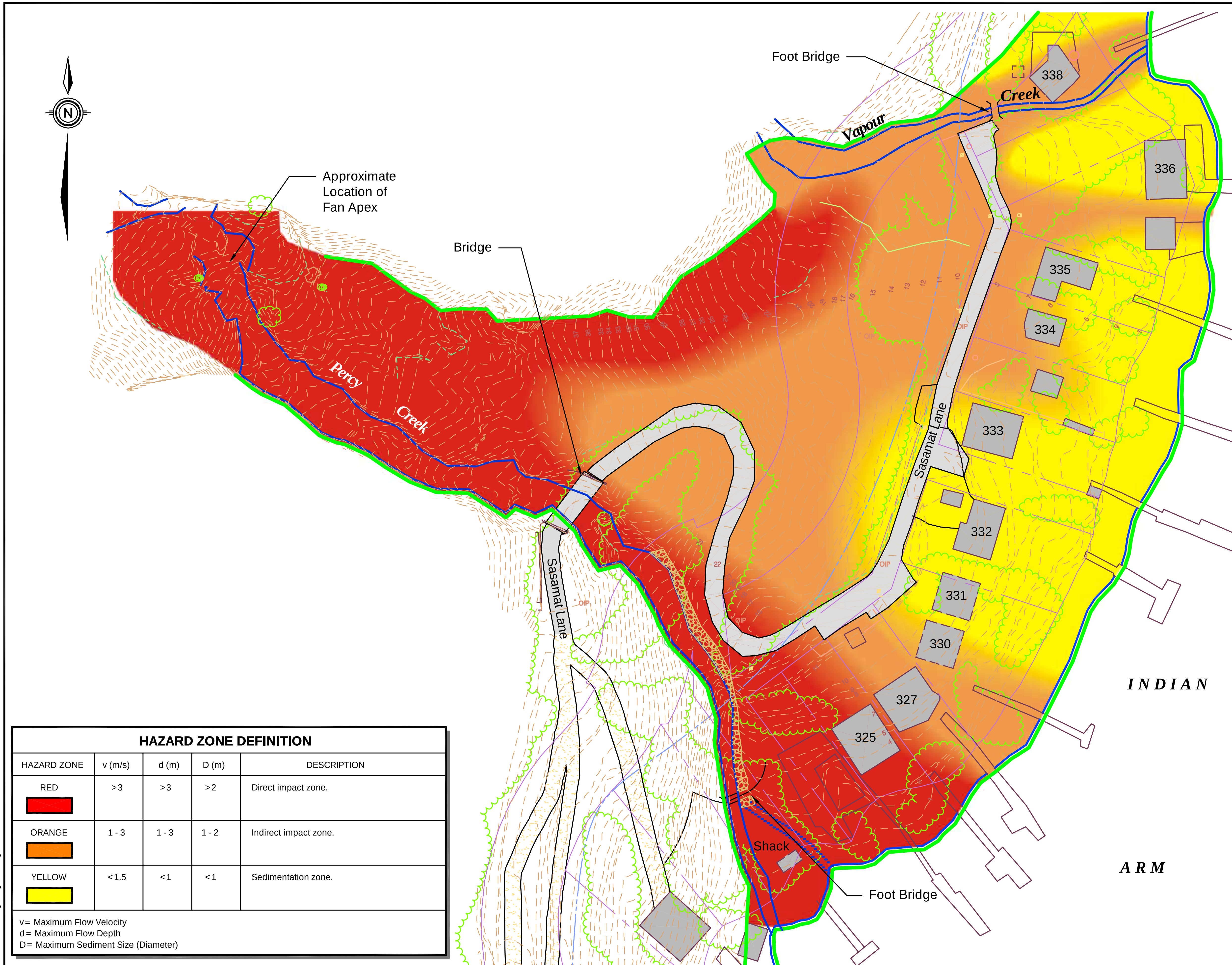
   - develop an appropriate funding mechanism;
   - determine future ownership of the works;
   - acquire any necessary property or right-of-way; and
   - establish maintenance requirements and responsibility.

10. Complete engineering design of mitigative works, with attention to environmental protection requirements, and with input from both residents and stakeholders.

11. Proceed with construction and follow up with post-construction monitoring.

In the event that the District does not proceed with implementation of mitigative measures at Percy Creek or Vapour Creek in the short term, as a minimum it is recommended that the District:

12. Perform periodic monitoring of both watersheds to identify future instabilities, which may warrant further public advisory or reconsideration of debris flow structures.



HAZARD ZONE DEFINITION

HAZARD ZONE	v (m/s)	d (m)	D (m)	DESCRIPTION
RED	>3	>3	>2	Direct impact zone.
ORANGE	1 - 3	1 - 3	1 - 2	Indirect impact zone.
YELLOW	<1.5	<1	<1	Sedimentation zone.

v = Maximum Flow Velocity
d = Maximum Flow Depth
D = Maximum Sediment Size (Diameter)

District of North Vancouver
Debris Flow Study and
Risk Mitigation Alternatives for
Percy Creek and Vapour Creek

Legend

- **Vegetation**
- **336** — **Building with No. (1996 Air Photo)**
- **Dock**
- **Property Boundaries**
- **Approximate Fan Boundary**

Notes:

1. Contours between the fan apex and the west side of Sasamat Lane are from a KWL ground survey.
2. Topography outside the fan and south of Sasamat Lane are generally based on 1996 colour air photographs.
3. The dimensions and location of mapping features are approximate and based on 1996 colour air photos.
4. Property lines are based on cadastral information provided by the District of North Vancouver.
5. The hazard map is basd on the medium probability debris flow (Percy Creek) or debris flood (Vapour Creek) event (500 - year return period).

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25 0 25
Scale in Metres

Project No.	Date
31.261	December 2003

Debris Flow Hazard Map for Percy Creek

Figure 2-2

Dec. 10/03

.031-261\Drawings\Fig2-2.dwg

Appendix H

Report Excerpts for Shone Creek

KERR WOOD LEIDAL
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CONSULTING ENGINEERS

EXECUTIVE SUMMARY

An Overview Report on Debris Flow Hazards was completed for the District of North Vancouver in April 1999 to identify the potential debris flow and debris flood hazards associated with the many creeks in the District. Following submission of the Overview Report, detailed debris flow and debris flood studies were initiated on several high-risk creeks, including Shone Creek which is the subject of this report.

The risk at Shone Creek is due to the combination of a significant debris flood hazard and the presence of about six houses and Camp Jubilee, a childrens' camp, on the lower creek fan. Underhill Creek is also included in this study because debris flows from Underhill Creek can impact the channel and fan of Shone Creek.

The study concludes that Shone Creek is subject to periodic large debris flow events. The estimated debris flow magnitude for a 500-year return period event is a volume of 50,000 m^3 with a peak discharge of up to 800 m^3/s at the upper fan. A debris flow will spill out of the channel and deposit most of its load on the upper fan. The debris flow is then expected to transform into a debris flood, which could travel down Gardner Brook, Reservoir Creek, and/or Shone Creek and reach developed areas. The design peak discharge of the 500-year return period debris flood is estimated at 90 m^3/s at the lower fan of Shone Creek, with an estimated volume of 10,000 m^3. Without debris mitigation structures, a debris flood of this size would cause considerable damage to houses and other infrastructure.

