CLIMATIC AND HYDROLOGIC CIRCUMSTANCES ANTECEDENT TO MASS WASTING EVENTS IN SOUTHEASTERN BRITISH COLUMBIA

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INTRODUCTION

In B.C. mass wasting events on forested land often differ between the coast and the interior. In coastal B.C., mass wasting is usually associated with intense rainfall events during the autumn and early winter months. Snowmelt may be a contributory, but the critical factor is usually the rainstorm itself (Church and Miles, 1987). In the interior, snowmelt becomes a more important factor. For example, VanDine(1985) states that in the Columbia Mountains in southeastern B.C. torrents usually occur during the early summer months--the snowmelt period. The hydrologic circumstances are important from a forest management perspective, because planning and mitigative measures must focus on the correct process. The two important snowmelt processes are rain-on-snow melt and radiation or warm weather melt. The effect of forest harvesting on each melt process is different, and it is useful to know which is operative. In this paper the hydrological and climatic circumstances surrounding some of the landslides occurring between 1981 and 1990 in the Nelson Forest Region in southeastern B.C. are discussed.

Mass wasting events can result in on-site damage to roads and loss of forest site. They can damage streams and cause long lasting changes in fisheries habitat and water quality. If they are in close proximity to transportation corridors, they can result in millions of dollars in direct damage as well as indirect losses due to disruption of roads, railways, and pipelines. Damage to private property can be a problem at those locations where public land and private land are contiguous. At the most severe level, loss of life may occur. In the case studies described here all of these consequences other than loss of life occurred.

Various inventories of slides have been conducted in the Pacific Northwest including ones by Bishop and Stevens (1964), Wilford and Schwab (1982), VanDine (1985), and Rood (1984) in the coastal forests and by Megahan <u>et al</u>. (1978) in Idaho. These surveys generally describe the landslides themselves, site and geological factors, and their relationship to land use activity. This inventory is different as it focuses on the climatic episode rather than the slides themselves.

Much discussion has taken place over the past decade on the topic of cumulative impacts of forest harvesting on streams in watershed management (Harr, 1981). One of the important ways that cumulative impacts of upland forest management activities are transferred to stream channels and aquatic resources downstream is through mass wasting events. Often by reviewing the impacts of the most severe episodes of damage one can learn lessons about how watersheds respond during the most severe situations that are known to occur.

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THE PHYSIOGRAPHIC AND HYDROLOGIC SETTING

This study area is termed the interior wet belt. Annual precipitation ranges from less than 300 mm in the southern Rocky Mountain Trench to over 1500 mm in the northern Selkirk mountains. The climate during major precipitation events is characterized by Pacific frontal systems that have moved over the Coast Mountains and the dry valleys of the Interior Plateau. As they encounter the Monashee, Selkirk, Purcell, and Rocky Mountains of the interior they again release precipitation as either snow or rain. The annual streamflow is dominated by spring snowmelt. The annual peak streamflows are virtually always during the April to June spring runoff period. Maximum streamflows may be due to either a combination of very warm weather and deep snowpacks or an unusual rainstorm occurring when the snowmelt runoff is peaking.

Mass wasting is an important geological process in much of the region. It appears to be much more frequent in the areas of highest precipitation in the Selkirk and Purcell Mountains in the vicinity of Revelstoke and Golden than elsewhere in the region. The frequency of debris torrents and debris slides is less than in areas of high precipitation on the coast of B.C. Nevertheless the possible occurrence of mass wasting is always a concern when planning timber harvesting on upland slopes. In an area where the uplands are forested land and the valley bottoms often have transportation corridors and private property, aquatic resources, and water users there is considerable potential for impact from activities in the upland timbered zones.

TERMINOLOGY

Most of the events described are classified as debris torrents, which are defined as "a mass movement that involves a water-charged, predominantly coarse grained inorganic and organic material flowing rapidly down a steep, confined, preexisting channel"(VanDine, 1985). A few of the events described are debris slides and avalanches. In this paper the terms mass wasting and landslide are used as a general terms to describe all modes of soil mass movement.