Underhill Creek is subject to debris flows on the return periods established for design. The estimated debris flow magnitude for design purposes is a volume of 5,000 m^3 and a peak discharge of 100 m^3/s.

The existing level of risk is rated high at Shone Creek and medium at Underhill Creek. The target level of risk is medium low, and mitigative measures would be required at Shone Creek and Underhill Creek to achieve this level.

A wide range of mitigative alternatives have been considered, including land use planning, warning systems, watershed management actions, and debris flow and debris flood mitigation structures (debris basin, debris barrier, channelization, overflow channel, and deflection berms). Mitigation of the hazard to any reasonable level will require the construction of a debris flow or debris flood mitigation structure. Section 3 of this report provides concept drawings of several possible alternative structures. The cost of effective hazard mitigation is in the range of \$2.9 million to \$3.9 million, depending on which alternative is selected. There may be the possibility of partially mitigating the hazard by constructing a smaller structure at a lower cost as an initial phase of a long-term program.

Section 4 outlines an approach to implementation of mitigation structures if the District wishes to proceed in this direction.

5. SUMMARY AND RECOMMENDATIONS

5.1 SUMMARY

The key points in this report are summarized as follows:

SHONE CREEK SYSTEM

1. For the purposes of this report, Shone Creek is defined as the watershed upstream of Indian Arm. The total watershed area is 2.9 km^2.

2. Key features in the watershed are very steep sections that actively shed rockfall and tributaries that are susceptible to debris flows and debris slides. Below 165 m elevation, the watershed is characterized by two fans. The upper fan is subject to debris flows and debris floods, while the lower fan is subject to debris floods and floods.

UNDERHILL CREEK SYSTEM

3. Underhill Creek is a tributary of Shone Creek with a watershed area of 0.4 km^2. The two creeks join at the lower fan apex of Shone Creek.

4. Underhill Creek has a straight channel with no significant tributaries, but considerable channel debris stemming from small sidewall debris slides and rockfall.

HAZARD ASSESSMENT

5. Appendix D provides a hydrologic analysis which results in the following 200-year return period peak instantaneous flood flow estimates:

Shone Creek	20 m^3/s
Underhill Creek	3 m^3/s

6. A watershed investigation has been performed to identify potential debris flow trigger mechanisms and determine the amount of available debris. A detailed watershed map has been produced (Figure 2-1) to document geomorphological conditions.

7. Appendix E provides an analysis of debris floods and debris flows, resulting in the following 500-year return period (10% chance in 50 years) magnitude estimates at the apex of the lower fan:

	Event Type	Peak Discharge	Volume
Shone Creek	Debris Flood	90 m^3/s	10,000 m^3
Underhill Creek	Debris Flow	100 m^3/s	5,000 m^3

8. Shone Creek is considered subject to infrequent large debris flows, as opposed to more frequent smaller events. Debris flows would deposit a majority of their sediment load on the upper fan due to poor confinement and reduced channel gradients. A majority of debris flows are expected to transform into debris floods before reaching the lower fan apex.

9. Underhill Creek is considered subject to frequent small debris flows, as opposed to larger infrequent events.

10. While the 500-year return period events provide a reasonable basis for design, the potential impact of smaller and larger events also needs to be considered.

RISK ASSESSMENT PROCEDURE

11. For the purposes of this report, risk is defined as the combination of hazard probability and potential consequence (i.e. vulnerability to damage should an event occur).

12. Hazard probability is classified as ranging from low to very high, and can be estimated in terms of magnitude and peak discharge for each classification.

13. The consequence of a debris flow or debris flood depends on the size of the event and on conditions in the developed area. Consequence can be classified on a similar system as hazard probability (i.e. low to very high).

14. A hazard map has been developed for the Shone Creek and Underhill Creek fan that allows the fan area to be classified in terms of potential debris impact, flow depth, and flow velocity (Figure 2-2).

DEBRIS FLOW AND DEBRIS FLOOD CONSEQUENCE AND RISK

15. A major debris flood at Shone Creek is likely to cause extensive bank erosion, and cause structural damage to existing buildings, particularly on the south side of the lower fan. It is also possible that a large debris flow at the upper fan apex could avulse into Gardner Brook and cause flooding damage in the community of Brighton Beach. There is potential for loss of life at Shone Creek.

16. A major debris flow at Underhill Creek could dam Shone Creek, causing an outbreak flood with similar consequences as described in Point 15. However, it would not affect Brighton Beach. In extreme cases, a debris flow on Underhill

Creek could avulse into Ragland Creek. In this case, houses on the north side of Shone Creek fan may suffer structural damage as well.

17. Under existing conditions, the risk is rated as high for a 500-year return period debris flood at Shone Creek, and medium for a 500-year return period debris flow at Underhill Creek.

ALTERNATIVE STRATEGIES FOR HAZARD MITIGATION

18. A wide range of strategies for debris flow and debris flood mitigation has been considered, including land use planning, warning systems, watershed management actions, and debris flow/debris flood mitigation structures.

19. While land use planning, warning systems, and watershed management actions may have some beneficial effect, effective mitigation of the hazard will require construction of a debris flow or debris flood mitigation structure.

20. Alternative types of structures for consideration at Shone Creek include a debris barrier upstream of the upper fan, a debris basin on the upper fan or the lower fan, deflection berms, and channelization. Section 3 provides a review of each of these alternatives, along with concept plans, and construction cost estimates for some possible configurations.

21. A small debris basin on the lower fan, training berms, an overflow channel at the Underhill Creek confluence, and channelization (at a cost of roughly $3.5 million) appears to be the most promising combination of mitigation measures. Regardless of the alternative chosen, there will always remain some level of residual risk.

22. The objective in implementing debris flow or debris flood mitigation measures would be to reduce the overall level of risk (i.e. the residual risk) to at least medium low. Regardless of the alternative chosen, there will always remain at least some level of residual risk.

23. The proposed mitigation of the debris flood hazard on Shone Creek and the debris flow hazard on Underhill Creek will also mitigate the 200-year return period floods on these creeks.

24. Consideration could be given to implementing an advance warning system as part of a broader initiative by the District.

25. It would be appropriate to perform periodic watershed monitoring to identify major watershed instabilities.

IMPLEMENTATION PLAN

26. Section 4 provides a basis for implementation of mitigative structures, should the District decide to proceed in this direction.

27. Consultation with residents and stakeholders should precede selection of an option for implementation.

28. For any option selected, land acquisition issues would need to be considered and alternative funding mechanisms reviewed. A policy for ownership of the constructed works (by the District or others) would also need to be developed.

29. Detailed design drawings and construction specifications would need to be prepared for the selected alternative. Environmental issues would need to be addressed under the environmental approval process.

30. Regular post-construction maintenance would need to be undertaken. Major maintenance work would be required after a debris flow event.

LAND USE PLANNING CONSIDERATIONS

31. In the absence of mitigative measures, changes in land use through rezoning and subdivision are not advisable until the risk is fully mitigated.

32. Following effective hazard mitigation, some further development on the fan may be possible.

5.2 RECOMMENDATIONS

It is recommended that the District disseminate the results of this study as follows:

1. Advise property owners and residents on the Shone Creek fan and the Gardner Brook fan regarding the findings of this report.

2. Submit copies of this report to the following organizations:

   - B.C. Ministry of Water, Land and Air Protection; and
   - Mount Seymour Provincial Park (regarding watershed management in the park).

It is also recommended that the District proceed directly with risk mitigation actions as follows:

3. Ensure that site-specific mitigative measures are incorporated into any land development approvals (building permit, etc.) that are issued in the mapped creek hazard areas.

4. Consider the possibility of placing warning signs at the Shone Creek trail crossing as part of a broader initiative by the District.

If the District decides to implement mitigation structures at Shone Creek and/or Underhill Creek, then it is further recommended that the District:

5. Consult with residents and stakeholders prior to selecting a preferred alternative for implementation.

6. Make arrangements for construction of mitigative measures, including:

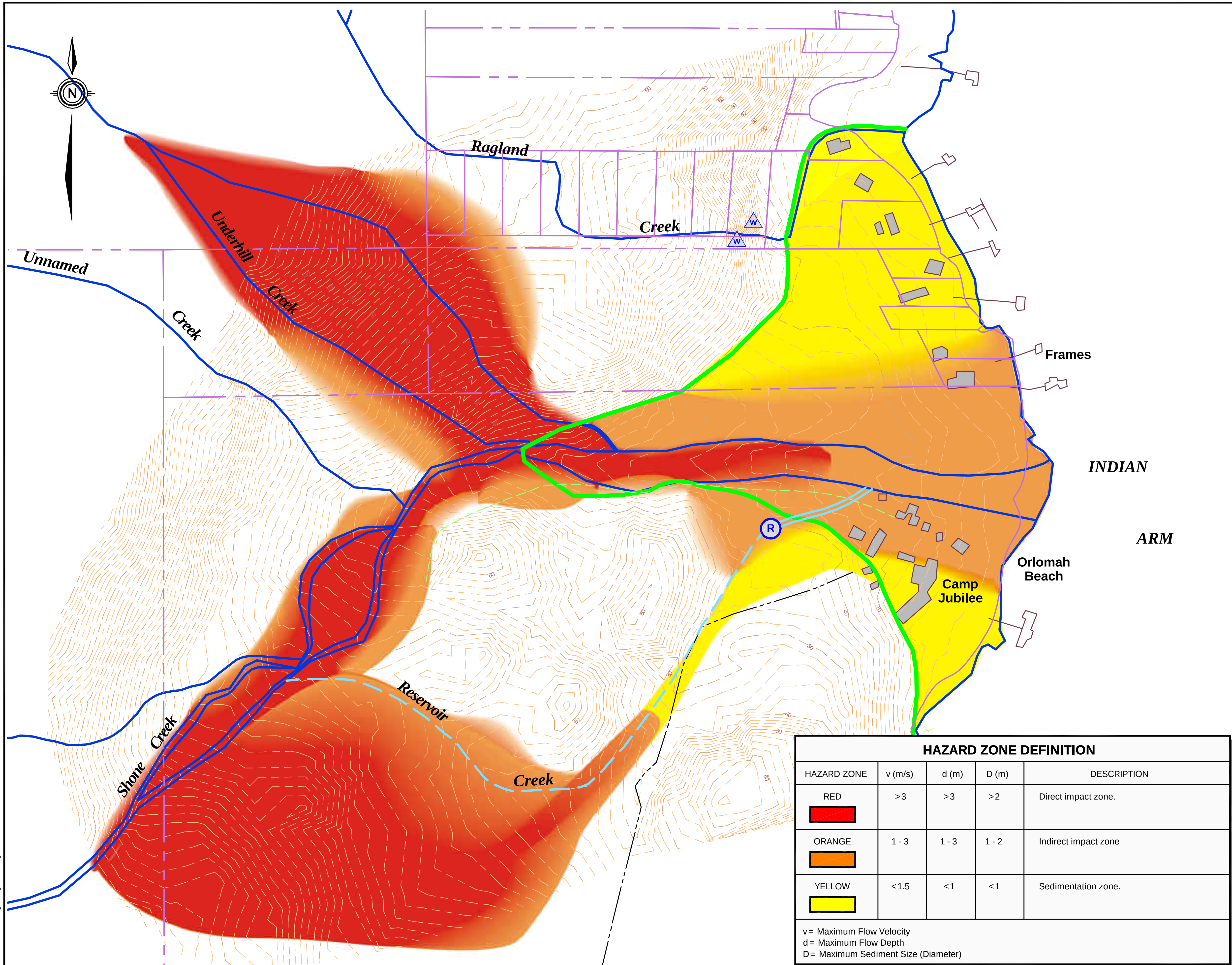
   - develop an appropriate funding mechanism;
   - determine future ownership of the works;
   - acquire any necessary property or right-of-way; and
   - establish maintenance requirements and responsibility.

7. Complete engineering design of mitigative works, with attention to environmental protection requirements, and with input from both residents and stakeholders.

8. Proceed with construction and follow up with post-construction monitoring.

In the event that the District does not proceed with implementation of mitigative measures at Shone Creek in the short term, as a minimum it is recommended that the District:

9. Perform periodic monitoring of the Shone Creek watershed to identify future instabilities, which may warrant further public advisory or reconsideration of debris flood structures.



District of North Vancouver
Debris Flow Study and
Risk Mitigation Alternatives for
Shone Creek

Legend

- **Vegetation**
- **Building (1996 Air Photo)**
- **Dock**
- **Property Boundaries**
- **Approximate Fan Boundary**
- **Water Reservoir**
- **Water Intake**

Notes:

1. Contours are based on photogrammetry and are approximate only.
2. The dimensions and location of mapping features are approximate and are based on 1996 colour air photos.
3. Property lines are based on cadastral information provided by the District of North Vancouver.
4. The hazard map is based on the medium probability debris flow or debris flood event.

HAZARD ZONE DEFINITION

HAZARD ZONE	v (m/s)	d (m)	D (m)	DESCRIPTION
RED	>3	>3	>2	Direct impact zone.
ORANGE	1 - 3	1 - 3	1 - 2	Indirect impact zone
YELLOW	<1.5	<1	<1	Sedimentation zone.

v= Maximum Flow Velocity
d= Maximum Flow Depth
D= Maximum Sediment Size (Diameter)

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CONSULTING ENGINEERS

50 0 50
Scale in Metres

Project No.	Date
31.262	December 2003

Debris Flow and Debris Flood Hazard Map for Shone Creek and Underhill Creek

Figure 2-2

Dec. 9/03
.031-262\Drawings\Fig2-2.dwg

Appendix I

Report Excerpts for Holmden Creek

KERR WOOD LEIDAL

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CONSULTING ENGINEERS

EXECUTIVE SUMMARY

An Overview Report on Debris Flow Hazards was completed for the District of North Vancouver in April 1999 to identify the potential debris flow and debris flood hazards associated with the many creeks in the District. Following submission of the overview report, detailed debris flow and debris flood studies were initiated on several high risk creeks, including Holmden Creek which is the subject of this report. The risk at Holmden Creek is due to a significant debris flow hazard and the presence of one house on the lower fan.