THE CASE STUDIES

The case studies are those events for which the date of occurrence could be determined (Table 1). They represent only a small fraction of the total number of events that have occurred in this vast area during the past decade. The locations of the case studies are shown in Figure 1. Emphasis in the discussion is given to those failure cycles that have relevance to forest land management.

Major Events

These four events illustrate the impacts of both rain-on-snow and radiation melt.

1. July 1983 Rainstorm near Revelstoke and Golden

This event was by far the most dramatic of the last decade. It resulted in more than a hundred debris torrents in many high elevation drainages in the Selkirk and Purcell Mountains. It particularly affected those drainages with a significant elevation above 2000 m. Drainages that were affected included Illecillewaet River and its tributaries, the Akolkolex River, Glacier Creek, Duncan River and many others in the Golden and Revelstoke vicinity. The snow line at the time the storm hit was at an elevation of about 2200 m. (Snow disappeared from nearby snow pillows at 2026 m and 1980 m on July 5 and June 30 respectively. As can be seen in Figure 2, the normal seasonal peak flow had already occurred in the Illecillewaet River when the storm occurred. The soils were likely highly saturated in the

Table 1. A list of mass wasting episodes that could be reliably dated that occurred between 1981 and 1990 in the Nelson Forest Region in southeastern B.C.

DATE	LOCATION	HYDROLOGICAL EVENT	DESCRIPTION OF SLIDES (Estimated no.)	RETURN INTERVAL 24hr. Ppt.	PROBABLE CAUSE (natural,roads, or clearcut)	COMMENTS	REFERENCE
		MAJOR	**EVENTS**				
1. July 11-13, 1983	Selkirk Mtn.; Illecillewaet, Akolkolex, & Duncan Rivers	Rain-on-snow; 148 mm of rain in 3 days; melting snowpack at highest elevations	Debris torrents >100	>200	Natural	Extensive damage to highway, railway,	Evans and Lister, 1984, Schaefer, 1985; author's observations
2. April 12-17, 1988	Southern Selkirks; Slocan,Nakusp area	Radiation melt; small rainfall event;	Debris slides and torrents >10	n.a.	Mainly road drainage	Extensive damage to logging roads, damage to highway	Chow, 1988; author's observations
3. Nov. 8-11, 1990	Nakusp, Fernie, Moyie Lake	Fall rain-on-snow; 56.4 mm at Nakusp on Nov.9; 182.9 mm in 3 days at Fernie	Debris torrents and slides >20	25 yr.; >100 yr. at Fernie	Natural and road drainage	Damage to logging roads and highway	Author's observations
4. May 29, 1990	near Slocan	Spring rain-on-snow following a wet spring. 24.8 mm of rain in 24hr, estimated local rainfall much greater	Debris torrents 4		Road drainage	Highway damage and damage to water system and private property	Curran et al.1990
		OTHER	**EVENTS**				
5. April 9, 1985	Hill Creek near Galena Bay	Radiation melt and rain-on-snow	Debris slides 3	<1yr	Roads and possibly clearcut	Sediment discharge into spawning channel	Toews and Grant, 1985
6. May 30, 1986	Albert Canyon near Revelstoke	Radiation melt	Debris torrents 2	n.a.	Road drainage	Numerous washouts throughout region	Toews and Still, 1986
7. May 1, 1987	Blueberry Cr. near Castlegar	Radiation and rain-on-snow	Debris slides 1	<1	Roads	Localized event	Gluns, 1987
8. April 27, 1983	Sutherland Cr. near Christina Lake	Radiation melt	Debris torrent 1	<1	Roads	Localized event	Ministry of Forest files
		SUMMER	**AND FALL**	**EVENTS**			
9. Sept. 4, 1982	Birchlands Cr. near Golden	Rainstorm, 47 mm in two days at nearest station	Debris torrent 1	<1	Natural	Alpine origin	Ministry of Environment (MoE) Files
10. June 29, 1986	Johnson Draw near Golden	Rainstorm,	Debris torrent 1		Natural	Alpine origin	MoE Files
11. Aug. 20, 1989	Beattie Cr.	Rainstorm	Debris torrent 1		Natural	Alpine origin	MoE Files

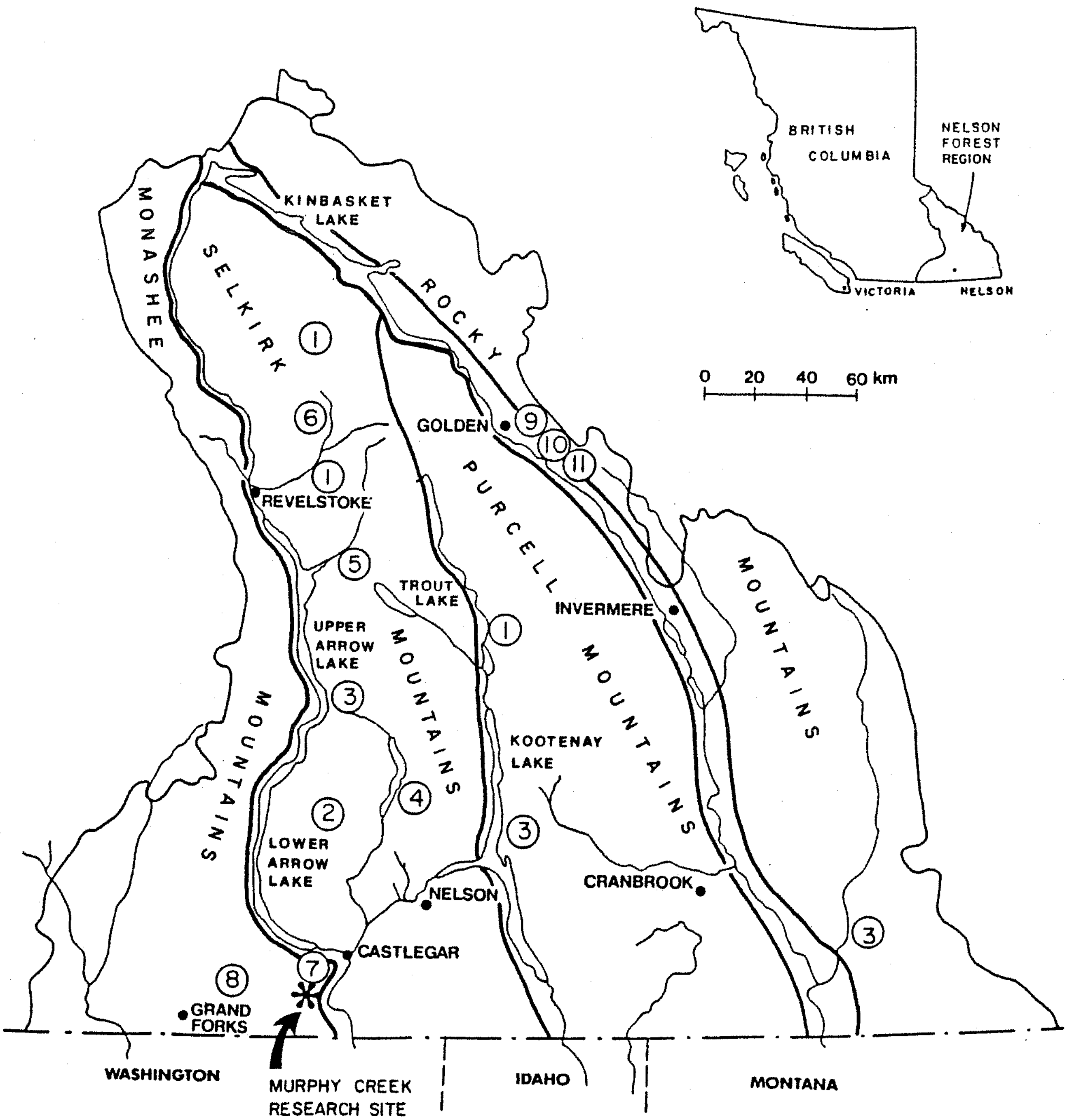

Figure 1. A map of the Nelson Forest Region of southeastern B.C. The numbers depict the vicinity of the mass wasting episodes listed on Table 1. The Murphy Creek research site is also shown.