Given the occurrence of two debris flows on Holmden Creek in the past decade, the study concludes that Holmden Creek is one of the most hazardous creeks in the District. The estimated debris flow magnitude for design purposes (a 500-year return period) is a volume of 40,000 m^3 with a peak discharge of approximately 700 m^3/s. Without a debris flow mitigation structure in place, an event of this size would cause considerable damage to the house.

The existing level of risk at Holmden Creek is rated high. The target level of risk is medium low and mitigative measures would be required to achieve this level.

A number of mitigative alternatives have been considered including land use planning, warning systems, watershed actions, and debris flow mitigation structures (debris basin, debris barrier, channelization and deflection berms). Given the low level of development on the fan, debris flow mitigation structures are not considered a cost-effective option. The most practical alternative for risk mitigation at Holmden Creek is to remove the existing house and two docks. A second possible mitigative approach would be to relocate the existing house to a safer part of the fan and construct a deflection berm along the south side of Holmden Creek. Cost estimates for the two options are $125,000 and $250,000 respectively.

4. SUMMARY AND RECOMMENDATIONS

4.1 SUMMARY

The key points in this report are summarized as follows:

HOLMDEN CREEK SYSTEM

1. For the purpose of this report, Holmden Creek is defined as the watershed upstream of Indian Arm. The total watershed area is 2.1 km^2.

2. Key features in the watershed are two debris flow fans: an upper fan at an elevation of 190 m to 275 m and a lower fan at the shore of Indian Arm.

HAZARD ASSESSMENT

3. Appendix D provides a hydrologic analysis which results in the following preliminary 200-year return period peak instantaneous flood flow estimate:

Holmden Creek	15 m^3/s

4. A watershed investigation has been performed to identify potential debris flow trigger mechanisms and determine the amount of available debris. A detailed watershed map has been produced (Figure 2-1) to document geomorphic conditions.

5. Relative to other watersheds along the west side of Indian Arm, Holmden Creek is a very active system with known debris flow events in the early 1990s and in 1998. The 1998 event damaged the house on the fan as well as two docks.

6. It is believed that Holmden Creek is prone to small frequent debris flows, but also produces infrequent large events.

7. Appendix E provides an analysis of debris flows, resulting in the following 500-year return period (10% chance in 50 years) magnitude estimate:

	Event Type	Peak Discharge	Volume
Holmden Creek	Debris Flow	700 m^3/s	40,000 m^3

8. While the 500-year return period event provides a reasonable basis for design, the potential impact of smaller and larger events also needs to be considered.

RISK ASSESSMENT PROCEDURE

9. For the purpose of this report, risk is defined as the combination of hazard probability and potential consequence (i.e. vulnerability to damage should an event occur).

10. Hazard probability is classified as ranging from low to very high, and can be estimated in terms of magnitude and peak discharge for each classification.

11. The consequence of a debris flow depends on the size of the event and on conditions in the developed area. Consequence can be classified on a similar system as hazard probability (i.e. low to very high).

12. A hazard map has been developed for the Holmden Creek fan that allows the fan area to be classified in terms of potential debris impact, flow depth, and flow velocity (Figure 2-2).

DEBRIS FLOW CONSEQUENCE AND RISK AT HOLMDEN CREEK

13. A major debris flow at Holmden Creek is likely to destroy the existing house on the southern half of the fan. There is potential for loss of life.

14. Under existing conditions, the debris flow risk is rated as high for a 500-year return period event.

ALTERNATIVE STRATEGIES FOR HAZARD MITIGATION

15. A range of strategies for debris flow mitigation have been considered, including land use planning measures, warning systems, watershed actions, and debris flow mitigation structures.

16. The objective in implementing debris flow mitigation measures would be to reduce the overall level of risk (i.e. the residual risk) to at least medium low. Regardless of the alternative chosen, there will always remain at least some level of residual risk.

17. The most practical alternative for risk mitigation at Holmden Creek is to remove the existing house and dock (valued at approximately $100,000).

18. A second possible mitigative approach would be to relocate the existing house to a safer part of the fan and construct a deflection berm along the south side of Holmden Creek. The cost would be approximately $250,000.

19. Further development on the Holmden Creek fan would not be appropriate in the absence of extensive and costly mitigative measures.

20. Consideration could be given to placing signs to warn users of the trail crossing about potential hazards.

21. It would be appropriate to perform periodic watershed monitoring to identify major watershed instabilities.

4.2 RECOMMENDATIONS

It is recommended that the District disseminate the results of this study as follows:

1. Advise property owners on and adjacent the Holmden Creek fan regarding the contents of this report.

2. Submit a copy of this report to the following organizations:

   - BC Ministry of Water, Land, and Air Protection; and
   - BC Parks (with respect to operational issues within Mount Seymour Provincial Park).

It is also recommended that the District proceed with risk mitigation actions as follows:

3. Avoid issuing building permits or other development approvals for development on the fan.

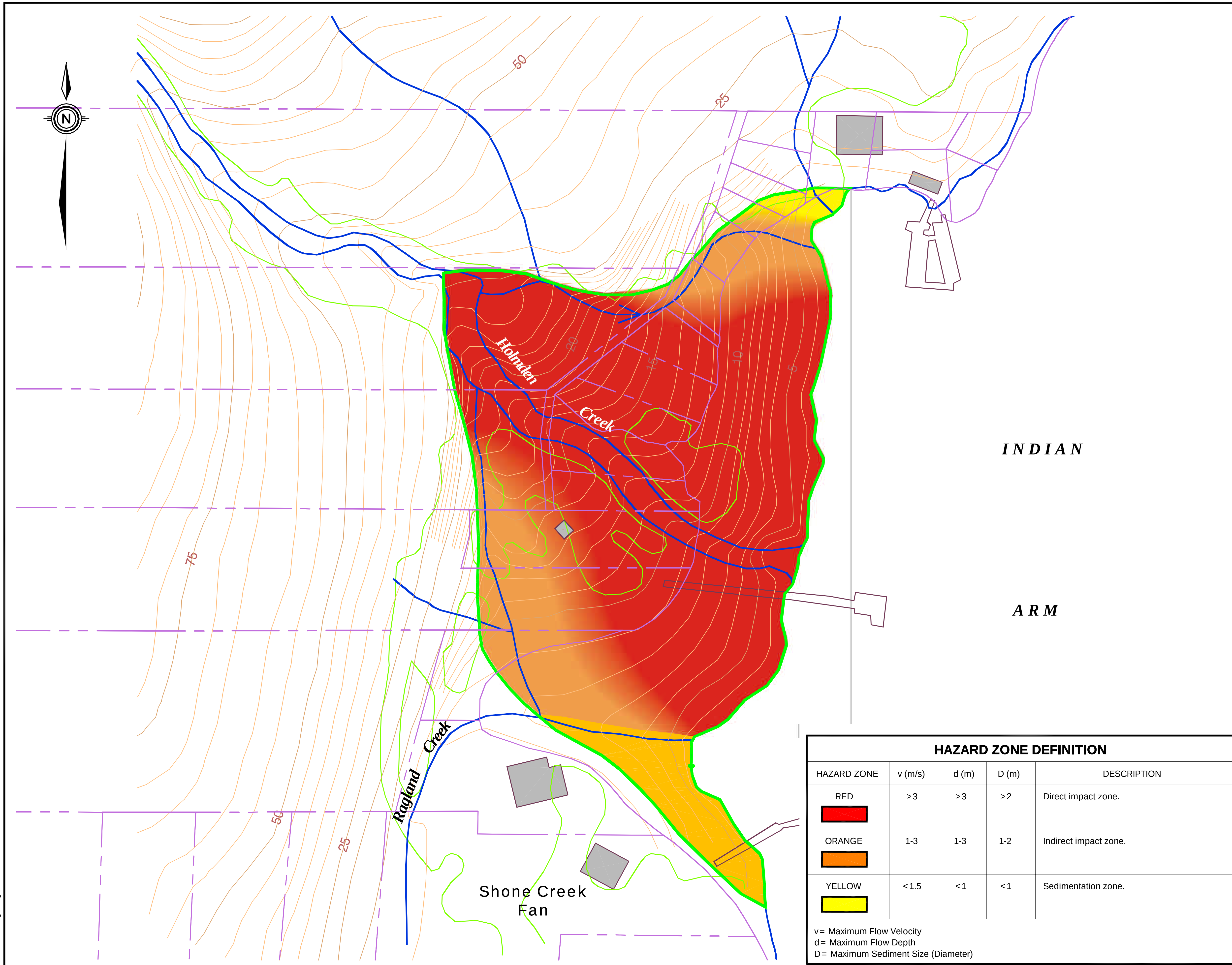
4. Investigate alternative means for removing the house on the fan.

5. Consider the possibility of relocating the two docks on the fan.

6. Perform periodic monitoring of the Holmden Creek watershed to identify future instabilities that may warrant further public advisory or reconsideration of mitigative measures.

7. Consider the possibility of placing warning signs at the Holmden Creek Trail crossing as part of a broader initiative by the District.

District of North Vancouver
Debris Flow Study and
Risk Mitigation Alternatives for
Holmden Creek



HAZARD ZONE DEFINITION

HAZARD ZONE	v (m/s)	d (m)	D (m)	DESCRIPTION
RED	>3	>3	>2	Direct impact zone.
ORANGE	1-3	1-3	1-2	Indirect impact zone.
YELLOW	<1.5	<1	<1	Sedimentation zone.

v= Maximum Flow Velocity
d= Maximum Flow Depth
D= Maximum Sediment Size (Diameter)

Legend

- Property Line
- Existing Building
- Approximate Fan Boundary

Notes:

1. Contours are based on photogrammetry and are approximate only.
2. The dimensions and location of mapping features are approximate and are based on 1996 colour air photos.
3. Property lines are based on cadastral information provided by the District of North Vancouver.
4. The hazard map is based on the medium probability debris flow (500 year return period).

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25 0 25
Scale in Metres

Project No.	Date
31.289	December 2003

Debris Flow
Hazard Map
for Holmden Creek

Figure 2-2

Dec.03/03

31-289\Drawings\Fig2-2.DWG

Appendix J

Report Excerpts for Coldwell Creek and Friar Creek

KERR WOOD LEIDAL
associates limited
CONSULTING ENGINEERS

EXECUTIVE SUMMARY

An Overview Report on Debris Flow Hazards was completed for the District of North Vancouver in April 1999 to identify the potential debris flow and debris flood hazards associated with the many creeks in the District. Following submission of the Overview Report, detailed debris flow and debris flood studies were initiated on several high-risk creeks, including Coldwell Creek, which is the subject of this report. The risk at Coldwell Creek is due to the combination of a significant hazard and the presence of 7 houses at Coldwell Beach at Indian Arm. Friar Creek is also included in this study in view of the fact that its fan overlaps the Coldwell Creek fan. There is one house on the Friar Creek fan.

The study concludes that Coldwell Creek is subject to periodic large debris flood events. The estimated debris flood magnitude for design purposes (a 500-year return period) is a volume of 8,000 m^3 with a peak discharge of approximately 150 m^3/s. Without debris flood mitigation structures, a debris flood of this size would cause considerable damage to houses and other infrastructure.

Friar Creek is subject to debris flows on the return periods established for design. The estimated debris flow magnitude for design purposes is a volume of 4,000 m^3 and a peak discharge of 90 m^3/s.

The existing level of risk is rated medium high at Coldwell Creek and high at Friar Creek. The target level of risk is medium low, and mitigative measures would be required at both Coldwell Creek and Friar Creek to achieve this level.

A wide range of mitigative alternatives have been considered, including land use planning, warning systems, watershed management actions, and mitigation structures (debris barrier, channelization and deflection berms). While land use planning, warning systems and watershed management actions may have some positive effects, mitigation of the hazard to any reasonable level will require the construction of a mitigation structure. Section 3 of this report provides concept drawings and costs of several possible alternative structures. The cost of effective mitigation of the debris flood hazard at Coldwell Creek is estimated at $1.5 million to $1.9, depending on which alternative is selected. Protection of the homes on the Coldwell Creek fan would also necessitate construction of a deflection berm on the south side of Friar Creek. There may be the possibility of partially mitigating the hazards by constructing smaller structures at a lower cost as an initial phase of a long-term program. As protection of the house on the Friar Creek fan is not considered practical or cost-effective, removal of the house could be considered.

Section 4 outlines an approach to implementation of mitigation structures if the District wishes to proceed in this direction.

5. SUMMARY AND RECOMMENDATIONS

5.1 SUMMARY

The key points in this report are summarized as follows:

COLDWELL CREEK SYSTEM

1. For the purposes of this report, Coldwell Creek is defined as the watershed upstream of the Indian Arm confluence. The total watershed area is 4.7 km^2.

2. Key features in the watershed are very steep sections that actively shed rockfall and are susceptible to tributary debris flows and debris slides.

FRIAR CREEK SYSTEM

3. Friar Creek is defined as the watershed upstream of the Indian Arm confluence. The total watershed area is 0.3 km^2.

4. Key features in the watershed are a steep lower channel with ample in-channel debris.

HAZARD ASSESSMENT

5. Appendix D provides a hydrologic analysis which results in the following 200-year return period peak instantaneous flood flow estimates:

Coldwell Creek	33 m^3/s
Friar Creek	2 m^3/s

6. A watershed investigation has been performed to identify potential debris flow and debris flood trigger mechanisms and determine the amount of available debris. A detailed watershed map has been produced (Figure 2-1) to document geomorphological conditions.