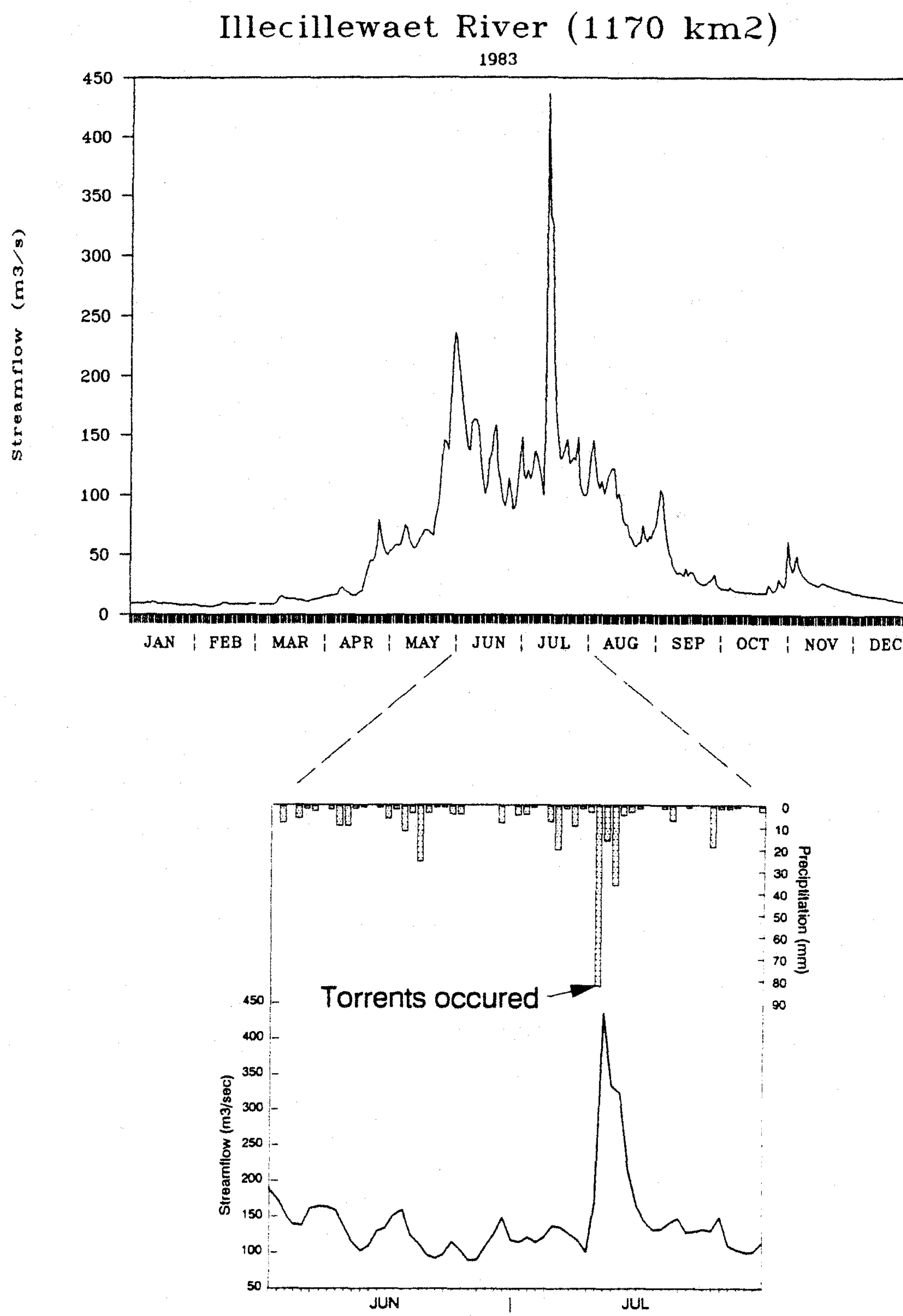

Figure 2. The 1983 hydrograph of the Illecillewaet River near Revelstoke with the precipitation at Glacier National Park (1323m) near Rogers Pass during June and July prior to the July 11-13 rainstorm shown below.

alpine areas from very rapid melt that had occurred since June 20. Observations in the drainages indicated that forest harvesting activities had virtually no impact on the initiation zones of the torrents because of the elevations of the starting zone.

Impacts during this event included damage to the Trans Canada highway, the railway line, and to logging roads in the region. Rainfall frequencies by Schaefer (1985) indicate that the return interval on this event was greater than 100 years at Revelstoke. The high elevation climatic stations at Mt. Fidelity had return intervals estimated at 220 years (Evans and Lister, 1984).

It is difficult to estimate the contribution of snowmelt to the storm. Observations made on July 20, about a week after the storm indicate that most of the snowpack that was present before melted during the storm.

Observations of the torrents indicate that they were initiated at a high elevation. For example, in the Akolkolex drainage few of the torrents start in the drainage below elevations of 1800 m where logging has taken place. Rather, they start at the headwaters of numerous gullies. This would indicate that the saturation of the soils by recently melted snow would be important in initiating these torrents. Although most of the watershed would have been snow-free before the slides started, a sizeable area of the watershed areas above the torrent initiation zone would have been snow covered at the time the storm started. Also, the soils in the area would be saturated, the snow having recently been melted.

The 1983 rainstorm event was an exceptional event from a rainstorm, streamflow, and debris torrent point of view. Both the streamflow and the rainfall exceed a recurrence interval of 200 years.

2. April 1988 Snowmelt Event

This episode is more typical of events in which forest harvesting effects mass wasting. A warm period in April 1988 resulted in at least 10 mass wasting events (Chow, 1988). The climatic situation and resulting snowmelt is illustrated in Figure 3. This data is taken from a snowmelt research site at an elevation of 1400 m and slightly to the south of the area where the slides occurred. Early in the month a minor rainfall primed the snowpack as shown on the precipitation graph. Warm weather set in on April 12 to 17 with average daily temperatures reaching 9 ^{0}C on April 16. A small amount of rain fell on April 17. The melt during the period of April 12 to 17 averaged 29.8 mm in the clearcut plot and 17.3 mm in the forest. On April 17, the day that most of the slides occurred, the melt was 21.8 mm in the forest and 40 mm in the clearcut. The hydrograph in figure 3 shows that this was a rather unexceptional flow event in the context of the annual streamflow hydrograph. The April 17 peak in the hydrograph is not the seasonal high.

Although this event is unexceptional by comparison to the last one it provides many more lessons for forest management. It occurred in the elevation zone where forest cover removal and disruption of drainage by roads can have a significant impact. Whereas the first event could be classified as exceptional, this one appears from climate and hydrological data to be in the range of a typical spring runoff event.

The question inevitably arises regarding the contribution of clearcutting to slides. A survey of the slides by Chow (1988) indicates that in every instance road drainage problems were implicated in initiating the slides. Clearcutting may have been a contributing factor in three of the 10 slides. Even though the melt on the clearcut estimated to be almost double that in the forest, Chow's observations indicate that road drainage is the probable initiating factor on most of the slides.