7. Appendix E provides an analysis of debris flows and debris floods, resulting in the following 500-year return period (10% chance in 50 years) magnitude estimates:

	Event Type	Peak Discharge	Volume
Coldwell Creek	Debris Flood	150 m^3/s	8,000 m^3
Friar Creek	Debris Flow	90 m^3/s	4,000 m^3

8. Coldwell Creek is considered subject to infrequent large debris floods. Debris flows are possible, but are considered outside the probability considered for design.

9. Friar Creek is considered subject to debris flows.

10. While the 500-year return period events provide a reasonable basis for design, the potential impact of smaller and larger events also needs to be considered.

RISK ASSESSMENT PROCEDURE

11. For the purpose of this report, risk is defined as the combination of hazard probability and potential consequence (i.e. vulnerability to damage should an event occur).

12. Hazard probability is classified as ranging from low to very high, and can be estimated in terms of magnitude and peak discharge for each classification.

13. The consequence of a debris flow or debris flood depends on the size of the event and on conditions in the developed area. Consequence can be classified on a similar system as hazard probability (i.e. low to very high).

14. A hazard map has been developed for the Coldwell Creek and Friar Creek fans that allows the fan area to be classified in terms of potential debris impact, flow depth, and flow velocity (Figure 2-2).

DEBRIS FLOOD CONSEQUENCE AND RISK AT COLDWELL CREEK

15. A major debris flood at Coldwell Creek is likely to cause structural damage to existing houses. There is potential for loss of life.

16. Under existing conditions at Coldwell Creek, the debris flood risk is rated as medium high for a 500-year return period event.

DEBRIS FLOW CONSEQUENCE AND RISK AT FRIAR CREEK

17. A debris flow at Friar Creek is likely to cause structural damage to one house.

18. Under existing conditions at Friar Creek, the debris flow risk is rated as high for a 500-year return period event.

ALTERNATIVE STRATEGIES FOR HAZARD MITIGATION

19. A wide range of strategies for debris flow and debris flood mitigation has been considered, including land use planning, warning systems, watershed management actions, and mitigation structures.

20. While land use planning, warning systems, and watershed management actions may have some beneficial effect, effective mitigation of the hazard will require construction of a mitigation structure.

21. Alternative types of debris flood structures for consideration at Coldwell Creek include a debris basin, debris barrier, deflection berms, and channelization. Section 3 provides a review of the applicability of each of these alternatives, along with concept plans and construction cost estimates for some possible configurations. A debris barrier on the upper fan in conjunction with channelization and training berms (at a total cost of roughly $1.9 million) appears to be the most promising debris flood mitigation measure at Coldwell Creek.

22. It is not considered practical or cost-effective to protect properties on the Friar Creek fan against the design debris flow. It would be more appropriate to remove the one existing house.

23. Construction of a deflection berm on the south side of Friar Creek would be necessary to protect the Coldwell Creek fan (cost approximately $300,000).

24. The objective in implementing debris flow and debris flood mitigation measures would be to reduce the overall level of risk (i.e. the residual risk) to at least medium low. Regardless of the alternative chosen, there will always remain at least some level of residual risk.

25. The proposed mitigation of the debris flood hazard on Coldwell Creek and the debris flow hazard on Friar Creek will also mitigate the 200-year return period floods on these creeks.

26. Consideration could be given to implementing an advance warning system as part of a broader initiative by the District.

27. It would be appropriate to perform periodic watershed monitoring to identify major watershed instabilities.

IMPLEMENTATION PLAN

28. Section 4 provides a basis for implementation of mitigative structures, should the District decide to proceed in this direction.

29. Consultation with residents and stakeholders should precede selection of an option for implementation.

30. For any option selected, land acquisition issues would need to be considered and alternative funding mechanisms reviewed. A policy for ownership of the constructed works (by the District or others) would also need to be developed.

31. Detailed design drawings and construction specifications would need to be prepared for the selected alternative. Environmental issues would need to be addressed under the environmental approval process.

32. Regular post-construction maintenance would need to be undertaken. Major maintenance work would be required after a debris flood event.

LAND USE PLANNING CONSIDERATIONS

33. In the absence of mitigative measures, changes in land use through rezoning and subdivision are not advisable until the risk is fully mitigated.

34. Following effective hazard mitigation, some further development on the fan may be possible.

5.2 RECOMMENDATIONS

It is recommended that the District disseminate the results of this study as follows:

1. Advise property owners and residents on the Coldwell Creek / Friar Creek fan regarding the contents of this report.

2. Submit copies of this report to the following organizations:

   - B.C. Ministry of Water, Land and Air Protection; and
   - Mount Seymour Provincial Park (regarding watershed management issues in the park).

It is also recommended that the District proceed directly with risk mitigation actions as follows:

3. Ensure that site-specific mitigative measures are incorporated into any land development approvals (building permit, etc.) that are issued in the mapped creek hazard areas.

4. Consider the possibility of placing warning signs as the Coldwell Creek trail crossing as part of a broader initiative by the District.

5. Investigate alternative means for removing the building on the Friar Creek fan.

If the District decides to implement mitigation structures at Coldwell Creek or Friar Creek, then it is further recommended that the District:

6. Consult with residents and stakeholders prior to selecting a preferred alternative for implementation.

7. Make arrangements for construction of mitigative measures, including:

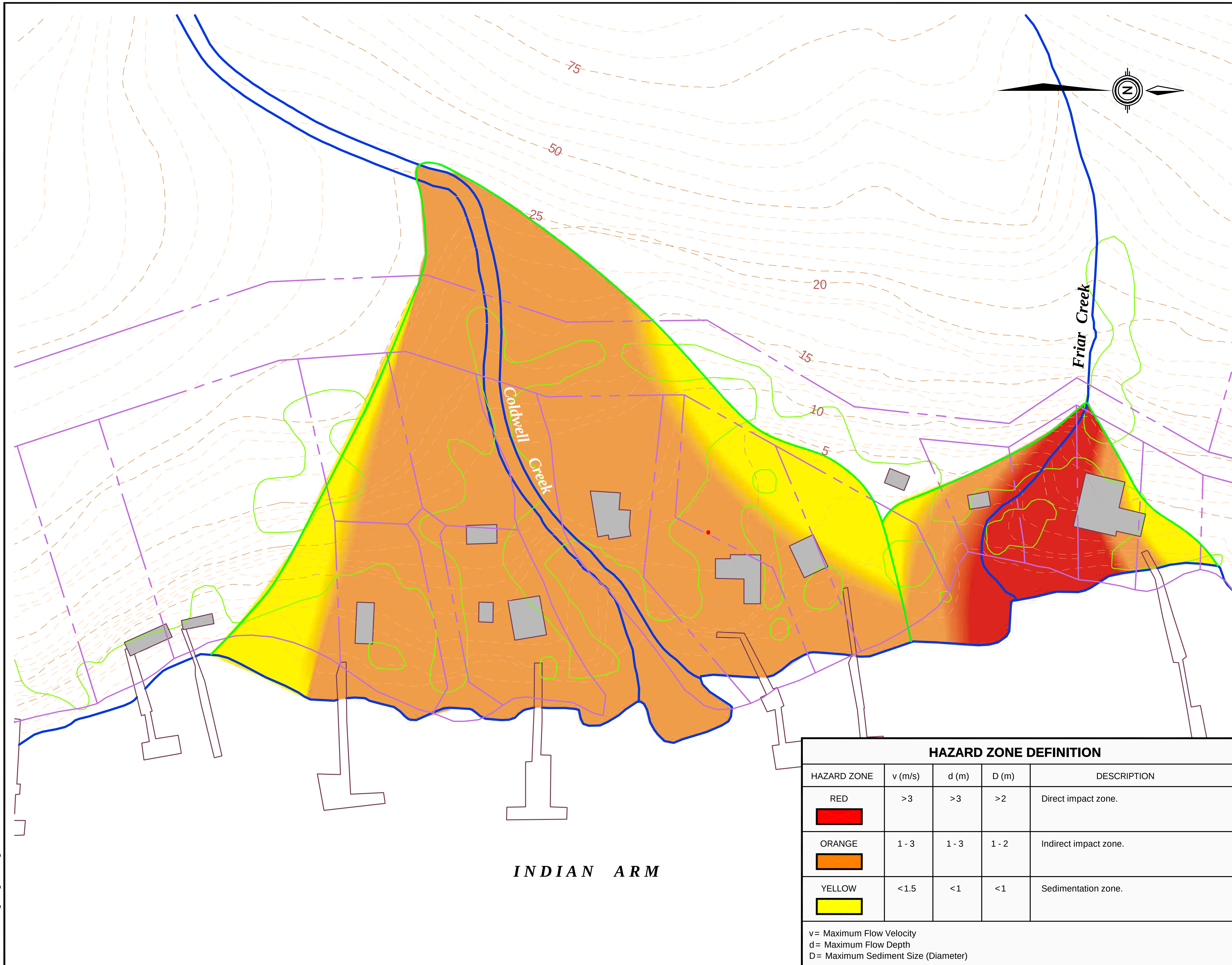
    - develop an appropriate funding mechanism;
    - determine future ownership of the works;
    - acquire any necessary property or right-of-way; and
    - establish maintenance requirements and responsibility.

8. Complete engineering design of mitigative works, with attention to environmental protection requirements, and with input from both residents and stakeholders.

9. Proceed with construction and follow up with post-construction monitoring.

In the event that the District does not proceed with implementation of mitigative measures at Coldwell Creek or Friar Creek in the short term, as a minimum it is recommended that the District:

10. Perform periodic monitoring of both watersheds to identify future instabilities, which may warrant further public advisory or reconsideration of debris flood structures.



HAZARD ZONE DEFINITION

HAZARD ZONE	v (m/s)	d (m)	D (m)	DESCRIPTION
RED	>3	>3	>2	Direct impact zone.
ORANGE	1 - 3	1 - 3	1 - 2	Indirect impact zone.
YELLOW	<1.5	<1	<1	Sedimentation zone.

v = Maximum Flow Velocity
d = Maximum Flow Depth
D = Maximum Sediment Size (Diameter)

District of North Vancouver
Debris Flow Study and
Risk Mitigation Alternatives for
Coldwell Creek and Friar Creek

Legend

Existing Building

Dock

Property Boundaries

Approximate Fan Boundary

Notes:

1. Topography is based on 1996 colour air photographs.
2. The dimensions and locations of mapping features are approximate and based on 1996 colour air photos.
3. Property lines are based on cadastral information provided by the District of North Vancouver.
4. The hazard map is based on the medium probability debris flood (Coldwell Creek) or debris flow (Friar Creek) event (500 - year return period).

KERR WOOD LEIDAL
associates limited
CONSULTING ENGINEERS

25 0 25
Scale in Metres

Project No.	Date
31.263	December 2003

Debris Flow and
Debris Flood
Hazard Map for
Coldwell Creek and
Friar Creek

Figure 2-2

Dec. 9/03

031-263\Drawings\Fig2-2.dwg

Appendix K

Report Excerpts for Clegg Creek

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EXECUTIVE SUMMARY

An Overview Report on Debris Flow Hazards was completed for the District of North Vancouver in April 1999 to identify the potential debris flow and debris flood hazards associated with the many creeks in the District. Following submission of the Overview Report, detailed debris flow and debris flood studies were initiated on several high risk creeks, including Clegg Creek which is the subject of this report. The risk at Clegg Creek is due to a significant debris flow hazard and the presence of one cabin on the southern half of the fan.

Clegg Creek is a typical debris flow basin characterized by very steep bedrock channels, a high drainage density and a steep fan. The estimated debris flow magnitude for design purposes (a 500-year return period) is a volume of 30,000 m^3 with a peak discharge of approximately 500 m^3/s. Without a debris flow mitigation structure in place, an event of this size could destroy the cabin.

The existing level of risk at Clegg Creek is rated high. The target level of risk is medium low and mitigative measures would be required to achieve this level.

A number of mitigation alternatives have been considered including land use planning, warning systems, watershed actions, and debris flow mitigation structures (debris basin, debris barrier, channelization and deflection berms). Given the high cost of mitigative works and the low level of development on the fan, the most practical alternative for risk mitigation at Clegg Creek is to remove or relocate the existing improvements (the cabin and an abandoned shack), valued at roughly $50,000. In the absence of extensive mitigative measures, further development on the fan would not be appropriate.

4. SUMMARY AND RECOMMENDATIONS

4.1 SUMMARY

The key points in this report are summarized as follows:

CLEGG CREEK SYSTEM

1. For the purpose of this report, Clegg Creek is defined as the watershed upstream of Indian Arm. The total watershed area is 1.2 km^2.

2. Clegg Creek is a typical debris flow basin characterized by very steep bedrock channels, a high drainage density and a large steep fan (approximately 15^o).

HAZARD ASSESSMENT

3. Appendix C provides a hydrologic analysis which results in the following preliminary 200-year return period peak instantaneous flood flow estimate:

Clegg Creek	9 m^3/s

4. A watershed investigation has been performed to identify potential debris flow trigger mechanisms and determine the amount of available debris. A detailed watershed map has been produced (Figure 2-1) to document geomorphic conditions.

5. Appendix D provides an analysis of debris flows, resulting in the following 500-year return period (10% chance in 50 years) magnitude estimate:

	Event Type	Peak Discharge	Volume
Clegg Creek	Debris Flow	500 m^3/s	30,000 m^3

6. While the 500-year return period event provides a reasonable basis for design, the potential impact of smaller and larger events also needs to be considered.

RISK ASSESSMENT PROCEDURE

7. For the purpose of this report, risk is defined as the combination of hazard probability and potential consequence (i.e. vulnerability to damage should an event occur).

8. Hazard probability is classified as ranging from low to very high, and can be estimated in terms of magnitude and peak discharge for each classification.

9. The consequence of a debris flow depends on the size of the event and on conditions in the developed area. Consequence can be classified on a similar system as hazard probability (i.e. low to very high).