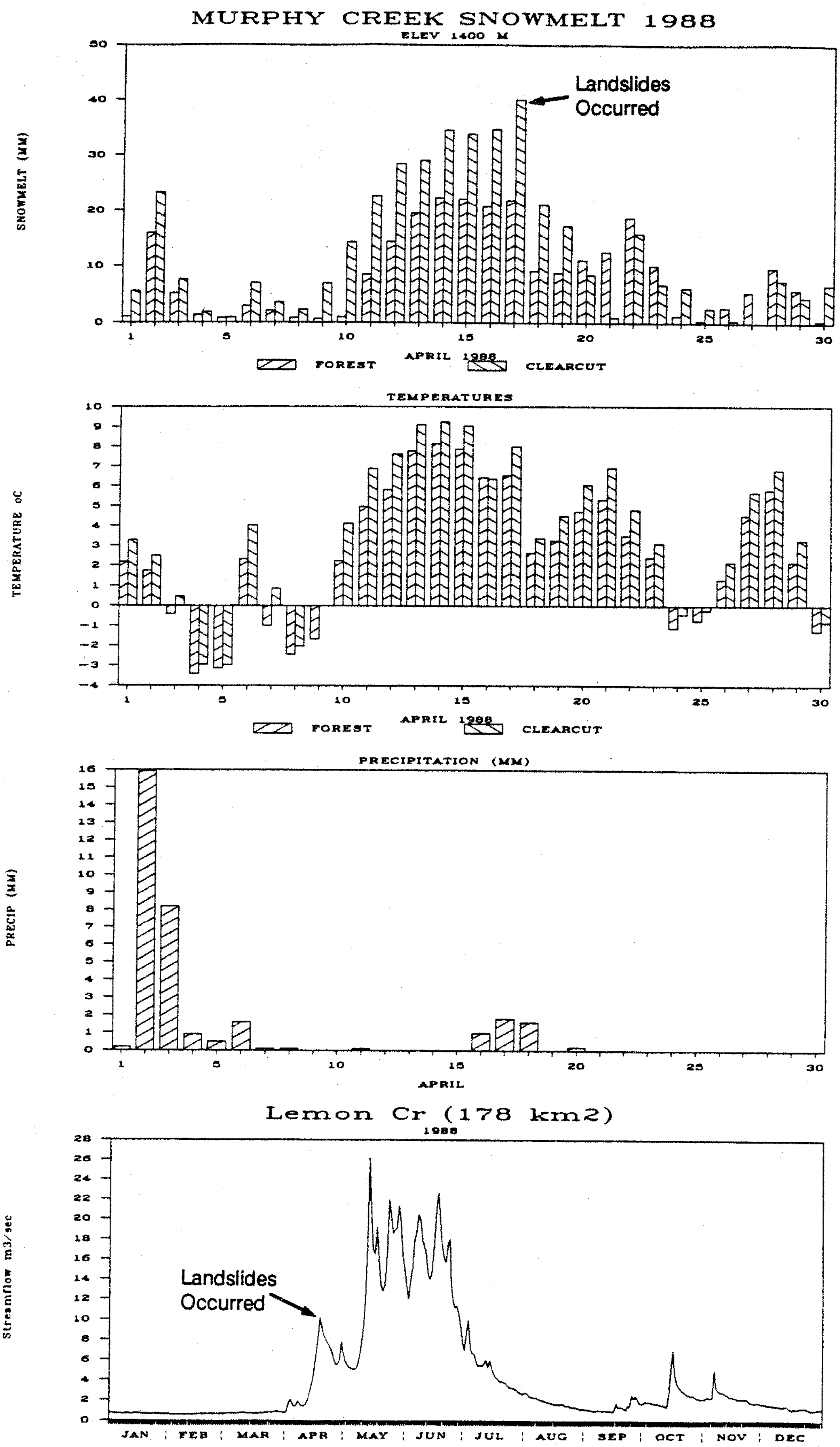

Figure 3. Climate and snowmelt data from the Murphy Creek Research Site near Castlegar during the 1988 landslide event. The timing of the event is shown on the Lemon Creek hydrograph.

3. May 29, 1990 Rain-on-snow Event near New Denver

This rain-on-snow episode caused 4 debris torrents at a site near New Denver (Curran et al, 1990). Damage occurred to a highway, a water intake and small hydro power facility, and slide debris was deposited on private property around a dwelling. This episode was the result of an high precipitation event following a month of record rainfall during the snowmelt season. Calculations were undertaken to determine the comparative melt values on a forest and a clearcut. The results are summarized in Table 2. It can be seen that on a watershed basis the contribution of clearcutting per se appears to be relatively minor. By comparison, calculations of drainage area change indicate that diversions by roads appeared to be a causal factor with drainage area changes as high as 171%.

Table 2. A summary of results of energy budget calculations estimating snowmelt on May 29, 1990 in the mid-elevation zone of the watershed above the debris torrents (after Curran et al, 1990)

	Clearcut Plot (mm)	Forested Plot (mm)
Snowmelt (M)		
Mlr(long wave radiation)	8.3	7.3
Mc(convection)	1.5	0.5
Me(condensation)	4.7	1.6
Mr(rain)	4.7	4.1
M (Total Melt)	19.2	13.5
Rain(assumed for example)	60.0	60.0
Total Rain and Melt	79.2	73.5
Percent Difference		8%

4. November 10, 1990 Rain-on-snow Event

This event caused debris torrents and slides near Nakusp, Fernie, and Cranbrook. It was the same storm that caused numerous slides and widespread flooding in areas of coastal B.C. and Washington.

Observations made immediately after the event near Nakusp indicated about 50 cm of snow in a clearcut area above the slide and only a few centimetres of snow in the adjacent forested area. This storm was accompanied by rising temperatures which would cause snowmelt to contribute to runoff at the slide initiation zones.

This is the first significant autumn event that was noted in this survey. In all other cases, major regional landslide episodes occur during the spring snowmelt. In southeastern B.C., the snowpack accumulates very rapidly in the fall and remains until the spring. There is a very short period of time in which the snowpack is shallow enough to release the water to the soils below. At this shallow depth it would be similar to the transient snow zone as described by Harr (1986). As more snow accumulates a storm of similar magnitude would be much less effective because the rain would be absorbed by the snowpack rather than released to the soil below.

Other Events

The four events in this section are typical of those that occur in the timbered intermediate elevation zones in southeastern B.C. They occur during a period of intense snowmelt. Typically the watershed upslope of the slide is partially covered with a ripe snowpack. The climatic and circumstances indicate that snowmelt has been occurring at an intense rate during the days preceding the slides. It is noteworthy that in every instance there has been some circumstance of altered drainage by roads. Although forest cover removal may be a factor in some of the slides, in most circumstances cover removal has also occurred.

The April 9, 1985 event at Galena Bay was the result of a rainfall event after a very hot spell of weather. The circumstances surrounding this event are typical of many of the smaller episodes in southeastern B.C. About half the snow in the slopes above the slides had melted when slides occurred. Much of the watershed contributing flow to the initiation zones was in a clearcut condition, even though the area had been logged about 16 years previous. This event is typical of many of the events in which both rain-on-snow and radiation melt is important. The dominant melt during the early April period prior to the slide was radiation melt; however intense rainfall when the snowmelt was peaking, added to the short term water input at that site.

Precipitation was not a factor in the April 27, 1983 and the May 30, 1986 slides. However, diversion of road drainage was a factor in both of these events.

The May 1, 1987 slide in the Blueberry Creek was the result of a similar set of circumstances. It is worth looking at in more detail because there is some data available from the Murphy Creek Research Site for that event. As in the Hill Creek failure, the slide was preceded by a period of very warm weather. As the snowmelt was peaking, rainfall at of 13.8 mm was recorded.