10. A hazard map has been developed for the Clegg Creek fan that allows the fan area to be classified in terms of potential debris impact, flow depth, and flow velocity (Figure 2-2).

DEBRIS FLOW CONSEQUENCE AND RISK AT CLEGG CREEK

11. A major debris flow at Clegg Creek could destroy the cabin on the southern half of the fan. There is potential for loss of life.

12. Under existing conditions, the debris flow risk is rated as high for a 500-year return period event.

ALTERNATIVE STRATEGIES FOR HAZARD MITIGATION

13. A range of strategies for debris flow mitigation has been considered, including land use planning measures, warning systems, watershed actions, and debris flow mitigation structures.

14. The objective in implementing debris flow mitigation measures would be to reduce the overall level of risk (i.e. the residual risk) to at least medium low. Regardless of the alternative chosen, there will always remain at least some level of residual risk.

15. The most practical alternative for risk mitigation at Clegg Creek is to remove the existing cabin (valued at roughly $50,000).

16. Further development on the Clegg Creek fan would not be appropriate in the absence of extensive and costly mitigative measures.

17. It would be appropriate to place signs to warn users of the trail crossing about potential hazards.

18. It would be appropriate to perform periodic watershed monitoring to identify major watershed instabilities.

4.2 RECOMMENDATIONS

It is recommended that the District disseminate the results of this study as follows:

1. Advise property owners on the Clegg Creek fan regarding the contents of this report.

2. Submit copies of this report to the following organizations:

   - BC Ministry of Water, Land, and Air Protection; and
   - BC Parks (with regards to operational issues within Mount Seymour Provincial Park).

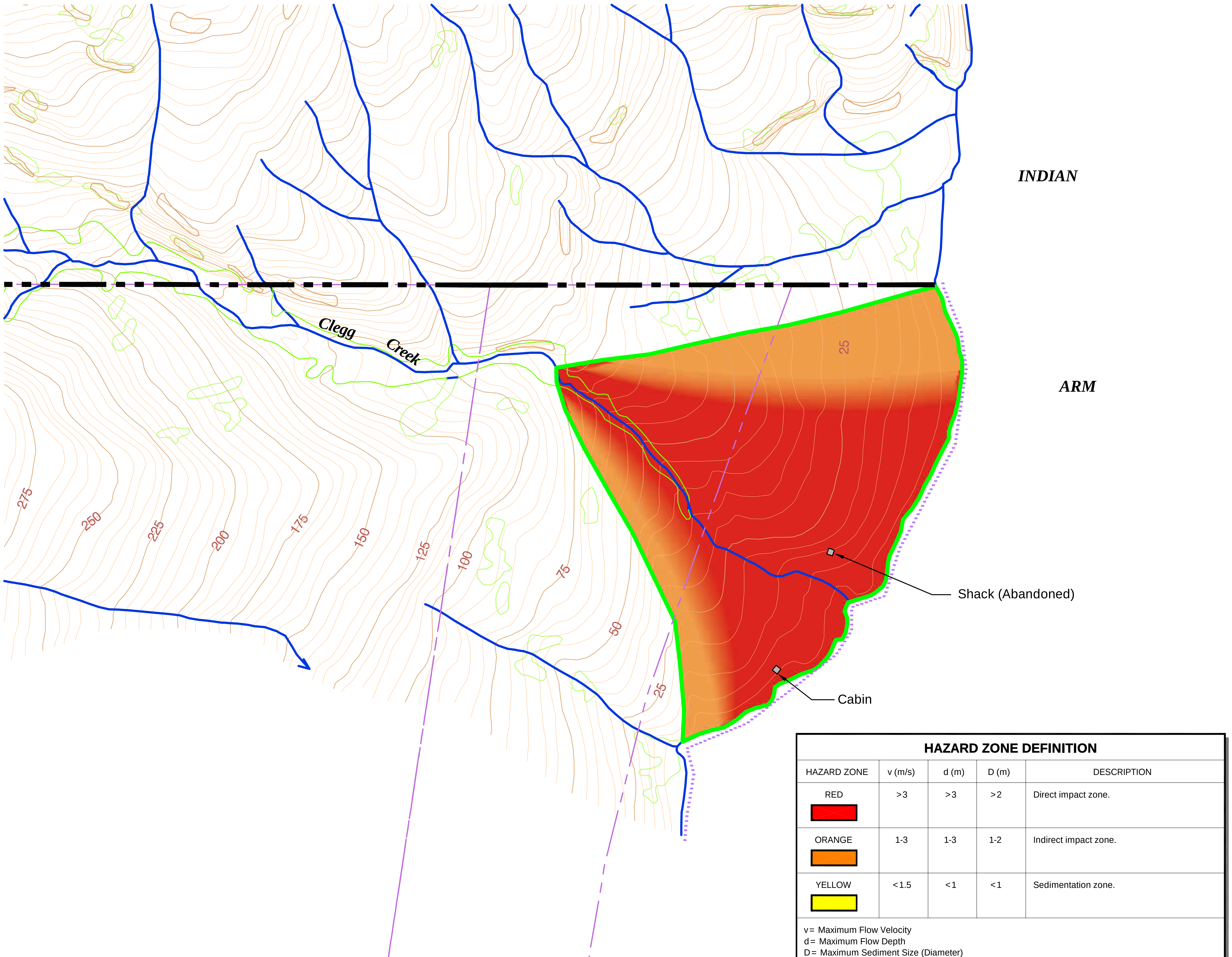
It is also recommended that the District proceed with risk mitigation actions as follows:

3. Avoid issuing building permits or other development approvals for development on the fan.

4. Investigate alternative means for removing the existing cabin and the abandoned shack on the fan.

5. Perform periodic monitoring of the Clegg Creek watershed to identify future instabilities that may warrant further public advisory or reconsideration of mitigative measures.

6. Consider the possibility of placing warning signs at the Clegg Creek trail crossing as part of a broader initiative by the District.



HAZARD ZONE DEFINITION

HAZARD ZONE	v (m/s)	d (m)	D (m)	DESCRIPTION
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YELLOW	<1.5	<1	<1	Sedimentation zone.

v = Maximum Flow Velocity
d = Maximum Flow Depth
D = Maximum Sediment Size (Diameter)

District of North Vancouver
Debris Flow Study and
Risk Mitigation Alternatives for
Clegg Creek

Legend

- **Building**
- **Property Line**
- **Assumed Property Line**
- **District Boundary**
- **Approximate Fan Boundary**

Notes:

1. Contours are based on photogrammetry and are approximate only.
2. The dimensions and location of mapping features are approximate and are based on 1996 colour air photos.
3. Property lines are based on cadastral information provided by the District of North Vancouver.
4. The hazard map is based on the medium probability debris flow event (500-year return period).

KERR WOOD LEIDAL associates limited
CONSULTING ENGINEERS

50 0 50
Scale in Metres

Project No.	Date
31.291	December 2003

Debris Flow Hazard Map for Clegg Creek

Figure 2-2

Dec.05/03

31-291\Drawings\Fig2-2.DWG