<u>Summer and Fall Events Near Golden</u>

These events are numbered 9 to 11 in Table 1. In the Rocky Mountains east of Golden, debris torrents occur during the summer and fall long after the snow has melted. This appears to be the only locality in the Nelson Forest Region where this is common. Although three occurrences are noted, a number of others are recorded in Ministry of Environment files. Their initiation zones are in the alpine areas and consequently their occurrence does not appear to be related to forest harvesting activities but to highly intense and localized convective storms.

<u>DISCUSSION</u>

Several generalizations can be made based on the events described. Seven of the eleven events involved some form of rain-on-snow event (Table 4). A typical situation prior to a slide is a ripe snowpack that is partially melted with bare ground showing in the contributing area. The most severe events appear to be the result of exceptional rainstorms on a melting snowpack. It appears that snowmelt is almost always an important factor in these occurrences.

In only a few of the occurrences was it obvious from the available climatic data that the event was exceptional in any way. The most exceptional event was the July 1983 event that Evans and Lister (1984) rated as being a greater than a 200 year return interval event.

From a forest management point of view the goal is to minimize the effect of the typical events. They appear to occur when snowmelt is peaking in the basin contributing to the slide initiation zone.

Table 4. A summary of processes during slide events.

Hydrological Circumstance	Event(numbers correspond to Table 1.)
Radiation Melt	6,8
Radiation/Rain-on-Snow Combination	2,5,7
Spring Rain-on-Snow	1,3
Fall Rain-on-Snow	4
Rain only/ no Snow	9,10,11

The following are some generalizations that could be made based on the case studies listed in Table 1.

1. Snowmelt is a factor in most episodes. Even if the snow has melted in the zone immediately above the mass wasting events, recent snowmelt is still contributing to soil saturation. Often the combination of snowmelt and rainfall intensity indicate a complex runoff generation. Guidelines and warning systems for mass wasting occurrence based on rainfall intensity alone are therefore inappropriate.
2. Fall rain-on-snow events that result in significant mass wasting are infrequent.
3. Summertime convective storms contributing to mass wasting are highly localized. In this survey their occurrence was noted only in the Rocky Mountains near Golden.
4. Changes in drainage due to roads are causal factors in many slides.
5. Clearcutting per se has not been a major contributing factor in any of the major slide cycles. In a few cases, a clearcut was situated directly above the slide and may have been a contributing factor. Snowmelt rates are clearly increased by removal of forest cover.
6. A few of the episodes are highly localized in occurrence. The May 29, 1990 at the Slocan Bluffs and the April 5, 1985 are examples of such events. Intense cells of precipitation unrecorded by nearby climatic stations may account for this pattern.
7. Events never occur after a substantial snowpack has accumulated in the December to March period. During April to July slides occur as the melt occurs in the drainage areas above the slide zones. Slides occur either during or immediately after the snowmelt. Snow may be gone for at least part of the watershed.

FOREST MANAGEMENT IMPLICATIONS

1. Maintenance of natural drainage patterns is the most important preventive factor that should be incorporated into all phases of forest harvest planning and operations. Detailed contour maps are a useful tool for this activity and should be prepared and utilized in situations where.
2. Alterations in snowpack volume and peak snowmelt should be considered when harvesting timber in areas that contribute flow to potentially unstable terrain downslope. In this area clearcutting increases snow accumulation by about 35% and can increase peak snowmelt rates by almost 100% (Toews and Gluns, 1986). Care should be taken that the entire drainage area of microdrainages above potential debris torrent tracks are not harvested. Snowmelt in a drainage occurs in a somewhat predictable pattern with elevation and aspect as key variables. Harvesting should be distributed in contributing drainages with these factors in mind.
3. A record keeping system of mass wasting occurrence should include the exact date of occurrence of the event where this is known. This would enable the development of a more complete data base of climatic conditions prior to mass wasting events.

SUMMARY

Debris slides and torrents in the Nelson Forest Region are usually associated with a combination of a rainstorm on a ripe melting snowpack. Occasionally radiation melt by itself is the important hydrological factor. The largest event was the result of a large rainstorm on a recently melted snowpack.

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